Density, abundance and distribution of the guiana dolphin, (*Sotalia guianensis* van Benéden, 1864) in Sepetiba Bay, Southeast Brazil

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ABSTRACT

Line transect surveys were conducted from August 2002 to July 2003 to examine the abundance and distribution of the guiana dolphin (*Sotalia guianensis*) in Sepetiba Bay-Southeast Brazil. A boat-based platform and 50 pre-determined line transects were used to assess the population on two main stratum-specific environments of the bay (entrance and interior). A total of 3,140km of transects were surveyed at 12-15km hr^{-1} and good sea conditions (Beaufort 0-2), resulting in 157 sightings of dolphin groups and 129 sightings after truncation of all sightings beyond 400m. From the 129 sightings the *DISTANCE* program generated a population density of 2.79 dolphins km^{-2} and calculated a population of 1,269 individuals (CI=739-2,196) for the bay. Sighting frequency (n=126 or 80.3%) was higher at the entrance of the bay compared with the interior (n=31 or 19.7%), although, the density and abundance were similar for the entrance (2.91 dolphins km^{-2} and 596 dolphins) and interior (2.69 dolphins km^{-2} and 672 dolphins). Results reveal an important population of guiana dolphin at Sepetiba Bay, the largest thus far studied off the South American coast, stressing the importance of the area for the conservation of this species. The study also indicated that line-transect sampling carried out from small boats in large bays can produce statistically robust estimates and therefore could be recommended for population monitoring in other areas of the Brazilian coast with similar characteristics.

KEYWORDS: CETACEANS; DISTANCE SAMPLING; SOUTH AMERICA; GUIANA DOLPHIN SURVEY-VESSEL; ABUNDANCE ESTIMATE; DISTRIBUTION; STATISTICS

INTRODUCTION

The guiana dolphin, *Sotalia guianensis*, is one of the smallest dolphins and is commonly seen in coastal areas of the southwest Atlantic Ocean. Its distribution ranges from Honduras in Central America to Santa Catarina in southern Brazil (Da Silva and Best, 1996). For the last ten years, a number of studies on reproduction, ecology and human impacts have been carried out on this species in Brazilian waters (Arruda Ramos *et al*., 2000; Rosas and Monteiro-Filho, 2002; Santos *et al*., 2001). However, very little information on population size and dynamics is available, despite the importance of these parameters for the successful management of cetacean populations.

The genus *Sotalia* is listed as Near-Threatened by the Brazilian list of threatened species (Machado *et al*., 2005) and IUCN (IUCN, 2007; Reeves *et al*., 2003). However, as anthropogenic activities have been increasing throughout the species' near-shore habitats, it is possible that some populations are at risk. Therefore, there is an immediate need for assessment of population sizes and threats from fishing activities (Reeves *et al*., 2003). In Sepetiba Bay, the guiana dolphins are known to be threatened by fishery activities and a variety of skin lesions (Flach *et al*., 2008b). The first documented case of Tattoo Skin Disease (TSD) for the species throughout its distribution was found here (Van Bressem *et al*., 2007).

There is little information on the status of the guiana dolphin population in the vast littoral of Brazil. Therefore the goals of this study were: (1) to estimate the abundance and density of one population of this species in Brazil; and (2) to evaluate the feasibility of using distance sampling techniques to estimate these parameters.

METHODS

Study area

Sepetiba Bay is an embayment located in the southern coast of Rio de Janeiro State (22°54'-23°04'S, 43°36'-44°02'W), southeastern Brazil (Araújo *et al*., 2002). The bay has a surface area of 526km² and an average depth of 8.0m, with some dredged channels 20-30m in depth. It is delimited in its southern portion by a sand spit, which separates it from the Atlantic Ocean, and in its northern portion by mountain chains and sandy beaches separated by rocky shores. Large mangrove areas and river drainage systems delimit the eastern part of the bay, with the western side containing a number of islands and rocks, and also the main connection with the Atlantic Ocean (Fig. 1). The western half of the bay exhibits characteristics of a coastal zone due to the influx of water from the Atlantic Ocean 'entrance', whereas the eastern region presents estuarine characteristics resulting from the influence of discharges from the rivers and the presence of the mangroves 'interior'. Over the last decade the area has been suffering considerable pressure stemming from the loss of mangrove areas, increasing industrial outflows, port activities, and industrial fishing activities (Araújo and De Azevedo, 2001; Pessanha and Araújo, 2003).

Survey design and data collection

Pilot surveys were conducted in Sepetiba Bay for three months in 2002 to evaluate the feasibility of the method in the region, and also to provide training for the observers. Systematic boat-based surveys were then conducted from August 2002 to July 2003. Two different stratum named 'entrance' and 'interior', as defined above, were considered

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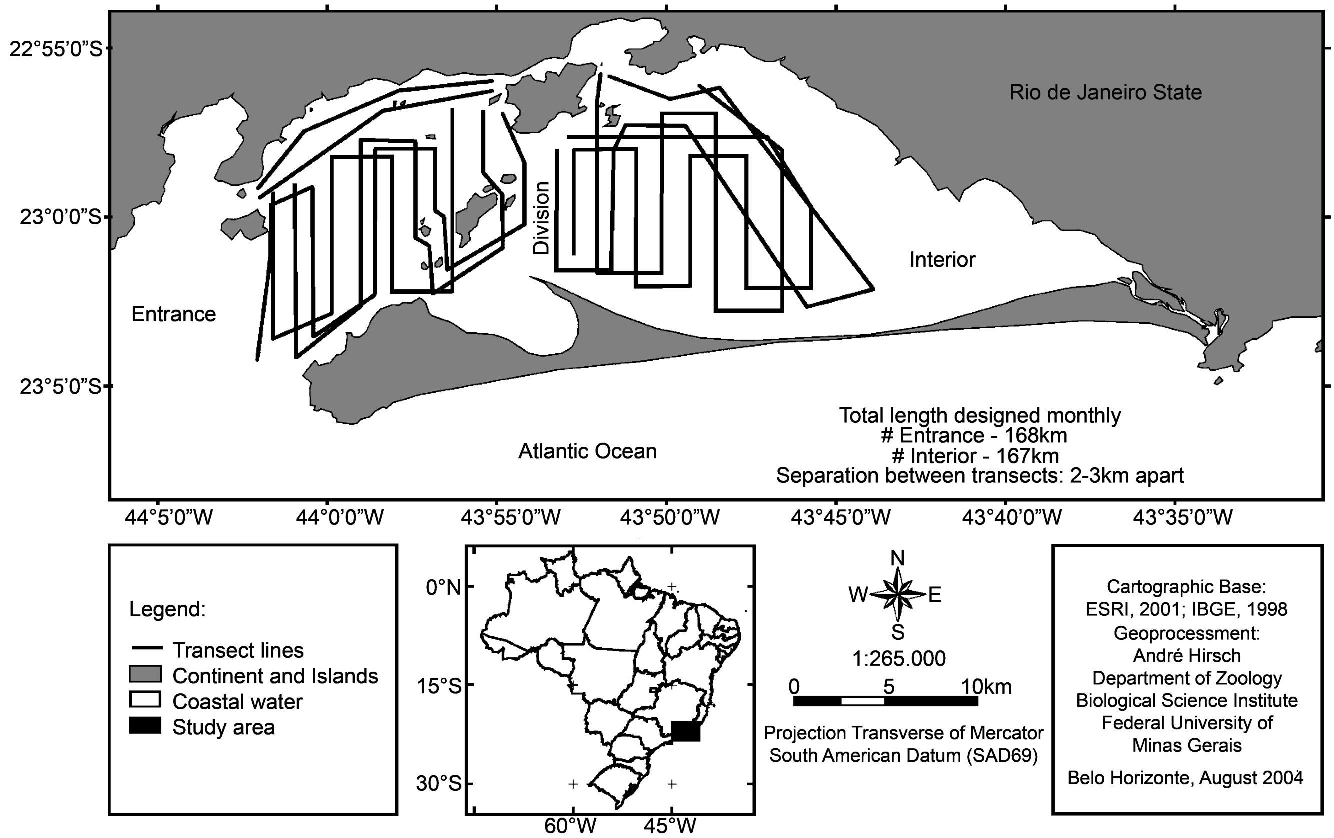

Fig. 1. Map of the study area showing the transect lines surveyed monthly at Sepetiba Bay, Rio de Janeiro state, southeast Brazil.

during the surveys. The density estimates were extrapolated only to the area surveyed at the entrance (205km^2) and at the interior of the bay (250km^2). Surveys were conducted at the 'entrance' and 'interior' of the bay with 25 transect lines placed for each stratum. Both strata had three different series of transect lines, two series had four main transects and one with five (8km of length on average each) placed in a north-south direction to cover different bathymetry. There were also intermediate transects (2-3km of length on average each) placed in east-west direction to connect the main transects. These intermediate transects were not used to estimate density, but were included in detection function and distribution analysis. The series were surveyed on different days, totaling six surveys per month covering the transect lines from the entrance and interior of the study area (Fig. 1).

The starting directions of pre-defined routes were alternated to assure coverage at different times of day. Surveys were conducted from a fiber hull boat 7.5m long equipped with a 225hp outboard motor, traveling at an average speed of 12-15km hr^{-1}. Two observers (one simultaneously drove the boat), were located near the bow at an eye-height of 2.2m above sea level and they alternated their position each time a transect was completed. A hand-held GPS unit was used to maintain a constant speed and correct course of the boat along the transects. Observations were conducted by naked eye, but the observer that was not driving the boat used TASCO 10×50 binoculars during some scans. A stopping mode survey was used, in which at every sighting, the effort is stopped and the boat leaves the transect line to record data. The main reason to use stopping mode was because during the pilot surveys, the guiana dolphins were commonly sighted in large groups whose sizes were difficult to estimate, even at close range, without stopping the boat.

When a group of dolphins was sighted either by naked eye or with binoculars, the speed of the boat was reduced, and the sighting angle was measured using a hand-held sighting compass (*Suunto* KB-20/360), and the radial distance (boat-dolphin group) was estimated by eye (to increase precision and accuracy of these visual estimates, usually before starting each survey, the observers used an optical rangefinder (*Range* 19-400m) to train distance estimation using buoys, boats and other floating objects as targets). After the angle and distance measurements were taken, the boat position was recorded using a GPS and search effort was temporally suspended. The group of dolphins was approached quickly in order to collect data on position, number of individuals, behaviour and environmental parameters. Once data collection was complete, search effort was resumed from the same position as the boat had been before stopping.

Analyses

Stratum-specific and global estimates of density and abundance were obtained using the program *DISTANCE* Version 5.0 (Thomas *et al*., 2002). Only data gathered under excellent sea state conditions (Beaufort 0-2) were included in the analysis. In order to remove outliers and improve the fit of the detection function (Buckland *et al*., 2001), perpendicular distance data were truncated at 400m. This resulted in the exclusion of about 10% of all observations. The detection probability was estimated using the Conventional Distance Sampling (CDS) and Multiple Covariate Distance Sampling (MCDS) approaches (Buckland *et al*., 2001; 2004; Marques and Buckland, 2003). Included covariates were 'method' (sightings with or without binoculars), 'Beaufort sea state', 'observer' and 'season'. Information on proposed models and covariates, with the final model used to estimate abundance are listed in

(Table 1). Exploratory analyses (regression of group size versus detection probability; Buckland *et al*. (2001)) indicated that detections were independent of group size. Therefore, mean group sizes were used to estimate abundance with CDS models. For MCDS models, individual group sizes were used in the estimation of the detection probability and an estimate of the expected mean group size was obtained as suggested by Marques and Buckland (2003). Abundance was computed using a Horvitz-Thompson-like estimator as described in Marques and Buckland (2003). Variance was obtained by bootstrap re-sampling samples as implemented in *Distance* 5.0 (Buckland *et al*., 2001; Thomas *et al*., 2002). When group size was used as a covariate, abundance and variance were computed for the whole survey area, while for models with other covariates, stratum-specific abundances were obtained. Global abundances were the sum of the stratum-specific abundances and for this study, the probability to detect dolphins on the trackline was $g(0)=1$.

Table 1

Models and covariates used to estimate the abundance according to AIC. The model selected according to the smallest change in AIC (delta AIC) is shown in **bold**.

Key function	Covariate	Covariate type	Covariate levels	Delta AIC
Hazard Rate	**Method**	**Factor**	**2**	**0.00**
Half Normal	Method	Factor	2	2.80
Hazard Rate	Beaufort	Continuous	3	10.34
Half Normal	Observer	Factor	2	11.02
Hazard Rate	Observer	Factor	2	11.15
Hazard Rate	Season	Factor	2	11.53
Half Normal	Beaufort	Continuous	3	11.56
Half Normal	Season	Factor	2	11.62

RESULTS

A total of 3,140km were surveyed in good sea state conditions (Beaufort 0-2), approximately 75% of the proposed trackline. A total of 169 sightings were made during the surveys, 157 of which were under Beaufort conditions between 0-2. This effort (3,140km) and sighting number (157) were included in the analyses detailed below.

The spatial distribution of sightings in the study area was uneven, with significantly more sightings (n=126 or 80.3%) and a higher encounter rate (0.61km^{-1}) at the entrance than at the interior of the bay (n=31 or 19.7%; encounter rate=0.24km^{-1}) (Chi-square with Yate's correction: χ^2=54, 396; d.f.=1; P<0.001). Regardless of the season, sightings made at the entrance were spread widely, with a slight concentration in the more central area. In contrast, the majority of sightings in the interior of the bay were made near the border between the entrance and interior, with a decreasing number of sightings as the distance from the entrance increased (Fig. 2).

A total of 129 sightings were retained for analyses after truncation of perpendicular distances and they were grouped in seven equal intervals for fitting the detection function (see Fig. 3). An exploratory analysis (covariate Method) indicated that the covariate 'observer' (sighting with binoculars or with naked eye), was the most important of all covariates included (Beaufort sea state, observer, season) to estimate detection probability, and from all proposed detection function models, the hazard rate model with no adjustments terms was selected according to Akaike Information Criterion (Akaike, 1973) as shown in Table 1.

A global density of 2.79 dolphins km^{-2} (2.5%-97.5% of the bootstrap estimates CI=1.62-4.82 dolphins km^{-2}) was estimated for the study area, generating an abundance of 1,269 dolphins (2.5%-97.5% of the bootstrap estimates CI=739-2,196 dolphins). There was no significant difference in the estimates between strata, with slightly higher estimates of density (2.91 dolphins km^{-2}) and abundance (596 dolphins), for the entrance than the interior (2.69 dolphins km^{-2} and 672 dolphins, respectively) as shown in Tables 2 and 3.

DISCUSSION

Feasibility of method

There are some important assumptions to be met in line-transect sampling. The main assumption is that all objects located on the trackline are detected by the observer, i.e. $g(0)=1$ (Buckland *et al*., 1993). Although the height of the observer's platform was relatively low, we judged that this assumption was met (or rarely, if ever, violated) in the present study because the dive time of the guiana dolphin from this area is short (often <70s/dive; L. Flach, unpublished data). In addition, the group sizes were large and only sightings from excellent sea conditions were analysed. These three factors reduce the chance of a dolphin group being missed along the transect line, even from the platform used. It is also relevant to mention that if a small bias resulted from this, then the resulting estimates (density and abundance) would be negatively biased and, consequently, the estimates presented here could be considered conservative.

The second main assumption states that objects (or animals) should not make responsive movements prior to detection by observers and that no objects are counted twice in the same sample (Buckland *et al*., 1993). Throughout the surveys, there was no indication that the dolphins approached or avoided the boat platform prior to detection. Rather, the dolphins appeared to be habituated to the intense boat traffic in the study area, presenting a neutral behavioural response to the survey platform. However, since the survey was not conducted in passing mode and that the boat platform left the trackline to approach the dolphins, there was potential for double counting from the same sample. In order to avoid this, one observer monitored the movement of the group sighted before the survey effort was resumed, and if this group positioned itself ahead of the trackline again, it was not recorded as a new sighting. In fact, in only three out of 169 sightings (1.8% of the cases) was there doubt about double counting and all these three cases were discarded from the analysis. It is also important to mention that the speed of the boat (12-15km hr^{-1}) was much faster than the average travelling speed of the guiana dolphin in the area (4-6km hr^{-1}; L. Flach, unpublished data), further decreasing the chances of double counting.

The third main assumption states that the angle, distance and group size are measured without errors (Buckland *et al*., 1993), something that is strongly dependent on the experience and training of observers. Angle readings might have been affected occasionally, because the angles were measured from a small boat, which drifts away from the transect line more easily than a larger boat, but the recordings were performed as quickly as possible before stopping the boat and with no rounding error. The latter was assessed by plotting the sighting angles in a histogram, which showed a scattered distribution. The same was done for sighting distances and there was also no indication of rounding errors for this variable. The training in sighting

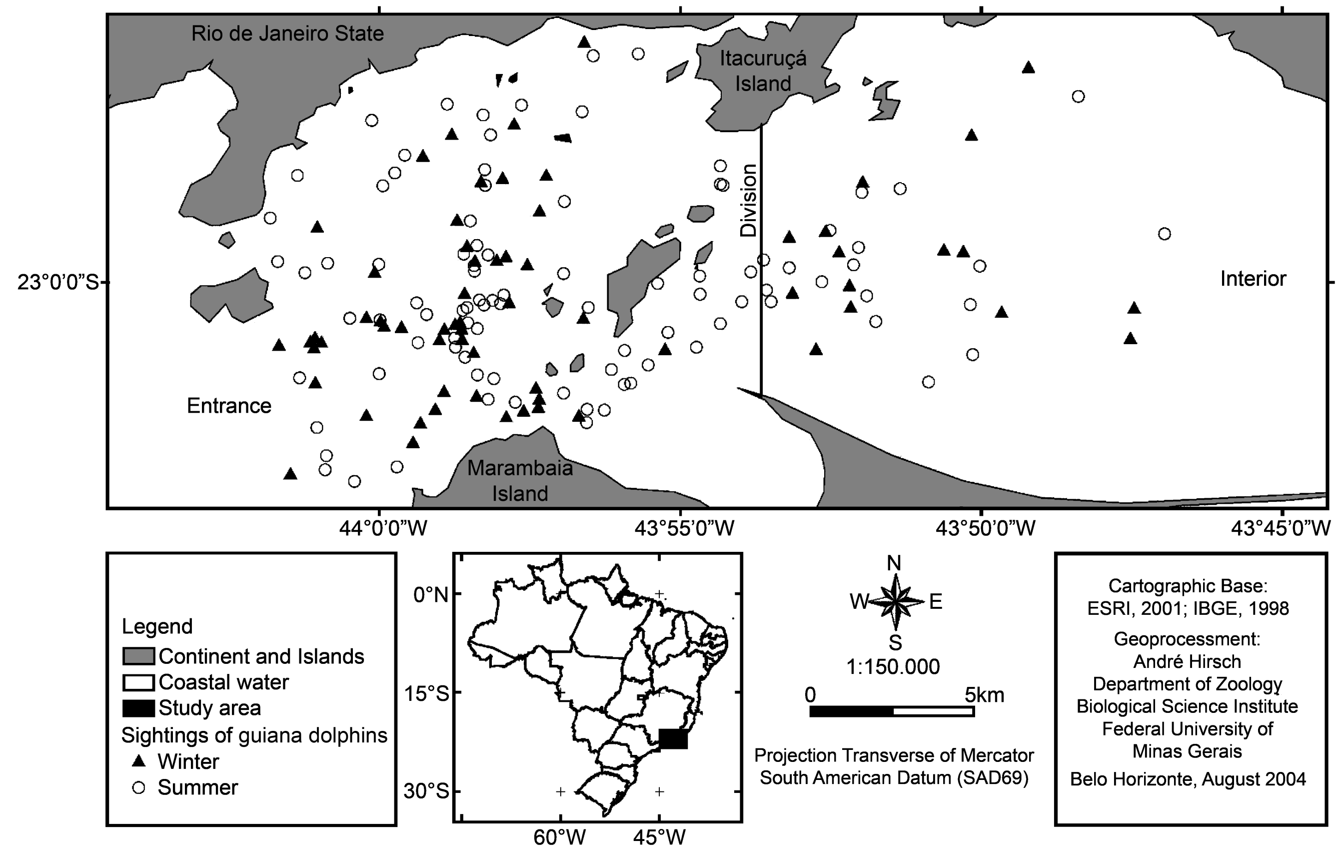

Fig. 2. Seasonal distribution of all on-effort sightings of *Sotalia guianensis* at Sepetiba Bay, southeast Brazil, during calm (Beaufort 0-2) sea states.

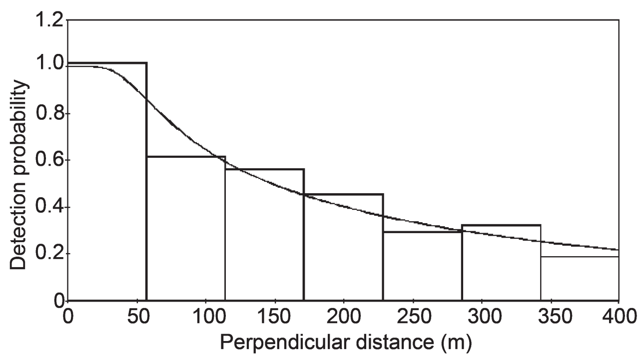

Fig. 3. Detection probability of guiana dolphins according to distance from the track-line during survey effort. The curve (line) represents the model that best fit to the observed values (bars) as determined by program *DISTANCE* (Hazard-Rate with no adjustments terms truncated for all sightings beyond 400m).

distance estimation (described earlier) before each transect sampling exercise with the aid of a rangefinder was important in reducing these errors. Additionally, inspection of the histogram of perpendicular distances did not show any signs of 'heaping' (Buckland *et al*., 1993). Finally, the grouping of distances into classes minimised possible bias in distance estimation, as recommended by Buckland *et al.* (1993). Regarding group size estimation, every dolphin group was approached before counting the individuals, both observers participated in estimating group size and a consensus estimate for 'best' group size was used.

Ecological aspects of distribution

A significant difference in the number of sightings and encounter rate was observed between the entrance and interior. The distribution and abundance of cetaceans are frequently directly influenced by distribution and movement

Table 2

Global density, abundance estimates and related parameters calculated with the program *DISTANCE* for guiana dolphins in Sepetiba Bay, Rio de Janeiro.

Parameter	# Bootstrap	Point estimate	% CV	95% CI	2.5%-97.5% CI
Global estimate (Entrance and Interior)					
p	-	0.49	7.38	0.424-0.568	-
Effective search half-width (m)	-	196.6	7.38	169-227	-
f(0)	999	0.481	21.58	-	0.361-0.731
Density of groups (groups km^{-2})	999	0.896	24.69	-	**0.144-0.585**
Density of individuals (ind km^{-2})	999	2.79	28.50	-	1.62-4.82
Abundance	999	1,269	28.50	-	739-2,196

Table 3

Stratum-specific densities, abundance estimates and related parameters calculated with the program *DISTANCE* for the guiana dolphin in Sepetiba Bay.

Parameter	Point estimate	% CV	2.5%-97.5% CI
Stratum-specific (Entrance)			
Average group size (s)	21.3	15.58	15.6-28.3
Density of individuals (ind km^{-2})	2.91	31.76	1.61-5.17
Abundance	596	31.76	331-1,061
Stratum-specific (Interior)			
Average group size (s)	52.6	24.95	31.6-87.5
Density of individuals (ind km^{-2})	2.69	36.48	1.22-5.02
Abundance	672	36.48	305-1,256

of prey species (Barros and Wells, 1998), and indirectly related to habitat characteristics such as bottom topography and sediment, water currents and temperature (Au and Perryman, 1985; Hui, 1985; Selzer and Payne, 1988). Higher depth and diversity of substrate, formed by gravel and rocks, are found in the central area of the entrance at Sepetiba Bay, and these characteristics are related to a high diversity of demersal fish (Araújo *et al*., 2002). Therefore, the higher sighting frequency at the entrance, notably in its central area, is probably linked to higher diversity and availability of prey. This has also been observed for bottlenose dolphins in Patagonia and Scotland (Wilson *et al*., 1997; Würsig and Würsig, 1979). For the interior, there is a small channel near the division area, where the majority of sightings occurred, following the same distribution pattern from the entrance, which is also likely to be linked to the ecological factors mentioned above (Fig. 2). The high abundance of few species of demersal fishes at the interior of the bay (Araújo *et al*., 2002) might force the dolphins to aggregate in large groups, which would account for the low number of sightings and encounter rate compared with the entrance. This probably explains why smaller groups of dolphins were sighted more frequently at the entrance, while larger groups were sighted more frequently in the interior of the bay. This difference in group size also explains why density and abundance were similar between the entrance and interior (see below). Further discussion of these ecological aspects is published elsewhere (Flach *et al*., 2008a)

Density and abundance estimates

The density (2.79 dolphins km^{-2}) and abundance (n=1,296 dolphins) estimated here for the Sepetiba Bay, are the highest estimates thus far for the species. There are only two estimates available for the guiana dolphins derived from line transect sampling, and both are from grey literature. These are from Cananéia, Sao Paulo state (Rollo, 2002) and from Babitonga, Santa Catarina state (Cremer *et al*., 2006), and show densities of 24.36 and 1.44 dolphins km^{-2}, respectively. An analysis of the coefficient of variation indicated that the total area estimate of abundance had a higher precision (a lower CV=0.28) than those obtained separately for the entrance (CV=0.31) or interior (CV=0.36), since the sample sizes were smaller for each of the stratum-specific estimates. Nevertheless, the relatively low CVs and the good fit of the detection function to the distance data, indicate that the estimates reported here are statistically robust. The boat-based line-transect sampling method may therefore work well to estimate density for *Sotalia* in other areas of Brazil with characteristics similar to Sepetiba Bay.

Future studies and conservation aspects

Assessment of abundance and population structure, as well as the understanding of the main threats to the guiana dolphin are priority recommendations (Reeves *et al*., 2003). Given the large size of the estimated population, Sepetiba Bay should be regarded as of great importance for the conservation of the species. In the last decades, industries, cities, port, tourism and fishing activities have all collaborated to increase the degradation of this bay (Araújo *et al*., 2002; Molisani *et al*., 2004). In fact, during this study, constant dredging and heavily artisanal and predatory fishing activities were observed. A high incidence of guiana dolphin bycatch has also been observed in this bay (L. Flach, pers. comm.) and, consequently, mortality due to this cause might be significant there. It is quite certain that these threats and habitat disturbances have negatively affected the guiana dolphin, but given the lack of previous population studies in the area, the degree of impact in terms of change in population size cannot be assessed. Thus the estimates provided by the present study can and should be used as baselines for future comparisons. As the impacts on populations of guiana dolphins caused by the ever increasing number of human activities along the coastal areas of Brazil are still unknown, population estimates along this vast littoral are needed before the conservation status of this species can be properly assessed.

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