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Analysis of the distribution patterns of southern right whale off the southern Brazilian coast

Análise do padrão de distribuição de baleia franca austral na costa sul brasileira

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Abstract

The southern right whale, *Eubalaena australis*, is a migratory baleen whale that uses southern Brazilian waters as a nursery and breeding ground from June to November. This study aims to determine the distribution patterns and main aggregation sites of southern right whales off the southern Brazilian coast from around Santa Catarina Island to Osório, and to investigate the population distribution according to the coastline and bathymetric features. The methods consisted in obtaining geographical coordinates for each individual, sighted through helicopter expeditions over a transect along the coastline, conducted once a year in September, from 2001 to 2010. This data was used to generate a density estimate surface map of southern right whales using the Kernel Density Estimator. Additionally, a digital bathymetry was overlaid to the density estimate map. The results pointed out a region of high density estimate of southern right whales, located from 28°12'22"S, 48°39'25"W to 28°33'58"S 48°47'19"W, respectively, from Imbituba to Santa Marta Cape. The largest aggregations were observed where the shelf declivity is higher, as a result from the bathymetric lines of 10 m and 40 m being closer to each other, and where the coastline shows great amount of bays. We highlight the importance of monitoring the southern right whales distribution patterns observed in this study, aiming to identify possible habitat changes that can be indicative of disturbances on their populations.

Key words: *Eubalaena australis*, reproductive grounds, Kernel Density Estimator

Resumo

A costa sul brasileira é um importante local de concentração reprodutiva para as baleias francas austrais *Eubalaena australis* (Desmoulins, 1822) (Cetartiodactyla, Balaenidae). Assim, este estudo teve como objetivo determinar o padrão de distribuição e as principais áreas de concentração das baleias francas na costa sul brasileira, no trecho entre a Ilha de Santa Catarina e Osório, bem como identificar a distribuição da espécie de acordo com as características das feições batimétricas e da linha de costa. Os métodos consistiram na obtenção de coordenadas geográficas de indivíduos de baleias francas austrais, avistadas através de expedições aéreas, conduzidas em transecção ao longo da linha de costa nos meses de setembro no período de 2001 a 2010. Esses dados foram utilizados para gerar um mapa de superfícies de estimativa de densidade de baleias francas utilizando o Estimador de Densidade *Kernel*, ao qual foi também sobreposta uma batimetria digital. Os resultados indicaram uma região com alta estimativa de densidade de baleias francas, localizada no entorno de 28°12'22"S, 48°39'25"W e 28°33'58"S 48°47'19"W, nos arredores de Imbituba ao Cabo de Santa Marta. As maiores concentrações de baleias francas estão localizadas onde a declividade da plataforma é maior, devido às cotas batimétricas de 10 m e 40 m estarem mais próximas, e onde a linha de costa apresenta grande quantidade

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de baías. Destacamos a importância de monitorar o padrão de distribuição das baleias francas observado, objetivando identificar possíveis mudanças de habitat que possam ser indicativos de distúrbios em suas populações.

Palavras-chave: Concentração reprodutiva, *Eubalaena australis*, Estimador de Densidade *Kernel*.

Introduction

The southern right whale, *Eubalaena australis* (Desmoulins, 1822), is a migratory baleen whale that uses southern Brazilian waters as a nursery and breeding ground from June to November (Santos *et al.*, 2001; Groch *et al.*, 2005). In the Southwest Atlantic, southern right whales breeding grounds have also been reported in Argentina (Payne *et al.*, 1990; Rowntree *et al.*, 2001) and Uruguay (Costa *et al.*, 2007).

Sightings of southern right whales off the Brazilian coast have been reported along a 3845 km stretch of the coast, extending from Forte Beach (12°34'39"S, 38°0'6"W) (Santos *et al.*, 2001), to Hermenegildo (33°39'55"S, 53°15'40"W) (Greig *et al.*, 2001). They are mostly concentrated off the southern coast, a well recognized breeding area for *E. australis* in the Southwest Atlantic (Greig *et al.*, 2001; Santos *et al.*, 2001; Groch *et al.*, 2005).

Southern right whales, especially females with calves, exhibit site fidelity for wintering areas generally returning to the same wintering region in every three years (Bannister, 1990; Best *et al.*, 2001; Rowntree *et al.*, 2001; Carroll *et al.*, 2011). Unaccompanied adults have been resighted at different time intervals, even though showing fidelity patterns for a specific wintering site (Payne *et al.*, 1990; Bannister, 2001; Carroll *et al.*, 2011).

Southern right whales were hunted to near extinction by commercial whaling until early in this century. Even after international protection in 1935, illegal whaling activities continued in some regions, including the South Atlantic (Klinowska, 1991; Tormosov *et al.*, 1998). The Southern Hemisphere populations did not show signals of recovery until 30 to 40 years ago (Whitehead *et al.*, 1986; Best, 1990; Tormosov *et al.*, 1998; Bannister, 2001).

Conservation of southern right whales populations relies on effective monitoring. As this species is a long-lived and slow reproducing species, long-term data collection is therefore required (Payne *et al.*, 1990; Best *et al.*, 1993; Rowntree *et al.*, 2001). Previous research regarding the abundance and distribution of southern right whales off the southern Brazilian coast have been conducted as part of photo identification studies through aerial surveys (Groch *et al.*, 2005), stranding events (Greig *et al.*, 2001) data compilation (Santos *et al.*, 2001) and opportunistic observations off the southeastern Brazilian coast (Lodi *et al.*, 1996; Lodi and Rodrigues, 2007). However, these studies do not include mapping of spatial distribution of southern right whales. Espírito Santo *et al.* (2009) published preliminary results of southern right whales mapping off the southern Brazilian coast from 1987 to 2003, based on sightings obtained from aerial surveys that had irregular area coverage from 1987 to 2000, and regular coverage after 2001.

Knowledge of the specific areas where a species occurs is fundamental for the implementation of adequate conservation strategies (Murison and Gaskin, 1989; Guisan and Zimmermann, 2000; Austin, 2002). Distribution patterns of marine mammals are potentially indicative of environmental factors that contribute for their aggregation in specific areas. Changes in population habitat can indicate disturbances in environment, caused by natural or anthropogenic factors (Schick and Urban, 2000; Rowntree *et al.*, 2001; Keiper *et al.*, 2004; Cañadas *et al.*, 2005; Tynan *et al.*, 2005)

Previous research on habitat use by cetaceans attested that several environmental factors contribute to the observed patterns. Coastline morphology and seabed topography are considered important factors in aggregating right whales in breeding grounds (Thomas and Taber, 1984; Elwen and Best, 2004; Oviedo and Solís, 2008). There are evidences that right whales prefer areas close to the coastline, protected bays and sandy substrates, because these characteristics offer protection to mother and calf pairs (Taber and Thomas, 1982; Payne, 1986; Burnell, 2001; Elwen and Best, 2004).

The southern Brazilian coast shows differences in declivity and amount of bays in the coastline (Castro and Miranda, 1998; Muehe, 1998; Siegle and Asp, 2007). Hence, distinct morphological characteristics along the coast may probably segregate southern right whales in certain sites, according to their preferred features. In this context, understanding and mapping aggregations of southern right whales is valuable in order to support the conservation and management of this species, and promoting sustainable basement for adequate planning of economical development to avoid impacts in the southern right whales breeding grounds.

Therefore, this study had the following objectives: firstly, determining and mapping the distribution patterns of southern right whales along the southern Brazilian coast; secondly, identifying the shelf bathymetry and coastline characteristics where the aggregations occur to investigate influences of this feature in habitat selection.

Methodology

Study area

The study area is located in the region between 27°40'0''S, 48°28'32''W to 30°40'0"S, 50°32'3"W, corresponding to off Santa Catarina Island, Santa Catarina State, and Osório, Rio Grande do Sul State, in the southern Brazilian coast, respectively (Figure 1). This region is marked by the transition between the Brazilian Southeastern Shelf and the Southern Shelf, exhibiting changes in the physiographic features. The orientation of the coast from the extreme north of Santa Catarina State (26°1'8"S 48°36'48"W) to Santa Marta Cape (28°36'14"S 48°48'50"W), is N-S, and from this part towards south, the coastline orientation is NE-SW (Muehe, 1998).

The Brazilian Southeastern Shelf begins in Santa Marta Cape and extends towards north to Cabo Frio (RJ). The widest part of the Southeastern Shelf, with 230 km wide, is located off Santos, SP, and its narrower parts are around Cabo Frio (RJ), with 50 km wide, and Santa Marta Cape (SC), with 70 km wide (Castro *et al.*, 2006). The Southeastern Shelf in the northern Santa Catarina State coast is monotonous and shows gentle declivity (Abreu, 1998), while towards south, the shelf is steeper.

The coastline morphology of the northern part of the state of Santa Catarina to Santa Marta Cape is mainly characterized by beach bays separated by rocky promontories with many rocky points and islands. From Santa Marta Cape towards South, the coastline morphology is formed by a single beach arc of more than 117 km, and the only interruptions are tidal channels (Muehe, 1998; Siegle and Asp, 2007).

The Southern Brazilian Shelf extends from Santa Marta Cape south towards Chuy city, in the border of Brazil and Uruguay, and it is delimited by the 180 m isobath, narrower in its northern part, at Santa Marta Cape, and progressively wider towards south (Muehe, 1998). The Southern Shelf presents rectilinear coastline, and sandy beaches are the predominant feature, especially towards south (Castro *et al.*, 2006).

The oceanographic processes in the study area are influenced by the phenomena of upwelling in spring and summer, around Santa Marta Cape, and the influence of the Coastal Current mainly in winter (Piola *et al.*, 2008; Pereira *et al.*, 2009).

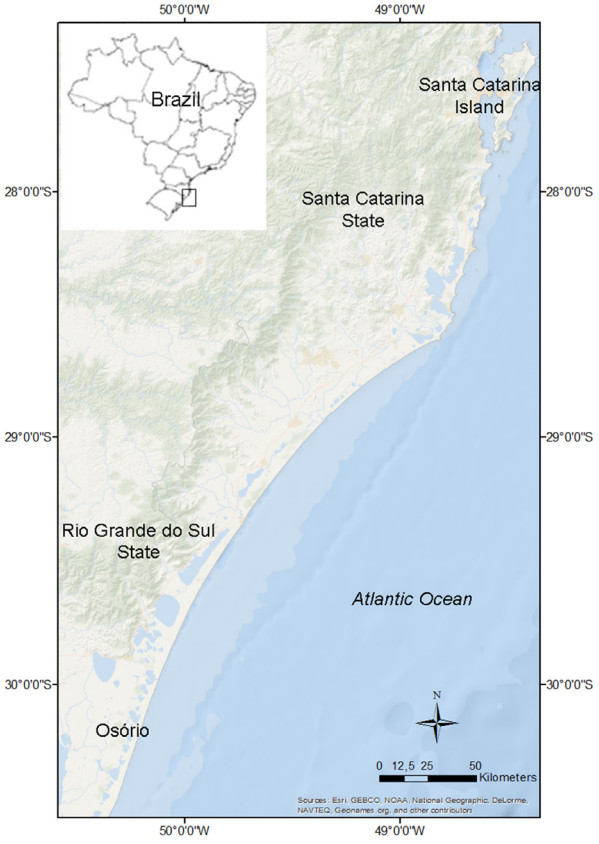

Figure 1. Study area in the southern Brazilian coast.

Southern right whales sightings

Southern right whales sightings were collected by the Brazilian Right Whale Project (*Projeto Baleia Franca*), once a year, in September from 2001 to 2010. September was chosen due to the better quality of available data in this month and also because that is the peak of occurrence of right whales off the Southern Brazilian coast.

Data collection followed a standard methodology that consisted in collecting photos and obtaining geographical coordinates for each individual, sighted through helicopter expeditions over a transect around the study area limits, along the coastline.

The path travelled by the aircraft departed from Itapirubá (28°20'18"S 48°42'29"W), towards south, performing counts up to the southern limit of the study area, and from this point, returning to the starting point in Itapirubá. Counts were not performed on returns. From the starting point, the aircraft continued towards north, performing counts up to the northern limit of the study area. The flyovers were conducted at approximately 500 m from shore, obtaining a field of view of approximately 1500 m.

Whenever an individual or group was sighted, the aircraft approached at a

minimum distance of 328 feet, and the number of southern right whales was counted. The helicopter glided on individuals, until the callosity patterns became visible, and then photos and geographical coordinates were obtained. This data was considered the minimum counts because some individuals underwater could not be seen through the over flights.

The expeditions had 3 observers. Sampling effort varied from 1 to 2 consecutive days of observations, during daytime. In the study region, the number of whales varied between different years. Therefore, years that showed higher number of whales demanded more hours for recording the data of sighted individuals in the same extension of the study area.

For each group of southern right whales sighted, the number of individuals was registered, as well as group composition (females with calves and unaccompanied adults) and geographic coordinates. The photo identification of individuals helped preventing data duplication and errors in the estimates. Such recognition was performed through the analysis of the callosity patterns of each southern right whale sighted, which is unique for each individual, according to the methodology described by Payne *et al.* (1983).

The automatic photo identification of southern right whales was performed using the software Right Whale Photo-identification developed by Hiby and Lovell (2001). The sightings and photo identification were analysed by the Brazilian Right Whale Project.

Data analysis

In order to study the spatial distribution patterns of southern right whales, we used the Kernel Density Estimator method (Bailey and Gatrell, 1995; Shawe-Taylor and Cristianini, 2004). This method is an efficient tool for mapping and analysing the spatial distribution of species in ecological research (Worton, 1989; Seaman and Powell, 1996; Righton and Mils, 2006; Nelson *et al.*, 2008). In this context, this tool was used to identify the southern right whales distribution patterns off the southern Brazilian coast. Additionally, it was used to analyse the influence of bathymetric features in the distribution patterns of southern right whales, a digital bathymetry was overlaid to the resultant map of Kernel Density Estimator analysis.

Kernel is a non-parametric method, which performs an analysis of intensity estimate of the punctual process occurrence in the study region. The estimate is calculated through an adjustment of a bidimensional function to the considered events, composing a surface in which each value will be proportional to the intensity of the events per unit of area. The objective is to generate a grid in which each cell represents a value of density (Câmara *et al.*, 1996).

The Kernel method consists of placing a probability density over each observed point in the sample (Seaman and Powell, 1996). A regular rectangular grid is superimposed to the data, and a density estimate is obtained for each grid intersection, using information from the entire sample (Seaman and Powell, 1996). The estimated density at each intersection is essentially the average of the densities of all the kernels that overlap that point. The density estimate will be high in areas with many observations, and low in areas with few. We used a quartic Kernel, and its formula is given by Equation 1:

$$\lambda = \sum_{i=1}^{n} \frac{3}{\pi\tau^2} \left(\frac{ss_i}{\tau} \right) y_i \qquad (1)$$

λ is the density estimate of an area. The area of influence within the events which contribute to the intensity calculation is a circle of radius τ centred in $\boldsymbol{s}$. $\boldsymbol{s}$ is the centre of the event on a regular grid, and $\boldsymbol{si}$ is the point location where the event occurred.

The area of influence τ is also called bandwidth, and it defines the area centred on the point of estimation, which indicates how many events contribute to the estimate of the intensity function. The result is the interpolation of an intensity value for each grid cell, considering a symmetric function, centred in the cell, used for the calculation of the points situated at a certain distance from the cell centre.We used a 1500 m bandwidth, chosen by testing the output results of the Kernel density estimate map using a variety of resolution sizes. The selection criteria consisted in considering a resolution with enough size to produce a good visualization in the resultant Kernel map, but also avoiding larger bandwidths that resulted in exaggerated data extrapolations.

We interpreted the scale of whale densities as following: 1-5 southern whales was considered low density and represented in yellow shades; 6-10 whales, medium densities (orange shades) and higher than 10 whales, high density (red shades). Sites without colour, just with the grey scale bathymetry, indicate no southern right whales observations.

A digital bathymetry was constructed and overlaid to the Kernel density estimate results, aiming to investigate whether there is some pattern of southern right whales distribution related to bathymetric features. The bathymetric data was obtained through the nautical charts available at Brazilian Hydrograph and Navigation Office - DHN (*Diretoria de Hidrografia e Navegação*).

We used the nautical chart n.1900 covering the region from Arvoredo Island (27°10'S, 48°0'W) to Torres (29°30S, 49°50'W) with 1:279329 resolution; and the nautical chart n. 2000 covering the region from Torres to Mostardas (RS) (29º08'S, 49º10'W; 31º27'S, 51º05W) with 1:274023 resolution. As a result, a numerical terrain model was obtained with 5 km resolution.

Results

The analysis of the southern right whales distribution patterns indicated that there are different densities of these whales over the study area (Figure 2).

The high density estimates of southern right whales, indicated by red shades in Figure 2, are located between 28°12'22"S, 48°39'25"W and 28°33'58"S 48°47'19"W, respectively, around Imbituba and Santa Marta Cape. Between these locations there are also medium density estimates, with aggregations of 6 to 10 individuals. This region showed the highest southern right whales aggregations in the surveyed area.

Low density estimates (1 to 5 individuals), indicated by yellow shades, are located between 28°80'00"S, 49°25'32"W to 30°00'00"S, 50°09'13"W, in the southern part of the map (Figure 2). Among these yellow shades, there are some points with medium density estimates, in orange shade, around 28°90'00"S, 49°25'18"W and 29°02'08"S, 49°27'58"W.

Towards south of 29°90'00"S, 50°70'31"W up to the study area limit, there are no density estimate shades, indicating absence of observed individuals. In the northern part of the map there is another area with no individuals observed, around 27°70'00"S, 48°38'90"W, followed by areas with medium density, in 27°50'33"S, 48°36'10"W.

The localization of aggregations, according to the bathymetric features, indicates that the higher density estimates of southern right whales are located between an area where the coastline curves and shows great amount of bays. Large aggregations are also located in places where the shelf declivity is steeper, from 28°60'00"S, 49°23'18"W towards north, where the 10 m and 40 m bathymetric quotas are closer.

Discussion

The areas with high density estimates of southern right whales, between Santa Catarina Island and Santa Marta Cape, should be considered important habitats for southern right whales off the southern Brazilian coast. A preliminary study analysing the distribution of southern right whales, using data from sightings from 1987 to 2003, off the southern Brazilian coast, conducted by Espírito Santo *et al.* (2009), demonstrated similar results, confirming that the distribution pattern of southern right whales remained the same.

The higher density estimations, located in an area with large number of bays, is concordant with results of other studies in South Africa (Best, 2000; Elwen and Best, 2004), Argentina (Payne, 1986) and New Zealand (Patenaude and Baker, 2001), showing the main aggregations of southern right whales according to the coastline morphological features, with fidelity to specific sites. Sheltered bays provide protection for mother and calf pairs against waves and currents (Taber and Thomas, 1982; Thomas and Taber, 1984; Payne, 1986). The potential benefit of such sites for right whales is energy conservation for lactation and avoiding physical damages, especially in calves (Taber and Thomas, 1982; Thomas and Taber, 1984; Best *et al.*, 2003).

The southern Brazilian shelf is wider towards south (Muehe, 1998) and the southeastern Brazilian shelf becomes wider towards north (Abreu, 1998). Results show that the sites containing high density of southern right whales are located in front of an area where the shelf break and slope, around 400-800m, around 29°00'00"S, 49°17'39"W, are closer to the coast compared to the adjacent regions. This region may represent an entry corridor on the migration route of southern right whales when arriving on their nursery ground. However, at the present time, knowledge about the southern right whales migration routes to the Brazilian breeding ground is scarce. Hence, for accurate conclusions about this hypothesis, future studies regarding the movements of southern right whales off the southern Brazilian coast are necessary.

The highest concentrations of southern right whales pointed out in this study are located in the environmen-

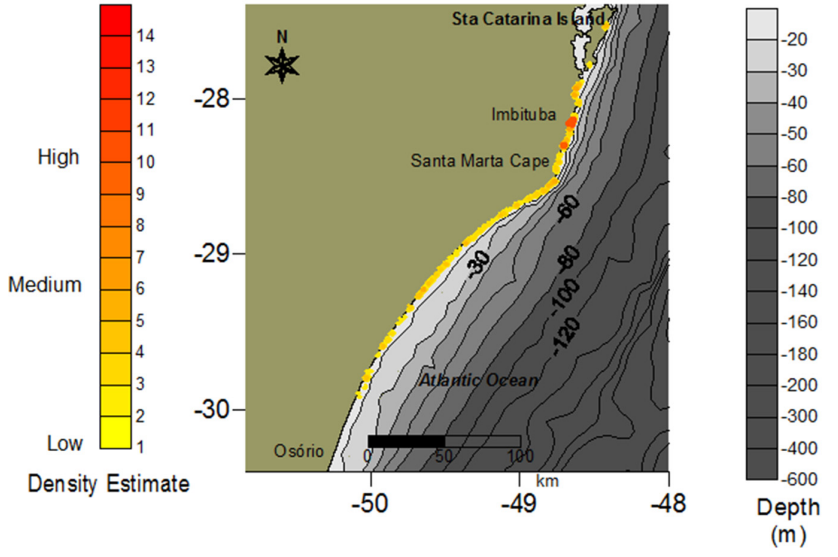

Figure 2. Resultant map of Kernel Density Estimator for southern right whales sightings off the Southern Brazilian coast, overlaid to the digital bathymetry. The densities are differentiated according to the colour scale on the map.

tal protection area for southern right whales (APA da Baleia Franca), which comprises the area from the southern part of Santa Catarina Island to Praia do Rincão (Brasil, 2000). This conservational area aims to promote the sustainable use of natural resources, as well as regulating tourism, research activities and local traffic of ships and airplanes. However, there are potential stressors for southern right whales in the region, such as the Imbituba Port, marinas, fishing and industrial activities located inside the APA da Baleia Franca. Despite the promotion of initiatives for monitoring its impacts on southern right whales, this port is responsible for the traffic of large vessels. In addition, it is currently expanding its installations, which will result in greater traffic and increasing size of ships.

The creation of more restrictive protection areas around the main southern right whales aggregations around Imbituba and Santa Marta Cape could be a relevant initiative for protecting these important southern right whale reproductive grounds. In this context, we highlight the importance of future monitoring of the southern right whales distribution patterns observed in this study, aiming to identify possible habitat changes that can be indicative of disturbances on this population.

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