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PAULA SOBENKO HATUM

THE SONG OF HUMPBACK WHALE AND THE POTENTIAL EFFECTS OF WHALE-WATCHING IN THE ABROLHOS BANK, BA, BRAZIL

Dissertação apresentada à Universidade Federal do Rio Grande do Norte, para obtenção do título de Mestre em Psicobiologia.

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Orientador: Renata S. Sousa-Lima Mobley

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RESUMO

Os machos de baleia jubarte (*Megaptera novaeangliae*) produzem o canto, uma longa e complexa sequência de sons. Este ocorre predominantemente em áreas de reprodução, e com menor frequência, em áreas de alimentação e migração. Uma das teorias predominante é que sua função seja de atrair parceiras. Estudos recentes mostraram que o canto muda frequentemente ao longo de uma ou mais estações reprodutivas dentro de uma população, um exemplo de evolução cultural. O turismo de observação de cetáceos (Whale-Watching) tem crescido com a recuperação das populações de baleias pós-caça comercial. Porém, ainda há uma crescente preocupação com os possíveis efeitos gerados sob os cetáceos, especialmente em áreas como o Banco dos Abrolhos, uma das principais áreas de reprodução da espécie. Este trabalho teve como objetivo (1) descrever a variação na estrutura do canto das baleias jubartes no Banco dos Abrolhos durante o período entre 2003-2005, baseados no nível hierárquico de frases, e definir linhagens de temas; (2) comparar o comportamento vocal de machos de baleia jubarte na presença e na ausência de barcos a motor associados à atividade turística na região do Banco dos Abrolhos; e, (3) caracterizar os ruídos das embarcações e identificar as características dos barcos que influenciam nas respostas comportamentais das baleias jubarte. Vinte e um temas foram descritos entre o período de 2003 a 2005. Para os temas que apresentaram frase padrão, foram definidas linhagens, através das quais observou-se diferentes tipos de mudanças entre os temas ao longo do período estudado. Tais mudanças ocorreram na estrutura espectral, introdução e remoção de unidades. Observou-se também variação na estrutura das frases tanto intra quanto interindividual. No capítulo 2, o canto foi adquirido sem a presença de barco a motor e durante a aproximação de um único barco a motor, o qual se aproximava seguindo as diretrizes para as atividades de "whale watching" nesta área. Foi visto que embora o número de frases por tema diminuam na presença de barco, esta diferença não é significativa. Similarmente, a duração da frase também é mantida durante a exposição ao ruído de barcos a motor, sugerindo que esta métrica apresenta uma forte pressão seletiva para que os machos mantenham o canto consistente. Adicionalmente, verificou-se que a duração das sessões do canto não apresentou diferença significativa entre as duas condições experimentais. Finalmente, no terceiro capítulo, os resultados sugerem que os sons produzidos pelos diferentes tipos de embarcações e de motor, não influenciam no comportamento acústico ou espacial das jubartes. Os valores encontrados para as métricas utilizadas na caracterização dos ruídos produzidos pelas embarcações parecem não apresentar nenhuma associação com os tipos de barcos de turismo considerados na análise. A maioria das embarcações apresentou níveis sonoros que se sobrepõem às frequencias do canto das baleias, sugerindo um possível mascaramento. Devido à importância da comunicação acústica para as jubartes, faz-se necessário compreender melhor os processos envolvidos na evolução do canto e os efeitos provocados pelos ruídos dos barcos a motor sobre a espécie. Assim, será possível gerar informações relevantes para a conservação e um melhor gerenciamento do turismo de observação das jubartes no Parque Nacional Marinho dos Abrolhos, ambiente extremamente importância para a espécie.

Palavras-chave: Mamíferos marinhos, atividade vocal, efeito antrópico, ecoturismo, evolução cultural.

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INTRODUÇÃO

Baleia jubarte: Comportamento reprodutivo e Canto

A baleia jubarte (*Megaptera novaeangliae*) pertence à família Balaenopteridae, possui um corpo robusto, com nadadeiras peitorais chegando a medir um terço do comprimento total do animal, sua principal característica morfológica. Apresenta coloração típica variando do cinza escuro ao negro, podendo ser observadas manchas brancas principalmente na região ventral. É uma espécie cosmopolita, e, anualmente, realiza migrações sazonais entre áreas de alimentação em altas latitudes durante o verão e áreas de reprodução em baixas latitudes durante o inverno (Dawbin 1996, Clapham & Mead 1999, Zerbini et al. 2011).

O Banco de Abrolhos é a principal área de reprodução da espécie no oeste do Oceano Atlântico Sul (Engel 1996, Martins et al. 2001, Andriolo et al. 2006). Durante a temporada reprodutiva, a abundância relativa de jubartes em volta do arquipélago dos Abrolhos cresce continuamente a partir do início de julho, atingindo um pico no final de agosto e começo de setembro, quando decresce até o final de novembro, período em que a maioria dos indivíduos já retornou para a área de alimentação (Morete et al. 2008).

Um dos comportamentos mais estudados das baleias jubarte é a sua vocalização e o seu complexo comportamento de canto (Darling et al. 2012, Cholewiak et al. 2013). As baleias jubarte são conhecidas por produzir alguns dos repertórios acústicos mais ricos, tanto na forma de sons sociais e no seu complexo canto (Payne e McVay 1971, Stimpert et al., 2007, Mercado, et al. 2010, Stimpert et al. 2011). Chamadas sociais e de alimentação não apresentam uma estrutura repetitiva e padrão comparáveis aos do canto e são produzidos por ambos os sexos (Silber 1986, Stimpert et al. 2007, Dunlop et al. 2008). Nas áreas de reprodução, os machos produzem uma longa e complexa sequência de sons denominado canto. Payne & McVay (1971) descreveram o canto da baleia jubarte como sendo subdivido em “unidades” que juntas formam uma “frase”, a repetição de frases semelhantes é denominada “tema” e o “canto” consiste em uma combinação de vários temas distintos.

A função do canto ainda não é conhecida, no entanto, foram levantadas diversas hipóteses a fim de investigar o papel desempenhado por essas complexas canções, que poderiam ser, por exemplo, uma forma de atrair a atenção das fêmeas (Tyack 1981, Clapham 1996); servir como uma forma de estabelecer dominância entre os machos (Darling & Bérubé 2001); um mecanismo para sincronizar o período de estro das fêmeas (Baker & Herman 1984); uma forma de navegação durante a migração (Clapham & Matilla 1990); servir como delimitação de território entre os machos (Frankel et al. 1995); ou funcionar como um tipo de sonar para localizar as fêmeas (Frazer & Mercado 2000). Dentre as hipóteses, a mais aceita é que as canções são utilizadas para a comunicação, em vez de navegação, e que o canto dos machos poderia atuar como um *display* sexual para atrair as fêmeas.

A formação de grupos competitivos é comum ao longo da temporada reprodutiva (Martins et al. 2001). Tais grupos são constituídos de um animal nuclear (fêmea em estro ou pré-estro), que pode ou não estar amamentando um filhote (Tyack & Whitehead 1983); esta fêmea é acompanhada por outros machos (escortes) que competem pela proximidade e acesso a ela.

Diversos autores sugerem que os grupos reprodutivos de jubartes seriam semelhantes a um sistema reprodutivo de leks (Herman & Tavolga 1980, Clapham 1996, Connor et al. 2000, Herman et al. 2013) No entanto, ao contrário do sistema reprodutivo em lek clássico, baleias jubartes machos não estabelecem território nem monopolizam o acesso as fêmeas, sendo, desta forma, denominado "floating lek" (Clapan *et al.* 1992). Machos maturos e imaturos cantam nas áreas de reprodução, e esta ampla participação dos machos em leks de agregação pode gerar um sinal acústico mais intenso, atraindo, desta forma, um maior número de fêmeas (Herman et al. 2013).

Smith et al. (2008) sugerem que o canto pode servir para transmitir certos atributos dos machos, e que, diferente da hipótese do canto ser utilizado para afugentar machos competidores, o canto poderia atrair machos que estavam próximos. Esses autores propõem que o canto poderia ser um sinal para outros machos da presença de uma fêmea reprodutora, ou seja, cantar poderia ter como custo atrair outros machos competidores, o que seria inevitável já que o canto funcionaria como um *display* sexual nas interações com as fêmeas. Desta forma, espera-se que o macho tenha maior sucesso reprodutivo quanto mais eficiente for a transmissão do seu canto para o maior número de fêmeas.

Apesar de haver uma consistência no padrão de canto exibido entre os machos de uma mesma população, estudos mostraram que há desde variações individuais nas repetições das frases, variações entre os indivíduos de uma mesma população, até mudanças ao longo de vários anos ou ao longo das estações reprodutivas (Payne et al. 1983, Payne & Payne 1985). Quando tais mudanças ocorrem, todos os machos cantores da mesma região incorporam as mesmas mudanças em seus cantos (Noad et al. 2000, Cerchio et al. 2001). Dentro de uma mesma população, a música muda, geralmente de forma progressiva e gradual, ao longo de vários anos ou entre as estações reprodutivas (Payne et al 1983, Payne & Payne 1985). Este processo tem sido referido como um exemplo de "evolução cultural" (Winn & Winn 1978, Payne & Payne 1985, Cato 1991, Noad et al. 2000) semelhante ao observado na canção de algumas espécies de aves (Slater 1986, Catchpole & Slater 2008). Noad et al. 2000, mostraram uma rápida mudança no canto de uma população australiana advinda da chegada de alguns poucos machos de outra população, e evidências recentes apontam para transmissão cultural horizontal do canto dentro de populações (Garland et al. 2011).

Ruídos de embarcações e seus potenciais efeitos sobre as baleias jubartes

O turismo de observação de mamíferos marinhos tem apresentado um rápido crescimento nas últimas décadas (Hoyt 2001, Muloin 1998, O'Connor et al. 2009). A observação de baleias, em particular, tem apresentado um grande crescimento, sendo uma das classes do turismo que mais cresce no mundo (Hoyt, 2001). Desde o início da moratória à caça, muitas populações de baleias vêm se recuperando em todo o mundo, e no Brasil, acompanhando o aumento da ocorrência das baleias jubarte, o turismo de observação desta espécie vem se tornando cada vez mais frequente no estado da Bahia (Cipolotti et al. 2005). A atividade de observação de baleias (*Whale-Watching*) foi definida pela IWC - *International Whaling Commission* - como qualquer empreendimento comercial que provê ao público a possibilidade de observar qualquer espécie de cetáceo em seu ambiente natural. Embora permita uma utilização mais sustentável das jubartes como um recurso natural, o rápido crescimento desse tipo de turismo vem gerando preocupação sobre os possíveis efeitos que a atividade pode causar na espécie, em especial nas áreas de reprodução, como é o caso do Banco dos Abrolhos, onde as jubartes estão expostas a várias atividades antropogênicas (Martins et al., 2013), dentre elas os ruídos produzidos por embarcações, que têm se mostrado prejudiciais ao comportamento vocal da espécie (Richardson et al. 1995, Sousa-Lima & Clark, 2004, 2008, 2009).

Ao longo das últimas décadas, tem sido notório o aumento dos níveis de ruído no ambiente subaquático provenientes de atividades antropogênicas, o que provavelmente gera impactos sobre os mamíferos marinhos (Risch et al. 2012). Tais impactos são oriundos de diversas fontes, como tráfego marítimo, dragagens, construções e cravação de estacas submersas, exploração de minérios, prospecções geofísicas, sonares, explosões subaquáticas e estudos científicos (Frantzis 1998, Finneran et al. 2000, Morton et al. 2002, Gordon et al. 2004, Madsen 2006, Di Iorio & Clark 2009, McCarthy et al. 2011). Possíveis efeitos destes ruídos incluem lesões, danos auditivos em curto a longo prazo, alterações no comportamento dos indivíduos (e.g., alimentação, acasalamento e comunicação), dificuldade na detecção de chamadas de coespecíficos, localização de presas e predadores, ou outros sons importantes (Richardson et al. 1.995, Weilgart 2007, Hatch et al. 2008, Martins et al. 2013, Nowacek et al. 2007, Southall et al. 2007).

Estudos investigando as possíveis respostas da baleia jubarte frente à aproximação de embarcações verificaram que o número de frases do canto foi alterada, podendo até mesmo levar à interrupção do comportamento vocal (Tyack 1981, Sousa-Lima et al. 2002, Sousa-Lima & Clark, 2008, 2009). Sousa-Lima & Clark (2004) sugerem que, em períodos de tráfego intenso, as baleias param de cantar ou têm seus cantos mascarados pelos ruídos das embarcações, o que pode ser um problema para detecção e localização de machos cantores e comunicação entre as baleias. As consequências dessa ruptura no sistema de comunicação podem resultar em graves efeitos sobre o sucesso de acasalamento individual, podendo até mesmo, em longo prazo, causar efeitos na viabilidade das populações (Sousa-Lima & Clark, 2004). Lesage et al. (1999), em um estudo realizado com beluga (*Delphinapterus leucas*), verificaram alterações no comportamento vocal dos indivíduos, como aumento da duração e repetição das vocalizações.

Todas as embarcações, desde os menores barcos até os grandes petroleiros, produzem ruídos, os quais variam com as características das mesmas. Assim, cada embarcação possui uma assinatura espectral específica que depende do tipo de propulsão, da velocidade, da condição da embarcação e das atividades desenvolvidas a bordo (Mitson 1993, Richardson et al. 1995, Jensen et al. 2009). As fontes de ruído de uma embarcação são diversas, podendo ocorrer pelo movimento da hélice, atrito da embarcação na água e funcionamento do motor (Richardson et al.1995). A maior parte dos ruídos subaquáticos produzidos pelas embarcações é causada pela cavitação (Ross 1976, Au & Green 2000), que ocorre em razão da formação de bolhas produzidas pela rotação das pás das hélices, que colapsam ou "cavitam" provocando um alto ruído (Studds et al. 2007).

Em um estudo realizado em Maui, no Havaí, Au & Green (2000) investigaram os níveis de ruído provocados por barcos de observação de baleias e seus possíveis efeitos sobre o comportamento das baleias jubarte. Nesse trabalho, foram fornecidas as assinaturas de ruído de cinco embarcações diferentes, e as respostas comportamentais relatadas foram, por exemplo, mudanças de curso abruptas e longos mergulhos, similarmente ao que já foi relatado anteriormente para as jubartes em águas havaianas conforme Green (1998). No entanto, Au & Green (2000) concluem que, em virtude dos níveis de ruídos produzidos pelas embarcações serem menores do que os níveis produzidos pelo canto das baleias, possivelmente os níveis de ruídos das embarcações não geram graves efeitos no sistema auditivo das jubartes que emitem o canto, mas pode estar afetando a recepção do canto por outros indivíduos na área afetada pelo ruído.

Devido ao som viajar muito melhor do que a luz no oceano (Urick, 1983), muitos animais marinhos, incluindo os mamíferos marinhos, utilizam o som para obter informações sobre o ambiente (Popper 2003, Tyack & Miller 2002). As baleias jubarte (*Megaptera novaeangliae*), em particular, são mamíferos marinhos que utilizam comumente a comunicação acústica em suas interações sociais (Clapham 2000). Seu uso varia desde a localização de indivíduos e comportamento alimentar até comportamento reprodutivo (Tyack 1981, Darling et al. 2006). O uso crescente da mecanização no mar está aumentando a quantidade de ruído introduzida pelos seres humanos nos oceanos. Com o aumento do ruído, pode haver a redução da capacidade do animal em detectar sons relevantes; o que é denominado mascaramento.

OBJETIVOS

1. Capítulo 1:
    - 1.1. Descrever os temas encontrados em cada um dos três anos analisados, definindo a frase tipo de cada tema por ano;
    - 1.2. Descrever as variações na estrutura dos temas e frases intra e interindivíduos;
    - 1.3. Comparar as mudanças estruturais dos temas entre os anos;
    - 1.4. Construir uma linhagem para cada tema, evidenciando as mudanças ocorridas entre os anos.

2. Capítulo 2:

2.1. Comparar a duração, o número médio de frases e as sessões do canto de machos focais de baleia jubarte na presença e na ausência de barcos a motor associados à atividade turística (*Whale-Watching*) na região do banco dos Abrolhos, litoral sul da Bahia, Brasil.

3. Capítulo 3:

3.1. Caracterizar os ruídos produzidos por diferentes embarcações utilizadas no turismo de observação de baleias na região do Parque Nacional Marinho dos Abrolhos;

3.2. Identificar as características dos barcos que influenciam na variação de respostas comportamentais das baleias jubarte observadas em relação à sua aproximação: parou ou continuou a cantar; permaneceu ou deixou a área.

CHAPTER I - Evolution of the humpback whale (*Megaptera novaeangliae*) song in the Abrolhos Bank, Bahia, Brazil

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Bioacoustics (Qualis: A2, Impact factor: 0.727)

A ser submetido.

Evolution of the humpback whale (*Megaptera novaeangliae*) song in the Abrolhos Bank, Bahia, Brazil

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ABSTRACT

Male humpback whales produce a long, complex, and stereotyped song on low-latitude breeding grounds; they also sing while migrating to and from these locations, and occasionally in high-latitude summer feeding areas. Considering the different existing hypothesis regarding the adaptive significance of complex songs, the most commonly accepted hypothesis is that the song is important for the reproductive success of the males. Initially described as fixed patterns, subsequent studies have shown that the song undergoes frequent changes over the course of one or more breeding seasons within a population and may be regarded as a evidence of cultural transmission. The present work investigated the structural variability of the humpback whales' song in the bank of Abrolhos during the period of 2003-2005, describing the variations found within the hierarchy levels of its phrases over the same period and to quantify the incremental changes of the themes through the years. Twenty-one themes were reported during this period, and continuity lineages of theme modification were built for the themes where it was possible to define a standard phrase through statistical testing (n=18). We observed changes in the spectral structure of the units, introduction of new units, removal of units and also variation in the general sentence structure intra- and interindividual.

Keywords: Cultural transmission, vocal activity, Abrolhos, humpback whale.

INTRODUCTION

In the Southern hemisphere, humpback whales (*Megaptera novaeangliae*) feed in Antarctic waters during the summer and migrate to tropical areas for reproduction and calving during the winter (Dawbin 1996, Clapham & Mead 1999, Zerbini et al. 2011). In the reproduction areas, the males emit a sequence of structured and repetitive sounds know as song which was first described by Payne & McVay in 1971. Although high-latitude song is less common than song on the breeding grounds, humpback song has also been recorded on the feeding grouds (Mattila et al. 1987, McSweeney et al. 1989, Stimpert et al. 2012, Vu et al. 2012) and during migration (Cato 1991, Norris 1999, Charif et al. 2001, Noad & Cato 2007) in multiple populations. Taking into account the different existing hypotheses regarding the functional role of these complex songs, the most commonly accepted hypothesis is that the song is important for the reproductive success of the males (Herman & Tavolga 1980, Tyack 1981). Herman & Tavolga (1980) and Clapham (1996) suggest that the reproductive groups of the humpback whales would be similar to the reproductive system of leks, in which the song could function as an intersexual display. Darling (1983) suggests an intrasexual function for the song that may enable the establishment of a dominance hierarchy among males.

Payne & McVay (1971) described the song of the humpback whale as being subdivided into “units” which together form a “phrase”, the repetition of similar phrases in known as “theme” and the “song” consists in a combination of several themes. These authors based this terminology on studies of bird song. Similar to birds, the sounds made by humpback whales present a structure of patterned sounds that are repeated through time. However, the song of the humpback whale is different from bird song in both duration and timing. Bird songs are usually separated from the next by an interval of silence whereas humpback whales may sing continuously without interruptions for several hours (Payne & McVay 1971). Winn & Winn (1978) reported a song from a single individual that lasted twenty two hours.

The humpback whale song is structured in several hierarchical levels. The simplest levels are subunits and units. The units are the shortest sounds that seem continuous when heard at a normal speed by humans, and the subunits are components of a unit which are not aurally discriminated from each other despite being separated pulses (Payne & McVay 1971). Phrases were initially described as a series of repeated units (Payne & McVay 1971). Later, Payne et al. (1983) highlighted that the phrases could be repetitions of different subphrases which contained repeated units. A repetition of similar phrases forms a theme (Payne & McVay 1971), and so, during a sequence of phrases, the introduction of a new phrase gives origin to a new theme. The song is a sequence of distinct themes and the series of songs, in which the pauses are no longer than a minute, is termed a song session (Payne & McVay 1971).

In addition to the structural definitions, the songs were described as cyclical and fixed patterns of sounds (Payne & McVay 1971). In 1985, Payne et al., classified the themes in three types: Static themes (static) constituted by phrases practically identical in each repetition; progressive themes (shifting), constituted by phrases which have a progressive change in each repetition, with the units suffering modifications of frequency and/or form, length, number of units or in the rhythm of its presentation, and themes without pattern (unpatterned), comprised by a varied number of units without any clear organization, making it impossible to visualize a subdivision of repeated phrases. In some cases it is possible to find transition phrases, which consist of a combination of units/phrases(?) from the precedent and following themes (Payne & McVay 1971, Payne & Payne 1985).

Within a single humpback whale population, all males sing songs that are very similar (Payne 1978, Winn & Winn 1978). However, those songs change progressively during their reproductive season so that all singing males of the same region incorporate the same changes in their songs (Payne et al. 1983, Payne & Guinee 1983, Payne & Payne 1985, Noad et al. 2000, Cerchio et al. 2001). The changes occur gradually but songs from different seasons can be very different (Payne et al. 1983, Payne & Payne 1985). The changes occur in all hierarchical levels: units, phrases, themes and songs (Payne et al. 1983).

Guinee et al. (1983) state that in a given moment the song of a whale may be more similar to the song of other whales in the same area than to their own song of previous years or months. These authors suggest that this is an evidence of learning and cultural transmission among individuals and that this progressive change would be an example of cultural evolution. Noad et al. 2000 documented a song change in the Australian humpback whale population in which the population's song was replaced rapidly and completely by a song used by the western Australian population over two years. This change was referred to as "cultural revolution".

Several studies have compared songs among populations (Winn et al. 1981, Guinee & Payne 1988, Cerchio et al. 2001, Darling & Sousa-Lima 2005). However, only a few studies evaluate the long-term evolution of the song within a unique population (Payne & Payne 1985, Garland et al. 2011, 2012, 2015). The comparison among different studies becomes difficult due to the subjectivity in the choice of criteria to analyze the humpback song, recently mentioned by Cholewiak et al. (2012). These authors make several suggestions in relation to the methodologies that could be used to facilitate the comparison among different studies for a better understanding of the the variations influencing the structure of humpback whale song, as well as its gradual evolution between years. They suggest that the construction of a lineage for each theme would be a better approach to explain the variation of the song and its temporal evolution for each studied population.

The Abrolhos Bank is the major area for the reproduction of the species in the western south Atlantic (Engel 1996, Martins et al. 2001, Andriolo et al. 2006). During the reproductive season, the relative abundance of humpbacks surrounding the archipelago of Abrolhos grows continuously from the beginning of July, reaching a peak in the end of August/beginning of September, when then it decreases until the end of November, period in which the majority of the individuals has already left to the feeding area (Morete et al. 2008). Other studies indicate that there is a continuous increase in the number of humpback whales that visit this area, presently estimated between 6,000-10,000 individuals (Andriolo et al. 2010, Zerbini et al. 2011).

The understanding of the variation in the songs of the humpback whales during consecutive years is important to elucidate the functions of the song and the evolution of the behavioral aspects of this species. Based on a better understanding of how these changes occur, it’s possible to speculate over the most likely selective forces which act on the song. Additionally, it’s possible to identify metrics capable of showing evidence of the likely impacts of anthropogenic activities in humpback whale communication (Sousa-Lima & Clark, 2008, 2009, Cerchio et al. 2014). The aim of this study is to describe the variation in the structure of the song of humpback whales in the Abrolhos bank between 2003-2005, based on the hierarchical level of phrase and to define the lineages of themes.

MATERIALS AND METHODS

Area of study

The bank of Abrolhos (16º40'-19º 30'S) is an enlargement of the continental shelf and is located between the south of the state of Bahia and the north of Espirito Santo covering an area of approximately 30,000 km² (Fainstein & Summerhayes 1982). The mean depth of ocean across the bank is 30 meters (Castro & Pires 2001, Dutra et al. 2006). The biological richness of the Abrolhos Bank motivated the creation of diverse protected areas or units of conservation. It was in the Abrolhos Archipelago that the first Nation Maritime Park, the Abrolhos National Marine Park (ANMP), was created, which consists of two distinct areas: the largest one surrounds the archipelago and a part of Abrolhos; the second is mostly terrestrial coastline, covers the Reef of Timbebas. This region is of extreme importance to the humpback whales since it represents the major area of reproduction in the west of the south Atlantic ocean (Engel 1996, Andriolo et al. 2006, Martins et al. 2001, Martins et al. 2013).

Data collection

Recordings of the humpback whale songs were made during the reproductive seasons (*state the months*) of 2003, 2004 and 2005. During this period, the songs were recorded using a single hydrophone (HTI-90 min or HTI-96 min) connected to a recorder (Sony DAT or Marantz Solid State PMD670).

Groups of humpback whales were located visually. After the detection of a focal group, selected when at least one individual was in a tail up posture (described by Morete et al 2003) or submerged but surfacing for exhalations in the same place, the motor of the vessel was turned off and the hydrophone was placed into the water. Once vocal activity was detected, a silent approach was made using an inflatable boat. During sound recordings to confirm the whale under observation was indeed the one being recorded, the researchers monitored the amplitude of the sound according to the approach of the group, and also tried to identify the attenuation of the sound when the focal individual came to surface (Sousa-Lima 2007). Phrases in which it was not possible to distinguish between the possible singers due to a high number of vocally active males at the same time were not considered.

Analyses of acoustic data

Sound files were analyzed from the spectrograms using the analysis software Raven Pro (version 1.5, Cornell Lab of Ornithology, Ithaca, NY). A Hann window function of 1024-points and a 1024-point FFT size were used. We analyzed 8 different recordings belonging to 8 distinct individuals in 2003, 21 recordings for 8 individuals in 2004, and 6 recordings for 4 individuals in 2005. Individuals analyzed within the survey period were not repeated through the years. For each individual we counted the number of phrase types per theme.

The definition of each theme, as well as the identification of each unit in the recordings from the years 2003, 2004 and 2005 was carried out following the work of Brito (2014) who described the songs of singing males from the same population between 2000-2002. The numbering schemes for themes over the years 2000-2002 (Brito 2014) and 2003-2005 (this study) were based on 2000 themes from signers in this population (Arraut & Vielliard, 2004). Therefore, the number of themes does not reflect any specific order in which the themes occur.

The types of themes were classified following Payne et al. 1985: Static themes, constituted by phrases practically identical in each repetition; Shifting themes, constituted by phrases which have a progressive change in each repetition, with the units suffering modifications of frequency and/or form, length, number of units or in the rhythm of presentation, and Unpatterned themes, themes without pattern comprised by a varied number of units without any clear organization, making it impossible to visualize a subdivision of repeated phrases. The classification of each theme within a year was done qualitatively based on phrase types, based in characteristics such as: unit types present in the phrases, number of units per phrase, number of repetitions of the same unit per phrase, acoustic characteristics of the units defined aurally and visually (length, frequency) following guidelines suggested by Cholewiak et al. (2012) for the definition of phrases:

(1) Consecutive units of similar structure should not be separated inside a phrase, but should be grouped as part of the same subphrase.
(2) Phrases should be delineated in a way to minimize the occurrence of incomplete phrases at the end of a similar sequence of phrases;
(3) "Transition" phrases combine units of two different types of phrases;
(4) Variations of the same phrase type should be distinguished from totally distinct phrases, where the variation inside a same phrase type can evolve structural differences or the repetition of units without a change in general phrase pattern.
(5) The phrase length should be measured including the interval between phrases.
(6) Phrase definition should be based in the analysis of multiple individuals.

The units were then identified according to the first visualization of each type of unit, where an uppercase letter indicates the position and order of the unit in the phrase, followed by a number that represents the year where the first detection of such unit happened for the theme in question. Such classification is necessary in order to allow the visualization of changes in the phrases between the years. When a new unit was added in a preexisting phrase (phrase identified in previous years), this unit was identified with a lowercase letter, followed by a number corresponding to the year in which this unit was introduced. For example, the pattern phrase *A3B3B3B3* of the theme 1 in 2003, the letters A and B indicate the notes; and the number 3, after each letter, indicates the year ending. In the phrase pattern *A3B5b5B5b5B5b5* of the theme 1 in 2005, the *B3* units are altered in 2005 and become *B5*. The new units entered in 2005 between the units *B*, were defined as *b5* because they are inserted between units *B* originating from a preexisting phrase (Figure 1).

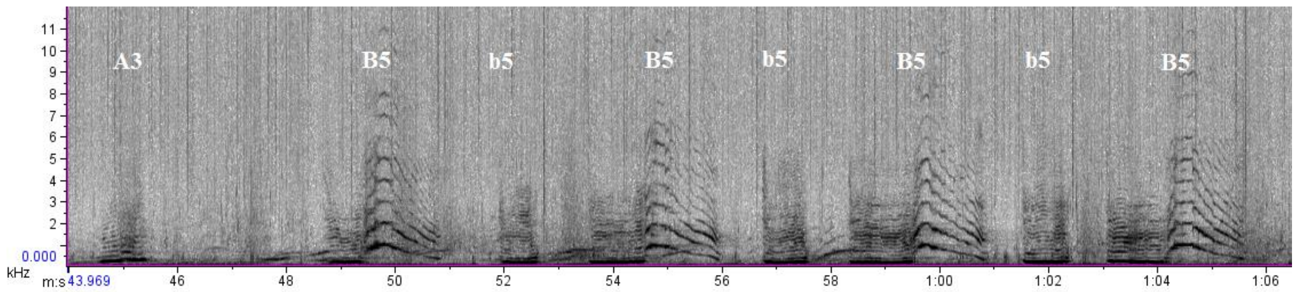

Figura 1: Spectrograms containing phrase pattern of the Theme 1 for year 2005. The letter (A and B) indicate the position of the notes; and the number (3 and 5), after each letter, indicates the year ending.

Intra and interindividual variations were considered based on qualitative analysis of the types of phrase. For the qualitative analysis, general characteristics were considered, such as: unit types present in the phrases, number of units per phrase, number of repetitions of the same unit per phrase, acoustic characteristics of the units defined aurally and visually (length, frequency).

Definition of the pattern phrase of each theme

For the themes with more than one repetition per phrase type, a Chi-Square Test was used to determine the standard phrase for each Theme (most frequently observed in the data). The analysis was made using the SPSS 20.0 program (SPSS Inc. 2011), with a significance level of 5% .

RESULTS

Intra and interindividual variations in the types of phrases by theme

Year 2003

In 2003, eight recordings from eight different individuals were analyzed, with a total of 4 hours and 23 minutes. Only the themes that showed pattern phrase (1, 2A, 2B, 3A, 3B, 3C and 6) were considered in the analysis. The theme 4A was not considered due its wide phrase structure variation.

Themes 1, 2A, 2B, 3B, and 3C showed no variation (Table 1). On the other hand, themes 3A and 6 showed phrase variations. Four types of phrases were found for the theme 3A. Two individuals, ADP140803-0917_ID5 and ADP20031017, showed at least two types of phrases for this theme, and one individual ADP210803_1, three variations (Table 1). In relation to the theme 6, three individuals (ADP140803-0917_ID5, ADP20031120; and RSA281003) presented two phrase variations (Table 1).

Table 1: Number of repetitions of each phrase type per theme in each individual recording for the year 2003. Themes 1, 2A, 2B, 3A, 3B, 3C and 6 were evaluated. The units are represented only by position (letter) without indication of the year of origin (number) for a better visualization of the variation.

		ADP_20031106	**ADP080803A**	**ADP140803-0917**	**ADP20031017**	**ADP20031112**	**ADP20031120**	**ADP210803_1**	**RSA281003**
THEME 1	ABBB	17	1	8	14	14	15	11	12
THEME 2A	CCdDd	–	–	–	–	4	6	2	2
THEME 2B	CPP	19	–	5	7	31	9	–	9
THEME 3A	EEF	–	–	7	1	–	–	–	–
	EeEF	34	–	1	38	30	30	18	30
	EF	–	–	–	–	–	–	2	–
	eEF	–	–	–	–	–	–	27	–
THEME 3B	EG	13	4	14	1	34	33	50	11
THEME 3C	EQe	11	–	–	–	12	22	26	1
THEME 6	STU	–	–	4	–	–	5	–	1
	ST	28	–	4	4	29	4	14	18

Year 2004

For the year 2004, 6 hours and 41 minutes of recording were analyzed belonging to eight individuals. The themes encountered were: 1, 2A, 2B, 3A, 3B, 3C and 6, themes 4A and 4C were excluded due to the high level of variation in their phrase structure.

Intra- and inter-individual variations occurred for each theme (Table 2). The theme 1 presented two distinct types of phrases. Only in the song of the individual (ROBERTO CARLOS) did both of these two phrases appear. For the theme 2A, were registered two variations in the phrase structure in only one individual (RAULZITO). The theme 2B presented three types of phrases; however none of the three individuals (RAULZITO and CHIFRE) with more than one type of phrase presented all three variations for this theme. The theme 3A presented a greater number of variations; four types of phrases were found. From the eight analyzed individuals, six presented more than one type of phrase, and one of them (CHIFRE) presented all the variations (Table 2). Theme 3C showed no variation (Table 2). In theme 6, were encountered two phrase variations. Six individuals presented the two types of phrases for this theme (table 2).

Table 2: Number of repetitions of each phrase type per theme in each individual recording for the year 2004. Themes 1, 2A, 2B, 3A, 3B, 3C and 6 evaluated. The units are represented only by position (letter) without indication of the year of origin (number) for a better visualization of the variation.

		RSL20040715	**ZODIAC**	**RSL20040807_P0**	**PAULINHO**	**RAULZITO**	**ROBERTO CARLOS**	**CHIFRE**	**CHICO BUARQUE**
THEME 1	ABBB	9	13	1	20	16	7	12	–
	AABBB	–	–	–	–	–	4	–	–
THEME 2A	CCdDd	2	3	–	8	8	4	–	–
	CCCdDd	–	–	–	–	4	–	–	–
THEME 2B	CPP	5	6	1	23	11	24	30	–
	CPPP	–	–	–	–	23	–	–	1
	CP	–	–	–	–	–	–	1	–
THEME 3A	EeEF	14	24	7	53	37	13	46	16
	EeEFF	–	–	5	81	5	30	53	9
	eEF	–	–	–	–	2	–	2	–
	EF	–	–	–	–	–	–	5	–
THEME 3B	EGg	3	7	4	37	9	26	–	10
	EG	–	2	1	1	6	–	–	–
THEME 3C	EQe	3	–	–	19	5	13	17	2
THEME 6	ST	7	14	–	106	22	23	32	–
	STU	6	14	–	14	23	18	15	–

Year 2005

In the year 2005, 5 hours and 20 minutes of recording were analyzed from four individuals. Three themes were considered: theme 1, theme 2B and theme 7. The progressive theme (theme 3B) was not considered due to its high variability.

The theme 1 presented three types of phrases; however, none of the four individuals presented more than one type of phrase (Table 3). Themes 2B and 7 showed no variation

Table 3: Number of repetitions of each phrase type per theme in each individual recording for the year 2005. Themes 1, 2B and 7 evaluated. The units are represented only by position (letter) without indication of the year of origin (number) for a better visualization of the different phrase variation.

		RSL20050923	**RSL20051011**	**RSL20051012**	**GIL**
THEME 1	ABbBbB	–	–	–	11
	ABbBbBb	–	41	12	–
	ABbBbBbB	4	–	–	–
THEME 2B	CCPP	11	42	–	39
THEME 7	VAA	4	34	8	5

Disregarding themes which was not possible to define a subdivision of repeated phrases (shifting and unpattern themes), through the years 2003 and 2004, the most recurring theme was the theme 3A, from lineage of theme 3; while in 2005, the theme 2B, from lineage of theme 2, showed the highest repetition values.

Lineages and description of themes through the years 2003, 2004 and 2005

Because of the availability of humpback song data over several years and from different individuals, it was possible to create theme lineages using the same terminology for units within phrases and themes along the sample period. Through the years 2003, 2004 and 2005, we identified the evolution of the themes described previously by Brito (2014) for years 2000, 2001 and 2002. Subdivisions within the lineages of the themes 2, 3 and 4; the exclusion of the theme 5 and the inclusion of two new themes (themes 6 and 7) were the main structural changes observed (Figure 2).

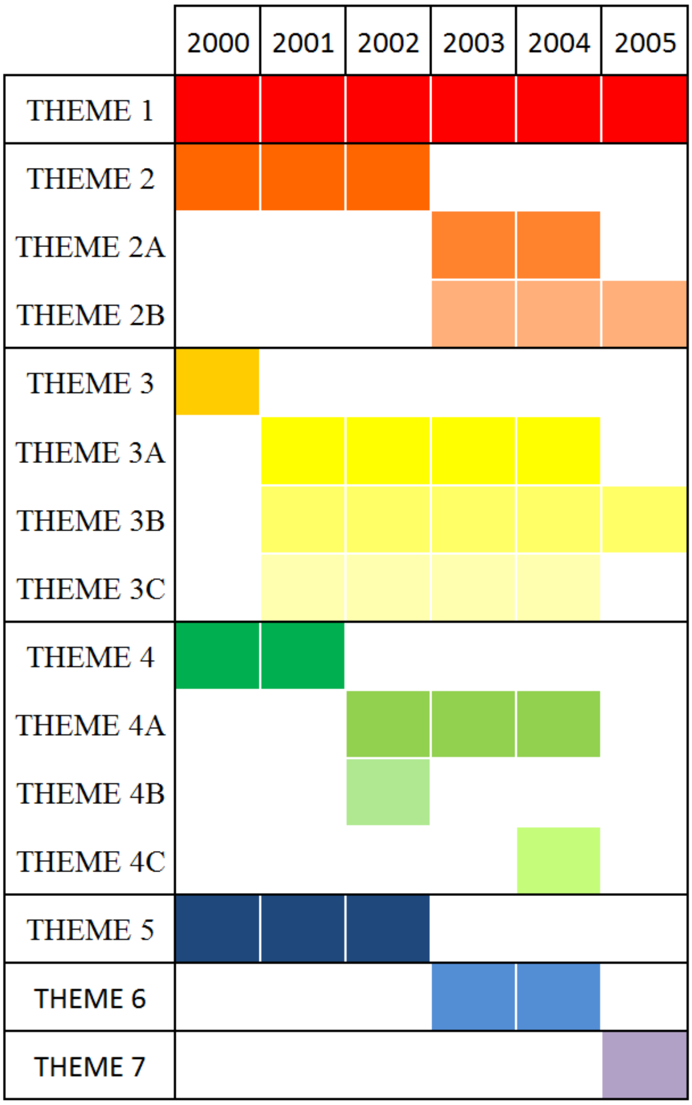

Figure 2: Song composition of the humpback whale in the region of Abrolhos, Brazil, from 2000 to 2005. Each color represents a theme and each lineage was represented by different shades of the same color.

The structure of the phrase pattern of the theme 1 was maintained throughout the three years (2003, 2004 and 2005) (Figure 2), always beginning with pulsed and noisy units followed by three harmonic units (Figure 3). The phrase pattern for the theme 1 (*ABBB* - 100%, n = 93) (Figure 2) presented two subphrases. The first subphrase was formed by a unique repetition of *A3*, a pulsed unit that sounds seemed an engine. The second subphrase was composed by three similar units, described as *B3*. This unit had several harmonics and could vary in length between each other. In 2004 the theme 1 had no change in their composition and retained the same phrase pattern (95.1%, n = 81; $\chi2 = 26.777$, $p < 0.05$). The phrase pattern (Figure 3) (*ABbBbBb* - 80%, n = 65; $\chi2 = 130$, $p < 0.05$) from the theme 1 for the year 2005 showed a similar structure to the phrase from the previous years. Although the structure of the phrase was maintained in 2005, the unit *b5* was inserted in the second subphrase and interpolated with unit *B5*. The second subphrase remained unchanged with three repeatitions of the unit *B*; however, the *B5* units had different spectral characteristics compared to the unit *B3* for the years 2003 and 2004. In comparison with *B3*, the unit *B5* presented two distinct regions, the first more noisy, and the second with well-defined harmonics, presenting a stretch of ascendant followed by a descendant frequency modulation.

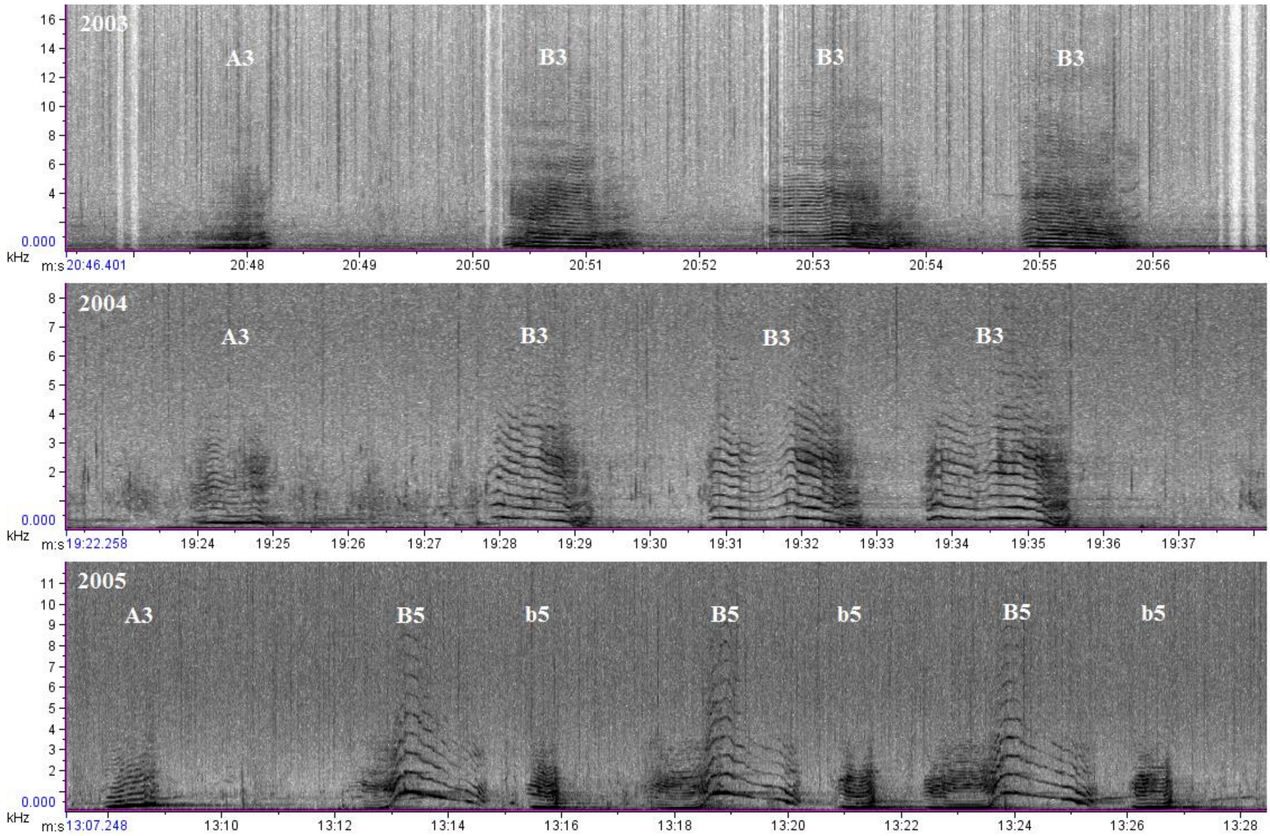

Figure 3: Spectrograms containing phrases of the Theme 1 lineage for years 2003, 2004 and 2005.

The phrase structure of the theme 2 composed by two subphrases was maintained throughout the years 2003, 2004 and 2005. The year 2003 (100%, n = 14) presented the phrase *CCdDd* (Figure 4) as the pattern phrase for the theme 2A. The first subphrase of the theme 2A was composed only by the units *C3*, which were very noise and with lots of harmonic. The second subphrase of the theme 2A maintained the unit *D0* for the years 2003 and 2004. The unit *D0* was found in two other units described as *d3*, which presents an ascendant frequency modulation. In 2004 the theme 2A showed two pattern phrases (85.7% and 14.3%, n = 28; $\chi 2 = 7.212$, p = 1.125) (Figure 4). Both types of phrases maintained the same phrase composition of the year 2003. The difference between the phrases was the number of units *C3*. Theme 2A did not occur in 2005.

The theme 2B occured from 2003 until 2005 (Figure 2). This theme presented the *CPP* phrase as pattern phrase for the year 2003 (100%, n = 80) and 2004 (80.5%, n = 123; $\chi 2$ = 76.727, $p < 0.05$) (Figure 4). The first sub-phrase was composed by the unit *C3*, the same unit found in the theme 2A. This unit was repeated only once. The second subphrase was composed by the units *P3*, which presented a modulation of ascendant frequency and a high number of harmonics. These units could range in length from each other. Throughout the duration of the unit *P3*, there was the presence of small fragments of this unit, which could occur in varying numbers. In 2005, the pattern phrase of the theme 2B (*CCPP* - 100%, n = 92) (Figure 4) was maintained with the same structure and units of the previous year. However, the note *C3* from the first subphrase was repeated twice and the unit *P*, first described in 2003 as *P3*, became unit *P5*.

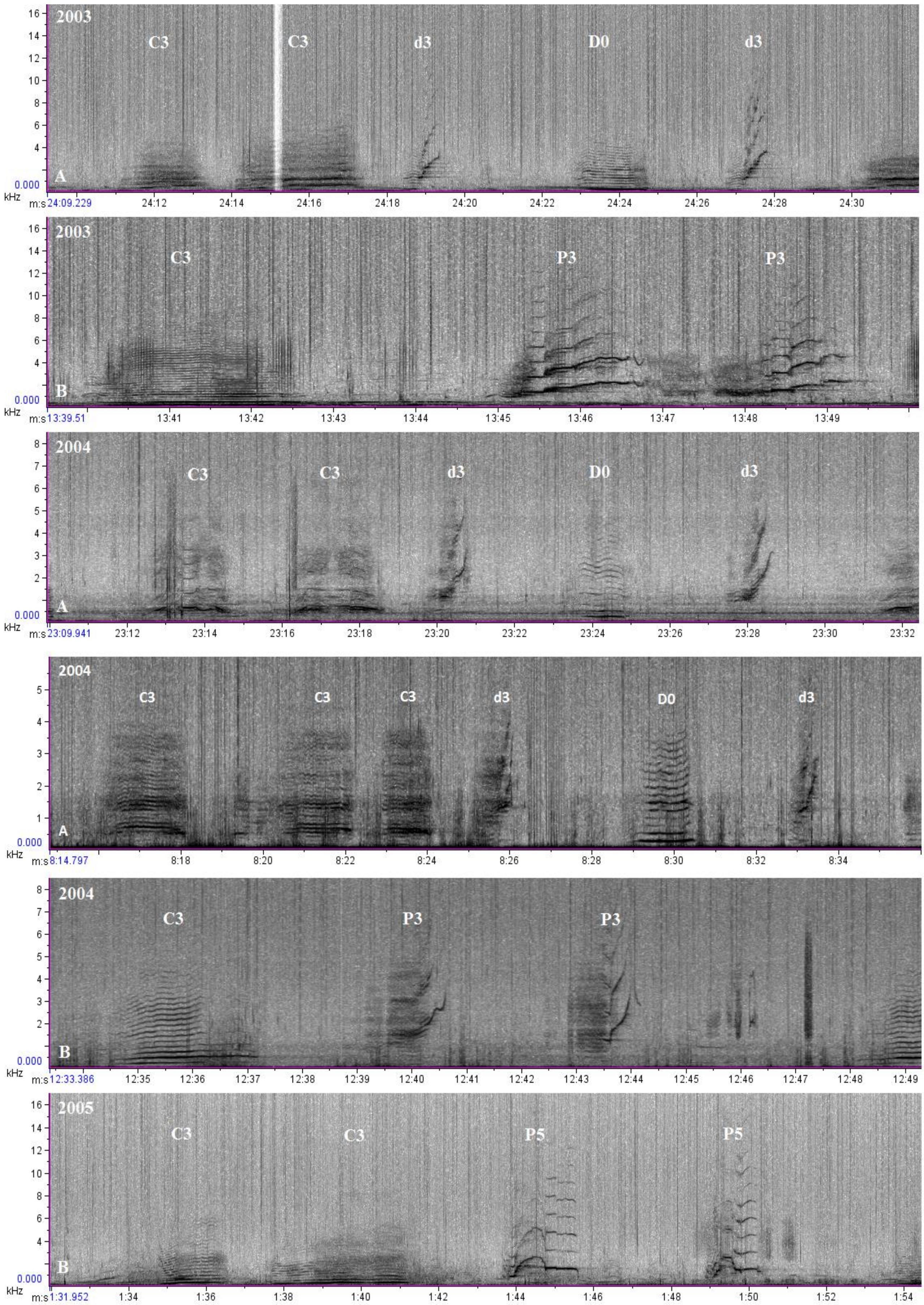
2003
C3
C3
d3
D0
d3
A
2003
C3
P3
P3
B
2004
C3
C3
d3
D0
d3
A
2004
C3
C3
C3
d3
D0
d3
A
2004
C3
P3
P3
B
2005
C3
C3
P5
P5
B
kHz

Figure 4: Spectrograms containing the line for Theme 2 for the years 2003, 2004 and 2005. The letters A and B indicate the subdivisions that the theme presented through the years analyzed.

From 2003 the theme 3 was subdivided into three distinct themes: theme 3A, theme 3B and theme 3C (Figure 2). The theme 3A had the phrase *EeEF* (Figure 5) as pattern phrase for the years 2003 (83.8%, n = 216; $\chi 2 = 280.252$, $p < 0.05$) and 2004 (46.1%, n = 375; $\chi 2 = 96.853$, $p < 0.05$). The first subphrase was composed by the units *E0,* with the duration of approximately two seconds. Between them, they had a short unit of a very low frequency, described as *e3*. The second subphrase of the theme 3A was composed by the unit *F3*.

In 2003, the pattern phrase of the theme 3B (*EG* - 100%, n = 160) (Figure 5) was composed by two units, the unit *E3* and the unit *G3*, with a long length. The unit *G3* began with well-defined harmonics up to half the duration of the note, becoming segmented into several fragments at its final portion. In 2004 occurred the inclusion of a third unit in the pattern phrase of the theme 3B (*EGg* - 90.3%, n = 93; $\chi 2 = 21.725$, $p < 0.05$) (Figure 5). The unit *E3* of the previous year was maintained, while the unit *G3* of the theme 3B became *G4*, because it lose the portion where the note was fragmented, remaining only the region where the harmonics were well defined. The new inserted note was defined as *g4*. This unit had a high rate of frequency modulation and could present several forms. Besides that, this note presented several fragments in its final portion.

The theme 3C was constituted by *E0* unit, followed by the units *Q3* and *e3* (Figure 5). The pattern phrase was maintained with the same structure and composition in the years 2003 (*EQe* - 100%, n = 72) and 2004 (*EQe* - 100%, n = 59) (Figure 5). The units *E0* and *e3* were the same that occurred in the theme 3A. The unit described as *Q3*, presented a long duration and a sound that similar to the creak of a door.

From 2005, the themes 3A and 3C disappeared, remaining only the theme 3B, which was classified as a shifting theme (according to Payne et al. 1985). The phrases of this theme evolve progressively from one form to another; and its units may change gradually in terms of frequency and/or form, duration, or the number of subunits.

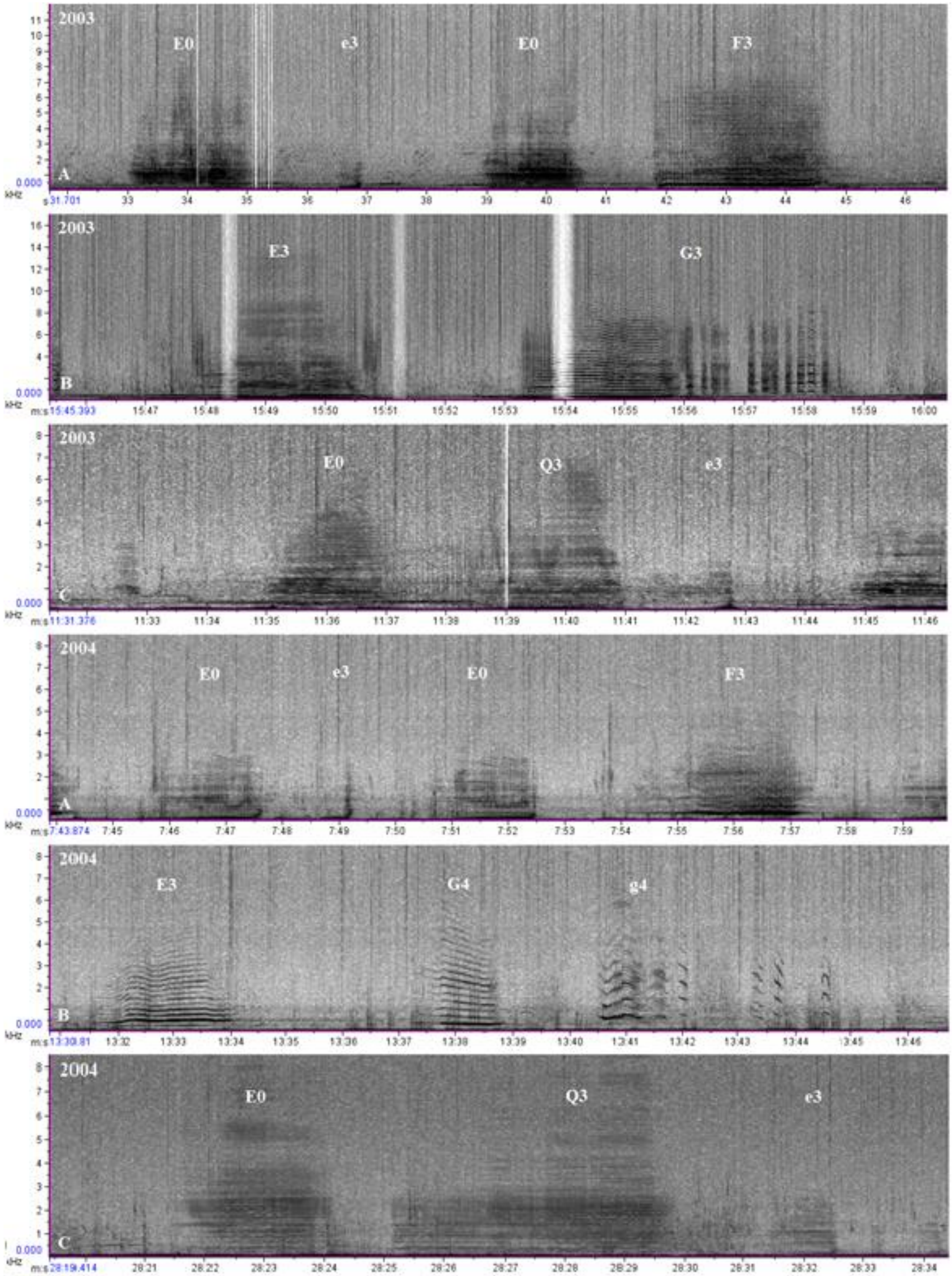

Figure 5: Spectrograms containing the lineage of the Theme 3 for the years 2003, 2004 and 2005. The letters A, B and C indicate the subdivisions present through the years analyzed.

The phrase of the theme 4A (Figure 6) was formed by two subphrases. The first subphrase had a sequence of units which had an ascendant frequency modulation, indicated as *J3*. These ones were intercalated by the units *K0*, which had a descending frequency modulation. The difference between 2003 and 2004 was the presence of the unit *L4* in 2004. This unit was absent in some subphrases The second subphrase was composed by two units, the first being shorter represented by L0 and the second being longest, represented by L2. Both had ascending modulation.

From 2004 a new theme appeared and was defined as theme 4C (Figure 6). This theme had two subphrases. The first subphrase was composed by a sequence of units *L4*, whose number was varied. The second subphrase was composed by a sequence of units *L0*, with varied number, followed by the unit *L2*. The major difference among the units *L0*, *L2* and *L4* was its length: *L0*, the shorter unit and *L2,* the longer unit. From 2005, the themes 4A and 4C disappeared (Figure 2).

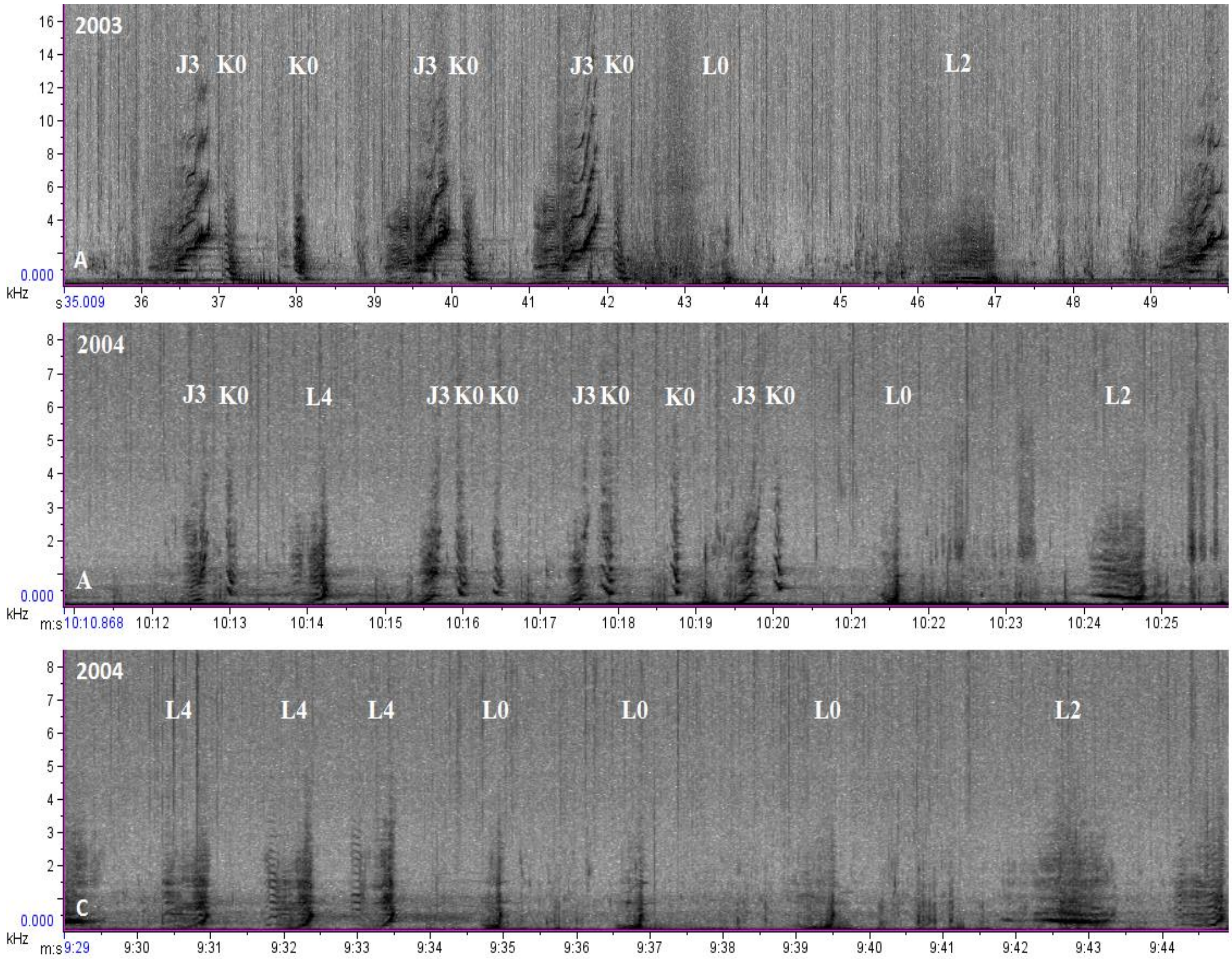

Figure 6: Spectrograms with examples of the phrase from the theme 4A for the year 2003, and examples of the phrases from theme 4A and 4C for the year 2004.

The theme 6 was first described in 2003. The pattern phrase for this theme was comprised by three different units (*STU* - 94.2%, n = 103; $\chi 2 = 45.223$, $p < 0.05$) (Figure 7). The first two units, indicated by *S3* and *T3* were quite noisy and with lots of harmonics. Besides that, they presented a different frequency structure in the final portion of these units, with an ascendant modulation. The third unit, described as *U3*, appeared in two ways, a longer unit, presenting in its final part, a fragmented region along its length and a shorter unit, without the presence of this fragmented region. In 2003, although the most common phrase was the phrase *STU*, the song of some individuals presented two types of phrases (*STU* and *ST*) which were interpolated between them. Because of this, both phrases were considered as components of the same theme.

The phrases of theme 6 in 2004 maintained the same structure and composition of the previous year. However, in 2004, the pattern phrase (*ST* - 69.4%, n = 294; $\chi 2$ = 39.060, $p < 0.05$) (Figure 7) was composed only by unit *S* and *T*. Similar to 2003; there were two types of phrases which, in general, appeared interpolated between them.

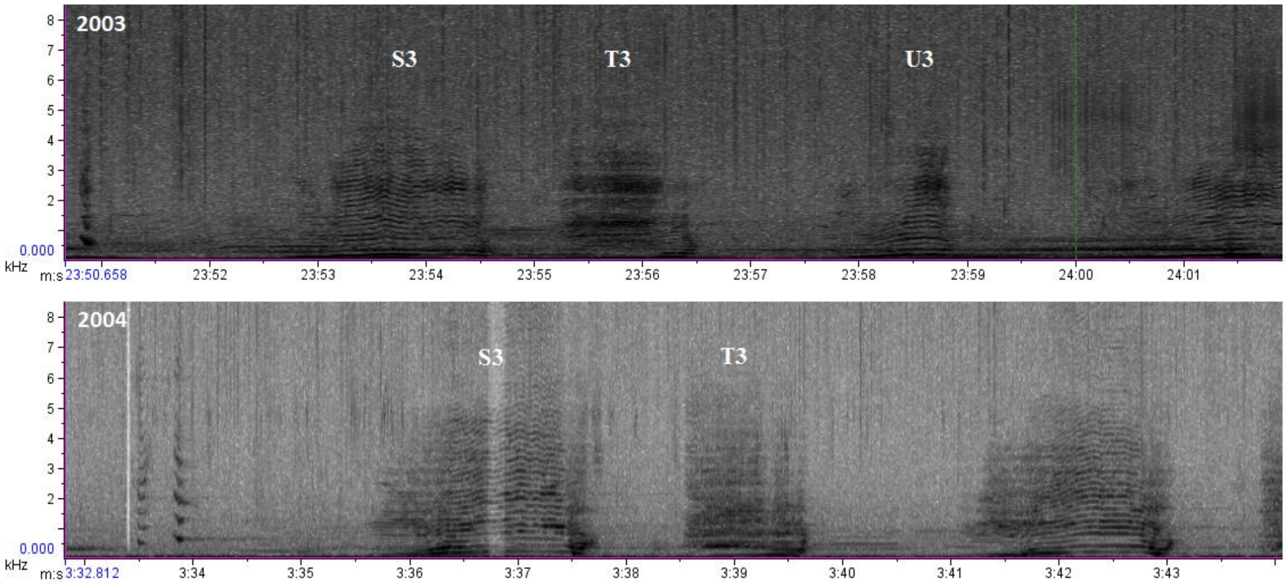

Figure 7: Spectrograms containing the lineage of the Theme 6 for the years 2003 and 2004.

The theme 7 occurred for the first time in the year of 2005 (Figure 2). Its pattern phrase (*VAA* - 73.9%, n = 69; $\chi 2$ = 69, $p < 0.05$) (Figure 8) had three units which were very noisy. Its structure was formed by two subphrases; the first, composed by the unit *V5*, with long length (e.g. up to six seconds) showing a structure with frequency modulations throughout its length, similar to fails. The second phrase was composed by the units *W5*, a pulsed unit that sounds like an engine, similar to unit *A* of the theme 1.

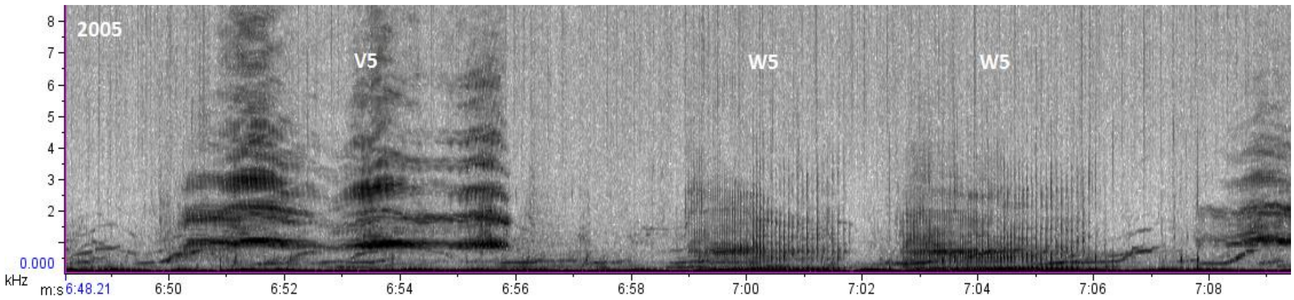

Figure 8: Spectrogram showing the pattern phrase of the theme 7 for the year of 2005.

DISCUSSION

Theme lineages since 2000

The evolution of the song may occur through progressive changes in the unit level, by stretching, or by dividing the units into smaller units, by the omission or inclusion of units in the composition of phrases, or, through the insertion or omission of entire themes (Winn & Winn 1978, Payne et al. 1983, Payne & Payne 1985, Cato 1991). Using the findings of the qualitative analysis, it's possible to verify that not all the themes evolve in a similar way and there may be different forms of origin, division and exclusion of the themes. The origin of the themes 4C, in 2004, and the theme 6, in 2003, are examples of different origin of the themes. The theme 4C, subdivision of the theme 4, showed similarities in the structure and the composition of phrases with the theme 4A. However, due to the addition and the removal of units, this theme was considered a new theme, but belonging to the same lineage of the theme

4A. The theme 6 added in 2003 was composed by totally different units from the ones described until that moment.

The theme 2, first described in 2000 (Brito 2014), remained with similar phrases through the years. However, from 2003 this theme was divided into two themes: 2A and 2B (Figure 2). This occurred because although they have similarities, such as the presence of the note *C3*, the different phrases did not interpolate in any moment of the song, and there was always the repetition of one type followed by the repetition of another. The theme 2A presented a very similar structure to the theme 2 of the year 2002 (Brito 2014). Although the units were the same, only the unit *D0* maintained the original characteristics since 2000 (Brito, 2014). The units *C* and *d*, became *C3* and *d3* in 2003. The first subphrase of the theme 2A was composed only by the units *C3*, similar to the units *C* encountered for the previous years (Brito 2014). The second subphrase of the theme 2A maintained the unit *D0* from the previous years (Brito 2014) and similar to the theme 2 in the year of 2002, this unit *D0*, was also found in two other units described as *d*. However they was defined as *d3*, once it's different from the year 2002. The small fragments along the length of the unit *P3* for theme 2B in 2004, were not defined as other units because aurally they sound like the continuation of the unit *P3*.

The theme 3 in 2000, described by Brito (2014), presented two pattern phrases, one composed by the units *E* and *F*, and the other, composed by the units *E* and *G*, which did not lead to differentiation into two themes due to a merging that occurred between their units (*F* and *G*). Furthermore these two types of phrases alternate with each other. In 2001, the theme 3 split in 3A and 3B, since the two forms did not alternate more, neither presented the units *F* and *G* in the same phrase (Brito 2014). A reduction in quantity of the repetitions per phrase, as well as a striking separation between the two forms of the theme ocurred in 2002. The theme 3B suffers a variation in the unit *E*, which becomes longer and low pitched, as it is then called as *E2*, while the theme 3A continues to present the unit *E0*. In 2003, the theme 3B maintained the unit *E*, which became shorter when compared to the previous year (Brito, 2014), additionally, the unit *F* from the theme 3A showed a low variation in frequency when compared to this unit in 2002.

The structure and composition of the phrases that compose the themes 4A and 4C were similar to the phrases of the theme 4 described for previous years (Brito 2014). Because of a high variability in the number and sequence of the units of the first subphrase, we were unable to set the pattern phrase and to create the lineage for these themes. Brito (2014) described the theme 5 for the years 2000, 2001 and 2002 as a shifting theme. Similar to the theme 4, the high variability of the theme 5 prevented the creation of its lineage. The theme 5 disappeared from the year 2003 and in the same year it was added the theme 6, which is kept by the year 2004 (Figure 2). The second subphrase of the theme 7 presented a unit similar to the unit *A0* of the theme 1, described by Brito (2014) for the song in the year 2000. However, this unit was defined as *W5* because it presented a different position set by the unit A0.

Theme evolution rules

Comparison of intra and interindividual variations in the types of phrase by theme was carried out only with themes where the phrases had pattern phrase – static themes – themes constituted by phrases practically identical in each repetition. The phrases of unpattern themes (constituted by phrases which have a progressive change in each repetition) and shifting themes (comprised by a varied number of units without any clear organization) were not considered, because each repetition of the phrases that make up these themes do not show a clear pattern, making it unfeasible this comparative analysis.

We observed similar characteristics to the hierarchical structure proposed by Payne & McVay (1971) from the quantitative analysis of the twenty one themes described between 2003 and 2005. Although the themes show a structure similar in population, intra and inter individual variations were observed throughout the repetitions of the phrases. Additionally, it was observed that the themes are not equally represented in the song; the animals tend to sing a higher number of repetitions in some themes than it does in others, observation already reported in other studies (Payne et al. 1983, Darling & Sousa-Lima 2005).

Intra-individual variations in what concerns to the number or/and the presence/absence of units were encountered in the song of the majority of the analyzed individuals. These facts favor the imitation, although maintaining the high level of intra- and inter-individual variation (Brito 2014). Brito (2014) suggests that the different types of phrase may be related with different aspects of the sexual behavior, varying within the intersexual interactions, in searching of partners, and intrasexual, for the formation of groups or agonistic behaviors. Though Payne & Mcvay (1971) verified the consistency of patterns of song between the males of a same population, there is also a reasonable variation in the song of the humpback whales at an inter- and intra- individual level. Arraut & Vielliard (2004) proposed that the song of the humpback whale is actually transmitted through learning and possibly the individual differences occurred due to different skills to compose and/or learn the song. In this way, the sexual selection occurred throught the capability of the individual in quickly acquire and properly execute the new structures that compose the song.

The themes were grouped throughout the sampling period in lineages following Cholewiak et al. (2012) criterias. Only those themes with a coherent pattern phrase were used in the creation of the lineages. Themes that were classified as progressive or unpatterned phrase were not considered. The analysis made from the lineages enables the visualization of the changes in the song that occur between the reproductive seasons. In addition, it helps to understand the evolution of themes, because by the comparison of similar phrases it becomes possible to identify the origin of each theme in relation to the themes of the previous year, emphasizing what kind of change occurred. Therefore, this approach helps to avoid misunderstandings among the evolutions of existing phrases with the introduction of new different phrases.

Similar to previous studies (Helweg et al 1990, 1992, 1998, Eriksen et al 2005), changes were observed in the song through the breeding seasons. The modifications occurred from changes in the form and frequency of the units or by the insertion or exclusion of units, according to the song of the humpback whale in Abrolhos between the period of 2000 and 2002 (Brito 2014). Due to the presence of different evolutionary trends possibly the themes that constitute the song of the humpback whale do not present an unique pattern of evolution.

The evolution of the song through the breeding seasons showed a small variation in the song composition between 2003 and 2004. However, in 2005 the song varied widely, with exclusion and inclusion of themes. Noad et al. (2000) showed a fast change in the song of an Australian population. These authors suggested that these changes occurred due to the arrival of some males from another population. It is possible that occur interaction among humpback whale of different populations ledding to acoustic overlap in their annual cycles. Darling & Sousa-Lima (2005), observed that the themes throughout two breeding seasons for the populations of Brazil and Gabon presented a lot of similarity. However it is difficult to investigate the causes of observed change without monitoring througout the year between reproductive and migratory seasons.

The importance of acoustic communication for the humpback whales population maintenance urges a good understanding about the evolution of their song through time. A continuous and long-term monitoring throughout the years is important to provide the information that is not already clear, and would enables the creation of robust criteria for the definition of hierarchy levels. The Abrolhos Bank is an environment of extreme importance for this specie, making it essential to comprehend the changes of their acoustic communication for a solid conservation plan for local populations. This would also help to contribute to the entire environment protection and the maintenance of the role and structure integrity of this unique ecosystem.

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REFERENCES

Andriolo A, Martins CCA, Engel MH, Pizzorno JL, Más-Rosa S, Freitas AC, Morete ME, Kinas PG. 2006. The first aerial survey of humpback whales (*Megaptera novaeangliae*) to estimate abundance in the breeding ground off Brazil (Breeding Stock A). J. Cetacean Res. Manag. 8: 307–311.

Andriolo A, Kinas PG, Engel MH, Martins CCA, Rufino AM. 2010. Humpback whales within the Brazilian breeding ground: distribution and population size estimate. Endang. Species Res. 11:233-243.

Arraut EM, Vielliard JME. 2004. The song of the Brazilian population of Humpback Whale *Megaptera novaeangliae*, in the year 2000: individual song variations and possible implications. An. Acad. Bras. Ciênc., Rio de Janeiro, 76(2):373-380.

Brito. 2014. Evolução do canto da baleia jubarte (*Megaptera novaeangliae*) no Banco dos Abrolhos, Bahia, Brasil, entre os anos 2000 e 2002 [Monograph]. Universidade Federal do Rio Grande do Norte, Natal, Brasil, 47 pp.

Castro CB, Segal B. 2001. The itacolomis: large and unexplored reefs at the arrival point of the first Europeans in Brazil. Coral Reefs. 20:18.

Cato DH. 1991. Songs of Humpback Whales: the Australian perspective. Mem. Queensl. Mus. 30: 277–290.

Cerchio S. 1993. Geographic variation and cultural evolution and in songs of humpback whales *(Megaptera novaeangliae)* in the eastern North Pacific. M.Sc. thesis, Moss Landing Marine Laboratories, San Jose State University, California, 83 pp.

Cerchio S, Jacobsen JK, Norris TF. 2001. Temporal and geographical variation in songs of humpback whales, Megaptera novaeangliae: synchronous change in Hawaiian and Mexican breeding assemblages. Anim. Behav. 62:313–329.

Cerchio S, Strindberg S, Collins T, Bennett C, Rosenbaum H. 2014. Seismic surveys negatively affect humpback whale singing activity off northern Angola. PLoS One. 9(3):e86464.

Charif RA, Clapham PJ, Clark CW. 2001. Acoustic detections of singing humpback whales in deep waters off the British Isles. Mar. Mamm. Sci. 17:751–768.

Cholewiak DM, Sousa-Lima RS, Cerchio S. 2012. Humpback whale song hierarchical structure: Historical context and discussion of current classification issues. Mar. Mamm. Sci. 29:312–332.

Clapham PJ, Mead JG. 1999. *Megaptera novaeangliae*. Mamm. Spec. 604:1-9.

Clapham PJ. 1996. The social and reproductive biology of humpback whales: an ecological perspective. Mammal Rev. 26:27-49.

Darling JD. 1983. Migrations, abundance and behaviour of Hawaiian humpback whales (*Megaptera novaeangliae*). Ph.D. thesis, University of California, Santa Cruz.

Darling JD, Sousa-Lima RS. 2005. Songs indicate interaction between humpback whale (*Megaptera novaeangliae*) populations in the western and eastern South Atlantic Ocean. Mar. Mamm. Sci. 21(3):557-566.

Dawbin WH. 1966. The seasonal migratory cycle of humpback whales. In Whales, dolphins and porpoises (K. S. Norris, ed.), University of California Press, Los Angeles, pp. 145-170.

Engel M. 1996. Comportamento reprodutivo da baleia-jubarte (*Megaptera novaeangliae*) em Abrolhos. Anais de Etologia. 14:275-284.

Eriksen N, Millar LA, Tougaard J, Helweg DA. 2005. Cultural change in the songs of humpback whales (*Megaptera novaeangliae*) from Tonga. Behaviour 142:305–328

Fainstein R., Summerhayes CP. 1982. Structure and origin of marginal banks off eastern Brazil. Mar. Geol. 46:199-215.

Frietas AC, Kinas PG, Martins CAC, Engel MH. 2004. Abundance of humpback whales on the Abrolhos Bank wintering ground, Brazil. J. Cetacean Res. Manage. 6(3):225-30.

Garland EC, Goldizen AW, Rekdahl ML, Constantine R, Garrigue C, Daeschler Hauser N, Poole MM, Robbins J, Noad MJ. 2011. Dynamic horizontal cultural transmission of humpback whale song at the ocean basin scale. Curr. Biol. 21**:**687–691.

Garland EC, Lilley MS, Goldizen AW, Rekdahl ML, Garrigue C, Noad MJ. 2012. Improved versions of the Levenshtein distance method for comparing sequence information in animals' vocalisations: tests using humpback whale song. Behaviour 149**:**1413–1441

Garland EC, Goldizen AW, Lilley MS, Rekdahl ML, Garrigue C, Constantine R, Daeschler Hauser N, Poole MM, Robbins J, Noad MJ. 2015. Population structure of humpback whales in the western and central South Pacific Ocean as determined by vocal exchange among populations. Curr. Biol. 0**:**0–10.

Guinee LN, Chu K, Dorsey EM. 1983. Changes over time in the song of known individual humpback whales *Megaptera novaeangliae*. In Communication and Behavior of Whales (R. Payne, ed.), Westview, Boulder, pp. 59– 80.

Guinee LN, Payne KB. 1988. Rhyme-like Repetitions in Songs of Humpback Whales. Ethology. 79:295-306.

Herman LM, Tavolga WN. 1980. The communication systems of cetaceans. In Cetacean behavior: mechanisms and functions (L. M. Herman, ed). Wiley Interscience, New York, pp. 149–209.

Helweg DA, Herman LA, Yamamoto S, Forestell PH. 1990. Comparison of songs of humpback whales (Megaptera novaeangliae) recorded in Japan, Hawaii, and Mexico during the winter of 1989. Sci. Rep. Cet. Res. Inst. 1:1–20.

Helweg DA, Frankel AS, Mobley JR, Herman LA. 1992. Humpback whale song: Our current understanding. In Marine mammal sensory systems (J. Thomas, R. Kastelein and A. Supin, eds). Plenum Press, New York, NY. pp. 459–483

Helweg DA, Cato DH, Jenkins PF, Carrigue C, McCauley RD. 1998. Geographic variation in South Pacific humpback whale songs. Behaviour 135:1–27.

Mcsweeny DJ, Chu KC, Dolphin WF, Guinee LN. 1989. North Pacific humpback whale songs: a comparison of southeast Alaskan feeding ground songs with Hawaiian wintering ground songs. Mar. Mamm. Sci. 5:139-148.

Martins CCA, Morete ME, Engel MH, Freitas AC, Secchi ER, Kinas PG. 2001. Aspects of habitat use patterns of humpback whales in the Abrolhos Bank, Brazil, breeding ground. Mem. Queensl. Mus. 47:563–570.

Martins CCA, Andriolo A, Engel MH, Kinas PG, Saito ACH. 2013. Identifying priority areas for humpback whale conservation at Eastern Brazilian Coast. Ocean Coast. Manage. 75:63-71.

Mattila DK, Guinee LN, Mayo CA. 1987. Humpback whale sounds on the North Atlantic feeding grounds. J. Mamm. 68:880-883.

Morete ME, Bisi TL, Pace RM III, Rosso S. 2008. Fluctuating abundance of humpback whales (*Megaptera novaeangliae*) in a calving ground off coastal Brazil. J. Mar. Biol. Assoc. UK. 88:1229–1235.

Noad MJ, Cato DH, Bryden MM, Jenner M-N, Jenner KCS. 2000. Cultural revolution in whale songs. Nature. 408:537.

Noad MJ, Cato DH. 2007. Swimming speeds of singing and nonsinging humpback whales during migration. Mar. Mamm. Sci. 23***:***481–495.

Norris TF, Mc Donald M, Barlow J. 1999. Acoustic detections of singing humpback whales (*Megaptera novaeangliae*) in the eastern North Pacific during their northbound migration. J. Acoust. Soc. Am. 106:506−514

Payne RS & McVay S. 1971. Songs of humpback whales. Science. 173(3997): 585-597.

Payne R. 1978. Behavior and vocalization of humpback whales (*Megaptera sp*.). In: Norris KS, Reeves RR, editors. Report on a Workshop on Problems Related to Humpback Whales (*Megaptera novaeangliae*) in Hawaii. U.S. Department of Commerce, NTIS PB 280–794. 56–78.

Payne R, Guinee LN. 1983. Humpbacks Whale (*Megaptera novaeangliae*) Songs as an Indicator of ‘‘Stocks’’. In Communication and Behavior of Whales (R. Payne, ed.), Westview Press, Boulder, pp. 333–358.

Payne K, Tyack P, Payne RS. 1983. Progressive changes in the song of humpback whales songs (*Megaptera novaengliae*): A detailed analysis of two seasons in Hawaii. In Communication and behavior of whales (R. Payne, ed.), Westview Press, Boulder, pp. 9–57.

Payne K, Payne R. 1985. Large scale changes over 19 years in songs of humpback whales in Bermuda. Z. Tierphysiol. Tierer. 68:89–114.

Sousa-Lima RS. 2007. Acoustic Ecology of Humpback Whales (*Megaptera novaeangliae*) in the Abrolhos National Marine Park, Brazil. Ph.D. Dissertation, Field of Zoology, Cornell University. 205 pp.

Sousa-Lima RS, Clark CW. 2008. Modeling the effect of boat traffic on the fluctuation of humpback whale singing activity in the Abrolhos National Marine Park, Brazil. Can. Acoust. 36(1): 174–181.

Sousa-Lima RS, Clark CW. 2009. Whale sound recording technology as a tool for assessing the effects of boat noise in a Brazilian marine park. Park Science, 26(1):59-63.

SPSS Inc. 2011. SPSS 20.0 for Windows. Chicago, IL: SPSS Inc.

Stimpert AK, Peavey LE, Friedlaender AS, Nowacek DP. 2012. Humpback Whale Song and Foraging Behavior on an Antarctic Feeding Ground. PLoS ONE 7:e51214.

Tyack P. 1981. Interactions between singing Hawaiian humpback whales and conspecific nearby. Behav. Ecol. Sociobiol. 13:49-55.

Vu ET, Risch D, Clark CW, Gaylord S, Hatch LT. 2012. Humpback whale song occurs extensively on feeding grounds in the western North Atlantic Ocean. Aquat. Biol. 14:175–183.

Winn HE, Winn LK. 1978. The song of Humpback whale, *Megaptera novaeangliae*, in the West indies. Mar. Biol. 47:97-114.

Winn HE, Thompson TJ, Cummings WC, Hain J, Hudnall J, Hays H, Steiner WW. 1981. Song of the Humpack Whale – Population Comparisons. Behav. Ecol. Sociobiol. 8:41-46.

Zerbini AN, Ward EJ, Kinas PG, Engel MH, Andriolo A. 2011. A Bayesian assessment of the conservation status of humpback whales (*Megaptera novaeangliae*) in the western South Atlantic Ocean. J. Cetacean Res. Manage. (Special Issue). 3:131-144.

Zerbini AN, Andriolo A, Heide-Jorgensen MP, Moreira S, Pizzorno JL, Maia YG, Vanblaricom GR, Demaster DP. 2011. Migration and summer destinations of humpback whales (*Megaptera novaeangliae*) in the western South Atlantic. Ocean. J. Cetacean Res. Manage. 3:113-118.

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CHAPTER II - **Do humpback whales (*Megaptera novaeangliae*) change their songs during motor boat approaches in the Abrolhos Bank of Brazil?**

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Do humpback whales (*Megaptera novaeangliae*) change their songs during motor boats approach in the Abrolhos Bank of Brazil?

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ABSTRACT

Humpback whale males are known to produce long and complex sequences of sounds. Males song notes are arranged in phrases that are repeated with some level of variation within themes that compose the song. In Brazil, the species congregate in the Abrolhos Bank during the austral winter. Continuous monitoring has shown that the population is growing. The whale watching activity also flourishes in the region and there is concern about the impacts of increasing boat noise on the reproductive processes of this population mediated by sound. The aim of this study was to compare the vocal behavior of males before and during exposure to motorboats by measuring the duration of their phrases and the mean number of phrases within themes. Song was acquired without the presence of any motorboat and during the approach of a single motor boat within the guidelines of the whale watching activities in the area. Recordings were digitized and manually analyzed. The results show that phrase duration and number of phrases per theme are be maintained even during exposure to motor boat noise and suggest that this metric might be important to the communication of reproductive males and may be under strong selective pressure to maintain consistency.

I. INTRODUCTION

Humpback whale (*Megaptera novaeangliae*) males produce a long and complex sequence of sounds termed song, which was primarily described by Payne & McVay (1971). These authors have described the singing of this species as being subdivided in “units,” i.e., continuous sounds, that together form a “phrase”; the repetition of several phrases in a series of similar phrases is named a “theme,” and an entire sequence of themes is the "song" (Payne & McVay 1971). The song happens mostly in areas of reproduction, however, males also sing in feeding areas, although less frequently (Mattila *et al*. 1987, McSweeney *et al*. 1989, Clark & Clapham 2004, Stimpert et al. 2012, Vu et al. 2012, Magnúsdóttir et al. 2014) and during migration (Clapham & Mattila 1990, Cato 1991, Norris 1999, Charif *et al*. 2001, Noad & Cato 2007). However, the function of song is not well understood, and between the innumerous hypotheses proposed (Baker & Herman 1984, Clapham & Mattila 1990, Frazer & Mercado 2000), the predominant theories are that the males sing to attract females (Winn & Winn 1978, Tyack 1981), or to establish and/or maintain the dominance between males (Herman *et al*. 1980, Darling 1983, Frankel *et al*. 1995, Pack *et al*. 1998, Darling *et al*. 2006, Smith *et al*. 2008).

The changes in the song usually occur gradually and progressively during several years or during breeding seasons (Payne *et al*. 1983, Payne and Payne 1985, Chapter 1). All the singing males from the same population incorporate the same changes in their songs (Noad *et al*. 2000, Cerchio *et al*. 2001). This process has been referred to as an example of “Cultural Evolution” (Winn & Winn 1978, Payne & Payne 1985, Cato 1991, Noad *et al*. 2000, Garland *et al*. 2013), similar to the one observed in the songs of some bird species (Slater 1986, Catchpole & Slater 2008).

Currently, the tourism for observing cetaceans is growing (Hoyt 2001, O'Connor *et al*. 2009, Cisneros-Montemayor *et al*. 2010). Whale and dolphin watching allows a more sustainable use of these mammals as a natural resource as an alternative to hunting. However, the fast growth of this kind of tourism is generating increasing concern about the possible negative effects that these activities may cause on individuals and populations. In searching to quantify how the disturbances caused by boats affects foraging activity of bottlenose dolphins (*Tursiops truncatus*), Pirotta *et al*. (2015) found a reduction of 49% in foraging activity during the traffic of motor boats. The study shows that in addition to the potential effect of the noise produced by the boats on the dolphins, the simple physical presence of the boats may disrupt the animals' behavior.

Although there are numerous studies about possible behavioral changes of baleen whales in response to the presence of vessels (Coscarella *et al*. 2003, Lusseau 2006, Noren *et al*. 2009, Stamation *et al*. 2010, Williams *et al*. 2002, Scheidat *et al*. 2004, Timmel *et al*. 2008, Williams *et al*. 2009), there are only a few published studies evaluating the possible vocal behavior changes of individuals (Sousa-Lima & Clark 2008, 2009, Di Iorio *et al*. 2010, Castellote *et al*. 2012, Blackwell *et al*. 2013).

Duarte *et al*. 2011 conducted a study to investigate whether the noise from vehicular traffic and visitors in an urban park in Brazil influences the use of home-range (space) by urban marmosets. The results of this study showed that noise is an important factor influencing marmosets' choice of home-range, because the marmosets systematically preferred the quieter areas, even with dynamic changes in the acoustic landscape of the park between weekdays and Sundays.

Effective communication requires the detection and the recognition of a signal emitted by a transmitter to a receptor. However, the increasing noise level in marine environments coming from anthropogenic activities can limit the active space and the range of the signal (Jensen *et al*. 2009, Clark *et al*. 2009, Parks *et a*l. 2011). In periods of increased noise, animals which produce acoustic signals can use distinct compensation mechanisms to increase the chances of detection. Such mechanisms include increasing the signal-to-noise ratio through the modification of the signal. For instance, increasing the amplitude of the signal or modifying its frequency away from noise, or also by adjusting the period of sound emission, and even ceasing vocal activity until the noise decreases, or adjusting the calling rate by increasing call repetition or the duration of the call (Doyle *et al*. 2008, Parks *et al*. 2010, Hotchkin & Parks 2013).

Acoustic compensation mechanisms have been proposed in acoustic communication of right whales (Eubalaena australis), which produce call at a lower rate in high noise conditions (Parks *et al*. 2007, Parks *et al*. 2009), and for blue whales (*Balaenoptera musculus*), which seem to increase the duration of their calls during seismic surveys, possibly to compensate for the masking effect of the noise (Di Iorio & Clark 2009). Castellote *et al*. (2012) observed acoustic and behavioral changes of fin whales *(Balaenoptera physalus*) in response to two kinds of anthropogenic noise: vessel traffic and seismic airguns. The results of this study provide evidence that the male fin whales change the characteristics of their song in response to the increasing background noise conditions, and leave the area for a longer period of time when submitted to noise from seismic activities. Miller *et al*. (2000) observed that during playback of the low frequency active sonar used by the American Navy (LFA), male humpback whales produced longer songs, and in some cases ceased their vocal activity. Additionally, Fristrup *et al*. (2003) noted that higher source levels of the LFA sonar playbacks resulted in longer songs. Differences in song length lasted up to 2 hours after the last broadcast (Fristrup *et al*. 2003).

The interaction of the singing humpback whales and vessels has also received attention from researchers. Studies about behavioral changes of *M. novaeangliae* in the presence of approaching boats showed that the animals change the number of phrases in their song and may even stop their vocal behavior (Sousa-Lima *et al*. 2002, Sousa-Lima & Clark 2008, 2009). Sousa-Lima & Clark (2004) suggest that in periods of intense traffic, the humpback whales stop singing or have their songs masked by the vessels, which could be a problem for the detection and location of singing males and the communication between whales. This disruption in the communication system may result in severe effects over the exposed individual's fitness, and may even cause detrimental effects in the viability of the entire population in the long term (Sousa-Lima & Clark 2004). Bejder *et al*. (2006) investigated the possible long-term impacts of tourism vessel traffic and research on bottlenose dolphins (*Tursiops sp*.) in Shark Bay, Australia. The results of this study suggest a decline in a coastal dolphin population exposed to increasing tourist boat traffic.

The Abrolhos National Marine Park in Brazil is known for being the major reproduction area of the species in the Western South Atlantic Ocean (Engel 1996, Martins *et al*. 2001, Andriolo *et al*. 2006). Studies indicate that there is a continuous growth of the whale population that visit this area (Andriolo *et al*. 2010, Zerbini *et al*. 2011). Following the increase in the occurrence of the humpback whales, the whale watching industry also became more important (Cipolotti *et al*. 2005, Sousa-Lima & Clark 2008), making whales vulnerable to this activity.

The song can be important for the reproductive success of the male (Cholewiak 2008, Smith *et al*. 2008, Cerchio *et al*. 2005, Cerchio *et al*. 2003). The interruption of this sexual display may have significant impacts on the males, negatively affecting their chances of getting a sexual partner, with possible negative impacts on the population level (Cerchio *et al*. 2014). Evaluating the effects caused by the noise of vessels on humpback whale males may generate important information regarding management of whale watching tourism in order to minimize the potential impact of this activity on humpback whale populations. The aim of this study was to compare metrics of the song of focal humpback whale males in the presence and absence of motor boats associated with touristic activity (whale watching) in the Abrolhos Bank, Bahia, Brazil.

II. METODOLOGY

A. Study Area

The Bank of Abrolhos is located along the Brazilian coast between 16° 40'-19° 30'S, covering an area of approximately 30,000km^2 (Fainstein & Summerhayes 1982). Created in 1983, the Abrolhos National Marine Park (ANMP) is located in the northeast area of the bank. The ANMP is a conservation unity, composed of two areas; the major one is formed by the parcel of Abrolhos and the archipelago of Abrolhos, and the other smaller area that includes the reefs of Timbebas.

The Abrolhos Bank is known for being the major reproduction area of humpback whales in the southwestern Atlantic Ocean (Engel 1996, Martins *et al*. 2001, Andriolo *et al*. 2006), showing signs of an apparent growing population, currently estimated between 6.000 - 10.000 individuals (Andriolo *et al*. 2010, Zerbini *et al*. 2011).

B. Data Collection

The data from the song of the humpback whales was collected during the breeding season, between July and November, during the years 2000, 2002, 2003, 2004 and 2005. Initially, vocal activity was monitored from the research boat and after the detection of a focal individual, chosen when the animal was in the position of “tail up,” or submerged and blowing in the same general place, the motor of the vessel was switched off and the hydrophone placed on the water. Once the vocal activity of the individual was detected, silent approaches were made using an inflatable boat to allow for recording of the songs. Recordings were stopped when there was more than one individual in the area in order to avoid confounding responses of the focal male due to interindividual interactions.

During the study period, the songs were recorded using a Hydrophone (HTI-90 min or HTI-96 min) connected to a recorder (Sony DAT or Marantz Solid State PMD670). The humpback whales were exposed to two interaction conditions with the motor boats: (1) no boat – the boat stayed far away (more than 2 miles) from the focal individual and with the motor off, and (2) boat – one boat approached the focal singer following the guidelines for humpback whales of the Brazilian Institute of Natural Resources and Environment (IBAMA), which establishes that vessels should maintain a distance of 100m from the animal, the engine should be kept on neutral. Additionally, approaching an individual or group of whales that are already submitted to approach at the same time from two or more other vessels is not permitted (IBAMA, 1996, 2002).

C. Data Analysis

1. Acoustic analysis

Spectrograms of the digitized songs were generated and analyzed using the Sound Analysis software Raven Pro (version 1.5, Cornell Lab of Ornithology, Ithaca, NY) with the following settings: Hann window function and a 1024-point FFT size. Seventeen recordings were analyzed containing the song of sixteen individuals, totaling approximately fifteen hours of recording (Table I). The phrases were counted by theme for each individual. Phrases with recording failures bigger or equal to a half second were not considered, as well as phrases in which it was not possible to distinguish between the possible singers due to a high number of active males at the same time.

Table I: Number of recording sessions, individuals and duration of analyzed recordings for each year.

	Recording	**Individuals**	**Duration**
2000	2	2	02:04:45
2002	1	1	00:41:12
2003	5	5	03:51:33
2004	5	5	02:44:51
2005	4	3	05:20:58
Total	**17**	**16**	**14:43:19**

The definition of themes for each year was realized by qualitative analyzes of the phrase types, based on general characteristics such as: unit types present in the phrase, number of units per phrase, number of repetitions of the same unit in the phrase, and spectrographic characteristics of the visually and aurally defined units (duration, frequency). The definition of phrases followed the guidelines suggested by Cholewiak *et al*. (2012). Additionally they suggest the adoption of the phrase as the main response variable, which is analogous to the bird's song, and the consequent exploitation of the analysis approaches that focus on the phrase sequences as in the bird song paradigm for analyzing song sequences. The number of phrases per theme was used to assess differences in song length between songs of males before and during boat approaches.

Cholewiak *et al*. (2012) suggest the abandonment of the classic use of the song length metric as a variable response to acoustic disturbance, with exception of specific cases where the order of the theme and the occurrence within and between singing males is invariant or almost invariant. Nonetheless, even when theme order is not fixed, some comparison of within male total singing activity could be used to detect an effect of the presence of a disturbance, such as boat aproaches. Inasmuch, to avoid an effect of the order of themes on the amount of singing activity, the duration of the song session was measured. To avoid overestimating the song session length before the exposure to the boat the first phrase sung within boat noise was considered as the beginning of the song session with boat (experimental condition = boat) and the first time that phrase appear before the boat turned the motor on and approached the singer was considered the beginning of the song session without boat (experimental condition = no boat). Recording sessions started when the animal was already vocally active, therefore, to avoid underestimating the song session length with no boat the maximum length of the song session with boat was used as the duration of the session with no boat, making them equal.

2. Statistical Analyzes

Data normality was tested using the Shapiro-Wilk test. The analyses were made using the SPSS 20.0 program (SPSS Inc. 2011), considering a significance level of 5%.

The length of the phrases and song sessions in the two experimental conditions – boat and no boat – was compared using the paired Wilcoxon test from the same individual singer that was recorded before and during the boat approaches. From the paired analysis it was possible to test whether there were differences in the phrases and song sessions between the experimental conditions alone, without any effect of individual variation, theme and the year. In order to obtain the same sample size for both experimental conditions, the phrases without the interference of the vessel were sampled to be equal to the highest number of phrases with boat interference. To this end, phrases that were closer in time to the ones that had the boat noise were selected and paired, and in this way any changes in environmental conditions were controlled.

The difference between the mean number of phrases for the two experimental conditions was tested using the paired Wilcoxon test, and the comparison between the pairs was realized from the phrases mean per individual, considering the year of the song and the theme of the phrase. Only phrases where the sequence within the theme occurred in only one of the two experimental conditions were selected. When the sequences of phrases of a specific theme occurred both before and during exposure to the boat, they were not selected.

III. RESULTS

The songs of 16 individuals were analyzed (approximately 15 hours of recordings). A total of 1,561 phrases were selected, however, only the duration of 480 phrases (240 pairs) were considered in the statistical analysis to control for undesirable effects.

As indicated in Table II, the mean length of phrases for the two experimental conditions had similar values (Figure 1) (n = 240, Z = -0.129, p = 0.898, paired Wilcoxon test).

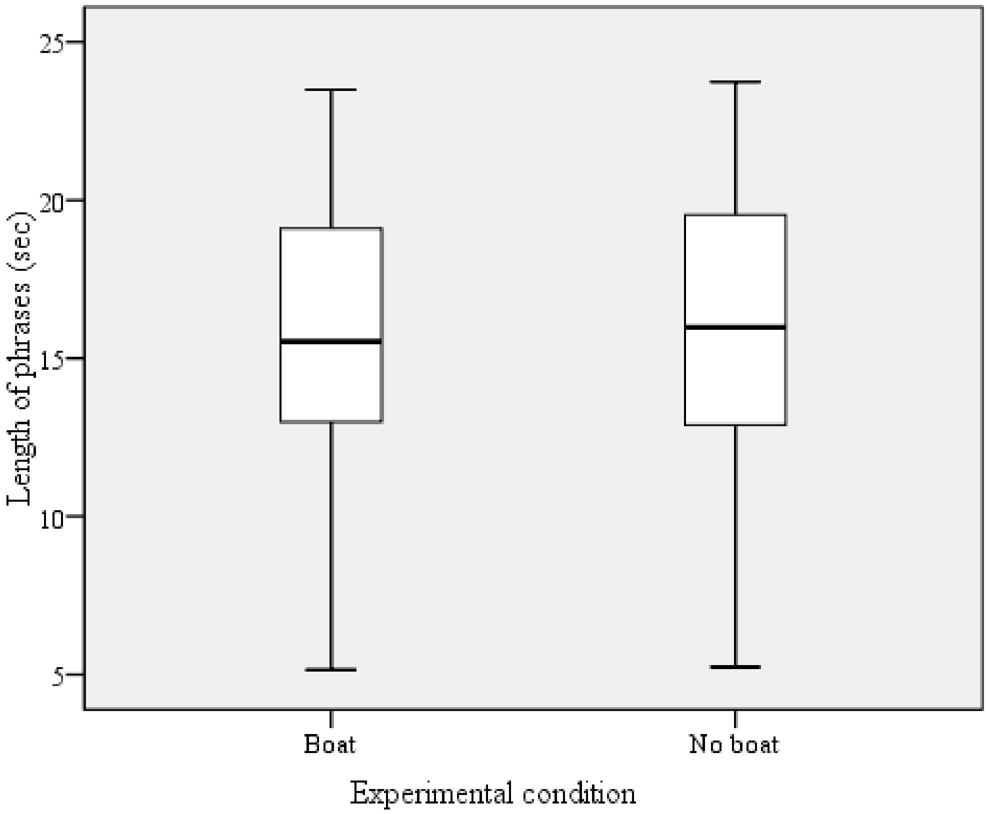

Figure 1: Box plot representing the data distribution of the length of phrases for both experimental conditions.

Table II: Maximum/minimum values, mean and standard deviation of the length of the phrases for both experimental conditions.

	N	Minimum	Maximum	Mean	Std. Deviation
Boat	240	5.15	23.49	15.68	4.38
No boat	240	5.24	23.74	15.70	4.48

The mean value for the number of phrases as lower in the presence of motor boats (Table III, Figure 2). However, similar to length of phrases, the difference in the average number of phrases for the two experimental conditions was not significant (n = 28, Z = -0.991, p = 0.322, paired Wilcoxon test).

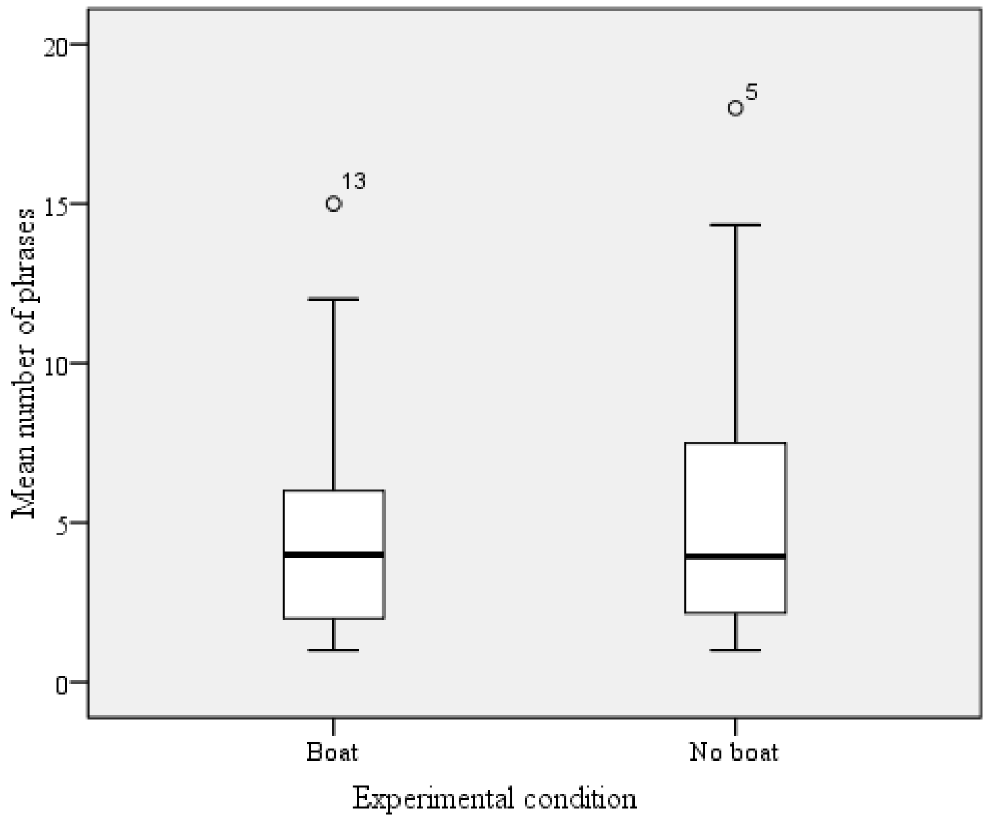

Figure 2: Box plot representing the data distribution of the mean number of phrases for the two experimental conditions.

Table III: Maximum/minimum values, mean and standard deviation of the mean number of the phrases for both experimental conditions.

	N	Minimum	Maximum	Mean	Std. Deviation
Boat	28	1	15	4.71	3.38

No Boat	28	1	18	5.31	4.13

As indicated in Table IV, the song session duration for the experimental conditions - No boat was lower (Figure 3), however the difference in the song session duration for the two experimental conditions was not significant (n = 13, Z = -1.342, p = 0.180, paired Wilcoxon test).

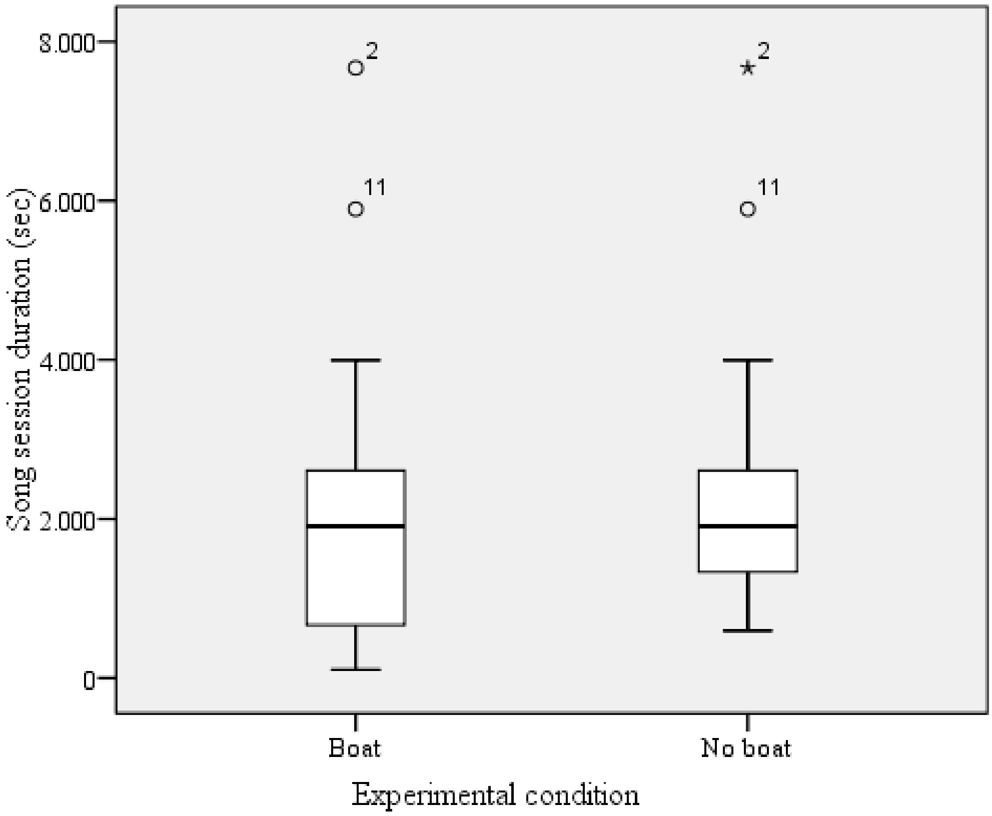

Figure 3: Box plot representing the data distribution of the song sessions duration for the two experimental conditions.

Table IV: Maximum/minimum values, mean and standard deviation of the song session duration for both experimental conditions.

	N	Minimum	Maximum	Mean	Std. Deviation
Boat	13	106	7671	2344.23	2262.76
No Boat	13	592	7671	2552.54	2096.23

IV. DISCUSSION

According to the results, the humpback whale males do not seem to change the lengths of phrases when exposed to the noise of motor vessels. Killer whales (*Orcinus orca*) that live in coastal areas of the state of Washington, U.S.A had longer calls when exposed to vessel noise from Whale-Watching (Foote *et al*. 2004). However, the authors only verified changes in the length of the calls in the period where there was an increase in the number of vessels, suggesting that these whales adjust their behavior to offset the anthropogenic noise from some threshold level proportional to the number of boats. Experiments in Abrolhos only looked at a single boat at a time because more than one boat observing whales in the area is unusual. Vocal adjustments may involve costs to the animals, and in this way, voice changes possibly occur only when the cost-benefit ratio is advantageous to the individual.

Miller *et al*. (2000) showed that, on average, songs of humpback whales are apparently longer in response to the playback of LFA sounds (low-frequency active), when compared to periods before and after the playback. Fristrup *et al*. (2003), similar to the results found by Miller *et al*. (2000), found an increase in the length of the song of humpback whale males when exposed to acoustic disturbance by LFA. These data are different from the present study, in which we used the length of the phrases as the metric, as suggested by Cholewiak *et al*. (2012). Both Miller *et al*. (2000) and Fristrup *et al.* (2003) used the duration of the entire song to compare the effects of the acoustic disturbance on the acoustic behavior of humpback whales. Therefore, differences in results may be related to the different metrics used. These authors may have found longer song duration as a result of the variability of theme order and number of themes that are arbitrarily defined as a song (see Cholewiak *et al*. 2012).

Other studies also suggest that, despite the consistency of the song patterns displayed among males within a population in the areas of reproduction, the structure of the song is not always as consistent as initially reported (Helweg *et al*. 1990, 1992, 1998, Eriksen *et al*. 2005). The order of the themes may vary considerably, both within and between individuals or between years (Cholewiak *et al.* 2012). Interpretation of changes in the length of the song in relation to noise interference is closely related to the order of themes. If the order is invariable and all themes occur in every cycle of song, the use of the metric "song duration" may be informative, because each repetition through the cycle includes the same number of themes. On the other hand, if the order of themes has a different sequence between the sessions of song, the use of the length of song as a metric becomes problematic (Cholewiak *et al*. 2012), since the different song lengths obtained may reflect the differences in the song composition.

Sousa-Lima *et al*. (2002) used the average length of phrases per individual and the number of phrases of each theme by individual to evaluate the song length differences before and during the approach of vessels. The authors verified that, similar to the present study, there was no change in the average length of phrases. Furthermore, they observed that the number of phrases for each theme decreases, suggesting that the whales sing shorter versions of their songs when exposed to the boat. This study found that the difference of the mean number of phrases for experimental conditions was not significant. The difference in the sample size between the studies may be associated to the results found, since in the study done by Sousa-Lima *et al*. (2002) the number of phrases is obtained from the song of two individuals in a single breeding season, but in the present study it was obtained from the song of eleven individuals over five breeding seasons.

Cetaceans can develop tolerance, habituation and sensitization, which may allow certain animals to remain in noisy environments (Richardson *et al*. 1995, Evans 2003, Campbell *et al*. 2014). Habituation and sensitization are adaptive behavioral changes exhibited by animals in response to exposure to a stimulus that is repetitive or continuous. Habituation is described as a process that involves a reduction of the response over time. The sensitization refers to the opposite phenomenon, with increased capacity in behavioral response over time, and the tolerance is defined as the intensity of disturbance that an individual tolerates without giving a response (Nisbet 2000).

Although the animals do not alter the length of their phrases or song sessions nor change the average number of phrases, studies suggest that the humpback whale males seem to react by ceasing their vocal activity and/or moving away from the motor vessels. Sousa-Lima & Clark (2009), in investigating the possible responses of humpback whale singers in the Abrolhos Bank, found that 44.5% of the males moved away from the boat and ceased their vocal activity, while 55.5% moved away and kept on singing. According to this study, all the whales moved away from their original positions with the approach of the boat and they also invariably left the area when they ceased singing. Research conducted in the Abrolhos Bank (Sousa-Lima & Clark 2009) also showed that singing whales changed direction of movement if the sound source was within an average of 7.5 km. Therefore, although it was considered for the experimental condition - boat, the phrases that occurred in the presence of boats at a distance of approximately 100 meters, the whales could already be under the possible effects of boats at further distances (Sousa-Lima & Clark 2009). Bejder *et al*. (2006) proposed that more sensitive individuals to the approach of the boats tended to abandon the preferential areas due to the increase of the noise disturbance caused by the boats, whereas less sensitive individuals to the disturbance from the boats tended to remain in the area. During the years 2000 to 2005, the maximum number of vessels in simultaneous operation in Abrolhos was 1 or 2 boats. Possibly the level of disturbance is not very large, thereby not causing the whales to adjust their vocal behavior, similar to that found in orcas by Foote *et al*. (2004).

However, the effects of the boat noise on males that are used to it are unknown. The consequences of boat disturbance could be the influence of boat noise over the choice of males by females, which may influence the reproductive success between the males of the population (Sousa-Lima & Clark 2009). Additionally, changes in vocalizations in noisy environments can lead to direct or indirect effects on the survival and reproductive success of the individual (Read *et al*. 2014). Therefore, the use of acoustic changes to compensate the masking caused by noises from boats can generate an energetic cost, and this fact may change the functionality of the song. Females of many species of birds use the vocalizations of males to determine if it is a potential partner. Therefore, when male birds of urban areas adjust the characteristics of the frequency of the temporal characteristics of their vocalizations to avoid the masking by noises, they are sometimes no longer recognized by the females of the same species (Slabbekoorn & Peet 2003, Wood & Yezerinac 2006). Similarly, male birds may present flexibility in the adaptation of their vocalization without suffering the cost of having their recognition diminished by females, however even if their songs are recognized, they may be perceived as less attractive by the females, in the case that they interpret the variations as an indicator of song learning (Nowicki *et al*. 2002).

The results of the present work show that the phrase duration and the average number of phrases remain unchanged, even during exposure to motorboats. Phrase length may be important for the communication of reproductive males which can be under strong selective pressure to maintain phrase consistency in their songs. Because of these potential selective pressures, the males may be maintaining the constant phrase/theme characteristics, however, showing other changes in relation to the noise disturbances, for example, by ceasing their vocal activity (Sousa-Lima and Clark 2009) or by replacing vocal sounds with sounds produced on the surface (pectoral slapping, tailing lob or tail slapping) (Dunlop *et al*. 2010).

Cetacean-watch tourism can be a beneficial activity if developed in accordance with the basic tenets of wildlife tourism. It can also generate jobs, can aid in the conservation of species, and be a good way of making the public aware and informed (Hoyt 2001, Martins 2004). Although this study shows that there is no change in vocal behavior of the humpback whale regarding motor boats, research conducted in the Abrolhos Bank (Sousa-Lima & Clark 2008, Sousa-Lima & Clark 2009) shows that humpback whales react to the presence of the tourist boats. In this way, it is not possible to affirm that the whale-watching activity in Abrolhos is sustainable. The Abrolhos Bank is an environment of extreme importance for the species, thus continuous monitoring of tourist activities in this region is necessary in order to reduce the impact on male singing behavior.

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VI. REFERENCES

Andriolo, A., Martins, C. C. A, Engel, M. H., Pizzorno, J. L., Más-Rosa, S., Freitas, A. C., Morete, M. E., Kinas, P. G. (**2006**). "The first aerial survey of humpback whales (*Megaptera novaeangliae*) to estimate abundance in the breeding ground off Brazil (Breeding Stock A)," J. Cetacean Res. Manag. **8**, 307–311.

Andriolo, A., Kinas, P. G., Engel, M. H., Martins, C. C. A. and Rufino, A. M. (**2010**). "Humpback whales within the Brazilian breeding ground: distribution and population size estimate," Endang. Species Res. **11**, 233-243.

Baker, C. S. & Herman, L. M. (**1984**). "Aggressive behavior between humpback whales (*Megaptera novaeangliae*) wintering in Hawaiian waters," Can. J. Zoo. **62**, 1922-1937.

Bejder, L., Samuels, A., Whitehead, H., Gales, N., Mann, J., Connor, R., Heithaus, M., Watson-Capps, J., Flaherty, C. and Krutzen, M. (**2006**). "Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance." Conserv. Biol. **20**, 1791–1798.

Blackwell, S. B., Nations, C. S., McDonald, T. L., Greene, C. R., Thode, A. M. (**2013**). "Effects of airgun sounds on bowhead whale calling rates in the Alaskan Beaufort Sea," Mar. Mam. Sci. **29**, E342–E365.

Campbell I. C. (**2014**). "The effects of phsysical, biological and anthropogenic noise on the occurrence of dolphins in the Pacific region of the Panama Canal," PhD thesis, University of St Andrews, Scotland, 263 pp.

Castellote, M., Clark, C. W., Lammers, M. O. (**2012**). “Acoustic and behavioural changes by fin whales (*Balaenoptera physalus*) in response to shipping and airgun noise,” Biol. Conserv. **147**, 115–122.

Catchpole, C. K., and Slater, P. B. J. (**1995**). “Bird Song: Biological Themes and Variations,” Cambridge University Press, Cambridge.

Cato, D. H. (**1991**). “Songs of Humpback Whales: the Australian perspective,” Mem. Queensl. Mus. **30**, 277–290.

Cerchio, S., Jacobsen, J. K., Norris, T. F. (**2001**). “Temporal and geographical variation in songs of humpback whales, Megaptera novaeangliae: synchronous change in Hawaiian and Mexican breeding assemblages,” Anim. Behav. **62**, 313–329.

Cerchio, S. (**2003**). “Paternity, polygyny and alternative mating tactics in humpback whales (Megaptera novaeangliae),” Doctoral Thesis, University of Michigan, Ann Arbor.

Cerchio, S., Jacobsen, J. K., Cholewiak, D. M., Falcone, E. A., Merriwether, D. A. (**2005**). “Paternity in humpback whales, *Megaptera novaeangliae*: assessing polygyny and skew in male reproductive success,” Anim. Behav. **70**, 267–277.

Cerchio, S., Strindberg, S., Collins, T., Bennett, C. and Rosenbaum, H. (**2014**). “Seismic surveys negatively affect humpback whale singing activity off northern Angola,” PLoS One 9(**3**), e86464.

Charif, R. A., Clapham, P. J., Clark, C. W. (**2001**). “Acoustic detections of singing humpback whales in deep waters off the British Isles,” Mar. Mamm. Sci. 17:751–768.

Cholewiak, D. M. (**2008**). “Evaluating the role of song in the humpback whale (*Megaptera novaengliae*) breeding system with respect to intra-sexual interactions,” Ph.D. dissertation, Cornell University, Cornell, United States.

Cholewiak, D. M., Sousa-Lima, R. S., and Cerchio, S. (**2012**). “Humpback whale song hierarchical structure: Historical context and discussion of cur- rent classification issues,” Mar. Mamm. Sci. **29**, 312–332.

Cipolotti, S. R. C., Morete, M. E., Basto, B. L., Engel, M. H., Marcovaldi, E. (**2005**). “Increasing of whale watching activities on Humpback whales in Brazil: implications, monitoring and research,” International Whaling Commission 57th Meeting. 15p.

Cisneros-Montemayor, A. M., Sumaila, U.R., Kaschner, K., Pauly, D. (**2010**). “The global potential for whale watching,” Mar. Policy 34:1273–1278.

Clapham, P. J. & Matilla, D. K. (**1990**). “Humpback whale songs as indicators of migration routes,” Mar. Mamm. Sci. **6**, 155-160.

Clark C. W., Clapham P. J. (**2004**). “Acoustic monitoring on a humpback whale (*Megaptera novaeangliae*) feeding ground shows continual singing into late spring,” P. Roy. Soc. Lond. **271**, 1051–1057 (B).

Clark, C. W., Ellison, W. T., Southall, B. L., Hatch, L., Van Parijs, S. M., Frankel, A., Ponirakis, D. (**2009**). “Acoustic masking in marine ecosystems: intuitions, analysis, and implication,” Mar. Eco, Prog. Ser. **395**:201–222.

Coscarella, M. A., Dans, S. L., Crespo, E. A. and Pedraza. S. N. (**2003**). “Potential impact of unregulated dolphin watching activities in Patagonia,” J. Cetacean Res. Manage. **5**, 77-84.

Darling, J. D. (**1983**). “Migrations, abundance and behaviour of Hawaiian humpback whales (*Megaptera novaeangliae*),” Ph.D. thesis, University of California, Santa Cruz.

Darling, J. D., Jones, M. E. & Nicklin, C. P. (**2006**). “Humpback whale songs: do they organize males during the breeding season?,” Behaviour 143:1051-1101.

Di Iorio, L., Clark, C. W. (**2009**). “Exposure to seismic survey alters blue whale acoustic communication,” Biol. Lett. **6**, 51–54.

Doyle, L. R., McCowan, B., Hanser, S. F., Chyba, C., Bucci, T., Blue, J. E. (**2008**). “Applicability of information theory to the quantification of responses to anthropogenic noise by southeast Alaskan humpback whales,” Entropy **10**, 33–46.

Duarte, M. H., Vecci, M. A., Hirsch, A., Young, R. J. (**2011**). “Noisy human neighbours affect where urban monkeys live,” Biol. Lett. **7**:840–842,

Engel, M. (**1996**). “Reproductive behavior of the humpback whale (*Megaptera novaeangliae*) in Abrolhos” (in Portuguese), Anais de Etologia, **14**, 275-284.

Eriksen, N., Millar, L. A., Tougaard, J. and Helweg, D. A. (**2005**). “Cultural change in the songs of humpback whales (*Megaptera novaeangliae*) from Tonga,” Behaviour **142**, 305–328.

Evans, P. G. (**2003**). "Shipping as a possible source of disturbance to cetaceans in the Ascobans region”. ASCOBANS 4th Meeting of the Parties, Esbjerg, Denmark, 19–22 August 2003, Document MOP4/Doc., 17(S), 88 pp.

Fainstein, R., Summerhayes, C. P. (**1982**). “Structure and origin of marginal banks off eastern Brazil,” Mar. Geol. **46**, 199-215.

Foote, A. D., Osborne, R. W., and Hoelzel, A. R. (**2004**). “Environment - Whale-call response to masking boat noise,” Nature **428**, 910.

Frankel, A. S., Clark, C. W., Herman, L. M., and Gabriele, C. M. (**1995**). “Spatial distribution, habitat utilization, and social interactions of humpback whales, *Megaptera novaeangliae*, off Hawaii, determined using acoustic and visual techniques,” Can. J. Zool. 73:1134–1146.

Frazer, L. M. & Mercado, E. III. (**2000**). “A sonar model for humpback whale song,” J. Ocean Eng. **25**, 160-182.

Fristrup, K. M., Hatch, L. T. and Clark, C. W. (**2003**). “Variation in humpback whale (*Megaptera novaeangliae*) song length in relation to low-frequency sound broadcasts,” J. Acoust. Soc. Am. **113**, 3411–3424.

Garland, E. C., Gedamke, J., Rekdahl, M. L., Noad, M. J., Garrigue, C., Gales, N. (**2013**). “Humpback whale song on the Southern Ocean feeding grounds: implications for cultural transmission”, PLoS ONE 8, e79422.

Helweg, D. A., Herman, L. A., Yamamoto, S. and Forestell, P. H. (**1990**). “Comparison of songs of humpback whales (*Megaptera novaeangliae*) recorded in Japan, Hawaii, and Mexico during the winter of 1989,” Scientific Reports of the Cetacean Research Institute **1**, 1–20.

Helweg, D. A., Frankel, A. S., Mobley, J. R. Jr and Herman, L. A.. (**1992**). “Humpback whale song: Our current understanding,”, in *Marine mammal sensory systems*, edited by J. Thomas, R. Kastelein and A. Supin (Plenum Press, New York, NY), pp. 459–483.

Helweg, D. A., Cato, D. H., Jenkins, P. F., Garrigue, C. and McCauley, R. D. (**1998**). “Geographic variation in South Pacific humpback whale songs,” Behaviour **135**, 1–27.

Herman, L. M., and Tavolga, W. N. (**1980**). “The Communication Systems of Cetaceans,” Wiley Interscience, New York.

Hotchkin, C. F. & Parks, S. (**2013**). “The Lombard effect and other noise-induced vocal modifications: Insight from mammalian communication systems,” Biol. Rev. 88(**4**):809–24.

Hoyt, E. (**2001**). “Whale watching 2001: Worldwide tourism numbers, expenditures, and expanding socioeconomic benefits,” Yarmouth Port: International Fund for Animal Welfare.

IBAMA, (**1996**). Portaria n°117, de 26 de dezembro de 1996. Diário Oficial da União, Seção I, pp. 028786.

IBAMA, (**2002**). Portaria n°24, de 13 de fevereiro de 2002. Diário Oficial da União, Seção I, pp. 67.

Jensen, F. H., Bejder, L., Wahlberg, M., Aguilar Soto, N., Johnson, M., Madsen, P. T. (**2009**) “Vessel noise effects on delphinid communication,” Mar. Ecol. Prog. Ser. **395**:161–175

Lusseau, D. (**2003**). “The effects of tour boats on the behavior of bottlenose dolphins: Using Markov chains to model anthropogenic impacts”, Conserv. Biol. **17**, 1785-1793.

Lusseau, D. (**2006**). "The short-term behavioral reactions of bottlenose dolphins to interactions with boats in Doubtful Sound, New Zealand," Mar. Mamm. Sci. **22**:802-818.

Magnúsdóttir, E. E., Rasmussen, M. H., Lammers, M. O., Svavarsson, J. (**2014**). "Humpback whale songs during winter in subarctic waters," Polar Biol. 37(**3**): 427-433.

Martins, C. C. A., Morete, M. E., Engel, M. H., Freitas, A. C., Secchi, E. R., Kinas, P. G. (**2001**). “Aspects of habitat use patterns of humpback whales in the Abrolhos Bank, Brazil, breeding ground,” Mem. Queensl. Mus. **47**, 563–570.

Martins, C. C. A. (**2004**). "O uso do sistema de informações geográficas como ferramenta na identificação de áreas prioritárias para a conservação da população de baleia jubarte, *Megaptera novaeangliae*, em seu sítio reprodutivo na costa leste do Brasil". Masters dissertation, Universidade de Brasília, Brasília, Brasil, 119 pp.

Mattila D. K., Guinee L. N., Mayo C.A. (**1987**). “Humpback whale songs on a North Atlantic feeding ground,” J. Mam. **68**, 880–883.

Mcsweeny, D. J., Chu, K. C., Dolphin, W. F., Guinee, L. N. (**1989**). “North Pacific humpback whale songs: a comparison of southeast Alaskan feeding ground songs with Hawaiian wintering ground songs”, Mar. Mamm. Sci. 5:139-148.

Miller, P. J. O., Biassoni, N., Samuels, A., Tyack, P. L. (**2000**). “Whale songs lengthen in response to sonar,” Nature **405**, 903.

Nisbet, I. C. T. (**2000**). “Disturbance, habituation, and management of waterbird colonies,” Waterbirds, **23**,312–332.

Noad, M. J., Cato, D. H., Bryden, M. M., Jenner, M. N., Jenner, K. C. S (**2000**). “Cultural revolution in whale songs,” Nature **408**, 537.

Noad, M. J., Cato, D. H. *(*2007)*. “*Swimming speeds of singing and nonsinging humpback whales during migratio,” Mar. MamM. Sci. 23***:***481–495.

Noren, D. P., Johnson, A. H., Rehder, D. and Larson, A. (**2009**). “Close approaches by vessels elicit surface active behaviors by southern resident killer whales,” Endang. Species Res. **8**, 179-192.

Norris, T. F., Mc Donald, M., Barlow, J. (**1999**). “Acoustic detections of singing humpback whales (*Megaptera novaeangliae*) in the eastern North Pacific during their northbound migration,” J. Acoust. Soc. Am. 106:506−514

Nowicki, S., Searcy, W. A. and Peters, S. (**2002**). “Quality of song learning affects female response to male bird song,” P. Roy. Soc. Lond. **269**,1949–1954 (B).

O’Connor S., Campbell R., Cortez H., Knowles T. (**2009**). Whale watching worldwide: tourism numbers, expenditures and expanding economic benefits, a special report from the International Fund for Animal Welfare, Yarmouth, USA. Prepared by Economists at Large. Yarmouth, International Fund for Animal Welfare.

Pack, A. A., Salden, D. R., Ferrari, M. J., Glockner-Ferrari, D. A., Herman, L. M., Stubbs, H. A., Straley, J. M. (**1998**). “Male humpback whale dies in competitive group,” Mar. Mamm. Sci. 14:861–873.

Payne, R. S. & McVay, S. (**1971**). “Songs of humpback whales,” Science **173** (3997), 585-597.

Payne, K.; Tyack, P.; Payne, R. S. (**1983**). “Progressive changes in the song of humpback whales songs (*Megaptera novaengliae*): A detailed analysis of two seasons in Hawaii”, in *Communication and behavior of whales*, edited by R. S. Payne (Westview Press, Boulder, CO), pp. 9–57.

Payne, K.; Payne, R. (**1985**). “Large scale changes over 19 years in songs of humpback whales in Bermuda,” Z. Tierphysiol. Tierer. **68**, 89–114.

Parks, S. E., Clark, C. W.,Tyack, P. L. (**2007**). "Short and long-term changes in right whale calling behavior: the potential effects of noise on communication," J. Acoust. Soc. Am. **122**, 3725–3731.

Parks, S. E.,Urazghildiiev, I., Clark, C. W. (**2009**). "Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas," J. Acoust. Soc. Am. **125**, 1230–1239.

Parks, S. E., Johnson, M., Nowacek, D., Tyack, P. L. (**2010**). "Individual right whales call louder in increased environmental noise," Biol. Lett. **7**, 33–35.

Parks, S. E., Johnson, M., Nowacek, D. & Tyack, P. L. (**2011**). "Individual right whales call louder in increased environmental noise," Biol. Lett. **7**:33-35.

Pirotta, E., Brookes, K. L., Graham, I. M., & Thompson, P. M. (**2014**). "Variation in harbour porpoise activity in response to seismic survey noise," Biol. Lett. 10 (**5**), 20131090.

Pirotta, E., Merchant, N. D., Thompson, P. M., Barton, T. R., Lusseau, D. (**2015**). "Quantifying the effect of boat disturbance on bottlenose dolphin foraging activity," Biol. Conserv. **181**, 82-89.

Read, J., Jones, G., Radford, A. N. *(***2014***). "*Fitness costs are as important as benefits when considering noise-induced behavioural responses*," Behav. Ecol.* **25**, 4–7.

Richardson, W. J., Greene, C. R., Mame, C. I. and Thomson, D. H. (**1995**). *Marine Mammals and Noise.* Vol. Academic Press: San Diego, CA.

Scheidat, M., Castro, C., González, J. & Williams, R. (**2004**). "Behavioural responses of humpback whales (*Megaptera novaeangliae*) to whale watching boats near Isla de la Plata, Machalilla National Park, Ecuador," J. Cetacean Res. Manage. **6**, 63-68.

Slabbekoorn, H. and Peet, M. (**2003**). “Birds sing at a higher pitch in urban noise”, Nature **424**,267.

Slater, P. J. B. (**1986**). “The cultural transmission of bird song,” Trends Ecol. Evol. **1**, 94–97.

Smith, J. N., Goldizen, A. W., Dunlop, R. A., Noad, M. J. (**2008**). “Songs of male humpback whales, *Megaptera novaeangliae*, are involved in intersexual interactions,” Anim. Behav. **76**, 467–477.

Sousa-Lima, R. S., Morete, M. E., Fortes, R. C., Freitas, A. C., Engel, M. H. (**2002**). “Impact of boats on the vocal behavior of humpback whales off Brazil,” J. Acoust. Soc. Am. **112**, 2430-2431.

Sousa-Lima, R. S. & Clark, C. W. (**2004**). “Potential impact of boat presence in the vocal behavior of humpback whales, *Megaptera novaeangliae*, in a Brazilian National Marine Park,” J. Cetacean Res. Manage. **56**, 1-6.

Sousa-Lima, R. S. (**2007**). “Acoustic Ecology of Humpback Whales (*Megaptera novaeangliae*) in the Abrolhos National Marine Park, Brazil,” Ph.D. dissertation, Cornell University, Cornell, United States.

Sousa-Lima, R. S. & Clark, C. W. (**2008**). “Modeling the effect of boat traffic on the fluctuation of humpback whale sinfging activity in the Abrolhos National Marine Park, Brazil,” Can. Acoust. **36**, 174-181.

Sousa-Lima, R. S. & Clark, C. W. (**2009**). “ Whale sound recording technology as a tool for assessing the effects of boat noise in a Brazilian marine park,” Park Sci. **26**, 59-63.

SPSS Inc. (**2011**). *SPSS 20.0 for Windows*. Chicago, IL: SPSS Inc.

Stamation, K. A., Croft, D. B., Shaughnessy, P. D., Waples, K. A. and Briggs, S. V. (**2010**). "Behavioral responses of humpback whales (*Megaptera novaeangliae*) to whale-watching vessels on the southeastern coast of Australia," Marine Mam. Sci. **26**, 98-122.

Stimpert, A. K., Peavey, L. E., Friedlaender, A. S., Nowacek, D. P. (**2012**). "Humpback Whale Song and Foraging Behavior on an Antarctic Feeding Ground," PLoS ONE 7: e51214.

Timmel, G., Courbis, S. Sargeant-Green, H. & Markowitz, H. (**2008**). "Effects of human traffic on the movement patterns of Hawaiian spinner dolphins (*Stenella longirostris*) in Kealakekua bay, Hawaii," Aquatic Mammals **34**, 402-411.

Tyack, P. (**1981**). "Interactions between singing Hawaiian humpback whales and conspecific nearby," Behav. Ecol. Sociobiol. **13**, 49-55.

Vu, E. T., Risch, D., Clark, C. W., Gaylord, S., Hatch, L. T. (**2012**). "Humpback whale song occurs extensively on feeding grounds in the western North Atlantic Ocean," Aquat. Biol. 14:175–183.

Williams, R., Trites, A. W. and Bain, D. E. (**2002**). "Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats: Opportunistic observations and experimental approaches," J. Zool. **256**, 255-270.

Williams, R., Bain, D. E., Smith, J. C. & Lusseau, D. (**2009**). "Effects of vessel on behaviour patterns of individual southern resident killer whales *Orcinus orca*," Endang. Species Res. **6**, 199-209.

Winn, H. E.; Winn, L. K. (**1978**). "The song of Humpback whale, *Megaptera novaeangliae*, in the West indies," Mar. Biol. **47**, 97-114

Wood, W. E. and Yezerinac, S. M. (**2006**). "Song Sparrow (*Melospiza melodia*) song varies with urban noise," BioOne **123**,650–659.

Zerbini, A. N., Andriolo, A., Heide-Jorgensen, M. P., Moreira, S., Pizzorno, J. L., Maia, Y. G., Vanblaricom, G. R., Demaster, D. P. (**2011**). "Migration and summer destinations of humpback whales (*Megaptera novaeangliae*) in the western South Atlantic Ocean," J. Cetacean Res. Manage. **3**, 113-118.

REGRAS DO PERIÓDICO

Journal of the Acoustical Society of America (JASA)

FORMAT REQUIREMENTS FOR MANUSCRIPTS

A. Overview

For a manuscript submitted by the online procedure to pass the initial quality control, it is essential that it adhere to a general set of formatting requirements. Such vary from journal to journal, so one should not assume that a manuscript appropriate for another journal's requirements would be satisfactory for the Journal of the Acoustical Society of America. The reasons for the Journal's requirements are partly to insure a uniform style for publications in the Journal and partly to insure that the copy-editing process will be maximally effective in producing a quality publication. For the latter reason, adequate white space throughout the manuscript is desired to allow room for editorial corrections, which will generally be hand-written on a printed hard-copy. While some submitted papers will need very few or no corrections, there is a sufficiently large number of accepted papers of high technical merit that need such editing to make it desirable that all submissions are in a format that amply allows for this.

The following is a list of some of the more important requirements. (More detailed requirements are given in the sections that follow).

1) The manuscript must be paginated, starting with the first page.
2) The entire manuscript must be doubled-spaced. This includes the author addresses, the abstract, the references, and the list of figure captions. It should contain no highlighting.
3) The title and author list is on the first page. The abstract is ordinarily on a separate page unless there is sufficient room on the title page for it, within the constraints of ample margins, 12 pt type, double-spacing, and ample white

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4) The title must be in lower case, with the only capitalized words being the first word and proper nouns.
5) No acronyms should be in the title or the running title unless they are so common that they can be found in standard dictionaries or unless they are defined in the title.
6) No unsupported claims for novelty or significance should appear in the title or abstract, such as the use of the words new, original, novel, important, and significant.
7) The abstract should be one paragraph and should be limited to 200 words (100 words for Letters to the Editor).
8) Major section headings should be numbered by capital roman numerals, starting with the introduction. Text of such headings should be in capital letters.
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B. Keyboarding instructions

Each submitted paper, even though submitted online, should correspond to a hard copy manuscript. The electronic version has to be prepared so that whatever is printed-out will correspond to the following specifications:

1) The print-out must be single sided.
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5) The authors are requested to use computers with adequate word-processing software in preparing their manuscripts. Ideally, the software must be sufficiently complete that all special symbols used in the manuscript are printed. (The list of symbols available to the AIP for the publication of manuscripts includes virtually all symbols that one can find in modern scientific literature. Authors should refrain from inventing their own symbols). Italics are similarly designated with a single straight underline in black pencil. It is preferred that vectors be designated by bold face symbols within a published paper rather than by arrows over the symbols.
6) Manuscript pages must be numbered consecutively, with the title page being page 1.

C. Order of pages

The manuscript pages must appear in the following order:

1) Title page. (This includes the title, the list of authors, their affiliations, with one complete affiliation for each author appearing immediately after the author's name, an abbreviated title for use as a running title in the published version, and any appropriate footlines to title or authors.)
2) Abstract page, which may possibly be merged with the title page if there is sufficient room. (This includes the abstract with a separate line giving a prioritized listing of the ASA-PACS numbers that apply to the manuscript. The selected PACS numbers should be taken only from the appendix concerned with acoustics of the overall PACS listing.) Please note that the Journal requires the abstract to be typed double spaced, just as for all of the remainder of the manuscript.
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5) Appendixes (if any).
6) Textual footnotes. (Allowed only if the paper cites references by author name and year of publication.)
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E. Abstract page

Abstracts are often published separately from actual articles, and thus are more accessible than the articles themselves to many readers. Authors consequently must write abstracts so that readers without immediate access to the entire article can decide whether the article is worth obtaining. The abstract is customarily written last; the choice of what should be said depends critically on what is said in the body of the paper itself.

The abstract should not be a summary of the paper. Instead, it should give an accurate statement of the subject of the paper, and it should be written so that it is intelligible to a broad category of readers. Explicit results need not be stated, but the nature of the results obtained should be stated. Bear in mind that the abstract of a journal article, unlike the abstract of a talk for a meeting, is backed-up by a written article that is readily (if not immediately) accessible to the reader.

Limit abstracts to 200 words (100 words for Letters to the Editor). Displayed equations that are set apart from the text count as 40 words. Do not use footnotes. If the authors decide that it is imperative to cite a prior publication in the abstract, then the reference should be embedded within the text and enclosed within square brackets. These should be in one of the two standard JASA formats discussed further below, but titles of articles need not be given. The abstract should contain no acknowledgments. In some circumstances, abstracts of longer than 200 words will be allowed. If an author believes that a longer abstract is essential for the paper, they should send an e-mail message to jasa@aip.org with the subject line “Longer abstract requested.” The text of the desired abstract should be included in the memo, along with a statement of why the author believes the longer abstract is essential. The abstract will be reviewed by the editors, and possibly a revised wording may be suggested.

Personal pronouns and explicit claims as to novelty should be assiduously avoided. Do not repeat the title in the abstract, and write the abstract with the recognition that the reader has already read the title. Avoid use of acronyms and unfamiliar abbreviations. If the initial writing leads to the multiple use of a single lengthy phrase, avoid using an author-created acronym to achieve a reduction in length of the abstract. Instead, use impersonal pronouns such as it and these and shorter terms to allude to that phrase. The shortness of the abstract reduces the possibility that the reader will misinterpret the allusion.

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The principal ASA-PACS number must be the first in this list. All of the selected PACS numbers must begin with the number 43, this corresponding to the appendix of the overall PACS listing that is concerned with acoustics. Authors are requested not to adopt a principal PACS number in the category of General Linear Acoustics (one beginning with 43.20) unless there is no specific area of acoustics with which the subject matter can be associated. The more specific is the principal PACS number, the greater likelihood that an appropriate match may be made with an Associate Editor, and the greater likelihood that appropriate reviewers will be recruited. When the paper is printed, the list of ASA-PACS numbers will be immediately followed on the same line by the initials, enclosed in brackets, of the Associate Editor who handled the manuscript.

F. Section headings

The text of a manuscript, except for very short Letters to the Editor, is customarily broken up into sections. Four types of section headings are available: principal heading, first subheading, second subheading, and third subheading. The principal headings are typed boldface in all capital letters and appear on separate lines from the text. These are numbered by uppercase roman numerals (I, II, III, IV, etc.), with the introductory section being principal section I. First subheadings are also typed on separate lines; these are numbered by capital letters: A, B, C, etc. The typing of first subheadings is bold-face, with only the first word and proper nouns being capitalized. Second subheadings are ordered by numbers (1, 2, 3, etc.) and are also typed on separate lines. The typing of second subheadings is italic bold-face, also with only the first word and proper nouns capitalized. Third subheadings appear in the text at the beginning of paragraphs. These are numbered by lower case letters (a, b, c, etc.) and these are typed in italics (not bold-faced). Examples of these types of headings can be found in recent issues of the *Journal*. (In earlier issues, the introduction section was not numbered; it is now required to be numbered as the first principal section.)

Headings to appendixes have the same form as principal headings, but are numbered by upper-case letters, with an optional brief title following the identification of the section as an appendix, as exemplified below:

APPENDIX: CALCULATION OF IMPEDANCES

If there is only one appendix, the letter designation can be omitted.

STYLE REQUIREMENTS

A. Citations and footnotes

Regarding the format of citations made within the text, authors have two options: (1) textual footnote style and (2) alphabetical bibliographic list style.

In the *textual footnote style,* references and footnotes are cited in the text by superscripted numerals, as in "the basic equation was first derived by Rayleigh[44] and was subsequently modified by Plesset[45]." References and footnotes to text material are intercalated and numbered consecutively in order of first appearance. If a given reference must be cited at different places in the text, and the citation is identical in all details, then one must use the original number in the second citation.

In the alphabetical *bibliographic list style*, footnotes as such are handled as described above and are intended only to explain or amplify remarks made in the text. Citations to specific papers are flagged by parentheses that enclose either the year of publication or the author's name followed by the year of publication, as in the phrases "some good theories exist (Rayleigh, 1904)" and "a theory was advanced by Rayleigh (1904)." In most of the papers where this style is elected there are no footnotes, and only a bibliographic list ordered alphabetically by the last name of the first author appears at the end of the paper. In a few cases[3], there is a list of footnotes followed by an alphabetized reference list. Within a footnote, one has the option of referring to any given reference in the same manner as is done in the text proper.

Both styles are in common use in other journals, although the *Journal of the Acoustical Society of America* is one of the few that allows authors a choice. Typically, the textual footnote style is preferred for articles with a smaller number of references, while the alphabetical bibliographic list style is preferred for articles with a large number of references. The diversity of the articles published in the Journal makes it infeasible to require just one style unilaterally.

B. General requirements for references

Regardless of what reference style the manuscript uses, the format of the references must include the titles of articles. For articles written in a language other than English, and for which the Latin alphabet is used, give the actual title first in the form in which it appeared in the original reference, followed by the English translation enclosed within parentheses. For titles in other languages, give only the English translation, followed by a statement enclosed in parentheses identifying the language of publication. Do not give Latinalphabet transliterations of the original title. For titles in English and for English translations of titles, use the same format as specified above for the typing of the title on the title page. Begin the first word of the title with a capital letter; thereafter capitalize only those words that are specified by standard dictionaries to be capitalized in ordinary prose.

One must include only references that can be obtained by the reader. In particular, do not include references that merely state: “personal communication.” (Possibly, one can give something analogous to this in a textual footnote, but only as a means of crediting an idea or pinpointing a source. In such a case an explanatory sentence or sentence fragment is preferred to the vague term of “personal communication.”) One should also not cite any paper that has only been submitted to a journal; if it has been accepted, then the citation should include an estimated publication date. If one cites a reference, then the listing must contain enough information that the reader can obtain the paper. If thesis, reports, or proceedings are cited, then the listing must contain specific addresses to which one can write to buy or borrow the reference. In general, write the paper in such a manner that its understanding does not depend on the reader having access to references that are not easily obtained.

Authors should avoid giving references to material that is posted on the internet, unless the material is truly archival, as is the case for most online journals. If referring to nonarchival material posted on the internet is necessary to give proper credit for priority, the authors should give the date at which they last viewed the material online. If authors have supplementary material that would be of interest to the readers of the article, then a proper posting of this in an archival form is to make use of the *American Institute of Physics* supplemental material electronic depository. Instructions for how one posts material can be found at the site <http:// www.aip.org/pubservs/epaps.html>. Appropriate items for deposit include multimedia (e.g., movie files, audio files, animated .gifs, 3D rendering files), color figures, data tables, and text (e.g., appendices) that are too lengthy or of too limited interest for inclusion in the printed journal. If authors desire to make reference to materials posted by persons other than by the authors, and if the posting is transitory, the authors should first seek to find alternate references of a more archival form that they might cite instead. In all cases, the reading of any material posted at a transitory site must not be a prerequisite to the understanding of the material in the paper itself, and when such material is cited, the authors must take care to point out that the material will not necessarily be obtainable by future readers.

In the event that a reference may be found in several places, as in the print version and the online version of a journal, refer first to the version that is most apt to be archived.

In citing articles, give both the first and last pages that include it. Including the last page will give the reader some indication of the magnitude of the article. The copying en toto of a lengthy article, for example, may be too costly for the reader's current purposes, especially if the chief objective is merely to obtain a better indication of the actual subject matter of the paper than is provided by the title.

The use of the expression "et al." in listing authors' names is encouraged in the body of the paper, but must not be used in the actual listing of references, as reference lists in papers are the primary sources of large data bases that persons use, among other purposes, to search by author. This rule applies regardless of the number of authors of the cited paper.

References to unpublished material in the standard format of other references must be avoided. Instead, append a graceful footnote or embed within the text a statement that you are making use of some material that you have acquired from another person—whatever material you actually use of this nature must be peripheral to the development of the principal train of thought of the paper. A critical reader will not accept its validity without at least seeing something in print. If the material is, for example, an unpublished derivation, and if the derivation is important to the substance of the present paper, then repeat the derivation in the manuscript with the original author's permission, possibly including that person as a coauthor.

Journal titles must ordinarily be abbreviated, and each abbreviation must be in a "standard" form. The *AIP Style Manual*[1] gives a lengthy list of standard abbreviations that are used for journals that report physics research, but the interdisciplinary nature of acoustics is such that the list omits many journals that are routinely cited in the *Journal of the Acoustical Society of America*. For determination of what abbreviations to use for journals not on the list, one can skim the reference lists that appear at the ends of recent articles in the Journal. The general style for making such abbreviations (e.g., Journal is always abbreviated by "J.," Applied is always abbreviated by "Appl.," International is always abbreviated by "Int.," etc.) must in any event emerge from a study of such lists, so the authors should be able to make a good guess as to the standard form. Should the guess be in error, this will often be corrected in the copy-editing process. Egregious errors are often made when the author lifts a citation from another source without actually looking up the original source. An author might be tempted, for example, to abbreviate a journal title as "Pogg. Ann.," taking this from some citation in a 19th century work. The journal cited is *Annalen der Physik*, sometimes published with the title *Annalen der Physik* und Chemie, with the standard abbreviation being "Ann. Phys. (Leipzig)." The fact that J. C. Poggendorff was at one time the editor of this journal gives very little help in the present era in distinguishing it among the astronomical number of journals that have been published. For Poggendorff's contemporaries, however, "Pogg. Ann." had a distinct meaning.

Include in references the names of publishers of book and standards and their locations. References to books and proceedings must include chapter numbers and/or page ranges.

C. **Examples of reference formats**

The number of possible nuances in the references that one may desire to cite is very large, and the present document cannot address all of them; a study of the reference lists at the ends of articles in recent issues in the Journal will resolve most questions. The following two lists, one for each of the styles mentioned above, give some representative examples for the more commonly encountered types of references. If the authors do not find a de finitive applicable format in the examples below or in those they see in scanning past issues, then it is suggested that they make their best effort to create an applicable format that is consistent with the examples that they have seen, following the general principles that the information must be sufficiently complete that: (1) any present or future reader can decide whether the work is worth looking at in more detail; (2) such a reader, without great effort, can look at, borrow, photocopy, or buy a copy of the material; and (3) a citation search, based on the title, an author name, a journal name, or a publication category, will result in the present paper being matched with the cited reference.

1. Textual footnote style

[1]Y. Kawai, "Prediction of noise propagation from a depressed road by using boundary integral equations" (in Japanese), J. Acoust. Soc. Jpn. 56, 143– 147 (2000).

[2]L. S. Eisenberg, R. V. Shannon, A. S. Martinez, J. Wygonski, and A. Boothroyd, “Speech recognition with reduced spectral cues as a function of age,” J. Acoust. Soc. Am. 107, 2704–2710 (2000).

[3]J. B. Pierrehumbert, *The Phonology and Phonetics of English Intonation* (Ph.D. dissertation), Mass. Inst. Tech., Cambridge, MA, 1980; as cited by D. R. Ladd, I. Mennen, and A. Schepman, J. Acoust. Soc. Am. 107, 2685– 2696 (2000).

[4]F. A. McKiel, Jr., “Method and apparatus for sibilant classification in a speech recognition system,” U. S. Patent No. 5,897,614 (27 April 1999).A brief review by D. L. Rice appears in: J. Acoust. Soc. Am. 107, p. 2323 (2000).

[5]A. N. Norris, “Finite-amplitude waves in solids,” in Nonlinear Acoustics, edited by M. F. Hamilton and D. T. Blackstock (Academic Press, San Diego, 1998), Chap. 9, pp. 263–277.

[6]V. V. Muzychenko and S. A. Rybak, “Amplitude of resonance sound scattering by a finite cylindrical shell in a fluid” (in Russian), Akust. Zh. 32, 129–131 (1986); English transl.: Sov. Phys. Acoust. 32, 79 –80 (1986).

[7]M. Stremel and T. Carolus, “Experimental determination of the fluctuating pressure on a rotating fan blade,” on the CD-ROM: *Berlin, March 14–19, Collected Papers, 137th Meeting of the Acoustical Society of America and the 2nd Convention of the European Acoustics Association* (ISBN 3-9804458-5-4, available from Deutsche Gesellschaft fuer Akustik, Fachbereich Physik, Universitaet Oldenburg, 26111 Oldenburg, Germany), paper 1PNSB_7.

[8]ANSI S12.60-2002 R2009 American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools (American National Standards Institute, New York, 2002).

2. Alphabetical bibliographic list style

American National Standards Inst. (**2002**). ANSI S12.60 R2009 American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools American National Standards Inst., New York.

Ando, Y. (1982). “Calculation of subjective preference in concert halls,” J. Acoust. Soc. Am. Suppl. 1 71, S4 –S5.

Bacon, S. P. (2000). “Hot topics in psychological and physiological acoustics: Compression,” J. Acoust. Soc. Am. 107, 2864 (A).

Bergeijk, W. A. van, Pierce, J. R., and David, E. E., Jr. (1960). Waves and the Ear (Doubleday, Garden City, NY), Chap. 5, pp. 104–143.

Flatté, S. M., Dashen, R., Munk, W. H., Watson, K. M., and Zachariasen, F. (1979). Sound Transmission through a Fluctuating Ocean (Cambridge University Press, London), pp. 31–47.

Hamilton, W. R. (1837). “Third supplement to an essay on the theory of systems of waves,” Trans. Roy. Irish Soc. 17 (part 1),1 –144; reprinted in: The Mathematical Papers of Sir William Rowan Hamilton, Vol. II: Dynamics, edited by A. W. Conway and A. J. McConnell (Cambridge University Press, London), pp. 162–211.

Helmholtz, H. (1859). “Theorie der Luftschwingungen in Röhren mit offenen Enden” (“Theory of air oscillations in tubes with open ends”), J. reine ang. Math. 57, 1 –72.

Kim, H.-S., Hong, J.-S., Sohn, D.-G., and Oh., J.-E. (1999). “Development of an active muffler system for reducing exhaust noise and flow restriction in a heavy vehicle,” Noise Control Eng. J. 47, 57–63.

Simpson, H. J., and Houston, B. H. (2000). “Synthetic array measurements for waves propagating into a water-saturated sandy bottom ...,” J. Acoust. Soc. Am. 107, 2329–2337.

Other examples may be found in the reference lists of papers recently published in the Journal.

D. Figure captions

The illustrations in the Journal have figure captions rather than figure titles. Clarity, rather than brevity, is desired, so captions can extend over several lines. Ideally, a caption must be worded so that a casual reader, on skimming an article, can obtain some indication as to what an illustration is depicting, without actually reading the text of the article. If an illustration is taken from another source, then the caption must acknowledge and cite that source. Various examples of captions can be found in the articles that appear in recent issues of the *Journal*.

If the figure will appear in black and white in the printed edition and in color online, the statement ("Color online") should be added to the figure caption. For color figures that will appear in black and white in the printed edition of the *Journal*, the reference to colors in the figure may not be included in the caption, e.g., red circles, blue lines.

E. Acknowledgments

The section giving acknowledgments must not be numbered and must appear following the concluding section. It is preferred that acknowledgments be limited to those who helped with the research and with its formulation and to agencies and institutions that provided financial support. Administrators, administrative assistants, associate editors, and persons who assisted in the nontechnical aspects of the manuscript preparation must not be acknowledged. In many cases, sponsoring agencies require that articles give an acknowledgment and specify the format in which the acknowledgment must be stated—doing so is fully acceptable. Generally, the *Journal* expects that the page charges will be honored for any paper that carries an acknowledgment to a sponsoring organization.

F. Mathematical equations

Authors are expected to use computers with appropriate software to typeset mathematical equations.

Authors are also urged to take the nature of the actual layout of the journal pages into account when writing mathematical equations. A line in a column of text is typically 60 characters, but mathematical equations are often longer. To insure that their papers look attractive when printed, authors must seek to write sequences of equations, each of which fits into a single column, some of which define symbols appearing in another equation, even if such results in a greater number of equations. If an equation whose length will exceed that of a single column is unavoidable, then the authors must write the equation so that it is neatly breakable into distinct segments, each of which fits into a single column. The casting of equations in a manner that requires the typesetting to revert to a single column per page (rather than two columns per page) format must be assiduously avoided. To make sure that this possibility will not occur, authors familiar with desk-top publishing software and techniques may find it convenient to temporarily recast manuscripts into a form where the column width corresponds to 60 text characters, so as to see whether none of the line breaks within equations will be awkward.

Equations are numbered consecutively in the text in the order in which they appear, the number designation is in parentheses and on the right side of the page. The numbering of the equations is independent of the section in which they appear for the main body of the text. However, for each appendix, a fresh numbering begins, so that the equations in Appendix B are labeled (B1), (B2), etc. If there is only one appendix, it is treated as if it were Appendix A in the numbering of equations.

G. Phonetic symbols

The total list of phonetic symbols that can be used by the AIP during the typesetting process is given in a document file *phonsymbol.pdf*, which can be downloaded by going to the JASA website <http://asa.aip.org/jasa.html> and then clicking on the item List of Phonetic Symbols. The table in the file gives 207 items, labelled P1 through P207, with each given descriptive names such as "inverted aye,""open aye," and "schwa."

The method of including such symbols in a manuscript is to use IPA font(s) in conjunction with a word processor. The IPA fonts should correspond to the International Phonetic Alphabet (IPA), which is maintained by the International Phonetics Association, whose home page is <http:// www2.arts.gla.ac.uk/IPA/ipa.html>. The display of the alphabet (1993, updated 1996) can be found at a variety of sites that are reached from the Association's home page. This site also provides links to some sources where one can obtain IPA fonts.

It should be noted that the portability of documents prepared using IPA fonts on individual computer systems is not guaranteed. Tests made to date on the uploading of manuscripts in either MS Word or LaTeX have achieved successful conversions at the PXP site when the fonts in use are the SIL IPA93 fonts (for MS Word) and the TIPA fonts (for LaTeX). In any event, authors should check the converted files carefully after the uploading to make sure that the symbols in the converted manuscript are as intended. A fuller discussion of these fonts and of how to use IPA fonts in preparing manuscripts for online submission to the *Journal* is given in a supplementary document. To download this document, go to http://asa.aip.org/jasa.html and then click on the item Use of IPA Fonts.

H. Figures

Each figure should be manifestly legible when reduced to one column of the printed journal page. Figures requiring the full width of a journal page are discouraged, but exceptions can be made if the reasons for such are sufficiently evident. The inclusion of figures in the manuscript should be such that the manuscript, when published, should ordinarily have no more than 30% of the space devoted to figures, and such that the total number of figures should ordinarily not be more than 12. In terms of the restriction of the total space for figures, each figure part will be considered as occupying a quarter page. Because of the advances in technology and the increasingly wider use of computers in desk-top publishing, it is strongly preferred that authors use computers exclusively in the preparation of illustrations. If any figures are initially in the form of hard copy, they should be scanned with a high quality scanner and converted to electronic form. Each figure that is to be included in the paper should be cast into one of several acceptable formats (TIFF, EPS, or PS) and put into a separate file.

The figures are numbered in the order in which they are first referred to in the text. There must be one such referral for every figure in the text. Each figure must have a caption, and the captions are gathered together into a single list that appears at the end of the manuscript. The numbering of the figures, insofar as the online submission process is concerned, is achieved by uploading the individual figure files in the appropriate sequence. The author should take care to make sure that the sequence is correct, but the author will also have the opportunity to view the merged manuscript and to check on this sequencing.

For the most part, figures must be designed so that they will fit within one column (3-3/8”) of the page, and yet be intelligible to the reader. In rare instances, figures requiring full page width are allowed, but the choice for using such a figure must not be capricious.

A chief criticism of many contemporary papers is that they contain far too many computer-generated graphical illustrations that present numerical results.An author develops a certain general computational method realized by software and then uses it to exhaustively discuss a large number of special cases. This practice must be avoided. Unless there is an overwhelmingly important single point that the sequence of figures demonstrates as a whole, an applicable rule of thumb is that the maximum number of figures of a given type must be four.

The clarity of most papers is greatly improved if the authors include one or more explanatory sketches. If, for example, the mathematical development presumes a certain geometrical arrangement, then a sketch of this arrangement must be included in the manuscript. If the experiment is carried out with a certain setup of instrumentation and apparatuses, then a sketch is also appropriate. Various clichés, such as Alice's—"and what is the use of a book without pictures?"—are strongly applicable to journal articles in acoustics. The absence of any such figures in a manuscript, even though they might have improved the clarity of the paper, is often construed as an indication of a callous lack of sympathy for the reader's potential difficulties when attempting to understand a paper.

Color figures can be included in the online version of the *Journal* with no extra charge provided that these appear suitably as black and white figures in the print edition.

I. Tables

Tables are numbered by capital roman numerals (TABLE III, TABLE IV, etc.) and are collected at the end of the manuscript, following the references and preceding the figure captions, one table per page. There should be a descriptive caption (not a title) above each table in the manuscript.

Footnotes to individual items in a table are designated by raised lower case letters (0.123[a], Martin[b], etc). The footnotes as such are given below the table and should be as brief as practicable. If the footnotes are to references already cited in the text, then they should have forms such as— [a]Reference 10—or—[b]Firestone (1935)—depending on the citation style adopted in the text. If the reference is not cited in the text, then the footnote has the same form as a textual footnote when the alphabetical bibliographic list style is used. One would cast the footnote as in the second example above and then include a reference to a 1935 work by Firestone in the paper's overall bibliographic list. If, however, the textual footnote style is used and the reference is not given in the text itself, an explicit reference listing must be given in the table footnote itself. This should contain the bare minimum of information necessary for a reader to retrieve the reference. In general, it is recommended that no footnote refer to references that are not already cited in the text.

CHAPTER III - Potential effects of noise from motor boats on humpback whales (*Megaptera novaeangliae*)

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Ocean & Coastal Management (Qualis: A2, Impact factor: 1.747)

A ser submetido.

Potential effects of noise from motor boats on humpback whales (*Megaptera novaeangliae*)

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1. INTRODUCTION

The marine mammals, more specifically, cetaceans, are highly vocal animals that use sound in almost all aspects of their lives (e.g. finding food, reproduction, communication, detection of hunters, and navigation), being possibly sensitive to anthropogenic noises (Weilgart 2007, Risch *et al.* 2012). The observed effects of noises on marine mammals include: changes in vocalizations, breathing, speed of swimming, diving, foraging, changes in the migration route, stress, hearing damages and strandings (Weilgart 2007). Some effects can be highly evident, such as those which affect the health of the animals. Other effects however, can be almost imperceptible, affecting indirectly in population dynamics, for example, interfering in the capacity of an individual within the population to forage, communicate and socialize. Besides that, studies also suggest that these animals apparently present a certain tolerance to noise (Madsen & Møhl 2000, Croll *et al*. 2001, Weilgart 2007).

Within marine mammals, humpback whale males (*Megaptera novaeangliae*) produce a long and complex sequence of sounds denominated song, which can be defined in a hierarchycal structure, consisting of subunits and units, sub phrases and phrases, themes, songs and song sessions (Payne & McVay 1971). The functions of the song are not yet known and although many hypothesis have been proposed (Baker & Herman 1984, Clapham & Mattila 1990, Frazer & Mercado 2000, Mercado *et al*. 2003, Smith *et al*. 2008, Herman *et al*. 2013), the predominant theories are that males sing to attract females (Payne and McVay 1971, Winn and Winn 1978, Tyack 1981, Payne & Guinee 1983, Payne *et al*. 1983, Tyack & Whitehead 1983, Mobley *et al*. 1988, Helweg *et al*. 1992, Clapham 1996, Smith *et al*. 2008), or to establish and/or maintain dominance between males (Darling 1983, Frankel et al. 1995, Darling & Berube 2001, Darling et al. 2006, Herman et al. 2013). There is good evidence showing that the song is important for the reproductive strategy of the male (Cholewiak 2008, Smith *et al*. 2008) and thus fundamental for the species' reproductive success (Cerchio 2003, Cerchio *et al*. 2005).

In many parts of the oceans, the low frequency bands that once were dominated by natural noises such as the ones produced from rain, wind and waves, are currently being dominated by noises originated by anthropogenic activities such as shipping (Andrew *et al.* 2011, Chapman & Price 2011, Hildebrand 2009, McDonald *et al*. 2006, Richardson *et al*. 1995). Since 1960, sound pressure levels resulting from anthropogenic noises increased at a rate of 2.5–3 dB per decade in the Northeast Pacific (McDonald *et al*. 2006), having vessel traffic as the major source of low frequency noise (Richardson *et al*. 1995, McDonald *et al*. 2006).

From minor boats to big tankers, all vessels generate noise, varying according to the characteristics of each vessel. And so, each vessel has a specific spectral signature which depends on the propulsion type, speed and activities held on board (Mitson 1993, Richardson *et al*. 1995, Jensen *et al*. 2009). The sources of noise within a ship are diverse, ranging from the movement of the propeller, friction of the ship in the water, and the operation of the engine (Richardson *et al*.1995). Most underwater noise produced by vessels is caused by cavitation (Ross 1976, Au & Green 2000), which occurs due to the formation of bubbles produced by the rotation of the blades from the propellers which collapse or cavitate causing an intense noise (Studds *et al*. 2007).

In this sense, noise from vessels have the potential to interfere in the complex vocal behavior of the humpback whale and therefore it is possible that the interruption of this sexual display may lead to significant impacts on males and negatively affect their reproductive success. Additionally, it is plausible that a certain number of affected individuals may lead to a negative impact at a population level (Sousa-Lima & Clark 2004).

Furthermore, due to the frequent surface activities, humpback whales are commonly observed through whale watching by humans everywhere in the world (Hoyt 2001, O'Connor *et al*. 2009, Cisneros-Montemayor *et al*. 2010). Although it has been considered an alternative to hunting that allows for a more sustainable use of these animals as a natural resource, the growing number of whale watching vessels is generating a growing concern over the possible effects that this activity may cause towards these animals.

In a study conducted in Maui, Hawaii, Au & Green (2000) investigated the levels of noise produced by whale watching vessels and the possible effects they could have on the behavior of humpback whales. This work provided the noise signatures of five different vessels, and behavioral responses reported were, for example, abrupt change in course and long dives, similar to what was already reported previously for humpback whales in Hawaiian waters according to Green (1998). However, Au & Green (2000) conclude that, due to the noise levels produced by the vessels being smaller than the levels produced by the song of the whales, and that even though vessel noise may affect the reception of the song by other individuals in the area, possibly no severe effects happen in the hearing system of the humpback whales that produce the song.

Aside from the noise generated by the vessels, their presence may also affect the behavior of whales (Noren *et al*. 2009), interrupting important activities such as mating and feeding (Williams *et al*. 2002, Noren *et al*. 2009). Although the biological consequences of background noise are not yet well comprehended, there is enough evidence to suggest that this increase could have a negative effect in the reproductive success of many baleen whales (Clark *et al*. 2009, Payne & Webb 1971, Tyack & Clark 2000).

Cetaceans may react by the proximity of humans, their typical response is to move away, either by splitting up groups or by swimming to a different location. Sousa-Lima &

Clark (2009), investigating the possible answers from singing humpback males facing the approach of a boat, verified that 44.5% of singing males moved away from boats and ceased their vocal activity, while 55.5% moved away and remained singing. According to the results from this study, all the whales moved from their original positions with the approach of boats, and when ceased singing, they invariably also left the area. Castellote *et al*. (2012) demonstrated that the fin whale behavior (*Balaenoptera physalus*) was affected in the presence of airgun operations for seismic studies. The authors verified a shift in bearing for singers, suggesting that the animals respond to the seismic activity by leaving the area or falling silent. Other studies show that the humpback whale moves away from preferential areas when there is a disturbance caused by the vessel noise (Baker *et al*. 1989, Borggaard *et al*. 1999). Behavioral responses such as leaving the area may have benefits such as the reducing the cumulative exposure, but may also have costs, such as the energetic costs in moving from the noisy area or reduce opportunities for reproduction and foraging (McEwen & Wingfield 2003).

The Abrolhos National Marine Park (ANMP), located in the northwest coast of Brazil, is know for being the main reproduction area of the species in the Southwest Atlantic Ocean (Engel 1996, Martins *et al*. 2001, Andriolo *et al*. 2006). Studies indicate that there is a continuous growth of the whale population which visits this area (Andriolo *et al*. 2010, Zerbini *et al*. 2011). Along with the humpback whale population increase, whale watching has also become more frequent (Cipolotti *et al*. 2005, Sousa-Lima & Clark 2008). Research conducted to investigate the spacial interaction of singing male humpback whales with vessel traffic around the ANMP area, verified that boat occurrence coincided with the areas of higher density of humback whale singers (Fernandes 2014). Additionaly the author verified that the noise produced by boats also presented a higher amount of energy under the same low frequency band used by humpback whale singers in the ANMP.

The present study has the purpose of characterizing the noise produced by the different vessels used for whale watching in the ANMP area and to identify the characteristics of the boats which influenced the variation of behavioral responses from humpback whales in relation to their approach (Sousa-Lima 2007, Sousa-Lima & Clark 2009): stopped or continued singing; stayed or left the area. With this, the intention is to better understand the effects of noise produced by motor boats on singing humpback whales.

2. METHODS

2.1 Study area

The Abrolhos Bank is located along the Brazilian coast between 16° 40'-19° 30'S, covering an area of approximately of 30.000km^2 (Fainstein & Summerhayes 1982) (Figure 1). The Abrolhos National Marine Park (ANMP), was created on April 6, 1983 (Decree 88.218), and is located on the northeast portion of the bank. This region is known for being the main reproduction area for humpback whales in the Southwest Atlantic Ocean (Engel 1996, Martins *et al*. 2001, Andriolo *et al*. 2006).

2.2 Data Collection

2.2.1 3dB bandwidth and source level of vessel sounds

The boat acoustic data were collected with an array of 4 MARUs ("Marine Acoustic Recording Units" developed by the Cornell Bioacoustics Research Program, USA – BRP). MARUs are recording systems concealed in a glass sphere, with an external hydrophone, and include a microprocessor, hard drives for data storage, acoustic communication circuitry and batteries. Such recording systems were programmed to record continuously at a sampling rate of 2,000 Hz (Sousa-Lima et al. 2013). Each recording system was placed in the bottom of the ocean, not intefering in the areas vessel traffic, and far from corals and/or other formations that could be an obstacle for sound propagation. By the end of the data collection, the MARUs were retrieved for the data extraction and analysis.

The array of MARUs was installed on the western portion of the archipelago, within the ANMP, aiming to monitor acoustically an area of around 60-315 km^2 during three consecutive years (2003, 2004 and 2005). The sounds from vessels were exctracted from the 2005 dataset. Data from 4 different whale watching vessels that operate the ANMP area were exctracted from the MARUs' recordings. These acoustic data were used to characterize the noise from different vessels two catamarans (Jubarte e Sanuk), three motorboats (Arisca, Paradise and Thaiana) and two trawlers (Piloto and Tomara). All the vessels had inboard engines. No detailed information regarding the vessels was available, since most of them are currently inactive or have undergone mechanical renovations.

2.2.2 Vessel characteristics and singer behavioral response

In order to identify which vessel characteristics may influence the variation in behavioral responses of humpback whales, recordings during an experiment that exposed humpbacks to two different interaction situations with the motor vessels were used: (1) no interference from the vessel, which remained far from the focal individual and with the engine switched off and (2) with the vessels' interference, which approached the focal individual following regulated guidelines. Throughout these experiments, the humpbacks behaviors were recorded (more informations in Chapter 2). Two behavioral response categories were defined according to Sousa-Lima (2007) and Sousa-Lima & Clark (2009), one regarding vocal activity: (1) Stopped singing; (2) Continued singing; and the other category regarding displacement: (1) Left the area; (2) Remained in the area. In relation to the boat characteristics, two different types of vessels were used: sailboat (n = 5) and trawler (n = 7); and two types of engines: outboard engine (n = 6) and inboard engine (n = 7).

2.3 Data analyses

2.2.1 3dB bandwidth and source level of vessel sounds

The vessel sounds were found to be overlapped, in some selections, by the presence of humpback whale sound. Thus, manual selections of the whales' songs were made, which were then filtered, enabling the analysis of the sounds of interest.

MARUs were not calibrated, therefore the sound data used in this analysis were extracted from only one unit in the array, avoiding bias in the results. For the characterization of the noise produced by the different boats, the 3 dB bandwidth and the source level (SL) of each vessel were measured. The software Raven Pro 1.4 (Bioacoustics Research Program, 2011) was used to analyze the sound data. In order to detect sounds from the vessels, initially a visual search was made, and after detection, the sound was extracted from a selection of 60 seconds containing the CPA (Closest Point of Approach) of the boats. A Hann window function and a 1024-point FFT size were used to generate spectrograms and sound spectra. A value of 3dB was reduced from the amplitude value of the peak frequency in order to identify the minimum and maximum frequency values of a 3dB bandwidth.

Due to the fact that the sound wave propagates through a medium, as the distance from the sound source increases, the intensity decreases, a phenomenon known as sound attenuation or propagation loss. Sound attenuation can be described through the formula:

$$RL = SL - TL$$

where TL represents energy loss through transmission and is used to relate the source level (SL), defined as the sound pressure level produced by a noise source at a distance of 1m, with the received level (RL) in a particular location. In order to calculate the source level, the following equation was used:

$$SL = RL + 10 \log R$$

Transmission loss was calculated considering a cylindrical spreading (10 log R meaning a loss of 3 dB per doubling of distance) for being the best loss transmission model in shallow waters (Ulrich 1983). R is equivalent to distance, measured in meters, between the source and the recording system (MARU).

The 3dB bandwidth and SL values found were subjected to a Kruskal-Wallis test in order to verify significant differences among types of vessels. Statistical analyses were performed using the SPSS 20.0 program (SPSS Inc. 2011).

2.3.2 Vessel characteristics and singer behavioral response

A chi-squared test was performed in order to investigate the influence of the vessels characteristics (type of vessel and type of engine) on the behavioral responses humpback whales (vocal activity: Stopped singing and Continued singing; displacement: Left the area and Remained in the area) exposed to boat approaches.

3. RESULTS

Examples of spectrograms centered on the CPA of two boats are shown in Figure 1. The first spectrogram corresponds to the sound produced by the catamaran Jubarte and the second by the trawler Piloto.

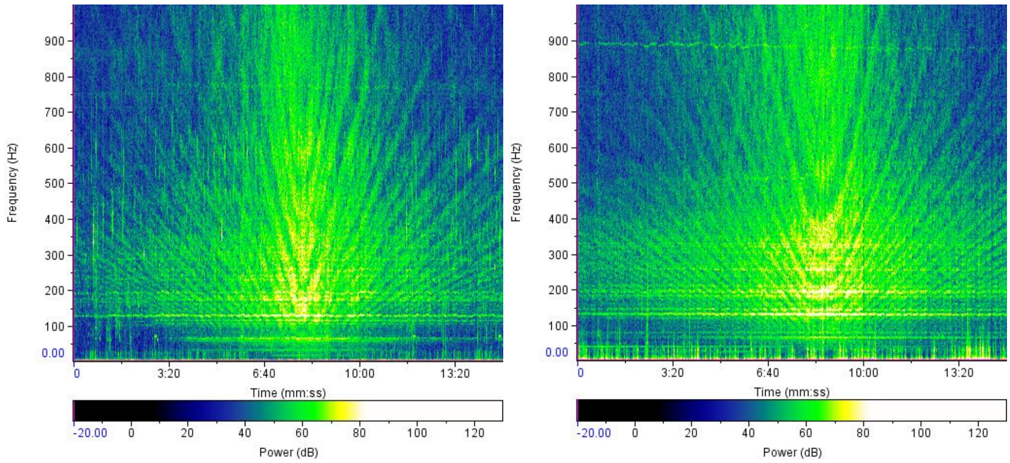

Figure 1: Example of spectrograms centered on the CPA of noises from the vessel Jubarte and Piloto that were recorded in the ANMP in the 2005 season.

3.1 3dB Bandwidth and source level of vessel sounds

The 3 dB bandwidth values were measured for seven sound files from seven different vessels that used the ANMP to operate whale watching trips. The different types of vessels considered in the analysis do not affect the size of the 3 dB bandwidth ($P > 0.05$, Kruskal-Wallis test). Among all motorboats, Arisca was the one that showed the highest peak frequency (Table 1). The 3 dB bandwidth value for this vessel occurred between 93.78 Hz and 96.77 Hz. However, the lowest frequency values for motorboats were found for Thaiana, which presented a peak frequency at 66.42 Hz and a 3 dB bandwidth between 64.14 Hz and 67.71 Hz. The catamarans Jubarte and Sanuk had distinct frequency values between them (Table 1). Só Deus was the trawler that showed the lowest peak frequency value (48.82 Hz) and the highest 3 dB bandwidth value (between 33.23 Hz and 49.70 Hz) for trawlers (Table 1).

Figure 2 contains a bar graph representing the maximum and minimum 3 dB bandwidth values for each vessel. The blue area represents the low frequency band of the humpback whales song in Abrolhos. From this graph it is possible to visualize that, with exception of the vessels Só Deus and Thaiana, all others (Arisca, Jubarte, Paradise, Piloto and Sanuk) produce sounds that overlap in frequency with the song of humpback whales.

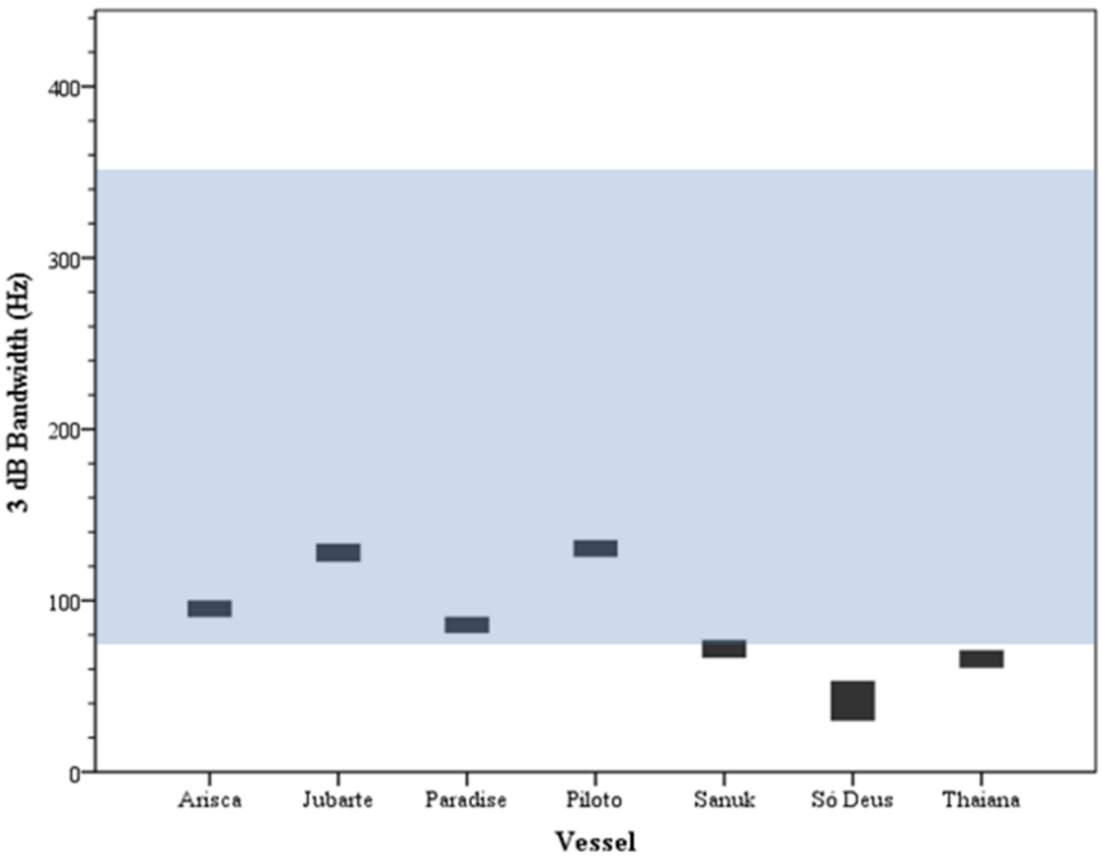

Figure 2: Plot of the 3 dB Bandwidth of vessel sounds. Blue area highlights the frequency band of humpback whale sounds in Abrolhos (75-354 Hz).

Table 4: Maximum and minimum values representing the 3 dB bandwidth (Hz) and peak frequency (Hz) of each vessel. Source level (dB) calculated for the different whale watching vessels in Abrolhos. Equation used: SL = RL + 10 log R, where SL is the noise source level, RL is the received noise level and 10 log R is the transmission loss in shallow water.

Boat	Boat Type	Distance (m)	Peak Frequency (Hz)	Minimum	Maximum	3 dB Bandwidth (Hz)	SL (dB)
Jubarte	Catamaran	196	128.9	126.11	129.92	3.81	111.52
Sanuk	Catamaran	586	72.24	70.04	73.68	3.64	97.28
Arisca	Motorboat	32	95.8	93.78	96.77	2.99	103.25
Paradise	Motorboat	42	85.9	84.53	87.14	2.61	101.73
Thaiana	Motorboat	1,151	66.42	64.14	67.71	3.57	75.01
Piloto	Trawler	6	130.9	128.94	131.92	2.98	108.18
So Deus	Trawler	404	48.82	33.23	49.70	16.47	91.76

Table 1 shows the SL values obtained for the seven vessels analyzed. The different types of vessels considered in the analysis do not affect the SL values (P > 0.05, Kruskal-Wallis test). Between the seven boats, the catamaran Jubarte was the one which produced the highest level of noise and Thaiana, a motorboat, was the vessel which produced the lowest noise level from all analyzed vessels (Figure 3).

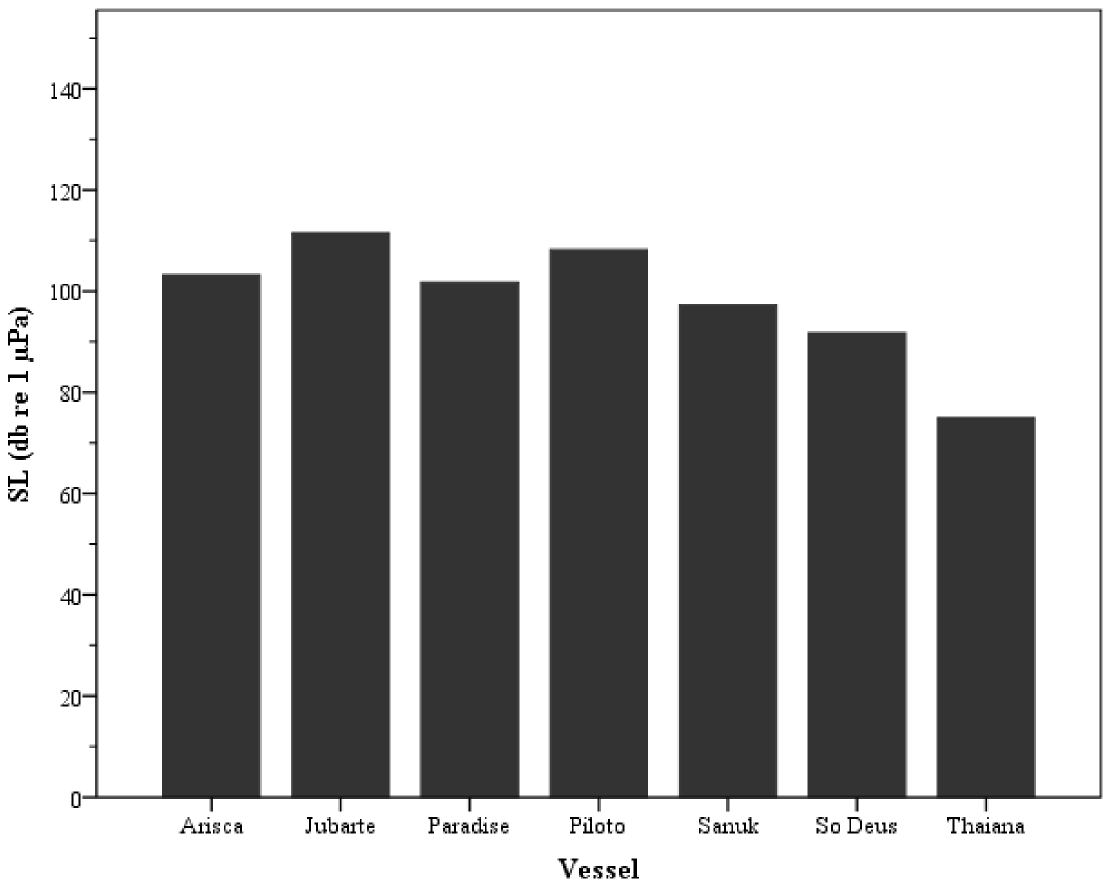

Figure 3: Plot of source level (SL) of vessel sounds.

3.3 Vessel characteristics and singer behavioral response

There was no significant association between vessel or engine type and the whales' vocal response to an approach ($\chi 2 = 1.03$, $p > 0.05$ and $\chi 2 = 0.44$, $p > 0.05$, respectively). Similarly, different types of vessels or engines seem to not influence whether or not the whales would leave or remain in the area ($\chi 2 = 0.07$, $p > 0.05$ and $\chi 2 = 0.00$, $p > 0.05$, respectively).

4. DISCUSSION

Whale watching activities have shown a major growth (Hoyt 2001), which is generating concerns regarding the possible deletirous effects over the individuals. This touristic activity is conducted with a wide variety of vessels. In Brazil, the presence and behavior of vessels is regulated through the Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA, 1996, 2002), which establishes that vessels may not produce any type of noise when in a distance of 300m from any cetacean and they may not approach any large whale (any mysticete, sperm whales and killer whales) and vessels should maintain a distance of 100m from the animal, and the engine should mandatorily be kept on neutral when the species is a humpback whale. Following IBAMA's ordinances the limit numbers of boats inside the ANMP allowed at the same time is 15 boats. It is also prohibited to approach an individual or group of whales that are already submitted to approach at the same time of at least two other vessels.

Different types of vessels seem to not have an association with the values found for the metrics, 3 dB bandwidth and SL, used to characterize the noise of the boats. In some cases, vessels of the same type presented different values for the metrics analyzed. The differences found for vessels of the same type may be related to the distances from the

MARU. Vessels with smaller values were also the ones that were located farther away from the recording device (Table 1 and 2). Some methodological correction may be due in order to control for this bias.

The sound levels of 16 vessels measured under controlled conditions in Glacier Bay National Park and Preserve ranged from 153 to 180 dB re 1 µPa at 1 m (Kipple & Gabriele 2004). The sound levels higher, on the average, were associated with larger vessels categories. Frankel (1994) estimated the source level of the humpback whale song to be between 170 and 175 dB re 1 µPa at 1 m, which is a higher value compared to the vessels in the present study even at small distances. Au e Green (2000) verified that the sound pressure level for the song of humpback males at a distance of 91m (safety distance established in the Maui, Hawaii area) is close to 130 ± 135 dB. These values are higher than the vessels at the same distance and the authors concluded that the vessels wouldn't cause any damage to the whales' auditory system. The hearing range for cetacean species is still not known, but in general, it's presumed that whales and dolphins can hear at a frequency band similar to the sounds that they produce, which can be extrapolated to the frequency bands used in their vocalizations (Southall *et al*. 2007, Todd *et al*. 2014).

Most vessels recorded in this study generated noise that overlapped in frequency with humpbacks (Figure 3). The reduction in the area over which an animal can successfully communicate due to increases in anthropogenic noise levels was referred to by Clark *et al*. (2009) as “lost communication space”. Acoustic interactions can possibly mask vocalizations from the humpback whale, interfering in this way in the animals' ability to detect and distinguish important signals for the species (Foote *et al*. 2004, Ellison et al. 2012, Rice *et al*. 2014).

The evolution of low frequency components in the song for long distance communication optimize the bandwidth in which the signal can be detected, a considered as an adaptation for when males don't know where the females are located (Brenowitz 1982, Croll *et al*. 2002, Darling *et al*. 2006). Thus, if we assume that the song of the humpback whale is used to attract females, the possible masking caused by noise from vessels, can reduce the bandwidth in which the signal can be detected and decrease the communication range of singing males in the search for a sexual partner (Richardson *et al*., 1995). The purpose of the use of low frequency components in the song may not only be to increase the chances of being detected, but also to announce personal characteristics, such as quality and fitness, to potential partners (Croll *et al*., 2002). In this way, masking can make it so that songs with lower frequencies will be dismissed by females, consequently decreasing the reproductive success of such individuals (Charlton *et al*. 2007).

Signals must be detectable in background noise to lead a response from a receiver. The detectability of a signal is determined by the signal-to-noise ratio (SNR) and the masked auditory detection threshold of the receiver (Marten & Marler 1977, Brenowitz 1982, Dooling 2004). Many species have developed a suite of noise-induced vocal modifications to increase the probability of successful communication during periods of increased noise. Such mechanisms include increasing the signal-to-noise ratio through the modification of the signal (Parks *et al*. 2010, Doyle *et al*. 2008, Hotchkin & Parks 2013). However these changes in vocalizations in noisy environments can lead to direct or indirect effects on the survival and reproductive success of the individual (Read *et al*. 2014). Luther & Magnotti (2014) observed that adjusted songs in male Northern cardinals (*Cardinalis cardinalis*) for anthropogenic noise resulted in weaker responses, suggesting that adjusted songs might be maladaptive in terms of intraspecific sexual selection.

Sounds produced by the different types of vessels in this study (sailboat and trawler) and the different types of engine (outboard and inboard engine), seem to not have any influence in the humpbacks short-term acoustic or spatial resposnse. Au & Green (2000) verified that smaller vessels with outboard engine produced sounds with equal or even higher levels than larger vessels with diesel inboard engine. These authors suggest that due to the fact that the most of the subaquatic sounds from the vessels are caused by the cavitation produced by the propellers, small vessels with outboard engines (due to having smaller propellers than the larger vessels with inboard engine) possibly need a much higher number of rotations per minute (RPM) that the rotation necessary for a larger boat with inboard engine and larger propellers. If we considered that boats of distinct sizes can produce sounds with similar levels, they can possibly provoque similar behavioral reactions from whales, which shows the importance to be kept the boats approach guidelines to two boats on the same individual or group of whales.

Sound, a result of the vibration in an elastic medium, is one of the most efficient ways to propagate energy through the aquatic environment. Many animals depend on the propagation of acoustic energy to survive and reproduce. However, this ease with which acoustic energy propagates may also lead to physiological damages or behavioral disturbance to aquatic animals (Tyack 1983, Baker & Herman 1989, Corkeron 1995, Constantine *et al*. 2004). The behavioral responses that individuals can present may also depend not only on the characteristics of the noise introduced, but also on age, sex, behavior, social status or on their physical and physiological conditions, with juveniles generally being more sensitive than adults (Erbe 2002, Thomsen *et al*. 2006).

Research along the south coast of New South Wales (NSW), Australia, on humpback whales, indicated that calf pods were more sensitive to the presence of vessels than were noncalf pods (Stamation *et al*. 2010). The authors suggest that the occurrence of calves may interfere with adult whales’ diving physiology, including dive times and the overall percentage of time whales spent submerged (Stamation et al. 2010). Ellison *et al*. (2012) proposed that behavioral change in response to low levels of noise is likely strongly dependent on the behavioral state of the individual as well as the exposure context. These authors suggested to evaluate animal behavioural responses to the sound in a "three-part approach", first, measurement and evaluation of context-based behavioral responses of marine mammals exposure to different sounds; second, includes new assessment metrics that emphasize relative sound levels; third, considers the effects of chronic and acute noise exposure.

Several coastal towns benefit from ecotourism developed in Abrolhos (Palazzo *et al*. 1994). Tourism development can have positive and/or negative impacts on wildlife. Intensive, persistent, and unregulated vessel traffic that focuses on animals while they are resting, feeding, nursing their young, or socializing can disrupt those activities, and possibly cause long-term problems for populations (Reeves *et al*. 2003). However, if tourism is developed in accordance with the basic tenets of wildlife tourism, such an activity can be sustainable and can aid the conservation of species and can be a good way of making the public aware and informed. It can also generate jobs and become an important tourist attraction for the areas where it is practised.

Actions to make this human activity less distressing to whales should be implemented. Measures such as the acoustic isolation of engines, scientifically validated approach protocols, and reinforcement of regulations of numbers and speeds of boats in areas used by marine mammals could be beneficial for humpbacks seeing that singing is an essential behavior that may guarantee the species reproductive success and maintain the population growing (Sousa-Lima & Clark 2008, Sousa-Lima & Clark 2009, Herman *et al*. 2013).

5. CONCLUSIONS

Differences sounds of vessels can not be explained by the metrics used, however we find possible masking the song of humpback whales. In addition, it was seen that different types of boats and engine types don't seem to be associated with the acoustic and surface behavioral responses of humpback whales.

6. REFERENCES

Andrew, R. K., B. M. Howe and J. A. Mercer. 2011. Long-time trends in ship traffic noise for four sites off the North American West Coast. Journal of the Acoustical Society of America 129:642–651.

Andriolo, A., C. C. A. Martins, M. H. Engel, J. L. Pizzorno, S. Más-Rosa, A. C. Freitas, M. E. Morete and P. G. Kinas. 2006. The first aerial survey of humpback whales (*Megaptera novaeangliae*) to estimate abundance in the breeding ground off Brazil (Breeding Stock A). Journal Cetacean Research Management 8:307–311.

Andriolo, A., P. G. Kinas, M. H. Engel, C. C. A. Martins and A. M. Rufino. 2010. Humpback whales within the Brazilian breeding ground: distribution and population size estimate. Endangered Species Research 11:233-243.

Au, W. W. L. and M. Green. 2000. Acoustic interaction of humpback whales and whale-watching boats. Marine Environmental Research 49:469-481.

Baker, C. S. and L. M. Herman. 1984. Aggressive behavior between humpback whales (*Megaptera novaeangliae*) wintering in Hawaiian waters. Canadinal Journal of Zoology 62:1922-1937.

Baker, C. S. and L. M. Herman. 1989. Behavioral Responses of Summering Humpback Whales to Vessel Traffic: Experimental and Opportunistic Observations; U.S. National Park Service, Alaska Regional Office: Anchorage, AK, p. 50.

Bejder, L., A. Samuels, H. Whitehead, N. Gales, J. Mann, R. Connor, M. Heithaus, J. Watson-Capps, C. Flaherty and M. Krutzen. 2006. Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. Conservation Biology 20:1791–1798.

Borggaard, D., J. Lien and P. Stevick. 1999. Assessing the Effects of Industrial Activity on Large Cetaceans in Trinity Bay, Newfoundland (1992-1995). Aquatic Mammals 25:149-161.

Brenowitz, E. A. 1982. The active space of Red-winged Blackbird song. Journal of Comparative Physiology A 147:511-522.

Castellote, M., C. W. Clark and M. O. Lammers. 2012. Acoustic and behavioral changes by fin whales (*Balaenoptera physalus*) in response to shipping and airgun noise. Biological Conservation 147:115–122.

Cerchio, S., J. K. Jacobsen, D. M. Cholewiak, E. A. Falcone and D. A. Merriwether. 2005. Paternity in humpback whales, *Megaptera novaeangliae*: assessing polygyny and skew in male reproductive success. Animal Behavior 70:267–277.

Cerchio, S. 2003. Paternity, polygyny and alternative mating tactics in humpback whales (*Megaptera novaeangliae*). Doctoral Thesis, University of Michigan, Ann Arbor.

Chapman, N. R. and A. Price. 2011. Low frequency deep ocean ambient noise trend in the Northeast Pacific Ocean. Journal of the Acoustical Society of America 129:161-165.

Charlton, B., D. Reby and K. McComb. 2007. Female red deer prefer the roars of larger males. Biology Letters 3:382-385.

Cholewiak, D. M. 2008. Evaluating the role of song in the humpback whale (*Megaptera novaengliae*) breeding system with respect to intra-sexual interactions. Doctoral Thesis, Cornell University.

Cipolotti, S.R.C., M. E. Morete, B. L. Basto, M. H. Engel and E. Marcovaldi. 2005. Increasing of whale watching activities on humpback whales in Brazil: implications, monitoring and research. International Whaling Commission 57th Meeting 15p.

Cisneros-Montemayor, A. M., Sumaila, U.R., Kaschner, K., Pauly, D. 2010. The global potential for whale watching, Marine Policy 34:1273–1278.

Clapham, P. J. and D. K. Matilla. 1990. Humpback whale songs as indicators of migration routes. Marine Mammal Science 6:155-160.

Clapham, P.J. 1996. The Social and Reproductive Biology of Humpback Whales: an Ecological Perspective. Mammal Review 26:27-49.

Clark, C.W., W. T. Ellison, B. L. Southall, L. Hatch, S. VanParijs, A. Frankel and D. Ponirakis. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implications. Marine Ecology Progress Series 395:201–222.

Constantine, R., Brunton, D., & Dennis, T. 2004. Dolphin-watching tour boats change bottlenose dolphin (*Tursiops truncates*) behaviour. Biology Conservation 117: 299-307.

Corkeron, P. J. 1995. Humpback whales (*Megaptera novaeangliae*) in Hervey Bay, Queensland: behaviour and responses to whale-watching vessels. Canadian Journal of Zoology 73: 1290-1299.

Croll, D.A., C. W. Clark, J. Calambokidis, W. T. Ellison and B. R. Ter-shy. 2001. Effect of anthropogenic low-frequency noise on the foraging ecology of Balaenoptera whales. Animal Conservation 4:13–27.

Croll, D. A., C. W. Clark, A. Acevedo, B. Tershy, S. Flores, J. Gedamke and J. Urban. 2002. Only male fin whales sing loud songs. Nature 417:809.

Darling, J. D. 1983. Migrations, abundance and behavior of Hawaiian humpback whales (*Megaptera novaeangliae*). Ph.D. thesis, University of California, Santa Cruz.

Darling, J.D. and M. Berube. 2001. Interactions of singing humpback whales with other males. Marine Mammal Science 17:570-584.

Darling, J. D., M. E. Jones and C. P. Nicklin. 2006 Humpback whale songs: do they organize males during the breeding season? Behavior 143:1051–1101.

Doyle, L. R., B. McCowan, S. F. Hanser, C. Chyba, T. Bucci, J. E. Blue. 2008. Applicability of information theory to the quantification of responses to anthropogenic noise by southeast Alaskan humpback whales. Entropy 10, 33–46.

Dooling, R. F. 2004. Audition: Can birds hear everything they sing? Pages 178–205 *in* Nature's Music (P. Marler and H. Slabbekoorn, Eds.). Elsevier Academic, London.

Ellison, W. T., B. L. Southall, C. W. Clark, A. S. Frankel. 2012. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. Conservation Biology 26(1): 21–28.

Engel, M., 1996. Comportamento reprodutivo da baleia-jubarte (*Megaptera novaeangliae*) em Abrolhos. Anais de Etologia 14:275-284.

Erbe, C., and D. M. Farmer. 2000. A software model to estimate zones of impact on marine mammals around anthropogenic noise. Journal of the Acoustical Society of America 108:1327-1331.

Erbe, C. 2002. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. Marine Mammal Science 18:394–418.

Fernandes, D. P. 2014. Spatial distribution of humpback whale singers in the Abrolhos Bank, BA, Brazil. Master dissertation. Univerisdade Ferderal do Rio Grande do Norte, Natal, RN. 163 pp.

Foote, A. D., R. W. Osborne and A. R. Hoelzel. 2004. Environment - Whale-call response to masking boat noise. Nature 428, 910.

Frankel, A. S. 1994. Acoustic and visual tracking revels distribution, song variability and social roles of humpback whales in Hawaiian waters. PhD thesis, University of Hawaii, Honolulu, HI.

Frankel, A.S., C. W. Clark, L. M. Herman and C. M. Gabriele. 1995. Spatial distribution, habitat utilization, and social interactions of humpback whales, *Megaptera novaeangliae*, off Hawai'i, determined using acoustic and visual techniques. Canadian Journal of Zoology 73:1134–1146.

Frazer, L. M. and E. Mercado III. 2000. An sonar model for humpback whale song. Journal Ocean Engineering 25:160-182.

Green, M. L. 1998. The effects of vessels on the Hawaiian Humpback Whale (*Megaptera novaeangliae*): an experimental study. Report submitted to the National Marine Fishery Service, Honolulu, HI.

Helweg, D. A., A. S. Frankel, J. R. Mobley and L. M. Herman. 1992. Humpback whale song: our current understanding. Pages 459-483 in J.A. Thomas, R.A. Kastelein and A.Y. Supin Eds. Marine Mammal Sensory Systems. Plenum Press, New York, NY.

Herman, LM, A. A. Pack, S. S. Spitz, E. Y. Herman, K. Rose, S. Hakala and M. H. Deakos. 2013. Humpback whale song: who sings? Behavior Ecology Sociobiology 67:1653–1663

Hildebrand, J. A. 2009. Anthropogenic and natural sources of ambient noise in the ocean. Marine Ecology Progress Series 395:5–20.

Hoyt, E. 2001. Whale watching 2001: Worldwide tourism numbers, expenditures, and expanding socioeconomic benefits. International Fund for Animal Welfare, Yarmouth Port, USA.

Hotchkin, C. F. & S. Parks. 2013. The Lombard effect and other noise-induced vocal modifications: Insight from mammalian communication systems. Biological Reviews 88(4):809–24.

IBAMA. 1996. Portaria n°117, de 26 de dezembro de 1996. Diário Oficial da União, Seção I, pp. 028786.

IBAMA. 2002. Portaria n°24, de 13 de fevereiro de 2002. Diário Oficial da União, Seção I, pp. 67.

Jensen, F., L. Bejder, M. Wahlberg, N. Aguilar de Soto, M. Johnson and P. Madsen. 2009. Vessel noise effects on delphinid communication. Marine Ecology Progress Series 395: 161-175.

Kipple, B. and C. Gabriele. 2004. Glacier Bay watercraft noise - Noise characterization for tour, charter, private, and government vessels. Naval Surface Warfare Center, Bremerton, WA, Technical Report NSWCCDE-71-TR-2004=545, prepared for Glacier Bay National Park and Preserve, pp. 1–47.

Luther, D.A. and Magnotti, J. 2014. Can animals detect differences in vocalizations adjusted for anthropogenic noise? Anim. Behav. 23:201–209

Lusseau, D. 2006. The short-term behavioral reactions of bottlenose dolphins to interactions with boats in Doubtful Sound, New Zealand. Marine Mammal Science 22:802-818.

Madsen, P.T. and B. Møhl. 2000. Sperm whales (Physeter catodon L. 1758) do not react to sounds from detonators. Journal of the Acoustical Society of America 107: 668–671.

Marten, K. and P. Marler. 1977. Sound transmission and its significance for animal vocalization. I. Temperate habitats. Behavioral Ecology and Sociobiology 2:271–290

Martins, C.C.A., M. E. Morete, M. H. Engel, A. C. Freitas, E. R. Secchi and P. G. Kinas. 2001. Aspects of habitat use patterns of humpback whales in the Abrolhos Bank, Brazil, breeding ground. Memoirs of the Queensland Museum 47: 563–570.

McDonald, M.A., J. A. Hildebrand and S. M. Wiggins. 2006. Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California. Journal of the Acoustical Society of America 120:711–717.

McEwen, B. and J. C. Wingfield. 2003. The concept of allostasis in biology and biomedicine. Hormones Behavior. 43:2–15.

Mercado III, E., L. M. Herman and A. A Pack. 2003. Stereotypical sound patterns in hump-back whale songs: usage and function. Aquatic Mammals 29(1):37–52

Mitson, R.B. 1993. Underwater noise radiated by research vessels. ICES Marine Science Symposium 196:147–152.

Mobley, J. R., L. M. Herman and A. S. Frankel. 1988. Responses of wintering humpback whales (*Megaptera novaeangliae*) to playback of recordings of winter and summer vocalizations and of synthetic sound. Behavioural Ecology and Sociobiology 23:211-223.

Noren, D. P., A. H. Johnson, D. Rehder and A. Larson. 2009. Close approaches by vessels elicit surface active behaviors by southern resident killer whales. Endangered Species Research 8:179-192.

O’Connor S., R. Campbell, H. Cortez and T. Knowles. 2009. Whale watching worldwide: tourism numbers, expenditures and expanding economic benefits, a special report from the International Fund for Animal Welfare, Yarmouth, USA. Prepared by Economists at Large. Yarmouth, International Fund for Animal Welfare.

Palazzo, J. T., M. Kammers and I. Linhares. 1994. Whalewatching sites in Brazil: a summary of available information. Working Group on Whale-watching, 46th IWC, IWC/46/WW, 8 pp.

Payne, R. and D. Webb. 1971. Orientation by means of long range acoustic signaling in baleen whales. Annals of New York Academic Science 188:110–142.

Payne, R.S. and S. McVay. 1971. Songs of humpback whales. Science 173(3997): 585-597.

Payne, R., and Guinee, L.N. 1983. Humpback whale (*Megaptera novaeangliae*) songs as an indicator of ‘‘stocks’’. In Communication and Behavior of Whales, R. Payne, ed. (Boulder, CO: Westview Press), pp. 333–358

Payne, K., P. Tyack and R. Payne. 1983. Progressive changes in the songs of humpback whales (*Megaptera novaeangliae*): A detailed analysis of two seasons in Hawaii. In Communication and Behavior of Whales, R. Payne, ed. (Boulder, CO: Westview Press), pp. 9–57.

Parks, S. E., I. Urazghildiiev, C. W. Clark. 2009. Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. J. Acoust. Soc. Am. 125:1230–1239.

Reeves R.R, B. D. Smith, E. A. Crespo, G. Notarbartalo di Sciara. 2003. In Dolphins, whales and porpoises: 2002–2010 conservation action plan for the world's cetaceans,Gland, Switzerland; Cambridge, UK*:*IUCN/SSC Cetacean Specialist Group.

Rice, A. N., J. T. Tielens, B. J. Estabrook, C. A. Muirhead, A. Rahaman, M. Guerra and C. W. Clark. 2014. Variation of ocean acoustic environments along the western north Atlantic coast: a case study in context of the right whale migration route. Ecological Informatics 21:89–99.

Richardson, W.J., C. R. Greene, C. I. Malme and D. H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA, 576 p.

Reeves, R.R., B. D. Smith, E. Crespo, G and Notarbartolo di Sciara. 2003. Dolphins, Whales, and Porpoises: 2000–2010 Conservation Action Plan for the World’s Cetaceans. IUCN: Gland, Switzerland, pp. 18-21.

Risch, D., P. J. Corkeron, W. T. Ellison and S. M. Van Parijs. 2012. Changes in Humpback Whale Song Occurrence in Response to an Acoustic Source 200 km Away. Plos ONE 7:1-6.

Ross, D. 1976. Mechanics of unterwater noise. New York: Pergamon Press.

Smith, J. N., A. W. Goldizen, R. A. Dunlop and M. J. Noad. 2008. Songs of male humpback whales, Megaptera novaeangliae, are involved in intersexual interactions. Animal Behavior 76: 467–477.

Southall, B.L., A. E. Bowles, W. T. Ellison, J. J. Finneran, R. L. Gentry, C. R. Greene and D. Kastak. 2007. Marine mammal noise exposure criteria, initial scientific recommendations. Aquatic Mammals, pp. 411–414.

Sousa-Lima, R.S. and C. W. Clark. 2004. Potential impact of boat presence in the vocal behavior of humpback whales, *Megaptera novaeangliae*, in a Brazilian National Marine Park. Journal of Cetacean Research Management 56:1-6.

Sousa-Lima, R. S. 2007. Acoustic ecology of humpback whales (*Megaptera novaeangliae*) in the Abrolhos National Marine Park, Brazil. Ph.D. thesis, Cornell University, Ithaca, NY. 205 pp.

Sousa-Lima, R.S. and C. W. Clark. 2008. Modeling the effect of boat traffic on the fluctuation of humpback whale sinfging activity in the Abrolhos National Marine Park, Brazil. Canadian Acoustic 36:174-181.

Sousa-Lima, R. S. and C. W. Clark. 2009. Whale sound recording technology as a tool for assessing the effects of boat noise in a Brazilian marine park. Park Science 26:59-63.

Sousa-Lima, R. S., T. F. Norris, J. N. Oswald and D. P. Fernandes. A review and inventory of fixed autonomous recorders for passive acoustic monitoring of marine mammals. Aquatic Mammals 39:23-53.

SPSS Inc. 2011. SPSS 20.0 for Windows. Chicago, IL: SPSS Inc.

Stamation, K. A., D. B. Croft, P. D. Shaughnessy, K. A. Waples and S. V. Briggs. 2010. Behavioral responses of humpback whales (*Megaptera novaeangliae*) to whale-watching vessels on the southeastern coast of Australia. Marine Mammal Science 26:98-122.

Studds, G. E. and J. Andrew. 2007. A Brief Review of Anthropogenic Sound in the Oceans. Journal of Comparative Psychology 20:121-133.

Todd, V. L. G., I. B. Todd, J. C. Gardiner, E. C. N. Morrin, N. A. MacPherson, N. A. DiMarzio and F. Thomsen. 2014. A review of impacts of marine dredging activities on marine mammals. ICES Journal Marine Science 72(2):328-340.

Thomsen, F., K. Lüdemann, R. Kafemann and W. Piper. 2006. Effects of offshore wind farm noise on marine mammals and fish. Biolar, Hamburg, Germany.

Tyack, P. 1981. Interactions between singing Hawaiian humpback whales and conspecific nearby. Behavavioral Ecology Sociobiology 13:49-55.

Tyack, P. 1983. Differential response of humpback whales, *Megaptera novaeangliae*, to playback of song or social sounds. Behavioral Ecology and Sociobiology, 13: 49-55.

Tyack, P. and H. Whitehead. 1983. Male Competition in Large Groups of Wintering Humpback Whales. Behaviour 83:132-154

Tyack, P.L. and C. W. Clark. 2000. Communication and acoustic behavior of dolphins and whales. In: Au, W. W. L., A. N. Popper, R. R. Fay Eds., Hearing by Whales and Dolphins. Springer-Verlag, New York.

Urick, R.J. 1983. Principles of Underwater Sound, McGraw-Hill.

Weilgart, L.S. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. Canadian Journal of Zoology 85:1091–1116.

Winn, H. E. and L. K. Winn. 1978. The song of Humpback whale, *Megaptera novaeangliae*, in the West Indies. Marine Biology 47:97-114

Williams, R., A. W. Trites and D. E. Bain. 2002. Behavioral responses of killer whales (*Orcinus orca*) to whale-watching boats: Opportunistic observations and experimental approaches. Journal of Zoology 256:255-270.

Zerbini, A.N., E. J. Ward, P. G. Kinas, M. H. Engel and A. Andriolo. 2011. A Bayesian assessment of the conservation status of humpback whales (*Megaptera novaeangliae*) in the western South Atlantic Ocean. Journal Cetacean Research Management (Special Issue) 3:131-144.

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DISCUSSÃO & CONCLUSÃO

Variações intraindividuais quanto ao número de unidades, presença/ausência de unidades foram encontradas no canto da maioria dos indivíduos analisados. De acordo com Brito (2014) os diferentes tipos de frase podem estar relacionadas a diferentes aspectos do comportamento sexual, variando entre as interações intersexuais, na busca por parceiros, e intrassexuais, na formação de grupos ou comportamentos agonísticos. Arraut & Vielliard (2004) sugerem que as diferenças individuais possivelmente ocorram devido a diferentes habilidades para compor e/ou aprender o canto. Desta forma, a seleção sexual ocorreria através da capacidade do indivíduo em adquirir rapidamente e executar adequadamente as novas estruturas que compõem o canto (Arraut & Vielliard 2004).

Através da análise qualitativa por linhagem verificamos que nem todos os temas evoluem de forma semelhante, podendo haver diferentes formas de origem, divisão e exclusão de temas. Estudos mostram que a evolução do canto pode ocorrer através da mudança progressiva nas unidades, através do alongamento, ou dividindo as unidades em unidades menores; pela omissão ou inclusão de unidades na composição das frases, ou, através da inserção ou omissão de temas inteiros (Winn &Winn 1978, Payne et al 1983, Payne & Payne 1985, Cato, 1991). Brito (2014) sugere que devido a existência de diferentes formas evolutivas, possivelmente os temas não apresentam um padrão único de evolução gradual, o que mostra a necessidade de criar diferentes critérios e mecanismos para avaliar os diferentes tipos de tema.

O uso de linhagens de temas facilita a visualização das mudanças no canto que ocorrem entre as estações reprodutivas. Além disso, elas auxiliam no entendimento da evolução dos temas, pois através da comparação de frases análogas torna-se possível a identificação da origem de cada tema em relação aos temas do ano anterior, destacando que tipo de mudança ocorreu. Esta abordagem ajuda a evitar confusões entre a evolução das frases existentes com a introdução de frases completamente diferentes.

Estudos mostram que o canto é fundamental para o sucesso reprodutivo do macho de baleia jubarte (Cerchio et al. 2003, Cerchio et al. 2005, Cholewiak 2008, Smith et al. 2008,). Desta forma, a interrupção do canto poderia gerar impactos significativos sobre os machos, afetando negativamente as suas chances de conseguir um parceiro sexual, podendo causar efeitos na viabilidade das populações (Sousa-Lima & Clark 2004, Cerchio et al. 2014).

Os resultados do presente trabalho mostram que a duração da frase e o número médio de frases se mantêm inalterados mesmo durante a exposição ao ruído de embarcações a motor. Desta forma, a métrica duração de frase e número médio de frases podem ser importantes para a comunicação dos machos reprodutores de baleia jubarte, que podem estar sob forte pressão seletiva para manter a consistência dos seus cantos.

Fêmeas de muitas espécies de aves utilizam as vocalizações dos machos para determinar se este é um potencial parceiro. Portanto, aves do sexo masculino de áreas urbanas quando ajustam as características de frequência ou características temporais de suas vocalizações para evitar o mascaramento por ruídos, podem deixar de ser reconhecidos pelas fêmeas da mesma espécie (Slabbekoorn & Peet 2003, Wood & Yezerinac 2006). Do mesmo modo, machos de aves podem apresentar flexibilidade na adaptação das suas vocalizações sem pagar o custo de ter seu reconhecimento reduzido pelas fêmeas, porém, mesmo que seus cantos sejam reconhecidos, eles podem ser vistos como menos atrativos pelas fêmeas, caso elas interpretem as variações como um indicador de aprendizagem do canto (Nowicki et al. 2002).

Sousa-Lima et al. (2002) utilizaram a duração média das frases por indivíduo e o número de frases de cada tema por indivíduo para avaliar as diferenças de comprimento do canto antes e durante a aproximação de barcos. Os autores verificaram que, similarmente ao presente estudo, não houve nenhuma alteração na duração média das frases. Além disso, observaram que o número de frases para cada tema,diminuiu, sugerindo que as baleias cantam versões mais curtas de seus cantos quando expostas a ruídos de barco a motor. No presente estudo também verificamos que a média do número médio das frases diminiu na presença de barcos, no entanto, esta diferença não foi significativa. A diferença do tamanho amostral entre os estudos pode estar relaciona aos resultados encontrados, uma vez que, enquanto no estudo realizado por Sousa-Lima et al. (2002) o número de frases é obtido a partir do canto de dois indivíduos em uma única estação reprodutiva, no presente estudo, o número de frases foi obtido a partir do canto de onze indivíduos ao longo de cinco estações reprodutivas.

Miller et al. (2000) e Fristrup et al. (2003) mostraram que, em média, cantos de baleias jubartes aparentam ser mais longos em resposta à reprodução de LFA, quando comparados aos períodos anteriores e posteriores ao playback. Diferentemente do presente estudo, em que utilizamos como métrica a duração de frases, conforme sugerido por Cholewiak et al. (2012), tanto Miller et al. (2000) como Fristrup et al. (2003) utilizaram a duração do canto para comparar os efeitos da pertubação acústica sobre o comportamento acústico das baleias jubartes. Desta forma, estes autores podem ter encontrado cantos de duração mais longas como resultado a variabilidade da ordem dos temas e do número dos temas que são arbitariamente definidos como um canto (Cholewiak *et al*. 2012).

O nível de pertubação das embarcações de turismo sobre o comportamento e a atividade vocal dos mamíferos marinhos pode estar relacionado com número de embarcações que operam na região. Sousa-Lima & Clark (2008) verificaram que o aumento do número de barcos a motor afeta significantemte a atividade vocal das baleias jubartes. Lusseau et al. (2006) verificaram sinais de declínio, a longo prazo, em uma população local de golfinhos (*Tursiops truncatus*) possivelmente causado pela elevada intensidade turística na região. Orcas (*Orcinus orca*) que vivem em águas costeiras do estado de Washington, E.U.A., apresentaram chamadas mais longas apenas no período em que houve aumento no tráfego de embarcações (Foote et al. 2004).

Os diferentes tipos de barcos parecem não apresentar associação com os valores encontrados para as métricas utilizadas para caracterizar o ruído das embarcações no presente estudo. Adicionalmente, verificou-se que a maioria das embarcações, produziram ruídos que se sobrepõe em frequência com o canto das baleias jubartes da região. Tais interações acústicam podem marcarar as vocalizações das baleias, interferindo, desta forma, na habilidade destes animais para detectar e distinguir sinais importantes para a espécie (Foote et al. 2004, Ellison et al. 2012, Rice et al. 2014).

O som produzido pelos diferentes tipos de barcos (sailboat e trawler) e diferentes tipos de motor (outboard e inboard engine) neste estudo, parecem não ter influência nas respostas acústicas e espaciais. Au & Green (2000) verificaram que barcos menores com motor de popa produziam sons com níveis igual ou até mesmo maiores do que barcos maiores com motor interno. Desta forma, se considerarmos que barcos de distintos tamanhos e motor podem produzir sons com níveis similares, possivelmente provoquem reações comportamentais similares sobre as baleias.

Devido a importância da comunicação acústica para as baleias jubartes, faz-se necessário compreender melhor os processos envolvidos na evolução do canto da espécie e os possíveis efeitos provocados pelos ruídos de barcos sobre a viabilidade de suas populações. Avaliação de impactos antropogênicos, como abordado no presente estudo, auxilia na elaboração de medidas de conservação gerando informações que podem vir a melhorar o gerenciamento do turismo de observação das jubartes no Parque Nacional Marinho dos Abrolhos, além de auxiliar na elaboração de estratégias de conservação para outros cetáceos.

REFERÊNCIAS BIBLIOGRÁFICAS

Andriolo, A., Martins, C.C.A, Engel, M.H., Pizzorno, J.L., Más-Rosa, S., Freitas, A.C., Morete, M.E. & Kinas, P.G. 2006. The first aerial survey of humpback whales (*Megaptera novaeangliae*) to estimate abundance in the breeding ground off Brazil (Breeding Stock A). *Journal Cetacean Research Management*, **8**, 307–311.

Arraut, E.M. & Vielliard, J. M. E. 2004. The song of the Brazilian population of Humpback Whale *Megaptera novaeangliae*, in the year 2000: individual song variations and possible implications. *Anais Acadêmicos Brasileiro de Ciências*, Rio de Janeiro, 76(**2**), 373-380.

Au, W. W. L. & M. Green. 2000. Acoustic interaction of humpback whales and whale-watching boats. *Marine Environmental Research*, **49**, 469-481.

Baker, C.S. & Herman, L.M. 1984. Aggressive behavior between humpback whales (*Megaptera novaeangliae*) wintering in Hawaiian waters. *Canadian Journal of Zoology*, **62**, 1922-1937.

Brito, M. R. M. 2014. Evolução do canto da baleia jubarte (*Megaptera novaeangliae*) no Banco dos Abrolhos, Bahia, Brasil, entre os anos 2000 e 2002 [Monograph]. Universidade Federal do Rio Grande do Norte, Natal, Brasil, 47 pp.

Catchpole, C.K. & Slater, P.B.J. 1995. "Bird Song: Biological Themes and Variations," Cambridge University Press, Cambridge.

Cato, D.H. 1991. Songs of Humpback Whales: the Australian perspective. Mem. Queensl. Mus. **30**: 277–290.

Cerchio, S., Jacobsen, J.K. & Norris, T.F. 2001. Temporal and geographical variation in songs of humpback whales, *Megaptera novaeangliae*: synchronous change in Hawaiian and Mexican breeding assemblages. *Animal Behaviour*, **62**, 313-329.

Cerchio, S. 2003. Paternity, polygyny and alternative mating tactics in humpback whales (Megaptera novaeangliae). Doctoral Thesis, University of Michigan, Ann Arbor.

Cerchio, S., Jacobsen, J. K., Cholewiak, D. M., Falcone, E. A., Merriwether, D. A. 2005. Paternity in humpback whales, *Megaptera novaeangliae*: assessing polygyny and skew in male reproductive success. *Animal Behavior*, 70, 267–277.

Cerchio, S., Strindberg, S., Collins, T., Bennett, C. and Rosenbaum, H. 2014. Seismic surveys negatively affect humpback whale singing activity off northern Angola. *PLoS One*, 9(**3**), e86464.

Cholewiak, D. M. 2008. Evaluating the role of song in the humpback whale (*Megaptera novaengliae*) breeding system with respect to intra-sexual interactions. Ph.D. dissertation, Cornell University, Cornell, United States.

Cholewiak, D.M., Sousa-Lima, R.S. & Cerchio S. 2012. Humpback whale song hierarchical structure: Historical context and discussion of current classification issues. *Marine Mammal Science*, **29**, E312–E332.

Cipolotti, S.R.C., Morete, M.E., Basto, B.L., Engel, M.H. & Marcovaldi, E. 2005. Increasing of whale watching activities on Humpback whales in Brazil: implications, monitoring and research. *International Whaling Commission 57th Meeting*, 15p.

Clapham, P.J. & Matilla, D.K. 1990. Humpback whale songs as indicators of migration routes. *Marine Mammal Science*, **6**, 155-160.

Clapham P. J., Palsboll, P. J., Matilla, D. K., & Vasquez, O. 1992 Composition and dynamics of humpback whale competitive groups in the West Indies. Behaviour, 122, 182-194.

Clapham, P.J. & Mead, J.G. 1999. *Megaptera novaeangliae*. *Mammal Species*, **604**, 1-9.

Clapham, P.J. 2000. The humpback whale: seasonal feeding and breeding in a baleen whale. In: *Cetacean Societies* (Eds.: Mann, J., Connor, R.C., Tyack, P.L. & Whitehead, H.). The University of Chicago Press, Chicago and London, pp. 173-196.

Connor, R.C., Read, A.J., Wrangham, R. 2000. Male reproductive strategies and social bonds. In: *Cetacean societies: field studies of dolphins and whales* (Eds.: Mann, J., Connor, R.C., Tyack, P.L., Whitehead, H.). University of Chicago Press, Chicago, pp. 173–196.

Darling, J.D. & Bérubé M. 2001. Interactions of singing humpback whales with other males. *Marine Mammal Science*, **17**, 570-584.

Darling, J. D., M. E. Jones and C. P. & Nicklin. 2006 Humpback whale songs: do they organize males during the breeding season? *Behaviour*, **143**, 1051–1101.

Darling, J.D., Jones, M.E. & Nicklin, C.P. 2012. Humpback whale (*Megaptera novaeangliae*) singers in Hawaii are attracted to playback of similar song (L). *Journal of the Acoustical Society of America*, **132**(5), 2955– 2958.

Dawbin, W.H. 1966. The seasonal migratory cycle of humpback whale. In: *Whales, dolphins, and porpoises* (Eds.: Norris, K. S.). Berkeley: University of California Press, cap. 9, pp. 146-170.

Di Iorio, L. & Clark, C.W. 2009. Exposure to seismic survey alters blue whale communication. *Biology Letters*, **6**(1), 51–54.

Dunlop, R.A., Cato, D.H. & Noad, M.J. 2008. Non-song acoustic communication in migrating humpback whales (*Megaptera novaeangliae*). *Marine Mammal Science*, **24**, 613−629.

Ellison, W. T., B. L. Southall, C. W. Clark, A. S. Frankel. 2012. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. *Conservation Biology*, 26(**1**): 21–28.

Engel, M. 1996. Comportamento reprodutivo da baleia jubarte (*Megaptera novaeangliae*) em Abrolhos. *Anais de Etologia*, **14**, 275-284.

Finneran, J.J., Schlundt, C.E., Carder, D.A., Clark, J.A. & Young, J.A. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. *Journal of the Acoustical Society of America*, **108**(1), 417–431.

Foote, A. D., R. W. Osborne and A. R. Hoelzel. 2004. Environment - Whale-call response to masking boat noise. *Nature*, 428, 910.

Frankel, A.S. Clark, C.W., Herman, L.M. & Gabriele, C.M. 1995. Spatial distribution, habitat utilization, and social interactions of humpback whales, *Megaptera novaeangliae*, off Hawaii, determined using acoustic and visual techniques. *Canadian Journal of Zoology*, **73**, 1134-1146.

Frantzis, A. 1998. Does Acoustic Testing strand Whales? *Nature*, 392: 29.

Frazer, L.M. & Mercado, E. III. 2000. A sonar model for humpback whale song. *Journal Ocean Engineering*, **25**, 160-182.

Fristrup, K. M., Hatch, L. T. and Clark, C. W. 2003. Variation in humpback whale (*Megaptera novaeangliae*) song length in relation to low-frequency sound broadcasts. Journal of the Acoustical Society of American, **113**, 3411–3424.

Garland, E. C., Goldizen, A. W., Rekdahl, M. L., Constantine, R., Garrigue, C., Daeschler Hauser, N., Poole, M. M., Robbins, J. and Noad, M. J. 2011. Dynamic horizontal cultural transmission of humpback whale song at the ocean basin scale. Current Biology, **21,** 687–691.

Gordon, J., Gillespie, D., Potter, J., Frantzis, A. and Simmonds, M.P. 2004. A review of the effects of seismic surveys on marine mammals. *Marine Technology Society Journal*, **37**(4), 16–34.

Green, M.L. 1998. The effects of vessels on the Hawaiian Humpback Whale (*Megaptera novaeangliae*): an experimental study. Report submitted to the National Marine Fishery Service, Honolulu, HI.

Hatch, L., Clark, C., Merrick, R., Van Parijs, S. & Ponirakis, D. 2008. Characterizing the relative contributions of large vessels to total ocean noise fields: A case study using the Gerry E. Studds Stellwagen Bank National Marine Sanctuary. *Environment Management*, **42**(5), 735–752.

Herman, L.M. & Tavolga, W.N. 1980. The communication systems of cetaceans. In: *Cetacean behavior: mechanisms and functions* (Eds.: Herman, L.M.). Wiley Interscience, New York, pp. 149–209.

Herman, L.M., Pack, A.A., Spitz, S.S., Herman, E.Y.K., Rose, K., Hakala, S. & Deakos, M.H. 2013. Humpback whale song: who sings? *Behavior Ecology Sociobiology*, **10**, 1653-1663.

Hoyt, E. 2001. Whale watching 2001: Worldwide tourism numbers, expenditures, and expanding socioeconomic benefits. International Fund for Animal Welfare, Yarmouth Port, USA.

Jensen, F., Bejder, L., Wahlberg, M., N. Aguilar de Soto, N., Johnson, M. & Madsen, P. 2009. Vessel noise effects on delphinid communication. *Marine Ecology Progress Series*, **395**, 161-175.

Lesage, V., Barrete, C., Kingsley, M.C.S. & Sjate, B. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River Estuary, Canada. *Marine Mammal Science*, **15**, 65-84.

Lusseau, D. 2006. The short-term behavioral reactions of bottlenose dolphins to interactions with boats in Doubtful Sound, New Zealand. *Marine Mammal Scienc,e* 22:802-818.

Martins, C.C.A., Morete, M.E., Engel, M.H., Freitas, A.C., Secchi, E.R. & Kinas, P.G. 2001. Aspects of habitat use patterns of humpback whales in the Abrolhos Bank, Brazil, breeding ground. *Memoirs of the Queensland Museum*, **47**, 563–570.

Martins, C.C.A., Andriolo, A., Engel, M.H., Kinas, P.G. & Saito, C.H. 2013. Identifying priority areas for humpback whale conservation at Eastern Brazilian Coast. *Ocean & Coastal Management*, **75**, 63-71.

Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K. & Tyack, P. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. *Marine Ecology Progress Series*, **309**, 279–295.

McCarthy, E., Moretti, D., Thomas, L., DiMarzio, N. & Morrissey, R. 2011. Changes in spatial and temporal distribution and vocal behavior of blainville's beaked whales

(*Mesoplodon densirostris*) during multiship exercises with midfrequency sonar. *Marine Mammal Science*, **27**(3), E206–E226.

Mercado, E., Schneider, J.N., Pack, A.A., Herman, L.M. 2010. Sound production by singing humpback whales. *Journal of the Acoustical Society of America*, **127**(4), 2678–2691.

Miller, P. J. O., Biassoni, N., Samuels, A., Tyack, P. L. 2000. Whale songs lengthen in response to sonar. *Nature*, **405**, 903.

Mitson, R.B. 1993. Underwater noise radiated by research vessels. *ICES Marine Science Symposium*, **196**, 147–152.

Morete, M.E., Bisi, T.L., Pace III, R.M. & Rosso, S. 2008. Fluctuating abundance of humpback whales (*Megaptera novaeangliae*) in a calving ground off coastal Brazil. *Journal of the Marine Biological Association of the UK*, **88**, 1229-1235.

Morton, A.B. & Symonds, H.K. 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. *ICES Jounral of Marine Science*, **59**(1), 71–80.

Muloin, S. 1998. Wildlife tourism: the psychological benefits of whale watching. *Pacific Tourism Review*, **2**, 199-213.

Noad, M.J., Cato, D.H., Bryden, M.M., Jenner, M.N. & Jenner, K.C.S. 2000. Cultural revolution in whale songs. *Nature***, 408**, 537.

Nowacek, D.P., Thorne, L.E., Johnston, D.W. & Tyack, P.L. 2007. Responses of cetaceans to noise. *Mammal Review*, **37**(2), 81–115.

Nowicki, S., Searcy, W. A. and Peters, S. 2002. Quality of song learning affects female response to male bird song. *Proceddings of the Royal Society of London*, **269**,1949–1954.

O'Connor, S., Campbell, R., Cortez, H. & Knowles, T. 2009. Whale Watching Worldwide: tourism numbers, expenditures and expanding economic benefits, a special report from the International Fund for Animal Welfare. Yarmouth MA, USA, prepared by Economists at Large.

Payne, R.S. & McVay, S. 1971. Songs of humpback whales. *Science*, **173**(3997), 585-597.

Payne, K., Tyack, P. & Payne, R. 1983. Progressive changes in the songs of humpback whales (*Megaptera novaeangliae*): A detailed analysis of two seasons in Hawaii. In: *Communication and Behavior of Whales* (Eds.: Payne, R.). Boulder: Westview Press Inc., 9–57.

Payne, K., Payne, R. 1985. Large scale changes over 19 years in songs of humpback whales in Bermuda. *Zeitschrift für Tierpsychologie*, **68**, 89–114.

Popper, A.N. 2003. Effects of anthropogenic sound on fishes. Fisheries, **28** (10), 24–31.

Rice, A. N., J. T. Tielens, B. J. Estabrook, C. A. Muirhead, A. Rahaman, M. Guerra and C. W. Clark. 2014. Variation of ocean acoustic environments along the western north Atlantic coast: a case study in context of the right whale migration route. *Ecological Informatics*, 21:89–99

Richardson, W.J., Greene, C. R., Malme, C. I. & Thomson, D. H. 1995. *Marine mammals and noise*. Academic Press, San Diego, CA, 576 p.

Risch, D., Corkeron, P.J., Ellison, W.T. & Van Parijs, S.M. 2012. Changes in Humpback Whale Song Occurrence in Response to an Acoustic Source 200 km Away. *Plos ONE* **7**, 1-6.

Ross, D. 1976. *Mechanics of unterwater noise*. New York: Pergamon Press.

Silber, G.K. 1986. The relationship of social vocalizations to surface behavior and aggression in the Hawaiian humpback whale (*Megaptera novaeangliae*). *Canadian Journal of Zoology*, **64**, 2075–2080.

Smith, J.N., Goldizen, A.W., Dunlop, R.A. & Noad, M.J. 2008. Songs of male humpback whales, Megaptera novaeangliae, are involved in intersexual interations. *Animal Behaviour*, **76**, 467-477.

Slater, P.J.B. 1986. The cultural transmission of bird song. Trends in Ecology & Evolution, **1**, 94–97.

Slabbekoorn, H. and Peet, M. 2003. Birds sing at a higher pitch in urban noise. *Nature*, 424, 267.

Smith, J. N., Goldizen, A. W., Dunlop, R. A., Noad, M. J. 2008. Songs of male humpback whales, *Megaptera novaeangliae*, are involved in intersexual interactions. *Animal Behavior*, **76**, 467–477.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J. & Gentry, R.L. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammal*, **33**(4), 411–521.

Sousa-Lima, R.S., Morete, M.E., Fortes, R.C., Freitas, A.C. & Engel, M.H. 2002. Impact of boats on the vocal behavior of humpback whales off Brazil. *Journal of the Acoustical Society of America*, 112: 2430-2431.

Sousa-Lima, R.S. & Clark, C.W. 2004. Potential impact of boat presence in the vocal behavior of humpback whales, *Megaptera novaeangliae*, in a Brazilian National Marine Park. *Journal of Cetacean Research Management*, **56**, 1-6.

Sousa-Lima, R.S. & Clark, C.W. 2008. Modeling the effect of boat traffic on the fluctuation of humpback whale sinfging activity in the Abrolhos National Marine Park, Brazil. *Canadian Acoustic*, **36**, 174-181.

Sousa-Lima, R. S. & Clark, C.W. 2009. Whale sound recording technology as a tool for assessing the effects of boat noise in a Brazilian marine park. *Park Science*, **26**, 59-63.

Stimpert, A.K., Wiley, D.N., Au, W.W.L., Johnson, M.P. & Arsenault, R. 2007. "Megapclicks": Acoustic click trains and buzzes produced during night-time foraging of humpback whales (*Megaptera novaeangliae*). *Biology Letters*, **3**, 467–470.

Stimpert, A.K., Au, W.W.L., Parks, S.E., Hurst, T. & Wiley, D.N. 2011. Common humpback whale (*Megaptera novaeangliae*) sound types for passive acoustic monitoring. *Journal of the Acoustical Society of America*, **129**, 476–482.

Studds, G.E. & Andrew, J. 2007. A Brief Review of Anthropogenic Sound in the Oceans. *Journal of Comparative Psychology*, **20**, 121-133.

Tyack, P. 1981. Interactions between singing Hawaiian humpback whales and conspecific nearby. *Behaviour Ecology of Sociobiology*, **13**, 49-55.

Tyack, P. & Whitehead, H. 1983. Male competition in large groups of wintering humpback whales. *Behaviour*, **83**(1/2), 132-154.

Tyack, P. L. & Miller, E. H. 2002. Vocal anatomy, acoustic communication, and echolocation. In Marine Mammal Biology: An Evolutionary Approach (R. Hoetzel, ed.), Oxford, UK: Blackwell Science, pp. 142–184.

Urick, R.J. 1983. Principles of Underwater Sound, McGraw-Hill.

Weilgart, L.S. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology*, **85**, 1091–1116.

Winn, H.E. & Winn, L.K. 1978. The song of Humpback whale, *Megaptera novaeangliae*, in the West indies. *Marine Biology*, **47**, 97-114.

Wood, W. E. and Yezerinac, S. M. 2006. Song Sparrow (*Melospiza melodia*) song varies with urban noise. *BioOne*, 123,650–659.

Zerbini, A.N., Andriolo, A., Heide-Jorgensen, M.P., Moreira, S., Pizzorno, J.L., Maia, Y.G., Vanblaricom, G.R. & Demaster, D.P. 2011. Migration and summer destinations of humpback whales (*Megaptera novaeangliae*) in the western South Atlantic Ocean. *Journal Cetacean Research Management*, **3**, 113-118.