Natureza & Conservação
Brazilian Journal of Nature Conservation

Research Letters

Natureza & Conservação 11(1):1-10, July 2013
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Handling Editor: Paulo De Marco Jr.

Distribution of *Tursiops truncatus* in Southeastern Brazil: a Modeling Approach for Summer Sampling

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Abstract

Distribution modeling is a relatively new tool to study cetaceans distribution and is used to understand their relationships with the habitat, which in turn, can be used for several purposes. This is the first attempt to model *Tursiops truncatus* distribution in South- Atlantic Ocean. A Generalized Additive Model (GAM) was developed to investigate how the distribution of *T. truncatus* in Cabo Frio, Brazil, during summer (December to February) is influenced by depth, distance to coast, slope,. Furthermore, we tested the efficiency of a model with number of groups (total occurrence) as response variable compared to a presence-absence data. Our results indicated that total occurrence model was more robust than presence-absence. Dolphins were found regarding to depth most frequently around 30-60 m and decreasing in more profound depths. Dolphins occurrence decreased as distance to coast increased. Our results show that Cabo Frio is an important site for *T. truncatus* since it may provides feeding resources and a safe place against predators. However the fast development of human activities may threaten this important area and therefore this dolphin species in Brazilian waters.

Key words: Bottlenose Dolphin, Cabo Frio, Arraial do Cabo, Habitat Modelling, Distribution Modelling

Introduction

Distribution studies of highly mobile marine species pose challenges for researchers for many years. Marine ecosystems are fluid and dynamic, in which large spatial and temporal differences may be observed in scales from meters to kilometers and on diel to decadal scales (Redfern *et al.* 2006). For large animals, such as cetaceans, the difficulties to study how they distribute are large. This is true because their extended life span, slow reproduction and high capacity of movement (Acevedo-Gutierrez 2008).

Distribution modeling is a relatively new tool to study distribution of cetaceans and intrinsic factors of this taxon (*e.g.* migratory behavior and social organization) hamper the fast development and application of the models (Redfern *et al.* 2006). In general, distribution modeling is used to determine their distribution within a given habitat and allow its use in a conservation biogeography framework (Corkeron *et al.* 2011). For species inhabiting coastal ecosystems, such as *Tusiops truncatus* (bottlenose dolphin) these studies are specially need, due tothe many anthropogenic threats that they are subjected. Some of these threats are: high boat traffic, which can alter dolphins behavior (Lusseau 2003), fisheries interaction resulting in injuries (Nery *et al.* 2008) and diseases resulting from human activities, such as lobomycosis-like disease (Van Bressem *et al.* 2009). Since the conservation of a species depends on the understanding of the relationship between populations and their habitat (Cañadas *et al.* 2005), modeling *T. truncatus* distribution may help to understand which habitats are used with higher frequency and what environmental features (biotic and/or abiotic) will improve their conservation.

Tursiops truncatus have a wide distribution range, occurring in tropical, sub-tropical and temperate habitats (45° N – 45° S; Wells & Scott 2008). In Brazilian waters, *T. truncatus* distribution is continuous from Amapá to Rio Grande do Sul states (IBAMA 2001), also occurring in some islands [Fernando de Noronha (Silva Jr. & Silva 2004), São Pedro e São Paulo (Caon & Ott 2004), Atol das Rocas (Baracho et al. 2008) and Cagarras (Lodi & Monteiro-Neto 2012)].

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Tursiops truncatus is one of the best known species of delphinids around the world, in which some populations have been continuously monitored in long-term [*e.g.* Shark Bay (Connor *et al.* 2000) and Sarasota Bay (Wells 1991)]. Despite being well studied in the world, just a few studies on ecological and behavioral aspects of this species were conducted in Brazilian waters. Distribution aspects in Brazilian waters are known for some areas [*e.g.* Trindade Island (Carvalho & Rossi-Santos 2011), Rio de Janeiro state (Lodi *et al.*, 2008)], but, until the present there is no published study that models *T. truncatus* distribution with environmental variables to the Southwestern Atlantic Ocean.

Since the National Action Plan of Small Cetaceans proposed by the *Instituto Chico Mendes de Conservação da Biodiversidade*, a governmental institute for conservation of biodiversity, reports that an important goal to *T. truncatus* conservation is to better investigate their distribution patterns in Brazilian waters (Barreto 2011), our objectives were to: a) formulate, develop and validate a distribution model to understand how some environmental variables influence distribution of this species in Cabo Frio, Rio de Janeiro state (RJ); b) test the efficiency of models using different response variables.

Methods

The Cabo Frio coast (22° 50’ 21” S; 41° 54’ 37” W-23º 00’ 18” S; 42º 05’ 53” W) is marked by a change in the shoreline from a north-south to a south-west to north-east orientation, and has a steep slope (Figure 1) (De Leo & Pires-Vanin 2006). Throughout the year, there is a mixture of two water masses (the Brazil Current and the South Atlantic Central Water), which is strongly influenced by the north-northeast wind regime, which produces an upwelling phenomenon that is especially prevalent during spring and summer (Carbonel 1998). The upwelling results in high primary productivity and high fish yields, favoring the occurrence of different cetacean species (Keiper *et al.* 2005), compared to non-upwelling habitats. These conditions allow these habitats to be important for these species, especially because cetaceans need high energetic requirements (Costa 2008).

We conducted four monthly boat trips (mean duration 5.8 h, minimum = 3.25 h, maximum = 8.00 h) during the summer (December, January and February) of 2011/2012 (10 boat trips in 2011 and 12 boat trips in 2012) using a 6.5m inflatable boat equipped with a 150-hp engine. Random routes were chosen to maximize coverage of the study area (Figure 1) and when we spotted a group of dolphins we slowed boat’s velocity. From 500 to 500 m we collected GPS location using a GPS GARMIN VISTA CX and number of groups was used as our response variable, since the group size varied greatly from 4 to 120 individuals (R. Tardin unpublished data). Visual counting was the method used to measure group size. We plotted the number of groups on the nautical chart (number 15051, Diretoria de Hidrografia e Navegação) using the software ArcGis®. Our definition of group followed the 10m chain rule proposed by Smolker *et al.* (1992), in which individuals 10m apart from each other were considered as belonging to the same group.

For the purposes of our analysis, the studied area was divided in 99 grids of 2x2km², where for each grid we accounted the number of groups and values of different environmental variables. We built two models using the same explanatory variables but with different response variables. Our response variable was treated in the first model as encounter rate (ER) and in the second model as presence-absence only. Encounter rate was calculated as just the number of sighted groups in each grid/number of days each grid was sampled.

We used the encounter rate in the first model because it assesses the frequency of usage of an area according to the first location of the dolphin group for each sighting (Blasi & Boitani 2012). Number of sighted groups was corrected by the number of days each grid was sampled, because our studied area was heterogeneously sampled. Therefore, if in a given grid we accounted four different groups and we sampled this grid eight different days, until the end of data collection, the final occurrence data was: 4/8 = 0.5 and not four as if it would be if effort was not corrected for each occurrence. Number of sighted groups was used, as done in Forney (2001), Bräger *et al.* (2003), Garaffo *et al.* (2011) and Blasi & Boitani (2012), instead of group size because groups varied greatly in respect of number of individuals.

In the second model, if a group was seen at a given grid we accounted only the presence (*i.e.* one occurrence) regardless how many different days it was observed at the area. The sampling design was corrected by adding an offset with the total number of times each grid was visited in the model.

The environmental variables that we chose as explanatory variables were: mean depth, distance to coast and slope. Mean depth was obtained or derived from the nautical chart, in which the three closest values of depth inside a particular grid from the GPS location were used to provide a mean number. Distance to coast was also measured from the nautical chart and was defined as the closest portion of land from the GPS position, including coastal reefs, islands, shoreline, etc. Slope was calculated following Garaffo *et al.* (2007): $(D_{max} - D_{min})/ DI$, where D_{max} is maximum depth in the grid, D_{min} is the minimum depth in the grid and DI is the distance (m) between the points of maximum and minimum depth, expressed in units of meters per kilometer. The potential distribution map was generated using Krigging technique included in ArcGis 9.2.

To investigate *T. truncatus* distribution we used a Generalized Additive Model (GAM) that is a semi-parametric form of the Generalized Linear Model (GLM). In GAM the only assumptions made is that components are smooth and functions are additive (Hastie & Tibshirani 1990). In this generalized model, there is a link function used to establish a relationship between the mean of the response variable and the smooth function of the explanatory

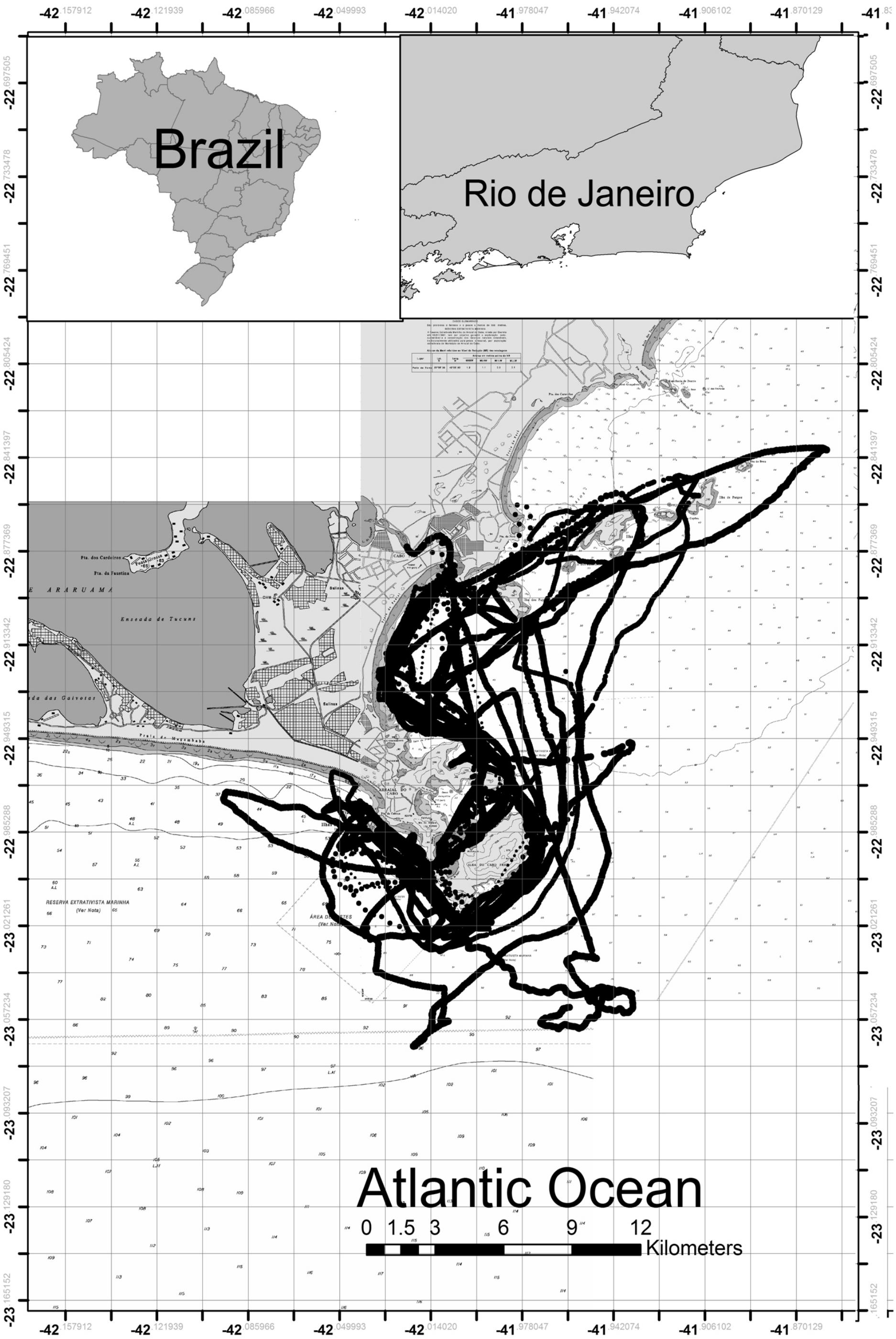

Figure 1. Study area, located at Cabo Frio coast, Rio de Janeiro, Southeastern Brazil. Lines indicate survey routes along the studied area during summer 2011 and 2012.

variable. The advantage in using GAMs is the ability to work with non-linear and non-monotonic relationships between the response variable and the set of explanatory variables (Guisan *et al.* 2002). Furthermore, in GAMs the association between response and explanatory variables derives from data itself and not from the model, because it does not assume any kind of parametric assumption (Yee & Mitchel 1991). Therefore, this model can help to develop more robust ecological relationships (Guisan *et al.* 2002). Therefore, we developed a GAM model using R software (R Core Developmental Team, 2012) with mgcv package (Wood 2011).

Our habitat model that used total occurrence assumed a Gamma distribution error structure, with a link log function. The presence-absence model assumed a binomial distribution error structure with a link logit function. For both models, to avoid overfitting of data, which can make biological data hard to interpret, the degrees of freedom were constrained to 4 (Marubini *et al.* 2009) and the Gamma argument set to 1.4 (Kim & Gu 2004). Therefore, we tested two different models with two different response variables:

- A model using as response variable total occurrence;
- A model using presence-absence of groups as response variable.

Thin Plate Regression Splines were used to adjust the penalized parameters. This method has the advantage of not put explicitly the knots or select the function basis (Wood 2006). Since model selection still is subject to debate, we used two different methods of model selection: Generalized Cross Validation scores (GCV) and Akaike's Criterion Information (AIC). Cross Validation is a technique that iteratively withheld subsets of original data to provide the best fit models (Redfern *et al.* 2006). The 'mgcv' package uses an automated generalized cross-validation for model fitting (GCV score), which has the advantage to effectively choose the degree of freedom when parameter scale is unknown (Wood 2006). This method was used in some cetacean distribution modeling (*e.g.* Gilles *et al.* 2011, Anderwald *et al.* 2012, Dalla-Rosa *et al.* 2012). The lowest the GCV score the best fit a model has. The AIC is a method that calculate the explanatory power of a variable against the decrease in the degrees of freedom while decreasing the number of variables included in the model, which reduces the bias in the model (Redfern *et al.* 2006). This is a largely used criterion for model selection in cetacean literature (*e.g.* Marubini *et al.* 2009, Garaffo *et al.* 2010, Keller *et al.* 2012). This criterion ranks models according the value of AIC of each model, in which the lowest value represent the most parsimonious model and therefore more plausible. Models presenting differences less than two were considered to have equivalent support (Burnham & Anderson 2002).

Furthermore, the method used to adjust the parameters was also useful at model selection because they present features that penalize the smoothing process, which includes a shrinkage component. Thus, when parameters are very large the smoothing becomes zero. This allows an automatic selection of the parameters that removes the model term (Wood 2006).

Results

We conducted twenty-two boat trips with 125.7 hours of effort and 8.3 hours of direct observation (6.6%). The suitability map shows the higher values near the islands far from the continent (Figure 2). A total of 36 *Tursiops truncatus* sightings were made and dolphins sighting rate was of 0.11 dolphins/grid, in which highest encounter rates are also around islands far from the continent (Figure 3). We observed dolphins in depths that varied from 12.7 to 83 m, from 0.3 to 3.8 km of the coast and maximum slope of 0.08 (Table 1).

The GAM using total occurrence as response variable explained 24.3% of the variance and variables retained in the final model were depth and distance to coast (Table 2). In this model, the relationship between depth and number of groups corrected by the effort had a peak of observations around 30-60 m with a slight decrease in deeper depths (Figure 4a) and a decrease in occurrence as distance to coast increased (Figure 4b).

The GAM using presence-absence data explained 33.9% of the variance and distance to coast and slope were retained in the final model (Table 2). In this model, the relationship between distance to coast and number of groups corrected by the effort showed an increase in occurrence as distance to coast increased (Figure 5a) and a decrease of occurrence as slope increased (Figure 5b). Both model selection criteria selected the total occurrences model as the best and most parsimonious model (Total Occurrences Model – d.f. = 11.5, AIC = –347.4 – GCV score = 2.76; Presence-absence Model – d.f = 10.8, AIC = 100.8 – GCV score = 71.4).

Discussion

Until now, this is the first study to model *T. truncatus* distribution in Southwestern Atlantic Ocean. The suitability and ER distribution maps showed that some highest values were found near the islands far from the continent. This occurred since these areas were less surveyed and almost always we sighted groups of dolphins. Our results indicated that the model that quantified the number of groups inside

Table 1. Summary statistics of explanatory variables where at least one group of *Tursiops truncatus* was observed in Cabo Frio, RJ, Brasil.

Variables	N	Mean	Median	Mode	SD	CV (%)
Depth	27	40.0	38	Multiple	16.8	42.0
Distance to coast	27	1.5	1.4	0.3	1.2	75.3
Slope	27	0.02	0.02	0.0009	0.02	96.1

Table 2. Generalized Additive Model results for Total Occurrence and Presence-absence Model for *Tursiops truncatus* in Cabo Frio, RJ, Brasil. D.F = Degrees of freedom.

Total Occurrence Model (F-ratio)			
Variables	D.F.	Estimate	P
Depth	2.1	5.0	<0.001
Distance to coast	2.4	10.3	<0.001
Slope	1.7	1.6	0.2
Presence-absence Model (F-ratio)			
Depth	1	0.3	0.6
Distance to coast	1	6.3	<0.001
Slope	1.8	6.5	<0.001

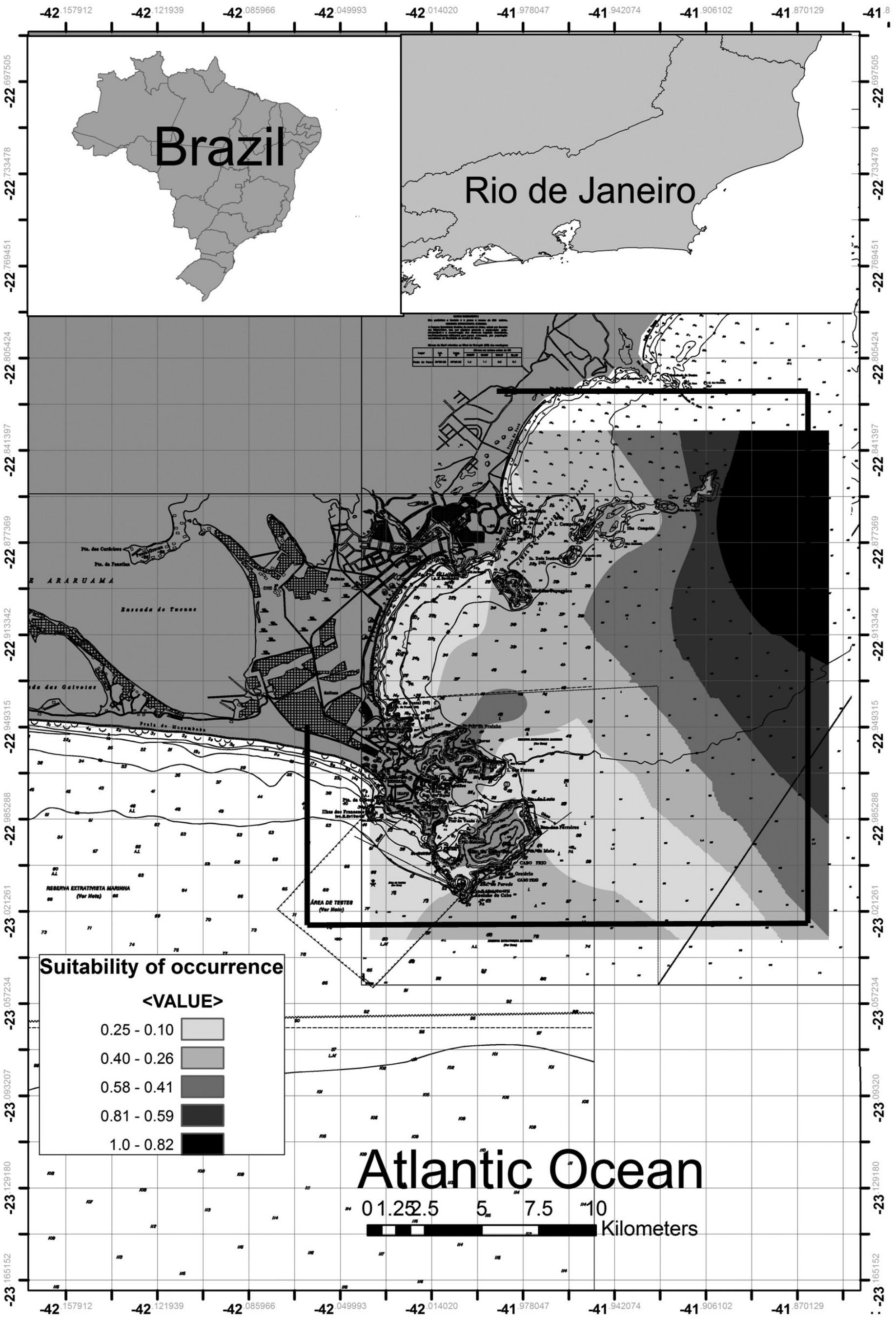

Figure 2. Suitability of occurrence given the empirical data for *Tursiops truncatus* located in State of Rio de Janeiro, Southeastern Brazil. Continuous black line delimitating a sub-area, inside the study area, indicates where boat trips were conducted. Grids in blank accounts for no observation.

each grid corrected by the effort presented a more robust framework to understand what environmental variables influenced *T. truncatus* distribution in Cabo Frio. This suggest that measuring the number of groups in quantitative way, presenting sighting rate data, may provide a more complete and solid understanding of species distribution models. Indeed, by only accounting presence-absence data, the model presents a more qualitative than quantitative data. However, in many situations this is the only way to register cetaceans distribution and yet, provide a solid database to develop a distribution model (*e.g.* Viddi *et al.* 2010). However, few studies compared model robustness regarding to different response variables as we did in the present study. In a study conducted in Golfo Nuevo, Argentina, that modeled dusky dolphin (*Lagenorhynchus obscurus*) distribution, the model with presence-absence data was more robust than with gamma error structure (Garaffo *et al.* 2010). In our case, we showed that total occurrence data produces

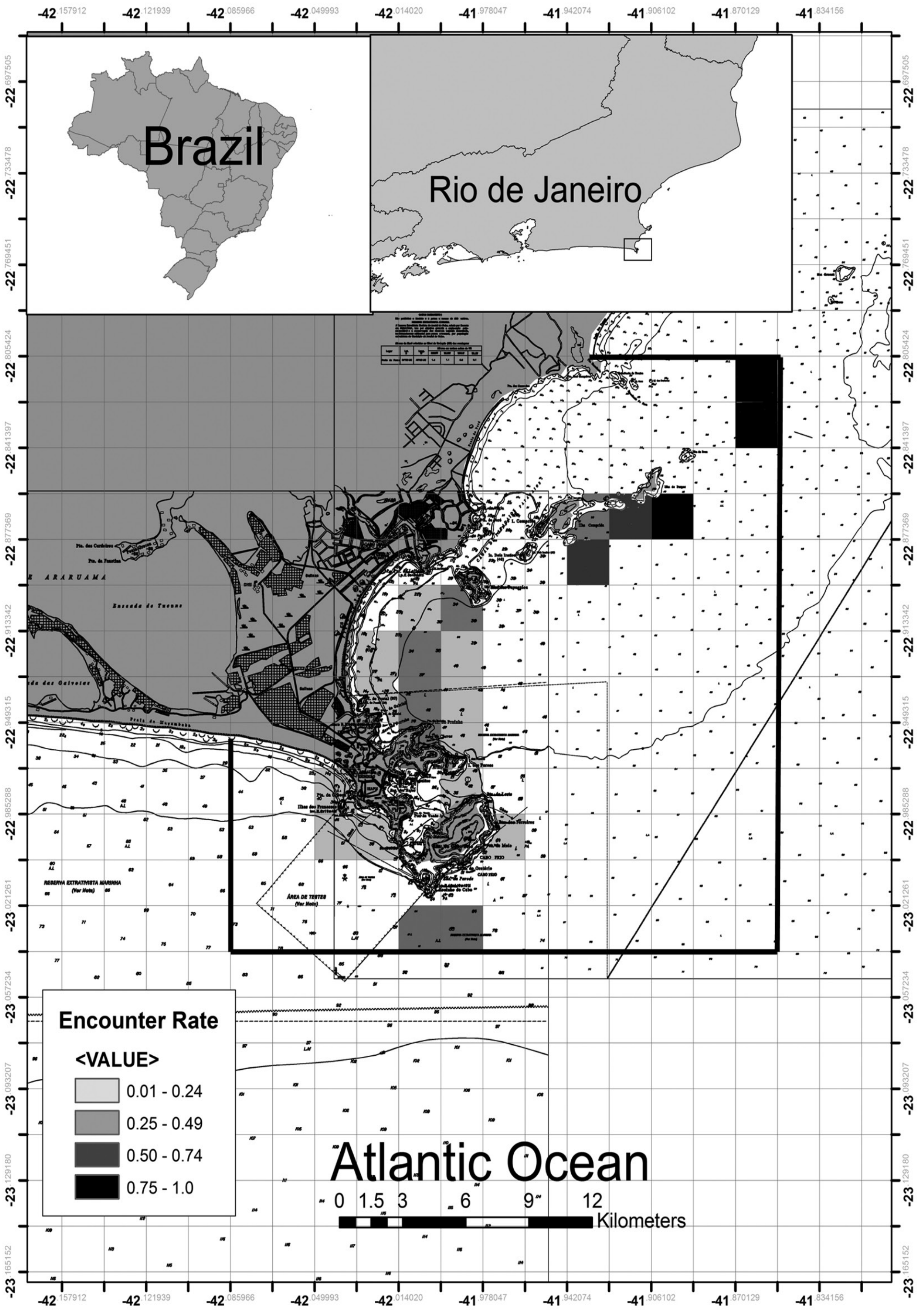

Figure 3. Study area showing encounter rates for *Tursiops truncatus* in each grid at Cabo Frio, Rio de Janeiro. Continuous black line delimitating a sub-area, inside the study area, indicates where boat trips were conducted. Grids in blank accounts for no observation.

better models than presence-absence data for *T. truncatus* and this approach must be used to better understand the distribution of this species in Cabo Frio.

In total occurrences model, depth and distance to coast were retained at the final model. Our results indicated that during summer, dolphins had a preference for waters around 30-60 meters of depth. According to Wells & Scott (2008), *T. truncatus* have an opportunistic feeding habit, preying pelagic, demersal or benthic species. Therefore, the distribution observed at the area, occupying different depths, may be a reflex of its feeding behavior, in which dolphins may be using these habitats to forage in search for potential prey, the most frequent behavior observed during the period (unpublished data). In fact, cetaceans have to be constantly foraging to attend their high energetic demand (Costa 2008). The influence of depth over *T. truncatus* distribution is reported to other regions. In a study conducted with this species in Alborán Sea, Spain, it was reported that depth significantly influenced *T. truncatus* distribution, in

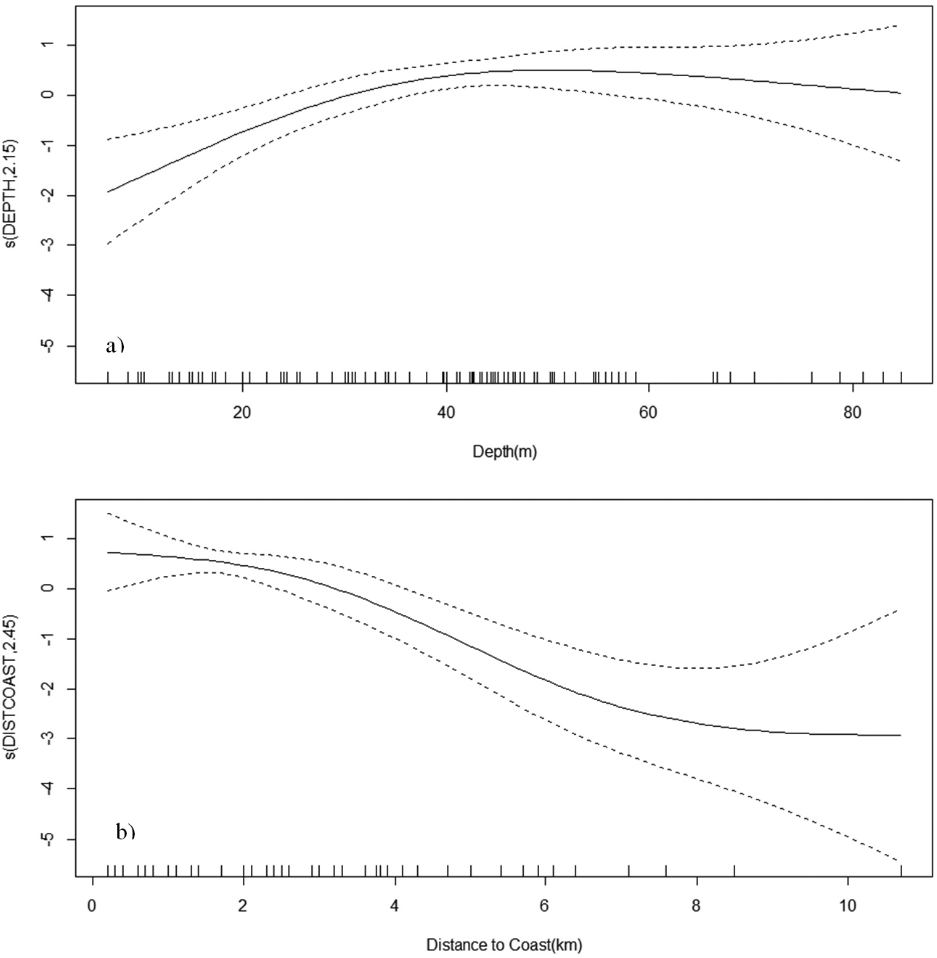

Figure 4. Generalized additive model smoothing curves for total occurrences model showing only significant parameters on *Tursiops truncatus* in Cabo Frio, RJ, Brazil. Y axis represents spline smooth functions and degrees of freedom are shown in parenthesis. Tickmarks in X axis indicate distribution of observations (with and without sightings). Dashed lines designate 95% confidence interval for smoothing functions. a) Depth, b) Distance to coast,

which the highest encounter rates were around 200m, the shallowest of the region (Cañadas *et al.* 2002).

Our model indicated that dolphins' occurrence was highest near the coast and lowest far from the coast. As the variable distance to coast included the closest portion of land from coastal reefs, islands and shoreline, the highest encounter rate around the islands far from continent (Figure 3) may have driven the model to select highest occurrence near the coast than far from the coast. In other words, coast in this case is not necessarily the same as continent. Thus, the distribution closer to the coast (mainly around the islands) as we observed in our study may also be a reflex of their feeding behavior. In this situation, dolphins may be searching for food near rocky coast, since some fishes that live associated to these habitats are part of *T. truncatus* diet (*e.g. Diplodus argenteus* (Di Beneditto *et al.* 2001)). Similarly, in a study conducted in northeast Scotland, *T. truncatus* were seen in regions closest to the coast (Bailey & Thompson 2009), as well as in a study carried out in Mediterranean Sea (Azzelino *et al.* 2012), corroborating our findings.

Tursiops truncatus living in close association with islands is not uncommon in the literature [*e.g.* Azores island, Portugal (Silva *et al.* 2008), Trindade island, Brazil (Carvalho & Rossi-Santos 2011), Aeolian archipelago, around French and Italian waters (Blasi & Boitani 2012)]. These habitats may be source of food resources and dolphins may gather around them to forage. The associated ictiofauna of the region presents fishes of tropical and sub-tropical species, in which most of them are omnivorous (Ferreira *et al.* 2004) and therefore, dolphins must be plastic in their behavior to take advantage from the situation.

Our results show that Cabo Frio is an important area for *T. truncatus* during summer. This region may provide energetic resources that are important to maintain these highly energetic predators. Moreover, Cabo Frio may be a valuable spot for these animals since it may represent a safer place than open ocean areas, in which predators such as *Orcinus orca* (Killer whales) and large sharks, such as

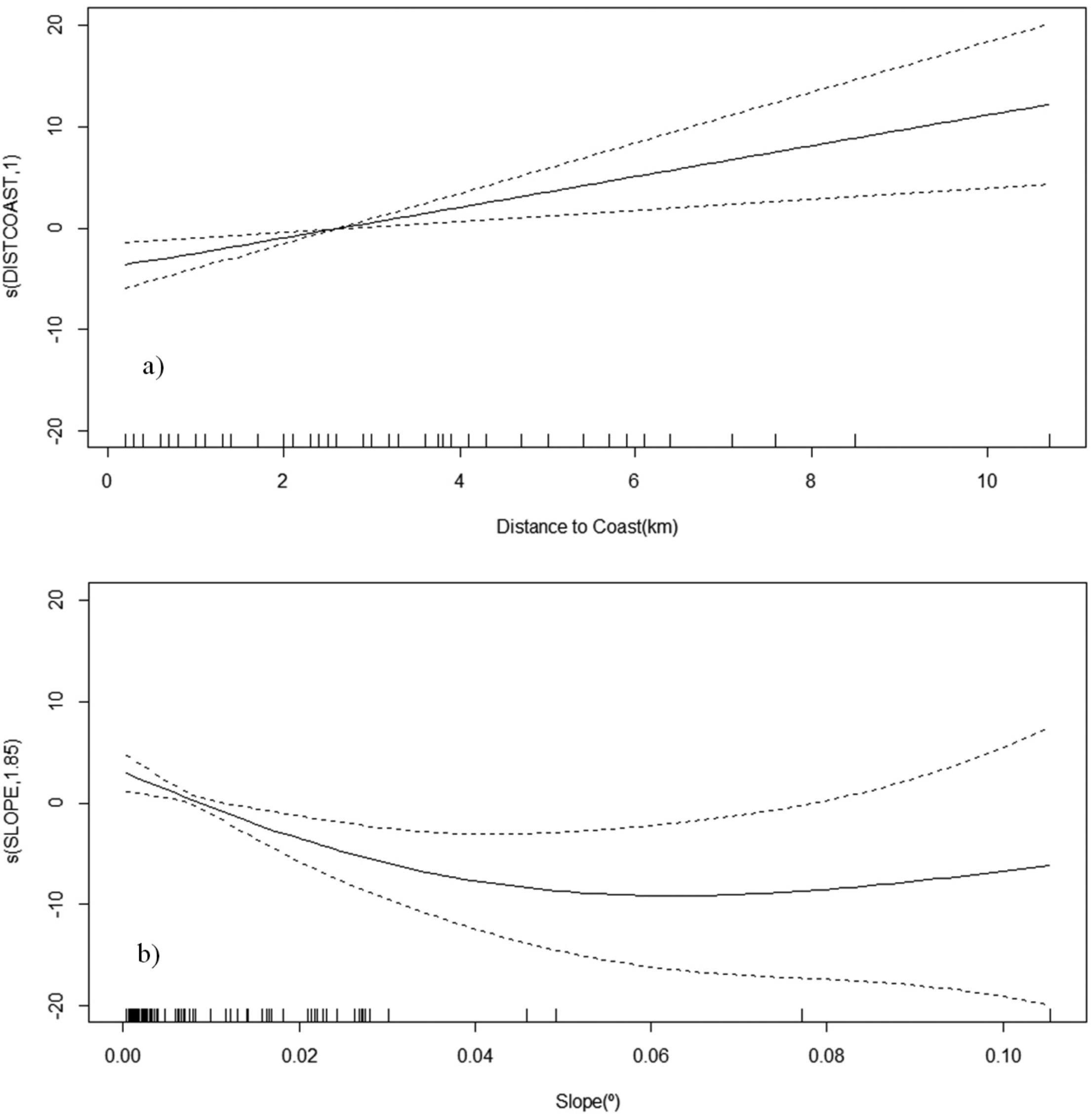

Figure 5. Generalized additive model smoothing curves for presence-absence model showing only significant parameters on *Tursiops truncatus* in Cabo Frio, RJ, Brazil. Y axis represents spline smooth functions and degrees of freedom are shown in parenthesis. Tickmarks in X axis indicate distribution of observations (with and without sightings). Dashed lines designate 95% confidence interval for smoothing functions. a) Distance to coast, b) Slope.

Sphyrna spp. threatens their survival, especially for calves. This seems to be true because Cabo Frio has a steep slope and connection with open ocean is, thus, closer. Therefore, the distribution pattern inside Cabo Frio region may be driven not only by feeding purposes but as a defense strategy against open ocean predators.

However, the fast human development in Cabo Frio may threaten this important area in terms of food resources and shelter against predators. The increasing fishing and touristic activities, especially during summer, are intense and may alter dolphins' behavior as seen in other places (*e.g.* such as in New Zealand - Lusseau 2003). Despite dolphin watching tourism seems not to be constant at the region, a high number of touristic and fishery boats, may be affecting their behavior. Thus, these activities may restrict dolphins' patterns of distribution in Cabo Frio, in which they could be avoiding areas with high concentration of boats and therefore constraining their home range. More data are needed to test this hypothesis, but these considerations may help to investigate if there are seasonal shifts of distribution driven by anthropogenic factors in Cabo Frio.

The formulation, development and validation of distribution models to the species at the area will allow a deeper understanding of how *T. truncatus* uses the region. This knowledge may allow that effective conservation actions may be used, especially in this highly touristic area. Furthermore, to understand the processes that drive the distribution of the species in this area is a beginning to understand general patterns that may influence *T. truncatus* distribution in Southwestern Atlantic Ocean.

Acknowledgments

We thank Sergio S. Moreira, Elaine Fidalgo and Lélis Antonio Carlos Junior for ARCGIS support. Luciana D. Figueiredo, Israel S. Maciel, Liliane Lodi, Marco Aurelio Crespo and Elaine C. S. Oliveira for their valuable support in the field. The authors gratefully acknowledge research grants from Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq (Grant # 479348/2010-3). We also thank the Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ) for scholarship to R.H.O. Tardin, (Process # E-26/100.866/2011) and Conselho Nacional de Pesquisa e Desenvolvimento for Productivity Grant to M.A.S. Alves (Process # 308792/2009-2).

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Received: January 2013
First Decision: February 2013
Accepted: May 2013