UNIVERSIDADE FEDERAL DE SANTA CATARINA
CENTRO DE CIÊNCIAS BIOLÓGICAS
PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA

Isadora da Matta Carletti

Título: Ecologia acústica e comportamental de baleias-francas (*Eubalaena australis*) durante a temporada reprodutiva no litoral sul do Brasil.

Florianópolis
2023

Isadora da Matta Carletti

ECOLOGIA ACÚSTICA E COMPORTAMENTAL DE BALEIAS-FRANCAS (*Eubalaena australis*) DURANTE A TEMPORADA REPRODUTIVA NO LITORAL SUL DO BRASIL.

Dissertação apresentada ao Programa de Pós-Graduação em Ecologia, Departamento de Ecologia e Zoologia do Centro de Ciências Biológicas da Universidade Federal de Santa Catarina, como requisito para obtenção do Título de Mestre em Ecologia.

Orientador: Prof. Dr. Fábio Daura-Jorge.

Coorientadora: Dra. Susan E. Parks.

Florianópolis

2023

Carletti, Isadora da Matta
Ecologia acústica e comportamental de baleias-francas (Eubalaena australis) durante a temporada reprodutiva no litoral sul do Brasil. : Environmental factors as potential drives of acoustic and surface behavior of Southern Right Whales (Eubalaena australis) in a Brazilian Calving Ground. / Isadora da Matta Carletti ; orientador, Fábio Gonçalves Daura-Jorge, coorientadora, Susan Elizabeth Parks, 2023.
63 p.

Dissertação (mestrado) - Universidade Federal de Santa Catarina, Centro de Ciências Biológicas, Programa de Pós-Graduação em Ecologia, Florianópolis, 2023.

Inclui referências.

1. Ecologia. 2. ecologia comportamental. 3. comportamento vocal. 4. monitoramento acústico passivo. 5. estimativa de densidade. I. Daura-Jorge, Fábio Gonçalves. II. Parks, Susan Elizabeth. III. Universidade Federal de Santa Catarina. Programa de Pós-Graduação em Ecologia. IV. Título.

Isadora da Matta Carletti

Título: Ecologia acústica e comportamental de baleias-francas (*Eubalaena australis*) durante a temporada reprodutiva no litoral sul do Brasil.

O presente trabalho em nível de Mestrado foi avaliado e aprovado, em 22 de novembro de 2023, pela banca examinadora composta pelos seguintes membros:

Prof.(a) Fabio Gonçalves Daura Jorge, Dr.(a)
Universidade Federal de Santa Catarina

Prof.(a) Paulo Cesar de Azevedo Simões Lopes, Dr.(a)
Universidade Federal de Santa Catarina

Prof.(a) Julia Ribeiro Guimarães Dombroski, Dr.(a)
Syracuse University

Certificamos que esta é a versão original e final do trabalho de conclusão que foi julgado adequado para obtenção do título de Mestre em Ecologia.

ICP-Edu
Documento assinado digitalmente
Eduardo Luis Hettwer Giehl
Data: 20/02/2024 21:42:02-0300
CPF: ***.442.380-**
Verifique as assinaturas em https://v.ufsc.br

Coordenação do Programa de Pós-Graduação

ICP-Edu
Documento assinado digitalmente
Fabio Goncalves Daura Jorge
Data: 20/02/2024 15:04:26-0300
CPF: ***.254.799-**
Verifique as assinaturas em https://v.ufsc.br

Prof.(a) Fabio Gonçalves Daura Jorge, Dr.(a)
Orientador(a)

Florianópolis, 2023.

AGRADECIMENTOS

Este trabalho foi realizado com o apoio e incentivo de diversas pessoas e instituições, seja com críticas e sugestões, ideias e inspirações, até ao carinho e força para continuar. Assim agradeço:

Ao meu orientador prof. Dr. Fábio Daura-Jorge, por me aceitar como aluna sem me conhecer, pelo incentivo constante, pelas valiosas conversas e sugestões, além da paciência e auxílio em todos os momentos. Sem sua ajuda eu não conseguiria. MUITO obrigada;

À minha coorientadora prof. Dra. Susan E. Parks, pela oportunidade e confiança na execução do projeto, desde coleta de dados até gerenciamento das equipes;

À minha grande amiga irmã e melhor pesquisadora desse mundo Dra. Julia Dombroski, por me ensinar tudo, por sempre acreditar em mim, pelos puxões de orelha, por sempre me mostrar que sou capaz e por todas as oportunidades que abriram meu caminho até aqui;

Aos meus queridos amigos, Dr. Paulo Flores - por me ensinar tanto e por me indicar para esse orientador incrível, e prof. Dra. Renata Sousa-Lima - por me mostrar e fazer eu me apaixonar pelo mundo incrível da bioacústica;

À toda equipe que participou do projeto desde 2018, seja pela ajuda e participação direta nas atividades de campo e coleta de dados, ou pela comidinha gostosa no final do dia e comemorações no final de cada temporada. Vocês foram extremamente essenciais e importantes em todo o projeto e até no meu crescimento profissional;

Ao pescador Leandro (e sua gata Julia), por todo ano embarcar nas nossas ideias, dar sugestões certeiras e o entusiasmo de colocar tudo em prática de maneira impecável. “Iiiiiiiiiiiiiiiissoooooooo Leandro!!”;

Aos professores e colegas do Programa de Pós-Graduação em Ecologia da UFSC, pelos ensinamentos, pela barra que passamos juntos durante a pandemia e às conversas em grupo online para manter o contato e chorar juntos... sem isso teria sido muito mais difícil;

Aos meus pais e família, pelo apoio diário, por todo amor e confiança nas minhas escolhas “doidas”, e pela curiosidade em ouvir minhas histórias e aventuras. Sempre foi bem difícil estar longe de todos vocês, mas matar a saudade é a melhor parte de todo esse processo;

Ao meu marido, Giácomo, por ter aparecido em minha vida para me mostrar o que é amor de verdade, por cuidar e acreditar em mim, e por todo o apoio nesta dissertação – seja pelos dias e noites construindo as poitas, ou por aguentar meus gritos de desespero “não sou capaz” e nunca me deixar desistir. Meu amor, finalmente esse ciclo está terminando. MUITO obrigada, te amo pra sempre!

À CAPES e FAPESC, pela concessão da bolsa de Mestrado;

Ao programa Living Marine Resources (LMR) do Programa de Monitoramento de Espécies Marinhas da Marinha Americana, pelo financiamento do projeto;

À Universidade de Syracuse e Instituto Australis, pela mediação dos fundos para a realização do projeto e apoio logístico;

Aos meus grandes amigos que sempre estiveram presentes, pela amizade e risadas, pelo apoio e abraços quentinhos, e inclusive pela companhia quando eu precisava escrever, mas não conseguia fazer em silêncio. Amo vocês!

Aos membros da pré-banca e banca, pelas importantes contribuições e sugestões;

E por fim, a mim mesma, que mesmo tendo perdido as esperanças com o meio acadêmico e com a profissão, não desisti de concluir este ciclo. Termino confiando que algum dia nossos objetivos de preservação e conservação, vão valer mais do que o ego alheio.

Obrigada!

"Tomorrow belongs to those who can hear it coming."

David Bowie

RESUMO

A comunicação acústica tem papel essencial em uma variedade de funções vitais de mamíferos marinhos. Compreender os mecanismos ecológicos que estimulam o comportamento acústico desses organismos é de grande importância para sua conservação e preservação de seus habitats naturais. Visando contribuir com o conhecimento necessário para a implementação de um Monitoramento Acústico Passivo (MAP) como ferramenta de pesquisa e conservação da baleia-franca no Brasil, este trabalho reúne informações sobre a ecologia comportamental e acústica de pares mãe-filhote avistados no litoral sul de Santa Catarina. Por meio de gravações acústicas e observações comportamentais sincrônicas, conduzimos um estudo para testar se as taxas de emissões acústicas variam em função de fatores ambientais e comportamentais, e se é possível inferir sobre a densidade de indivíduos presentes a partir das taxas de emissões acústicas. Gravadores acústicos foram instalados na Praia de Itapirubá, localizada na APA Baleia Franca, para que juntamente com o esforço visual fosse possível monitorar o ambiente e os sons produzidos pelas baleias-francas entre agosto e setembro de 2021 e 2022. A análise minuciosa das gravações obtidas revelou 4896 chamados, sendo que 76% foram "upcalls" – chamado de contato mais comum entre um par mãe-filhote. Paralelamente, ao longo do monitoramento visual, foi possível registrar um total de 235 atividades de superfície, desde saltos à batidas de cauda e nadadeira peitoral. A partir de modelos lineares generalizados mistos (GLMM) ajustados, observamos que a intensidade do vento aumenta as taxas de emissão acústicas, enquanto o número de baleias presentes na área tem influência negativa sobre o comportamento acústico. Já para as atividades de superfície, o modelo mais parcimonioso sugere que a ocorrência desses comportamentos pode variar com a intensidade do vento também de forma positiva, varia entre anos, e também diminui com aumento no número de baleias no local. O resultado da diminuição da atividade comportamental, de superfície ou acústica, com o aumento no número de baleias, além de sugerir uma tendência à densidade-dependência, pode estar relacionado às estratégias de prevenção de detecção por outros grupos de baleias e/ou por predadores, e também ao contexto de grupo que se encontram. A inclusão de mais dados e variáveis pode indicar outros fatores determinantes para nossas variáveis resposta, e aumentar a precisão dos modelos, em especial do modelo ajustado para emissões acústicas, possibilitando sua utilização para fins de estimativa de indivíduos em uma determinada área. Este trabalho representa um avanço importante no entendimento do comportamento acústico de pares mãe-filhote e fornece informações fundamentais para a aplicação futura de metodologias que visam estimar a densidade da espécie com base em emissões acústicas, considerando um conjunto de covariáveis ambientais que podem influenciar no comportamento dos indivíduos.

Palavras-chave: Comportamento vocal, ecologia comportamental, par mãe-filhote, monitoramento acústico passivo, estimativa de densidade.

ABSTRACT

Acoustic communication plays a crucial role in various vital functions of marine mammals. Understanding the ecological mechanisms that drive the acoustic behavior of these organisms is of great importance for their conservation and the preservation of their natural habitats. With the aim of contributing to the knowledge needed for implementing Passive Acoustic Monitoring (PAM) as a research and conservation tool for the southern right whale in Brazil, this study compiles information on the behavioral and acoustic ecology of mother-calf pairs of the species observed on the southern coast of Santa Catarina. Through acoustic recordings and simultaneous behavioral observations, we conducted a study to test whether acoustic emission rates vary based on environmental and behavioral factors and whether it is possible to deduce the density of individuals present from their acoustic emission rates. Acoustic sensors were installed at Praia de Itapirubá, located in the Right Whale Environmental Protection Area (RWEPA), to enable the monitoring of the environment and the sounds produced by southern right whales present between August and September in 2021 and 2022, in conjunction with visual monitoring efforts. Manual inspection of the recordings revealed 4.896 calls, with 76% being "upcalls", which are the most common contact calls between mother-calf pairs. Alongside visual monitoring, a total of 235 surface activities were recorded, ranging from breaches to tail and pectoral fin slaps. From the generated Generalized Linear Mixed Models (GLMM), we observed that wind intensity positively affected acoustic emission, while an increase in the number of whales reduced the acoustic behavior activity of the species. Regarding surface activities, the most parsimonious model suggests that the occurrence of these behaviors may also positively vary with wind intensity, between years, and decrease with the increase in the total number of whales in the area. The result, which indicates a decrease in behavioral activity, both acoustic and surface, with an increasing number of whales, suggest a trend toward density-dependence in this species. This could be related to strategies for avoiding

detection by other whale groups or predators, as well as the group context in which they find themselves. The inclusion of more data and variables may enhance the quality of our models, identify new factors influencing individual behaviors, and improve the precision of the models, particularly those using acoustic emissions as response variables, enabling their use for estimating the number of individuals in a specific area. This work represents a significant advancement in understanding the acoustic behavior of mother-calf pairs and provides essential information for the future application of methodologies aimed at estimating the species' density based on acoustic emissions, considering a range of environmental covariates that can influence individual behaviors.

Keywords: Vocal behavior, behavioral ecology, mother-calf pairs, passive acoustic monitoring, density estimation.

LISTA DE FIGURAS

LISTA DE TABELAS

SUMÁRIO

1. INTRODUÇÃO GERAL

A compreensão da ecologia comportamental e acústica de mamíferos marinhos é de grande importância para sua conservação e para a preservação de seus habitats naturais. Sons têm papéis essenciais para uma variedade de funções vitais e na manutenção de interações intra e interespecíficas desses organismos (PAYNE & McVAY, 1971; WATKINS & SCHEVILL, 1976). Servindo como uma ferramenta multifuncional, utilizado como instrumento de navegação e orientação, o som vai influenciar desde o comportamento de um indivíduo e como este utiliza o ambiente adjacente, à comunicação social com coespecíficos e a detecção de presas (SAYIGH, 2014). Esta diversidade de funções tem estimulado uma série de estudos científicos que buscam compreender os mecanismos ecológicos subjacentes ao comportamento acústico. Isto não é diferente para a baleia-franca austral (*Eubalaena australis*), que tem no comportamento acústico um elemento chave de seu repertório comportamental (CLARK, 1982; SIMÕES-LOPES et al., 1992; LODI et al., 1996; GROCH et al., 2005a; GROCH & FLORES, 2011; SEYBOTH et al., 2015; DOMBROSKI et al., 2016).

1.1 Bioacústica

A comunicação é a base de interações sociais entre animais, caracterizando-se pelo processo em que emissores utilizam diversos tipos de sinais para transmitir informações a receptores (BRADBURY & VEHRENCAMP, 1998; DAVIES et al., 2012). Esses sinais podem ser expressos de maneiras variadas, incluindo formas visuais, elétricas, químicas, táteis e/ou acústicas, dependendo das pressões evolutivas e características do ambiente (BRADBURY & VEHRENCAMP, 1998; SMITH & HARPER, 2003).

O estudo da bioacústica explora a maneira pela qual os animais empregam e se comunicam por meio de sinais acústicos (TYACK, 2001). Nos ambientes aquáticos, onde a propagação do som é mais rápida e eficaz do que no ar, os sinais acústicos desempenham um papel vital (AU & HASTINGS, 2008). Os cetáceos, por exemplo, dependem do som em diversos aspectos de sua ecologia comportamental (TYACK, 2000). No caso dos misticetos, suas vocalizações compreendem sons de baixa frequência que podem se propagar por longas distâncias (PAYNE & WEBB, 1971), e seus repertórios acústicos podem ser categorizados em sons vocais e não-vocais (CLARK, 1990).

Os sons não-vocais compreendem os "sopros", que consistem em sons de baixa intensidade originados durante a expiração ou inspiração, e os "slaps", que são sons intensos, curtos e percussivos, gerados como resultado de comportamentos de superfície (CLARK, 1990). Os sons vocais, por sua vez, podem ser distinguidos em duas categorias: "canções", caracterizadas por vocalizações longas e estruturalmente complexas (PAYNE & McVAY, 1971), e "chamados", que se apresentam como vocalizações discretas e de curta duração (CLARK, 1990).

Diversas espécies se destacam na produção de canções, como por exemplo, as baleias azuis (*Balaenoptera musculus*) (CUMMINGS & THOMPSON, 1971), as baleias fin (*Balaenoptera physalus*) (CROLL et al., 2002), as baleias minke (*Balaenoptera acutorostrata*) (GEDAMKE et al., 2001), e as baleias jubarte (*Megaptera novaeangliae*) (PAYNE & McVAY, 1971). No entanto, as baleias francas (*Eubalaena* sp.) produzem exclusivamente chamados, conforme registrado por Clark (1983). Entretanto, a aplicabilidade da bioacústica para a conservação dessas espécies exige um conhecimento prévio em relação à ecologia comportamental e acústica das mesmas, englobando informações sobre suas taxas de emissão e variação temporal de chamados em relação aos comportamentos dos animais (MELLINGER et al., 2007; VAN PARIJS et al., 2009; MARQUES et al., 2012; SOUSA-LIMA et al., 2013).

1.2 A paisagem sonora

Como uma abordagem para a compreensão da interação entre os sons do meio e os animais que ali vivem, o estudo da paisagem sonora se concentra na investigação de padrões acústicos de um hábitat e em seus papéis na ecologia e comportamento de diferentes espécies presentes (PIJANOWSKI et al., 2011; MIKSIS-OLDS et al., 2018). Nos oceanos, a paisagem acústica é caracterizada por uma variedade de fontes sonoras, que envolvem tanto ruídos bióticos e abióticos quanto ruídos antropogênicos (MIKSIS-OLDS et al., 2018). Diversos estudos têm se concentrado em fontes antropogênicas, porém os efeitos a longo prazo do ruído ambiental sobre os organismos marinhos ainda não são amplamente compreendidos (NATIONAL RESEARCH COUNCIL, 2003).

Sons abióticos são gerados por eventos naturais, incluindo o som das ondas quebrando na costa, movimentação de correntes oceânicas, intensidade do vento, terremotos, precipitação e até o rompimento de gelo (NATIONAL RESEARCH COUNCIL, 2005; ERBE, 2012). Já os ruídos bióticos, referem-se aos sons produzidos por organismos vivos, incluindo desde vocalizações de baleias até os sons emitidos por peixes durante suas interações sociais (NATIONAL RESEARCH COUNCIL, 2005; ERBE, 2012). Muitas dessas fontes sonoras existem desde a formação da Terra e dos oceanos, sendo provável que tenham influenciado a evolução do sistema auditivo, comunicação e ecologia dos organismos (FAY & POPPER, 2000). Esses sons desempenham então funções na comunicação intraespecífica, sendo uma parte intrínseca da paisagem sonora marinha (NATIONAL RESEARCH COUNCIL, 2003; MIKSIS-OLDS et al., 2018).

Em ambientes ruidosos, para que haja uma comunicação eficaz (onde o emissor consegue transmitir a mensagem desejada para o receptor) é possível que o indivíduo utilize estratégias como modificar e/ou utilizar frequências de som específicas, e aumentar a complexidade do sinal transmitido (ZIMMER, 2011). Além disso, como uma maneira de evitar que a mensagem transmitida seja recebida por um predador em potencial, indivíduos podem reduzir as taxas de vocalização, diminuir as amplitudes dos sinais ou até mesmo suspender completamente a comunicação (MORISAKA & CONNOR, 2007; MARTIN et al., 2018; NIELSEN et al., 2019; PARKS et al., 2019a; ZEH et al., 2022). Ou seja, existe toda uma plasticidade do comportamento acústico que se ajusta ao contexto ecológico e à paisagem acústica.

1.3 A baleia-franca austral

A baleia-franca austral é um cetáceo da família Balaenidae da subordem Mysticeti (SHIRIHAI & JARRET 2006; KENNEY, 2008), encontrada principalmente nos oceanos do hemisfério sul. A migração é um aspecto notável da biologia dessa espécie. Durante o período de inverno austral, elas realizam extensas jornadas migratórias, deixando as águas frias da Antártica onde se alimentam para áreas de reprodução em águas mais quentes (KENNEY, 2008; ZERBINI et al., 2016; RENAULT-BRAGA et al., 2018). As áreas costeiras da Argentina (PAYNE et al., 1990), Brasil (CASTELLO & PINEDO, 1979), África do Sul (BEST, 1990), Austrália (BANNISTER, 2020) e Nova Zelândia (RICHARDS, 2002) são os locais mais comuns de agregação para essa espécie durante a temporada reprodutiva.

No Brasil, entre os meses de julho e novembro, é possível observar a chegada de baleias-franca no litoral de Santa Catarina (GROCH et al., 2005b; GROCH & FLORES, 2011). Por ser uma região com águas mais quentes, calmas e rasas, a maioria das avistagens ao longo da temporada consiste em pares de mãe-filhote (Fig. A), presumindo-se que grande parte dos nascimentos ocorram nesta região (PAYNE, 1986; BURNELL & BRYDEN, 1997; PALAZZO & FLORES, 1998; SEYBOTH, 2015).

Figura A - Par mãe-filhote de baleia-franca austral no litoral sul de Santa Catarina. Foto: Carletti, I.

A caça comercial causou uma drástica redução na população de baleias-francas no Brasil, embora não haja registros oficiais que quantifiquem o número de animais abatidos no país (TORMOSOV et al., 1998). Estudos recentes indicam que populações de baleias-francas austrais estão mostrando sinais de recuperação e crescendo a taxas de aproximadamente 7-8% ao ano desde o fim da caça (COOK et al., 2001; GROCH et al., 2005b; GROCH & FLORES, 2011; COOKE & ZERBINI, 2018). De fato, *E. australis* está listada como "de menor preocupação" na Lista Vermelha de Espécies Ameaçadas da IUCN (COOKE & ZERBINI, 2018). Isso sugere uma melhoria na situação de conservação das baleias-francas, embora seja importante continuar monitorando e protegendo essa espécie para garantir sua recuperação contínua, visto que ainda sofre ameaças para sua sobrevivência, como colisões com embarcações, emalhes em redes de pesca e a degradação do ambiente marinho (OTT et al., 2008).

1.4 Comportamento e comunicação

Em termos de comportamento, a baleia-franca austral demonstra um alto grau de proteção e investimento nos cuidados parentais, fornecendo amamentação e atenção intensiva durante os primeiros meses de vida dos filhotes (THOMAS & TABER, 1983; GROCH, 2000; WHITEHEAD & MANN, 2000; KRAUS et al., 2001; ELWEN & BEST, 2004). Durante esse período, observam-se diversas interações à medida que os filhotes desenvolvem suas habilidades sociais, de natação e de mergulho (THOMAS & TABER, 1983; GROCH, 2000; DOMBROSKI, 2015; HAMILTON et al., 2022).

Atividades de superfície, como por exemplo saltos, batidas de cauda e batidas de nadadeira peitoral, são realizadas pelo par mãe-filhote, e por produzirem sons não-vocais, podem ser importantes para a comunicação, embora ainda não se saiba ao certo o significado funcional de tais sinais (WHITEHEAD, 1985; CLARK, 1990). Já a comunicação vocal desempenha um papel fundamental na vida dessa espécie. Utilizando uma ampla gama de sons e vocalizações de baixa frequência, estabelecem desde vínculos sociais à atração de parceiros (CLARK, 1982; PARKS & TYACK, 2005). Estudos realizados com as diferentes espécies de baleias-francas (*E. japonica*, *E. glacialis* e *E. australis*), demonstraram que os repertórios acústicos são similares, com os mesmos tipos de chamados descritos para cada espécie (CLARK, 1982; DOMBROSKI et al., 2016; WEBSTER et al., 2016).

A baleia-franca austral, especificamente, apresenta um repertório acústico com diversas classes de chamados. O “upcall”, por exemplo, é referido como um chamado de contato (CLARK, 1983), usado em diferentes contextos comportamentais (PARKS & TYACK, 2005) e dentro de grupos de mães e filhotes (DOMBROSKI et al., 2016). Até o momento, sabe-se que a taxa de emissão vocal de “upcalls” em pares de mãe-filhote de baleias-franca, no entanto, varia de acordo com seu estado comportamental (DOMBROSKI et al., 2016; PARKS et al. 2019b). Além disso, essas taxas de vocalizações também podem ser afetadas pela composição do grupo (MELLINGER et al., 2007; VAN PARIJS et al., 2009).

1.5 “Ver com os ouvidos”

Diferentes abordagens metodológicas vêm sendo desenvolvidas e aplicadas com sucesso em estudos acústicos com diversas espécies de mamíferos marinhos, desde baleias (por exemplo, *Eubalaena australis* e *Megaptera novaeangliae*; CLARK, 1983; CLARK & CLAPHAM, 2004) a golfinhos (por exemplo, *Stenella* sp. e *Tursiops truncatus*; OSWALD et al., 2003). Uma abordagem recente e amplamente utilizada atualmente é o Monitoramento Acústico Passivo (MAP). O MAP utiliza sons produzidos por animais para fazer inferências sobre seu comportamento, ocorrência, distribuição e migração (CATO et al., 2006; MARQUES et al., 2012).

Um monitoramento acústico é passivo quando registra apenas o som ambiente, enquanto em um monitoramento ativo um som é emitido e seu eco é analisado (MELLINGER et al., 2007). Uma forma comum de realizar o MAP é via o uso de gravadores autônomos (MELLINGER et al., 2007), que consistem em hidrofones conectados a gravadores de som ou “gravadores” de dados, alimentados por baterias, que podem operar por meses (SOUSA-LIMA et al., 2013). Quando alguns hidrofones são utilizados simultaneamente, em um arranjo amostral adequado, o MAP pode identificar a localização aproximada do indivíduo emissor do som (YACK et al., 2013). O MAP vêm sendo usado em diversos estudos que avaliam impactos e a possibilidade de mitigação de atividades antropogênicas, como em prospecção de petróleo; ou, em estudos científicos com perguntas diversas, relacionadas a descrições de uso de habitat, ocorrência ou mesmo abundância de uma espécie em uma determinada área (DAVIS et al., 2017; PALMER et al., 2019)

O MAP oferece diversas vantagens para a detecção de mamíferos marinhos que produzem som, principalmente quando combinado com observações visuais. Algumas dessas vantagens incluem uma melhor cobertura da área de estudo e também a possibilidade de detecção constante por longos períodos, incluindo o monitoramento noturno (MELLINGER et al., 2007). Essa tecnologia vem evoluindo significativamente nos últimos vinte anos, levando ao potencial uso do MAP para estimativas de densidade (MARQUES et al., 2012). Além disso, o MAP é uma ferramenta de conservação e monitoramento bem estabelecida para todas as espécies de baleias-franca (VAN PARIJS et al., 2009). Para a baleia-franca do Atlântico Norte (*Eubalaena glacialis*), por exemplo, o uso do MAP é eficiente para identificar sua presença acusticamente (VAN PARIJS et al., 2009). Somado ao monitoramento visual, a aplicação de MAP também forneceu uma ampla compreensão dos comportamentos e respostas comportamentais à ruídos de baleias-franca austrais (CLARK, 1982).

O conhecimento prévio do comportamento vocal da espécie, no entanto, é essencial para a análise e utilização dos sons gravados em um contexto de MAP (CATO et al., 2006). Por exemplo, o uso de taxas de emissões acústicas para estimar densidade de indivíduos em uma área seria uma contribuição valiosa do MAP. Porém, a contagem de indivíduos via taxas acústicas pode ser extremamente difícil, pois mesmo enumerando as vocalizações gravadas, em geral, existem incertezas sobre quantos animais estão acusticamente ativos e como essas taxas variam em função de diferentes contextos comportamentais em que os inidivíduos se encontram (DOMBROSKI et al., 2016), dificultando uma inferência de qual o real número de indivíduos presentes na área (MARQUES et al., 2012).

Dentre o repertório acústico das baleias-franca, o “upcall” é o chamado mais frequentemente detectado no MAP (VAN PARIJS et al., 2009). Esse chamado tem sido usado em tentativas para estimar as taxas de vocalizações, com o objetivo de gerar estimativas de densidade acústica (MATTHEWS et al., 2001; PARKS et al., 2019), mas estudos prévios sugerem que estas taxas são, de fato, contexto-dependentes (PARKS & TYACK, 2005), e um entendimento dessas variações é essencial para definir essa relação. A população brasileira de baleias-franca encontra-se próxima à costa durante a temporada reprodutiva (GROCH et al., 2005a), em áreas com encostas elevadas e adequadas para realização de um Monitoramento Acústico Passivo simultâneo a um monitoramento visual de indivíduos. A sincronia desses esforços, visual e acústico, permite avaliar as variações nas taxas de emissão acústica em função de diferentes variáveis registradas via monitoramento visual, desde ambientais, a comportamentais, possibilitando um refinamento na compreensão da ecologia comportamental e acústica dessa espécie, e assim um melhor entendimento na relação potencial entre taxas de emissões acústicas e abundância de indivíduos em uma determinada área.

2. OBJETIVOS E ESTRUTURA DA DISSERTAÇÃO

Dada a escassez de estudos relacionados à ecologia acústica da baleia-franca austral no Brasil e para expandir nosso conhecimento sobre o sistema de comunicação e comportamento dessa espécie, esta dissertação tem como objetivo inicial investigar o comportamento acústico da espécie durante a temporada reprodutiva nas águas costeiras do estado de Santa Catarina. De forma mais específica, duas hipóteses foram testadas: 1. As taxas de emissão acústicas são contexto-dependentes, ou seja, variam em função de condições ambientais e comportamentais; 2. É possível inferir a variação na densidade de indivíduos na área a partir da variação nas taxas de emissão acústicas. A região para a realização desse estudo foi selecionada devido à presença consistente da espécie, durante a temporada reprodutiva, o que possibilita uma amostragem adequada para a realização de uma análise dos sons e comportamentos dos grupos ali presentes.

Os resultados dessa dissertação estão apresentados em um capítulo único – "*Environmental factors as potential drives of acoustic and surface behavior of Southern Right Whales (Eubalaena australis) in a Brazilian calving ground*" – organizado em formato de artigo científico a ser submetido à revista especializada *Marine Mammal Science.* O manuscrito aqui apresentado descreve a influência de contextos e fatores ambientais na ocorrência de chamados e atividades de superfície produzidos pela espécie, a partir de um monitoramento acústico e visual simultâneo. As informações resultantes desse esforço representam uma contribuição singular sobre a bioacústica da baleia-franca no Brasil, sendo importante para o desenvolvimento e experimentação de novas ferramentas de monitoramento que facilitem e otimizem um acompanhamento de questões comportamentais e de dinâmica populacional da espécie ao longo do tempo.

3. REFERÊNCIAS

Au W.W.L., Hastings M.C. (2008) Principles of marine bioacoustics. Springer, New York.

Bannister J. (2020) Status of southern right whales (*Eubalaena australis*) off Australia. J Cetacean Res Manage p 103-110.

Bradbury J.W., Vehrencamp S.L. (1998) Principles of animal communication. Sinauer Associates, Sunderland, MA.

Burnell S.R., Bryden M.M. (1997) Coastal residence periods and reproductive timing in southern right whales, *Eubalaena australis*. J Zool 241:613-621.

Castello H.P., Pinedo M.C. (1979) Southern right whales (*Eubalaena australis*) along the southern Brazilian coast. J Mamm 60(2):429-430.

Cato D., McCauley R., Rogers T., Noad M. (2006) Passive acoustics for monitoring marine animals - progress and challenges. First Australasina Acoustical Societie Conference, Noise of Progress p 453-461.

Clark C.W. (1982) The acoustic repertoire of the Southern Right Whale, a quantitative analysis. Animal Behavior 30:1060-1071.

Clark C.W. (1983) Acoustic communication and behavior of the Southern Right Whale (*Eubalaena australis*). In: Payne R. (ed) Communication and Behavior of Right Whales. Westview Press for the American Association for the Advancement of Science Boulder, Colorado, p 163-198.

Clark C.W. (1990) Acoustic behavior of mysticete whales. In: Thomas J., Kastelein R. (ed) Sensory Abilities of Cetaceans. Plenum Press, New York, p 571-583.

Clark C.W., Clapham P.J. (2004) Acoustic monitoring on a humpback whale (*Megaptera novaeangliae*) feeding ground shows continual singing into late Spring. Proceedings of the Royal Society 271:1051-1057.

Cooke J.G., Rowntree V., Payne R. (2001) Estimates of demographic parameters for southern right whales (*Eubalaena australis*) observed off Península Valdés, Argentina. J Cetacean Res Manage, special issue 2:125-132.

Cooke J.G., Zerbini A.N. (2018) *Eubalaena australis*. The IUCN Red List of Threatened Species: e.T8153A50354147.

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

Cummings W.C., Thompson P.O. (1971) Underwater sounds from the Blue Whale, *Balaenoptera musculus*. J Acoust Soc Am 50:1193-1198.

Davies N.B., Krebs J.R., West S.A. (2012) An introduction to behavioral ecology. John Wiley & Sons.

Davis G.E., Baumgartner M.F., Bonnell J.M., Bell J., Berchok C., Bort Thornton J., Brault S., Buchanan G., Charif R.A., Cholewiak D., Clark C.W., Corkeron P., Delarue J., Dudzinski K., Hatch L., Hildebrand J., Hodge L., Klinck H., Kraus S., Martin B., Mellinger D.K., Moors-Murphy H., Nieukirk S., Nowacek D.P., Parks S.E., Read A.J., Rice A.N., Risch D., Sirovic A., Soldevilla M., Stafford K., Stanistreet J.E., Summers E., Todd S., Warde A., Van Parijs S.M. (2017) Long-term passive acoustic recordings track the changing distribution of North Atlantic right whales (*Eubalaena glacialis*) from 2004 to 2014. Scientific Reports 7:13460.

Dombroski J.R.G. (2015) Ecologia acústica de pares fêmea-filhote de baleia franca austral (*Eubalaena australis*) (Desmoulins, 1822) em águas costeiras do Estado de Santa Catarina, Brasil. Universidade Federal do Rio Grande do Norte, Natal.

Dombroski J.R.G., Parks S.E., Groch K.R., Flores P.A.C., Sousa-Lima R.S. (2016) Vocalizations produced by southern right whale (*Eubalaena australis*) mother-calf pairs in a calving ground off Brazil. J Acoust Soc Am 140:1850-1857.

Dunlop R.A., Noad M.J., Cato D.H., Kniest E., Miller P.J.O., Smith J.N., Stokes M.D. (2013) Multivariate analysis of behavioral response experiments in humpback whales (*Megaptera novaeangliae*). Journal of Experimental Biology 216(5):759-770.

Elwen S.H., Best P.B. (2004) Environmental factors influencing the distribution of southern right whales (*Eubalaena australis*) on the south coast of South Africa: broad scale patterns. Marine Mammal Science 20(3):567-582.

Erbe C. (2012) Effects of underwater noise on marine mammals. In: Popper A.N., Hawkins A. (ed) The effects of noise on aquatic life. Advances in Experimental Medicine and Biology, Springer, New York. 730:17-22.

Gedamke J., Costa D.P., Dunstan A. (2001) Localization and visual verification of a complex minke whale vocalization. The Journal of the Acoustical Society of America 109:3038.

Groch K.R. (2000) Ocupação preferencial de áreas de concentração pela Baleia Franca Austral, *Eubalaena australis* (Desmoulins, 1822), CETACEA, MYSTICETI, no litoral sul do Brasil. Biociências. Universidade Federal do Rio Grande do Sul, Porto Alegre.

Groch K.R., Jr J.T.P., Flores P.A.C., Fabian M.E. (2005a) Right Whales (*Eubalaena australis*) off Southern Brazil: annual and seasonal patterns of occurrence, site fidelity and group structure. Abstract of the 16th Biennial Conference on the Biology of Marine Mammals Annals, 113.

Groch K.R., Palazzo J.J.T., Flores P.A.C., Adler F.R., Fabian M.E. (2005b) Recent rapid increases in the right whale (*Eubalaena australis*) population off southern Brazil. Latin American Journal of Aquatic Mammals, 4.

Groch K.R., Flores P.A.C. (2011) Census of the Southern Right Whales off Brazil. IWC Southern Right Whale Assessment Workshop.

Hamilton P.K., Frasier B.A., Conger L.A., George R.C., Jackson K.A., Frasier T.R. (2022) Genetic identifications challenge our assumptions of physical development and mother-calf associations and separation times: a case study of the North Atlantic right whale (*Eubalaena glacialis)*. Mammalian Biology 102:1389-1408.

Kenney R.D. (2008) *Eubalaena glacialis*, *E. japonica* and *E. australis*. In: Perrin W.F., Wursig B., Thewissen J.G.M. (ed) Encyclopedia of Marine Mammals. Academic Press, San Diego, CA. p 926-972.

Kraus S.D., Hamilton P.K., Kenney R.D., Knowlton A.R., Slay C.K. (2001) Reproductive parameters of the North Atlantic right whale. J Cetacean Res Manag p 231-236.

Lodi L., Siciliano S., Bellini C. (1996) Ocorrências e conservação da baleia-franca-do-sul, *Eubalaena australis*, no litoral do Brasil. Papéis Avulsos de Zoologia 39:307-328.

Martin M.J., Gridley T., Elwen S.H., Jensen F.H. (2018) Heavisides dolphins (*Cephalorhynchus heavisidii*) relax acoustic crypsis to increase communication range. Proc R Soc 285:20181178.

Marques T.A., Thomas L., Martin S.W., Mellinger D.K., Ward J.A., Moretti D.J., Harris D., Tyack P.L. (2012) Estimating animal population density using passive acoustics. Biological reviews of the Cambridge Philosophical Society 88:287-309.

Matthews J.N., Brown S., Gillespie D., Johnson M., McLanaghan R., Moscrop A., Nowacek D., Leaper R., Lewis T., Tyack P. (2001) Vocalization rates of the North Atlantic right whale (*Eubalaena glacialis*) J Cetacean Res Manage 3(3):271-282.

Mellinger D.K., Stafford K.M., Moore S.E., Dziak R.P., Matsumoto H. (2007) An overview of fixed passive acoustic observation methods for cetaceans. Oceanography 20:36-45.

Miksis-Olds J.L., Martin B., Tyack P.L. (2018) Exploring the ocean through soundscapes. Acoustics Today, Spring 14(1):26-34.

Morisaka T., Connor R.C (2007) Predation by killer whales (*Orcinus orca*) and the evolution of whistle loss and narrow-band high frequency clicks in odontocetes. J Evol Biol 20:1439-1458.

National Research Council (2003) Ocean Noise and Marine Mammals. The National Academic Press, Washington, DC.

National Research Council (2005) Marine Mammal Populations and Ocean Noise: Determining when noise causes biologically significant effects. The National Academic Press, Washington, DC.

Nielsen M.L.K., Bejder L., Videsen S.K.A., Christiansen F., Madsen P.T. (2019) Acoustic crypsis in southern right whale mother-calf pairs: infrequent, low-output calls to avoid predation? J Exp Biol 222:jeb190728.

Oswald J.N., Barlow J., Norris T.F. (2003) Acoustic identification of nine Delphinid species in the Eastern Tropical Pacific Ocean. Marine Mammal Science 19(1):20-37.

Ott P., Groch K.R., Danielwicz D. (2008) *Eubalaena australis* (Desmoulins, 1822). In: Machado A.B.M, Drummond G.M., Paglia A.P. (ed) Livro Vermelho da Fauna Brasileira Ameaçada de Extinção. Ministério do Meio Ambiente, Brasília, DF, p 801-803.

Palazzo Jr J.T., Flores P.A.C. (1998) Right whales *Eubalaena australis* in southern Brazil: a summary of current knowledge and research needs. International Whaling Commission.

Palmer K.J., Brookes K.L., Davies I.M., Edwards E., Rendell L. (2019) Habitat use of a coastal delphinid population investigated using passive acoustic monitoring. Aquatic Conservation: Marine and Freshwater Ecosystems 29:254-270.

Parks S.E., Tyack P. (2005) Sound production by North Atlantic right whales (*Eubalaena glacialis*) in surface active groups. J Acoust Soc Am 117:3297-3306.

Parks S.E., Cusano D.A., Van Parijs S.M., Nowacek D.P. (2019a) North Atlantic right whale (*Eubalaena glacialis*) acoustic behavior on the calving grounds. J Acoust Soc Am 146:EL15-EL21.

Parks S.E., Cusano D.A., Van Parijis S.M., Nowacek D.P. (2019b) Acoustic crypsis in communication by North Atlantic right whale mother-calf pairs on the calving grounds. Biology Letters 15:20190485.

Payne R.S., McVay S. (1971) Songs of Humpback Whales. Science 173:585-597.

Payne R.S., Webb D. (1971) Orientation by means of long-range acoustic signaling in baleen whales. Ann New York Acad Sci 188:110-141.

Payne R.S. (1986) Long term behavioral studies of the Southern Right Whale (*Eubalaena australis*). In: Brownell Jr R.L., Best P.B., Prescott J.H. (ed) Right Whales: Past and Present status. Report of the International Whaling Commission, special issue 10:161-167.

Payne R.S., Rowntree V., Perkins J.S., Cooke J.G., Lankester K. (1990) Population size, trends, and reproductive parameters of right whales (*Eubalaena australis*) off Peninsula Valdés, Argentina. In: Hammond P.S., Mizroch S.A., Donovan G.P. (ed) Individual recognition of cetaceans: use of photoidentification and other techniques to estimate population parameters. Report of the International Whaling Commision, special issue 12:271-278.

Pijanowski B.C., Villanueva-Rivera L.J., Dumyahn S.L., Farina A., Krause B.L., Napoletano B.M., Gage S.H., Pieretti N. (2011) Soundscape Ecology: The science of sound in the landscape. BioScience 61(3):203-2016.

Renault-Braga E.P., Groch K.R., Flores P.A.C., Secchi E.R., Dalla-Rosa L. (2018) Area usage estimation and spatiotemporal variability in distribution patterns of southern right whales, *Eubalaena australis*, of southern Brazil. Marine Ecology, 39(3):EL12506.

Richards R. (2002) Southern right whales: a reassessment of their former distribution and migration routes in New Zealand waters, including on the Kermadec grounds. Journal of the Royal Society of New Zealand 32(3):355-377.

Sayigh L.S. (2014) Cetacean acoustic communication. In: Witzany G. (ed) Biocommunication of animals. Springer, Dordrecht, p 275-297.

Seyboth E., Groch K.R., Secchi E.R., Dalla Rosa L. (2015) Habitat use by southern right whales, *Eubalaena australis* (Desmoulins, 1822), in their main northernmost calving area in the western South Atlantic. Marine Mammal Science, n.a-n.a.

Shirihai H., Jarret B. (2006) Whales, Dolphins and other Marine Mammals. Princeton University Press, Princeton, New Jersey.

Simões-Lopes P.C., et al. (1992) Identificação, movimentos e aspectos biológicos da baleia-franca-austral (*Eubalaena australis*) na costa sul do Brasil. III Reunión de Trabajo de Expertos en Mamíferos Acuáticos de América del Sur, p 62-65.

Smith J.M., Harper D. (2003) Animal signals. Oxford University Press.

Sousa-Lima R.S., Norris T.F., Oswald J.N., Fernandes D.P. (2013) A review and inventory of fixed autonomous recorders for passive acoustic monitoring of marine mammals. Aquatic Mammals 39:23-53.

Thomas P.O., Taber S.M. (1983) Mother-infant interaction and behavioral development in southern right whales, *Eubalaena australis*. Behavior 88:42-60.

Tyack P.L. (2000) Functional aspects of cetacean communication. In: Mann J., Connor R.C., Tyack P.L., Whitehead H. (ed) Cetacean societies: field studies of dolphins and whales. The University of Chicago, Chicago Press, IL p 270-307.

Tyack P.L. (2001) Bioacoustics. Encyclopedia of Ocean Sciences, 2nd ed. p 357-363.

Tormosov D.D., Mikhaliev Y.A., Best P.B, Zemsky V.A., Sekiguchi K., Brownell R.L. (1998) Soviet catches of southern right whales *Eubalaena australis*, 1951-1971. Biological data and conservation implications. Biological Conservation 86:185-197.

Van Parijs S.M., Clark C.W., Sousa-Lima R.S., Parks S.E., Rankin S., Risch D., Van Opzeeland I.C. (2009) Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. Mar Ecol Prog Ser 395:21-36.

Watkins W.A., Schevill W.E. (1976) Right whale feeding and baleen rattle. Journal of Mammalogy, 57(1):58-66.

Webster T.A., Dawson S.M., Rayment W.J., Parks S.E., Van Parijs S.M. (2016) Quantitative analysis of the acoustic repertoire of southern right whales in New Zealand. J Acoust Soc Am 140(1):322-333.

Whitehead H. (1985) Why whales leap. Scientific American 252:84-93.

Whitehead H., Mann J. (2000) Female reproductive strategies of cetaceans. In: Mann J., Connor R.C., Tyack P.L., Whitehead H. (ed) Cetacean societies: field studies of dolphins and whales. The University of Chicago, Chicago Press, IL p 219-246.

Yack T.M., Barlow J., Calambokidis J., Southall B., Coates S. (2013) Passive acoustic monitoring using a towed hydrophone array results in identification of a previously unknown beaked whale habitat. The Journal of the Acoustical Society of America 134(3):2589-2595.

Zerbini A.N., Rosenbaum H., Mendez M., Sucunza F., Andriolo A., Harris G., Clapham P.J., Sironi M., Uhart M., Ajó A.F. (2016) Tracking southern right whales through the southwest Atlantic: an update on movement, migratory routes and feeding grounds. Committee of the International Whaling Commission SC66b, Bled, Slovenia.

Zeh J.M., Dombroski J.R.G., Parks S.E. (2022) Preferred shallow-water nursery sites provide acoustic crypsis to southern right whale mother-calf pairs. Royal Society Open Science 9:220241.

Zimmer W.M.X. (2011) Passive Acoustic Monitoring of Cetaceans. Cambridge University Press, New York.

Environmental factors as potential drives of acoustic and surface behavior of Southern Right Whales (*Eubalaena australis*) in a Brazilian Calving Ground.

Isadora M. Carletti, *Graduation Program in Ecology, Laboratory of Aquatic Mammals (Lamaq), Department of Ecology and Zoology, Federal University of Santa Catarina, Brazil.*

Fábio G. Daura-Jorge, *Laboratory of Aquatic Mammals (Lamaq), Department of Ecology and Zoology, Federal University of Santa Catarina, Brazil.*

Susan E. Parks, *Department of Biology, Syracuse University, United States.*

Prepared to be submitted to *Marine Mammal Science*

Abstract

Acoustic communication plays a crucial role in disparate vital functions of marine mammals. Understanding the ecological mechanisms that drive the acoustic behavior of these organisms is of great importance for their conservation and the preservation of their natural habitats. Through passive acoustic monitoring and simultaneous visual observations, we conducted a study focused on southern right whale mother-calf pairs found in a Brazilian calving ground to better understand their acoustic and behavioral ecology. Our recordings revealed 4.896 calls, mainly “upcalls”, and 235 surface events during the 2021 and 2022 breeding season. Wind intensity and the number of whales in the area influence acoustic behavior, while surface activities may vary with wind intensity, between years and the total number of whales in the study site. Our findings suggest density-dependent behaviors, possibly related to group dynamics. This research contributes to understanding mother-calf pairs’ acoustic behavior and lays the foundation for estimating this species density through acoustics rates.

Keywords

Vocal behavior, behavioral ecology, mother-calf pairs, passive acoustic monitoring, density estimation.

Introduction

Sound stands as an indispensable component within the communication repertoire of marine mammals, playing a fundamental role in their ecological and behavioral interactions (PAYNE & McVAY, 1971; WATKINS & SCHEVILL, 1976). Given the limitations of visual cues underwater, sound can serve as a means of conveying information, maintaining social bonds, coordinating group activities, establishing individual identities, locating food sources, mate attraction and facilitating navigation (TYACK, 2000; SAYIGH, 2014). Cetaceans have evolved a remarkable array of vocal-sounds, ranging from the melodic songs of humpback whales (CLARK & CLAPHAM, 2004) to the intricate calls exchanged among right whales (CLARK, 1983), as well as clicks and whistles emitted by dolphins (OSWALD et al., 2003). Surface behaviors also play a crucial role in marine mammal's communication, generating distinctive non-vocal sounds and visual cues that may transmit messages, whether for socialization or mating purposes (DUNLOP et al., 2008; 2013).

Extensive research efforts have been conducted to attain a deeper understanding of the behavioral and acoustic communication within diverse Southern right whales (SRW - *Eubalaena australis*) populations. The ultimate focus of these efforts has been to elucidate the factors that have contributed to their population growth and recovery over the past years (GROCH et al., 2005; RENAULT-BRAGA et al., 2018). Annually, from July to November, the sheltered and shallow waters bays along the coast of Santa Catarina, Brazil, serve as a nursery site during the SRW breeding season, being one of the areas where research into communication and reproduction-related issues is facilitated (GROCH et al., 2005; SEYBOTH et al., 2015). The predominant composition of groups within these areas consist of mother-calf pairs (SIMÕES-LOPES et al., 1992; GROCH et al., 2005; SEYBOTH, 2015). Consequently, local research mainly focuses on investigating the functional ecology of these groups, including how mother and calf pairs communicate during this crucial period in the life cycle.

Due to the proximity of these aggregation areas to the coastline, individuals can be easily observed and monitored through visual surveillance and aerial censuses allowing for local-scale monitoring of various population and behavioral aspects, including the role of the mother-calf relationship (BEST & RUTHER, 1992; SIMÕES-LOPES et al., 1992; LODI et al., 1996; GROCH et al., 2005; GROCH & FLORES, 2011; SEYBOTH et al., 2015). The relationship between a mother and calf in SRW is characterized by a strong bond, distinguished by nurturing and protective behaviors exhibited by the mother towards her offspring (NIELSEN et al., 2019). This bond plays a vital role in ensuring the calf's survival, growth and development (THOMAS & TABER, 1983). Their preference for calmer and shallower areas can then be attributed to two primary factors: 1) it reduces the risk of detection by potential predators, thereby increasing the chances of the calf's survival; and 2) it facilitates energy conservation, ensuring that the calf has sufficient energy for its developmental requirements and growth (GROCH, 2000; ELWEN & BEST, 2004).

Mother-calf pairs engage in a range of physical interactions and vocalizations (CLARK, 1982; 1983) that, aside from strengthening their bond, play a pivotal role in locating and maintaining close contact with one another (NIELSEN et al., 2019). Surface activities, including breaching (Fig. 1), tail and flipper-slapping, are also performed by both mothers and calves, yet the precise purpose of these behaviors remains not fully understood. Together, these activities generate loud sounds and conspicuous splashes, which may imply their involvement in multifaceted functions such as non-vocal communication, territoriality, and even mate attraction (WHITEHEAD, 1985; CLARK, 1990; DUNLOP et al., 2008).

Figure 1 - Breaching, a surface behavior seen being displayed by Southern Right Whales. Photos: Carletti, I.

The SRW exhibits a vocal repertoire consisting of numerous distinct call classes, originally characterized by Clark (1983) and more recently, with a specific focus on mother-calf pairs, by Dombroski et al. (2016). Among these, the upcall stands out as the most frequently detected call type through Passive Acoustic Monitoring (VAN PARIJS et al., 2009) (Fig. 2a). Termed as a contact call (CLARK, 1983), the upcall serves various behavioral contexts (PARKS & TYACK, 2005) and holds significance within mother-calf groups as well (DOMBROSKI et al., 2016). Additionally, other tonal calls such as 'downcall', 'pulsive', 'hybrid', 'tonal variable', 'tonal constant' and 'down-upcall' (Fig. 2b-g) are also emitted at the studied site, though to a lesser extent due to the contextual group dynamics (CLARK, 1983; PARKS & TYACK, 2005; DOMBROSKI et al., 2016).

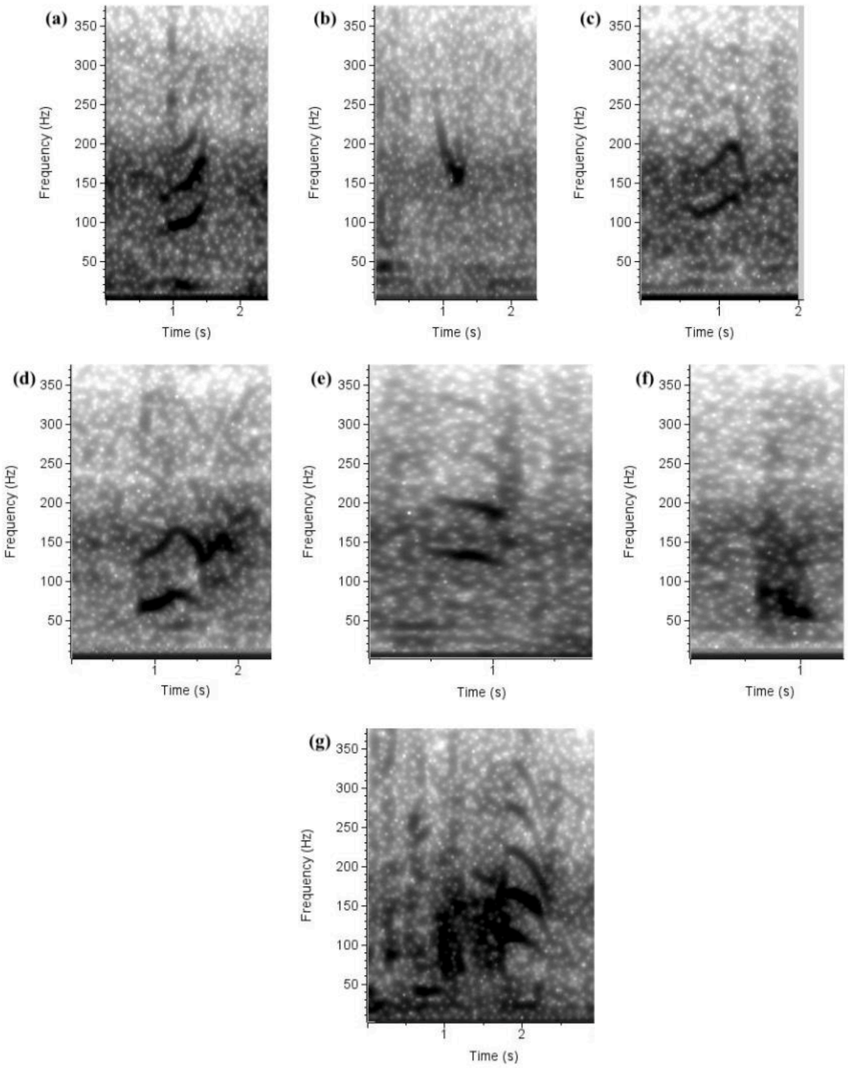

Figure 2 - Spectrogram of Southern Right Whale call classes recorded off Brazil: (a) upcall, (b) downcall, (c) down-upcall, (d) tonal variable call, (e) tonal constant call, (f) pulsive call, and (g) hybrid call.

The influence of anthropogenic noises on the communication of marine mammal species has been extensively documented (NOWACEK et al., 2007; WEILGART, 2007; CLARK et al., 2009). In response to these disturbances, these animals have demonstrated the ability to modify the structure of their vocalizations in order to uphold efficient communication (MILLER et al., 2000). Additionally, numerous species also have a common adaptive reaction aimed at evading detection by potential eavesdroppers, a phenomenon referred to as acoustic crypsis (RUXTON, 2009). This encompasses strategies such as diminishing their vocalization rates, lowering signal amplitudes, employing specific sound frequencies, or even entirely suspending communication (MORISAKA & CONNOR, 2007; MARTIN et al., 2018; NIELSEN et al., 2019; PARKS et al., 2019ab; DOMBROSKI et al., 2020). It is also well established that environmental factors, including wind, tides and temperature, wield influence over the acoustic behavior of marine mammals (URICK, 1983; ROGERS & COX, 1988). Strong winds, for instance, can create surface noise and turbulence, potentially masking or distorting vocalizations (WENZ, 1962; URICK, 1983; LARSEN & RADFORD, 2018). Changes in tidal rhythms can similarly wield an impact on communication; in turbulent waters, sound might scatter or undergo distortion (WENZ, 1962; URICK, 1983; LARSEN & RADFORD, 2018). The transmission and reception of signals can also be affected by variations in water temperature, resulting in divergent sound propagation (WENZ, 1962; URICK, 1983).

In calving grounds, SRW mothers exhibit a distinct form of acoustic crypsis: they opt for shallow-water nursery locations where the signal propagation and the detection ranges are limited (ZEH et al., 2022). In this scenario, the propagation traits of the environment play a crucial role to ensure a safe communication between mother-calf pairs (PARKS et al., 2019b; ZEH et al., 2022). Given that SRW mothers already adjust their vocal behavior to ensure effective communication with their offspring by choosing specific sites, we propose that there is an intricate relationship between environmental factors and the communication behavior of SRW. Currently, our understanding of vocal emission rates within right whale mother-calf pairs indicates variability based on their behavioral states (DOMBROSKI et al., 2016). It is also acknowledged that vocal rates can be influenced by the composition of the group (MELLINGER et al., 2007; VAN PARIJS et al., 2009). However, there remains a significant gap in our comprehension of their acoustics behavior. This gap encompasses the absence of data on both non-vocal and vocal cue rates, which are vital for utilizing PAM to gauge density estimations (CLARK et al., 2010; MARQUES et al., 2011).

Gaining a better understanding of SRW sounds production is extremely important not only to enhance our understanding of the functionality of acoustic behavior for communication among individuals, especially mothers and calves, but also to describe their cue rates and then inform the process of acoustic density estimation. Our aim here is to utilize both PAM and visual observations to elucidate the influence of the context and diverse environmental factors, such as wind, temperature and tide, on the incidence of calls and surface activities. By identifying the variables that exert an impact on right whale's communication, we pave the way for constructing predictive models for cue rates, utilizing the available covariates in distinct locations for future investigations.

Methodology

Data sampling

Uninterrupted acoustic data recording and visual monitoring were conducted within the Right Whale Environmental Protection Area (RWEPA), located at Praia de Itapirubá, in Santa Catarina State, Brazil (Fig. 3a-c). These monitoring efforts were carried out during the Southern Right Whale (SRW) breeding season in 2021 and 2022, between August and September. The monitored site was chosen because it offers an elevated vantage point conducive for shore-based observations. Additionally, the site was chosen due to the recognized concentration of SRW within the shallow and sheltered waters, rendering it a suitable location for simultaneous visual and acoustic monitoring.

Visual monitoring was undertaken to record surface activities, density and individual tracking of whales using shore-based equipment. In 2021, a Topcon CTS3007 total station was employed, while in 2022, a Topcon DT-05 theodolite was utilized. These instruments were linked to a laptop running *Mysticetus* software. Data collection transpired whenever meteorological conditions permitted, characterized by wind speeds below 10 m/s, absence of rain and no dense fog. A six-hour data collection window was adopted each day, with a deliberative break to mitigate peak sun glare. Additionally, data collection times were diversified across days to encompass potential diurnal behavioral trends.

Hourly environmental data encompassing temperature (ºC), wind speed (m/s), and an assessment of sea state both within and beyond the hydrophones array (graded on a scale from 0 denoting calm to 5 indicating numerous whitecaps) were systematically recorded. To monitor tidal dynamics and subsequent change in land station evaluation relative to underwater equipment, the position of the nearest buoy (ST1) was logged on an hourly basis. Tide predictions were sourced from the Brazilian Navy, with measurements recorded from the Imbituba Port in Santa Catarina State (28º13'.8 S 048º39'.0 W).

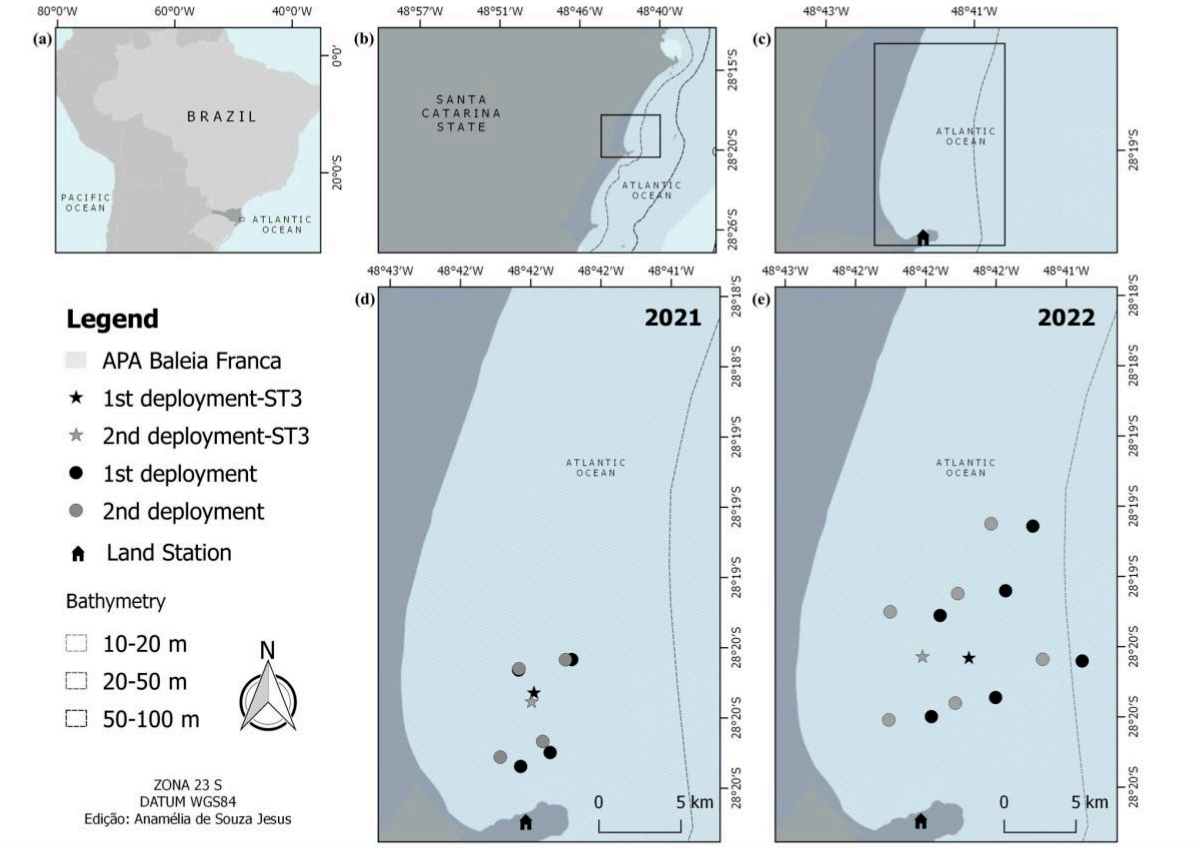

Figure 3 - Map of the study area. Array position of each deployment conducted in 2021 (d) and 2022 (e), with the central hydrophone (ST3) being acoustically analyzed.

The primary objective of the visual data collection was to validate the presence of whales within the acoustic array's detection range. To achieve this, focal-follow observations were conducted on whales located within the array polygon and approximately 500 meters surrounding its perimeter. These observations involved the additional recording of the following information: time, group composition (i.e. mother-calf, calf alone, adult alone or unknown), group position in the area (measured through angle determinations taken with the equipment's; whenever the group's position or behavioral state changed) and behavioral state of the group (recording the occurrence of specific behavioral events such as breaching, tail and flipper-slapping). Scans were conducted at 15-minutes intervals, thereby enabling the continuous tracking of the number of whales within the study area. Additionally, efforts were made to observe whale groups positioned beyond the buffer zone, where all the previous information was collected as well.

In 2021, acoustic data was collected during 20 days utilizing a 5-unit array of floor-mounted acoustic recorders (Ocean Instruments NZ Soundtrap ST300), configured to maintain continuous sampling at 48kHz/16bit. These recorders were synchronized at the moment they were placed. For the subsequent year, 2022, we collected acoustic data during 22 days using a 7-unit floor-mounted array of acoustic recorders (comprising ST300 and ST400 models) which sampled at a higher resolution of 96kHz/24bit. Throughout both years, the inter-unit spacing for the Soundtrap devices was maintained at approximately 500 meters. This specific distance was chosen to consider the propagation and transmission loss characteristics relevant to the nearshore habitats of Santa Catarina wintering ground. For deployment, each recorder was attached to a mooring made with a car tire filled with concrete, and two iron loops (Fig. 4a). The taller loop, approximately one meter in height, supported the recorder itself. Meanwhile, the smaller loop facilitated the management of cables connecting the mooring to surface buoys or markers (Fig. 4b).

Figure 4 – (a) Layout of the mooring used, with the SoundTrap attached to the taller loop; (b) Buoy used to mark the recorder's position.

Two deployments were performed annually (Fig. 3d,e) to facilitate the unloading and recharging of batteries for the Soundtraps units. After each deployment and before the recovery, an array calibration was carried out. This step was necessary to quantify the extent of clock drift in devices, including those associated with GPS, SoundTrap units, and total station/theodolite fixes. Subsequently, in-water time sync trials were initiated. This procedure entailed generating controlled noise within the array at predefined moments and known location. In 2021, employing a 2.5-meter iron bar and a hammer, distinct sounds were produced across the array's detection area. At each point, a series of 10 sound strikes (one every 10 seconds) were produced, with the GPS marking the waypoint for each sound and position of the iron bar (submerged in water) recorded using the total station. For 2022, a pinger (Sonotronics EMT-01-3) was adopted for array calibration. This involved placing the pinger within the water at various points within the array, ensuring its submersion for at least 2 minutes. Subsequent to each instance, GPS waypoints were marked, and the positions were ascertained through theodolite measurements. On-land time sync was also performed, in both years, before deployments and after the recovery, using the iron bar and following the previous protocol.

Data processing

Surface activities that could produce sound, such as breaching, tail and pectoral fin slapping, were selected from the visual monitoring records and summarized into 15-minutes intervals throughout the entire monitoring seasons. When assessing SRW vocalizations, only recordings from periods in which there was simultaneous visual monitoring were analyzed and this analysis was exclusively conducted using data from the central recorder unit (ST3 - Fig. 3d, e) within the array. This approach ensured the avoidance of double-counting calls and the overestimation of vocalizations. To execute this analysis, Raven PRO 1.6 software was employed. The spectrogram parameters were as follows: year 2021) sample rate = 48kHz/16bit; window = Hann; FFT = 7680; and overlap = 90%; year 2022) sample rate = 96kHz/24bit; window = Hann; FFT = 20000; and overlap = 90%. Energy levels (in dB) were quantified for each call, serving as a criterion to filter out those that could be emitted beyond the study area. Therefore, only calls with an estimated received level above 76 dB were considered. This threshold was determined by considering the overall energy (in dB) produced by calls close to the array (where calls with energy reaching 76dB appeared less faint) and the energy produced by humpback whale calls recorded during data collection (64±10 dB). Calls from SRWs that were masked by extremely high ambient noise, rendering accurate energy level determination unfeasible, were also excluded. Notably, on days when ambient noise was too high, the energy of the calls could appear artificially inflated. Thus, calls that met the threshold but appeared visually faint in comparison to others were omitted from the analysis. SRW vocalizations were then sorted into two classes - (1) upcall and (2) others, consisting of all the other call types produced by this species in the area - and also summarized into 15-minute intervals.

Data analysis

After following predefined data exploration protocols (see ZUUR et al, 2010), a set of generalized linear mixed models (GLMM) were fitted with a negative binomial error structure and a log link function (BOLKER et al., 2009; ZUUR et al., 2009) to assess whether the response variables total calls, upcalls and surface events showed variation based on each explanatory variable. In all models, a first-order autocorrelation term was included nested to the sampling day when the sample was collected to account for autocorrelation. The sampling day was also included as a random variable to address data overdispersion and we added a zero inflated term to deal with the excess of zeros in the response variables. The fixed explanatory variables included in the model encompassed the total number of whales in the area, surface temperature, wind speed, tide height and direction and the year. Interaction terms were not included to avoid convergence issues in model fitting. We also included the total number of whales as an offset since the more whales in the area, the greater the number of calls and surface events should be.

We built addictive models, including all predefined explanatory variables, selecting those determinants by simplifying the model from stepwise backward elimination. We then used Akaike Information Criterion (AIC) and Akaike weight to rank and find the most parsimonious model (BURNHAM & ANDERSON, 2002). Models were fitted in the R environment (R DEVELOPMENT CORE TEAM, 2019) with package 'glmmTMB' (MAGNUSSON et al., 2017). The model selection protocol used the R package 'MuMIn' (BARTON, 2022).

Collinearity was assessed after fitting the initial model with all possible explanatory variables. We considered plausible models when ΔAIC (model-minimum) < 2 (BURNHAM & ANDERSON, 2022). Scaled residuals checking was executed with the 'simulateResiduals' function of DHARMa package (HARTIG, 2018). Selected model predictions were plotted using the sjPlot package (LUDECKE, 2020). The significance level in all statistical tests was 95% ($p < 0.05$).

Finally, to evaluate the feasibility of predicting the number of whales based on the number of upcalls, total calls or surface events in 15-minutes intervals, we constructed three additional models using a Poisson distribution and log link function. Wind speed was included in all models as covariate, and then we fitted one model including the number of upcalls divided by the total number of whales in the respective interval as explanatory variables, a second model including total calls divided by the total number of whales, and a last model including surface events divided by the total number of whales. Again, in all models, a first-order autocorrelation term was included nested to the sampling day when the sample was collected to account for autocorrelation. Subsequently, we evaluated whether the observed values fell within the confidence intervals predicted by the fitted model. If so, based on upcalls, total calls and/or surface events, we assumed that our model could be used to predict the number of whales in the area, while accounting for the effects of context and environmental variables.

Results

Summary of vocal behavior

In the total of 112 analyzed hours of acoustic recordings, 4896 SRW calls were extracted for analysis. During the sample period (12 days in 2021 and 17 days in 2022), there were predominantly mother-calf pairs, with an emission average of 2.38 calls/hour in 2021 and 8.96 calls/hour in 2022. Upcalls were the most frequent vocalization type representing 76% of calls, which was already expected due to the group's composition on site.

Summary of surface behavior

During the visual monitoring period carried out in 2021 and 2022, a total of 235 surface activities events displayed by SRWs were recorded, of which 122 were breaching's, 74 tail-slapping's and 37 flipper-slapping's. Those activities are here considered a form of non-vocal communication as they produced sounds that could be heard on the analyzed SoundTrap, but the scope of this paper did not include the acoustic description of these activities.

Factors affecting acoustic and surface behaviors

For the response variables total calls, among the nine models fitted the most parsimonious model suggests a significant effect only from the total number of whales in the area and, marginally, wind speed (Table 1). Total call emission declined when more whales occupied the area (estimate = -0.053, se = 0.035, z-value = -2.121, p = 0.033; Fig. 5a) while increasing in higher wind intensity (estimate = 0.099, se = 0.058, z-value = 1.720, p = 0.085; Fig. 5b). Regarding upcalls, among the eight fitted models, the most parsimonious one suggests an effect of wind speed and a variation between years in the emission frequency (Table 1). These calls were more frequent with an increase in wind intensity (estimate = 0.116, se = 0.058, z-value = 1.985, p = 0.047; Fig. 5c) and were used more often throughout 2021 when compared to 2022 (estimate = -0.753, se = 0.375, z-value = -2.006, *p* = 0.044; Fig. 5c), regardless of the number of whales. Regarding surface events, among the six adjusted models, the most parsimonious one suggests that the occurrence of these behaviors may vary depending on wind intensity, the year, and the total number of whales in the area (Table 1). Wind intensity marginally increases the number of surface events (estimate = 0.116, se = 0.074, z-value = 1.576, *p* = 0.109; Fig. 5d), and these events were more frequent in 2021 when compared to 2022 (estimate = -1.252, se = 0.467, z-value = -2.679, *p* = 0.007; Fig. 5e). Interestingly, the likelihood of surface events occurring marginally decreases with an increase in the number of whales in the area (estimate = -0-062, se = 0.039, z-value = -1.572, *p* = 0.115; Table 1; Fig. 5f).

Table 1 – Generalized linear mixed models (GLMMs) for the response variables as function of explanatory variables. Only model fixed structure showed. Tide direction (TideD), surface temperature (Temp). Models are ranked by the lowest Akaike Information Criterion (AICc). Relative support for the models is given by the difference in delta AIC and AIC weights, while the model's goodness of fit is given by log-likelihood (logLik). df: degrees of freedom.

<u>GLMMs Models</u>: Total calls ~ <u>fixed structure</u>	df	logLik	AICc	delta	weight
Total whale + Wind speed	8	-1357.72	2731.75	0.00	0.321
Total whale + Wind speed + Year	9	-1356.95	2732.30	0.54	0.244
Year	8	-1358.21	2732.75	0.99	0.195
Total whale + Year	8	-1358.82	2733.97	2.22	0.105
Total whale + Temp + Wind speed + Year	10	-1356.93	2734.36	2.61	0.087
Total whale + Temp + Tide + Wind speed + Year	11	-1356.86	2736.30	4.55	0.032
Sea state + Total whale + Temp + Tide + Wind speed + Year	13	-1356.04	2738.90	7.15	0.009
Sea state + Total whale + Temp + Tide + TideD + Wind speed + Year	14	-1356.01	2740.97	9.21	0.003
<u>GLMMs Models</u>: Upcalls ~ <u>fixed structure</u>	df	logLik	AICc	delta	weight
Wind speed + Year	8	-1236.93	2490.17	0.00	0.583
Wind speed * Year	9	-1236.80	2492.01	1.83	0.233
Sea state + Total whale + Wind speed + Year	11	-1235.40	2493.39	3.21	0.117
Sea state + Total whale + Tide + Wind speed + Year	12	-1235.39	2495.49	5.32	0.040
Sea state + Total whale + Temp + Tide + Wind speed + Year	13	-1235.16	2497.14	6.97	0.017
Sea state + Total whale + Temp + Tide + TideD + Wind speed + Year	14	-1235.11	2499.16	8.99	0.006
Sea state + Wind speed + Year	9	-1242.01	2502.43	12.26	0.001
<u>GLMMs Models</u>: Surface events ~ <u>fixed structure</u>	df	logLik	AICc	delta	weight
Total whale + Wind speed + Year	8	-368.82	753.96	0.00	0.376
Total whale + Year	7	-370.06	754.37	0.41	0.307
Total whale + Tide + Wind speed + Year	9	-368.49	755.38	1.41	0.185
Total whale + Temp + Tide + Wind speed + Year	10	-368.14	756.77	2.80	0.092
Total whale + Temp + Tide + TideD + Wind speed + Year	11	-368.13	758.85	4.89	0.032
Sea state + Total whale + Temp + Tide + TideD + Wind speed + Year	13	-367.90	762.63	8.67	0.004

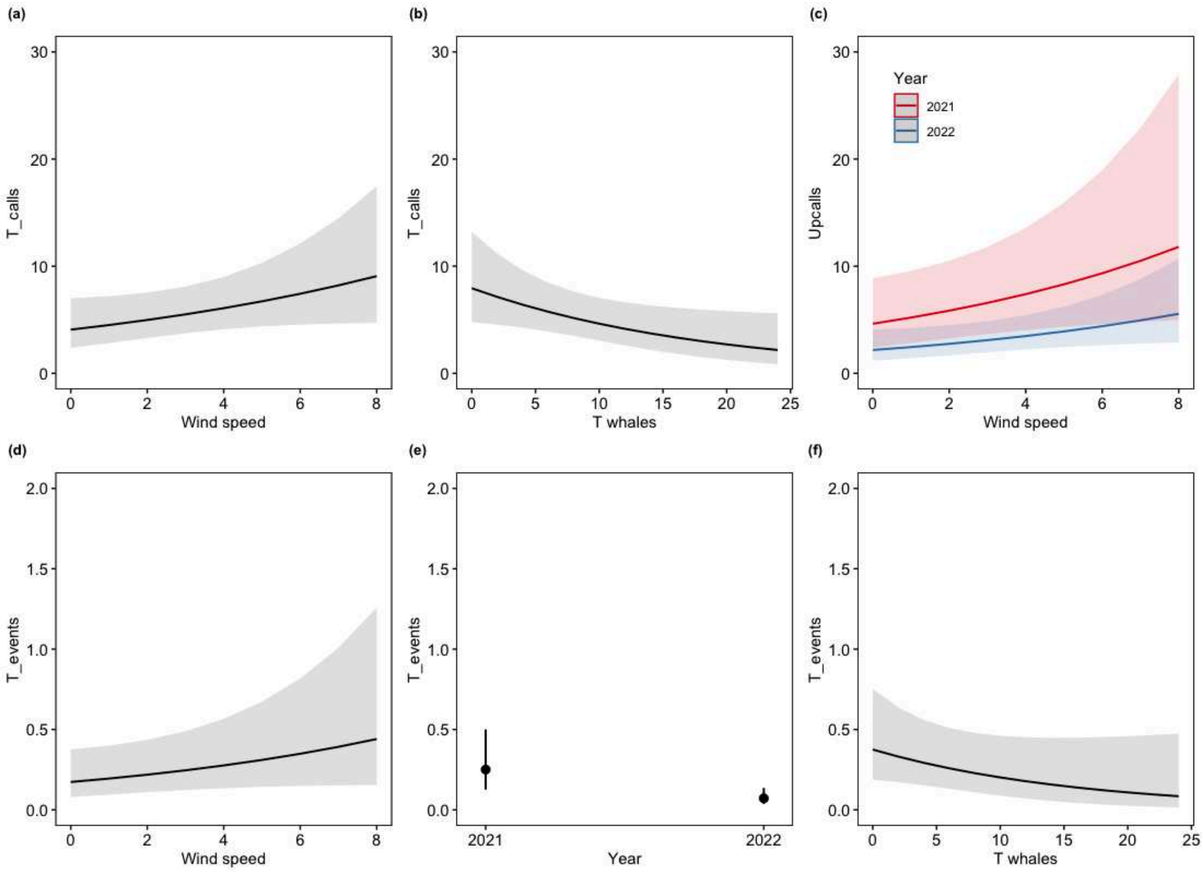

Figure 5 – Predicted values of fixed effects from the most parsimonious models (Tables 1, 2 and 3) describing the total calls emission (a, b), upcalls emission (c) and total surface events (d-f) of SRW as a function of wind speed, total whales or sampling years. Whiskers represent standard errors.

Predicting whale's abundance

Considering the effect of wind and the total number of whales on the emission of acoustic signals and/or surface behaviors, the adjusted models for predicting whale abundance included wind and the density of upcalls, wind and total calls, or wind and surface events as response variables (dividing the number of records of upcalls, total calls and surface events by the total number of whales observed within a 15-minute interval). Both the model including upcalls and the models including total calls and surface events demonstrated reasonable predictive capability, as the observed data fell within the confidence intervals predicted by the models with the following similar proportions: 79.8 (upcalls), 79.8 (total calls) and 80.22 (surface events). However, there is still some imprecision in the models, with a coefficient of variation in their predictions of: 35.6% (upcalls), 35.4% (total calls) and 34.8% (surface events; Fig. 6).

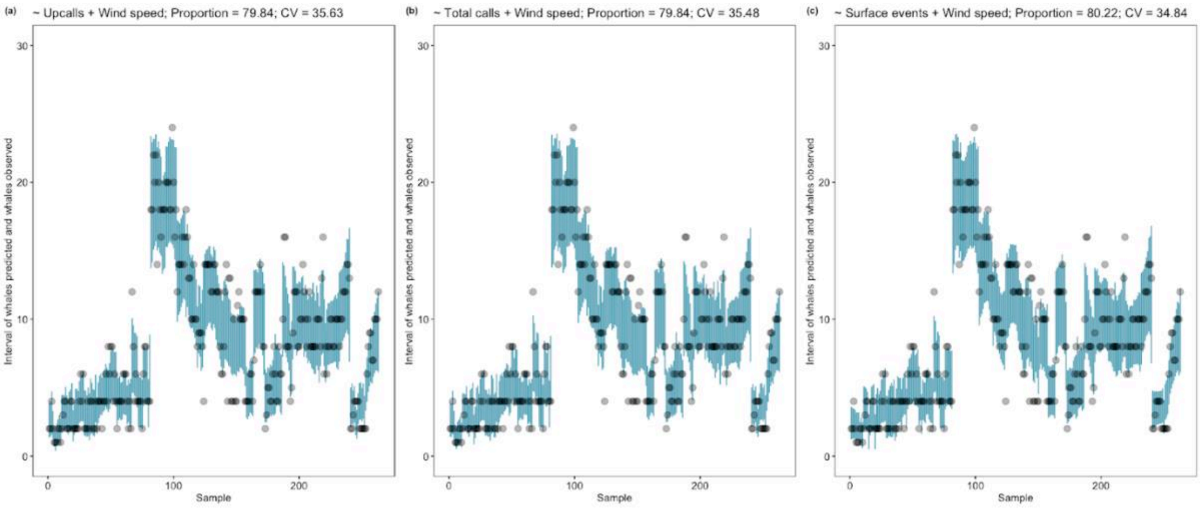

Figure 6 – Predicted values by the models aiming to predict whale abundance based on the number of upcall records (a), total call records (b), and surface behavior events (c). Green bars represent the confidence intervals of the values predicted by each model, and black dots represent the observed data.

Discussion

When investigating the relationship between environmental factors and the behavioral and acoustical ecology of Southern Right Whales (SRW) in southern Brazil, we have uncovered results that contribute to the understanding of how these marine mammals interact with their environment and employ acoustics for this purpose. Additionally, we assessed the effectiveness of using rates of acoustic cue emissions to estimate the density of these species through passive acoustic monitoring, an approach that has been explored in previous works with other species (e.g, MARQUES et al., 2012). Concurrently, as we evaluated the rates of surface behavior occurrences, we discussed the potential role of these behaviors in the non-vocal communication of the SRW, as also explored for other studies and species (WHITEHEAD, 1985; DUNLOP et al., 2008; SERRES et al., 2023), especially in the context of mother-calf pairs. If non-vocal sounds of surface behaviors serve as an alternative to vocalizations when conditions for the latter are not suitable, perhaps these sounds can also serve as cues to assist in predicting the density of individuals in a specific area.

One of the key findings of our study was the evidence of a density-dependent relationship between the emission of calls and surface activities in SRW. We observed that as the number of whales in the area increases, both the individual acoustic emissions and surface behavioral events decrease. This modulation related to the number of individuals, particularly in the context of acoustic emissions, which are widely accepted as having a communication function, has also been documented for SRW populations in New Zealand (WEBSTER et al., 2019) and South Africa (HOFMEYR-JURITZ & BEST, 2011). This suggests that these species might employ a form of acoustic crypsis, potentially aiding them in avoiding predators or reducing interactions with conspecifics in densely populated areas (MELLINGER et al., 2007; VAN PARIJS et al., 2009; DOMBROSKI et al., 2016).

Our analysis also revealed a correlation between wind intensity and the emission of calls and surface activities. Since only this environmental variable positively influences acoustic emissions and the occurrence of surface behaviors, it is not possible to support the hypothesis that the use of surface behaviors is an alternative form of communication when environmental conditions are not favorable for acoustic emissions. We found that when wind intensity increased, there was a corresponding increase in the frequency of calls, as well as surface behaviors. This can be attributed to the role of wind in the transmission and propagation of sounds underwater (URICK, 1983; MENZE et al., 2017). Turbulence in the water caused by strong winds can distort the signals emitted, making a higher emission rate necessary, whether through vocal or non-vocal signals, for the signal to reach the receiver correctly. Therefore, SRW might be responding to the increased noise levels by being more acoustically active. This interaction highlights the influence of environmental factors on the species' acoustic behavior and underscores the need to consider the context and environmental conditions when quantifying acoustic emissions, especially when attempting to use these emissions to infer the density of individuals in an area. Furthermore, it shows the need to include other environmental variables in future studies, e.g. precipitation, as is a factor known for producing noise (URICK, 1983). While many describe how anthropogenic noise affects marine mammals (PARKS et al., 2007; RICHARDSON et al., 2013; ERBE et al, 2018), this is the first study to demonstrate the influence of abiotic noise on the acoustic and behavioral ecology of SRW.

Our results also revealed variation between years in the rates of acoustic emissions and the occurrence of surface behaviors. Specifically, we found that calls and surface behaviors were more frequent in 2021 than in 2022. This difference in behavior could be attributed to the number of whales in each breeding season, or even variations in environmental factors not assessed by this study, or simply individual variations, as not necessarily, the same individuals visited the area in both study years (LIN et al., 2015; MENZE et al., 2017; WARREN et al., 2017; FILÚN & VAN OPZEELAND, 2023). According to aerial surveys carried out by the *Instituto Australis* during the breeding season in 2021 and 2022, a total of 120 and 228 whales, respectively, were sighted inside the RWEPA (data obtained from *Instituto Australis* website). As discussed above, density dependence can directly affect the acoustics and behavior of SRWs, so in the years with more whales, there was less behavioral activity. This finding highlights the importance of considering temporal variability when studying the ecology of these whales and underscores the need for further research, including additional variables and longer monitoring periods, to elucidate and validate these patterns.

Assessing the feasibility of estimating SRW abundance based on the variation in acoustic emission rates (MARQUES et al, 2011; 2012; PARKS et al., 2019; DOMBROSKI et al 2016; 2017; 2020) was one of the primary objectives of this study. To achieve this, we fitted a model considering behavioral variables and wind, the only environmental variable influencing behavior, as predictors of the number of whales. The results indicate that such predictions are indeed possible, suggesting that the considered behavioral variables have the potential to serve as reliable indicators of population density. However, it is worth noting that the models used in this study could be further improved. To enhance the precision and accuracy of predictions, it is recommended to include additional covariates and expand the dataset. This underscores the need for ongoing research and data collection. Furthermore, it indicates that the attempt to estimate the density of SRW individuals from acoustic emission rates recorded in the context of a PAM is promising.

Acoustic monitoring allows researchers to gather valuable data on acoustic behavior of SRW, offering insights into their communication strategies. Meanwhile, visual monitoring gathers additional information complementing acoustic data and providing direct observations of surface behaviors, weather conditions, and groups context (size, sex and age). Combining these two methods offers a more comprehensive view of SRW ecology and allows researchers to account for the limitations of each approach (CATO et al., 2006; WOOD, 2010; RAYMENT et al., 2018; DALPAZ et al., 2021). On the other hand, there are several advantages of acoustic observations, as compared to visual ones (Ichikawa et al., 2006), such as the ability to maintain constant detection over extended periods, including nighttime monitoring and in periods with rain and fog. Reasons that also had influence on our data collection, such as rainy days or suspending the visual observations when the wind intensity reached 10 m/s, are directly linked to our limitations with visual monitoring. Therefore, data were not visually collected under these conditions, presenting a lack of valuable information for a complete understanding of the influence of these abiotic variables on the acoustic and behavioral ecology of right whales.

This is the first in-depth exploration of how environmental factors influence the behavioral and acoustical ecology of SRW in Brazil. Our data set was not large enough to deeply address our questions, but the results reported here is a valuable standard that can be compared in the future. Limitation in time to synchronize the array and then be able to precisely locate the acoustically active whale was also the reason we could not describe the acoustic parameters of surface events and have a more precise emission call rate. Nevertheless, the results obtained here indicate that further research on SRW non-vocal communication is needed. Nevertheless, our results demonstrate the intricate relationship between the variables, shedding light on the complex nature of their communication. The ability to predict whale abundance based on these variables holds promise for conservation efforts, but further research is required to enhance the precision of such models. This study emphasizes the importance of disparate approaches to gain a more complete understanding of SRW and their interactions with the environment.

ACKNOWLEDGMENT

Funding for fieldwork was granted to S.E.P, L.T. and J.R.G.D., and provided by the Living Marine Resources, the U.S Navy Marine Species Monitoring Program. License for data collection at Right Whale EPA was granted to J.R.G.D. through SISBIO number 60324. Thanks to CNPq, FAPESC and the UFSC Graduation Program in Ecology for providing master scholarships to I.M.C. We acknowledge all people that collaborated with us in order to make this research possible, including P.A.F. from ICMBIO, Instituto Australis and Syracuse University for all the logistical support; and colleagues for assistance with data processing. F.G.D-J. received research funding from Conselho Nacional de Pesquisa e Desenvolvimento Tecnológico (308913/2022-0), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (88887.374128/2019-00), and Fundação de Amparo à Pesquisa do Estado de Santa Catarina (2021TR387 and 2021TR000581). We are also grateful for P.S-L. and B.R. comments on early drafts of our manuscript, and A.S.J. for creating the map.

CITED LITERATURE

Barton K. (2022) Package 'mumin'. R package Version 1.18, 439.

Best P.B., Ruther H. (1992) Aerial photogrammetry of southern right whales, *Eubalaena australis*. J. Zool. 228:595-614.

Bolker B.M., Brooks M.E., Clark C.J., Geange S.W., Poulsen J.R., Stevens M.H.H., White J.S.S. (2009) Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology & Evolution 24(3):127-135.

Burnham K.P., Anderson D.R. (2022) Model selection and multimodel inference: a practical information-theoretic approach. New York, Springer-Verlag.

Cato D., McCauley R., Rogers T., Noad M. (2006) Passive acoustics for monitoring marine animals - progress and challenges. Proceedings of Acoustics, p 453-460.

Clark C.W. (1982) The acoustic repertoire of the Southern Right Whale, a quantitative analysis. Animal Behavior 30:1060-1071.

Clark C.W. (1983) Acoustic communication and behavior of the Southern Right Whale (*Eubalaena australis*). In: Payne R. (ed) Communication and Behavior of Right Whales. Westview Press for the American Association for the Advancement of Science Boulder, Colorado, p 163-198.

Clark C.W. (1990) Acoustic behavior of mysticete whales. In: Thomas J., Kastelein R. (ed) Sensory Abilities of Cetaceans. Plenum Press, New York, p 571-583.

Clark C.W., Clapham P.J. (2004) Acoustic monitoring on a humpback whale (*Megaptera novaeangliae*) feeding ground shows continual singing into late Spring. Proceedings of the Royal Society 271:1051-1057.

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 Ecol Prog Ser, 395:201-222.

Clark C.W., Brown M.W., Corkeron P. (2010) Visual and acoustic surveys for North Atlantic right whales, *Eubalaena glacialis*, in Cape Cod Bay, Massachusetts, 2001-2005: management implications. Marine Mammal Science, 26:837-854.

Dalpaz L., Paro A.D., Daura-Jorge F.G., Rossi-Santos M., Norris T.F., Ingram S.N., Wedekin L.L. (2021) Better together: analysis of integrated acoustic and visual methods when surveying a cetacean community. Marine Ecology Progress Series, 678:197-209.

Dombroski J.R.G., Parks S.E., Groch K.R., Flores P.A.C., Sousa-Lima R.S. (2016) Vocalizations produced by southern right whale (*Eubalaena australis*) mother-calf pairs in a calving ground off Brazil. J Acoust Soc Am 140:1850-1857.

Dombroski J.R.G., Parks S.E., Groch K.R., Flores P.A.C., Sousa-Lima R.S. (2017) Upcall production by southern right whale (*Eubalaena australis)* mother-calf pairs may be independent of diel period in a nursery area. Marine Mammal Science, 33(2).

Dombroski J.R.G., Parks S.E., Flores P.A.C., Martín Lopes L.M., Shorter K.A., Groch K.R. (2020) Animal-borne tags provide insights into the acoustic communication of southern right whales (*Eubalaena australis*) on the calving grounds. J Acoust Soc Am 147:EL498-EL503.

Dunlop R.A., Cato D.H., Noad M.J. (2008) Non-song acoustic communication in migrating humpback whales *(Megaptera novaeangliae*). Marine Mammal Science, 24(3):613-629.

Dunlop R.A., Noad M.J., Cato D.H., Kniest E., Miller P.J.O., Smith J.N., Stokes M.D. (2013) Multivariate analysis of behavioral response experiments in humpback whales (*Megaptera novaeangliae*). Journal of Experimental Biology 216(5):759-770.

Elwen S.H., Best P.B. (2004) Environmental factors influencing the distribution of southern right whales (*Eubalaena australis*) on the south coast of South Africa: broad scale patterns. Marine Mammal Science 20(3):567-582.

Erbe C., Dunlop R., Dolman S. (2018) Effects of noise on marine mammals. In: Effects of anthropogenic noise on animals, p 277-309.

Filún D., van Opzeeland (2023) Spatial and temporal variability of the acoustic repertoire of Antarctic minke whales (*Balaenoptera bonaerensis*) in the Weddell Sea. Sci Rep, 13:11861.

Groch K.R. (2000) Ocupação preferencial de áreas de concentração pela Baleia Franca Austral, *Eubalaena australis* (Desmoulins, 1822), CETACEA, MYSTICETI, no litoral sul do Brasil. Biociências. Universidade Federal do Rio Grande do Sul, Porto Alegre.

Groch K.R., Palazzo J.J.T., Flores P.A.C., Adler F.R., Fabian M.E. (2005) Recent rapid increases in the right whale (*Eubalaena australis*) population off southern Brazil. Latin American Journal of Aquatic Mammals, 4.

Groch K.R., Flores P.A.C. (2011) Census of the Southern Right Whales off Brazil. IWC Southern Right Whale Assessment Workshop.

Hartig F. (2018) DHARMa: residual diagnostics for hierarchical (multi-level mixed) regression models. R package version 0.2,0.

Larsen O.N., Radford C. (2018) Acoustic conditions affecting sound in communication in air and underwater. In: Slabbekoorn H., Duolingo R., Popper A., Fay R. (ed) Effects of anthropogenic noise on animals. Springer Handbook of Auditory Research, Springer, New York. 66.

Lin T-H., Yu H-Y., Chen C-F., Chou L-S. (2015) Passive acoustic monitoring of the temporal variability of Odontocete tonal sounds from a long-term marine observatory. PLoS ONE, 10(4):e0123943.

Lodi L., Siciliano S., Bellini C. (1996) Ocorrências e conservação da baleia-franca-do-sul, *Eubalaena australis*, no litoral do Brasil. Papéis Avulsos de Zoologia 39:307-328.

Ludecke D. (2020) sjPlot: Data visualization for statistics in social science. R package version 2.8,6.

Magnusson A., Skaug H., Nielsen A., Berg C., Kristensen K., Maechler M., van Bentham K., Sadat N., Bolker B., Brooks M. (2017) Package 'glmmtmb'. R Package Version 0.2. 0, 25.

Marques T.A., Munger L., Thomas L., Wiggins S., Hildebrand J.A. (2011) Estimating North Pacific right whale *Eubalaena japonica* density using passive acoustic cue counting. Endangered Species Research, 13:163-172.

Marques T.A., Thomas L., Martin S.W., Mellinger D.K., Ward J.A., Moretti D.J., Harris D., Tyack P.L. (2012) Estimating animal population density using passive acoustics. Biological reviews of the Cambridge Philosophical Society 88:287-309.

Martin M.J., Gridley T., Elwen S.H., Jensen F.H. (2018) Heavisides dolphins (*Cephalorhynchus heavisidii*) relax acoustic crypsis to increase communication range. Proc R Soc 285:20181178.

Mellinger D.K., Stafford K.M., Moore S.E., Dziak R.P., Matsumoto H. (2007) An overview of fixed passive acoustic observation methods for cetaceans. Oceanography 20:36-45.

Menze S., Zitterbart D.P., van Opzeeland I., Boebel O. (2017) The influence of sea ice, wind speed and marine mammals on Southern Ocean ambient sound. R Soc Open Sci, 4:160370.

Miller P.J., Biassoni N., Samuels A., Tyack P.L. (2000) Whale songs lengthen in response to sonar. Nature, 405(6789):903.

Morisaka T., Connor R.C (2007) Predation by killer whales (*Orcinus orca*) and the evolution of whistle loss and narrow-band high frequency clicks in odontocetes. J Evol Biol 20:1439-1458.

Nielsen M.L.K., Bejder L., Videsen S.K.A., Christiansen F., Madsen P.T. (2019) Acoustic crypsis in southern right whale mother-calf pairs: infrequent, low-output calls to avoid predation? J Exp Biol 222:jeb190728.

Nowacek D.P., Thorne L.H., Johnston D.W., Tyack P.L. (2007) Responses of cetaceans to anthropogenic noise. Mammal Review, 37(2):81-115.

Oswald J.N., Barlow J., Norris T.F. (2003) Acoustic identification of nine Delphinid species in the Eastern Tropical Pacific Ocean. Marine Mammal Science 19(1):20-37.

Parks S.E., Tyack P. (2005) Sound production by North Atlantic right whales (*Eubalaena glacialis*) in surface active groups. J Acoust Soc Am 117:3297-3306.

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 acoustic communication. J Acoust Soc Am, 122(6):3725-3731.

Parks S.E., Cusano D.A., Van Parijs S.M., Nowacek D.P. (2019a) North Atlantic right whale (*Eubalaena glacialis*) acoustic behavior on the calving grounds. J Acoust Soc Am 146:EL15-EL21.

Parks S.E., Cusano D.A., Van Parijis S.M., Nowacek D.P. (2019b) Acoustic crypsis in communication by North Atlantic right whale mother-calf pairs on the calving grounds. Biology Letters 15:20190485.

Payne R.S., McVay S. (1971) Songs of Humpback Whales. Science 173:585-597.

R Development Core Team (2019) R: a language environment for statistical computing.

Raven Pro: Interactive Sound Analysis Software (Version 1.6) Ithaca, NY: The Cornell Lab of Ornithology.

Rayment W., Webster T., Brough T., Jowett T., Dawson S. (2018) Seen or heard? A comparison of visual acoustic autonomous monitoring methods for investigating temporal variation in occurrence of southern right whales. Marine Biology, 165:12.

Renault-Braga E.P., Groch K.R., Flores P.A.C., Secchi E.R., Dalla-Rosa L. (2018) Area usage estimation and spatiotemporal variability in distribution patterns of southern right whales, *Eubalaena australis*, of southern Brazil. Marine Ecology, 39(3):EL12506.

Richardson W.J., Greene C.R.Jr, Malme C.I., Thompson D.H. (2013) Marine mammals and noise. Academic Press.

Rogers P.H., Cox M. (1988) Underwater sound as a biological stimulus. In: Atema J., Fay R.R., Popper A.N., Tavolga W.N. (ed) Sensory biology of aquatic animals. Springer, New York. p 131-149.

Ruxton G.D. (2009) Non-visual crypsis: a review of the empirical evidence of camouflage to senses other than vision. Phil Trans R Soc B, 364:549-557.

Sayigh L.S. (2014) Cetacean acoustic communication. In: Witzany G. (ed) Biocommunication of animals. Springer, Dordrecht, p 275-297.

Serres A., Lin W., Liu B., Chen S., Li S. (2023) Context of breaching and tail slapping in Indo-Pacific humpback dolphins in the northern South China Sea. Behavioral Ecology and Sociobiology,77:64.

Seyboth E., Groch K.R., Secchi E.R., Dalla Rosa L. (2015) Habitat use by southern right whales, *Eubalaena australis* (Desmoulins, 1822), in their main northernmost calving area in the western South Atlantic. Marine Mammal Science, n.a-n.a.

Simões-Lopes P.C., et al. (1992) Identificação, movimentos e aspectos biológicos da baleia-franca-austral (*Eubalaena australis*) na costa sul do Brasil. III Reunión de Trabajo de Expertos en Mamíferos Acuáticos de América del Sur, p 62-65.

Thomas P.O., Taber S.M. (1983) Mother-infant interaction and behavioral development in southern right whales, *Eubalaena australis*. Behavior 88:42-60.

Tyack P.L. (2000) Functional aspects of cetacean communication. In: Mann J., Connor R.C., Tyack P.L., Whitehead H. (ed) Cetacean Society: Field studies of dolphins and whales. The University of Chicago Press, Chicago, p 270-307.

Urick R.J. (1983) Principles of underwater sound. 3rd ed. McGraw Hill Book Company, New York.

Van Parijs S.M., Clark C.W., Sousa-Lima R.S., Parks S.E., Rankin S., Risch D., Van Opzeeland I.C. (2009) Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. Mar Ecol Prog Ser 395:21-36.

Warren V.E., Marques T.A., Harris D., Thomas L., Tyack P.L., Soto N.A., Hickmott L.S., Johnson M.P. (2017) Spatial-temporal variation in click production rates of beaked whales: Implications for passive acoustic density estimation. J Acoust Soc Am, 141:1962-1974.

Watkins W.A., Schevill W.E. (1976) Right whale feeding and baleen rattle. Journal of Mammalogy, 57(1):58-66.

Weilgart L.S. (2007) The impacts of anthropogenic ocean noise on cetaceans and implications for management. Canadian Journal of Zoology, 85(11):1091-1116.

Wenz G.M. (1962) Acoustic ambient noise in the ocean: spectra and sources. J Acoust Soc Am, 34:1936-1956.

Whitehead H. (1985) Why whales leap. Scientific American 252:84-93.

Wood J. (2010) Marine Mammal Species Conservation: A review of developments in the uses of acoustics. J International Wildlife Law & Police, 13:311-325.

Zeh J.M., Dombroski J.R.G., Parks S.E. (2022) Preferred shallow-water nursery sites provide acoustic crypsis to southern right whale mother-calf pairs. Royal Society Open Science 9:220241.

Zuur A.F., Ieno E.N., Walker N.J., Savaliev A.A., Smith G.M. (2009) GLMM and GAMM. Mixed effects models and extensions in ecology with R, p.323-341.

Zuur A.F., Ieno E.N., Elphick C.S. (2010) A protocol for data exploration to avoid common statistical problems. Methods in Ecology and Evolution 1(1):3-14.

4. CONSIDERAÇÕES FINAIS DA DISSERTAÇÃO

- Esta é a primeira discussão sobre o impacto de fatores ambientais na ecologia acústica e comportamental de baleias-francas austrais.

- Até o momento, poucos estudos abordaram os comportamentos de superfície da espécie e suas potenciais funções como meio de comunicação não-vocal.

- Observamos uma clara tendência de dependência de densidade, onde tanto a emissão de vocalizações quanto as atividades de superfície diminuem com o aumento do número de baleias presentes.

- Nossas análises revelaram que a intensidade do vento está correlacionada com a emissão de chamados e a realização de comportamentos de superfície. Portanto, em condições de vento mais intenso, tanto as vocalizações quanto as atividades de superfície aumentam.

- Demonstramos que variáveis comportamentais e ambientais podem ser utilizadas como preditores do número de baleias presentes em uma determinada área. Com base em nossos modelos e resultados, concluímos que é possível realizar estimativas de densidade por meio de metodologias acústicas, embora seja necessário aprimorar os modelos incorporando novas covariáveis e aumentando a quantidade de dados disponíveis.

- Salientamos a importância de complementar as metodologias acústicas com outras abordagens para enriquecer a qualidade e a quantidade de informações coletadas.

- Este estudo enfatiza a necessidade de adotar diversas abordagens metodológicas para obter uma compreensão mais abrangente sobre a ecologia acústica e comportamental da baleia-franca austral.