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Abundance Estimates of Guiana Dolphins (*Sotalia guianensis*; Van Bénéden, 1864) Inhabiting an Estuarine System in Southeastern Brazil

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Abstract

Baseline demographic information is essential for effective conservation and management strategies for most living species. The abundance of Guiana dolphins (*Sotalia guianensis*) is poorly known, yet species conservation is considered a high priority in areas where human activities may induce population declines. This study estimated abundance for Guiana dolphins in the Cananeia estuary (25° 03' S, 47° 55' W) in southeastern Brazil using mark-recapture data and Pollock's Robust Design Model. Systematic boat-based photo-identification surveys were based on data collected in the summer and winter of 2015 and in the summer of 2016. A total of 55 capture events allowed identification of 133 different individuals. The best model indicated a population with random temporary emigration, a time-constant survival rate, and heterogeneous time-varying capture probabilities among primary periods. The temporary emigration rate ($\gamma'' = \gamma'$) was 0.05 (± 0.03). Estimated population sizes were 430 (95% CI: 410 to 451) individuals in the summer of 2015, 384 (95% CI: 366 to 403) individuals in the winter of 2015, and 414 (95% CI: 392 to 438) individuals in the summer of 2016, indicating that environmental variables among seasons may have a mild effect on the estimated size of this surveyed population. These estimates should stand as an important baseline for future comparisons. Systematic, long-term monitoring of this population is recommended, and is required to accurately assess population trends.

Key Words: abundance, mark-recapture, robust design, photo-identification, Guiana dolphins, *Sotalia guianensis*

Introduction

The Guiana dolphin (*Sotalia guianensis*; Van Bénéden, 1864) is a small cetacean (Delphinidae) that inhabits estuarine and shallow coastal waters (up to 30 m) along the western coast of the Atlantic Ocean in Central and South America (Borobia et al., 1991; Da Silva et al., 2010). Although common in most of its range, little is known about population parameters for *S. guianensis*; the species is listed as "Data Deficient" by the International Union for Conservation of Nature (Secchi, 2012). Methods used for most abundance estimates presented in the past 30 years violated important analytical assumptions, generating high levels of uncertainty for many of the gathered results (Santos et al., 2010c). As the species is susceptible to multiple human-related threats throughout its whole distribution (Crespo et al., 2010), robust abundance estimates are needed for effective conservation strategies for locally surveyed populations (Wilson et al., 1999).

Individual identification of wild cetaceans based on their natural markings has provided relevant information in the field of marine mammal science, especially for population dynamics (Hammond, 1990; Würsig & Jefferson, 1990). In general, natural markings on cetaceans comprise fluke morphology and color patterns (e.g., Katona et al., 1979), callosity patterns (e.g., Payne et al., 1983), and nicks and notches along the dorsal fin (e.g., Würsig & Würsig, 1977). In photo-identification studies, these marks are photographed and then used for non-invasive re-identification of recognized individuals for spatial and temporal studies (Hammond et al., 1990).

Mark-recapture methods applied to photo-identification data have been widely used to estimate population sizes because they also allow the observers to estimate other demographic parameters such as apparent survival and temporary emigration (Pollock, 1982; Kendall et al., 1997; Smith et al., 2013). Closed population models assume that, throughout the study, no individuals are added to, or subtracted from, the surveyed population; while open population models allow for temporary emigration and immigration, deaths, and births. Pollock's Robust Design Model combines advantages of closed and open models, providing more reliable and accurate estimates (Kendall et al., 1995). The use of this model requires a specific survey design; multiple assumptions must be met to ensure that the estimated parameters are unbiased (Lebreton et al., 1992; Kendall, 1999).

The technique of photo-identification was first applied to study Guiana dolphins in 1993 (Flores, 1999). Since then, mark-recapture methods have been used to investigate ecological aspects of different populations (see Simão et al., 2000; Santos et al., 2001; Azevedo et al., 2004; Flores & Bazzalo, 2004; Rossi-Santos et al., 2007; Hardt et al., 2010; Batista et al., 2014). However, a robust design framework has been used to estimate demographic parameters of a surveyed population only in the last few years (Cantor et al., 2012; Azevedo et al., 2017).

The Cananeia estuary is one of the main areas inhabited by *S. guianensis* in southeastern Brazil, hosting a year-round resident population (Santos et al., 2000). The estuary has high species diversity in an important nursery area for many marine organisms, bordered by a highly productive and protected mangrove forest (Besnard, 1950; Schaeffer-Novelli et al., 1990). These characteristics prompted environmental stakeholders to establish a growing mosaic of protected areas, beginning in 1962 (Ministério do Meio Ambiente [MMA], 2006). On 4 September 2017, the Environmental Protected Area of Cananeia-Iguape-Peruibe was designated as a new Ramsar site, highlighting that protection for the local ecosystem is of international interest. Several attempts to estimate the local population were conducted since the 1990s using either line-transect protocols or mark-recapture models, but none covered the whole area used by local dolphins in this estuary (see Santos & Rosso, 2007; Santos et al., 2010c).

The aim of this study was to estimate the abundance and the temporary emigration rates of Guiana dolphins inhabiting the Cananeia estuary between 2015 and 2016. To investigate these population parameters, photo-identification data were collected in three different seasons, and Pollock's Robust Design Model was applied.

Methods

Study Area

The Cananeia estuarine system (25° 03' S, 47° 55' W) is located in the Southwestern Atlantic on the southeastern coast of Brazil (Figure 1). The 132 km^2 area surveyed includes the waters encircling Cananeia Island, extending approximately 12 km northwards (Figure 1). To simultaneously cover the entire estuarine area where dolphins can be found, the total area was divided into three smaller sub-areas. There are no physical/oceanographic barriers isolating these subsets of the estuary.

Data Collection

Mark-recapture analyses were based on data collected in summer (January 2015 and February 2016) and winter (July and August 2016). Summer and winter were chosen to contrast the extreme differences in the environment between these two seasons, which could affect the way dolphins use the local estuary (Santos & Rosso, 2007).

Photographs of individual Guiana dolphins were gathered via systematic boat-based surveys conducted whenever the sea state was adequate (Beaufort ≤ 2). Two small boats operated at the same time, covering two of the three sub-areas. The whole study site was surveyed twice during each 3-d survey, using a zig-zag route to maximize group encounters. Once a group of dolphins was found, the boat approached slowly to gather dorsal fin photographs. An attempt was made to take good quality photographs of all marked and unmarked individuals. Images were captured by experienced researchers using digital SLR cameras equipped with an AF 70-300-mm zoom lens. The analyses of all photographs to identify individuals in the surveyed population was described in detail by Santos & Rosso (2008), including details of the two main features considered: (1) the quality of each analyzed photograph and (2) the distinctiveness of the marks/notches.

Individuals with distinctive marks that would allow future identification were classified as *marked* and catalogued. All adults without long-term natural marks were classified as *unmarked* and included in the analysis of total population size. Calves were not considered in the analyses because they are usually unmarked and likely to exhibit different capture rates. Selected photographs were analyzed and compared visually by two experienced researchers at the end of each sampling season, and *Darwin* software (Stewman et al., 2006) was used for further comparisons.

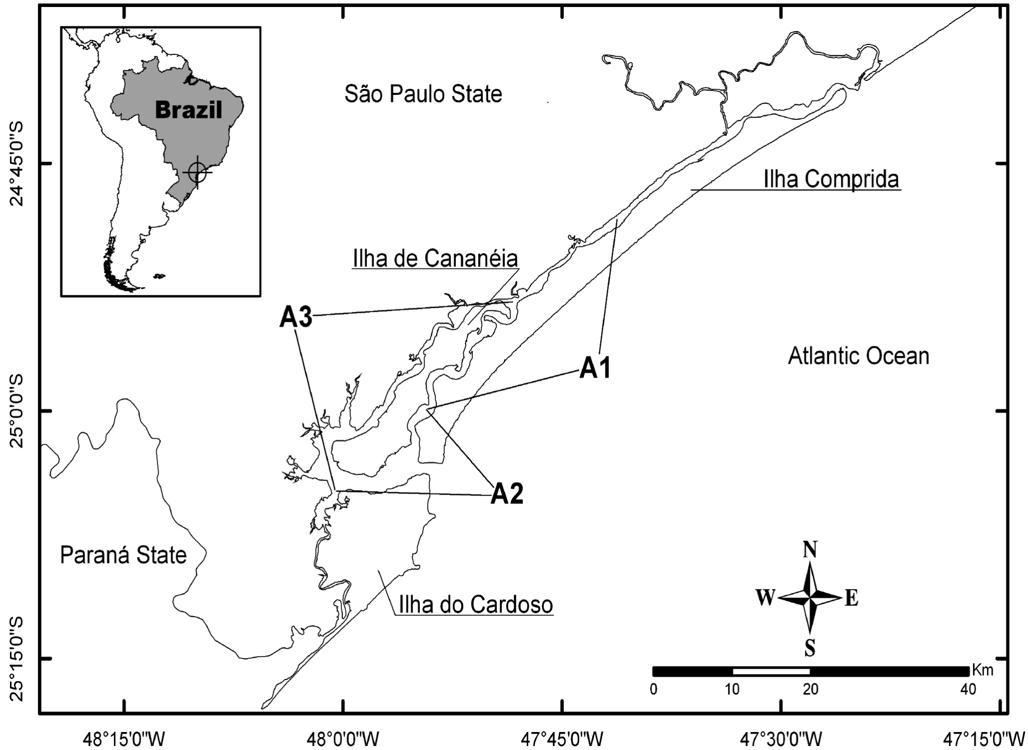

Figure 1. Map of the study site in southeastern Brazil showing the sub-areas A1, A2, and A3 covered when investing on photo-identification surveys of Guiana dolphins (*Sotalia guianensis*) between 2015 and 2016

Mark-Recapture Analysis

Mark-recapture analyses were carried out using Pollock's robust design (RD) framework (Pollock, 1982; Kendall et al., 1995, 1997) within *MARK* (White & Burnham, 1999). The RD combines open and closed population models and allows simultaneous estimation of abundance and probabilities of apparent survival and temporary emigration (Williams et al., 2002). Therefore, the dataset of this model includes information from both open and closed sampling periods. The primary sampling periods are separated in time by longer intervals where gains (birth and immigration) and losses (death and emigration) to the population may occur. Each primary sampling session consists of several secondary capture periods that are close in time, thus making the assumption of closure acceptable (Kendall et al., 1995, 1997). In the present study, the three primary periods (seasons) were divided into 18 to 19 distinct secondary occasions where the whole study area was surveyed. A sighting of a marked individual in at least one of the sub-areas was regarded as a capture event.

We assumed that capture (p) and recapture (c) probabilities were equal (p = c) as the probability of recapturing a dolphin is unlikely to have been affected by the initial capture since the individuals are not physically captured or handled (Boyd et al., 2010). We also assumed that survival probability was constant during the study since there was no reason to believe it changed over such a relatively short time period. We selected the best model among options that incorporated random (y''= y') and Markovian (y'', y') emigration. Under the Markovian temporary emigration, the probability of an individual to be temporarily unavailable for capture in the study area at a specific time (t) is conditional on whether the same individual was available (y'') or unavailable (y') at time t–1; while in random temporary emigration, being temporarily unavailable for capture in the area in time (t) is independent of the individual's availability in the previous sampling period (Kendall et al., 1997).

The best model was selected using Akaike's Information Criterion adjusted for small sample sizes (AIC_c) (Burnham & Anderson, 2002). Models with AIC_c weight < 0.01 were excluded from the analyses.

Total Population Size
Abundance estimates are related to the marked proportion of the population (*N*). To estimate the total abundance (N_{total}) of Guiana dolphins in each season, we determined the proportion of marked individuals (θ) by dividing the total number of photographs of marked individuals by the total number of photographs of marked and unmarked individuals. Total population size estimates were then calculated using the ratio. Variances and standard errors were extrapolated to the estimated total populations using the delta method (Wilson et al., 1999). The 95% confidence intervals (CI) were calculated following Burnham et al. (1987).

Results

Survey Effort and Photo-Identification
A total of 55 capture occasions resulted in the observation of 1,139 groups of *S. guianensis*. Survey effort did not vary with time. A summary of the photo-identification efforts and results is presented in Table 1. Out of 132,486 analyzed photographs, 10,686 were considered to have adequate photographic quality and distinctiveness to allow unambiguous identification of individuals. In this study, 133 individuals were identified. Discovery rates of new individuals decreased after the first field season when most dolphins (approximately 79%) had been identified (Figure 2). The sighting frequency of individually identified dolphins ranged from one to 29, with a mean of nine (± SE 0.5; Figure 3). Resighting rates were high within and between sampling seasons; only seven individuals (5.3%) were seen only once in all seasons, indicating high site fidelity to the investigated area.

The best model resulted in a difference of more than two AIC_c units from all the others, and it included constant survival probabilities, random temporary emigration, and heterogeneous

Table 1. Summary of survey effort for mark-recapture analysis of Guiana dolphins (*Sotalia guianensis*) in the Cananeia estuary between 2015 and 2016

Season	Sampling season (secondary period)	No. of capture occasions	No. of groups encountered	No. of high-quality photos	No. of new marked individuals
Summer 2015	7 Jan. - 12 March	19	369	4,065	115
Winter 2015	2 June - 14 Aug.	18	403	3,530	12
Summer 2016	5 Jan. - 25 Feb.	18	367	3,091	6
Total		55	1,139	10,686	133

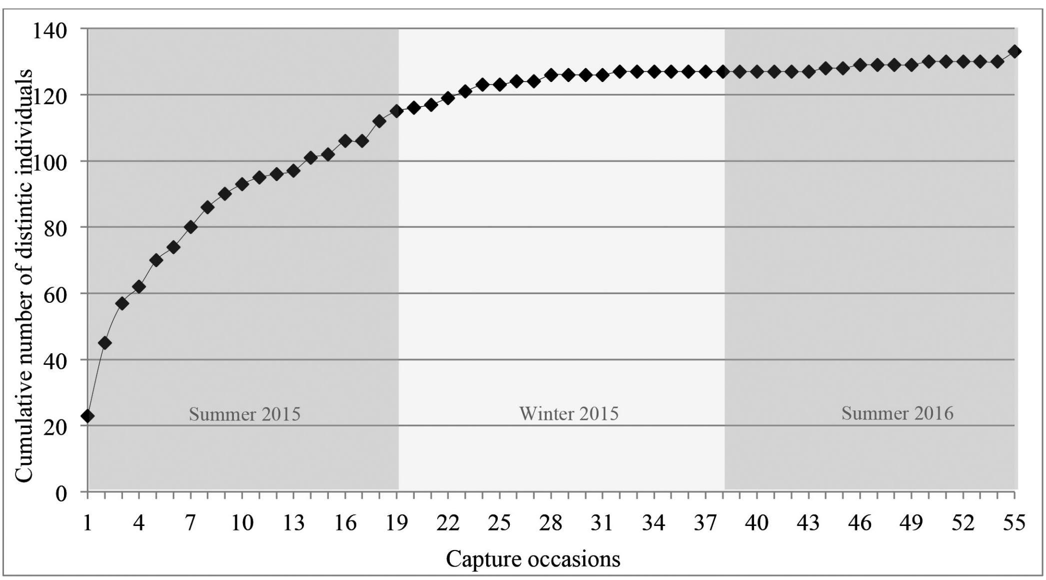

Figure 2. Discovery curve showing the cumulative number of photo-identified Guiana dolphins in the Cananeia estuary during the 55 capture occasions completed between January 2015 and February 2016

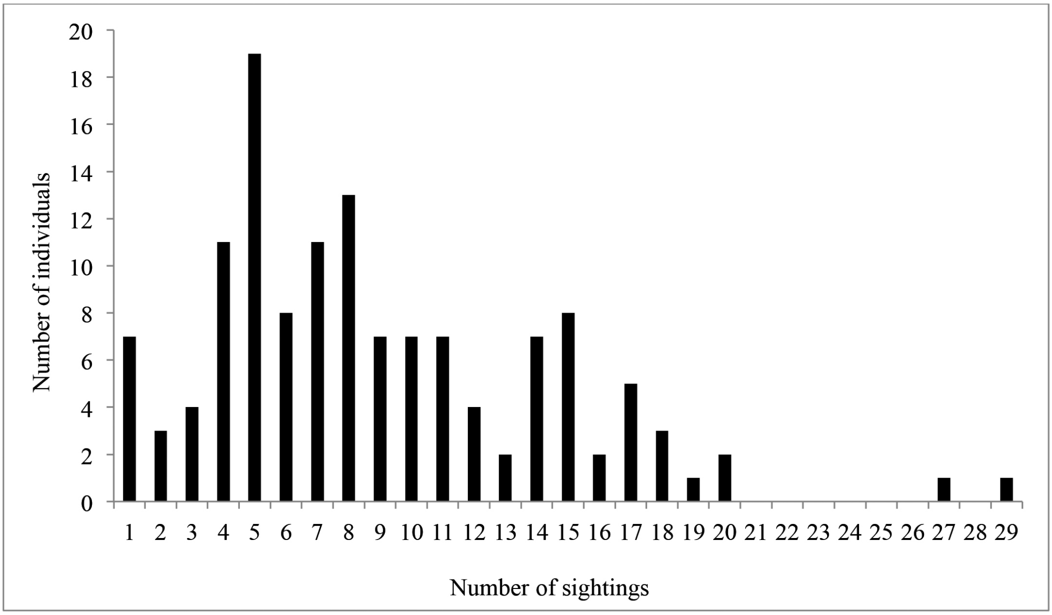

Figure 3. Sighting frequency of individually identified Guiana dolphins in the Cananeia estuary between January 2015 and February 2016

Table 2. Model selection results obtained using Pollock's Robust Design Model in program *MARK*. Models are in decreasing order of the Akaike Information Criterion (AICc). Notations: s = primary capture periods, t = time, (.) = constant, (*) = interaction, pi = mixture proportion, p(x) = c(x) = no behavior effect, y''= y'= 0 = no emigration, y''= y' = random emigration, and y'', y' = Markovian emigration. Models with AICc weight < 0.01 are not shown.

#	Model	AIC_c	Δ AIC_c	AIC_c weight	Likelihood	No. par.	Deviance
1	$\phi(.)\ \gamma'' = \gamma'\ pi(.)\ p(\mathrm{s*t}) = c(\mathrm{s*t})$	3,571.40	0.00	0.598	1.000	116	4,547.71
2	$\phi(.)\ \gamma''(.)\gamma'(.)pi(.)\ p(\mathrm{s*t}) = c(\mathrm{s*t})$	3,573.56	2.16	0.203	0.340	117	4,547.41
3	$\phi(.)\ \gamma'' = \gamma' = 0\ pi(.)\ p(\mathrm{s*t}) = c(\mathrm{s*t})$	3,574.57	3.17	0.122	0.205	116	4,550.88
4	$\phi(.)\ \gamma''(t)\ \gamma'(.)\ pi(.)\ p(\mathrm{s*t}) = c(\mathrm{s*t})$	3,576.01	4.61	0.060	0.100	118	4,547.39
5	$\phi(.)\gamma''(.)\ \gamma'(.)\ pi(s)\ p(\mathrm{s*t}) = c(\mathrm{s*t})$	3,578.60	7.20	0.016	0.027	119	4,547.51

time-varying capture probabilities among primary periods (Table 2, Model 1, AIC_c 3,571.40). The model that considered no temporary emigration was poorly supported by the data (Table 2, Model 3, AIC_c = 3,574.57).

Apparent Survival, Temporary Emigration, and Capture Probabilities
Examining the best model (Table 2, Model 1), the apparent survival rate was 0.864 (± SE 0.066), and the temporary emigration probability was 0.051 (± SE 0.031). Capture probabilities were low to moderate and varied within primary periods, with mean values of 0.24 (± SE 0.02) in the summer of 2015, 0.34 (± SE 0.03) in the winter of 2015, and 0.24 (± SE 0.03) in the summer of 2016.

Abundance Estimates
Marked population estimates had minimal variation across seasons (CVs from 0.02 to 0.04) and were highly precise (low CIs [see below]; Figure 4). The proportion of marked individuals was consistent over the seasons with values of 0.29 in the summer of 2015, 0.30 in the winter of 2015, and 0.28 in the summer of 2016.

Total population sizes were estimated as 430 (95% CI: 410 to 451) individuals in the summer of 2015, 384 (95% CI: 366 to 403) individuals in

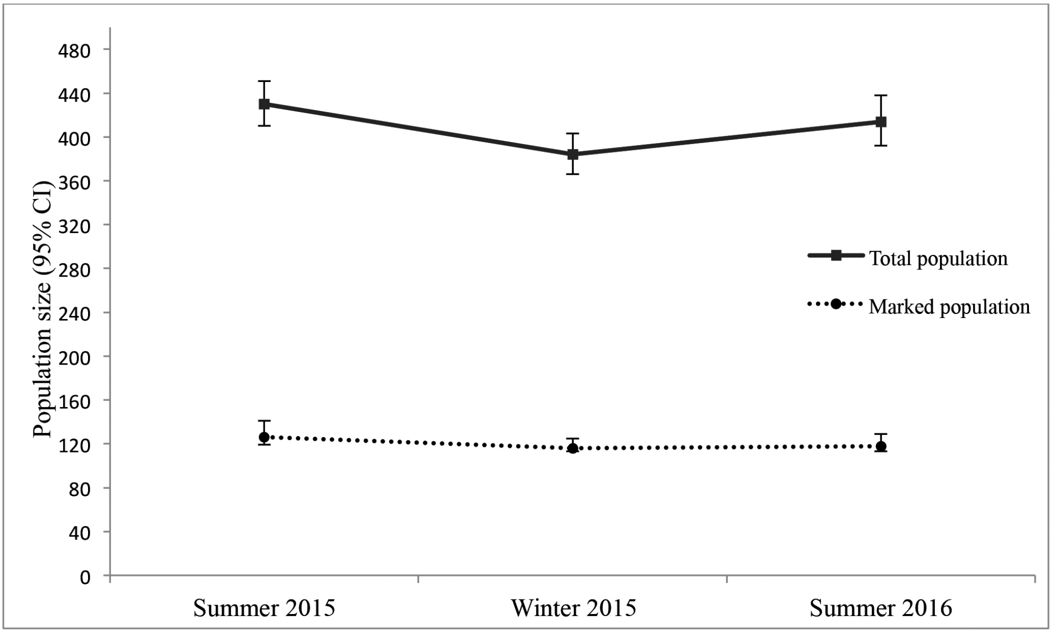

Figure 4. Seasonal abundance estimates for the Guiana dolphin population found in the Cananeia estuary between 2015 and 2016, and their associated levels of uncertainty. Dotted and solid lines are estimates for marked and total population size, respectively. Vertical bars indicate the 95% CI.

the winter of 2015, and 414 (95% CI: 392 to 438) individuals in the summer of 2016 (Figure 4).

Discussion

The application of the RD mark-recapture models must follow several important assumptions: (1) marks are permanent in the period of study; (2) marks are unique and correctly recognized; (3) individuals are immediately released after "marking"; (4) capture probabilities are homogeneous for all marked and unmarked individuals; (5) captures are independent between occasions; (6) the population is closed within primary periods; and (7) survival probabilities are the same for all individuals (Pollock, 1982; Williams et al., 2002). To conduct this study, efforts were directed towards establishing a survey design and a field protocol that would minimize any possibility of not respecting the listed assumptions.

Abundance estimates can be severely biased if mark-recapture assumptions are violated (Kendall, 1999). The correct identification of marked individuals is one of the most important assumptions to be met in mark-recapture studies as identification errors lead to negatively (error type I) and positively (error type II) biased estimates of abundance (Gunnlausson & Sigurjónsson, 1990; Stevick et al., 2001; Urian et al., 2014). We eliminated this bias by opting to use only the highest quality of photographs and only well-marked individuals with unique and permanent large nicks and notches in our catalog.

The assumption of equal capture probabilities for all individuals may become a great cause of concern in mark-recapture studies of Guiana dolphins. The species is shy when approached by boats, is usually found in murky waters, and has a relatively small dorsal fin in comparison to the whole body (Santos et al., 2000). The spatial distribution of Guiana dolphins in the Cananeia estuary is also not homogeneous, and an individual's home range size may vary greatly (Oshima & Santos, 2016). Therefore, to minimize the effects of heterogeneity on capture probability, several steps were undertaken: (1) the whole estuarine area used by dolphins was covered; (2) the sampling effort was equally distributed throughout the study period; (3) boat-based surveys were only carried out in good sea state conditions (Beaufort ≤ 2); (4) considerable effort was applied to photograph all individuals in a group; and (5) capture heterogeneity was incorporated in the fitted models. Researchers involved in fieldwork and photo analyses did not change during data collection, following strict criteria for including new individuals in the catalog.

The assumption of population closure was probably not satisfied. Although primary periods were relatively short (about 2 mo) in relation to the estimated life span of Guiana dolphins (29 y estimated for the local population; see Santos et al., 2003), births may have occurred in all seasons, and deaths had been reported in local areas. Geographic closure could also not be guaranteed because well-marked adults were inconsistently added to the population and captured across primary periods. The Cananeia estuary is connected to the Atlantic Ocean and to the Paranaguá Estuarine Complex, 80 km southwards through estuarine waters where Guiana dolphins can be found (see Geise et al., 1999; Santos et al., 2010a). Thus, as the presence of transient individuals within the studied area may affect demographic parameters, temporary emigration models were fitted to the analyzed data. Even though the temporary emigration rate was low (5%), temporary emigration models fit the data better than models with no emigration. Temporary emigration was also reported for another population of Guiana dolphins (Cantor et al., 2012). The incidence of temporary emigration combined with sighting frequency and individual home ranges in the Cananeia estuary (see Oshima et al., 2010; Oshima & Santos, 2016) indicate that a few individuals from the surveyed population may use adjacent regions. Therefore, movements in and out of the surveyed estuary should be considered when conducting mark-recapture studies.

Apparent survival rate was relatively high and consistent with the results observed for Guiana dolphins inhabiting the Caravelas River estuary (Cantor et al., 2012); however, such comparisons should be interpreted with caution because the length of sampling periods from this and the cited Cantor study were different. In this study, the time period adopted in the analyses was not related to the biological cycle of the species, which may influence the gathered results. Nevertheless, the present study provides the first insight into the survival probability of local Guiana dolphins, representing the first step for further studies. RD models yield reliable estimates of apparent survival rates in the presence of transients and capture heterogeneity (Pollock, 1982; Kendall et al., 1995).

Abundance estimates did not vary among seasons, suggesting that resources are available to local predators such as S. *guianensis* year-round. As habitat use and spatial distribution of aquatic mammals are determined by the availability of prey, it is necessary to comprehend which environmental variables might influence the abundance and distribution of relevant resources for the species of interest (Ballance, 1992). Lopes et al. (2012) reported that Guiana dolphins in the Cananeia estuary are opportunistic feeders; their main food items are abundant year-round. The Cananeia estuary possibly hosts a stable population of Guiana dolphins, with population abundance estimates ranging from 366 to 451 individuals. Continued, systematic long-term monitoring of this population is important to provide an accurate assessment of population trends and a more accurate estimate of long-term survival rates. Future studies may consider shorter secondary periods and longer intervals among primary sessions, and may also incorporate covariates, which can be used to explore the reasons for heterogeneity in capture probabilities.

The Cananeia estuary is an important breeding and calving area for Guiana dolphins and is still well-preserved. However, severe anthropogenic disturbances have been locally reported (see Santos & Rosso, 2007; Santos et al., 2010b). Therefore, we strongly recommend that management strategies be adopted to regulate the expansion of boating activities, dolphin-watching tourism, and urban development. Because the area is already a Conservation Unit, we also recommend that monitoring demographic parameters of Guiana dolphins should be included in the management plan of the Cananeia-Iguape-Peruíbe Environmental Protection Area. The reinforcement of past regulations, the creation of new ones to protect local dolphins throughout the whole estuarine area, and the establishment of capacity building programs directed towards local stakeholders to understand the way they may take part in local conservation actions must be listed as the main priorities for protection of the local Guiana dolphin population.

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