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STRUCTURE OF THE CETACEAN COMMUNITY AROUND THE ANTARCTIC PENINSULA

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Cauê Zirnberger Lazaneo*, Luciano Dalla Rosa, Eduardo Resende Secchi

Instituto de Oceanografia, Universidade Federal do Rio Grande - FURG,
Av. Italia, Km 8, Centro, CEP 96201-900, Rio Grande, RS, Brazil

*e-mail: cauezlazaneo@gmail.com

Abstract: *The aim of the present study was to investigate if cetacean diversity varies among areas with different oceanographic conditions around the Antarctic Peninsula. The study area consisted of the Drake Passage, Bransfield and Gerlache Straits and the Weddell Sea. This region has a complex circulation pattern, including mesoscale jets and eddies, which together with dimensions of shallows and canyons in bays, fjords and straits make the complexity of current fields. These characteristics play an important role in the transportation, concentration and retention of nutrients, favoring primary and secondary productivity and attracting the top consumers. The area was divided into 10 sub-areas based on oceanographic features such as surface circulation patterns. Cetacean distribution data were obtained during ship-based surveys run by the Brazilian Antarctic Program from 1998 to 2011 austral summers. Line transect sampling methods were used to calculate cetacean encounter rates. The diversity index for each area was determined by the Shannon-Weaver diversity index. Humpback, minke and killer whales were the most frequently sighted species, predominating in areas with low species richness such as Gerlache Strait. Areas without species dominance (e.g. Elephant Island and Weddell Sea) showed greater diversity. Our results suggest that open areas and areas close to oceanographic fronts sustain lower encounter rates for individual species but support greater diversity than confined areas.*

Keywords: Diversity, Encounter Rate, Distribution

Introduction

A biological community, defined as coexisting organisms in an ecosystem or habitat, maybe described with respect to all taxonomic groups in a particular ecosystem, or regarding a single functional group (*e.g.* cetaceans). Characterizing biological communities is important not only to understand the functionality and structure of ecosystems but also to assess the effects of environmental changes and to identify critical areas for conservation (Kiszka *et al.*, 2010). Cetaceans occupy upper trophic levels in marine ecosystems and have an important role as sentinels of the environment (*e.g.* Bowen 1997). Their distribution, diversity and some ecological aspects have been described from tropical to polar regions (Thiele *et al.*, 2000, 2004; Gannier 2002; Secchi *et al.*, 2001; Moreno *et al.*, 2005). However, knowledge is still limited on cetacean spatial diversity and community structure in the Southern Ocean.

Waters around the Antarctic Peninsula show a great mix of circumpolar and shelf water processes (Martinson *et al.*, 2008). In general, these waters are characterized by high nutrient concentration and low productivity in the upper ocean (El-Sayed and Tomo, 1987). Mesoscale processes together with dimensions of shallows and canyons in bays, fjords and straits makes the complexity of current fields (Zhou *et al.*, 2002). The intricate circulation and the high productivity present at all trophic levels in the Antarctic Peninsula and adjacent waters have been of interest to research groups from several institutions and international programs, including the Brazilian Antarctic Program (PROANTAR). Biological productivity in the Southern Ocean is particularly evidenced by high concentration of zooplankton (Marrari *et al.*, 2011) and abundance of upper level consumers such as marine mammals (Thiele *et al.*, 2000;

Secchi *et al.*, 2001, 2011; Dalla Rosa, 2010;Friedlaender *et al.* 2011; Santora & Reiss, 2011).

Prey availability is likely to be a major factor driving cetacean distribution patterns among different areas, resulting in observed variation in encounter rates (ER) (Secchi *et al.* 2001). The hypothesis is that rich areas support higher cetacean diversity or densities mainly due to prey availability. In this study, we investigate whether the diversity and relative abundance of cetaceans vary between different oceanographic areas surrounding the Antarctic Peninsula.

Materials and Methods

Cetacean sighting data were collected between 1998 and 2011, during the austral summer (January to March), except for the summers of 2006/2007 and 2007/2008. Two ships (*R/V Ary Rongel* and *P/V Almirante Maximiano*) were used during cetacean dedicated studies or as platforms of opportunity operating in the Drake Passage and around the Antarctic Peninsula. Sampling is described following Secchi *et al.* (2001). All the information was recorded using specific software (WINCRUZ or LOGGER) in a computer linked to the vessel's GPS system.

Because both dwarf and Antarctic minke whale (*B. acutorostrata* and *B. bonaerensis*) as well as beaked whales (Ziphiidae) were, on many occasions, difficult to identify to species level, they were grouped into one taxonomic group each, herein referred to as minke whales and ziphiids, respectively.

The study area was split into 10 sub-areas based on oceanographic features such as surface circulation patterns, bathymetry, primary productivity and oceanographic fronts. The oceanographic front positions in the Drake Passage were obtained through the Australian Antarctic Data Center. The spatial divisions included: (1) Southern (GS) and (2) Northern (GN) Gerlache Strait, (3) Southwestern (BS) and (4) Northeastern (BN) Bransfield Strait, (5) surroundings of Elephant Island (IE), (6) Subantarctic Front (SAF), (7) Polar Front (PF) and (8) Southern Antarctic Circumpolar Current Front (SAC), (9) coastal area of the Weddell Sea (WC) and (10) Weddell gyre region (WG) (figure 1). The most sheltered regions such as Gerlache and Bransfield Straits were systematically and widely surveyed while the other areas were only opportunistically sampled.

Effort and sighting data were imported to an ArcGis 9.3 database. Transect lines crossing sub-areas were divided into segments and assigned to their respective area. Transect segments less than five nautical miles were eliminated from statistical analyses. Encounter Rate (ER) was defined as the number of individuals sighted per nautical mile navigated (ind/NM). ER of all identified species was calculated for each sub-area to investigate variability in relative abundance. The significance of the variability of ER among sub-areas was tested by a Kruskall-Wallis test with α=0.05, while the Species Richness, Shannon-Weaver and Equitability indices were calculated to investigate cetacean spatial diversity.

Results

Approximately 7000 nautical miles were navigated along the 10 sub-areas, during which 1823 sightings of ten species were recorded around the Antarctic Peninsula and in the Drake Passage. Survey effort and sightings were distributed unevenly among sub-areas. The most frequently sighted cetacean species were humpback and minke whales. Humpbacks presented the highest encounter rate (ER) in Gerlache Strait. These two species showed a coastal distribution dominating the Gerlache and Bransfield Straits as well as the coastal areas in the Weddell Sea while Fin whales (*Balaenoptera physalus*) were recorded near Elephant Island, close to the Polar Front and in Bransfield Strait. Only these species showed significant differences in ER between sub-areas ($p_{hw}<0.001$; $p_{mw}<0.001$; $p_{fw}=0.001$). The remaining baleen whale species were registered mainly in pelagic sites. With the exception of killer whales that showed the highest ER in southern Gerlache Strait, few sightings of other odontocetes were made in the study area, and they were restricted to pelagic areas. However, all odontocetes, except the ziphiids, showed significant differences ($p < 0.05$) in ER among sub-areas.

Diversity showed a great variation among sub-areas. The coastal area of Weddell Sea presented the highest value of Shannon-Weaver index (H = 1.418) (Figure 1 left). The species richness in this area (S = 5) was lower than the surroundings of the Elephant Island (S = 7), though the abundance was more evenly distributed, which might explain the greater diversity (Figure 1 right). Despite its highest ER, Gerlache Strait presented the lowest richness (S = 3). Due to the equitability among species, the northern portion of the strait showed low diversity (H = 0.526) while the southern portion showed higher diversity (H = 1.006).

Discussion and Conclusion

Our results suggest that coastal areas are preferred by humpback, minke and killer whales. Dalla Rosa (2010) suggests that the high abundance of humpback whales in the Gerlache Strait may be explained by high productivity, as evidenced by the high primary productivity (*e.g.* Lorenzo *et al.*, 2002). The higher ER of killer whales in southern Gerlache Strait might be explained by the higher minke whale concentration and the abundance of crabeater seals floating in growlers that concentrate at several bays in this area (authors pers. obs.). These are two of the most frequently preyed species by killer whales in the Southern Ocean (Pitman & Ensor, 2003). Despite of some significant differences among sub-areas, this result should be interpreted with caution because the variation of ER could be an artifact of reduced sample size in some areas.

High chemical and biological gradients (Kahru *et al.*, 2007; Reiss *et al.*, 2009) associated with mesoscale circulation patterns in this area (Zhou *et al.*, 2010) likely influence prey and, consequently, cetacean distribution. In general, the distribution patterns observed in this study were similar to those reported in eastern parts of the Southern Ocean (Thiele *et al.*, 2000, 2004; Williams *et al.*, 2006). Baleen whales tend to be abundant in productive areas with high concentration of sea ice during the previous winter.

The structure of the cetacean community around Antarctic Peninsula, considering the data grouped over the years, indicates that the region has low relative diversity (H = 0.9451) compared to tropical regions such as Mayotte Island in the Indian Ocean (H = 1.76) (Kiszka *et al.*, 2010) and French Polynesia (H = 1.57) (Gannier, 2002). Nevertheless, waters around Elephant Island showed similar diversity values as those tropical areas. Elephant Island exhibits a complex topography and the influence of a variety of hydrographic properties from the Antarctic Circumpolar

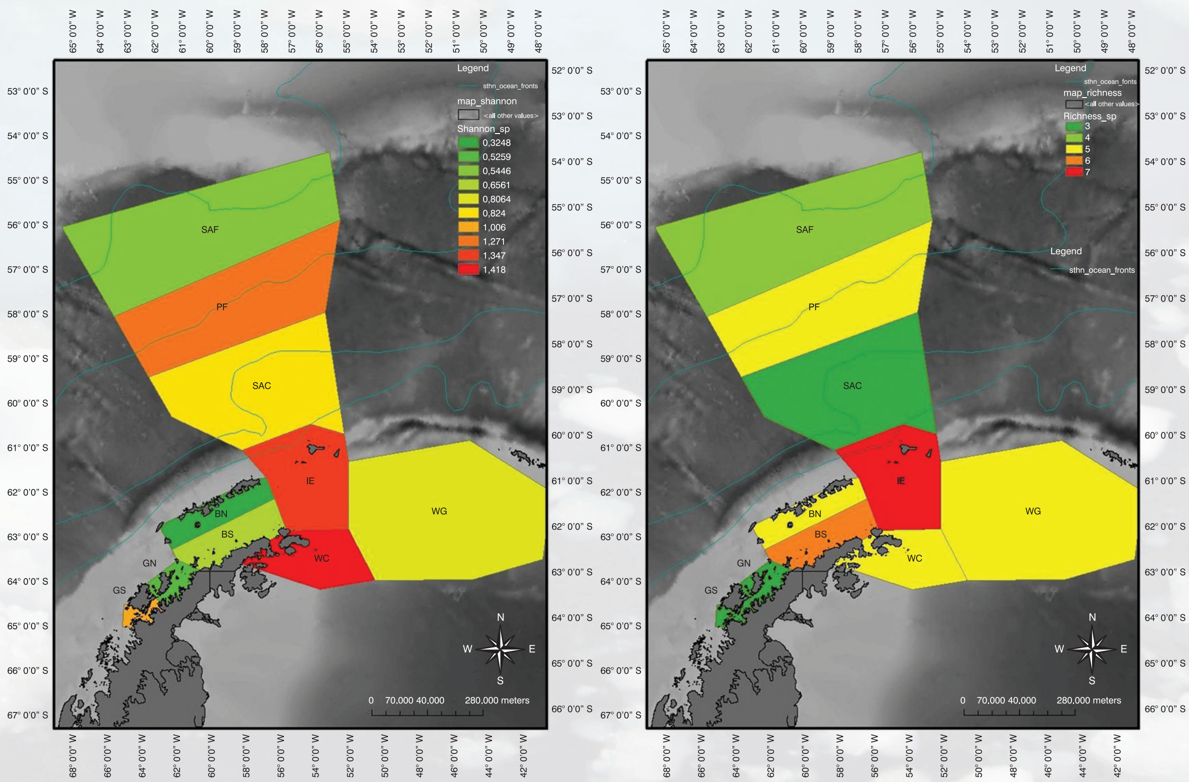

Figure 1. Shannon -Weaver index (H) distribution among sub – areas (left); Species Richness index (S) distribution among sub-areas (right). Acronyms are described in Material and Methods.

and Bransfield currents, Weddell Sea and local waters might promote diversity of primary producers, grazers and their predators. Species richness around Elephant Island was also the highest among all the study areas. The southern right whale (*Eubalaena australis*) and ziphiids were seen only on a few occasions near Elephant Island and Weddell Sea, and thus, were considered rare in the study area during the summer. Stone & Hamner (1988) reported few sightings of southern right whales in the Gerlache Strait later in the feeding season (April) and Aguayo-Lobo *et al.* (2008) reported this species in the Drake Passage and around Antarctic Peninsula between August and October. The southern bottlenose whale, *Hyperoodon planifrons*, occurs near oceanographic fronts like the Southern Antarctic Circumpolar Current front (Santora & Brown, 2010).

In general, relatively high diversity indices were observed in areas with complex topography and prominent fronts, which suggest the relevance of oceanographic features in shaping the spatial pattern of cetacean diversity on a regional scale. The physical mechanisms promote prey availability, which attracts higher trophic level predators (*e.g.* Bost *et al.*, 2009). Kasamatsu (2000) suggested that cetacean diversity increases as a function of the distance to coast, which in turn causes a decrease in cetacean density. Seasonal and geographical changes in diversity may also be explained by the convex function of sea surface temperature (SST) (Whitehead *et al.*, 2008). Some authors suggest that hotspots of marine mammals, areas of high biological activity (*e.g.* Sydeman *et al.*, 2006), are associated with peaks of primary productivity (Field *et al.*, 1998). The overall empirical evaluation over large spatial scales, however, suggests that SST is the major force in determining the distribution of marine biodiversity, including cetaceans from zooplankton (Rutherford *et al.*, 1999), tuna (Worm *et al.*, 2005) and cetaceans (Whitehead *et al.*, 2008, 2010; Kaschner *et al.*, 2011). Whitehead *et al.* (2010) showed that, on a large spatial scale, cetacean diversity is best explained by SST, whereas chlorophyll-a concentration, as a proxy of primary productivity, did not increase the models predictive ability. These authors stated that peaks in cetacean richness occur at 40º N and S, and that this pattern is rather associated with SST than primary productivity. Certain areas around the Antarctic Peninsula that showed high cetacean densities may be considered biological hotspots. Upwelling, melting sea ice and oceanographic frontal zones can support high density of few species, such as Gerlache Strait, or more richness, for example near Elephant Island and Weddell Sea. Both can be considered hotspots due the high biological activity.

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