UNIVERSIDADE FEDERAL DE JUIZ DE FORA PÓS-GRADUAÇÃO EM CIÊNCIAS BIOLÓGICAS MESTRADO EM COMPORTAMENTO E BIOLOGIA ANIMAL

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CAN LONG-FINNED PILOT WHALE SOCIAL STRUCTURE BE ACCESSED BY THEIR CALLS?

Juiz de Fora

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Dissertação apresentada ao Instituto de Ciências Biológicas, Programa de Pós-Graduação em Ciências Biológicas – Comportamento e Biologia Animal da Universidade Federal de Juiz de Fora como requisito parcial para a obtenção do grau de Mestre.

Orientador: Prof. Dr. Artur Andriolo

Coorientador: Dr. Thiago Orion Simões Amorim

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Ellen Fernandes de Freitas Pires

CAN LONG-FINNED PILOT WHALE SOCIAL STRUCTURE BE ACCESSED BY THEIR CALLS?

A ESTRUTURA SOCIAL DAS BALEIAS-PILOTO-DE-PEITORAIS-LONGAS PODE SER ACESSADA PELOS SEUS CHAMADOS?

Dissertação apresentada ao programa de Pós-Graduação em Ciências Biológicas, área de concentração: Comportamento e Biologia Animal, Universidade Federal de Juiz de Fora, como requisito parcial para obtenção do título de Mestre.

Aprovada em 25 de fevereiro de 2019.

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“Palavra puxa palavra, uma ideia traz outra, e assim se faz um livro, um governo, ou uma revolução, alguns dizem que assim é que a natureza compôs as suas espécies”.

Machado de Assis

RESUMO

Os chamados das baleias-piloto-de-peitorais-longas (*Globicephala melas*) ainda são sinais acústicos pouco estudados, possuem estruturas complexas e funções ainda não compreendidas. Além disso, esses sinais parecem ser associados à linguagem própria de um grupo, o que os tornam ainda mais instigantes. Neste estudo foram investigados e comparados os parâmetros dos chamados de dois grupos de *G. melas* registrados em duas ocasiões durante pesquisas com cetáceos da Universidade Federal do Rio Grande em parceria com o Instituto Aqualie, a bordo do R / V Atlântico Sul realizadas na costa do Brasil, da região do Chuí a Cabo Frio. O primeiro registro acústico ocorreu em 26 de maio de 2013 em 33º18'S - 50º16'W, já o segundo registro acústico ocorreu em 12 de maio de 2014 em 33º27'S - 50º35'W. O sistema de gravação para ambos os registros foi composto por uma matriz rebocada de 250m de comprimento com três elementos omnidirecionais (-40 dB, -161 dB re: 1V / µPa, Auset®), distantes cinco metros entre si e dispostos a cinco metros da extremidade do cabo. A matriz foi conectada a um sistema de gravação composto por um gravador digital Fostex® FR-2 LE (com frequência de amostragem de 96 kHz / 24 bits e 48 kHz / 24 bits, respectivamente e configurado com um filtro passa-alta de 1952 Hz). Parâmetros espectrais da componente fundamental de cada chamado como frequência inicial, final, duração total, frequência máxima, mínima e variação de frequência foram extraídos usando o software Raven Pro 1.5. Para validar se os chamados pertenciam a grupos distintos usamos uma Máquina de Vetor Suporte (SVM), análise supervisionada, que auxilia na classificação de dados ou grupos de dados conhecidos, implementada no programa R. O resultado da análise de classificação (SVM) permitiu a separação dos chamados em dois grupos (clãs) com um percentual de erro de 18,81%. Para investigar possíveis unidades sociais dentro de cada clã encontrado, foi utilizada uma análise de agrupamento do tipo k-means, e o resultado da análise em questão apontou possíveis unidades sociais a partir de subconjuntos de chamados indicando pela primeira vez uma possível estrutura social complexa da espécie *Globicephala melas* para o Oceano Atlântico Sul Ocidental.

Palavras-chave: *Globicephala melas*, chamados, comunicação, Oceano Atlântico Sul, organização social.

ABSTRACT

The pulsed calls of long-finned pilot whales, *Globicephala melas*, are still poorly studied acoustic signals, they have complex structures and functions not yet understood, and these signals seem to be associated with a group's own language which makes them even more instigating. In this study, we investigated and compared the parameters of two groups of long-finned pilot whales that were recorded on two occasions during cetacean surveys of the Federal University of Rio Grande in partnership with the Aqualie Institute, aboard the R / V Atlântico Sul on the coast of Brazil, from the region of Chuí to Cabo Frio. The first acoustic recording occurred in May 26th, 2013 at 33º18'S – 50º16'W, while the second acoustic recording occurred in May 12th, 2014 at 33º27'S – 50º35'W. The acoustic recording system was composed by a 250m long towed array with three omnidirectional elements (-40 dB, -161 dB re: 1V / µPa, Auset®), distant five meters apart and arranged five meters from the end of the cable. The array was connected to a digital recording system composed by a Fostex® FR-2 LE digital recorder (with sampling frequency of 96 kHz/ 24 bits and 48 kHz/ 24 bits, respectively and configured with a high pass filter of 1952 Hz). Spectral parameters of the fundamental component of each call such as initial frequency, final frequency, total duration, maximum frequency, minimum frequency variation were extracted using Raven Pro software 1.5. In order to validate whether the calls belonged to different groups, we used a Vector Support Machine (SVM), implemented in the program R. The result of discriminant analysis (SVM) was positive, where we obtained the separation of the calls in two groups (clans) with an error rate of 18.81%. In order to investigate possible social units within each clan found, a k-means analysis was used, and the results of this analysis pointed out possible social units from calls subsets indicating for the first time a possible complex social structure of the species *Globicephala melas* for the Western South Atlantic Ocean.

Keywords: *Globicephala melas*, pulsed calls, communication, South Atlantic Ocean, social organization.

RESUMO DE DIVULGACÃO CIENTÍFICA

As baleias-piloto-de-peitorais-longas são cetáceos ainda pouco estudados de uma maneira geral, seus comportamentos, repertório acústico, principalmente com relação a chamados e estrutura social não são totalmente conhecidos. Chamados são um dos tipos de sinais acústicos desses animais e parecem ser associados à linguagem própria de um grupo e através deles informações importantes podem ser transmitidas entre os indivíduos o que os tornam ainda mais instigantes. Neste estudo, foram investigados e comparados os parâmetros dos chamados de dois grupos de baleias-piloto-de-peitorais-longas, que foram registrados em duas ocasiões durante pesquisas com cetáceos da Universidade Federal do Rio Grande em parceria com o Instituto Aqualie, a bordo do R / V Atlântico Sul realizadas na costa do Brasil, da região do Chuí a Cabo Frio. O primeiro registro acústico ocorreu em 26 de maio de 2013 em 33º18'S - 50º16'W, já o segundo registro acústico ocorreu em 12 de maio de 2014 em 33º27'S - 50º35'W. Informações sobre as características acústicas de cada chamado foram extraídas usando o programa Raven Pro 1.5, afim de se obter uma melhor compreensão desse tipo de sinal. Para verificar se os chamados pertenciam a diferentes grupos foi usada uma análise estatística de Máquina de Vetor Suporte (SVM), que permite a separação de dados ou grupos de dados conhecidos, implementada no programa R. O resultado da análise de classificação (SVM) foi positivo e obtivemos a separação dos chamados em dois grupos (clãs) com erro de 18,81%. Para investigar possíveis unidades sociais dentro de cada clã encontrado, foi utilizada uma análise estatística de k-means, e os resultados das análises indicaram a existência de possíveis unidades sociais a partir de subconjuntos de chamados. Esse estudo foi um primeiro esforço para demostrar que chamados podem revelar uma possível estrutura social desses animais para o Oceano Atlântico Sul Ocidental, afim de conhecer melhor como esses animais se organizam.

Palavras-chave: Chamados, comunicação, baleias-piloto-de-peitorais-longas, Oceano Atlântico Sul, estrutura social.

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BF – Beginning Frequency

DD – Data Deficient

DF – Delta Frequency

DFT – *Discrete Fourier Transform*

EF – Ending Frequency

HF – High Frequency

kHz – KiloHertz

Hz – Hertz

IUCN– *International Union for Conservation of Nature and Natural Resources*

LF – Low Frequency

SVM – Support Vector Machine

TD – Total Duration

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INTRODUÇÃO GERAL

Cetáceos são mamíferos muito adaptados ao meio aquático, tendo representantes em todos os oceanos, em alguns mares e bacias fluviais, são divididos em Odontoceti, animais portadores de dentes, como Boto-rosa (*Inia geoffrensis*), Belugas (*Delphinapterus leucas*), Toninha (*Pontoporia blainvillei*) e Cachalote (*Physeter macrocephalus*) e Misticeti, animais que possuem cerdas bucais, conhecidos como baleias verdadeiras, tendo como exemplos a Baleia Franca (*Eubalaena australis*), Jubarte (*Megaptera novaeangliae*) e a Baleia Azul (*Balaenoptera musculus*) (LODI & BOROBIA, 2013). Alguns cetáceos como Cachalotes, Baleias-piloto-de-peitorais-curtas (*Globicephala macrorhynchus*), entre outros são animais de difícil avistagem e portanto, algumas ferramentas de estudo como a bioacústica tornam-se necessárias para estudá-los, dado que os cetáceos produzem uma ampla série de sons, que vão de baixas frequências até altas frequências (CARWARDINE et al. 2007; AU & HASTINGS, 2008).

Bioacústica é o estudo dos sons emitidos por animais que representam formas de comunicação e nos auxilia na distinção das espécies de interesse e na compreensão do comportamento dessas (VIELLIARD & SILVA, 2006). Identificar e quantificar os sinais acústicos de uma espécie pode ser o início necessário para investigar e entender suas utilizações e funções. Os sons subaquáticos de cetáceos geralmente são classificados em três tipos principais, sendo esses os cliques, assobios e chamados (LILLY & MILLER, 1961; FORD 1987; NEMIROFF & WHITEHEAD, 2009; ANDRIOLO et al. 2015).

Chamados são sons pulsados com altas taxas de repetição de pulsos (SCHEVILL & WATKINS, 1966; FORD 1989; NEMIROFF & WHITEHEAD, 2009). É um dos tipos de sinais acústicos que compõe o repertório vocal de *Globicephala melas* (Traill, 1809), Baleias-piloto-de-peitorais-longas, já que esses animais também são capazes de produzir cliques, assobios e sons explosivos (WEILGARD & WHITEHEAD, 1990).

Em Orcas (*Orcinus orca)* e Baleias pilotos os chamados parecem estar relacionados com a transmissão cultural na forma de aprendizado, passado de mãe para filhote (DEECKE et al. 2000; NEMIROFF & WHITEHEAD, 2009; SAMARRA & DEECKE, 2015), e através dessa aprendizagem vocal ocorre a transmissão de tradições vocais, permitindo aos indivíduos a capacidade de diferenciar grupos com base em repertórios vocais aprendidos (RENDELL & WHITEHEAD, 2001; NEMIROFF & WHITEHEAD, 2009).

Chamados podem refletir também a estrutura social de uma espécie assim como foi encontrado para Orcas, em estudos no Atlântico Norte (FORD 1989, 1991) aonde grupos familiares residentes possuem dialetos próprios compostos por chamados e estes são aprendidos através das mães e outros membros do grupo aparentados.

As Baleias-pilotos-de-peitorais-longas são cetáceos ainda pouco estudados de uma maneira geral, seus comportamentos, repertório acústico, principalmente com relação a chamados, e estrutura social não são totalmente conhecidos (NEMIROFF & WHITEHEAD, 2009), além disso a espécie está na lista vermelha da IUCN como dados deficientes (DD) (TAYLOR et al. 2008).

As duas espécies de baleias piloto do gênero *Globicephala*, são animais que apresentam um corpo longo e robusto, coloração preta ou cinza-escuro, cujos filhotes são mais claros podendo ser amarronzados. Estas são pertencentes à família Delphinidae e estão entre os maiores odontocetos representantes desta (LODI & BOROBIA, 2013). Apresentam uma mancha branca com formato de uma âncora na região da garganta podendo se estender até a área genital. E uma faixa diagonal acinzentada na parte posterior dos olhos em direção a nadadeira dorsal (LODI & BOROBIA. 2013). A cabeça destes cetáceos caracteriza-se por ser arredondada, em formato de globo, apresentando um melão maior em machos, sendo nos espécimes jovens menos proeminente, dando à cabeça um aspecto mais pontiagudo. A nadadeira dorsal é próxima à cabeça, larga na base e falcada, já a nadadeira caudal possui uma discreta reentrância e extremidades pontiagudas, e o pedúnculo desta é robusto e alongado (LODI & BOROBIA, 2013).

Quanto às nadadeiras peitorais as de *G. melas* são muito longas, finas e com extremidades pontiagudas, correspondem cerca de 18% a 27% do comprimento do corpo, em *G. macrorhynchus* as peitorais também são finas, com extremidades pontiagudas, mas são menores e correspondem cerca de 14% a 19% do comprimento do corpo (LODI & BOROBIA, 2013).

Dentre os comportamentos típicos de *G. melas*, estão o borrifo baixo que pode chegar até 1m de altura, e o comportamento de espiar quando o animal ergue a cabeça na direção vertical na superfície da água (LODI & BOROBIA, 2013). Observou-se que *G. melas* jovens saltam mais que os adultos, que estes cetáceos possuem uma capacidade de submersão que varia de 5 a 10 minutos e podem expor a nadadeira caudal antes de um mergulho profundo. Parecem viver em grupos familiares semelhantes aos observados em Orcas, compostos de 20 a 100 indivíduos. É uma das espécies mais envolvidas em encalhes em massa o que mostra uma forte coesão social. Costumam descansar boiando na superfície da água e podem ser avistadas na companhia de outros cetáceos como Baleia-minke (*Balaenoptera acutorostrata*), Baleia-fin (*Balaenoptera physalus*), Golfinho Comum (*Delphinus delphis*) e Orcas (*Orcinus orca*) (LODI & BOROBIA, 2013).

As baleias-piloto-de-peitorais-longas, são amplamente distribuídas no hemisfério Sul preferindo áreas com águas mais frias. São encontradas com frequência na borda da plataforma continental, em zonas costeiras de ilhas oceânicas como Maldivas e as Geórgias do Sul e por ocasião em áreas costeiras (LODI & BOROBIA, 2013). Já a *G. macrorhynchus* está amplamente distribuída em águas tropicais, temperadas quentes e subtropicais, talude continentais em áreas com topografia complexas (LODI & BOROBIA, 2013).

Os esforços para investigação da acústica de *G. melas* estão concentrados no norte da Noruega, e no Oceano Atlântico Norte (VESTER et al. 2014, 2016, 2017; TARUSKI 1979; WEILGARD & WHITEHEAD, 1990; NEMIROFF & WHITEHEAD, 2009; ZWAMBORN & WHITEHEAD, 2016, 2017). Já a estrutura social das baleias-pilotos-de-peitorais-longas foi estudada em três locais: Ilhas Faroé (território da Dinamarca situado entre a Escócia e a Islândia), Ilha de Cape Breton (Nova Escócia, Canadá) e Estreito de Gibraltar (canal que liga o mar Mediterrâneo com o Oceano Atlântico Norte) (AMOS et al. 1993a, 1993b; OTTENSMEYER & WHITEHEAD, 2003; DE STEPHANIS et al. 2008; AUGUSTO et al. 2017a). Assim, como observado em Orcas, a estrutura social das Baleias-pilotos-de-peitorais-longas é composta de clãs e estes são compostos por unidades sociais (famílias) que por sua vez são formadas por linhagens matrilineares (OTTENSMEYER & WHITEHEAD, 2003; DE STEPHANIS et al. 2008; NEMIROFF &WHITEHEAD, 2009; AUGUSTO et al. 2017a), o que mostra a existência de uma estrutura social complexa para esses animais e que até então não foi investigada no Oceano Atlântico Sul.

Logo, entender como os chamados de *G. melas* podem refletir uma possível estrutura social, e se estas emissões acústicas podem conectar os indivíduos de um mesmo grupo, como ocorre em orcas, é um passo importante, já que esses sinais acústicos ainda foram pouco estudados para essa espécie e possuem funções não compreendidas. Neste estudo os parâmetros dos chamados de *G. melas* foram investigados e comparados observando se esses sinais acústicos poderiam indicar uma possível estrutura social para dois grupos de Baleias-piloto-de-peitorais-longas no Oceano Atlântico Sul, costa do Brasil.

Figura 1. Registro da espécie, *Globicephala melas*, Baleia-piloto-de-peitorais-longas, costa do Brasil, Oceano Atlântico Sul. Foto: Projeto Talude (ECOMEGA/ FURG). Pesquisadora: Elisa Seyboth.

Figura 2. Registro das espécies *Globicephala melas* e *Tursiops truncatus* em grupo misto, costa do Brasil, Oceano Atlântico Sul. Foto: Projeto Talude (ECOMEGA/ FURG). Pesquisadora: Elisa Seyboth.

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CAPÍTULO II

CAN LONG-FINNED PILOT WHALE SOCIAL STRUCTURE BE ACCESSED BY THEIR CALLS?

Abstract

The long-finned pilot whale (*Globicephala melas*) (Traill, 1809) calls have complex structures and their functions remain unclear. These calls appear to be associated with the language of a group and seem to reflect its social organization. Long-finned pilot whales are known to have a stable matrilineal social structure composed of social units that together form large groupings called clans. In this study, the hypothesis that different groups of *Globicephala melas* could be differentiated by their calls and that these acoustic signals could reflect the social structure of these animals in the South Atlantic Ocean was tested. Recordings were made in two occasions during cetacean research aboard the R / V Atlântico Sul conducted on the southern coast of Brazil. Spectral and temporal parameters of the fundamental frequency of each call such as: beginning frequency, ending frequency, duration, low and high frequencies and delta frequency were extracted using the software Raven Pro 1.5. Herein, it was compared the parameters of calls of two groups of long-finned pilot whales. A support vector machine (SVM) was implemented in software R to investigate the calls differences among groups. The social groups (clans) were significantly classified, where the accuracy of the SVM classification was 81.19%. In order to evaluate the possible existence of social units (families) within each clan, a k-means clustering analysis was implemented in software R. The results indicate that different clans of long-finned pilot whales have specific features in their calls and through analysis it was possible to evidence the occurrence of possible social units reflecting a potential complex social organization of these animals, which likely play an important role in this species social organization.

Keywords: *Globicephala melas*, pulsed calls, communication, South Atlantic Ocean, social organization, social units.

1. Introduction

Identifying, quantifying, classifying and describing the acoustic signals of a species is the first step necessary to investigate and understand their uses and functions, since cetaceans produce a wide range of sounds, ranging from low frequencies to higher frequencies (Carwardine et al. 2007; Au and Hastings 2008). The underwater sounds of cetaceans are usually classified into three main types: clicks, whistles and calls (Lilly and Miller 1961; Ford 1987; Weilgard and Whitehead 1990; Nemiroff and Whitehead 2009; Andriolo et al. 2015). Clicks are pulsed sounds and usually repetitive that are used in echo localization (Kellogg et al. 1953, Au et al. 2003; Nemiroff and Whitehead 2009). Whistles are continuous tonal sounds sometimes with harmonics, perhaps used to establish contact among individuals in the group (Sayigh et al. 2007; Nemiroff and Whitehead 2009), or to promote greater group cohesion during migration or foraging events (Ford 1989; Wielgard and Whitehead 1990; Nemiroff and Whitehead 2009).

Calls are pulsed sounds with high pulse repetition rates (Schevill and Watkins 1966; Ford 1989; Nemiroff and Whitehead 2009). The pulse repetitions are reflected at the intervals between the sidebands and it is generally modulated along call durations (Watkins 1967; Ford 1989; Nemiroff and Whitehead 2009). These acoustic signals seem to be related to cultural transmission in the way of social learning, transmitted from mother to calf (Deecke et al. 2000; Samarra and Deecke 2015). Through this vocal learning occurs the transmission of vocal traditions, allowing individuals the ability to differentiate groups based on learned vocal repertoires (Rendell and Whitehead 2001; Nemiroff and Whitehead 2009).

This species have the ability to produce and reproduce calls, which can be related to vertical (mothers) or horizontal (relatives) learning (Sayigh et al. 1990; Deecke et al. 2000; Yurk et al. 2002; Nemiroff 2009) for example during alloparental care already observed in *G. melas* (Augusto et al. 2017b). Calls may also reflect the social structure of a species as found for killer whales, registered by studies in the North Atlantic Ocean (Ford 1989, 1991), where resident family groups have their own dialects composed of calls and these are learned through the mothers and other members of the related group.

Long-finned pilot whales, *Globicephala melas* (Traill, 1809) are still a poorly studied species, since many aspects of their behaviors, acoustic signals like clicks, whistles and especially their calls and their social structure are not completely known (Nemiroff and Whitehead 2009). In addition, the species is listed on the IUCN Red List as Data Deficient (DD) (Taylor et al., 2008). Research efforts on the acoustics of this species are concentrated in the north of Norway and in the North Atlantic Ocean, (Vester et al. 2014, 2016, 2017; Taruski 1979; Ford 1989,1991; Weilgart and Whitehead 1990; Nemiroff and Whitehead 2009; Zwamborn and Whitehead 2016, 2017).

The social structure of long-finned pilot whales has already been studied at three sites: Faroe Islands (territory of Denmark), Cape Breton Island (Canada) and Strait of Gibraltar (between the Mediterranean Sea and North Atlantic Ocean) (Amos et al. 1993a, b; Ottensmeyer and Whitehead 2003; de Stephanis et al. 2008; Augusto et al. 2017a). As observed in killer whales, the social structure of long-finned pilot whales is composed by clans formed by social units (Ottensmeyer and Whitehead 2003; de Stephanis et al. 2008; Nemiroff and Whitehead 2009; Augusto et al. 2017a). These social units probably represent matrilineal lineages composed of adult females and their descendants (Amos et al. 1993b; Ford 1989; Nemiroff and Whitehead 2009). Resident killer whales in British Columbia use vocal repertoires of specific calls as identifiers of their own group, which serve as a link between members of the same social unit (Ford 1989, 1991), and these family groups that share one or more calls belong to the same clan (Ford 1989).

Understand how long-finned pilot whale calls may reflect in a possible social structure, and whether these acoustic emissions may aid in linking individuals inside the same group, as occurs in killer whales, is an important step since these signals have been poorly studied for this species and have functions not understood. In this study we investigated and compared the parameters of *Globicephala melas* calls, observing whether these acoustic signals can indicate a possible social system for long-finned pilot whales in the South Atlantic Ocean.

2. Methods

2.1. Study site and data collection

The acoustic encounters of *G. melas* were recorded during a cetacean monitoring survey (Talude Project), aboard the R / V Atlántico Sul of the Federal University of Rio Grande, along the southern outer continental shelf and slope of Brazil. Long-finned pilot whales groups were recorded in two different years. The first recording occurred in May 26th, 2013 at 33º18'S – 50º16'W, and the second one was in May 12th, 2014 at 33º27'S – 50º35'W **(Figure 3)**. Species identification and group size estimation related to each encounter was visually performed by trained observers on the bridge of the vessel.

The acoustic recording system was composed by a 250m long towed hydrophone array with three omnidirectional elements (-40 dB, -161 dB re: 1V / µPa, Auset®), distant five meters apart and arranged five meters from the end of the cable (Andriolo et al. 2018). The array was connected to a digital recording system composed by a Fostex® FR-2 LE digital recorder (sampling frequency of 96 kHz/ 24 bits and 48 kHz/ 24 bits, and configured with a high pass filter of 1952 Hz).

Figure 3. Locations of the *Globicephala melas* encounters in the Brazilian outer continental shelf and slope, western South Atlantic Ocean.

2.2. Acoustical analyses

The calls were aurally and visually selected and its their acoustical parameters were measured through spectrograms generated by the software Raven Pro 1.5 (Cornell Laboratory of Ornithology, Cornell University, NY, USA). The chosen and extracted parameters were established based on Nemiroff (2009); Nemiroff and Whitehead (2009), where the authors studied the structural characteristics of *G. melas* calls in the North Atlantic Ocean, Canada region. Spectral and temporal parameters of the fundamental component of each call were extracted, such as: beginning frequency, ending frequency, low and high frequency, delta frequency and duration. The spectrograms were configured with Hamming window 1024 points, 50% overlap and DFT of 1024 samples **(Figure 4)**.

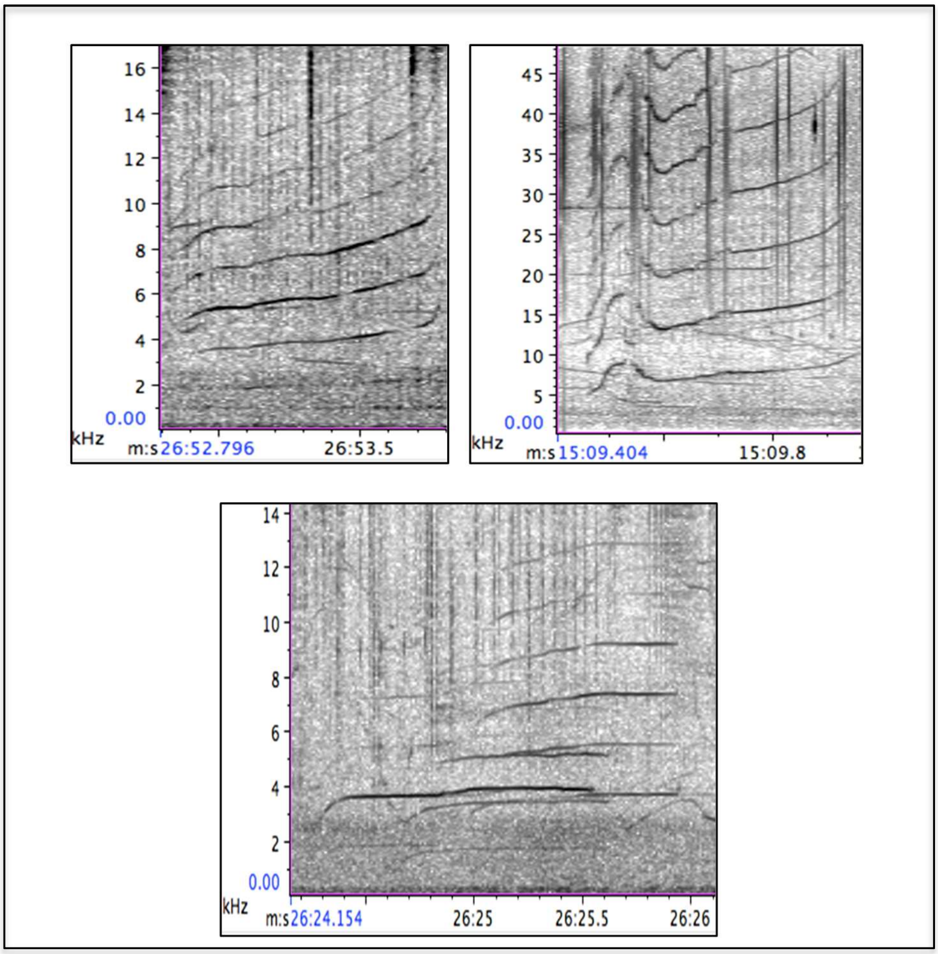

Figure 4. Spectrograms of *Globicephala melas* calls recording in the Brazilian Coast, western South Atlantic Ocean.

2.3. Statistical analyses

2.3.1. Descriptive statistics and permutation test

The descriptive statistics of each parameter of the selected calls was performed using R (R Core Team, 2017). Box plots of parameters of *G. melas* calls were made to evaluate the data and through the results it was possible to verify indications that they did not follow a normality (**Figure 5**). Therefore, Shapiro Wilk tests were performed, presenting evidences that the data of the parameters are not normality distributed (**Table 2**). Moreover, in order to evaluate if the parameters are significantly different in each group, we opted to test if their means differ by using permutation tests (Efron and Tibshirani 1994). For all tests, we considered the level of significance of 0.05.

2.3.2. Support Vector Machine

Support Vector Machine (SVM) is a supervised statistical learning tool, useful for classification of subjects based on prior information provided by historical datasets whose class of each datum is known (see, e.g., James et al. 2013). The SVM classifier considered in this work was developed using the R package e1071 (Meyer et al. 2017).

2.3.3. K-means clustering

K-means clustering is an unsupervised learning method useful to find clusters (subgroups or subsets) in a certain dataset. A clustering analysis using k-means was implemented in R through the command k-means in the package stats (R Core Team, 2017). The k-means analysis was used to detect homogeneous subgroups among the features (see, e.g., James et al. 2013).

3. Results

From 3 hours and 25 minutes of long-finned pilot whale's recordings for both groups, a total of 104 calls, 79 of them belonging to Group 1 (encounter1) and 25 to Group 2 (encounter 2), were discretized and measured. The descriptive statistics of the parameters of the fundamental frequency of *G. melas* calls is presented in **Table 1**.

The calls parameters were represented in Box plots (**Figure 5**), where one can see indicatives of non-normality, such as asymmetry. The evidences of non-normality were reinforced by the Shapiro Wilk test (**Table 2**). For this reason, one cannot use the well-known t test to compare group means. Therefore, we this kind of comparison were performed by permutation tests (see e.g. Efron and Tibshirani 1994), whose p-values are presented in **Table 3.**

In order to develop the SVM classifier, we considered as informative features for classification the significant parameters for the permutation tests presented in **Table 3**. The 104 *G. melas* calls (database) were split into two datasets, namely, the training data (60% of the observations) and testing data (remaining 40%). The separation was done randomly and replicated one thousand time, always preserving the same percentage of the groups (76% of Group 1 and 24% of Group 2). The reason to do so is to use the training data to estimate the tuning parameters (cost and precision) among the sets of candidates. The precision parameter had as candidates a sequence of ten equally spaced values from 0.1 and 100. For the cost, the candidates were 10^k, k = -2, -1, 0, 1, 2. The selected values were 0.1 for the precision and 100 for the cost. Once the tuning parameters were selected, the testing data were classified by the SVM. Therefore, such a data plays the role of "new observations" and it is useful to evaluate the performance the classifier.

The SVM performance replicated one thousand times presented an average error rate of 18.81% (**Figure 6**), where the histogram represent an approximation of the distribution of the error rate during the replications aforementioned. In **Table 4** we have an example of the representation of one of the random replicates with a misclassification rate of 16.66%, both misclassification rates of the SVM are within the larger range of the mean error percentage in (**Figure 6**).

The K-means clustering of the two groups found were able to indicate the existence of calls subsets: in a possible social unit level, and in group 1 we could observe indicatives of 8 subsets (**Figure 7**) and in group 2 five subsets (**Figure 8**).

Table 1. Descriptive statistics of fundamental frequency of *Globicephala melas* calls parameters recorded in the Brazilian Coast, western South Atlantic Ocean.

	D	LF	HF	BF	EF	DF
Minimum	0.3430	991.2	1655.5	1330.5	1084.7	212.1
1st Quartile	0.5528	2142.6	3657.0	3398.4	2223.4	754.5
Mean	0.7150	2604.2	4027.9	3774.4	2785.0	1423.8
Median	0.6810	2697.5	4093.8	3746.0	2830.1	1253.1
3rd Quartile	0.8558	3205.9	4636.1	4455.2	3342.4	2064.7
Maximum	1.2290	3844.3	5246.4	5113.8	4760.1	3073.5
Default Error	0.0211	61.4	73.9	80.3	70.2	78.7
Standard deviation	0.2152	626.6	753.9	818.9	715.9	802.6
Coefficient of variation	0.3010	0.2406	0.1872	0.2170	0.2571	0.5637

D = duration; LF = low frequency; HF = high frequency; BF = beginning frequency; EF = ending frequency; DF = delta frequency.

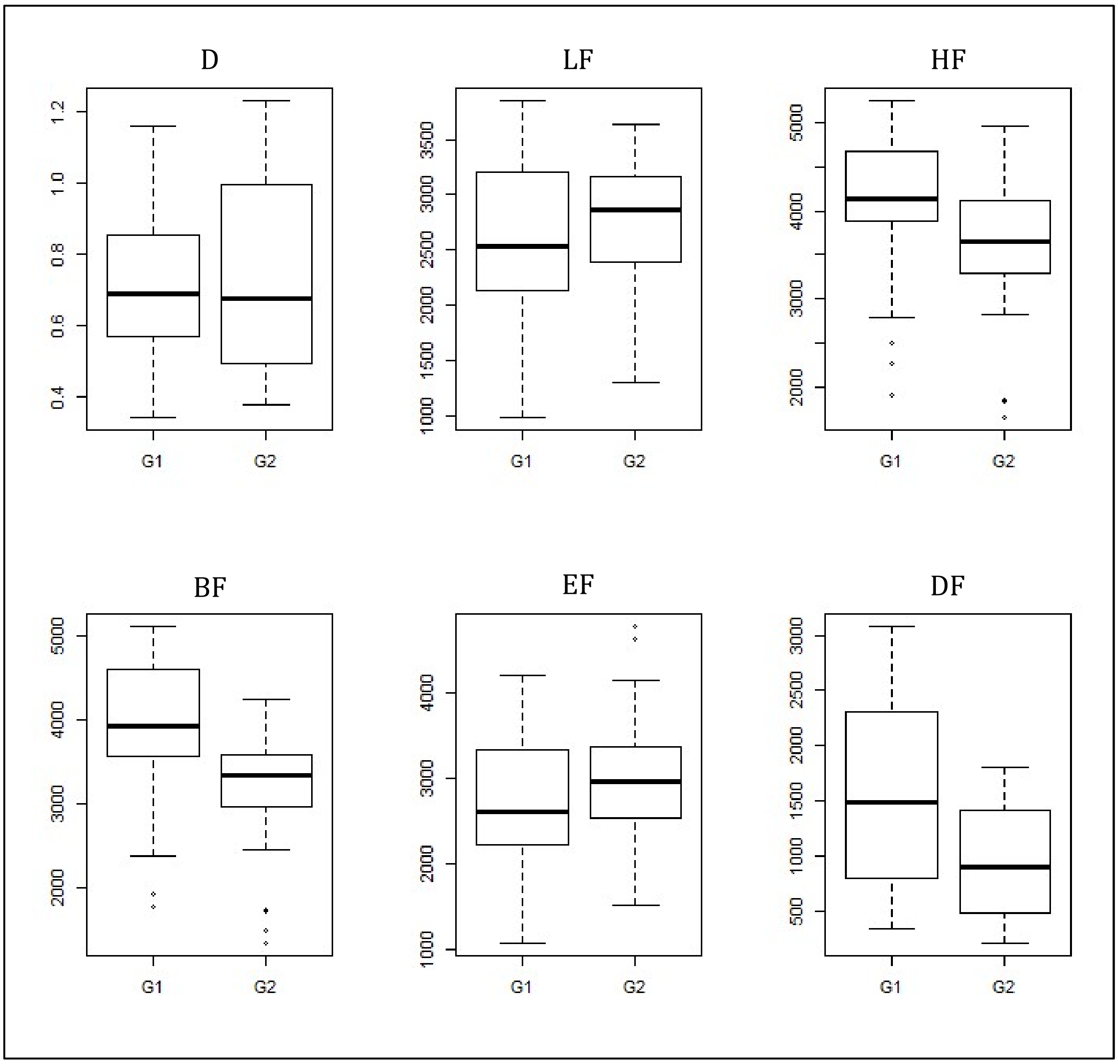

Figure 5. *Box Plots* of the parameters of *Globicephala melas* calls that did not follow a normality, showing an asymmetry in the means.

Table 2. The values found in the Shapiro-Wilk normality test using the software R.

	D	LF	HF	BF	EF	DF
P-value	0.007692	0.0008815	0.00001862	0.0002041	0.03601	0.00001824

D = duration; LF = low frequency; HF = high frequency; BF = beginning frequency; EF = ending frequency; DF = delta frequency.

Table 3. Results of the permutation test used to compare the parameters the fundamental frequency between two groups of *Globicephala melas* recorded in Western South Atlantic Ocean.

	D	LF	HF	BF	EF	DF
P-value	0.952426	0.556477	0.001198	0.000002	0.085608	0.00036

D = duration; LF = low frequency; HF = high frequency; BF = beginning frequency; EF = ending frequency; DF = delta frequency.

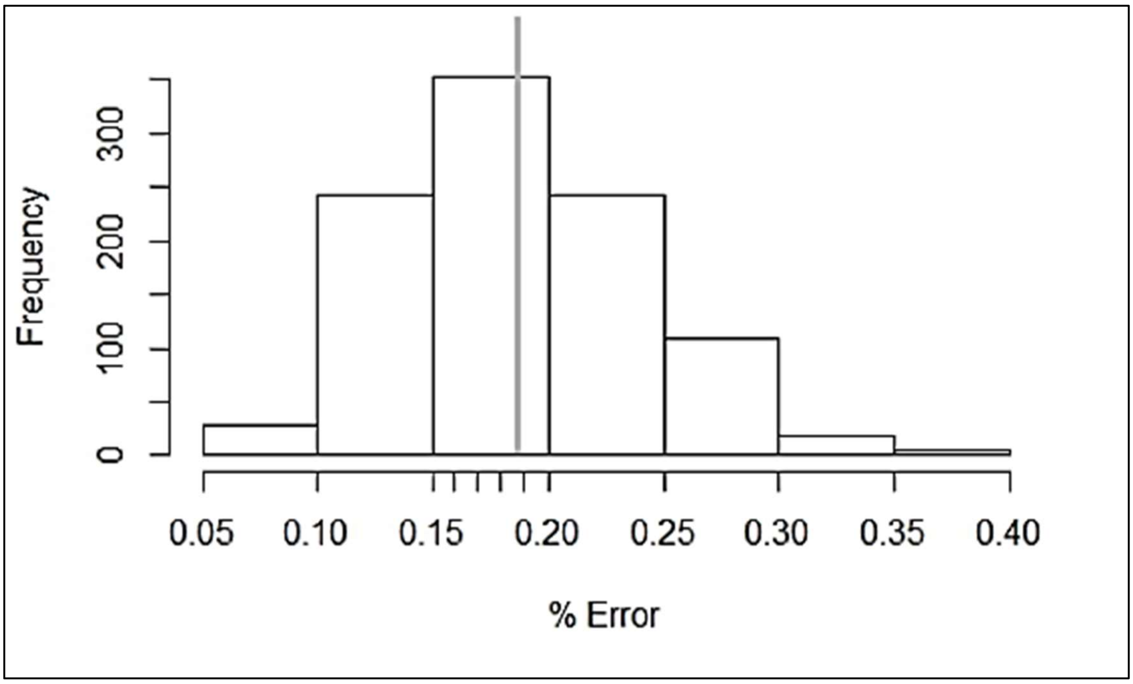

Figure 6. Histogram of the percentage of error in the classification of *Globicephala melas* calls, in the thousand times by SVM.

Table 4. Example of a random replication obtained by SVM analysis during the classification of the calls of *Globicephala melas* in two groups.

	Predictive Counting	
	Group 1	Group 2
Group 1	30	2
Group 2	5	5
Misclassification percentage: 16.66%		

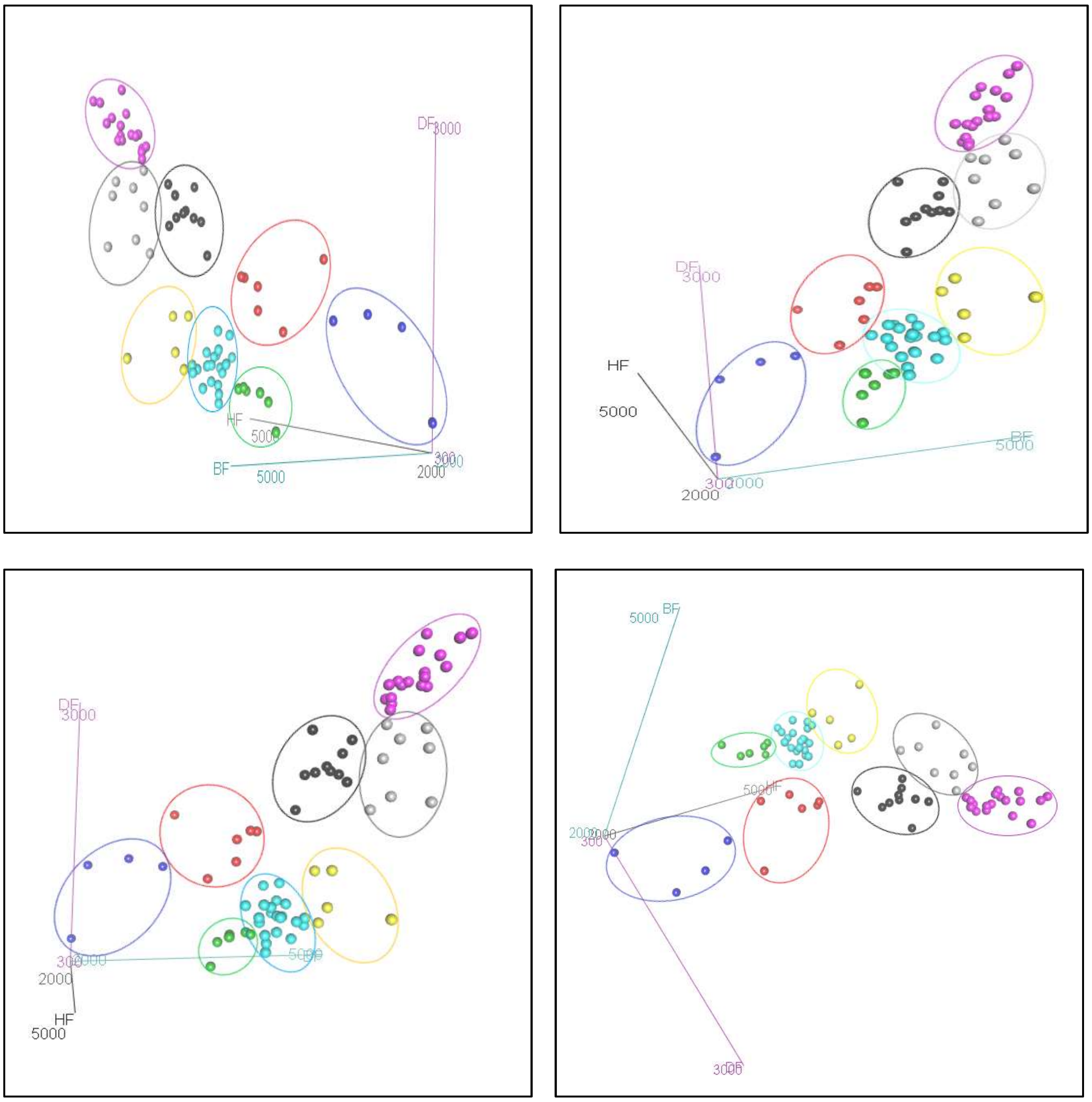

Figure 7. Results of the analysis of k-means clustering in different conformations for better visualization of the 8 subsets of *Globicephala melas* calls in the Group 1.

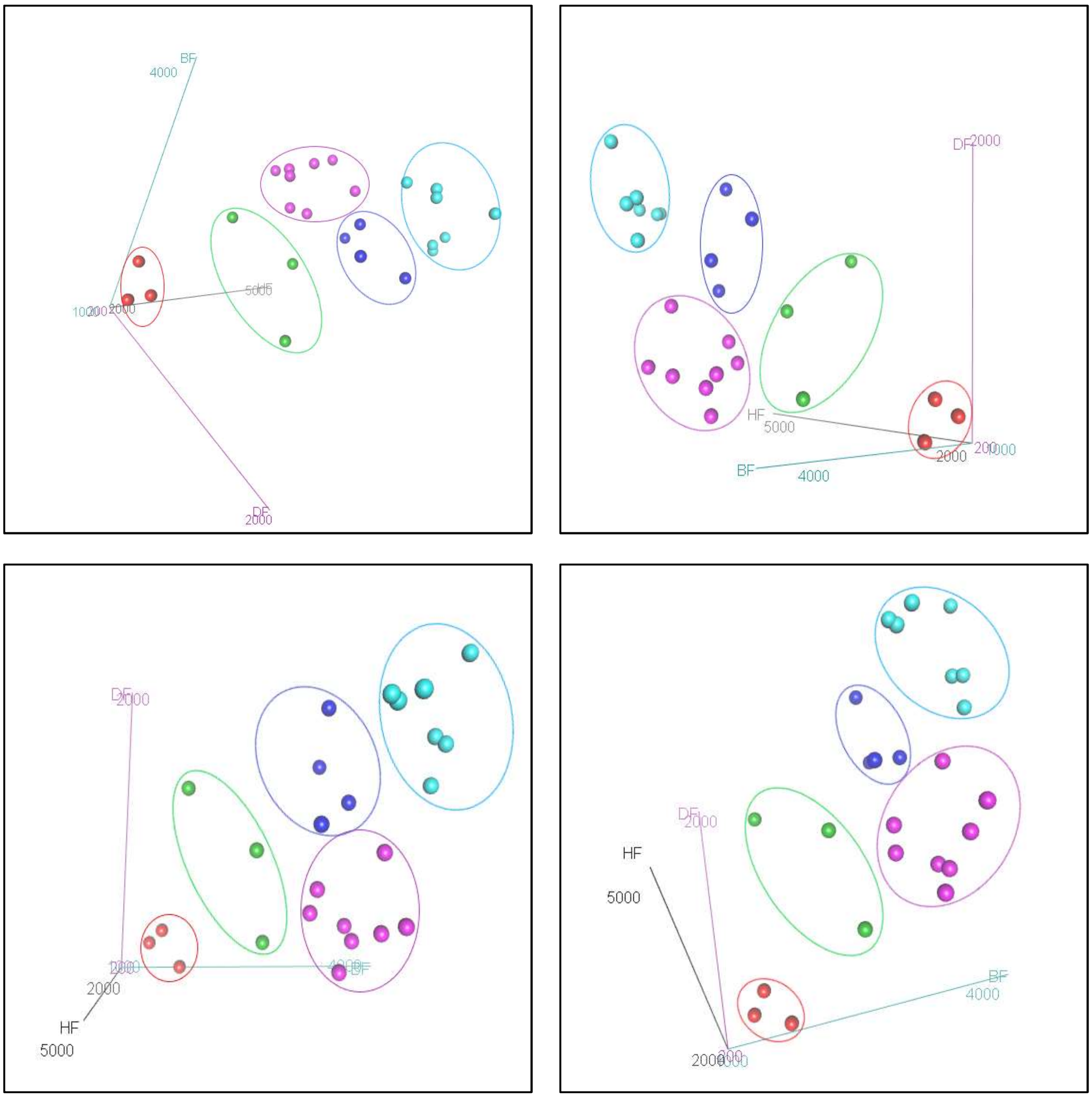

Figure 8. Results of the analysis of k-means clustering in different conformations for better visualization of the 5 subsets of *Globicephala melas* calls in the Group 2.

4. Discussion

The hypothesis that different groups of *G. melas* could be differentiated by their calls and that these acoustic signals potentially reflecting a social structure composed of clans was confirmed. The calls have specific characteristics that possibly play an important role in the social organization of *G. melas*, as already described for killer whales (Ford 1989, 1991; Ivkovich et al. 2010).

Investigating and seeking a better understanding of the social structure of long-finned pilot whales is not an easy task, some studies on the subject have been conducted in the Faroe Islands, Cape Breton Island and the Strait of Gibraltar (Amos et al. 1991, 1993, Ottensmeyer and Whitehead 2003, de Stephanis et al. 2008, Augusto et al. 2017a). In the Faroe Islands, large groups ("grinds") of long-finned pilot whales were found with more than 100 individuals. The authors made a genetic study of these animals and found that individuals of both sexes were related and this was suggested which was a case of group natal phylogeny, but these studies in the Faroe Islands did not provide information on possible temporal variations of associations of these groups (Amos et al. 1991, Augusto et al. 2017a).

Ottensmeyer and Whitehead (2003) studied the population of *G. melas* from Cape Breton Island through photo identification, and found that there was a certain difficulty reported by the authors during the observations that they made, and the lack of opportunity of events that could help them to further deepen the results obtained. They discovered a society composed of stable units with an average size of 8 individuals interacting forming large ephemeral groups, but no kinship information was reported and the authors propose that the units found are matrilineal with natal group philopatry, confirming the ideas of Amos et al. (1991, 1993) in studies on the Faroe Islands (Ottensmeyer and Whitehead 2003, Augusto et al. 2017a).

In another study done performed with genetics and photo identification of long-finned pilot whales in the Gibraltar Strait, the social structure of the resident population of these animals was investigated and according to de Stephanis et al. (2008) the animals of this region exhibit a social organization based on clans, formed by many social units (pods) composed of both sexes, with estimated average size of 2 to 3 individuals who join temporarily in large groups (clans) that may contain up to 150 animals. And these clans are formed by several matrilineal groups that seem to favor a greater bond between the animals, but no analysis of kinship was done (de Stephanis et al., 2008).

Augusto et al. (2017a), the authors further deepened into the question of understanding social dynamics in Cape Breton Island's social units and stated that they have an average size of 7 to 8 individuals, and can be of both sexes confirming the results of Ottensmeyer and Whitehead with the same population in 2003. They found that these social units can undergo fission events when they reach a certain size and sexual maturity and with this the difficulty of maintaining social ties becomes larger, these fissions usually occur in the matrilineal lineages, but it is still something that needs to be further investigated. According to them the idea that these social units of long-finned pilot whales are stable still remains (Augusto et al. 2017a), but some questions about how the dynamics within social units are, such as possible fission events and if the long-finned pilot whales of Cape Breton Island are genetically related and if they really belong to the same matrilineal have not been solved, but they came to the conclusion that the social structure found by them is similar to that found in the Strait of Gibraltar (de Stephanis et al. 2008, Augusto et al. 2017a).

With the results of the SVM it was possible to separate the calls of *G. melas* indicating that the groups (encounters) configure two distinct acoustic clans with a classification accuracy of 81.19%, showing good separation when compared to the work of Van Cise et al. (2018), where the SVM had an accuracy of 60% for the same purpose. In order to better visualize the possible social units that make up these two acoustic clans, the results of clustering analysis by k-means were positive, showing a visual separation of the calls subsets of each clan. In clan 1(Group 1) it was possible to see eight calls subsets (**Figure 7**) and in clan 2 (Group 2), five subsets (**Figure 8**), evidencing that through the analysis of the long-finned pilot whales calls is possible to get a complex social structure, that is, two different clans were found and within each clan called subsets that may indicate a more basal level than would be the social units of *G. melas*.

The social structure of killer whales living in the British Columbia region has been intensively studied. According Bigg et al. (1990), killer whales clans were defined as acoustic groups of social units that share one or more calls. We have adopted this definition for *G.melas*, since the social structure of this species and its calls are very similar when compared to killer whales (de Stephanis et al. 2008; Nemiroff 2009). Therefore, it can be propose that within each clan of long-finned pilot whales there are social units that share calls and these signals can be useful for identifying members of the unit, in group cohesion and in the transmission of information during social interactions (Nemiroff 2009; Nemiroff and Whitehead 2009). Each social unit (pod) of killer whales residing in British Columbia has its own dialect composed of about twelve discrete calls that provide each unit with a unique acoustic signature (Ford 1989, 1991; de Stephanis et al. 2008) and appear to be learned by the calf through their mothers or relatives. Social units that are able to share one or more calls to each other belong to the same clan.

A lasting and complex hierarchical social structure can provide a greater complexity of the acoustic repertoire (Ford 1991; Van Cise et al. 2018). In social odontocetes species such as *G. melas*, *G. macrorhynchus* and *O. orca*, this complexity can be observed in the diversity of call types and in the quantity of these signals, these species have quite complex vocal repertoires that are shared between the members of the social units that make up the acoustic clans (Ford 1991; Van Cise et al. 2018).

Despite the relative distance in the phylogenetic tree between *G. melas* and *O. orca* (LeDuc et al. 1999; May-Collado & Agnarsson 2006; Nemiroff 2009), both species produce structurally calls almost indistinguishable (Nemiroff 2009). This structural similarity between calls raises the question whether these relatively distant species, which have a rare and similar social structure, have developed similar call structures to solve similar communication challenges, such as espionage by part of other species, transmission of information among group members, avoid masking by environmental and anthropogenic noise (Nemiroff 2009; Nemiroff and Whitehead 2009).

The results of this work show that acoustic signals may reflect a social structure for this species. These clans have their own calls that characterize them and can transmit information among the individuals of the group, promoting associations between the animals and thus strengthening more lasting bonds within the social units of *G. melas* (Miller et al. 2004; Nemiroff 2009).

The social structure proposed in this study appears to be very similar to what has already been described for resident killer whales in Bigg (1990), Ford (1989, 1991) and for long-finned pilot whales of the Straits of Gibraltar in de Stephanis et al. (2008), on Cape Breton Island in Ottensmeyer and Whitehead (2003) and Augusto et al. (2017a).

The results of this study were positive, the indicative that the social units of *G. melas* exist has been confirmed and can be visualized through the subsets of calls that we found in the two clans, and besides we obtained results that evidenced the existence of a structure social complex of long-finned pilot whales for the first time in the South Atlantic Ocean.

Further studies are recommended to understand how the dynamics of associations occur in these social units and clans based on calls, in order to better define the social structure components of these animals in the South Atlantic. Calls are complex acoustic signals with a great potential and through them we can study and know a little more about species that are still not well-known as *G. melas*, which can even help in the conservation and management of these animals.

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