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The first confirmed decline of a delphinid population from Brazilian waters: 2000–2015 abundance of *Sotalia guianensis* in Guanabara Bay, South-eastern Brazil

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ABSTRACT

The abundance of Guiana dolphins (*Sotalia guianensis*) in Guanabara Bay, Rio de Janeiro, South-eastern Brazil, was investigated during the period 2000–2015 using mark-recapture models applied to photo-identification data. A combination of Pradel's model and Pollock's robust design was applied to estimate abundance and other population parameters, such as apparent survival (Φ), capture probability (p) and seniority probability (γ). Total population size was estimated by correcting the estimates derived from the Pradel robust design model for the proportion of marked individuals in the population. The corrected abundance estimates decreased drastically (37%) between 2000 (62, 95% CI 59–65) and 2015 (39, 95% CI 37–40), and can be explained by a combination of low survival and recruitment rates. Determining the ultimate causes for the decline in this Guiana dolphin population is difficult, but the likely reasons are of anthropogenic nature, such as by-catch, habitat degradation, intense traffic of vessels and exposure to immunosuppressive and endocrine-disrupting pollutants. We provide the first quantitative evidence of population decline in a delphinid from Brazilian waters. Conservation and management actions are urged to change this scenario. Other local dolphin populations in Brazil, which are exposed to the same impacts, may also be currently declining or are expected to do so in the near future. For this reason, we emphasize that anthropogenic impacts upon estuarine/coastal species that exhibit site fidelity warrant greater attention, because such impacts may lead to the same negative scenario observed in Guanabara Bay.

1. Introduction

Identifying population size and trends in decline is an important step to understand the conservation status and mitigate problems that could lead to the local or global extinction of a species (Currey et al., 2011; Di Fonzo et al., 2013). For cetaceans, one of the most used methods to assess such parameters is the mark-recapture method, based on photographic identification (Hammond, 1990). Further, depending upon their residency patterns, coastal cetaceans are easily monitored on a long term basis, especially when they are year-round residents of a habitat and not just transient (Balmer et al., 2008; Fury and Harrison, 2008; Maze and Würsig, 1999). Among the small delphinids, the bottlenose dolphins (*Tursiops spp*) are by far one of the most studied species in which population parameters are assessed using mark-recapture methods (Conn et al., 2011; Currey et al., 2011; Reisinger and Karczmarski, 2010; Smith et al., 2013; Wilson et al., 1999). In the Southwestern Atlantic Ocean, although all bottlenose dolphins occur close to the coast, *Sotalia guianensis* is one of the most studied coastal species (Azevedo et al., 2009, 2004; Azevedo and Van Sluys, 2005; Bittencourt et al., 2016; Cremer et al., 2011; Daura-Jorge et al., 2011; Flach et al., 2008; Hardt et al., 2010; Lailson-Brito et al., 2010; Rossi-Santos et al., 2007; Santos et al., 2001; Van Bressem et al., 2009). However, knowledge of the population parameters for *S. guianensis* remains scant in terms of long term studies, and little information has been reported (Cantor et al., 2012).

The Guiana dolphin, *Sotalia guianensis* (Van Bénéden, 1874), is a small delphinid that inhabits the coastal waters of South and

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Central America, from southern Brazil (27°35′S) to central Honduras (da Silva et al., 2010). Due to its near-shore distribution, the Guiana dolphin is susceptible to the effects of human activities such as changes in habitat characteristics, chemical pollution, noise and by-catch (Reeves et al., 2003). The impacts of these threats are exacerbated by the fact that many populations of *S. guianensis* have high site fidelity (Flores and da Silva, 2009).

Human development in Brazilian coastal areas has been uncontrolled with limited or no planning for sustainability. Guanabara Bay (22°50′S, 43°10′W) is a typical example (Azevedo et al., 2009). This bay, located in the State of Rio de Janeiro, south-eastern Brazil, is one of the most populated areas in South America, with an estimated population of 11 million people. In addition, Guanabara Bay is surrounded by the second largest industrial concentration in Brazil, with nearly 10,000 industries, the Rio de Janeiro Port Authority, 16 oil terminals and 12 shipyards (Kjerfve et al., 1997; Perin et al., 1997).

The presence of Guiana dolphins in Guanabara Bay has been known since the end of the 19th century (Van Bénéden, 1874). This bay, one of the most degraded water bodies in the species' range (Lailson-Brito, 2007), is still the main habitat for a population of Guiana dolphins that is present year-round (Azevedo et al., 2004). Habitat degradation does seem to affect the species' habitat use pattern, as the dolphins avoid the most degraded zones within the bay (Azevedo et al., 2007). In the study area, aggregations of up to 50 dolphins had been seen in the past, but currently, groups with two to ten members are more frequently observed (Azevedo et al., 2005).

The first study on the abundance of this population was conducted in the mid-1980s, and the results revealed 398 individuals (Geise, 1991). Since 1995, a systematic photo-identification study has been undertaken in the bay, and results revealed the high site fidelity of some individuals (Azevedo et al., 2004). Females had consecutive offspring in Guanabara Bay, and calves consistently remained in this area even after attaining sexual maturity (Azevedo et al., 2004). For a small dolphin population composed mostly of resident individuals, the dependence on such a degraded area may seriously hamper its persistence and conservation. Therefore, monitoring the abundance and detecting population trends is critical to assessing the long-term viability of this population and developing mitigating measures. This study reports the abundance estimates of *S. guianensis* in Guanabara Bay using mark-recapture methods applied to photo-identification data and provides the first quantitative evidence of the decline of a delphinid population from Brazilian waters.

2. Materials and methods

2.1. Study area

Guanabara Bay (Fig. 1) has a total water surface of 328 km^2, with an entrance that is 1.8 km wide. Its overall mean depth is 5.7 m, but along the main channel, which follows the central south-north axis of the bay, the average depth is 20 m (Kjerfve et al., 1997). The bay is similar to an estuarine system. The freshwater contribution is derived from 35 rivers that flow into the bay and from waste inputs (Kjerfve et al., 1997). The estuary is highly degraded by anthropogenic impacts, including overfishing, harbour activities, sewage and chemical contamination (Kjerfve et al., 1997; Perin et al., 1997).

2.2. Photo-identification

Photo-identification surveys have been conducted in Guanabara Bay for sixteen years, starting in 2000, and are ongoing, but here, we used only the data from ten years, which were obtained with varying sampling effort (Fig. 1; Table 1). In 2000, surveys covered approximately 120 km^2, and the effort was concentrated in the northern areas of the main channel and adjacent waters, which were the sites of major dolphin concentrations (Azevedo et al., 2007). Since then, to sample a larger proportion of Guanabara Bay, the area surveyed has been expanded. In 2003, the sampling covered approximately 200 km^2, and from 2005 to 2015, the surveys covered approximately 280 km^2, including those areas sampled in 2000 and 2003, and others not previously sampled. Zigzag boat routes covered the sampling area to provide extensive spatial and temporal coverage of the study area. The starting point of each survey was selected randomly to avoid oversampling sections or isobaths. All surveys were carried out in Beaufort sea states <3, in small (4.5-6.6 m) outboard-powered boats at constant speeds, between 0600 and 1700 h.

Under Brazilian law (*Instrução Normativa ICMBio n° 03/2014*), since the classification of *Sotalia guianensis* as "vulnerable" (in December 2014), fieldwork involving this species in federal protected areas requires a permit. Photo-identification fieldwork in the *Área de Proteção Ambiental de Guapi-Mirim* was conducted under permit 30180-1, issued by the *Instituto Chico Mendes de Conservação da Biodiversidade* (*ICMBio-Brasil*).

Photographs were taken at close range (usually <10 m). From 2000–2005, an auto-focus camera with a 70–300 mm zoom lens was used, with *ASA 400* colour and black-and-white film. From 2009–2015, a digital reflex camera with a 100–400 mm lens was used. Nicks and notches on the dorsal fin were used to distinguish individual dolphins. Only high quality photographs were used to identify individuals. These images were characterized by sharpness, adequate distance and perpendicular angle for identifying marks (or their absence). Each marked individual was given an identification code and had its dorsal fin contour catalogued. Matches were made by comparing each new photograph with dorsal fins from the catalogue (Defran et al., 1990). The matches were independently confirmed by at least two researchers, and each match was considered a re-sighting. Although there were long time gaps between photo-identification sessions to estimate abundance, from 2000 to 2015, other photo-identification surveys were conducted to keep the dorsal fin catalogue updated, thus avoiding misidentification throughout the study.

2.3. Population parameter estimation

To understand the variation in the abundance of this local population, we were primarily interested in the temporal patterns of survival and seniority probability (see below). These are parameters that can be modelled using a Pradel parameterization parallel to the Pollock's robust design framework in the MARK program (Cooch and White, 2010). The robust design framework allows obtaining estimates of population abundance within the short time periods when the population is closed to any changes (births, deaths, immigration or emigration). Simultaneously, changes in population parameters such as mortality and recruitment are allowed, and can be estimated for the intervals between the primary sampling occasions.

Combining the robust parameterization with Pradel's includes the seniority probability parameter, γ, which represents the probability that an individual captured in the current sampling occasion was also present during the previous population assessment. The complementary measure to seniority probability ($1-\gamma$) represents recruitment. Our extensive sampling had covered a great proportion of Guanabara Bay by 2015, making it less likely that there were many undetected individuals left in the population.

Our data consisted of 10 primary sampling occasions from 2000 to 2015 (months, Table 1), with varying number of secondary occasions (days, Table 1). The design of the analysis accounted for