UNIVERSIDADE DOS AÇORES
DEPARTAMENTO DE OCEANOGRAFIA E PESCAS

"Temporal variability of cetaceans in the Azores and its relation with oceanographic features as derived by satellite imagery"

A Thesis Presented to the Faculty of the Department of Oceanography and Fisheries at the University of the Azores in Partial Fulfilment of the Requirements for the Degree of Master of Integrated Studies of the Oceans

Marilia Pereira Olio

Horta

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-2016-

PUBLICATIONS

Results of this study were already presented in two international conferences:

Olio M., Santos R.P, Tepsich P. and Martins A. (2015). A three year study of humpback whale (*Megaptera novaeangliae*) occurrence in Faial-Pico islands of the Azores and its relation to satellite-derived surface biophysical products. *29th Annual Conference of the European Cetacean Society*. Malta: European Cetacean Society.

Olio M., Santos R.P, Tepsich P. and Martins A. (2016). A Three Year Study of Four Species of Baleen Whales Occurrence in Faial-Pico Islands of the Azores and its Relation to Satellite-derived Surface Biophysical Products. *2016 Ocean Sciences Meeting*, USA: American Geophysical Union.

One paper is under preparation for publication in international peer reviewed scientific journal:

Olio M., Santos R.P, Tepsich P. and Martins A. (2017). Temporal variability of cetaceans in the Azores and its relation with oceanographic features. In Prep.

ABSTRACT

The Archipelago of the Azores (Portugal) is composed of nine volcanic islands in the northeast Atlantic Ocean and it holds a high diversity of cetaceans, with 28 species documented. This is the first study in the Azores that assesses the utility of whale watching data for scientific studies on cetacean distribution, and that relates their occurrence and variability with 1 km resolution MODIS/AQUA near-surface chlorophyll a (Chla) and Sea Surface Temperature (SST) data obtained from NASA Ocean Color website. In this study, five years of field data (2010-2014) were used to evaluate blue, fin, sei and humpback whales presence. Three temporal scales (four years, yearly, and monthly) were considered. Given that effort was not consistent throughout, then encounter rates (ER=sightings.effort^{-1}) were used as standardized measures for presence temporal comparisons. Daily satellite Chla concentrations and SST values were statistically processed such as to obtain monthly, seasonal, annual averages, trends and anomalies for the period 2010 to 2014 for the Azores region. Baleen whales presence was related with the oceanographic data to infer possible causes for whales inter-annual variability Main results showed that the presence of the four baleen whale species in the Azores varied among the years. Intra-seasonal differences were found for presence rates and these varied with the species. The Bm presence was observed during the springtime suggesting that they use the Azores for foraging activity during these months while they are in their migration journey to north and that the variation of Chla and the initiation of the bloom could determine their time in the area. Similar results were found for Bp but their association with Chla and the timing of the bloom is later than the Bm. Since Bp is more opportunistic and has a varied diet, this happened since their prey could be in another level of the food chain. The peak for Bb varied in the spring and summer months and these differences could be explained by the assumption previously made by other authors, that maybe the Azores is visited by two different stocks of Bb, one during the migration in spring time and the second during late summer and autumn. Furthermore, the Chla concentration could be a biological parameter associated with the peak of Bb only for one stock. Lastly, the presence peaks of Mn were observed mostly during the spring and the number of sightings per month doubled in 2014 and 2015, suggesting that Mn could have foraged during these months while they were in their migration journey to north. Sea surface temperature and Chla concentration overall averages, adjusted averages (trends) and anomalies, as well as, calculations of the timing of the blooms show that the seasonal cycle is strong at these latitudes and inter-annual variability may explain differences in whales presence over the years. By removing the seasonal cycle, SST is very conservative over the years, and its trend reveals slight increase with time. Regarding Chla concentrations, spring blooms are not always observed in the region, but 2010 and 2014 reveal the strongest ones, coincident also with an overall increase in baleen whales observation, particularly for 2014. The use of platforms of opportunity may provide scientists a means of collecting data on a wide range of marine fauna when research funding is limited. Nevertheless, and in face with all the limitations found in the cetacean data, this study presents new suggestions for sampling protocols improvement such data from whale watching in MONICET might yield better possibilities for scientific purposes in the Azores.

Keywords: Baleen whales, occurrence, Azores; SST; Chla.

RESUMO

O Arquipélago dos Açores (Portugal) é composto por nove ilhas vulcânicas no nordeste Oceano Atlântico e detém uma elevada diversidade de cetáceos, com 28 espécies documentadas. Este é o primeiro estudo nos Açores, que avalia a utilidade de dados do turismo de observação de baleias para estudos científicos sobre a distribuição dos cetáceos, e que relaciona a sua ocorrência e variabilidade com imagens MODIS/AQUA de clorofila a (Chla) e temperatura à superfície (SST) com 1 km de resolução obtidas através do site da *NASA Ocean Color*. Neste estudo, cinco anos de dados de campo (2010-2014) foram utilizados para avaliar a presença das baleias azul, comum, sardinheira e bossas. Fora consideradas três escalas temporais (quatro anos em conjunto, anuais e mensais). Dado que o esforço não foi consistente ao longo dos anos, as taxas de avistamento (*Encounter rate*, ER=avistamentos.esforço^{-1}) foram utilizadas como medidas padronizadas para comparações temporais de presença. Imagens diárias de Chla e SST foram processadas estatisticamente, obtendo-se médias mensais, sazonais, anuais, tendências e anomalias para o período de 2010 a 2014 para a região dos Açores e relacionados com a variabilidade local de quatro espécies de baleias de barbas para tentar explicar as diferenças registadas ao longo dos anos. Os principais resultados mostraram que a presença das quatro espécies de baleias de barbas nos Açores variou entre os anos. Diferenças intra-sazonais foram encontradas para as taxas de presença e estas variaram de acordo com a espécie. A presença de Bm foi observada durante a primavera sugerindo que estas baleias usam os Açores como área de alimentação durante estes meses enquanto estão na sua rota de migração para norte e que, a variação de Chla e o início do crescimento do fitoplâncton são bons indicadores do tempo efectivo destas na região. Resultados semelhantes foram encontrados para a BP, mas a sua associação com Chla e o momento do crescimento do fitoplâncton é posterior à Bm Sendo a Bp mais oportunista e tendo uma dieta mais variada, as suas presas podem estar a níveis diferentes cadeia alimentar. O pico de Bb variou nos meses de primavera e verão e estas diferenças podem ser explicadas pela suposição, já referida por outros autores, de que os Açores provavelmente são visitados por duas populações diferentes de Bb, uma durante a fase de migração na primavera e a segunda durante o final do verão e no outono. Assim sendo, a concentração de Chla seria um parâmetro biológico associado com o pico de Bb apenas para uma das populações. Por último, os picos de presença de Mn foram observados principalmente durante a primavera e o número de meses dos avistamentos duplicou em 2014 e 2015, sugerindo que Mn poderia utilizar os Açores como área de alimentação durante estes meses, durante o seu caminho de migração para norte. A temperatura da superfície do mar, a concentração de Chla e o início do crescimento do fitoplâncton, aqui ilustrados como médias gerais, médias ajustadas (tendências) e anomalias, suportam a hipótese de que o ciclo sazonal e a variabilidade inter-anual são bem demarcados nesta região podendo explicar as diferenças observadas na presença das baleias ao longo os anos. Ao remover o ciclo sazonal, SST é muito conservador ao longo dos anos, com uma ligeira tendência de aumento com o tempo. Com relação à Chla, nem todos os anos apresentam floração de primavera, mas 2010 e 2014 revelam os picos maiores de Chla, coincidindo também com um aumento global de observação das baleias, particularmente para 2014. O uso de plataformas de oportunidade pode dar aos cientistas um meio de recolha de dados sobre uma ampla gama de fauna marinha quando o financiamento da investigação é limitada. No entanto, face às limitações encontradas nos dados de cetáceos, este estudo apresenta novas sugestões de introdução nos protocolos de amostragem por forma a que os dados MONICET possam produzir dados detalhados para fins científicos.

Palavras-chave: Baleias de barbas; Açores; Temperatura superficial; Clorofila.

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INTRODUCTION

Cetacean distribution and relative abundance in offshore waters of the North Atlantic remain largely unknown. Previous research studies, particularly those related with the North Atlantic Sighting Surveys (NASS 1985-2001), allowed some new information regarding cetacean distribution and population size. However, none of these surveys covered the mid-Atlantic waters (Silva et al., 2014). The first systematic survey information on cetacean distribution and density in this region was realized during the Mid-Atlantic Ridge Ecology Program (MAR-ECO) in June-July 2004 (Waring et al., 2008).

The Archipelago of the Azores (Portugal) is composed of nine volcanic islands and several small islets in the northeast Atlantic Ocean about 1,360 km (850 mi) west of continental Portugal. The islands form three main groups: Flores and Corvo, to the west; Graciosa, Terceira, São Jorge, Pico, and Faial in the centre; and São Miguel, Santa Maria, and the Formigas Reef to the east. They extend along a west-northwest to east-southeast orientation (between 36.5°– 40° North latitudes and 24.5°– 31.5° West longitudes) in an area approximately 600 km (373 mi) wide.

The marine environment of the Azores Archipelago and its surrounding Economic Exclusion Zone (EEZ), of more than 1 million km^2, holds considerable marine biodiversity, conservation, geostrategic and economic interests (e.g. Santos et al., 1995; Bashmachnikov et al., 2009; Ciancia et al., 2016). The area holds a high diversity of cetaceans, with 28 species documented (reviewed in Prieto and Silva 2010; Silva et al., 2012). The first assessment of the spatial and temporal distribution patterns of cetaceans around the Azores has been provided by Silva (2014), who used data collected during sighting surveys from land-based observations to provide the first assessment of the spatial and temporal distribution patterns of cetaceans around the Azores.

The use of platforms of opportunity, such as whale watching vessels (Magalhães et al., 2002; Croll et al., 2005; Ingram et al., 2007; Esteban et al., 2013; Randage et al., 2014; Tepsich, 2015; Vinding et al., 2015), seismic survey vessels (Fernandes et al., 2007; Muir et al., 2015), commercial ships (Viddi et al., 2010; Correia et al., 2015) or ferries (Morgado, 2013; Aïssi et al., 2015; Cominelli et al., 2015; Arcangeli et al.,

2016) is currently recognized as a valuable alternative to dedicate research effort, that is usually expensive and time consuming. Data collected from these platforms have been widely used to provide alternative sources of data on cetaceans, especially in developing countries, and information on spatial distribution, temporal patterns in abundance, and behaviour have been acquired (Ingram et al., 2007; Esteban et al., 2013; Morgado, 2013; Cominelli et al., 2015; Correia et al., 2015; Vinding et al., 2015). However, such data need to be interpreted with caution, especially given spatial or temporal differences in effort or variation in observer ability to correctly identify species (Tepsich, 2015; Vinding et al., 2015).

In the Azores archipelago, whale watching has been occupying an increasingly important role at a socio-economical level and it is growing rapidly (Magalhães et al., 2002). In 1989 there was some experimental activity with some foreigner (English and French) local entrepreneurs, but it was in 1993 that this activity was fully initiated) (Hoyt, 1992). In 2011, within the framework of project MONICET, funded by the Regional Government of the Azores, a first whale watching database platform was constructed. Since then, MONICET has been collecting cetaceans' observation of several whale watching companies in Portugal, providing free data for scientific studies and public information. However, to the best our knowledge, with an exception a graduate thesis (Silva, 2013), this database has never been used for scientific publication.

Increased interest in understanding the occurrence, distribution and behaviour patterns, of different cetacean species present in Azores waters resulted in a number of research programs and/or projects in the region in the past decade. These studies show strong seasonal and inter-annual cetacean variability in the region (Silva et al., 2014), others suggest physical/biological mechanisms responsible for this variability (e.g. frontal thermal structures (Silva, 2013; Prieto et al., 2016). However, most fail to relate inter-annual and seasonal variability in the region with biotic and abiotic anomalies or to compare episodic events with mesoscale dynamics.

In order to overcome this limitation, this study uses *in situ* data and MODIS/AQUA satellite derived imagery to provide new understanding of how the occurrence of cetacean might be linked/connected to large and/or mesoscale physical/biological processes in Azores waters.

Main objectives of this work are: first, to assess the utility of whale watching data for scientific studies on cetacean distribution; and second, to assess cetacean occurrence (i.e. presence/absence) in the Azores by relating its variability with satellite derived Ocean Colour (OC) and Sea Surface Temperature (SST) geophysical parameters. For this, five years of *in situ* cetacean data and satellite-derived imagery are used, comprising three seasons of the year (winter-spring-summer). To explain major cetacean occurrences, seasonal, annual, inter-annual and specific events anomalies are analysed to infer (local and regional) cetacean variability in the Azores.