Geostatistical density analysis of Southern right whale (*Eubalaena australis*) occurrences along the coast of Santa Catarina, Southern Brazil – preliminary information

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ABSTRACT

Southern Right whales (*Eubalaena australis)* use Southern Brazilian waters as a reproductive wintering ground, particularly between the coast of Santa Catarina Island (27º25'S, 48º30'W) and Cabo de Santa Marta (28º36'S, 48º48'W), in Santa Catarina State. As this region is an important southern right whales wintering ground for these animals which were depleted by commercial whaling in the past, the use of geostatistic tools for monitoring this population can be very useful for the understanding and mapping of right whale aggregations, in order to support the conservation and management of this species, as well as for the adequate planning of economical development and urban expansion projects in order to avoid impacts at in the right whales´ breeding grounds. Therefore, this work aimed to analyze the distribution patterns of right whales observed along Santa Catarina coast, to confirm the hypothesis that the observed events have some systematic patterns, e.g. they are not randomly distributed, and to determine the highest right whale density sites through density estimate maps. The methodology consisted of the analysis of sightings of right whales from aerial surveys conducted between 1987 to 2003 by the Brazilian Right Whale Project, over a track between approximate coordinates 27°S to 30°S along the coastline. Geostatistical analysis of density estimate of the right whale sightings was done using the Kernel Density estimator, with Spring software version 4.3.3. This tool performs a counting of all points inside the influence region, generating a grid, in which each cell represents the intensity value, density and reason between the attributes. A digital bathymetry was constructed and overlaid into the results of density analysis. Kernel Density analysis map pointed out two large regions of right whale aggregations, approximately in coordinates 28.16°S and 28.6°S. The first region is around Ibiraquera beach, in Imbituba city, and the second is located in Santa Marta Cape, demonstrating that these locations have the highest density of whale groups. Other sites had lower densities or no whale occurrences. From the analysis of bathymetric features, it was observed that the largest aggregations described above are situated on places where the coastline shows a high number of bays, where shelf declivity is high and depth increases quickly, as a result from the bathymetric lines of 10m and 40m being close to each other.

KEY-WORDS: SOUTHERN RIGHT WHALE, GEOSTATISTICS, KERNEL DENSITY ESTIMATOR, SANTA CATARINA COAST, BRAZIL

INTRODUCTION

On the Western South Atlantic, Southern right whales (*Eubalaena australis*) have been reported during winter months in Argentina (Payne *et.al.*, 1990), Uruguay (Garcia, 2000; Costa *et al*. 2007) and around Southern and Southeastern Brazilian coasts (Lodi and Bergallo 1984; Câmara and Palazzo 1986; Groch *et al*. 2005; Palazzo and Flores, 1996, 1998; Simões-Lopes *et al.*, 1992; International Wildlife Coalition/Brazil 1999; Santos et al., 2001). From May to December, right whale groups use coastal Brazilian waters as winter breeding grounds. The main site is along the coast of Santa Catarina State, particularly from the central-southern coast of Santa Catarina Island (48º30'W 27º25'S) to Santa Marta Cape (48º48'W 28º36'S) (Simões-Lopes *et al.* 1992; Palazzo and Flores 1996, 1998; International Wildlife Coalition/Brazil 1999). The abundance peak occurs between August and October (Groch *et. al.*,

2005). According to these authors, there are sites with higher right whale concentrations, on shallow waters and protected bays which favor breeding and the protection of calves.

Many authors state that physical oceanographic variables are determinants to site preferences for whale aggregations around the world. In South Africa, Elwen and Best (2004) found associations between right whales and sedimental substracts and gentle slopes. Keller *et al.* (2006) found that sea surface temperature (SST) play an important rule in the distribution of Northern right whales (*Eubalaena glacialis)* in their calving grounds off the Southeastern coast of the United States. Forcada *et al. (*1996) found relationships between fin whale (*Balaenoptera physalus*) distribution and cold and deep waters. Studies on other marine mammals' occurrence also indicated relationships with bathymetric features. For example, Selzer and Payne (1988) found links between the occurrence of *Delphinus delphis* and *Lagenorhynchus acutus* with SST, salinity and depth.

Right whale studies at the species wintering ground in Santa Catarina State that they prefer certain sites for resting and reproduction (Groch, 2000; Groch, 2005; Groch *et al*., 2005). Therefore there must be some factor that attracts whales to those sites, which can probably be bathymetric features, SST and/or ocean circulation patterns.

Since the Santa Catarina coast is such an important reproductive site for right whales and these animals were depleted by commercial whaling in the past, the use of geostatistic tools for managing this species can be very useful. Use of geotechnologies for the understanding and mapping of right whale aggregations can be important in order to support the conservation and management of this species, as well as for the adequate planning of economical development and urban expansion projects so that avoiding impact in the right whales breeding grounds.

Therefore, this work aimed to analyze the distribution patterns of right whales along Santa Catarina coast, to confirm the hypothesis that the observed events have some systematic patterns, that is, they are not randomly distributed, and to determine the highest right whale density sites through density estimate maps.

In order to study right whale spatial distribution patterns, geostatistic analysis, was applied. This tool allows for describing the distribution of the studied elements, identifying atypical observations and searching for spatial distribution patterns (Druck, 2004).

METHODS

Right whale sighting data from 1987 to 2003 were collected by the Brazilian Right Whale Project (www.baleiafranca.org.br). Data collection followed a standard methodology that consists of airplane and helicopter expeditions to search for whales aggregations and photoidentify individuals (see details in Groch 2005 and Groch *et al.*, 2005). For each group sighted the number of whales was registered, as well as group composition and geographic coordinates. The photoidentification of the individuals helped to prevent duplication in the number of whales and errors in the estimates. Such recognition is done through the analysis of callosity patterns in their heads, which is unique for each individual. All sighting data processing was done by the Right Whale Project.

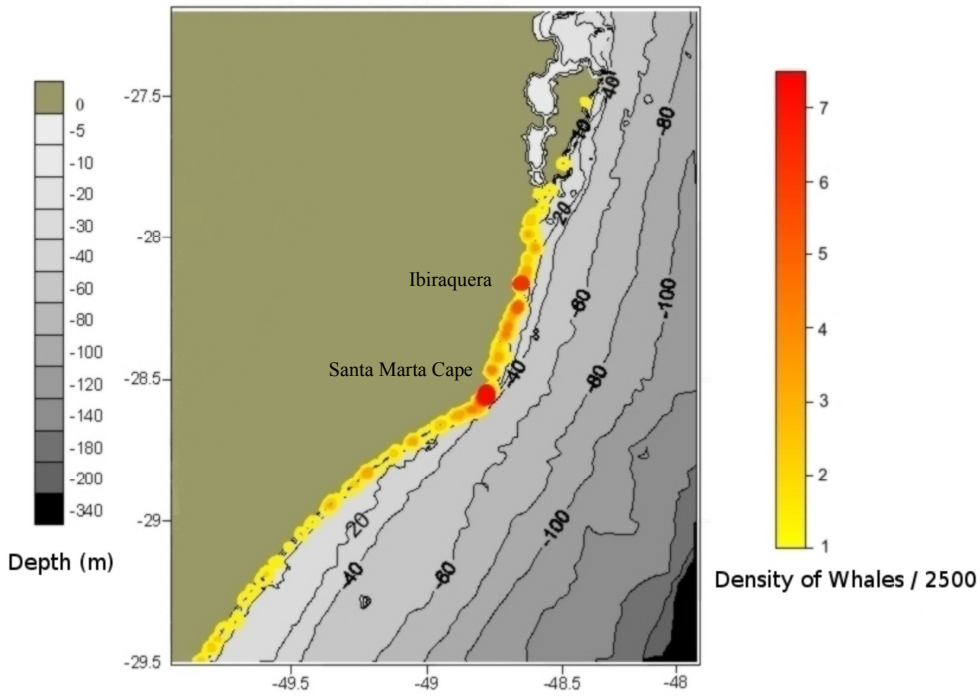
Geostatistic analyses were performed using the Spring software v. 4.3.3. The estimate of sites with higher whale density was performed using Kernel density estimator on simple reason mode and 2500m bandwidth due to the data distribution being concentrated on a narrow line along the coast. Higher bandwidths were tested but resulted in exaggerated extrapolations.

The Kernel method performs an intensity estimate analysis of the punctual process occurrence in all studied 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 area. The aim is to generate a grid in which each cell represents the intensity value and density (Câmara *et. al.*, 1996). Density estimator has been proved to be a very useful tool for giving a general view of events´ spatial distribution.

A digital bathymetry was constructed and overlaid to the Kernel density analysis results with the aim to investigate links between whale concentrations and bathymetric features. The bathymetry was obtained through the nautical chart available at Brazilian Hydrography and Navigation Office - DHN (Diretoria de Hidrografia e Navegação) n°1900, covering the region from Arvoredo Island (48°0'W 27°10'S) to Torres (49°50'W 29°30,20S), with 1:279329 resolution. This chart was georeferenced and digitalized.

RESULTS AND DISCUSSION

The result of this research is illustrated in Figure 1. Kernel density estimator analysis highlights right whale aggregations points, overlaid to the digital bathymetry between longitudes 48°W to 50°W and latitudes 30°S to 28°30'S. Points of higher right whale concentrations are represented in red, gradually turning to yellow, indicating lower concentrations. Sites without filling color, just with bathymetry in grey scale indicate no whales' presence.



F**igure 01**: Map of Kernel density analysis of right whales on Santa Catarina continental shelf.

Through this analysis, it was possible to identify two high right whale aggregations, between 28.16ºS to 28.6ºS. The first aggregation is located around Ibiraquera beach and the second is around Santa Marta Cape. Between these locations there is also a medium right whale density shown by orange shade in the map, indicating that this region has the highest whale aggregation in the surveyed area.

By analyzing whale concentration in relation to the bathymetric features, it was concluded that the higher aggregations described above are located between in an area where the coastline curves, and has a higher number of bays. The higher concentration observed occurs in places where shelf declivity is higher, depth increases quickly, from 28,6°S to the North where the 10m and 40m bathymetric quotas are very close. Nevertheless, there are several bays in which right whale concentrations were low. Therefore, such distribution is probably influenced by another environmental factor which favors right whale presence on specific sites. The hypothesis is that these environmental factors can be SST, ocean circulation patterns, among others, which must be investigated through more detailed studies.

One of the sites with higher right whale aggregation is located close to Santa Marta Cape, where there is an extension of the coast towards the sea. There are some evidences of upwelling in this place, which could play some rule in attracting right whales. However because this is not a feeding area for the species, some other intrinsic factor such as temperature must be investigated. Tinan *et. al*. (2005) found evidence of relationships between the distribution of several cetaceans and upwelling. Jaquet *et. al.* (2002) suggests that oceanographic factors such as submarine topography must influence sperm whales (*Physeter macrocephalus)* distribution. Payne *et. al*. (1990) reported the preference of right whales mother-calf pairs for waters of 5m depth in Península Valdés and also in South Africa, with few sightings on depths higher than 15m. Those authors also identified whales' preference for places close to the coast, behind the breaking wave zone. On the Southern Brazilian coast, the same pattern of distribution is observed in relation to whales´ preference for shallow waters and proximity to the coast (Groch, 2000;

Groch, 2005; Groch *et. al*., 2005). These areas are the preferred habitat of females with calves, mainly because they enable energy conservation by the calves (Lockyer 1981; Thomas and Taber 1984; Corkeron and Connor 1999). Thomas (1987) found that the shallow waters and gently sloping beaches of the Peninsula Valdés, Argentina, are preferred for being areas free from underwater obstacles where whales can drift freely following the tides. In fact, most of the whales in data analysed here were females with calves (see details in Groch, 2005, and Groch *et al.*, 2005). Additionally, it has been suggested that shallow waters offer protection against killer whales (Thomas and Taber, 1984; Thomas, 1987; Corkeron and Connor, 1999; Sironi *et al.*, 2008).

CONCLUSIONS

From the analysis presented in this research, it was concluded that right whales show an aggregation range between 27,5°S and 29,5°S, with the coastline between 28.1ºS and 28.6ºS presenting the highest right whale density. In this region the coastline has a higher number of bays than the southern portion [of what?] and also a higher shelf declivity. In addition, on Santa Catarina's coast right whales are concentrated in shallow depths.

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