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# Are marine protected areas and priority areas for conservation representative of humpback whale breeding habitats in the western South Atlantic?

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ABSTRACT

The establishment of marine protected areas (MPAs) is an important component of conservation strategies for large marine vertebrates. Thus, quantitative evaluations are necessary to assess whether their habitats are protected by these areas. In this study, the representativeness of government-established MPAs and identified priority areas for conservation (PACs) relative to the Brazilian wintering habitat of humpback whales was assessed using satellite telemetry data ($n = 74$ individuals). Argos-derived location data were filtered and modeled using a switching state space model (SSSM) and overlaid on shapefiles for MPAs and PACs. Humpback whales occurred in only 18.31% of the 71 MPAs observed within the species range. A lower frequency of locations was recorder inside rather than outside these areas. MPAs of Integral Protection used by humpback whales correspond to only 0.64% of the species wintering habitat. In contrast, a total of 40% of the 55 PACs observed within the same area was occupied by the whales, with a higher frequency of locations documented inside the PACs. Our results suggest that PACs encompass the species habitat in a more representative manner than MPAs. Because the former do not provide legal protection, they do not effectively contribute to the species conservation. We suggest PACs used by the species, especially Abrolhos Bank PAC, can be used as basis to refine conservation efforts of humpback whales in their breeding grounds in light of increased anthropogenic stressors. We also demonstrate that animal movement data obtained from satellite telemetry studies are useful for assessing the representativeness of MPAs and to improve management of whales.



## 1. Introduction

Establishing effective and representative systems of marine protected areas (MPAs) is part of a global strategy to conserve biodiversity (Convention on Biological Diversity – CBD, 2014; Kelleher, 1999; Prates, 2007). In the face of increasing threats, the use of MPAs is rising globally because these areas are viewed as an important management tool to prevent, reduce, or even reverse ongoing loss in marine biodiversity (Agardy, 1994; Agardy et al., 2003; Gormley et al., 2012; Hoyt, 2005; Spalding et al., 2008; Wood et al., 2008).

Because of their broad seasonal habitat, highly-mobile and migratory species typically offer a major challenge for spatial management (Game et al., 2009; Hyrenbach et al., 2000). Even though the usefulness of MPAs to protect these species is debatable (Notarbartolo di Sciara, 2007) because MPAs may only include a small portion of a species range, they may represent an effective measure for protecting part of their habitats (Game et al., 2009; Hoyt, 2005). However, the use of these areas as a management

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appliance depends on properly identifying and delineating spatial and temporal appropriate boundaries around important habitats (Ashe et al., 2010; Schofield et al., 2013; Silva et al., 2012; Williams et al., 2009).

The humpback whale (*Megaptera novaeangliae* Borowski, 1781) is a clear example of such migratory species, as it performs some of the longest migrations of any mammal (Rasmussen et al., 2007; Robbins et al., 2011; Stevick et al., 2011; Stone et al., 1990). Western South Atlantic humpback whales only occur off the eastern coast of Brazil during their wintering season (Martins et al., 2001) and typically occupy breeding habitats over continental shelf waters from 4°S to 24°S (Andriolo et al., 2010; Mamede, 2011; Zerbini et al., 2004). This population was nearly extirpated by commercial whaling in the beginning of the 20th century, but has been recovering since protection was afforded in the late 1960s (Ward et al., 2011; Zerbini et al., 2011a). Currently, this population is subject to other human stressors, including offshore development, fisheries and habitat degradation (e.g., Rocha-Campos and Câmara, 2011; Zappes et al., 2013; Zerbini and Kotas, 1998). Conflicts with such anthropogenic activities are expected to increase as these stressors expand and this population continues to grow and to re-occupy historical habitats (Andriolo et al., 2010; Zerbini et al., 2004).

Brazil signed and ratified the CBD in 1992. As such, the country has committed to improve conservation of biodiversity in the marine environment (CBD, 2014; Magris et al., 2013). Over the past 30 years, a series of protected areas have been established by the Brazilian government (e.g., Rylands and Brandon, 2005), yet only a small portion (1.87%) of the marine environment under Brazil's jurisdiction is currently under protection (Magris et al., 2013). Brazilian MPAs are unevenly distributed among the North, the East Coast and the South Brazilian continental shelves, with the largest protected extension corresponding to the North shelf and the largest number of MPA located in the East Coast shelf (Schiavetti et al., 2013). The Brazilian Ministry of Environment (MMA) has also identified a number of priority areas for conservation of the Brazilian biodiversity (hereafter referred to as PACs). These areas typically do not provide legal protection, but are proposed as useful approaches to guide future public policies (e.g., definition of areas for the creation of new MPAs) contributing to 'the conservation of biological resources, their sustainable use and sharing of benefits derived of this use' (MMA, 2002, 2007).

MPAs and PACs include a portion of the habitat of humpback whales in their breeding grounds off Brazil, but the representativeness of these areas relative to the species distribution and movements is poorly known and the efficiency in providing proper habitat protection needs to be evaluated. Since 2001, satellite tagging has been conducted to assess this species' habitat use and migration (e.g. Zerbini et al., 2006, 2011b) in the western South Atlantic. This research method has proven to be effective in assessing animal movements and occurrence relative to the boundaries of protected areas (e.g., Maxwell et al., 2011; Tancell et al., 2013; Witt et al., 2008). In this study, we conduct the first quantitative assessment of the representativeness of protected and priority conservation areas for western South Atlantic humpback whales using Argos tracking data in order to evaluate whether these areas are consistent with the primary habitat used by this species. Representation of their habitat can be obtained by selecting protected areas where the species occurrence is more predominant (e.g., ANZECC, 1999; Harris and Whiteway, 2009), both on a spatial and temporal scale. Results of the analysis presented here can be used to improve conservation and management efforts for humpback whales and can serve as a model for assessing the representativeness of protected areas for whales in other parts of the world where satellite telemetry efforts have been implemented.

## 2. Methods

### 2.1. Study area and data collection

Tagging operations were conducted off Brazil during the humpback whale breeding season (August–November) from 2003 to 2009. Tags were deployed near coastal locations (Conceição da Barra, Espírito Santo State, and Nova Viçosa and Barra Grande, Bahia State) or during a tagging cruise conducted from Cabo Frio, Rio de Janeiro State to Natal, Rio Grande do Norte State (Fig. 1). Tagging operations were undertaken during good weather conditions (Beaufort sea state $\leqslant 4$) from a rigid hull inflatable boats ranging from 5.5 to 6.7 m in length.

SPOT 3, 4 and 5 satellite transmitters from Wildlife Computers were employed in multiple configurations, including mini-can and implantable transmitters ($n = 69$, Heide-Jørgensen et al., 2003, 2006; Zerbini et al., 2006, 2011b), and LIMPET tags ($n = 5$, Andrews et al., 2008). Tag deployment was carried out with (i) an 8 m-long fiberglass pole (for mini-can and implantable tags, Heide-Jørgensen et al., 2003), (ii) a pneumatic delivery system (ARTS, for implantable tags, Heide-Jørgensen et al., 2001) or (iii) a 150 lb crossbow (for LIMPET tags, Andrews et al., 2008).

### 2.2. Data filtering and modeling

Satellite locations were received from Service Argos, which classifies each location into different quality categories of decreasing accuracy: 3, 2, 1, 0, A, B (Argos, 1990). Argos-derived satellite location data were filtered to remove unrealistic locations using the SDA-filter based on swimming speed, distance between successive locations, and turning angles (Freitas et al., 2008). This study has considered only positions located in the breeding ground for the analysis, thus locations recorded after whales initiated their migration toward the feeding grounds were removed following the criteria adopted by Andriolo et al. (2006, 2010) and Mamede (2011).

A Bayesian switching state space model (SSSM) (Jonsen et al., 2007) was applied to the filtered data from each humpback whale track. Model predicted locations were computed at 6-h intervals (e.g. Andriolo et al., 2014) from the observed data (Argos locations) by accounting for errors caused by inaccurate observations (measurement equation) and the dynamics of the movement process (transition equation) (Patterson et al., 2008). The SSSM was implemented using the open source software packages R (R Core Team, 2012) and WinBugs (Lunn et al., 2000). Two Markov chains were run in parallel, producing a total of 50000 Markov Chain Monte Carlo (MCMC) samples for each chain. The first 20000 samples were discarded as burn-in, and every 15th remaining sample was retained to reduce autocorrelation. The posterior distribution of the model parameter estimates was computed with the remaining 2000 samples. The SSSM outputs include the estimation of behavioral states, which ranged in value between 1 and 2 (Jonsen et al., 2005). Jonsen et al. (2007) divided these states in three categories according to the direction and speed of movement: 'transiting' (state values between 1 and 1.25) was associated with more linear and faster movement, 'uncertain' (state values between 1.25 and 1.75) was associated with undefined movements, and 'area restricted search' (ARS) (state values ranging between 1.75 and 2) was associated to more convoluted and slower movements.

### 2.3. Representativeness analysis

In this study the Brazilian MPAs evaluated were the conservation units. These areas are divided in two classes according to the National System of Conservation Units (SNUC, 2000): (1) areas of Integral Protection (or no-take areas), and (2) areas of Sustainable