UNIVERSIDADE FEDERAL DE JUIZ DE FORA

PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA APLICADA AO MANEJO E

CONSERVAÇÃO DE RECURSOS NATURAIS

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Juiz de Fora

2019

Dedico a todas aquelas cujo mar
reverbera em sua ciência -
The oceans are rising and so are we

AGRADECIMENTOS

"Às vezes é difícil entender quem está observando quem"
Graeme Ellis, sobre o comportamento "spy hoping" em cetáceos.

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CAPÍTULO I

INTRODUÇÃO GERAL

A comunicação acústica é essencial para sobrevivência de muitos animais, sendo caracterizada pela emissão de sinais especialmente modelados e usados pelos indivíduos emissores para modificar o comportamento do receptor (Krebs & Davies, 1996). A emissão de vocalizações pode ser um processo dispendioso para os animais em termos energéticos e, muitas vezes, para aumentar a eficiência da transmissão é necessário ajuste da amplitude do sinal, da composição de frequências, do padrão temporal e da direcionalidade do som. (Bradbury & Vehrencamp, 2011).

O monitoramento acústico passivo (MAP) é um método que permite o monitoramento espécies de interesse através da acústica por intermédio de dispositivos que podem realizar gravações contínuas 24 horas por dia, por vários dias consecutivos (Pieretti et al. 2015). O MAP representa um método inovador e eficiente para estudar comunicação acústica animal (Bridges & Dorcas, 2000) permitindo acessar a ecologia acústica e o comportamento de muitos vertebrados (Duarte et al. 2017; Madalozzo et al. 2017; Zimmer, 2011).

As técnicas de monitoramento acústico passivo (MAP) fornecem oportunidades de investigação das diferenças acústicas entre espécies simpátricas (Steiner et al. 1981, Rendell et al. 1999), entre comunidades que ocorrem em áreas distintas (Lellouch et al. 2014), comprovação da ocorrência de novas espécies em determinado ambiente (Angulo et al. 2008) e de entender as relações entre espécies e elementos externos, por exemplo, o ruído (Pijanowski et al. 2011). Estas técnicas também nos permitem avaliar o grau de conservação de ambientes e as consequências de diferentes atividades antrópicas na natureza (Blumstein et al., 2011; Mennit e Fristrup, 2012, Duarte et al. 2015).

A hipótese de nichos acústicos, cuja definição é amplamente discutida propõe que as espécies tendem a distribuir suas emissões sonoras nas dimensões de frequência e tempo a fim de diminuir a competição interespecífica e otimizar os mecanismos de comunicação intraespecífica (Krause, 1993; Farina, 2013). Deste modo, o estabelecimento de um nicho acústico proporcionaria melhor detecção dos sinais sonoros emitidos por uma espécie em um ambiente compartilhado (Mossbridge & Thomas, 1999).

A simpatria entre espécies é caracterizada pela ocorrência de duas ou mais espécies em uma mesma área geográfica (Begon, 2006; Quammen, 2008). Grupos mistos são associações interespecíficas entre espécies simpátricas que tendem a ocorrer de forma temporária (Quérouil et al. 2008). Considerando o papel da comunicação e o estabelecimento de nichos, os contextos de simpatria podem influenciar fortemente nas vocalizações das espécies envolvidas (Rendell et al. 1999).

Os cetáceos são mamíferos exclusivamente aquáticos que dependem fortemente da comunicação acústica para a sobrevivência, uma vez que a maioria das informações do ambiente é por eles obtida através do som de fontes naturais e de membros da própria espécie (Richardson et al. 1995). O som, devido às suas propriedades físicas, propaga-se mais rapidamente na água do que no ar fazendo com que a audição apresente uma maior vantagem em relação aos demais sentidos em ambientes aquáticos (Pough et al. 2003; Dudzinski et al., 2002). Além disso, a baixa visibilidade característica de alguns locais onde essas espécies ocorrem, como rios de águas turvas, estuários e águas oceânicas ricas em plâncton, faz com que o som seja um importante meio de comunicação (Parsons & Dolman, 2003).

Dentre os cetáceos, os indivíduos pertencentes à subordem Odontoceti, caracterizada por possuir espécies com alto nível de encefalização (Marino, 1998), emitem vocalizações divididas em dois grandes grupos, os sons tonais contínuos (ex.: assobios) e sons pulsados (ex.: sons pulsados explosivos e cliques) (Tyack & Clark, 2000, Au & Hastings, 2008). Os sons pulsados explosivos são frequentemente emitidos em contextos sociais, como encontros agonísticos (Lammers et al. 2003), mas também foram documentados durante atividades de forrageio (Janik, 2000; May-Collado & Wartzok, 2010). Os cliques apresentam larga banda de frequência e são extremamente direcionais, auxiliando, dessa forma, na detecção e persuasão da presa (Janik, 2000), na navegação e na localização e prevenção de predadores, principalmente em regiões onde a visibilidade na água é limitada (Au & Hastings, 2008). As emissões acústicas produzidas pelos odontocetos vêm sendo continuamente estudadas em diferentes contextos, através da descrição de seus parâmetros (p.ex.: Morisaka & Connor 2007; Andriolo et al. 2015; Kaplan, 2015).

Os assobios são sons tonais de banda de frequência geralmente estreita, e geralmente modulados na frequência. Estão envolvidos na comunicação intraespecífica (Herman & Tavolga, 1980) para uma função social (Janik & Slater, 1998; Herzing, 2000; Lammers et al., 2003). Estudos mostram que estes sinais são importantes na regulação,

organização (Norris et al. 1994) e na manutenção da coesão (Lammers et al. 2006) dentro do grupo, além de conter informações acerca da identidade dos indivíduos (Au et al. 2000). A descrição das características dos assobios usados por uma população pode fornecer informações sobre como espécies simpátricas usam e variam seus repertórios de assobios em diferentes ambientes sociais e físicos (Kaplan, 2015). No entanto, informações se a estrutura do assobio específica para cada espécie é mantida ou alterada durante interações interespecíficas são escassas (May-Collado, 2010).

A baleia-piloto-de-peitorais-longas (*Globicephala melas*, Traill 1809), encontra-se distribuída preferencialmente em águas temperadas e polares (Olson & Reilly, 2002) e está classificada na lista da IUCN como "insuficientemente conhecida" (Taylor et al. 2008). Apresenta coloração cinza-escuro ou preta, nadadeira dorsal de aparência falcada e nadadeiras peitorais amplas em forma de foice. Associações com golfinhos nariz de garrafa (*Tursiops truncatus*, Montagu 1821) são frequentemente avistadas (Olson & Reilly, 2002; Di Tullio et al. 2016). O repertório acústico da baleia-piloto-de-peitorais-longas é pouco conhecido, existindo, portanto, lacunas a serem preenchidas a respeito de seu comportamento acústico.

O golfinho de Risso (*Grampus griseus*, Cuvier 1812) encontra-se distribuído mundialmente a partir da quebra do talude continental, constando na lista vermelha da IUCN como "pouco preocupante" (Hartman, 2018). De coloração acinzentada, possui a superfície do corpo e nadadeira dorsal coberta de cicatrizes, causadas principalmente por interações intraespecíficas (Baird, 2002). Geralmente são avistados em grupos pequenos (5 a 10 indivíduos) podendo ser vistos em associação com outras espécies de cetáceos (Jefferson et al. 1993; Shelden et al. 1995). Assim como a espécie *Globicephala melas*, há uma lacuna de estudos em relação ao seu repertório acústico.

O golfinho-nariz-de-garrafa (*Tursiops truncatus*) possui distribuição ampla, podendo ser encontrado em águas costeiras e oceânicas das regiões temperadas e tropicais (Wells & Scott, 2002). Diferentemente das espécies anteriormente citadas, *T. truncatus* é a espécie mais estudada dentre os cetáceos, constando como "de menor preocupação" na lista da IUCN (Hammond et al. 2012). Sua coloração varia do cinza-claro ao escuro nas regiões dorsal e lateral, apresentando o ventre com a pigmentação mais clara, nadadeira dorsal moderadamente falcada e o rostro curto. Existem diversos estudos relacionados a seu repertório acústico, destacando-se aqueles referentes aos assobios (Caldwell, 1965; Tyack, 1997; Azevedo et al., 2007; Sayigh, 2007; Kriesel et al. 2014). Esta espécie é conhecida por sua capacidade de aprendizagem vocal (Janik 2014), habilidade na

plasticidade acústica (Mccowan et al., 1995; La Manna, 2013), na imitação de vocalizações de coespecíficos, (King et al. 2013) e outros sons não biológicos (Kuczaj & Yeater, 2006).

Embora exista um número crescente de estudos sobre as associações interespecíficas entre golfinhos, se e como estes animais mudam a estrutura de seus assobios durante essas associações em grupos mistos ainda permanece como algo pouco conhecido (May-Collado, 2010). Considerando a função comunicativa dos assobios e com base na plasticidade acústica de *T. truncatus* relatada na literatura (Mccowan et al., 1995; La Manna, 2013), utilizamos estes sons para investigar as relações acústicas entre *T. truncatus* e *G. melas*; e *T. truncatus* e *G. griseus*. Portanto, este trabalho busca compreender os contextos de grupos mistos pela perspectiva acústica, visando investigar, se as espécies se comportam como prediz a hipótese de nichos acústicos, organizando-se no espaço acústico, ou, baseando na plasticidade acústica de *T. truncatus*, se esta espécie muda a estrutura de seus assobios entre os grupos mistos com as diferentes espécies. Considerando que *T. truncatus* teria a capacidade de modular seus assobios de acordo com o contexto de cada grupo.

CAPÍTULO II

Are *Tursiops truncatus* modulating the whistles parameters in different mixed-groups contexts?

Abstract

Cetacean mixed groups usually are temporary and opportunistic encounters between different species. This context may play an important role on the acoustic dynamics of the species involved. Considering the communicative function of whistles, here, such were used sounds to investigate the mixed-group context by the acoustic perspective. Mixed groups of *Tursiops truncatus* with *Globicephala melas* and with *Grampus griseus* were visually confirmed by observers during recordings on Talude Project, aboard the R/V Atlântico Sul, with a three-element omnidirectional hydrophone array Auset® coupled to a digital recorder Fostex® FR-2 LE (sampling frequency of 96 kHz/24 bits) on the Brazilian shelf break, western South Atlantic Ocean. A total of 1126 whistles were analyzed and the following acoustical parameters were extracted using Raven Pro 1.5 (Hann window 1843 of points, DFT of 2048 points and 50% overlap): low frequency, high frequency, delta frequency, center frequency, beginning and ending frequencies, 1st and 3rd quartile of frequency, inter-quartile range of frequency bandwidth, 1st and 3rd quartiles of duration, inter-quartile range of duration, 95% of frequency, 5% of frequency, and whistle duration. A visual classification of the extracted whistles was performed and compared with a k-means clustering based on the three first principal components formed by a Principal Component Analysis of the whistle's parameters. A discriminant function analysis with the k-means cluster groups was performed based on less-correlated variables resulting in 9.42% of misclassification. The discrimination highlights that *T. truncatus* whistles may be modified in different interspecific contexts. A comparison between two possible *T. truncatus* whistles groups provided by a Mann-Whitney test presented beginning frequency as a possible species identity parameter. A possible explanation for this strategy would be an attempt of *T. truncatus* to acoustically interact with other species. Acoustic relations on multi-species associations of odontocetes remain poorly understood, but these findings can contribute to investigate the driving factors behind these interactions.

Key words: *dolphins; PAM; communication; Western South Atlantic Ocean, acoustic interaction.*

1. Introduction

Mixed groups in cetaceans usually are temporary and opportunistic encounters between different species (Quérouil et al. 2008). These encounters can be advantageous in foraging and on predator's detection and avoidance (Norris and Schilt 1988, Kiszka et al. 2011). Social factors may also induce the association of different species (e.g.: Rossi-Santos et al. 2009), such as dominance, reproduction and practice of sexual behaviors (Bearzi 1997, Baraff and Asmutis-Silvia 1998; Stensland et al. 2003). However, few studies have attempted to investigate the driving factors and functions behind these interactions (Zaeschmar et al. 2013).

Sympatry may lead to interespecific acoustic variations (Steiner, 1981; Rendell et al., 1999). Given that, the mixed group context may play an important role on the acoustic dynamics of the species involved (Ding et al., 2001; May-Collado, 2010), because there are evidences that aquatic mammals when sharing the same acoustic environment adjust their sound characteristics on an adaptative way, in order to avoid the signal masking and to increase the acoustic communication effectiveness (Mossbridge & Thomas, 1999). However, studies investigating interspecific interaction by the acoustic perspective are sparse (e.g.: Ding et al., 2001; May-Collado, 2010; Herzing, 2015). The acoustic niche comprehends the micro-habitat used to vocalize, the time that the vocal activity occurs and the acoustic structure of the vocalization (Sinsch et al., 2012). Therefore, by establishing an acoustic niche in a shared environment, species involved potentially reduce the acoustical competition among them (Mossbridge & Thomas, 1999; Krause, 1993).

Whistles are narrow-band frequency-modulated tonal sounds produced by dolphins and are involved with intraspecific communication (Herman, 1980) in a social function (Janik and Slater 1998, Herzing 2000; Lammers et al. 2003). These signals are important for regulating group organization and for the maintenance of group cohesion (Norris et al., 1994; Lammers et al., 2006). However, information on whether the whistle's structure of a species is maintained or altered during interspecific interactions is scarce (May-Collado, 2010).

The bottlenose dolphin (*T. truncatus,* Montagu 1821*)* is known for its acoustical plasticity (e.g. McCowan et al., 1995; La Manna, 2013) and interspecific associations between this species and other delphinids have been documented in captivity (e.g: Terry, 1984; Favaro et al. 2016) and in the wild (Herzing, 1996; Bearzi, 1997; Wedekin et al.

2004; Acevedo-Gutierrez et al. 2005; Cotter et al. 2012; Zaeschmar et al. 2014). Such cited interactions include foraging, travelling, playing, alloparental care, aggressive behavior and sexual activity.

Considering the communicative function of whistles and based on the described *T. truncatus* acoustic plasticity, we used such sounds to investigate the acoustic relationships between *T. truncatus* and long-finned pilot whale (*Globicephala melas,* Traill 1809) and Risso's dolphin (*Grampus griseus*, Cuvier 1812), in a mixed group context with each species separately. This work investigated the mixed-group context by the acoustic perspective, considering the acoustic niche theory. Changes in the structure of whistles of *T. truncatus* between the two contexts (two different species) of mixed groups are expected due to the capacity of *T. truncatus* to modulate its whistles according to the group context in which it is found.

2. Material and methods

2.1 Data collection

Recordings were made during Talude Project expeditions on the western South Atlantic Ocean, at the Brazilian shelf break aboard the research vessel Atlântico Sul (Figure I). A total of five cruises were conducted, among these, acoustical data of mixed groups recorded in four cruises were used: *G. griseus* and *T. truncatus* on 2013 (27° 6' 25" S, 46° 28' 37" W) and 2015 (30° 43' 55" S, 48° 39' 25" W); and sightings of *G. melas* and *T. truncatus* (Figure II) on 2013 (28° 58' 1" S, 47° 39' 36" W) and 2014 (33° 27' 0" S, 50° 34' 58.8" W). The species were visually confirmed by marine mammals' observers aboard.

The data were collected with a 250 meters matrix array Auset® with three-elements (-40 dB, -161 dB re: 1V / μPa) distant five meters from each other, coupled to a digital recorder Fostex® FR-2 LE (sampling frequency of 96 kHz / 24 bits and configured with a high pass filter of 0.499 Hz). Whenever possible, the acoustic signals were transmitted to a digitizer board (Iotech model - PersonalDaq / 3000 Series) sampling at 100 kHz / 24 bts (table I).

Figure I: Study site map indicating the places where the acoustic recordings of the mixed groups were made.
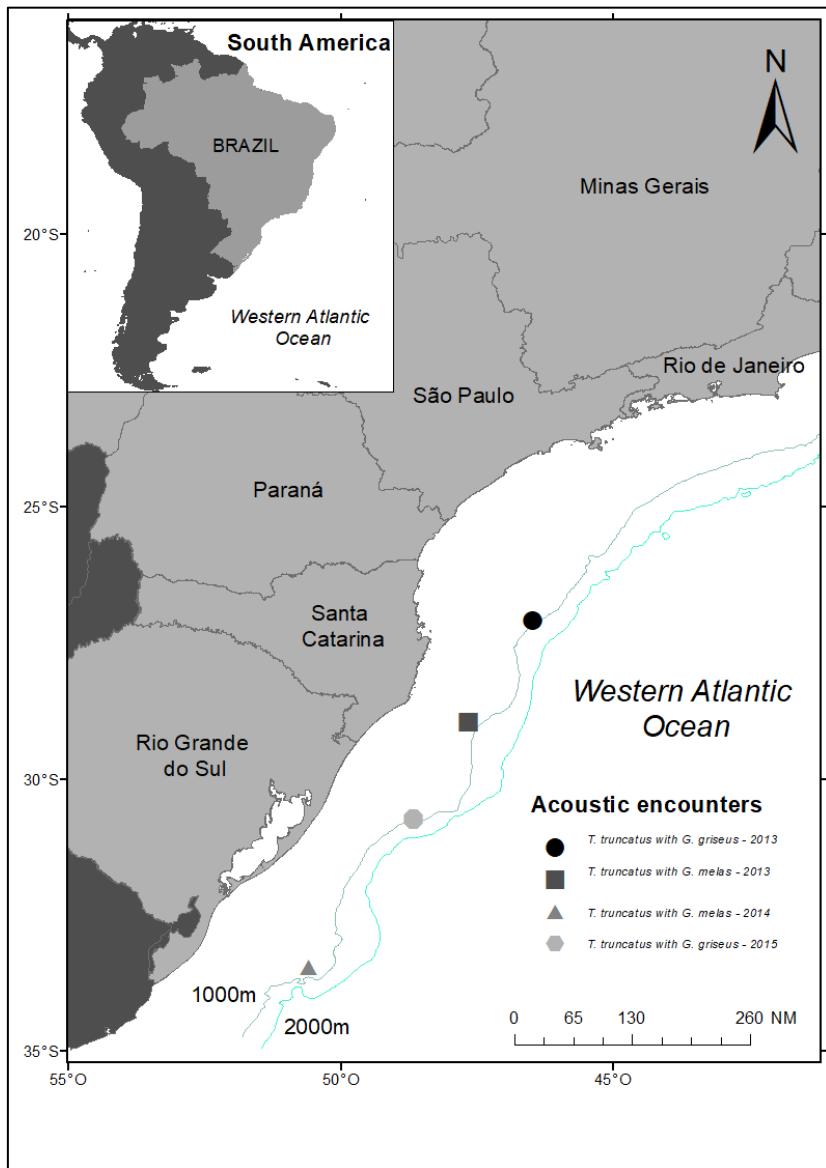
Figure II: *Globicephala melas* and *Tursiops truncatus* in a mixed group in the Western South Atlantic. Photo: Elisa Seyboth, Talude project.

TABLE I. Encounters data from groups of *Tursiops truncatus, Grampus griseus* and *Globicephala melas.*

Encounters	Coordinates		Recording year	Group size			Recording effort	Total of wistles	Group context
	long	lat		*T. truncatus*	*G. griseus*	*G. melas*			
I	-46.477	-27.107	2013	~25	~230	-	1h19m41s	287	*Tursiops truncatus* with *Grampus griseus*
II	-47.66	-28.967	2013	~120	-	~60	1h55m23s	332	*Tursiops truncatus* with *Globicephala melas*
III	-50.583	-33.45	2014	~70	-	~60	2h45m41s	258	*Tursiops truncatus* with *Globicephala melas*
IV	-48.657	-30.732	2015	~20	~80	-	1h47m30s	249	*Tursiops truncatus* with *Grampus griseus*

2.2 Acoustical analysis

      Recordings of the mixed groups were analyzed using Raven Pro 1.5 (Cornell Laboratory of Ornithology, NY). The spectrograms were visually and aurally inspected to manually extract the following whistles parameters (Hann window of 1843 points, DFT of 2048 points and 50% overlap): low frequency, high frequency, delta frequency - the difference between high and low frequencies, center frequency, beginning and ending frequencies, 1st and 3rd quartile of frequency, inter-quartile range of frequency bandwidth, 1st and 3rd quartiles of duration, inter-quartile range of duration, 95% of frequency, 5% of frequency, and whistle duration. The selection was based on the signal to noise ratio (SNR $\geq$ 10 dB) for whistles with a clear contour shape, measurements were made only on the fundamental frequency of whistle contours, harmonics were not considered.

      Then, as it was not possible to assign a specific whistle to one of the species presented in the mixed group, a visual and aural species classification of each whistle was made (Figure III). For this classification, we relied on the frequency and duration parameters presented on the following supported literature: Weilgart e Whitehead (1990) for *G. melas*, Corkeron (2001) for *G. griseus* and Azevedo et al. (2007) for *T. truncatus*.
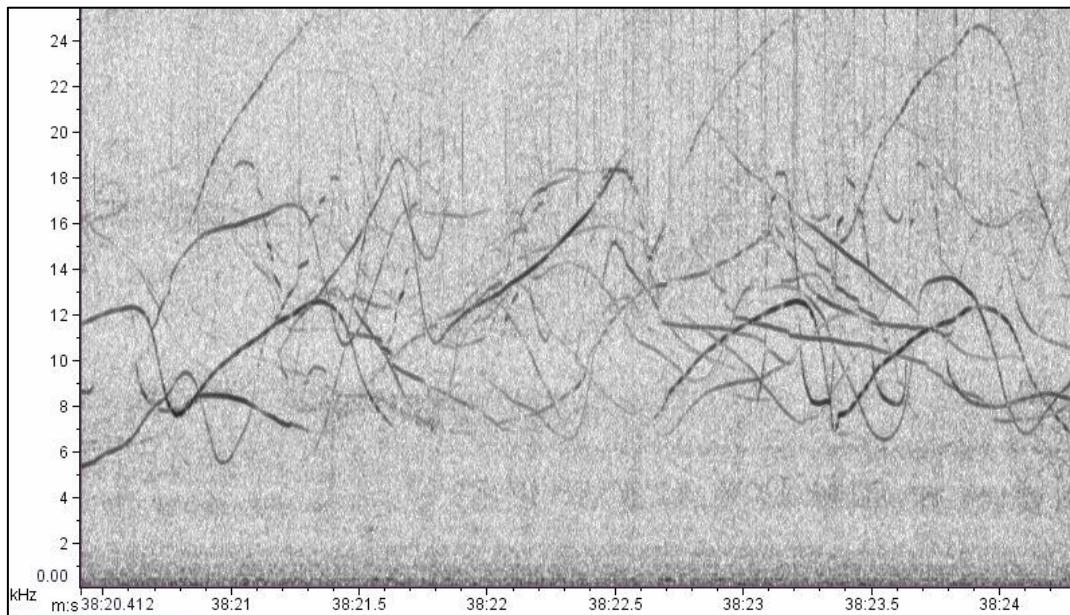
Figure III: Example of mixed group spectrogram between *Tursiops truncatus* and *Globicephala melas.*

2.3 Statistical Analysis

In order to validate the visual/aural classification, a Principal Component Analysis (PCA) on the extracted whistles parameters was performed (the first three principal components calculated by PCA accounted for 85.82% of the total variation in the data) and then, the first three principal components were used in a K-means cluster analysis. In order to reduce the parameters variability, the low and high frequencies were excluded considering that their difference are represented by delta frequency, and the same for 1st and 3rd Quartile of Frequency and Time, given that they are represented by IQRf and IQRt respectively (once inter-quartiles were calculated by the difference between 3rd and 1st quartiles). The analyzes were performed with the software R 3.5. The choice of k-value (number of groups to be clustered) was based on the *Tursiops truncatus* plasticity previously referred, therefore, even the whole recording data counted three species, we supposed that four groups have the potential to be formed: one group characterizing *G. melas* whistles' characteristics, other group characterizing *G. griseus* whistles' characteristics and the two other groups containing *T. truncatus* modulated whistles in each of the two interspecific contexts. Therefore, k=4 was used. The cluster analysis by the k-means method established the four groups according to the similarity of each whistle from the 4 established centers

The k-means classification assigned for each of the observations (whistles) a number from 1 to 4. Then, in order to verify the matches between the visual and k-means analysis, the k-means classified data were compared to the visual classified data. Thus, it was accounted how many matches of *T. truncatus* whistles were present on each of the four cluster groups. Then, it was considered as *T. truncatus* those groups with the highest number of matches. A high number of matches means that both classifications are similar.

After a comparative validation of the species classification, a discriminant function analysis (DFA) was performed with the four groups using the JMP 15 software (SAS Institute Inc.). The DFA assumptions were verified: Normality, the data were logaritimized and outliers excluded; Multicollinearity, through a matrix of multicollinearity, the variables Frequency 5% and Frequency 95% were excluded, and Homoscedasticity, the quadratic discriminant method was chosen given the heterogeneity of the variances showed by the Bartlett test ($p < 0,05$). The groups that presented the highest misclassification rates had their parameters compared by the Mann-Whitney test on R 3.5 for the purpose of verifying which parameters were significantly different between groups. The level of significance adopted was $\alpha=0.05$.

3. Results

A total of 1126 whistles were analyzed from the spectrograms, among them 590 whistles from *G.melas* and *T. truncatus* encounters and 536 whistles from *G. griseus* and *T. truncatus* encounters. The first three components contributed 39.38%, 35.08%, and 11.36% for the total variation respectively, and were used as k-means inputs (Figure IV).

From a total of 584 whistles visually classified as *Tursiops truncatus*, group 1 had 19.3% of matches; group 2 had 55.99%; group 3, 1.02% and group 4, 23.6%. Thus, groups 2 and 4 of cluster had the highest number of matches (Figure V).
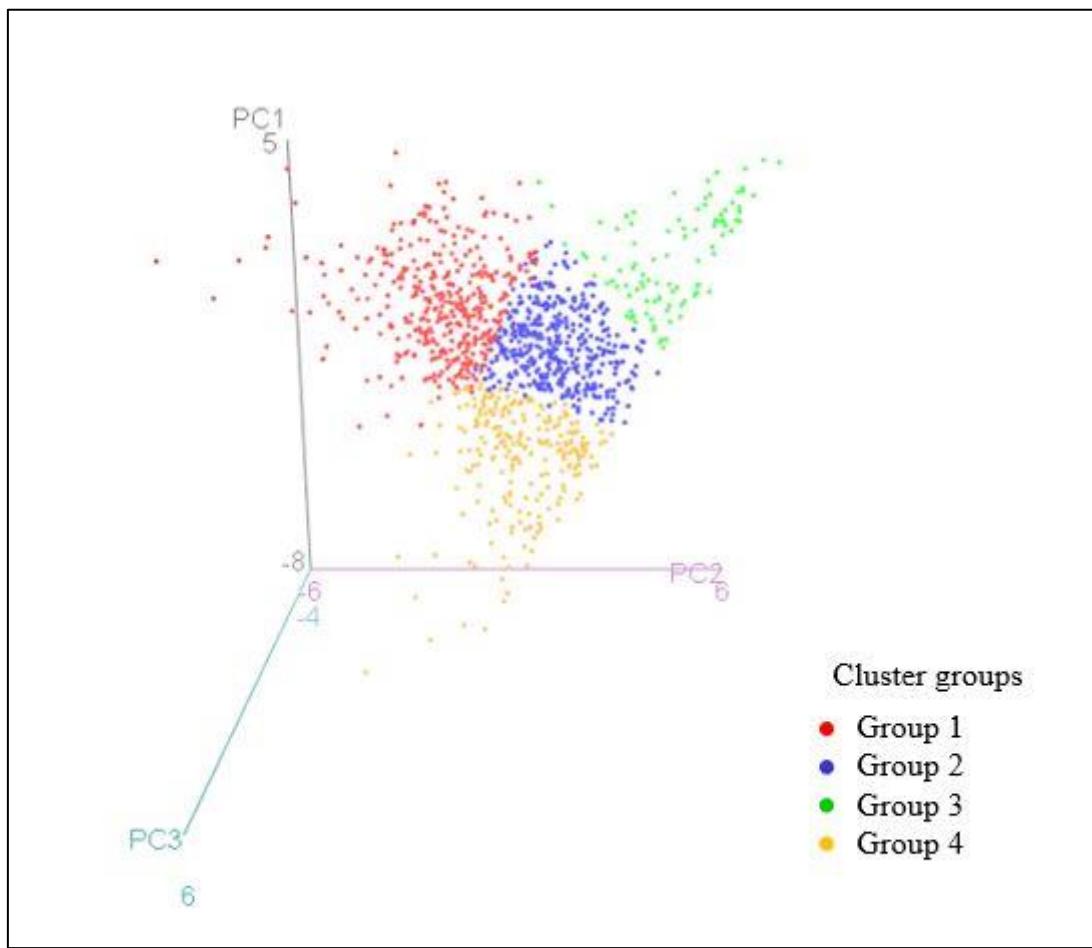
Figure IV: k-means clustering in 4 groups for the three first principal components of the whistle's parameters.
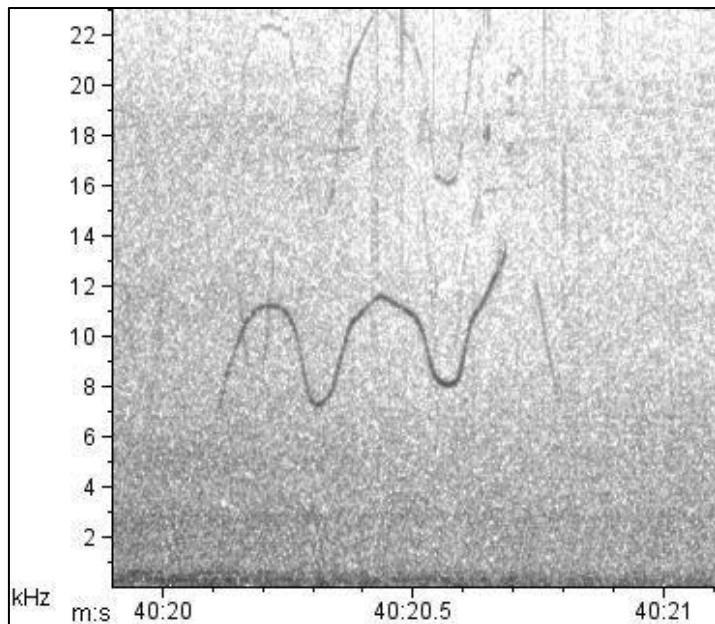
Figure V: example of *Tursiops truncatus* whistle match between visual classification and k-means cluster analysis

The Discriminant Function Analysis presented a misclassification of 9.42% among groups (Entropy Rsquare 0.76, Wilks $\lambda > 0.001$, Approximated F=109,86) (Figure VI). The groups 2 and 4 that presented the highest misclassification rates (table II). The comparison between the whistles parameters of these two groups resulted from the Mann-Whitney test showed significant differences between all variables, except for beginning frequency table III).
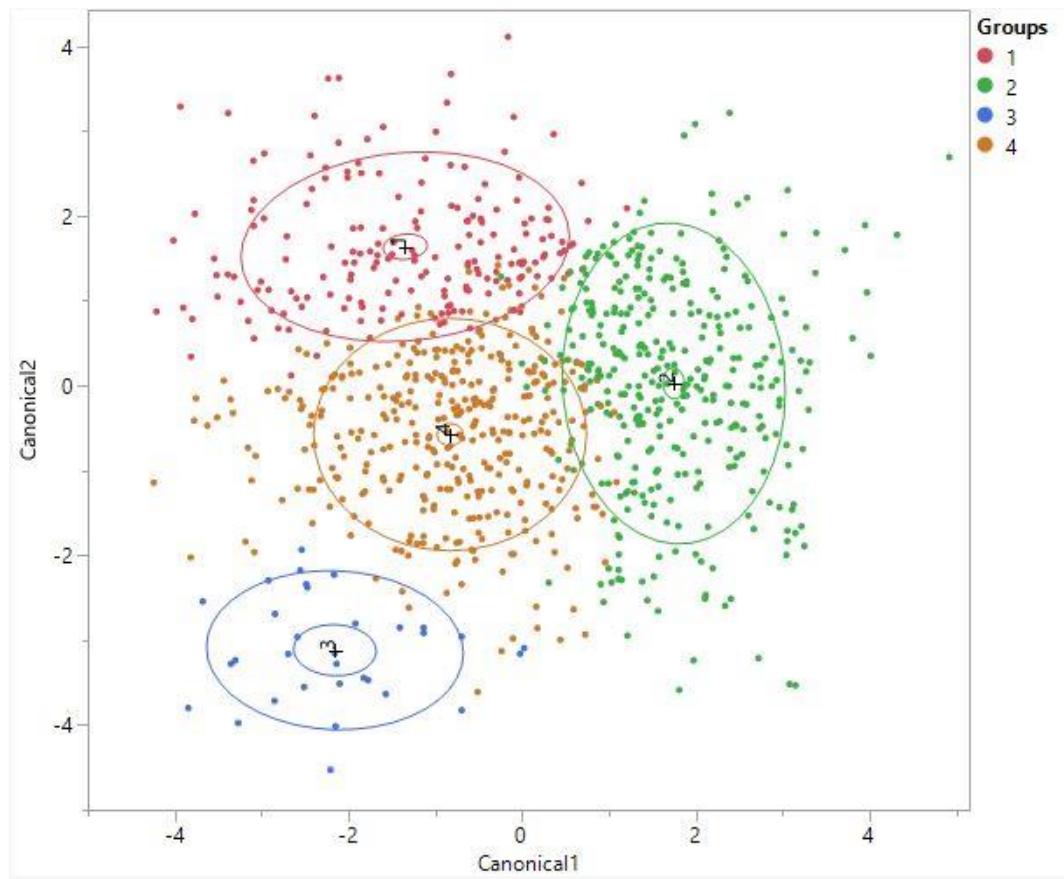
Figure VI: Canonical plot of the four groups provided by the k-means cluster analysis.

TABLE II. Discriminant Function Analysis matrix showing the misclassified whistles among the groups

Actual	Predicted			
	Count			
Group	1	2	3	4
1	165	11	0	8
2	5	338	0	11
3	0	0	32	0
4	24	21	8	311

TABLE III. Comparison of the parameters between groups 2 and 4 by Mann-Whitney test. Duration, CF: Center Frequency, DF: Delta Frequency, IQRt: Inter-Quartile Range of Duration, IQRf: Inter-Quartile Range Frequency Bandwidth, BF: Beginning Frequency, EF: Ending Frequency

Parameters	W value	p-value
Duration	133380	< 0,001
CF	90062	< 0,001
DF	136590	< 0,001
IQRt	129230	< 0,001
IQRf	133920	< 0,001
BF	73900	0.856
EF	59663	< 0,001

4. Discussion

The high number of whistles found in this study corroborates with other studies on dolphin interspecific groups that indicate high whistle activity (e.g., Herzing et al. 2003; Herzing 2000; Oswald et al. 2008, May-Collado, 2010). Oswald et al. (2008) showed that whistle activity in interspecific groups tend to be higher in tropical latitudes when compared to temperate latitudes possibly in function of a combination of factors (group size, morphological constraints and behavioral activities).

The results showed a reliable aural/visual *T. truncatus* classification for the 2 and 4 clusters, confirming that the majority of *T. truncatus* whistles are included on these two groups. Due to the high variability and overlapped frequency characteristics of many delphinid calls, the species identification is challenging (Oswald, 2007). The results of this study showed that the combination of whistle visual classification with cluster categorization may increase the power of classification.

From all the four cluster groups, the 2 and 4 clusters also presented the highest misclassification number among groups (20 and 74 false classifications respectively (Table II). This finding can be an evidence that *T. truncatus* whistles can be modified in different interspecific contexts. The high acoustic plasticity (McCowan et al., 1995; La Manna, 2013), vocal learning capacity (Janik 2014) and mimicry hability (Kuczaj & Yeater, 2006; King et al. 2013) has been described for this species, which makes the misclassification results an indicative of acoustical approximation between the species involved. A possible explanation for this strategy would be an attempt of *T. truncatus* to acoustically interact with the other species.

It is known that *T. truncatus* interacts with other species in mixed groups contexts, and these interactions involve foraging; travelling and social behaviors, such as play, alloparental care, cooperative interactions, sexual and aggressive activities (Herzing & Johnson, 1996; Herzing & Johnson, 1997; Zaeschmar, 2013; Kaplan, 2015). Herzing & Johnson (1996) discussed that spotted dolphins (*Stenella frontalis*) and bottlenose dolphins shared the vocal repertoire and gestural signals in mixed groups in the Bahamas. Moreover, the signal recognition ability has been already described between these two species in captivity (Caldwell, 1972). May-Collado (2010) indicated a change in whistle acoustic structure occurring in social events between bottlenose dolphins and Guiana dolphins (*Sotalia guianensis*), specifically, the species presented whistles with intermediate structure compared to those emitted in intraspecific groups. The author also

related that this pattern, however, was not verified when interspecific groups were traveling, rising the hypothesis of signal convergence between interacting species. Therefore, an attempt to communicate, at least in social interactions, becomes plausible in mixed-group contexts.

In this work, by comparing the parameters of whistles belonging to the groups inferred as *T. truncatus* (groups 2 and 4), the Mann-Whitney test showed that all parameters used in the DFA were significantly different, excepting for beginning frequency. This means that it was the parameter that did not have significant changes between the groups in which *T. truncatus* were inserted. In McCowan et al. (1998) the best predictor of social group membership on whistles was the beginning frequency. Kaplan (2015) found that beginning frequency was the second strongest predictor in a whistle classification between *T. truncatus* and *S. frontalis*, which had 85.9% of correct classification. For Ding et al. (1995), species specific whistle characteristics may play an important role on sympatry given the necessity to distinguish between inter- and intraspecies whistles. Based on the previous studies cited above beginning frequency may be one of the distinguishing parameters between species. Thus, it is likely that *T. truncatus* does not change this parameter as an attempt to keep the species identity.

By comparing both *T. truncatus* whistles for groups 2 and 4, Mann-Whitney test showed that duration was one of the parameters that have a significant difference between groups. This finding corroborates with other studies that found duration as a parameter that indicates intraspecies variation (Bazúa-Durán & Au, 2004; Ding et al., 1995; Oswald et al., 2003; Rendel et al., 1999; Steiner, 1981; Kaplan, 2015), probably being related to individual identity (Kaplan, 2015).

Overall results indicate that *T. truncatus* may adapt its acoustical parameters due to the interspecific context, by emitting similar whistles to those emitted by the other species present. May-Collado (2010) observed that both *T. truncatus* and *S. guianensis* when associated, also showed intermediate acoustic characteristics when compared to intraspecific contexts.

Although the primary function of mixed groups in the majority of mammals is antipredator and/or foraging benefits for one or both species (Stensland et al. 2003), Herzing and Johnson (1997) found that the primary function of interspecies encounters for sympatric dolphins, does not appear to be related to anti predator or foraging behaviors. The authors supposed that social interactions were the reason for the interspecies encounters. In this study, we found close proximity from *T. truncatus*

whistles parameters to the whistles of the species involved. But what would lead this species to acoustically interact with other species in a mixed group?

The chance of involving/engaging in a mixed group for a species is related to the differential costs of association resulted from dominance relations between interspecific individuals (Windfelder, 2001). Closely related species may have a degree of dominance depending on the phylogenetic relation, ecological similarity, and size of the species involved (Wilson, 2000). Different studies with mixed groups of bottlenose dolphins showed that aggression is usual and generally occurs with larger species dominating the smaller one: bottlenose dolphins with Atlantic spotted dolphins (Herzing and Johnson 1997, Herzing et al. 2003); with harbour porpoises (*Phocoena phocoena*) (Ross and Wilson 199; Patterson et al. 1998; Cotter et al. 2011); and with Guiana dolphins (Wedekin et al. 2004). In addition, different stranded species – including both species of this study from the mixed groups with *T. truncatus* - were found dead in south-west England with traumatic lesions possibly caused by *T. truncatus* (Barnett et al. 2009). The authors suggest that the interactions did contribute to stranding and/ or death in all animals examined. It is important to point out that the dead *G. melas* and *G. griseus* found on Barnett et al. (2009) were juveniles, corroborating with the findings of dominance cited above.

Different studies with interspecies association between bottlenose and spotted dolphins on the Bahamas bank showed that bottlenose dolphins always dominate spotted dolphins, with the exception of when the spotted dolphins are the majority, with the alliances playing a major role for spotted dolphins (Herzing, 1996; Herzing and Johnson, 1997; Elliser, 2010). Elliser (2010) discussing the fitness of male bottlenose dolphins, observed that dolphins resort for mating with other species since they were not able to mate with conspecifics. Even with evidences of *T. truncatus* hybrids with *G. griseus* (Shimura et al. 1985; Miyazaki et al. 1992; Fraser, 1940; Hodgins, 2014) documented in the wild, and with *Globicephala macrohynchus* (Antrim & Cornel, 1981) documented in captivity, interspecific communication, in order to practice dominance for mating purposes, is unlikely since documentation on hybridism of *T. truncatus* with the studied species is sparse. Therefore, it is likely that hybridism may not be the reason why the species came together in a mixed group in the present data.

The hypothesis of other social interaction between the studied species cannot be discarded, once it was observed individuals joining on mixed species groups to practice social behaviors that could be used within their conspecifics (Stensland et al. 2003). In

addition, Cotter et al. (2011) elucidates the hypothesis that *T. truncatus* can use interspecies contexts for the practice of behaviors like fighting skills.

On the handful advantages on the interspecific associations, there is the foraging activity (Stensland et al. 2003, Zaeschmar, 2013). In Curé et al. (2012) long fined pilot whales were attracted to fish-eating killer whales (*Orcinus orca*) sounds, showing that is advantageous for the pilot whales to detect the killer whales foraging activity through their social feeding vocalization signal. The animals would probably also spend less energy by eavesdropping others species sound than searching for food by themself. Eavesdropping advantages are also found on navigation activity, where an animal spend less energy by reducing the sonar activity and eavesdropping conspecifics (Gotz et al. 2005). High frequency whistles were related to avoid eavesdropping by preys on mammal-eating killer whales (Andriolo et al. 2015). Due to the many advantages provided by an interspecies foraging context (Stensland et al. 2003), it would be advantageous to one species to be eavesdropped by another on foraging mixed groups, since they can combine feeding efforts.

The acoustic niche hypothesis presupposes that one species may organize its sounds emissions in the frequency and time domains to avoid acoustic overlap with other species by signal masking (Krause, 1987). The results of this work show that individuals in interspecific associations do not compete for the acoustic space but develop a cooperative relationship, perhaps communicating with each other.

5. Conclusion

It is known that sympatry may lead to interspecific differences on the acoustic parameters among species optimizing intraspecies communication. However, our findings evidence that is possible that the advantages provided by an association on a mixed group may overcome the competition on the acoustic space between species, leading to interspecies acoustics similarities and maybe acoustic interactions. Therefore, simpatry and mixed group acoustic adaptation can occur independently. The results highlight that mixed groups associations are potentially different from a simple sympatry, in which acoustic differences between species enable individuals to differentiate conspecifics and non-conspecifics. More studies characterizing the repertoire of each species in different contexts are necessary for a better understanding of these interspecific relationships. Studies between sympatric associations and social complexity among delphinids are needed to investigate the driving factors behind these interactions and the motivations that lead different species to join in mixed groups.

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