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USO DO HABITAT POR CETÁCEOS NO SUL E SUDESTE DO BRASIL

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"I thought I would sail about a little and see the watery part of the world..." Herman Melville, Moby Dick

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RESUMO

A distribuição das espécies de cetáceos, que em sua maioria são predadores superiores, é influenciada principalmente pela disponibilidade de suas presas que, por sua vez, têm uma dinâmica que depende das relações tróficas e das características ambientais. Os cetáceos que habitam áreas oceânicas apresentam distribuições amplas, enfrentando poucas barreiras físicas para realizar grandes deslocamentos, e, em geral, estão preferencialmente associados a relevos oceânicos mais proeminentes (e.g. quebra da plataforma continental) e locais mais produtivos como áreas próximas de ressurgências e frentes térmicas. Por outro lado, cetáceos costeiros tendem a formar populações menores, residentes e habitam áreas geográficas restritas, como desembocadura de rios e estuários que apresentam maior estabilidade na disponibilidade de presas. Identificar padrões de distribuição de cetáceos pode auxiliar o desenvolvimento de ações para sua conservação. Os principais objetivos dessa tese foram investigar os padrões de distribuição e diversidade dos cetáceos na plataforma continental externa e talude do sul e sudeste do Brasil e o padrão de uso do habitat por uma população do boto (Tursiops truncatus) que habita uma área costeira no sul do Brasil. No ANEXO I realizou-se uma análise exploratória utilizando índices ecológicos de diversidade e densidades de kernel para investigar padrões de diversidade e distribuição de todas as espécies identificadas em 8 cruzeiros dedicados à observação de cetáceos realizados em áreas oceânicas do sudeste e sul do Brasil. Foram avistados um total de 503 grupos e identificadas 21 espécies. A diversidade de espécies variou sazonalmente. Em geral, densidades de cetáceos foram maiores na primavera do que no outono. O cachalote (Physeter macrocephalus) foi a espécie mais frequente e se distribuiu principalmente na área sul e em profundidades maiores que 1000m nas duas estações. Avistagens do golfinho-comum (Delphinus delphis) ocorreram somente na área sul e sua densidade diminuiu em áreas de maior densidade de golfinhos-pintados-do-Atlântico (Stenella frontalis) principalmente próximos à isobata de 250m. As densidades de golfinho-rotador (Stenella longirostris) e golfinho-pintado-pantropical (Stenella attenuatta) aumentaram em menores latitudes e além da quebra de plataforma. Tursiops truncatus e a baleia-piloto-de-peitorais-longas (Globicephala melas) formaram grupos mistos e foram observados ao longo da área de estudo próximos à isóbata de 500m. O golfinho-de-Risso (Grampus griseus) ocorreu em maior frequência na área sul e sua densidade aumentou em profundidades maiores que 600m. Como era esperado, a densidade de baleias foram maiores durante a primavera na área sudeste. No ANEXO II os padrões de abundância e distribuição do cachalote no talude sul e sudeste do Brasil foram modelados utilizando amostragem de distâncias em transecções lineares e modelos aditivos generalizados. A taxa de encontro e o número de avistagens do cachalote foram maiores na primavera de 2012, representando cerca de 1/3 de todos os registros. A estimativa de abundância variou entre 177 (CV = 0,44) no outono de 2013 e 1516 (CV = 0,34) na primavera de 2012, considerando a máxima probabilidade de detecção na transecção ($g_{(0)} = 1$). Esses valores aumentaram para 204 (CV = 0,46) e 1743 (CV = 0,34), respectivamente, quando considerado um $g_{(0)} = 0.87$. De acordo com as curvas suavisadoras estimadas pelo modelo, a densidade do cachalote aumentou em águas mais profundas, em maiores latitudes e onde houveram um maior valor de densidade acústica biológica(NASC) e gradiente de temperatura superficial do mar. No ANEXO III foram descritos os padrões de distribuição do ecótipo costeiro do boto (Tursiops truncatus) e os períodos de maiores riscos de captura acidental por redes de emalhe da pesca artesanal no estuário da Lagoa dos Patos e águas adjacentes no sul do Brasil entre 2006 e 2009. Para isso também utilizou-se modelos aditivos generalizados selecionados utilizando o algoritmo

"spatially adaptive local smoothing". As densidades de botos aumentaram em áreas próximas ao estuário. Ao longo da área costeira, a densidade dos botos aumentou em áreas próximas a costa e na área norte durante o período quente. Estes padrões de distribuição são causados provavelmente pela presença das presas preferenciais ou para evitar distúrbios relacionados as atividades antrópicas na área sul durante este período. O esforço pesqueiro se distribuiu ao longo de toda a área de estudo dentro do estuário. Na área costeira adjacente o esforço pesqueiro foi maior na área sul comparada a área norte durante o período quente. Variações sazonais na distribuição do esforço pesqueiro influenciaram a sobreposição e, portanto, o risco de captura acidental do boto. Uma área de proteção dos botos foi criada por meio de uma Instrução Normativa Interministerial, baseando-se nestes resultados. A partir destes trabalhos, pode-se concluir que, independente da área (costeira ou oceânica), os padrões de distribuição dos cetáceos são relacionados a variáveis ambientais que indicam áreas mais produtivas e fornecem evidencias da importância dessas áreas para essas populações.

PALAVRAS-CHAVE: Baleias, Golfinhos, Diversidade, Abundância, Distribuição, Ecologia, Oceanografia, Modelagem, Conservação

ABSTRACT

Cetaceans are often high trophic level predators and their distribution patterns are mainly influenced by availability of their prey, which depends on environmental characteristics and foodweb dynamics. Therefore, higher densities of cetaceans are often found in productive areas. Oceanic species present relatively wider distribution and face fewer physical barriers than coastal cetaceans. In general these oceanic species are commonly found associated with conspicuous bottom relief features (e.g. shelf break) and upwellings or thermal fronts. On the other hand, coastal waters are more productive and preys availability is higher and more predictable. Coastal cetaceans tend to form smaller resident populations restricted to smaller areas. These species are often vulnerable to a variety of anthropic activities. Incidental takes in fishing gear is the main threat to cetaceans worldwide. Although the extent and potential human impacts are higher for coastal cetacean, oceanic species are also vulnerable to bycatch and sound pollution. The main aims of this thesis were to investigate cetacean distribution patterns and diversity on the outer continental shelf and slope in the south and southeast Brazil and habitat use of the common bottlenose dolphin (*Tursiops truncatus*) population inhabiting a coastal area in southern Brazil. In ANEXO I, ecological diversity indexes and kernel density patterns were investigated for all identified species recorded during eight ship-based surveys dedicated to cetacean sightings in offshore waters of southern and southeastern Brazil. A total of 503 sightings of 21 species were observed and species diversity varied seasonally. Overall higher densities were observed in spring compared to autumn. Sperm whale (Physeter macrocephalus) was the most frequent species and was found mainly in the south area at depths over 1000m. Common dolphins (Delphinus delphis) sightings were only recorded in the south and its density decreased in areas where the presence of Atlantic-spotted dolphins (Stenella frontalis) increased, mainly beyond the 250m isobath. Densities of spinner (S. longirostris) and pantropical-spotted dolphins (S. attenuata) increased at lower latitudes and beyond the shelf break. The common-bottlenose dolphin (Tursiops truncatus) and the short-fin-pilot whale (Globicephala melas) formed mixed groups in many occasions and were observed along the study area around depths of 500m. Risso's dolphin (Grampus griseus) was twice as frequent in the south area and densities increased in waters deeper than 600m. As expected, densities of both small and large migratory whales were higher during spring, over the continental slope, in the southeast. In ANEXO II, sperm whale distribution and abundance patterns along the slope off southern and southeastern Brazil were modeled using line transect distance sampling methods and generalized additive models (GAM). Sperm whales' encounter rate was higher in 2012 spring, representing 1/3 of overall sightings. Abundances were consistently higher during spring and varied from 177 (CV = 0.44) in autumn 2013 to 1516 (CV=0.34) in spring 2012 considering a maximum detection probability at the trackline (i.e. g(0) = 1). These values changed to 204 (CV=0.46) and to 1743 (CV=0.34) if g(0) = 0.87, respectively. The best-fitted GAM smooth functions showed that higher densities occurred in deeper waters, higher latitudes and where NASC and TSM gradient presented higher values. In ANEXO III, distribution patterns of coastal bottlenose dolphins (Tursiops truncatus) and periods of higher entanglement risk by the artisanal gillnet fishery in the Patos Lagoon estuary and adjacent coast of southern Brazil were described between 2006-2009. Data were analyzed in relation to environmental, spatial and temporal variables using Generalized Additive Models and a spatially adaptive local smoothing algorithm for model selection. In general, dolphin densities increased as distance to the estuary mouth decreased. Along the adjacent coast, dolphin densities were higher with distance to shore as well

as in the north during the warm period. Patterns of dolphin distribution were probably a response to the presence of preferred prey or avoidance of human-related disturbance. Fishing effort was distributed along the entire surveyed area inside the estuary, while along the adjacent coast it was higher in the south compared to the north in the warm period. Seasonal variation in fishing effort and distribution affect the overlap and the risk of dolphin entanglement. Based on the findings of this study, a fishing exclusion area aimed at reducing bottlenose dolphin's bycatch was established by through an Interministerial Norm.

KEYWORDS: Whales, Dolphins, Diversity, Abundance, Distribution, Ecology, Oceanography, Modelling, Conservation

1. INTRODUÇÃO

Os cetáceos, grupo que inclui baleias e golfinhos, podem ser encontrados em quase todos os ambientes aquáticos, ocupando rios, estuários, regiões costeiras e oceânicas, desde águas tropicais às polares (Bastida *et al.*, 2007). Independentemente de seus padrões, a distribuição dos cetáceos é principalmente influenciada pela disponibilidade de suas presas que, por sua vez, têm uma dinâmica dependente das relações tróficas e das características ambientais (Springer *et al.*, 1999; Stevick *et al.*, 2008). Porém, estudos sobre as relações entre a distribuição de predadores com a abundância e distribuição das presas são raros devido às dificuldades de amostragem e análises sobre a disponibilidade das presas (Acevedo-Gutierrez & Parker, 2000; Heithaus & Dill, 2002; 2006). Torres *et al.* (2008) sugerem que a capacidade de identificar os habitats preferenciais de mamíferos marinhos pode ser atingida sem incorporar a distribuição das presas em modelos preditivos. Esses autores obtiveram o mesmo sucesso em predizer a ocorrência dos golfinhos ou de suas presas utilizando modelos que levavam em consideração as mesmas variáveis ambientais (*e.g.* batimetria, salinidade).

Muitos métodos robustos de modelagem de habitat estão sendo desenvolvidos e utilizados com sucesso em estudos que visam identificar variáveis oceanográficas que influenciam a distribuição de cetáceos. Temperatura superficial do mar, produtividade primária, topografia, frentes térmicas, proximidade de estuários e rios e tipo de substrato são exemplos de variáveis que tem sido utilizadas como "proxy" para predizer seleção de habitat em espécies de cetáceos ao redor do mundo, tanto em grandes quanto pequenas escalas espaço-temporais (*e.g.* Redfern *et al.*, 2006; Doniol-Valcroze *et al.*, 2007; Pirotta *et al.*, 2011; Forney *et al.*, 2012; Di Tullio *et al.*, 2015). No entanto, alguns fatores podem interferir na identificação e interpretação das variáveis selecionadas. A relação entre variáveis oceanográficas e a distribuição de uma

determinada espécie migratória, como a baleia-jubarte (*Megaptera novaeangliae*), por exemplo, pode ser mal interpretada quando estas são registradas em transito entre áreas de reprodução e de alimentação (Balance *et al.*, 2006). Outros fatores como composição (*e.g.* presença de filhotes, indivíduos solitários) e comportamento (*e.g.* alimentação, deslocamento) também podem introduzir viéses, devido aos distintos habitats preferenciais associados a determinados grupos (Cañadas & Hammond, 2008; Whitehead, 2002). Nesses casos, se esses fatores não forem levados em consideração, a interpretação dos dados pode mascarar as variáveis ambientais realmente significativas que determinam sua distribuição. Além disso, a relação entre a ocorrência de predadores superiores e variáveis ambientais dependem fortemente da escala temporal e espacial do estudo (Redfern *et al.*, 2006).

Existe um intervalo temporal e espacial na resposta da distribuição de predadores em relação às variáveis ambientais, como o tempo que medidas de produtividade primária podem influenciar na distribuição e abundância de consumidores e conseqüentemente em toda cadeia trófica (Croll *et al.*, 2005). Portanto, é essencial coincidir as escalas espaciais e temporais dos objetivos da pesquisa com a coleta dos dados (Redfern *et al.*, 2006). Em geral, padrões de distribuição em grandes escalas espaciais e temporais podem ser relacionados com massas d'água, eventos climáticos (*e.g.* El Niño), enquanto que características oceanográficas locais podem ser mais significativas na determinação de padrões de distribuição em áreas geográficas mais restritas e em estudos de curta duração (Ballance *et al.*, 2006; Hamazaki, 2002; Salvadeo *et al.*, 2011; Springer *et al.*, 1999; Whitehead, 2010).

Atualmente, as modelagens de habitat utilizam diversas fontes de dados para inferir áreas ecologicamente importantes para espécies de cetáceos, como por exemplo, observações diretas a partir de embarcações ou aeronaves, detecções acústicas e marcações por telemetria.

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Dependendo da origem dos dados é preciso considerar diferentes pressupostos e, assim, diferentes métodos de análises (*e.g.* modelos de presença ou presença-ausência) (Gregr *et al.*, 2013). Independente das análises e modelos de habitat utilizados, o objetivo principal desses estudos é identificar com a maior precisão possível a relação entre a ocorrência e abundancia das espécies com as variáveis físicas e/ou biológicas do ambiente. Assim, os resultados desses estudos podem auxiliar na compreensão e delimitação de áreas críticas para essas espécies levando em consideração o habitat essencial para sua sobrevivência. Sendo assim, a identificação dessas áreas críticas são fundamentais para realizar atividades que visem a conservação dos cetáceos.

Áreas produtivas oceânicas podem ser identificadas onde a biomassa de organismos é maior do que nas áreas adjacentes e são frequentemente caracterizadas pela presença de cetáceos. Os cetáceos que habitam áreas oceânicas apresentam distribuições amplas, enfrentando poucas barreiras físicas, e, em geral, estão associadas a relevos oceânicos mais proeminentes (*e.g.* quebra da plataforma continental) e locais próximos a eventos de ressurgência e frentes térmicas (Croll *et al.*, 2005; Baumgartner *et al.*, 2000; Davis *et al.*, 2002; Gill *et al.*, 2015).

A grande diversidade de cetáceos que ocorre ao longo da plataforma e talude continental do Brasil inclui tanto espécies associadas às águas tropicais e temperadas, bem como aquelas consideradas cosmopolitas (Zerbini *et al.*, 2004, Bastida *et al.*, 2007, Amaral *et al.* 2015). No entanto, a maioria das informações sobre a distribuição e avistagens de cetáceos em águas brasileiras são fornecidas pelos programas nacionais de observadores a bordo de navios de sísmica a serviço da indústria petroleira (*e.g.* Parente *et al.*, 2007), os quais não utilizam métodos adequados e, muitas vezes, carecem de pesquisadores experientes. As poucas expedições realizadas por pesquisadores experientes para coletar dados sobre a distribuição dos cetáceos em

águas oceanicas do sul e sudeste do Brasil foram oportunistas e restritas no espaço e no tempo (Pinedo *et al.*, 2002, Zerbini *et al.*, 2004), portanto, a riqueza de espécies de cetáceos registrada durante estas expedições está provavelmente subestimada. Um número muito maior de espécies de cetáceos que ocorrem em águas oceânicas é registrado em encalhes ao longo da costa sudeste e sul brasileira (*e.g.* De Vivo *et al.*, 2011, Ott *et al.*, 2013, Prado *et al.*, *in press*). Resultados referentes a expedições científicas realizadas nesta área na região sudeste-sul demonstraram diferentes padrões na distribuição de cetáceos em relação à profundidade. Baleias-piloto-depeitorais-longas (*Globicephala melas*), cachalotes (*Physeter macrocephalus*) e o glofinho-de-Clymene (*Stenella clymene*) foram observados sobre o talude, enquanto que outros pequenos delfinídeos (*Stenella* spp., *Delphinus delphis*) e a orca (*Orcinus orca*) foram encontradas tanto sobre o talude como na plataforma continental (Zerbini *et al.*, 2004).

O talude continental e a plataforma externa do sudeste e sul do Brasil sempre foram economicamente importantes em termos de recursos pesqueiros e, mais recentemente, para a indústria petroleira. A biomassa de peixes demersais no sudeste e sul representa mais de 60% da produção pesqueira comercial do Brasil (Knoppers *et al.*, 2010). Portanto, essa área vem sofrendo uma série de impactos antrópicos causados principalmente pelas atividades pesqueiras, que é responsável pela redução de importantes estoques comercialmente explorados (Brasil, 2006). Estas duas regiões são caracterizadas por diferentes características hidrográficas dominantes. A plataforma continental sudeste é influenciada predominantemente pelas águas tropicais e oligotróficas da Corrente do Brasil. Nesta área, zonas de maior produtividade são ocasionalmente desencadeadas por ressurgências que alteram a composição e densidades das comunidades de fitoplâncton (Brandini, 1990). Por outro lado, a plataforma continental e talude sul são influenciados pela Corrente do Brasil, águas subantárticas transportadas pela Corrente

das Malvinas e águas continentais que formam a Frente Subtropical de Plataforma (FSP) (Möller *et al.*, 2008, Piola *et al.*, 2008). A FSP é caracterizada por uma transição termohalina abrupta e sua intensidade e localização ao longo da plataforma continental são alteradas de acordo com a predominância do regime sazonal de ventos, os quais podem forçar a exportação dessas águas para a plataforma externa e talude continental (Piola *et al.*, 2000, 2008). Estes processos e ressurgências aumentam a produtividade em águas oceânicas aumentando a concentração de nutrientes, clorofila-a e densidade de zooplâncton (Braga *et al.*, 2008, Muelbert *et al.*, 2008).

Cetáceos associados a ambientes costeiros, os quais são mais produtivos e apresentam maior estabilidade na disponibilidade de presas (e.g. desembocaduras de rios e estuários, baías e fiordes) tendem a ser residentes a áreas geograficamente pequenas, onde procuram abrigo para evitar predadores e beneficiarem-se de recursos alimentares mais previsíveis no espaço e tempo (e.g. Wells et al. 1987; Ingram & Rogan, 2002). Por habitarem lugares de fácil acesso ao homem e de grande valor econômico, essas espécies estão sujeitas a ameaças antrópicas frequentes, como por exemplo, a captura acidental em redes de emalhe - reconhecida como uma ameaça global a conservação dos cetáceos (Reeves et al. 2003). Em conjunto com outros fatores como a perda do habitat (e.g. utilização das águas para fins comerciais, poluição), as capturas acidentais são responsáveis pelo declínio de várias populações de cetáceos (e.g. golfinho-sem-dorsal do Rio Amarelo, Neophocaena asiaeorientalis asiaeorientalis, Mei et al. 2012; população de botos de Fiordland, Nova Zelândia, Currey et al., 2009). No Brasil, as espécies costeiras mais afetadas pelas capturas acidentais e destruição de habitat são a toninha (Pontoporia bainvillei, Secchi et al., 2003; Secchi, 2010), e populações locais do boto-cinza (Sotalia guianensis, Azevedo et al., 2008) e do boto (*Tursiops truncatus*, Fruet *et al.*, 2012).

Populações de boto têm sido vítimas de capturas acidentais na pesca com redes de emalhe ao longo das águas costeiras do sul do Brasil, especialmente no estuário da Lagoa dos Patos (ELP) e águas costeiras adjacentes. O estuário da Lagoa dos Patos é uma região altamente produtiva, sendo uma importante área de criação e alimentação de muitas espécies de peixes comercialmente exploradas (Haimovici *et al.*, 2006). Esta área abriga uma pequena população de boto estimada em aproximadamente 87 indivíduos (Fruet *et al.*, 2011; 2015), a qual utiliza a área para realizar suas atividades vitais durante todo o ano. Estudos embarcados conduzidos na área estuarina sugerem que os botos são encontrados preferencialmente nas proximidades da boca da barra de Rio Grande (Castello & Pinedo, 1977; Möller, 1993; Mattos *et al.*, 2007; Dalla Rosa, 1999).

Segundo Fruet *et al.* (2015), o número de botos encalhados na praia com evidências de interações com atividade pesqueiras (*i.e.* carcaças com marcas de redes, mutilações ou redes enroladas no corpo) aumentou a partir de 2002 e segue um padrão sazonal (novembro a março). Esta sazonalidade coincide com o período de intenso esforço pesqueiro artesanal com redes de emalhe em águas costeiras de baixa profundidade adjacente ao estuário (Klippel *et al.*, 2005).

Até a década de 80 a pesca artesanal era restrita ao estuário, no entanto, a exaustão dos estoques pesqueiros estuarinos, devido ao esforço pesqueiro excessivo causado pelas melhorias dos petrechos de pesca (redes de fibras sintéticas) e das embarcações (maiores tamanhos, capacidade de armazenamento e motores de 10 a 25 hp), resultou na intensificação do uso das águas costeiras rasas pelos pescadores artesanais (Haimovici *et al.*, 1998; Kalikoski *et al.*, 2002).

A pesca artesanal nesta região segue um padrão sazonal de acordo com as espécies mais abundantes (Reis *et al.*, 1994). Alguns exemplos de peixes comercialmente explorados pela pesca artesanal são: a corvina (*Micropogonias furnieri*), a pescadinha-real (*Macrodon* ancylodon), o linguado (*Paralichthys orbignyanus*) e o bagre (*Netuma barba*) durante a primavera; no outono a pesca visa a tainha (*Mugil platanus*) e o papa-terra (*Menticirrhus americanus*) (Leal & Bemvenuti, 2006). Além da intensa atividade pesqueira artesanal, na porção final do estuário da Lagoa dos Patos existe um risco permanente de acidentes ecológicos causados pela intensa atividade humana (Tagliani *et al.*, 2003). Em suas margens, se estabeleceram indústrias petroquímicas e terminais portuários, apresentando um intenso tráfego de embarcações comerciais e atividades relacionadas à manutenção do canal de acesso ao porto (*e.g.* dragagens).

2. OBJETIVOS E ESTRUTURA DA TESE

De acordo com os processos oceanográficos e variações sazonais na produtividade da plataforma continental externa e talude do Brasil e que a região sul está sob a influência de uma maior variedade de massas d'água, a hipótese desse trabalho é de que a riqueza e as variações sazonais na diversidade de cetáceos sejam maiores na região Sul. É também esperado que a densidade de cetáceos seja maior em áreas próximas a quebra de plataforma, onde os processos oceanográficos que aumentam a produtividade predominam. Além disso, a distribuição do cachalote (*Physeter macrocephalus*) está provavelmente associada à áreas de menor temperatura superficial e feições batimétricas conspícuas. Sendo assim, os dois primeiros artigos dessa tese têm os seguintes objetivos:

• Avaliar espacialmente e sazonalmente os padrões de distribuição e diversidade dos cetáceos na plataforma continental externa e talude do sul e sudeste do Brasil. (ANEXO I)

• Estimar a abundância sazonal (Primavera e Outono) do cachalote (*P. macrocephalus*) e verificar padrões de distribuição em relação as características oceanográficas no talude do sul e sudeste do Brasil. (ANEXO II)

De acordo com a situação preocupante descrita sobre a população do boto residente na Lagoa dos Patos e os riscos de captura acidental em redes de pesca, o objetivo do terceiro trabalho foi:

• Investigar os padrões de distribuição do boto (*T. truncatus*) no estuário da Lagoa dos Patos e áreas adjacentes e o grau de sobreposição com o esforço da pesca artesanal com redes de emalhe. (ANEXO III)

3. Síntese dos Resultados

3.1. (ANEXO I) – Padrões de diversidade e distribuição de cetáceos em águas oceânicas do Oceano Atlântico Sudoeste.

Os padrões temporais e espaciais da diversidade e distribuição de cetáceos foram investigados através de oito cruzeiros realizados entre a primavera de 2009 e 2014 a bordo do Navio Oceanográfico Atlântico Sul da Universidade Federal do Rio Grande (FURG). A área de estudo compreendeu a plataforma continental externa (~150m) e o talude (1500m) no sudeste e sul do Brasil, sendo estas duas áreas divididas de acordo com suas características oceanográficas. Um total de 503 avistagens foram realizadas, o que resultou na identificação de 21 espécies de cetáceos.. O número de espécies identificadas foi similar entre as duas áreas; entretanto, durante a primavera, a riqueza foi maior na área sul. A diversidade de espécies variou mais sazonalmente do que espacialmente. Em geral, a densidade de cetáceos foi maior na primavera do que no outono. P. macrocephalus foi a espécie mais frequente e ocorreu principalmente na área sul e em profundidades maiores que 1000m nas duas estações. Espécies de pequenos golfinhos, apesar da sobreposição em sua distribuição em uma maior escala, apresentaram um gradiente latitudinal e algumas variações sazonais em sua distribuição. Avistagens de golfinhos-comuns, Delphinus delphis, ocorreram somente na área sul e sua densidade diminuiu em áreas de maior densidade do golfinho-pintado-do-Atlântico, Stenella frontalis, principalmente próximos a isóbatas de 250m. As densidades do golfinho-rotador, S. longirostris, e golfinho-pintado-pantropical, S. attenuatta, aumentaram em menores latitudes e além da quebra de plataforma. As espécies de golfinhos maiores, como o Tursiops truncatus e a baleia-piloto-de-peitorais-longas, Globicephala melas, formaram grupos mistos em muitas ocasiões e foram observados ao longo da área de estudo próximos a isóbata de 500m. O golfinho-de-Risso, Grampus griseus, ocorreu

em maior frequência na área sul e sua densidade aumentou em profundidades maiores que 600m. Como era esperado, a densidade de baleias foi maior durante a primavera na área sudeste. Os resultados apresentados aqui fornecem evidencias da importância dessa área para a diversa comunidade de cetáceos que ocorrem em águas subtropicais do Oceano Atlântico Sul Ocidental.

3.2. (ANEXO II) – Padrões espaços-temporais na abundância e distribuição do cachalote (*Physeter macrocephalus*) em relação às características oceanográficas no Oceano Atlantico Sudoeste.

O cachalote (Physeter macrocephalus) é amplamente distribuído em todas as bacias oceânicas do equador até as áreas polares. Estudos de uso do habitat indicam que a espécie tem preferência por profundidades maiores que 1000m e são associadas a locais de maiores produtividades e feições batimétricas conspícuas. Neste trabalho investigou-se os padrões de abundancia e distribuição do cachalote na plataforma externa e talude continental no sudeste e sul do Brasil. Foram realizados oito cruzeiros durante a primavera (n=4) e o outono (n=4) entre 2009 e 2014. O navio percorreu transecções lineares pré-determinadas entre as isóbatas de 150 e 1500m. A taxa de encontro e abundância foram estimados utilizando o método convencional de amostragem por distância em transecções lineares e multi-covariado para cada cruzeiro. A taxa de encontro e o número de avistagens do cachalote foram maiores na primavera de 2012, representando 1/3 de todos os registros. A estimativa de abundância variou entre 177 (CV = (0,44) no outono de 2013 e 1516 (CV = 0,34) na primavera de 2012, considerando a máxima probabilidade de detecção no transecção ($g_{(0)} = 1$). Esses valores aumentaram para 204 (CV = 0,46) e 1743 (CV = 0,34), respectivamente, quando considerado um $g_{(0)} = 0,87$. Modelos aditivos generalizados (GAM) com função de ligação logarítmica (ligação log) e distribuição de erro

binomial negativo foram utilizados para investigar a relação da densidade do cachalote com variáveis ambientais da área de estudo. O modelo com menor valor ddo critério de Akaike (AIC) incluiu a profundidade, a latitude, o gradiente de TSM (temperatura superficial do mar) e a NASC (densidade acústica biológica) como variáveis explicativas. Estas variáveis ambientais explicaram 60,9% da variância total da densidade estimada de cachalote. De acordo com as curvas suavisadoras estimadas, a densidade do cachalote aumentou em águas mais profundas, em maiores latitudes e onde houveram um maior valor de NASC e gradiente de TSM. Apesar do valor da deviância explicada ser considera boa (60,9%), os resíduos apresentaram certa heterogeneidade. Esses padrões foram similares aos encontrados em outras áreas de ocorrência desta espécie.

3.3. (ANEXO III) – Identificação de áreas críticas para reduzir o risco de captura acidental do boto (*Tursiops truncatus*) em redes de emalhe da pesca artesanal no estuário da Lagoa dos Patos e áreas adjacentes.

Golfinhos costeiros são impactados por diversas ações antrópicas, sendo a captura acidental uma das maiores ameaças. Neste trabalho foram descritos os padrões de distribuição do boto (*Tursiops truncatus*) e os períodos de maiores riscos de captura acidental por redes de emalhe da pesca artesanal no estuário da Lagoa dos Patos e águas adjacentes no sul do Brasil. Para tanto, transecções lineares previamente estabelecidas foram percorridas a procura dos botos e redes de pesca entre 2006 e 2009. Um total de 136 grupos de botos e 187 redes de pesca foram encontrados em 69 saídas de campo realizadas. Modelos aditivos generalizados (GAM) com função de ligação log e distribuição quasi-poisson foram selecionados utilizando o algoritmo "spatially adaptive local smoothing" para seleção de modelo. As densidades de botos

aumentaram em áreas próximas ao estuário. Considerando apenas a área interna do estuário, a salinidade e a temperatura influenciaram a distribuição dos botos. Ao longo da área costeira, a densidade dos botos aumentou em áreas próximas à costa e na área norte durante o período quente. Estes padrões de distribuição são causados provavelmente pela presença das presas preferenciais ou para evitar distúrbios relacionados às atividades antrópicas na área sul durante este período. Densidades de kernel foram estimadas para avaliar a sobreposição entre a ocorrência dos botos e a pesca de emalhe artesanal. O esforço pesqueiro se distribuiu ao longo de toda a área de estudo dentro do estuário. Na área costeira, o esforço pesqueiro foi maior na área sul comparada a área norte durante o período quente. A área de sobreposição entre os botos e as redes de pesca aumentaram consideravelmente do período frio (33.8%) para o período quente (48.6%). Variações sazonais na distribuição do esforço pesqueiro influenciaram a sobreposição e, portanto, o risco de capturas acidentais dos botos. Com o objetivo de reduzir a captura acidental nesta área, o Ministério Público Federal, baseando-se nos resultados preliminares deste estudo, criou uma Instrução Normativa que delimita uma área de exclusão de pesca.

4. Discussão

Os resultados destes trabalhos descrevem os padrões de uso do habitat de cetaceos que habitam a plataforma externa e talude continental do sudeste e sul do Brasil e de uma população de boto residente no estuário da Lagoa dos Patos e águas costeiras adjacentes. Além disso, foi possível identificar variáveis que influenciam nas densidades do cachalote e do boto através de modelagens de habitat. No caso da população costeira do boto, os resultados forneceram informações para avaliar a sobreposição entre a distribuição dos animais com o esforço

pesqueiro artesanal, as quais foram utilizadas para criar uma área de exclusão de pesca e minimizar este tipo de impacto.

A riqueza de espécies que ocorrem na plataforma externa e talude continental do sul e sudeste do Brasil é similar a outras áreas oceânicas produtivas como o sul da Austrália (n≥15, Gill *et al.*, 2015) e Sistema da Corrente da California (n=21, Barlow & Forney, 2007), as águas tropicais do Golfo do México (n=28, Davis et al., 2002) e as águas frias dos giros subárticos no Pacífico (n=24, Springer et al., 2002). O fato de 90% do número de espécies serem identificadas nos primeiros quatro cruzeiros indica que a área foi bem amostrada. Porém os cruzeiros foram restritos as estações opostas primavera e outono, portanto o número de espécies é maior considerando que espécies tipicamente tropicais e de águas frias ocorram nessa área durante o verão e inverno, respectivamente. Durante o verão, toda a área de estudo é dominada por águas oligotróficas tropicais, portanto a dominância de espécies tropicais é esperada. A maior similaridade foi encontrada entre estações na área sudeste e menor entre áreas durante o outono. Durante o inverno, parte da área sul é influenciada por águas mais produtivas e frias transportadas pela Frente Subtropical de Plataforma (FSP) que permanecem até a primavera (Möller et al., 2008). Portanto, tanto espécies tropicais como de águas temperadas fazem parte da comunidade de cetáceos nesta área. Isto pode explicar a menor similaridade entre estações do que entre áreas, além da maior riqueza de espécies e densidades durante a primavera, principalmente na área sul.

A maior densidade de cetáceos durante a primavera era esperada para a maioria das espécies, pois o aumento da produtividade primária na área de estudo (Signorini *et al.*, 2006) possivelmente aumentou a densidade de presas disponíveis. Os processos físicos sazonais que causam o aumento da produtividade sobre a plataforma externa e talude continental são

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descontínuos (e.g. áreas de ressurgencia) e também afetam as distribuições dos organismos pelágicos. Pequenos peixes da família Myctophidae, lulas e zooplanctons (para os Misticetos) são as presas mais consumidas por cetáceos que habitam essas áreas oceânicas (Signorini *et al.*, 2006; Santos & Haimovici, 2001; Benoit-Bird & Au, 2003; Macleod *et al.*, 2004). Estudos anteriores mostraram que o peixe-lanterna (*Maurolicus stehmanni*) e espécies de Myctophidae são comuns e associam-se a águas tropicas e áreas sobre quebra de plataforma (Madureira *et al.*, 2004). A lula-Argentina (*Illex argentinus*) preda sobre esses pequenos peixes pelágicos e é associada com águas frias. Todas essas espécies apresentam um imporante papel na cadeia trófica desta área e são consumidos por muitas espécies de peixes (Madureira *et al.*, 2004; Martins *et al.*, 2005), aves marinhas (dos Santos & Haimovici, 2002) e cetáceos (Santos & Haimovici, 2001; dos Santos & Haimovici, 2002). A maior densidade de peixes demersais na plataforma externa e talude continental na área sul também pode ser relacionada à proximidade de águas mais produtivas ao sul da área de estudo (Hanimovici *et al.*, 2009).

Durante os cruzeiros sobre a plataforma exerna e talude continental, o cachalote foi a espécie mais frequente, representando 30% de todas as avistagens encontradas nessa área. Assim este estudo fornece a primeira estimativa de abundância e padrões de distribuição para essa espécie no Atlantico Sul Ocidental. A abundância do cachalote foi maior durante a primavera, coincidindo com a densidade da maioria das espécies observadas neste trabalho. Variações na abundancia podem estar diretamente relacionadas a variações interanuais das condições oceanográficas e, consequentemente, na produtividade local. No Golfo da California, os padrões de distribuição do cachalote variam em resposta ao declínio da abundancia de sua principal presa. Nessa área, esta espécie se distribui mais homogeneamente e em pequenos grupos quando a abundancia de sua presa era baixa, ao contrário do ano em que a abundância de sua presa

aumentou, quando foram encontrados em grandes grupos (Jaquet and Gendron, 2002). Espécies de lulas pertencentes às famílias Octopoteuthidae, Histioteuthidae e Ommastrephidae aão possivelmente presas importantes do cachalote nesta área (e.g. Clarke et al., 1980; EcoMega unpubl. data); portanto os padroes de distribuição possivelmente se associam a disponibilidade dessas lulas. Muitas espécies dessas famílias são abundantes em águas frias e profundas do talude continental no sul do Brasil, Uruguai e Argentina (Santos and Haimovici, 2007; Haimovici *et al.*, 2014). A menor abundância do cachalote durante o outono pode estar realcionada a movimentos sazonais para águas mais produtivas em maiores latiudes. O cachalote é frequentemente observado em águas oceânicas da Argentina e no entorno das Malvinas (e.g. Yates and Brickle, 2007; Mandiola et al., 2015).

Modelos aditivos generalizados foram utilizados para identificar as variáveis que melhor descrevem os padrões de distribuição do cachalote. As variáveis selecionadas no melhor modelo demosntraram que maiores gradientes de temperatura e valores de densidade acústica biológica (NASC) afetaram positivamente a densidade do cachalote. Latitude é fortemente correlacionada com clorofila-a (ver tabela 5), portanto é indiretamente relacionada a águas frias e produtivas. De acordo com Jaquet et al. (1996), o cachalote se distribuem em grupos com maior número de indivíduos em áreas mais produtivas. Entrentanto, a interpretação da relação entre este predador com a produtividade primária e secundária não pode ser direta. Segundo Vinogradov (1981), a transferencia de energia entre o fitoplancton e grandes espécies de lulas leva aproximadamente quatro meses. Por outro lado, essas áreas onde se encontram maiores densidades do cachalote podem ser caracterizadas pela presença de declives acentuados, onde as presas tendem a se agregar. Em outras áreas, a distribuição do cachalote é relacionada a areas de fundo com relevos acentuados (e.g. Whitehead et al., 1992; Jaquet and Whitehead, 1996; Jaquet et al., 2000). As maiores densidades do cachalote em áreas de maior gradiente de temperatura superficial do mar sugere que a espécie se concentre em águas sob influencia de diferentes massas d'águas. A densidade acústica biológica (NASC) foi geralmente maior ao sul da área de estudo e, na maiora das vezes, associada a ressurgencias de subsuperfície (Pinho, 2015). Portanto, a área sul da área de estudo parece ser ecologicamente importante para uma variedade de organismos que dependem tanto do estrato epi-mesopelágicos quanto do meso-batipelágico.

Os resultados apresentados demonstram que a plataforma externa e talude continental, principalmente ao sul do Cabo de Santa Marta, apresenta uma comunidade diversa de cetaceos persistente ao longo de duas estações opostas (primavera e outono). Esta área deve ser considerada como áreas biologicamente significantes, recebendo atenção especial para a conservação e mitigação de situações de conflitos com atividades antrópicas (e.g. prospecção sísmica e esforço de pesca).

Os padrões de distribuição do ecótipo costeiro do *T. truncatus* (boto) também foi analisado aravés de modelo de habitat o qual selecionou principalmente as variáveis espaciais distancia da costa e da boca da barra de Rio Grande. EM estudos prévios, indivíduos de boto são comumente observados com comportamento de alimentação com freqüencia na porção final do estuário, reforçando ainda a hipótese de que a maior densidade pode estar relacionada com a disponibilidade de presa (Mattos et al., 2007. Em outros estuários, áreas de alta concentração de botos também foram relacionadas com áreas de alimentação (Ballance, 1992; Hastie *et al.*, 2003, 2004). A maior densidade de botos nas proximidades da boca da barra pode estar relacionada com a presença da tainha (*Mugil* spp.) e corvina (*Micropogonia furnieri*), respectivamente, que são espécies estuarino-dependentes (Chao *et al.*, 1985), e presas importantes da espécie (Pinedo, 1982; Mehsen *et al.*, 2005). Tanto a tainha como a corvina utilizam o estuário para seu

desenvolvimento até a maturidade. Sabe-se que entre os meses de abril e maio adultos de tainha formam grandes cardumes dentro do estuário para iniciarem a migração reprodutiva nas áreas costeiras (Vieira & Scalabrin, 1991). Do mesmo modo, indivíduos maturos de corvina iniciam sua migração reprodutiva para o oceano durante a primavera (Castello, 1986). Portanto, durante o outono e a primavera deve haver uma alta concentração de presas nesta área, já que os cardumes precisam sair para o oceano através do único canal de acesso ao estuário. Em outras populações dessa espécie, observa-se o mesmo padrão aqui descrito, no qual os botos se concentram em canais pequenos por haver uma maior abundância de presas (Shane, 1990; Wilson *et al.*, 1997; Ingram & Rogan, 2002). Mattos *et al.*, (2007) observaram o comportamento de alimentação com maior freqüencia na porção final do estuário, reforçando ainda a hipótese de que a maior densidade pode estar relacionada com a disponibilidade de presa. Em outros estuários, áreas de alta concentração de botos também foram relacionadas com áreas de alimentação (Ballance, 1992; Hastie *et al.*, 2003, 2004).

A menor densidade de botos na área sul durante o período quente pode ter sido causado por um aumento nas atividades antrópicas, como o turismo e maior esforço pesqueiro nessa área, durante esses meses. Allen & Read (2000) sugerem que movimentações de embarcações interferem na disponibilidade das presas, afetando a distribuição de golfinhos indiretamente.

Durante este estudo, dados sobre a distribuição dos botos e das redes de pesca foram obtidos simultaneamente. Os resultados mostraram claramente que o esforço pesqueiro artesanal se expande para a área costeira durante o período quente, resultando em um aumento considerável na sobreposição entre a distribuição dos botos e o esforço pesqueiro, indicando também a área de maior risco de emalhamento. Fruet *et al.* (2012) investigaram a mortalidade dos botos entre 1969 e 2006 e encontraram um aumento no número de carcassas com evidencias

de interação com pesca após 2002, além de um marcado padrão sazonal. Estas informações em conjunto com os resultados deste trabalho reforça que esse padrão sazonal na mortalidade dos botos está relacionado com o aumento do esforço pesqueiro na área costeira adjacente ao estuário da Lagoa dos Patos.

5. Conclusões

Anexo I

- Existe uma alta diversidade de cetáceos que habita a plataforma continental externa e sua riqueza é maior durante a primavera;
- A diversidade de espécies em águas oceânicas no sul do Brasil variou sazonalmente
- A densidade de cetáceos foi maior na primavera;
- O cachalote é a espécie mais frequente em águas com profundidade superior a 1000m;
- Espécies de pequenos golfinhos apresentam um gradiente latitudinal; e
- O golfinho comum (*D. delphis*) ocorre apenas na área sul em águas da plataforma externa do Brasil.

Anexo II

- A abundância do cachalote foi maior durante os cruzeiros de primavera; e
- A densidade do cachalote aumentou em águas mais profundas, em maiores latitudes e onde houve um maior valor de NASC e gradiente de TSM.

Anexo III

- O boto *Tursiops truncatus* apresenta maiores densidades em áreas próximas da barra do estuário da Lagoa dos Patos;
- A densidade dos botos é restrita em áreas próximas da costa nas áreas adjacente a ELP; e
- A área de sobreposição entre os botos e as redes de pesca aumentaram consideravelmente do período frio (33.8%) para o período quente (48.6%).

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ANEXO I

Diversity and Distribution Patterns of Cetaceans in the Subtropical Western South Atlantic Offshore Waters

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Abstract

Temporal and spatial patterns of cetacean diversity and distribution were investigated through eight ship-based surveys carried out during spring and autumn between 2009 and 2014 on the outer continental shelf (~150m) and slope (1500m) off southeastern and southern Brazil (~23°S to ~34°S). The survey area was divided into southeast and south areas according to their oceanographic characteristics. A total of 503 sightings of 21 species were observed. The overall number of species was similar between the two areas, though it was higher in the spring in the

south area. Five species were dominant and diversity varied more seasonally than spatially. ANOVA and kernel analyses showed that overall cetacean densities were higher in spring compared to autumn. Physeter macrocephalus, the most frequent species, concentrated throughout the south area at depths over 1000m in both seasons. Despite the overlapped occurrence in a broader scale, small delphinids presented latitudinal and in-offshore gradients as well as seasonal variation in distribution patterns, which indicate habitat partitioning between some species. Delphinus delphis was only recorded in the south and its density decreased in areas where the presence of *Stenella frontalis* increased, mainly beyond the 250m isobath. Densities of S. longirostris and S. attenuata increased in lower latitudes and beyond the shelf break. The large delphinids *Tursiops truncatus* and *Globicephala melas* formed mixed groups in many occasions and were observed along the study area around depths of 500m. Grampus griseus was twice as frequent in the south area and densities increased in waters deeper than 600m. As expected, densities of both small and large migratory whales were higher during spring, over the continental slope, in the southeast area. The results presented here provided strong evidence on the importance of the outer continental shelf and slope to a diverse community of cetaceans occurring in the subtropical Southwestern Atlantic.

Introduction

Oceanic productive areas are known to aggregate high species richness and abundance of top predators, such as cetaceans, and are usually situated near hydrographic fronts and abrupt topographies which are characterized by strong sea surface temperature gradients and high chlorophyll concentrations [1,2,3]. In southern Australia, for example, the most common cetacean species were associated to upwelling season and migration cycles [4]. In the oceanic waters of Gulf of Mexico species appeared to concentrate near the slope or around eddies, where the amount of potential prey for cetaceans may be consistently greater in some seasons [5,6]. Six of the most common cetaceans recorded off Southern California had seasonal different spatial distribution and abundance oscillation which can be related to water masses, depth and El Nino and La Nina events [7]. Hence, habitat features such as depth, slope, distance from oceanographic processes (*e.g.* upwelling) that enhance local productivity and prey aggregations are key factors to determine patterns of cetacean distribution [5, 8, 9, 10].

There is a high diversity of cetaceans along the continental shelf and slope off Brazilian waters, including species associated with tropical and temperate waters as well as those considered cosmopolitan [11,12,13). However, most information on cetacean distribution in Brazilian offshore waters comes from the national observers programs of the oil and gas industry (*e.g.* [14]), which lacks standardized procedures, sampling methods and experienced researchers. A few research expeditions made by experienced researchers to collect data on cetacean distribution in offshore waters of southern and southeastern Brazil were opportunistic and restricted in space and time [15,11], therefore the richness of cetacean species recorded in those surveys is probably underestimated. In fact, stranding records along the southeastern and southern Brazilian coasts suggest that a much higher number of cetacean species may occur in offshore waters of these regions [16,17,18]. Furthermore, spatial and seasonal variation in distribution and occurrence patterns has yet to be determined.

The Brazilian continental shelf and slope is an economically important region for fisheries and the oil and gas industries. Approximately 60% of the national commercial fish catch come from highly productive waters of the southeastern and southern continental shelf and slope [19]. These two regions are characterized by different dominant hydrographic dynamics.

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The southeastern continental shelf and slope is mostly influenced by the tropical waters of the Brazil current, which transports tropical warm and oligotrophic water. In this area, higher productive zones are occasionally triggered by upwellings that pump the South Atlantic Central Water to superficial layers, changing composition and enhancing densities of phytoplankton communities [20]. During winter, the upwellings are associated with cyclonic meanders of Brazil current and in summer by a combination of the steep topography of the shelf break and wind driven upwelling [21,22]. On the other hand, the southern continental shelf and slope are under the influence of the Brazil current, the sub-Antarctic waters transported by the Malvinas/Falkland currents (M/FC) and continental waters from La Plata River and Patos Lagoon plumes, which form the subtropical shelf front (STSF) [23,24]. The STSF is characterized by a sharp thermohaline transition between these water masses. This front changes its intensity and location over the continental shelf according to predominance of southerly and northerly wind seasonal regimes and the continental water is exported towards the shelf break and slope [25, 24]. These processes and surface and subsurface upwelling events influence the productivity in offshore waters by enhancing concentration of inorganic nutrients, chlorophyll-a (Chl-a) and density of zooplankton [26, 27].

A global meta-analysis on diversity and predictors of cetacean occurrence suggests that a larger number of species are expected to inhabit the subtropical waters of southeastern and southern Brazil compared to tropical waters of the northeastern Brazil and are related to oceanic productive areas [2]. Since oceanographic processes and productivity in the outer continental shelf and slope vary seasonally and the southern region is under the influence of a variety of water masses, it is anticipated that richness and seasonal variations in cetacean diversity is higher in the southern region. It is also expected that the density of cetaceans is higher at closer

proximity to the shelf break, where subsurface processes that enhance productivity predominate in this region. The present study aimed at assessing spatial and seasonal (spring and autumn) distribution patterns and diversity of cetacean in the outer continental shelf and slope off southern and southeastern Brazil. Our results showed that less than five species presented relative abundance above 10% of overall cetacean, and that diversity varies more seasonally than spatially. The overall cetacean densities were higher in spring compared to autumn. Furthermore, we provided a more accurate description of the spatial and seasonal distribution patterns of the most frequent species inhabiting this area during the austral spring and autumn seasons. This information can be useful for identifying biological and ecological significant areas for these cetacean species.

Materials and Methods

Survey design and data collection

Eight surveys were conducted during austral spring (n=4) and autumn (n=4) between 2009 and 2014 onboard the 36 meter-long R/V *Atlântico Sul* of the Federal University of Rio Grande (FURG) following approximately the same transect lines (Fig 1). Zig-zag transect lines were pre-designed to cover the outer continental shelf and slope of southeastern (22.9°S) and southern (33.7°S) Brazil, from approximately the 150 to the 1500 meter isobaths (Fig 1). This area is within the Brazilian Economic Exclusive Zone and did not include any protected area, thus no specific permissions were required. For logistic reasons, the surveys started at the southernmost transect line. The vessel's steering speed varied between 14.4 - 18.5 km/h (8-10kt). Due to weather conditions or ship schedule, the surveys started at different dates and effort varied along the study area (Table 1).



Fig. 1. Ship-based cetacean survey tracks and effort in outer continental shelf and slope off southern and southeastern Brazil between 2009-2014. A) Zig-zag transects lines followed by the ship. B) Grid cells are $0.25^{\circ}x0.25^{\circ}$ and darker shading indicates greater searching effort. Acronyms represent the Brazilian states of Rio Grande do Sul (RS); Santa Catarina (SC); Paraná (PR); São Paulo (SP) and Rio de Janeiro (RJ).

Table 1. Summary of the survey effort (km) for each year and season in south and southeastBrazil between 2009 and 2014.

		Area				
Survey	Season	South	Southeast	Total	Starting date	N days
(year)				(km)	(day/month)	
1 (2009)	Spring	1267.6	1028.2	2295.7	22/10	15
2 (2010)	Autumn	1688.8	488.6	2177.4	22/04	22
3 (2010)	Spring	1543.0	1969.5	3512.5	20/10	31
4 (2011)	Autumn	1786.8	1678.2	3465.1	13/04	29
5 (2012)	Spring	1827.6	1443.9	3271.5	26/10	29
6 (2013)	Autumn	1786.5	1347.6	3134.1	07/05	34
7 (2014)	Autumn	1375.4	925.2	2300.6	10/05	30
8 (2014)	Spring	1604.6	881.7	2486.3	12/11	30
Тс	otal	12880.4	9762.8	22643.2		220

Starting date, day which the survey started; N days, duration of each survey in days. Effort considered only with sea state \leq 5 of Beaufort scale

Two researchers (henceforth referred as observers) searched for cetacean from the flying bridge (observation height ~ 8.6 meters). The observers, positioned in the port and starboard sides, were responsible for the on-effort data collection scanning from 10° right or left to 90° left or right of the tracking line, respectively. The searching procedure alternated scannings with the use of Fujinon 7x50 reticule binoculars and with unaided eyes. A third researcher (henceforth referred as assistant) was positioned behind the observers to help species identification and group

size estimates after detection. The main role of this assistant was to minimize the time that the observers take to resume scanning after detection. A fourth researcher was in charge to record the data in a notebook connected to the vessel's navigation system using program WinCruz (available at:

http://swfsc.noaa.gov/textblock.aspx?Division=PRD&ParentMenuId=147&id=1446). The information recorded included effort (*e.g.* date, time, coordinates), sighting conditions (*e.g.* sea stated in Beaufort scale), sighting data (*e.g.* species, number of individuals, and position based on the radial distance – calculated from the binocular's reticles – and angle relative to the ship's heading – measured using an angle board) and observers' position. Six to eight trained observers rotated though the observation positions every 30 minutes. Group size was estimated by consensus between the observer and the assistant. Best, low and high estimates of group size were recorded, though only "best" was used in the analyses. Cetacean were identified to the lowest possible taxonomic level and attributed to generic categories (*e.g.* large whale, small dolphin) for some analyses.

Most of the time transects were surveyed using passing mode in which species and group size were determined without the vessel diverting from the trackline [28]. In a few occasions, however, effort was halted and the ship closed in the sighting, for no longer than one hour, in order to identify the species and/or to better estimate group size. This happened only when the detected group had passed abeam and no other group had been seen. After species identification and/or group size estimation the effort was resumed at the location where it ended. In order to standardize sighting effort, only sightings made by the two observers and at sea state 5 or lower (Beaufort scale) were considered in the analyses. Although endangered and protected species

were considered in the present study, methodological procedures did not involve biological sampling and, therefore, approval from animal ethics committee was not required.

Analyses

The study area was divided into areas north (herein referred as southeast) and south of Santa Marta Grande Cape (28.6°S) (Fig 1) which was due to the distinct oceanographic characteristics influencing these areas [19]. The southeast area is predominantly influenced by the oligotrophic waters of Brazil Current and higher productive zones are occasionally triggered by upwellings [22]. In the south area, the Brazil current, upwellings and seasonal influences of rich coastal water discharge enhances the productivity [24,20]. Effort was measured (in kilometres) as the distance travelled on transects for each area and season.

Species Richness and Diversity

Species diversity between areas and seasons was measured using beta-diversity index of Whittaker with Harrison et al.'s modification to account for differences in sampling effort [29]. Based on four criteria, this index performed better against other five indexes [30, 31]. The Whittaker plot was also used to visually represent species richness (S, the number of species) and evenness. This plot considers the relative abundance as a proportion of the total number of individuals of each species in relation to the total number of individuals of all species [31]. The similarity (1- β diversity) between areas and seasons was evaluated using the index of Morisita-Horn as it is less influenced by species richness and sample size. Given that this index is sensitive to species abundance, the number of individuals of each sighting was square-rooted to

minimize this effect [31-33]. The beta-diversity indices were calculated using vegdist and ht functions in vegan and MBI packages, respectively [34-35] in R version 3.1.2 [36].

Spatial and Temporal Variation in Distribution Patterns

Encounter rate (ER), as the number of individuals per distance surveyed on effort (ind/km), was assumed to represent density and was used to investigate spatial (south versus southeast) and temporal (spring versus autumn) variation in distribution patterns of cetacean in the study area. In order to overcome small sample size issues (low sighting frequency for some species), sightings were pooled into four group categories according to body size or likely ecological niche: small delphinids, medium-large delphinids (herein referred as large delphinids), small-medium whales (herein referred as small whales) and large whales (Table 2). Due to the high sighting frequency of sperm whale (*Physeter macrocephalus*) and its particular niche (*i.e.* deep-water squid feeder), this species was not grouped in any of those categories. Because only one beaked whale (Ziphiidae) was sighted (Table 2), this record was excluded from the analyses. Encounter rate values were square-rooted through box-cox power transformation to maximise normality and homoscedasticity [37]. The normality and variance of the transformed values were then investigated with Shapiro-Wilk and Levene's test [38]. Spatial and temporal variations in ER, calculated by survey, were assessed through ANOVA followed by post-Hoc Tukey tests for both group categories and individual species when the number of sightings was higher than 15. Analyses were performed using the MASS and car packages in R version 3.1.2 [39,40,36].

Table 2. Species richness and summary of cetacean sightings distribution considering species, group categories, seasons, areas and depth										lepth.			
			South Area					Southeast Area					
											Study		
												Area	
Species	Scientific	S	pring		Autumn	Total		Spring	Autumn		Total	Total	Depth
group	names	()	S=15)		(S=9)	(S=16)	((S=14)		(S=14)	(S=17)	(S=21)	(m)
categories													
		N	NI	Ν	NI	NI	Ν	NI	Ν	NI	NI	NI	Depth
			Mean		Mean	Mean		Mean		Mean	Mean	Mean	Mean
			(se)		(se)	(se)		(se)		(se)	(se)	(se)	(se)
	Delphinus	22	136.68	5	214.8	151.15	0	0	0	0	0	151.15	243.2
	delphis		(65.22)		(139.86)	(58.24)						(58.24)	(14.2)
	Feresa	0	0	0	0	0	1	10	0	0	0	10	834
	attenuata												
	Stenella	0	0	0	0	0	6	117.5	1	25	104.29	104.29	755.7
	attenuata							(48.88)			(43.38)	(43.38)	(19.2)
	Stenella	2	178	0	0	178	1	10	0	0	10	122	1171
	clymene		(172)			(172)						(114.1)	(14.8)
Small	Stenella	2	110	0	0	0	0	0	0	0	0	110	1299
delphinids	coeruleoalba		(10)									(10)	(13.6)
	Stenella	15	205.07	10	25.1	133	10	189.1	5	66.4	148.2	138.75	397.5
	frontalis		(69.02)		(6.88)	(44.7)		(66.19)		(42.56)	(47.85)	(32.83)	(16.1)
	Stenella	2	495	0	0	495	11	258.18	2	450	287.69	315.33	692.5
	longirostris		(405)			(405)		(52.98)		(350)	(62.84)	(69.64)	(17.6)
	Steno	1	20	0	0	0	0	0	0	0	0	20	145
	bredanensis												
	Unidentified	7	4.85	2	8.5	5.67	4	1.75	4	2.5	2.13	4	*
	Dolphin		(1.4)		(1.5)	(1.22)		(0.25)		(0.65)	(0.35)	(0.79)	

Species	Scientific	S	pring		Autumn	Total		Spring		Autumn	Total	Total	Depth
group	names	(S=15)		(S=9)	(S=16)	((S=14)		(S=14)	(S=17)	(S=21)	(m)
categories													
		Ν	NI	Ν	NI	NI	Ν	NI	Ν	NI	NI	NI	Depth
			Mean		Mean	Mean		Mean		Mean	Mean	Mean	Mean
			(se)		(se)	(se)		(se)		(se)	(se)	(se)	(se)
	Globicephala	10	121.5	5	80	107.46	1	35	1	15	25	97.76	637.9
	melas		(56.81)		(30.49)	(38.71)					(10)	(34.67)	(18.4)
	Globicephala	0	0	0	0	0	0	0	0	0	0	3	1223
	spp												
	Grampus	3	30.67	3	23.33	27	1	13	2	265	181	78.33	1095.8
Large	griseus		(13.37)		(10.14)	(7.68)				(35)	(86.39)	(108.39)	(16.3)
delphinids	Orcinus orca	3	9	0	0	9	0	0	2	6.5	6.5	8	550.9
			(3.79)			(3.79)				(1.5)	(1.5)	(4.95)	(22.1)
	Pseudorca	0	0	0	0	0	1	40	1	30	35	35	705.7
	crassidens										(5)	(5)	(25.5)
	Tursiops	6	47.33	9	64.89	57.87	12	19.75	6	17	18.83	36.58	575.3
	truncatus		(31.29)		(18.43)	(16.17)		(5.68)		(6.81)	(4.31)	(8.32)	(19.3)
	Balaenoptera	3	1.33	1	1	1.25	1	3	2	2	2.33	1.72	553.7
	acutorostrata		(0.33)			(0.25)				(1)	(0.67)	(0.36)	(19.9)
	Balaenoptera	1	2	1	2	2	0	0	1	8	8	4	410.7
	bonaerensis											(2)	(17.2)
Small whales	Balaenoptera	4	1.5	1	1	1.4	8	1.37	2	1	1.3	1.3	635.9
	spp (like		(0.5)			(0.4)		(0.18)			(0.15)	(0.16)	(19.6)
	minke whale)												
	Unidentified	2	1	1	1	1	2	1	0	0	0	1	*
	small whale												

Species	Scientific	S	pring		Autumn	Total		Spring		Autumn	Total	Total	Depth
group	names	(S=15)		(S=9)	(S=17)	((S=14)		(S=14)	(S=17)	(S=21)	(m)
categories			•		-								
		Ν	NI	Ν	NI	NI	Ν	NI	Ν	NI	NI	NI	Depth
			Mean		Mean	Mean		Mean		Mean	Mean	Mean	Mean
			(se)		(se)	(se)		(se)		(se)	(se)	(se)	(se)
	Balaenoptera borealis	1	1	0	0	1	0	0	0	0	0	1	471
	Balaenoptera	1	1	0	0	1	9	1.56	4	1.25	1.46	1.42	755.2
	brydei							(0.18)		(0.25)	(0.14)	(0.14)	(18.6)
	Balaenoptera	0	0	1	1	1	0	0	2	6	6	4.33	585.8
	physalus											(1.67)	(11.7)
Largo wholes	Megaptera	0	0	0	0	0	11	2.36	3	1	2.07	2.07	560.2
Large whates	novaeangliae							(0.43)		(0)	(1.38)	(1.38)	(21.6)
	Balaenoptera	1	2	4	1.5	1.6	2	1	4	1.25	1.16	1.36	*
	spp.				(0.29)	(0.24)				(0.25)	(0.17)	(0.15)	
	Unidentified	41	1.46	6	1.17	1.42	32	1.06	1	1.07	1.07	1.25	*
	large cetacean		(0.16)		(0.17)	(0.14)		(0.04)	4	(0.07)	(0.04)	(0.08)	
	Unidentified	5	1.2	3	1.3	1.25	3	1	6	1.16	1.1	1.18	*
	large whale		(0.2)		(0.33)	(0.16)		(0)		(0.17)	(0.11)	(0.09)	
Sperm	Physeter	86	3.35	27	7.56	4.35	19	2.26	8	15.75	6.26	4.72	1223.6
Whale	macrocephalus		(0.37)		(3.99)	(0.99)		(0.37)		(12.07)	(3.62)	(1.06)	(19.8)
Unidentified	ziphiid whale	0	0	0	0	0	1	1	0	0	1	1	601
Ziphiidae													
Whale													

S, species richness is the number of species identified. Total spring richness was 20 and total autumn richness 15. N, number of sightings; NI Mean,

mean number of individuals; se, standard error.* depths of unidentified species were not considered.

Grid cells of 0.25 x 0.25 degrees were generated in maps built in QGIS 12.12 – Lyon (http://qgis.org) and used to represent the distribution patterns of cetacean group categories. For each cell ER values were summarized by season as $\text{ER}_{ij} = \sum n_i *10/\sum \text{eff}_j$ where: n_i is the number of individuals of species i, j is the cell, eff is the distance travelled, and was calculated through spatial and temporal functions using PostgreSQL 9.3 and PostGIS 2.1 [41]. Kernel density plots were used to investigate the seasonal patterns of cetacean species distribution in regard to latitude and depth weighted by ER for each cell. Plots were also produced for species with small number of sightings (> 4, the least number of events necessary for the kernel plot) in order to provide a preliminary view on the distribution of infrequent species in this region. The kernel density bandwidth was determined using SJ method [42]. The plots were made using stat_density function in ggplot2 package [43] in R version 3.1.2 [36].

Results

Effort varied between surveys from 2177.4 km to 3512.5 km, mainly due to weather conditions, and was higher during spring and in the south area (Tables 1 and 3), which was more evenly covered between seasons (Table 3, Fig 1).

A total of 503 sightings were recorded during this study. Identification to species level (for a total of 21 species) was possible for 344 sightings (Table 2). Cetaceans were identified to genus level or were classified as unidentified in 26 and 133 occasions, respectively. Baleen whales were represented by six species of the family Balaenopteridae. Toothed cetaceans were represented by fourteen species in the Delphinidae, Physeteridae and Ziphiidae families.

Table 3. Differences in survey effort tested between areas and									
seasons using Chi-square test (X ²).									
	X ²	p-value							
Total effort between	8.4	0.0038							
seasons									
Total effort between	93.1	0.0001							
areas									
During spring	8.5	0.0037							
between areas									
During autumn	116.8	0.0001							
between areas									
South Area: between	3.13	0.0784							
seasons									
Southeast Area:	37.642	0.0001							
between seasons									

X², values of the chi-square test; p-value, values <0.05 were considered significant.

Species Richness and Diversity

Most (90%) of the 21 identified species were recorded during the first four surveys (Fig 2). Species richness (S) was similar between areas and seasons in southeast area, however, when considering only the south area, S was almost twice as high in spring (15) as compared to autumn (9) (Table 2). Less than five species were dominant (*i.e.* presented relative abundance above 10% of overall number of individuals, considering all species) in each area and season

(Fig 3). Beta-diversity (Harrison's et al. modification of Whittaker index) ranged from 0.4 to 0.5, showing moderate turnover between seasons and areas. The Morissita-Horn similarity index varied from 0.12 (spring - autumn) to 0.38 (south - southeast) and from 0.18 (spring - autumn in the southeast) to 0.59 (south - southeast during autumn). Intermediate values were found in other pair comparisons. These values demonstrate that diversity is higher between seasons than between areas. It also suggests a higher diversity between seasons in the southeast and lower diversity between areas during autumn.



Fig. 2. Discovery curve of species identified during the present study.

Cumulative number of species recorded according to distance travelled (lower x-axis) and the surveys (upper x-axis).



Fig. 3. Whittaker plot of the relative species abundance by each area (South, Southeast) and season (Spring, Autumn). This plot considers the relative abundance as a proportion of the total number of individuals of each species in relation to the total number of individuals of all species.

Mixed species assemblages were found in 5.2% of the cetacean sightings (n=26). Half of the mixed groups had the presence of the common bottlenose dolphin (*Tursiops truncatus*). This species occurred in association with long-finned pilot whale (*Globicephala melas*, n=10), Atlantic spotted dolphin (*Stenella frontalis*, n=3), Risso's dolphin (*Grampus griseus*, n=4), false-killer whale (*Pseudorca crassidens*, n=1) and sperm whale (*Physeter macrocephalus*, n=1). The other species found in mixed groups were spinner (*S. longirostris*) and pantropical spotted (*S. attenuata*) dolphins (n=3), dwarf minke whale (*B. acutorostrata*) and *S. frontalis* (n=1), *B. acutorostrata* and an unidentified cetacean (n=1), Antarctic minke (*B. bonaerensis*) and fin (*B. physalus*) whales (n=1), and *G. melas* with an unidentified whale (n=1).

Overall cetacean ER did not differ between areas, however it was higher in spring compared to autumn (Tables 4 and 5). Furthermore, when considering the cetacean at groups and species levels, ER varied between areas and seasons (Tables 4 and 5).

Table 4. Mean ER values for each area (South and Southeast) and season (Spring and Autumn).								
Group	Areas	Seasons	South Area	Southeast area				
categories/	(S x SE)	(Spr x Aut)	(Spr x Aut)	(Spr x Aut)				
Species								
Total Cetaceans	SE=0.73(0.23)	Spr=1.25(0.44)	Spr=1.49(0.59)	Spr=1.01(0.28)				
	S=0.96(0.37)	Aut=0.44(0.17)	Aut=0.44(0.16)	Aut=0.44(0.18)				
Small delphinid	SE=0.61(0.19)	Spr=1.05(0.26)	Spr=1.18(0.48)	Spr=0.93(0.27)				
	S=0.71(0.29)	Aut=0.26(0.09)	Aut=0.23(0.13)	Aut=0.29(0.17)				
Large delphinid	SE=0.09(0.05)	Spr=0.15(0.07)	Spr=0.25(0.13)	Spr=0.06(0.02)				
	S=0.21(0.07)	Aut=0.15(0.06)	Aut=0.17(0.05)	Aut=0.12(0.11)				
Small whale	SE=0.003(0.001)	Spr=0.003(0.001)	Spr=0.003(0.001)	Spr=0.003(0.001)				
	S=0.002(0.001)	Aut=0.002(0.001)	Aut=0.001(0.0003)	Aut=0.003(0.001)				
Large whale	SE=0.007(0.002)	Spr=0.005(0.001)	Spr=0.002(0.001)	Spr=0.008(0.002)				
	S=0.002(0.001)	Aut=0.004(0.002)	Aut=0.002(0.001)	Aut=0.007(0.005)				
Stenella frontalis	SE=0.21(0.08)	Spr=0.39(0.18)	Spr=0.44(0.36)	Spr=0.36(0.11)				
	S=0.24(0.18)	Aut=0.05(0.02)	Aut=0.05(0.02)	Aut=0.05(0.04)				
Stenella	SE=0.35(0.13)	Spr=0.32(0.12)	Spr=0.17(0.15)	Spr=0.47(0.17)				
longirostris	S=0.09(0.08)	Aut=0.12(0.09)	Aut=0	Aut=0.23(0.19)				

Delphinus			Spr=0.48(0.16)	
delphis*	S=0.33(0.11)		Aut=0.19(0.11)	
Tursiops	SE=0.03(0.01)	Spr=0.04(0.02)	Spr=0.05(0.03)	Spr=0.04(0.02)
truncatus	S=0.07(0.02)	Aut=0.06(0.02)	Aut=0.09(0.03)	Aut=0.02(0.02)
Globicephala	SE=0.005(0.003)	Spr=0.1(0.06)	Spr=0.19(0.09)	Spr=0.006
melas**	S=0.13(0.05)	Aut=0.03(0.02)	Aut=0.07(0.02)	Aut=0.004
Physeter	SE=0.01 (0.01)	Spr=0.026(0.01)	Spr=0.05(0.01)	Spr=0.01(0.003)
macrocephalus	S=0.04(0.01)	Aut=0.027(0.01)	Aut=0.03(0.02)	Aut=0.02(0.01)

ER, encounter rate; (), Standard error values; *, this species only occurred in the south area; **, species with one sighting and no standard error; S.south area; SE, southeast; Spr, spring; Aut, autumn.

Table 5. ANOVA and post-hoc Tukey tests results of ER comparisons between areas south and southeast and seasons.								
Group categories/	Areas	Seasons	South	Southeast	Spring	Autumn		
Species	(S x SE)	(Spring x Autumn)	(Spring x Autumn)	(Spring x Autumn)	(S x SE)	(S x SE)		
Total Cetaceans	p=0.69	p=0.03	p=0.26	p=0.56	p=0.52	p=0.99		
Small delphinid	p=0.88	p=0.01	p=0.09	p=0.33	p=0.98	p=0.95		
Large delphinid	p=0.23	p=0.99	p=0.97	p=0.97	p=0.97	p=0.57		
Small whale	p=0.39	p=0.43	p=0.89	p=0.96	p=0.95	p=0.87		
Large whale	p=0.09	p=0.40	p=0.98	p=0.82	p=0.44	p=0.74		
Stenella frontalis	p=0.72	p=0.01	p=0.62	p=0.06	p=0.94	p=0.70		
Stenella longirostris	p=0.11	p=0.26	p=0.91	p = 0.75	p=0.54	p=0.74		
Delphinus delphis*			p=0.15					
Tursiops truncatus	p=0.23	p=0.78	p=0.56	p=0.34	p=0.91	p=0.12		
Globicephala melas	p=0.01	p=0.66	p=0.91	p=0.99	p=0.29	p=0.10		
Physeter macrocephalus	p=0.03	p=0.86	p=0.92	p=0.98	p=0.17	p=0.62		

ER, encounter rate; *, this species only occurred in the south area, thus the only difference tested was between seasons; S.south area;

SE, southeast. p values in bold (p<0.05) represent statistically significant results

Cetacean distribution patterns

Sperm Whale

The sperm whale (*P. macrocephalus*) was the most frequent species in the study area (n=140), representing 27.8% of the all sightings (Table 2). Sperm whales occurred throughout the south area with only 19.2% (n=27) of the sightings in the southeast. The ER was higher in the former at depths over 1000 m (Tables 4 and 5, Fig 4). During autumn, fewer sightings (representing 25%, n=35) of larger mean group sizes were registered (Table 2).



Fig. 4. Kernel density of *Physeter macrocephalus* **distribution.** Plots were according to depth (left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.

Small Delphinids

The small delphinids (n=113 sightings) were evenly distributed along the study area with higher ER observed during spring (Tables 4 and 5, Fig 5). The most frequent species was *S. frontalis* (n=40), followed by the common dolphin (*Delphinus delphis*, n=27), which occurred only in the south area. Higher densities of *S. frontalis* were observed in spring over depths around 250 meters and to the north of 31°S (Tables 4 and 5, Fig 6). However this difference in ER across seasons is apparently due to an increase in use of the southeast area during autumn. *D. delphis* was only recorded to the south of 32°S. Although there was no difference in ER between seasons (Tables 4 and 5), larger mean group size were observed in autumn, mostly from the outer continental shelf to the upper slope (Table 2, Fig 7). Encounter rates of *S. longirostris* (n=15) and the few sightings of *S. attenuata* (n=7), which was observed only in the southeast, were also higher in spring and in deep waters over the continental slope (Tables 2, 4 and 5, Figs 8 and 9). The least frequent species, *S. clymene* (n=3) *S. coeruleoalba* (n=2), *F. attenuata* (n=1) and *S. bredanensis* (n=1) were registered only during spring surveys (Table 2).



Fig. 5. Encounter rate (ER) distribution of small delphinids during spring (left) and autumn (right) surveys in the south and southeastern Brazil. Acronyms represent the Braziliam states of Rio Grande do Sul (RS); Santa Catarina (SC); Paraná (PR); São Paulo (SP) and Rio de Janeiro (RJ). Dashed line is the limit between south and southeast areas. Solid grey lines are 200m, 1500m, 2000m isobaths.



Fig. 6. Kernel density of *Stenella frontalis* distribution. Plots were according to depth (left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.



Fig. 7. Kernel density of *Delphinus delphis* distribution. Plots were according to depth (left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.



Fig. 8. Kernel density of *Stenella longirostris* distribution. Plots were according to depth (left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.



Fig. 9. Kernel density of *Stenella attenuata* distribution. Plots were according to depth (left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.

Large Delphinids

This group represented 13% (n=67) of all sightings and occurred in both areas and seasons (Tables 2, 4 and 5; Fig 10). *Tursiops truncatus* was the most frequent (n=33) species within this group and was distributed along the study area around depths of 500m (Fig 11). Although differences in ER were non-significant, higher densities shifted between seasons and areas. Densities were higher in the southeast during spring and in the south during autumn around the latitude of 29° (Tables 4 and 5, Fig 11). The second most frequent large delphinid, *G. melas* (n=17), presented higher densities in the south and during spring, in waters over the continental slope, similar to *T. truncatus* (Tables 4 and 5, Fig 12). *Grampus griseus* (n=9) was twice as frequent in the south as in the southeast, with higher densities beyond the 600m isobath (Table 2, Fig 13). *Orcinus orca* was seen in five occasions, three in the south area during spring

and two in the southeast area during autumn (Table 2). The only two sighting of *Pseudorca crassidens* occurred in the southeast, one in each season (Table 2).



Fig. 10. Encounter rate (ER) distribution of large delphinids during spring (A) and autumn (B) surveys in the south and southeastern Brazil. Acronyms represent the Brazilian states of Rio Grande do Sul (RS); Santa Catarina (SC); Paraná (PR); São Paulo (SP) and Rio de Janeiro (RJ). Dashed line is the limit between south and southeast areas. Solid grey lines are 200m, 1500m, 2000m isobaths.



Fig. 11. Kernel density of *Tursiops truncatus* **distribution.** Plots were according to depth (left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.



Fig. 12. Kernel density of Globicephala melas distribution. Plots were according to depth

(left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.



Fig. 13. Kernel density of *Grampus griseus* **distribution.** Plots were according to depth (left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.

Small Whales

This was the least sighted group (n=30) and most sightings occurred in spring (n=21). A large proportion of small whale sightings (48%) could not be identified to species level. Unidentified minke whale and the two minke whale species altogether accounted for 80% of the sightings within this group. There was no difference in the ER between areas and seasons (Tables 4 and 5), though sightings predominated in spring (Fig 14). In general, higher densities of minke whales occurred around latitude 28°S during spring and 25°S in autumn, mainly in waters up to 500m deep (Fig 15).



Fig. 14. Encounter rate (ER) distribution of small whale during spring (left) and autumn (**right) surveys in the south and southeastern Brazil.** Acronyms represent the Brazilian states of Rio Grande do Sul (RS); Santa Catarina (SC); Paraná (PR); São Paulo (SP) and Rio de Janeiro (RJ). Dashed line is the limit between south and southeast areas. Solid grey lines are 200m, 1500m, 2000m isobaths.



Fig. 15. Kernel density of unidentified minke whale *Balaenoptera* spp. distribution. Plots were according to depth (left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.

Large Whales

This group accounted for 11.9% (n=60) of all sightings (Table 2). No differences in ER were found between areas or seasons (Tables 4 and 5; Fig 16). The two most frequently sighted large baleen whale species were Bryde's (*B. brydei, sensu* Pastene et al. 2015; n=14) and the humpback (*M. novaeangliae*, n=14) whales (Table 2). Both species were mostly observed in the northern part of the southeast area during spring (Table 2, Figs 17 and 18). In the southeast, higher densities of *B. brydei* were observed near the latitude of 25°S in both seasons (Fig 17). In the south, the species was only recorded twice in spring. Higher concentrations of *B. brydei* occurred in waters between 500 and 1000m during spring (Fig 17). In autumn, sightings of *M. novaeangliae* were composed of one individual, while in spring the species was mostly seen in

pairs near the shelf break (Table 2, Fig 18). *Balaenoptera physalus* was recorded only in three occasions during autumn surveys in both areas. Mean group size was larger compared to other large baleen whales (mean=4.3, Table 2). Only one sei whale *B. borealis* was registered in the south in spring (Table 2).



Fig. 16. Encounter rate (ER) distribution of large whales during spring (left) and aumtumn (right) surveys. Acronyms represent the Brazilian states of Rio Grande do Sul (RS); Santa Catarina (SC); Paraná (PR); São Paulo (SP) and Rio de Janeiro (RJ). Dashed line is the limit beween south and southeast areas. Solid grey lines are 200m, 1500m, 2000m isobaths.


Fig. 17. Kernel density of *Balaenoptera brydei* **distribution.** Plots were according to depth (left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.



Fig. 18. Kernel density of *Megaptera novaeangliae* **distribution.** Plots were according to depth (left) and latitude (right) during spring (dashed lines) and autumn (solid black lines) surveys.

Discussion

General Pattens of Cetacean Distribution

This study provides a comprehensive description of seasonal (autumn and spring) density and distribution for the most commonly encountered cetaceans in southern and southeastern Brazilian offshore waters based on long term dedicated surveys. Despite differences in temporal and spatial coverage as well as methodological approaches (e.g. aerial vs ship-based surveys), species richness ($n \ge 21$) was similar to other productive areas worldwide such as the temperate waters of southern Australia ($n \ge 15$, [4]) and the California current system (n = 21, [44]), the tropical waters of Gulf of Mexico (n=28, [6]), the eastern Pacific (n=30, [45]) and the cold waters in the Pacific sub-Arctic gyres (n=24, [46]). The fact that 90% of the species richness was recorded within the first four cruises indicates that the area was properly surveyed. Nevertheless, it is worth noting that our surveys were restricted to spring and autumn seasons, hence species richness for this area is possibly higher as typical tropical and cold-water cetaceans are most likely to occur in this area during summer and winter months, respectively. Furthermore, some cryptic species that are typically ungregarious or solitary and unconspicuous such as beaked (Ziphiidae) as well as pygmy and dwarf sperm (Kogiidae) whales are known to occur in this area [18] but were not recorded in this study, except for one sighting of an unidentified ziphiid. Although the turnover of species between areas and seasons was moderate, diversity was higher between seasons than between areas. Diversity was also higher between seasons in the southeast and lower between areas during autumn. The moderate turnover suggests that there is no important variation in species composition when moving from one season or area to another. Higher turnover rates are likely to occur between seasons with extreme oceanographic variations, *i.e.* summer vs winter. In summer the entire area is dominated by the

oligotrophic tropical water, therefore a dominance of tropical species is expected. During winter, while the southeast remains influenced by the tropical water, part of the south area receives inflow of cold and productive waters from Malvinas/Falkland current and subantarctic shelf water as well as the La Plata river plume, which together form the subtropical shelf front [24]. Thus, both tropical and cold-water species are likely to form the cetacean community in the study area. The influence of these productive waters extends towards the spring, at least in the south area. This is likely to explain both the higher diversity between seasons than between areas as well as a higher overall cetacean richness and density in spring, especially in the south area.

Cetacean densities were investigated through encounter rate index and were not corrected for animals missed on observation effort due to perception or availability bias (animals submerged, avoidance of or attraction to the vessel). Therefore the ER used as density index in this study reflects how these cetacean species used this area during the sampled years and does not show realistic estimates of densities values for this area. Overall, cetacean density was higher in spring compared to autumn surveys. Despite the fact that this pattern is mainly influenced by the most frequent and gregarious species (e.g. P. macrocephalus, S. frontalis), this was expected as local productivity in subtropical/temperate waters of the Southwestern Atlantic [47] and hence prey availability is enhanced in spring. Although the outer continental shelf and slope of southeastern and southern Brazil are dominated by the oligotrophic tropical water carried out by the Brazil current, seasonal wind patterns control the behaviour of water masses and the occurrence of upwelling events affecting the local productivity, mainly in continental shelf waters [23,24,26]. The prevailing northeasterlies during spring and summer allow the southward tropical water and subtropical shelf water to reach the continental shelf and also promote the occurrence of local upwellings of the South Atlantic central water and transfer of continental

derived materials to offshore areas [23]. On the other hand, the frequent southwesterlies during autumn and winter inhibit lateral circulation preventing offshore dispersion of nutrient rich coastal waters (specially in the south area) [23,24]. In the southeast, however, upwellings associated with cyclonic eddies enhance productivity on the outer continental shelf and slope [21,22]. The seasonal physical enrichment processes over the outer continental shelf and slope causes environmental discontinuities and are reflected in biological processes, such as patchiness of pelagic organisms. Small fishes of the family Myctophidae, squids and zooplankton (for baleen whales) are the most commonly prey species consumed by cetacean inhabiting offshore waters [46, 48-50). Their distribution patterns are likely to affect the distribution and movements of their predators. Seasonal acoustic assessment studies carried out in the same area of this study have shown that lanternfish (Maurolicus stehmanni) and Myctophidae species are the most common mesopelagic fish with strong association with the tropical water over the continental slope [51]. The short fin squid (Illex argentinus) preys upon these small pelagic fish and is associated with cold waters. All these species play an important role in the pelagic food web of the outer continental shelf and slope of southern Brazil. They are preyed upon by a variety of fish [51,52], seabirds [53] and cetaceans [48, 53]. Densities of demersal fish species in the outer shelf and upper slope of southern Brazil are higher compared to the southeast area due to the influence of the southern nearby richer water masses [54].

Spatial and Temporal Variation in Density of Cetacean Species

Higher densities of *P. macrocephalus* were found in the deep waters over the continental slope of the south area in both seasons. The only few records in the southeast occurred in the southern end of that area. Furthermore, the species was more evenly distributed during spring

while fewer groups composed of a larger mean number of individuals were observed during autumn. This species feed upon large squids [55] that are probably more associated to a demersal food web with different temporal pattern of productivity. Therefore the distribution pattern found in this study is possibly related to abundance of the short fin squids, one of the species' main prey in this area [56,57]. The short fin squid is associated with cold waters presenting high abundance during autumn mainly over the continental slope and a more sparse distribution with low abundances in late spring [57]. Probably this higher abundance of the short fin squid in autumn is a result of the enhanced productivity during spring as the development of all trophic levels between phytoplankton and large squids takes approximately four months [58]. The combination of oceanographic and topographic features appears to be relevant to sperm whales inhabiting other areas (e.g. in Mediterranean waters – [59,60]). In the Gulf of California, sperm whales appear to change their distribution in response to a decline in abundance of squid species known to be their main prey [55]. In that area, during years of lower prey abundance, P. macrocephalus were evenly distributed compared with a year of prey's high abundance, in which they were found in large aggregations.

The small delphinids were frequent in both areas along the outer continental shelf and slope, with higher densities observed in spring. Since the surveyed area is a transitional zone between oceanic and continental shelf water, the occurrence of representative species of both habitats was expected. Densities presented some latitudinal structure with varying overlaping between species. Although similar patterns were described in previous studies [11, 61, 62, 13], our results add resolution on time and space scales of these species disrbution over the outer continental shelf and slope.

Delphinus delphis only occurred in the south area and presented higher densities south of ~32°S and in waters shallower than 500m. According to Tavares et al. [62] the distribution of this species ranges from the outer continental shelf to upper slope (70-1500m), between southern Brazil and central Argentina, and is more restricted to shallower waters (18-70m) in southeastern Brazil. This pattern might explain the lack of sightings of D. delphis in southeast outer continental shelf and slope. Stenella frontalis occurred throughout the study area, though higher density was observed north of 32°S, with only a few records south of this latitude. This latitude coincides with the northern limit of D. delphis distribution during this study, suggesting some degree of habitat partitioning. Although S. frontalis is found over the shallow continental shelf waters (20m) and slope (~1000m) in southeastern and southern Brazil [61, 63], areas south of 27°S and deeper than 200m are suggested to be less suitable for this species [11]. In our study, higher densities were observed beyond the shelf-break, which is consistent with previous studies that showed greater density of S. frontalis at the outer shelf and slope [11, 61]. Despite methodological differences between studies, our findings show that waters beyond 200m are a suitable habitat for S. frontalis both in spring and autumn as opposed to the model predictions by Amaral *et al.* [13].

Higher densities of *S. longirostris* occurred in lower latitudes and beyond the shelf break. This species has been described to occur beyond the outer continental shelf in tropical waters of the Southwestern Atlantic Ocean [61, 13]; however, a few records exist south of 31°S, in spring. Sightings in autumn were rare and restricted to the southeast. This pattern is consistent with the preference of this species for a more tropical habitat and suggests that seasonal movements occur, possibly associated to foraging in more productive area in the south during spring. The few sightings of *S. attenuata* and *S. clymene* recorded in this study coincide with their more

tropical distribution as proposed in preview studies [64, 61]. Both species, however, occurred further south of their predicted suitable habitat, as proposed by Amaral *et al.* [13]. These two species have similar habitat requirements and are reported in mixed associations in both the tropical Pacific and the Atlantic Oceans [45, 13]. Mixed groups involving small delphinids, as defined here, were registered only between *S. attenuata* and *S. longirostris* in the northern part of the southeast area and between *S. frontalis* and *T. truncatus*. Although it has been proposed that the two species of spotted dolphins (*S. frontalis and S. attenuata*) are parapatric [61], the small overlap area in distribution was found at the north of the study area, as previously suggested [13].

Rare sightings of pygmy killer whales (*F. attenuata*), stripped (*S. coeruleoalba*) and rough-toothed (*S. bredanensis*) dolphins were consistent with their known distribution patterns [12]. The first is typically a tropical species, while the latter tends to occur over the continental shelf and *S. coeruleoalba* seems to be rare in the Southwestern Atlantic [12,13].

Tursiops truncatus was the most frequent species within the large delphinid group. The distribution of *T. truncatus* is spread along the Southwestern Atlantic at both nearshore (coastal ecotype) and offshore (oceanic ecotype) waters [12]. The coastal ecotype concentrates in areas near river discharge, estuaries and bays of Argentina, Uruguay and southern Brazil [65]. The oceanic ecotype, on the other hand, seems to be widely distributed in tropical and subtropical deep waters along the outer continental shelf and beyond and in association with oceanic islands [12]. Nevertheless, small groups of the oceanic ecotype were shown to occur near shore in Rio de Janeiro (~23°S) during winter and spring and were inferred to be part of a larger offshore population using a wider geographic region [66]. In this study, only the oceanic ecotype was recorded. Higher densities of *T. truncatus* were observed between 28°S and 30°S, from the outer

continental shelf to the upper slope, in both seasons. *Tursiops truncatus* was also the species mostly seen (53% of its records) in multispecific associations. These associations occurred with five species, though no more than two species were involved each time. Most of the associations were observed with *G. melas* and *G. griseus* and occurred over the continental slope of the south area. The reasons of these multispecific associations are unknown but are likely related to foraging or predator avoidance [67].

Sightings of *G. melas* occurred mainly south of 30° S and depths between 500 and 1000m, similarly to previous reports [15]. This depth range is comparable to that of *T. truncatus* and might explain the relatively frequent occurrence of mixed groups of these two species reported here. Despite the limited number of records of *G. griseus* during this study, the higher densities between 28°S and 30°S in offshore waters is in accordance with the preference for subtropical/temperate waters of continental shelf and slope described as the species distribution pattern worldwide [60, 68].

Although sightings of killer whale (*O. orca*) were rare, this species was shown to frequently depredate the catch of longline fisheries near the shelf break and beyond in this region [69, 70].

Most sightings of small whales included minke whales that could not be identified to species level due to the difficulty in assessing differences in colour patterns between the two species at long distances. Minke whales were present in both seasons with a higher frequency and density in spring. This pattern coincides with sighting and stranding records of these species in this region [71,72,18]. The high occurrence of these species in spring is probably related to the use of the outer continental shelf and upper slope as part of the migration pathway from tropical and subtropical breeding grounds off Brazil towards feeding grounds. It has been suggested that

B. bonaerensis occupies deeper waters beyond the 200m isobath while *B. acutorostrata* is distributed primarily in shallower waters over the continental shelf (71,72,73,17). Although our survey area does not cover the mid and inner continental shelf, the high number of sightings (both species) beyond the shelf break and the fact that few confirmed sightings of *B. acutorostrata* occurred in deeper waters (mean depth of 553m – Table 2) suggest that both species are commonly distributed along the shelf break and slope. The few sightings of both species in autumn are evidence that some individuals do not migrate to sub-Antarctic and Antarctic feeding grounds or are arriving earlier at the breeding grounds. This has been suggested in previous studies based on summer and autumn records in stranding, sighting and whaling data [71,72, 18] and indicates that a small fraction of the population of both species can be maintained by local productivity in subtropical waters.

Higher densities of *Megaptera novaeangliae* and *Balaenoptera brydei* were observed in the southeast area and this is to opposite examples of large whale behaviour. Bryde's whale has been referred as *Balaenoptera edeni* until recently when a phylogenetic analysis confirmed that in South America the species is *B. brydei* [74]. The Bryde whale occupied a wide area from the outer continental shelf to the slope; however, higher densities were observed over the upper slope (~ 750m isobath), during spring and at lower latitudes. This species has been reported to occur year round in coastal areas of southeast Brazil [75]. *B. brydei* does not perform long-distance seasonal movements as other balaenopteriids, though, despite the limited number of sighting in autumn also corroborates with other studies which proposed that this species perform movements to other feeding grounds, including coastal areas not surveyed in this study [72, 75]. Changes in the species distribution have been related to prey availability [76,77].

Megaptera novaeangliae, on the other hand, is well known to perform long-distance seasonal migrations between winter/breeding and summer/feeding areas in low and high latitudes [78]. During winter and spring, *M. novaeangliae* occurs from northeastern Brazil (~5°S) to Rio de Janeiro state (~23°S) [73]. Therefore, the higher densities observed in spring surveys and only in the southeast area were expected, particularly because the northern range of this study area is used by humpback whales during their southbound spring migration [79]. At the time of the surveys (approaching mid spring), the whales were starting their southward migration to feeding grounds in sub-Antarctic waters. The lack of sightings in the south area coincides with the species' far offshore migration pathway [80, 79].

The low number of sightings of *B. physalus* and *B. borealis* is probably related to their relatively lower abundances and/or further offshore distribution in lower latitudes of the Southwestern Atlantic [81, 82, 83].

The results presented here strongly emphasizes the importance of the outer continental shelf and slope to a diverse community of cetaceans in the subtropical Southwestern Atlantic. This work contributed to improve in description of the distribution pattern at both temporal and spatial scales for the most frequent cetacean species. Areas of higher diversity and density that are persistent in time are strong candidates to be declared as ecologically and biologically significant areas and to receive special attention for conservation in situations of conflict with human activities.

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ANEXO II

Spatial and temporal patterns of sperm whale abundance and distribution in relation to physiographic and oceanographic features in the subtropical Southwestern Atlantic Ocean

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Spatial and temporal patterns of sperm whale abundance and distribution in relation to physiographic and oceanographic features in the subtropical Southwestern Atlantic Ocean

Headings: Abundance and distribution of sperm whales

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Abstract

The sperm whale (*Physeter macrocephalus*) is widely distributed throughout all ocean basins from equator to polar seas and occurs over the continental slope. Its preferential habitats are generally beyond the 1000m isobaths and places of high biological productivity and conspicuous bathymetric features, such as canyons and steep slopes. In the present study, we hypothesize that variations in sperm whale abundance and distribution on the continental slope of the subtropical Southwestern Atlantic (ca. 33.7°S - 22.9°S) are determined by oceanographic (e.g. sea surface temperature, chlorophyll-a concentration) and ocean floor bottom physiography. Eight surveys were conducted during austral spring (n=4) and autumn (n=4) between 2009 and 2014 from approximately the 150 to 1500m isobaths. Encounter rate and abundance of sperm whales were estimated using both conventional and multicovariate distance sampling methods. Best-fit model for detection function was the half-normal with cluster size as a covariate. Abundances were consistently higher during spring and varied from 177 (CV = 0.44) in autumn 2013 to 1516 (CV=0.34) in spring 2012 considering a maximum detection probability at the trackline (*i.e.* $g_{(0)} =$ 1). These values changed to 204 (CV=0.46) and to 1743 (CV=0.34) if $g_{(0)} = 0.87$, respectively. We used generalized additive models (GAMs) with a a negative binomial error distribution to model the relationship between the sperm whale density and biological, oceanographic and bathymetric explanatory variables that described the species habitat. The best-fit model, indicated that 60.9% of the variation of sperm whales' density was explained by depth, sea surface temperature, NASC (considered

as an index of local productivity) and location. This is similar to distribution patterns observed worldwide. The results presented here contributes to knowledge on the species ecological requirements and, therefore, are relevant for the formulation of hypothesis on the species ecology as well as for decision makers to design conservation strategies that minimise potential conflicts with human activities.

Keywords: Cetaceans, habitat modelling, habitat use, oceanography, ecology

Introduction

The understanding of spatial and temporal patterns of a species distribution is essential before taking actions to minimize potential conflicts with human activities such as fisheries, seismic activities, oil and gas exploration as well as navigation. Linking distribution to environmental variables sheds light on the understanding of the species ecological requirements. The sperm whale (*Physeter macrocephalus*) is widely distributed throughout all ocean basins and most semi-enclosed seas from equator to polar seas (Rice, 1989; Mesnick, 2014). Females and juveniles have a more restricted distribution than males and are typically constrained to latitudes lower than 50° and to regions where sea surface temperature is above 15°C (Rice, 1989). The species occurs over the continental slope, though its preferential habitats are generally beyond the 1000 m isobaths (Rice, 1989). In some regions, however, it can be found in shallower waters (e.g. Northwestern Atlantic - Scott and Sadove, 1997). Sperm whales tend to be more numerous in areas of high productivity (e.g. Jaquet et al., 1996).

Some of these higher sperm whale abundance areas have been targeted by whaling activities for centuries where the species was extensively hunted by both small and large scale commercial whaling (e.g. Tønnessen and Johnsen, 1982; Jaquet et al., 1996; Bannister et al., 2007). When the whaling activity was completely ceased by the early 1990s, global sperm whale population was estimated to have collapsed almost 70% of its pre-whaling abundance (Whitehead, 2002). In the Southwestern

Atlantic Ocean (SWAO), however, the rate of removal is unknown as there are no abundance estimates available for this region. Despite the low potential for population recovery (Whitehead, 2002), because the SWAO was not a major whaling ground (Tønnessen and Johnsen, 1982; Bannister et al., 2007), it is likely that this "subpopulation" has not been much affected by whaling. This is valid assuming that there is population structuring between ocean basins (e.g. Rendell and Whitehead, 2005). It is important to emphasize, however, that some indirect potential threats such as noise and chemical pollution, collisions with vessels and entanglement in fishing gears are potentially threats to this species (e.g. IWC, 1994; Gordon and Moscrop, 1996; Nielsen et al., 2000; Donoghue et al., 2003). Thus, abundance estimates and the characterisation of sperm whales' habitat is relevant for establishing a baseline for long-term monitoring on the species trend as well as to identify its major ecological requirements. This is essential for understanding the species ecology and for decision makers to define scientific-based conservation strategies when potential conflicts with human activities exist.

The waters over the southern and southeastern Brazilian continental shelf and slope are economically important for fisheries and the oil and gas industries. Approximately 60% of the national commercial fish catch comes from these two regions (Knoppers et al., 2010), which are characterized by different dominant hydrographic dynamics. On one hand, the surface and subsurface waters over southeastern continental shelf and slope are relatively stable as they are mostly influenced by the dominant Brazil current (BC), which transports tropical warm and oligotrophic water (TW). In this area, increases in productive are locally and occasionally triggered by upwellings that pump the South Atlantic Central Water (SACW) to superficial layers, changing composition and increasing productivity of phytoplankton (Brandini, 1990). The southern continental shelf and slope, on the other hand, are influenced by TW of the BC, the sub-Antarctic waters (SABW) carried by the Malvinas/Falkland currents (M/FC) and continental waters from La Plata River and Patos Lagoon plumes, which form the subtropical shelf front (STSF) (Möller et al., 2008; Piola et al., 2008). This front, characterized by a sharp thermohaline transition between these water masses, changes its intensity and location over the continental shelf according to seasonal wind regimes and shifts to offshore waters towards the shelf break and slope (Piola et al., 2000; 2008). These processes and surface and subsurface upwelling events influence the productivity in offshore waters by enhancing concentration of inorganic nutrients, chlorophyll-a and density of zooplankton (Braga et al., 2008; Muelbert et al., 2008).

Because of the ecological and economical relevance of the Brazilian southern and southeastern outer continental shelf and slope, a series of surveys were carried out in spring and autumn (from 2009-2014) to assess patterns of cetacean and seabird distribution in relation to environmental variables, named Slope Project (*Projeto Talude*/EcoMega-FURG). A cetacean community of relatively high richness was observed in both seasons. Out of the 21 identified species, sperm whale was the most frequently observed cetacean (~28% of 503 sightings), especially in the southern area (Di Tullio et al., under review). The species occurs year round in the SWAO (e.g. Toledo and Langguth, 2009; Di Tullio et al., under review), although its distribution pattern has not been investigated so far. The combination of oceanographic and topographic features appears to be relevant to sperm whales inhabiting other areas (e.g. Whitehead et al., 1992; Jaquet, 1996; Jaquet and Gendron, 2002; Pirotta et al., 2011; Azzelino et al., 2012). We hypothesize that sperm whale abundance and distribution in the study area are associated to waters of lower sea surface temperature and higher productivity as well as areas of conspicuous bathymetric features. Thus, the present study aims at estimating seasonal (spring and autumn) abundance and distribution of sperm whales and their relationship with physiographic and oceanographic features on the continental slope of the subtropical Southwestern Atlantic.

Material and Methods

Survey design and data collection

Eight surveys were conducted during austral spring (n=4) and autumn (n=4) between 2009 and 2014 onboard the 36 meter-long R/V Atlântico Sul of the Federal University of Rio Grande (FURG) (Fig. 1). Zig-zag transect lines were pre-designed to cover the outer continental shelf and slope of southern and southeastern Brazil (ca. 33.7°S - 22.9°S), from approximately the 150 to 1500m isobaths (Fig. 1). Effort varied among surveys mainly due to weather conditions. The first survey was exploratory and much shorter in time and effort (Table 1). For logistic reasons, the surveys always started at the southernmost transect line. The vessel's steering speed varied between 14.4 - 18.5 km/h (8-10kt). Two observers searched for cetaceans from the bridge's deck (observation height ~ 8.6 meters). The observers, stood in the port and starboard sides, scanned from 10° right or left to 90° left or right of the tracking line, respectively. The searching was conducted by alternated scannings with the use of Fujinon 7x50 reticule binoculars and with unaided eyes. An assistant was positioned a few metres behind the observers to help species identification and group size estimation after detection. The assistant's main role was to minimize the time that the observers took to resume scanning after detection. A recorder was in charge of inserting the data in a notebook connected to the vessel's navigation system using the WinCruz program (available at:

http://swfsc.noaa.gov/textblock.aspx?Division=PRD&ParentMenuId=147&id=1446). Stored data included effort (e.g. date, time, coordinates), weather and sighting conditions (e.g. Beaufort sea state, swell height, visibility, glare), sighting information (e.g. observer, sighting cue, group size and position). Group size was estimated by consensus between the observer and the assistant. Best, low and high estimates of group size were recorded, though only "best" was used in the analyses. The position of each sighting was based on the radial distance – calculated from the binocular's reticles – and angle relative to the ship's heading – measured using an angle board. Six to eight trained observers rotated though the observation positions every 30 minutes during a 2-h shift, followed by a 60 min break. Most of the time transects were surveyed using passing mode in which species and group size were determined without the vessel diverting from the trackline (e.g. Hiby and Hammond, 1989). In a few occasions, however, effort was halted and the ship closed in the sighting, for no longer than one hour, in order to identify the species and/or to better estimate group size. This happened only when the detected group had passed abeam and no other group had been seen. After species identification and/or group size estimation, the effort was resumed at the location where it ended. In order to standardize sighting effort, only sightings made by the two observers and at sea state 5 or lower were considered in the analyses. Survey effort was halted during poor sighting conditions (i.e. sea state above 5, fog, rain or low light levels).

Table 1. Surveys effort in kilometres for each season in south and southeast Brazil,2009-2014. Starting date: day at the start of the survey. N days: duration of each

Region (km)									
Survey (year)	South	Southeast	Total (km)	Starting date (day/month)	N days				
Spring 2009	1267.5	1006.8	2274.3	22/10	15				
Autumn 2010	1688.8	488.6	2177.4	22/04	22				
Spring 2010	1543.1	1934.2	3477.3	20/10	31				
Autumn 2011	1786.8	1678.2	3465.1	13/04	29				
Spring 2012	1827.6	1443.9	3271.5	26/10	29				
Autumn 2013	1786.5	1347.6	3134.1	07/05	34				
Autumn 2014	1375.4	925.2	2300.6	10/05	30				
Spring 2014	1604.6	881.7	2486.3	12/11	30				
Total	12880.4	9706.4	22586.9	-	220				

survey in days.

Abundance estimates

Encounter rates and abundance of sperm whales were estimated by using conventional (CDS) and multi-covariate (MCDS) distance sampling methods (Buckland et al., 2001, 2004; Marques and Buckland, 2003; Buckland, 2004; Thomas et al., 2010) as implemented in the mark-recapture distance sampling (mrds) package (Laake et al., 2007) for R version 3.2.1 (R development Core Team, 2015). Detection function was modelled by pooling the sightings from all surveys with no truncation of the perpendicular distance. Detection probability was estimated by fitting hazard-rate and half-normal key functions with cosine series expansion terms with and without covariates (Buckland et al., 2001, Buckland, 2004). The numerical covariates sea state, cluster size and swell height were explored alone and combined. The detection function with the lowest Akaike's Information Criteria (AIC) score was selected and assessed using diagnostic quantile-quantile plots (Burnham & Anderson, 2002; Thomas et al., 2010). The observed cluster size was regressed against the detection

probability to estimate the expected cluster size corrected for size bias (*i.e.* tendency to observe larger clusters at large distance). The encounter rate, density and abundance were estimated assuming maximum detection probability at the trackline (*i.e.* $g_{(0)}=1$) and considering the availability bias based on the diving behaviour cycles of sperm whales $g_{(0)}=0.87$ (Barlow and Sexton, 1996). Estimates also considered two alternative scenarios of estimated cluster size: survey-specific and global (all surveys pooled). The latter is useful when survey-specific sample size was reduced. The coefficients of variation (CV) of the fitted models were estimated by taking into account the variance of the encounter rate estimator, which usually dominates the overall variance of object density in line transects surveys (e.g. Buckland, 2004). The variance of the encounter rate was estimated by S2 estimator, which accounts for systematic survey designs (Fewster et al., 2009). Survey-specific abundances were estimated only for areas surveyed and that were considered potential habitat of sperm whales (i.e. beyond the 200m isobath) (Fig. 1).



Fig. 1. Distribution of sightings (black dots) overlaid on transects (gray-lines) and area (gray surface) considered for abundance estimates for the eight surveys over the continental slope. Dashed line indicates the limit between southern and southeastern Brazil.

Habitat modelling

Samples for modelling were created by splitting on-effort transect lines into segments with a nominal length of ca. 10 km. This segment length was chosen to match the resolution of the environmental variables obtained remotely. The estimated number of sperm whales per segment $(\mathbf{\hat{N}})$ used the Horvitz-Thompson-like estimator, which considers the number of sightings corrected by the detection probability

divided by the mean size of all groups in the segment (Marques and Buckland, 2003). The area for each segment was calculated by multiplying its length in km by 2 times the effective strip width (ESW), which was previously estimated by the detection function.

In addition to the estimated number of individuals and effective area covered, a set of 11 environmental variables of interest was gathered and associated to with each segment for modelling purposes (Table 2). Bathymetry data were obtained during the surveys through an echo sounder and plotted along the transect lines. Positive values of depth and Δ depth were considered as the midpoint segment depth and the difference between the maximum and minimum depth for each segment, respectively. Chlorophyll-a monthly mean concentration in mg/m³ was used as a proxy for primary productivity and was obtained as monthly images from the Giovanni Ocean Color Radiometric Data (http://gdata1.sci.gsfc.nasa.gov/daac-<u>bin/G3/gui.cgi?instance_id=ocean_8day</u>) for the month of the survey (chla) and the mean of 4 months prior to the surveys (mean chla) (Table 2). Daily values of sea surface temperature (sst) were obtained through OSTIA (Operational Sea Surface *Temperature* Sea http://ghrsstand Ice Analysis pp.metoffice.com/pages/latest_analysis/ostia.html) (Donlon et al., 2012) and were considered to the nearest value to centre of each segment during the surveys. Values of the sst were used to estimated the gradient (sst_grad) using a database management system to determine oceanic thermal fronts with a threshold of 0.02°C/km (PostgreSQL 9.3, Obe & Hsu 2011). Distance to 200 metres isobath (dist200) and to conspicuous bathymetric features (distf) were measured as the shortest straight-line distance between that feature and the segment midpoint. The nautical area scattered coefficient (nasc), expressed in m².nmi⁻², was used as proxy of the estimated fish acoustic biomass. NASC was obtained simultaneously during the surveys and was vertically integrated in 1.8km segments along the ship's trackline and was summed for each on-effort segment. The logarithmic (base 10) transformation was applied to sst_grad and depth and log (x+1) was used to chla, mean_chla, Δ depth, and nasc due to the presence of zeros. Squared root transformation was used to dist200 and distf variables. The geographic variables latitude and longitude were also tested in the models in order to account for any spatial residual pattern that could not be explained by the environmental variables included in the models (Table 2).

Variables and groups (unit)	Definition	Transformation	
	Geographic		
lat (UTM) Latitude		-	
long (UTM)	Longitude	-	
	Physiographic		
depth (m)	Depth at the sighting	log	
$\Delta depth(m)$	Difference between the minimum and maximum depth	$\log + 1$	
dist200 (m)	Distance from 200m isobath	square root	
distf (m)	Distance from bathymetric conspicuous features (e.g. canyons, rises)	square root	
	Oceanographic		
sst (°C)	Sea surface temperature	-	
sst_grad (°C)	Sea surface temperature gradient	log	
mean_chla (mg/m ³)	Four-months mean chlorophyll-a concentration	log +1	
chla (mg/m ³)	Mean survey month chlorophyll concentration.	log +1	
nasc (am ² /nmi ²)	Nautical Area Scattering Coefficient - (a proxy for fish biomass)	log +1	

Table 2. Candidate explanatory variables obtained for each segments and their transformation (when needed) for the data analyses.

Statistical modelling

Habitat models were developed combining the entire dataset (2009 to 2014) due the small sample of segments with sperm whale sightings in each year.

Exploratory data analyses were conducted following Zuur et al. (2007, 2010) to check for outliers, collinearity and heterogeneity. Pearson's correlation tests were used to assess the collinearity between explanatory continuous variables (Zuur et al., 2010). The explanatory variables that showed a significant correlation ($|\mathbf{r}| > 0.5$) were not used together in the same model.

The relationship between the response variable \hat{N} and a set of environmental variables in each segment (*i*) was built within a generalized additive modelling (GAM, Hastie and Tibshirani 1990), using the "mgcv" package in R version 3.1.2 (R Development Core Team, 2015). GAM are extensions of generalized linear models which uses a logarithimic link function to model the relationship between the response and explanatory variables without imposing parametric constraints (Hastie and Tibshirani, 1990; Venables and Dichmont, 2004). We used a log-link function and a negative binomial error distribution to account for over-dispersion to model the relationship between the sperm whale density and explanatory variables that describe the characteristics of the species habitat. Because this distribution is a discrete probability function we rounded the estimated number of individuals to the nearest integer. Smoother terms were derived using penalised regression splines to avoid overfitting (Wood, 2006). As the effective area covered by each segment (*i.e.* the segment length multiplied by twice the effective strip half-width estimated as 1.69 km) did not have the same area, we included it as an offset term in the model.

The general model formulation was represented as following:

$$\hat{N}_i \sim NB(\mu_i, \phi)$$

$$\log(\mu_i) = \sum_{k} S_k(X_{ik}) + offset(\log[segment \ area]_i)$$

where S_k is the smooth function for explanatory variables and ϕ is the overdispersed parameter.

A forward stepwise selection was used to obtain the best-fitting models based on Akaike's Information Criterion (AIC), deviance explained and diagnostic plots (Wood 2006). The model that had the lowest AIC and improvements in explained deviance and residual plots was selected for further analysis. Once the model reached the best fit, some variables in the models were replaced, one at a time, by another variable that had been correlated on the data exploration. The procedure was repeated until the removal or replace of any variable resulted in a higher AIC score.

Results

Survey effort and sperm whale distribution and abundance

Sperm whales were observed in all surveys and observation effort per survey varied from 2177 km (autumn 2010) to 3477 km (spring 2010), totalizing 22587km in 2727 segments. Lower effort occurred during the first and last two surveys while higher effort and more evenness between areas were attained during the four intermediate surveys (Table 1). Although distribution patterns were similar among years, sightings predominated in the southern area and during spring surveys. Only a few sperm whales sightings were recorded in the southeastern area and those were concentrated in its southern portion (Fig. 1). The number of sightings during autumn was smaller compared to spring surveys, however the mean observed cluster size in spring was 3.1 (se=1.8), which is smaller compared to the mean cluster size of sightings occurred in autumn (mean=9.4, se=5). Small cluster size (1-10 individuals) predominated (Fig. 2). Most sightings of sperm whales occurred during sea state 5 and low swell height (between 1.0 and 2 m) (Fig. 2). Large aggregations, which included hundreds of individuals (at the spatial scale of the sightings), were rare and occurred twice during two autumn surveys (~100 individuals). Fit for the detection

function resulted in 21 proposed models. The best models selected for the detection function were fitted with half-normal key functions with one cosine series expansion term and considering cluster size as covariate (Table 3). Two other well supported models ($\Delta AIC \leq 2$) were fitted with the same key function (Table 3), though only the model with the lowest AIC was taken into account for estimates of encounter rate, density and abundance (Fig. 3).

Table 3. Summary of model selection for well supported models with $\Delta AIC \leq 2$ compared to the best- fit detection function model. HN: halfnormal; size: group size; swell: swell height; sea state: considering Beaufort numeric; ESW: effective width strip; *p*: average detection probability; CV: coefficient of variation of the averaged detection probability.

Detection function models	Covariates	Δ AIC	Par	р	CV	ESW (km)
HN, cosine, 1 adjustment	Size	0	3			
HN, cosine, 1 adjustment	size + swell	1.29	4	0.39	0.07	1.69
HN, cosine, 1 adjustment	size + sea state	1.41	4			


Fig. 2. Number of sightings according to sea state (A), swell height (B) and group size (C).



Fig. 3. Perpendicular distances (km) and fitted detection function for the best fitted model selected by Akaike's Information Criteria for sperm whales sightings (dots represent detection probability for each individual sighting).

Encounter rates and number of sightings of sperm whales were higher in spring 2012, accounting for nearly one-third of all records (Table 4). Abundance estimates considered different areas according to the effort for each survey (Fig. 1, Table 4) and were consistently higher during spring. Abundance estimates varied from 177 (CV = 0.44) in autumn 2013 to 1516 (CV=0.34) in spring 2012 considering a maximum detection probability at the trackline (*i.e.* $g_{(0)} = 1$). These values change to 204 (CV=0.46) to 1743 (CV=0.34) if $g_{(0)} = 0.87$ (Table 4). The lower abundance estimated for the autumn 2013 survey is increased more than threefold when obtained taking the survey-specific expected rather than global (*i.e.* mean from all surveys) cluster size into account. The decision on the procedure to estimate cluster size had lower effect on the remaining surveys (Table 5).

Table 4. Area considered in abundance estimates. Number of sperm whales'

sightings (n), mean observed number of individuals (ni) and standard error (se),

encounter rate (ER/km), encounter rate coefficient of variation (ER CV) by surveys.

Survey	Area (km ²)	n	ni (se)	ER	ER CV
Spring 2009	82878.2	12	2.7 (1.6)	0.0054	0.27
Autumn 2010	71843.8	9	3.4 (1.7)	0.0039	0.59
Spring 2010	95615.6	32	3.3 (1.9)	0.0091	0.27
Autumn 2011	90362.1	12	10.2(5.3)	0.0035	0.59
Spring 2012	94046.2	49	3.1(1.8)	0.0149	0.32
Autumn 2013	85415.8	6	23(6.5)	0.0019	0.42
Autumn 2014	86737.3	8	4.9(2.0)	0.0036	0.39
Spring 2014	71176.3	12	3.2 (1.7)	0.0049	0.39

Table 5. Estimated group size (ES), estimated group size coefficient of variation (ES CV), density (D), abundance (N), abundance coefficient of variation (N CV) and 95% confidence interval estimates (95%CI) for all surveys using distance sampling methods.

Model estimation	Model estimation $g_{(0)}=1$, expected cluster size by survey.						
Survey	ES	ES CV	D	Ν	N CV	95% CI	
Spring 2009	2.54	0.19	0.0042	345.9	0.47	134-897	
Autumn 2010	3.19	0.28	0.0038	271.55	0.69	72-1021	
Spring 2010	3.07	0.13	0.0084	802.76	0.25	484-1330	
Autumn 2011	5.96	0.44	0.0061	554.05	0.51	206-1487	
Spring 2012	2.98	0.13	0.0133	1253.08	0.32	660-2378	
Autumn 2013	14.68	0.61	0.0073	627.69	0.67	178-2216	
Autumn 2014	4.56	0.52	0.0047	406.79	0.42	179-927	
Spring 2014	3.07	0.18	0.0045	320.33	0.49	121-846	
Model estimation	g ₍₀₎ =1, ex	pected clus	ster size est	imates with	overall sig	htings.	
Survey	ES	ES CV	D	N	N CV	95% CI	
Spring 2009	-		0.0059	485	0.29	269-876	
Autumn 2010			0.0043	308	0.61	94-1007	
Spring 2010			0.0098	942	0.29	532-1667	
Autumn 2011	3.64	0.86	0.0038	343	0.60	109-1082	
Spring 2012	5.04		0.0161	1516	0.34	772-2979	
Autumn 2013	-		0.0021	177	0.24	74-423	
Autumn 2014	-		0.0038	333	0.41	145-764	
Spring 2014			0.0053	377	0.41	164-865	
Model estimation	g(0)=0.87	, expected o	cluster size	estimates wi	th overall	sightings.	
Survey	ES	ES CV	D	Ν	N CV	95% CI	
Spring 2009			0.0067	558	0.29	308-1009	
Autumn 2010			0.0049	354	0.61	108-1159	
Spring 2010			0.0113	1082	0.29	609-1922	
Autumn 2011	3.64	0.86	0.0044	395	0.62	125-1245	
Spring 2012		0.00	0.0185	1743	0.34	885-3433	
Autumn 2013			0.0024	204	0.44	85-487	
Autumn 2014			0.0044	382	0.42	166-879	
Spring 2014			0.0061	433	0.42	188-996	

Habitat models

The Pearson correlation coefficients were higher than $|\mathbf{r}| > 0.5$ between six explanatory variables (Table 6). Among the environmental variables, strong correlation was observed between depth and depth variation and between depth and distance from the 200m isobath. Sea surface temperature and chlorophyll-a concentration were negatively correlated.

Table 6. Pearson correlation coefficients (r) for the explanatory variables after transformation (if needed; in italics). Values of $|\mathbf{r}| > 0.5$ are in bold.

	∆depth	long	lat	sst	mean_ chla	depth	chla	dist200	distf	nasc	sstgrad
ddepth	1										
long	0.12	1									
lat	0.05	0.98	1								
sst	0.10	0.71	0.73	1							
mean_chla	-0.16	-0.47	-0.48	-0.63	1						
depth	0.65	0.18	0.09	0.23	-0.35	1					
chla	-0.20	-0.47	-0.47	-0.59	0.67	-0.37	1				
dist200	0.23	0.17	0.12	0.24	-0.28	0.72	-0.29	1			
distf	-0.4	0.35	0.48	0.40	-0.30	0.04	-0.30	0.18	1		
nasc_sum	-0.02	-0.02	-0.02	-0.14	0.28	-0.13	0.19	-0.15	-0.07	1	
sstgrad	-0.16	-0.32	-0.32	-0.46	0.22	-0.37	0.46	-0.35	-0.18	-0.03	1

From 43 developed habitat models, the final model for sperm whales contained ddepth, lat, sst_grad, and nasc (Table 7). These environmental variables accounted for 60.9% of the total variance of the estimated sperm whale density. The depth and latitude smooth functions showed an increase of the sperm whales' estimated densities in deeper waters and in the south area (Fig. 4A and 4B). Higher whales' densities were also associated with increase of sea surface temperature gradient and in areas of higher nasc values (Fig. 4C and 4D). Despite the high deviance explained of the selected model, diagnostic plots showed that residuals are reasonable near to normality (Fig. 5A), however there is some degree of heterogeneity in residuals (Fig. 5B, C, D).

		dispersion purun	ιστοι (φ).
Models	φ	Deviance	AIC
\widehat{N} ~sst_grad+nasc+lat+depth	0.02	60.9 %	1311.1
\widehat{N} ~sst_grad+nasc+depth+sst	0.02	58.6 %	1323.5
\widehat{N} ~sst_grad+nasc+lat+ Δ depth	0.01	48.9 %	1353.9
\widehat{N} ~sst_grad+nasc+lat+ Δ depth+chla	0.01	48.9 %	1355.5
\widehat{N} ~sst_grad+lat+ Δ depth+chla	0.01	48.3 %	1356.0

Table 7. GAM results for the five best models. Over-dispersion parameter (ϕ).



Fig. 4. Partial functional relationship for the estimated number of sperm whale from multivariate GAM incorporating (A) depth (log), (B) latitude, (C) sst_gradient (log+1) and (D) nasc (log+1) as explanatory variables. Estimated smooth function (solid line) with 95% confidence interval (dashed lines) for the fitted GAM from 2009 to 2014. Y-axis = fitted function with estimated degrees of freedom in parentheses.



Fig. 5. Diagnostics information of the best-fitted GAM model selected. (A) Quantilecomparison plot of the residuals, (B) Residuals vs linear predictors, (C) Histogram of the residuals, (D) Response vs fitted values.

Discussion

The present study provides the first attempt to estimate abundance and characterise distribution patterns of sperm whales (*P. macrocephalus*) and associated with environmental variables in the continental slope of the subtropical Southwestern Atlantic Ocean (SWAO). During the cetacean dedicated surveys conducted during the present study, sperm whales were the most frequent and represented nearly 30% of all cetacean species sightings in this area (Di Tullio et al., under review).

The main biases in abundance estimates are caused by availability, which is related to the presence of the animal in the surveyed area, and perception bias, associated with imperfect detection probability (Marsh and Sinclair, 1989). Perception bias is likely to be small during this study as the observers were either experienced or well trained and data considered here are restricted to observation effort carried out at sea state 5 or below. Availability bias was accounted for by considering two scenarios of detection probability at the trackline (i.e. $g_{(0)}=0.87$ and $g_{(0)}=1$). Although these issues were taken into account, abundance was probably underestimated due to cluster size estimates. Sperm whales present asynchronously long diving behaviour that generally results in downward bias in cluster size estimates (Barlow and Taylor, 2005). These authors suggest that group size estimates were considered reasonable after 90 minutes of observation. It is recommended, however, that uncertainty in cluster size estimates be taken into account in future abundance estimates.

Regarding the models that took global cluster size estimates into account, sperm whale abundance and densities was higher in spring as compared to autumn. Densities of other cetaceans were also higher in spring than in autumn in this area (Di Tullio et al., under review), which is expected, as local productivity is enhanced in subtropical/temperate waters of the SWAO in spring (e.g. Signorini et al., 2006). Variation in abundance is likely related to inter-annual variation in oceanographic conditions and the consequent changes in local productivity. In the Gulf of California, sperm whales appear to change their distribution in response to a decline in abundance of squid species known to be their main prey. In that area, sperm whales were evenly distributed in years of lower prey abundance compared with an year of prey's high abundance, in which they were found in large aggregations (Jaquet and Gendron, 2002). Given sperm whale' size and body mass, it is estimated that the

species remove as much biomass from the oceans as humans (Whitehead, 2003). It is expected, therefore, that temporal changes in abundance observed in the present study represent a significant variation on the level of pressure this large predator exerts on its prey or that availability of large squids vary seasonally. Squids of the families Octopoteuthidae, Histioteuthidae, Ommastrephidae seem to be important prey for sperm whales' in this area (e.g. Clarke et al., 1980; EcoMega unpubl. data); therefore, abundance and distribution patterns of sperm whales are possibly related to availability of these large squids. Many species of these families are abundant in deep and cold waters over the continental slope of southern Brazil, Uruguay and Argentina (Santos and Haimovici, 2007; Haimovici et al., 2014). The lower abundance observed during autumn surveys might be related to seasonal movements of the species to more productive foraging grounds at higher latitudes. Sperm whales are frequently observed in offshore waters of Argentina and around Malvinas/Falkland Island (e.g. Yates and Brickle, 2007; Mandiola et al., 2015).

Generalized additive models (GAMs) offer a robust framework to predict cetacean densities and patterns of habitat use, as long as sufficient observations of species are available and surveys adequately characterise the full range of oceanographic variability (e.g. Dalla Rosa et al., 2012; Forney et al., 2012). The high explained deviance in our selected GAM model probably captured the dominant habitat characteristics affecting sperm whale distribution in this area for spring and autumn seasons. The physiographic and geographic variables selected in the model corroborated a previous study, which showed that sperm whale densities increase in water depths over 1000m and higher latitudes (Di Tullio et al., under review). The oceanographic variables used in the model also showed that higher sea surface temperature gradients and biomass of epi-mesopelagic fish, as inferred by NASC values, positively affect sperm whales densities. Latitude is strongly correlated with sea surface temperature, which in turn is correlated with chlorophyll-a (see Table V). Therefore, these correlations indirectly suggest that, in the study area, sperm whales predominate in colder waters with higher primary productivity. This corroborates our hypothesis and is consistent with other studies. According to Jaquet et al. (1996) sperm whales tend to be more numerous in areas of higher productivity. Despite lack of direct evidence, it is expected that primary productivity and fish biomass in the pelagic stratum is coupled to productivity in the bathypelagic environment. Interpreting the relationship between this highly mobile predator and primary/secondary productivity concominant with its occurence, however, is not straightforward neither in spatial nor temporal scales. The development of all trophic levels between phytoplankton and large squids, the sperm whales main prey, takes approximately four months (Vinogradov, 1981). Efficient predation upon these squids could be enhanced in places of high contour index (as defined in Hui, 1979), such as canyons and steep slopes, where the prey can be aggregated. In different parts of the world, sperm whales' distribution shows strong association with places of marked bathymetric contrast (e.g. Whitehead et al., 1992; Jaquet and Whitehead, 1996; Jaquet et al., 2000).

Although the outer continental shelf and slope of southeastern and southern Brazil are dominated by the oligotrophic tropical water transported by the Brazil current, seasonal wind patterns control the behaviour of water masses and the occurrence of upwelling events affecting local productivity, mainly in continental shelf waters (Möller et al., 2008; Piola et al., 2008; Braga et al., 2008). The prevailing northeasterlies during spring and summer allow the southward tropical water and subtropical shelf water to reach the continental shelf and promote local upwellings of the South Atlantic central water and transfer of continental derived materials to offshore areas (Möller et al., 2008). The higher densities of sperm whales in areas of higher sea surface temperature gradients suggest that the species concentrate in areas with influence of different water masses. The seasonal physical enrichment processes over the outer continental shelf and slope cause environmental discontinuities such as thermohaline fronts and are reflected in biological processes, such as patchiness of pelagic organisms. Relative epipelagic fish biomass (as indicated by NASC values) was generally high in the southern portion of the study area and, in many cases, was associated with subsurface upwellings (Pinho, 2015). Thus, the southern portion of the study seems ecologically important to a variety of organisms that depend on both the epi-mesopelagic and meso-bathypelagic strata.

The results presented here can be used as baselines to monitor temporal variations and trends in abundance as well as to address specific research questions regarding ecological requirements (e.g. demand for primary productivity – Barlow et al., 2008) and the role played by sperm whales on the SWAO continental slope ecosystem. Furthermore, the pattern of sperm whale habitat use and its link to environmental and spatial variables described here are relevant for decision makers to design conservation strategies that minimise potential conflicts with human activities.

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ANEXO III

Identifying critical areas to reduce bycatch of coastal common bottlenose dolphins *Tursiops truncatus* in artisanal fisheries of the subtropical western South Atlantic

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Identifying critical areas to reduce bycatch of coastal common bottlenose dolphins *Tursiops truncatus* in artisanal fisheries of the subtropical western South Atlantic

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ABSTRACT: Many anthropogenic actions have an impact on coastal dolphins, with bycatch being one of the main threats. We describe the distribution patterns of common bottlenose dolphins Tursiops truncatus and periods of higher entanglement risk by the artisanal gillnet fishery in the Patos Lagoon estuary and along the adjacent coast of southern Brazil. A total of 136 dolphin groups and 187 gillnets were encountered in 69 surveys conducted between September 2006 and July 2009. Data were analyzed in relation to environmental, spatial and temporal variables using generalized additive models and a spatially adaptive local smoothing algorithm for model selection. In both areas, dolphin densities increased as distance to the estuary mouth decreased. For the estuary area, water salinity and temperature influenced dolphin distribution. Along the adjacent coast, dolphin densities were higher with distance to shore as well as in the north area during the warm period. Patterns of dolphin distribution were probably a response to the presence of preferred prey or avoidance of human-related disturbance. Kernel density showed that fishing effort was distributed along the entire surveyed area inside the estuary, while along the adjacent coast it was higher in the south compared to the north area in the warm period. The overlap between gillnets and dolphins increased considerably from the cold (33.8%) to the warm (48.6%) period. Seasonal variation in fishing effort and distribution affect the overlap and the risk of dolphin entanglement. Based on the findings of this study, a fishing exclusion area aimed at reducing bycatch was established by the Brazilian Environmental Agency.

KEY WORDS: Conservation strategies - Artisanal gillnet fisheries - Patos Lagoon estuary -Generalized additive models - Fisheries-dolphin overlap

INTRODUCTION

The coastal habitat of many dolphin populations overlaps with human activities, and these populations face the impacts, for example, of competition with fisheries, pollution, habitat degradation, coastal development and increasing underwater noise (Reeves et al. 2003, 2013). However, mortality due to entan-

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glement in fishing gears such as gillnets, trawls and crab pots is the main threat to the survival of many of these populations (e.g. Noke & Odell 2002, Díaz López 2006, Gonzalvo et al. 2008). In recent years there have been increased efforts to investigate the impact of fisheries on cetaceans and how to mitigate it (e.g. Brown et al. 2013, Stolen et al. 2013, Waples et al. 2013). Understanding distribution patterns of

© The authors 2015. Open Access under Creative Commons by Attribution Licence. Use, distribution and reproduction are unrestricted. Authors and original publication must be credited. Publisher: Inter-Research · www.int-res.com dolphins threatened by human activities can be of particular use in informing decision makers about appropriate actions for their protection.

Prey distribution and abundance are key factors in determining the spatial and temporal patterns of dolphins. In fine-scale studies, however, it is often challenging to collect and analyze the prey availability data required to understand this relationship (Acevedo-Gutierrez & Parker 2000, Heithaus & Dill 2002, 2006). Habitat features such as depth, slope and distances from rivers, estuaries or coast might trigger oceanographic processes that enhance local productivity or favor prey capture (e.g. Ballance 1992, Parra 2006, Pirotta et al. 2011). Therefore, these variables are often considered useful proxies for prey availability, and dolphins preferred habitats have been identified without direct prey distribution data (e.g. Torres et al. 2008, MacLeod et al. 2014).

The common bottlenose dolphin Tursiops truncatus has a wide range and is found in coastal and pelagic waters (Wells & Scott 1999). Long-term studies of coastal bottlenose dolphins around the world have shown that local communities generally number few individuals, display small home ranges and form genetically distinct units even at small geographic scales (Parsons et al. 2002, Tezanos-Pinto et al. 2009, Fernández et al. 2011). In southern Brazil, coastal bottlenose dolphins are structured into several coastal communities (Genoves 2013), some with remarkably low genetic diversity (Fruet et al. 2014). The term 'community' refers to a group of individuals that share large portions of their ranges and interact with each other more than with other members in adjacent waters (sensu Wells et al. 1987). The largest known discrete community, recently estimated at 86 individuals (95% CI: 78 to 95) (Fruet et al. 2011, 2015), inhabits the Patos Lagoon estuary (PLE) and surrounding coastal areas year round (Mattos et al. 2007). This community occasionally interacts with coastal communities to the north and south of the estuary (Genoves 2013, Fruet et al. 2014). An analysis based on more than 30 yr of stranding data revealed a marked increase in mortality of bottlenose dolphins in the vicinities of the estuary after 2002 (Fruet et al. 2012). This mortality also exhibited a strong seasonal pattern, from mid austral spring to late summer (November to March), which coincides with an intensive artisanal gillnet fishery in coastal waters adjacent to the PLE (Klippel et al. 2005). Many of the dolphins found washed ashore during this season present net marks or body mutilations and bycatch is considered the major source of dolphin mortality (Fruet et al. 2012). Hence any conservation plan for this dolphin community should take into account information on the relevant habitat characteristics that determine dolphin and artisanal fishery distributions. In this study we aimed to investigate the distribution patterns of bottlenose dolphins in PLE and the adjacent marine coast, to determine the extent to which their distribution overlaps with artisanal gillnet fisheries, and to identify variables that might explain these patterns.

MATERIALS AND METHODS

Study area

The Patos Lagoon is located along Rio Grande do Sul state coast, southern Brazil (Fig. 1), and is connected to the Atlantic Ocean through a permanent narrow channel (0.5 to 3.0 km wide) fixed by 2 rocky jetties, approximately 4 km long (Kjervfe 1986). The estuarine area is in the southern portion of the lagoon and is characterized by shallow bays, 80% of which are <2 m in depth. Deeper waters are restricted to the navigation channel and can reach up to 20 m at the entrance of the estuary where the Rio Grande Port, one of the major ports in Brazil, is located. The lower estuary is subject to intense cargo-ship and fishingboat traffic as well as to extensive artisanal fishing and industrial activities (Tagliani et al. 2003).

The discharge of nutrient-rich water from the lagoon into the oceanic coastal areas and the intrusion of seawater into the estuary play crucial roles in the maintenance of productivity of this coastal ecosystem (Abreu & Castello 1998). The PLE and the adjacent marine system are biologically connected as the life cycles of many invertebrates and fish depend on both systems, making the estuary an important breeding and feeding area of many fish and crustacean species (Haimovici et al. 2006, Dumont & D'Incao 2011, Garcia et al. 2012).

The artisanal fishing fleet operates year round and follows a seasonal pattern according to local changes in abundance of target species (Reis et al. 1994, Kalikoski & Vasconcellos 2012). Until the early 1980s, artisanal fisheries were restricted to the estuary. The collapse of estuarine fish stocks, caused by increased fishing effort and power, resulted in an expansion of the fishing areas to the adjacent marine coast (Reis & D'Incao 2000). Despite a generally decreasing trend in artisanal fishing effort in the PLE, the number of trammel, fixed and drift gillnets in the lower estuary and adjacent marine coast (i.e. the area preferred by bottlenose dolphins) is still high, especially during the whitemouth croaker (*Micropogonias furnieri*) season in summer (Reis & D'Incao 2000, Kalikoski et al. 2002, Kalikoski & Vasconcellos 2012).

Survey design

Surveys were carried out from a 4.8 m aluminum boat with a 60 HP outboard engine at speeds around 18 to 22 km h^{-1} . The speed was set based on a trade-



Fig. 1. Study area (black square) where surveys of bottlenose dolphins *Tursiops truncatus* and artisanal fisheries activity were conducted in the mouth of the Patos Lagoon estuary and along the adjacent coast of southern Brazil between 2006 and 2009. Inset: Transect lines (black lines) followed during boat surveys. Dolphin sightings within a strip 500 m wide along each side of the transect line (areas enclosed by thinner light grey lines) were recorded. Dolphins or nets slighted within a strip 500 m wide along each side of the transect line (areas enclosed by thinner light gray lines) were recorded. These areas are approximately 1 km² (grid) and were used for modeling purposes. Asterisks show sampling stations where environment data were measured

off between sampling area coverage and chances of detecting dolphins. For logistical reasons, the study area was divided into 3 sub-areas (estuary, north coastal and south coastal), such that each could be fully surveyed in 1 d (Fig. 1). Inside the estuary, 32 pre-defined zigzag transects (mean length 1.48 km, SE 0.07 km) were followed between the inner part of the lower estuary and the mouth, giving a total surveyed area of approximately 40 km². The coastal area was split into areas south and north of the jetties, each being covered by 10 linear transects. The closest transects to the estuary followed the length of the jetties (2.8 km in the south and 3.2 km in the north areas) and angle. The other 9 transects were each 5 km long and 2 km apart. Each transect line was placed roughly perpendicular to the coastline and isobaths, aiming at a homogenous effort with respect to depth, and distance from shore and from the entrance of the estuary (Buckland et al. 2001). The initial point of surveys was alternated within the areas

Data collection and analyses

The survey team included 1 observer responsible for detecting and for counting the dolphins, i.e. the data recorder, who was in charge of both sighting dolphins and counting fishing nets, and the helmsman. Whenever dolphins were sighted, the transect line was abandoned and the boat was slowed to approach the animals for a better estimation of group size. The geographical position of the group was recorded using a hand held Global Positioning System (GPS). Time spent at each sighting was no longer than 30 min, at which point the survey was resumed from the initial sighting location. The fishing buoys and sticks with flags used by the artisanal fishermen to fix their nets were counted along transects, and the geographic position was taken when nets were perpendicular to the observer. The number of buoys and/or flags was used as a relative index of fishing effort (nets km-2).

The detectability of dolphins can vary depending on e.g. distance from transect line, observer and weather conditions. The latter 2 were minimized as the surveys were undertaken by the same observers and restricted to sea states ≤ 3 on the Beaufort scale. To minimize dolphin and net counting errors or variation in detection probability, only sightings and nets detected within a strip 500 m wide along each side of the transect line were taken into account. Thus, the prior assumption that all dolphins (and nets) would be detected within the buffer area is probably met. This buffer area was split into grid cells of approximately 1 km² (Fig. 1). Each grid was characterized by spatial (e.g. distance from coast and estuary mouth, depth, slope) and environmental covariates (e.g. temperature, salinity, transparency). The former were fixed covariates and their values were measured on the center of each grid. Environmental covariates, on the other hand, were collected in all surveys on predefined sampling stations. Since values of temperature and salinity did not vary between sampling stations within transect in the same survey, no interpolation was necessary. The values in each station were thus assigned to the nearest grids.

Data on water transparency (Secchi disk), surface and bottom temperature and salinity were taken in pre-established sampling stations along transects (Fig. 1), using a thermometer attached to a Nansen bottle and a salinometer, respectively. Three field trips using a jet ski equipped with a DGPS (Differential Global Positioning System) coupled to an echo sounder were conducted following the same survey design to obtain detailed bathymetric data with accurate positioning for the entire study area. These data were used to generate a bathymetric raster using a natural neighbor method interpolation, which does not generate values out of the range data (Watson 1992). The slope values were acquired using the slope tool from the Spatial Analyst extension in the ArcGIS program (ESRI version 9.2). The spatial covariates distance to shore and distance to the estuary mouth were determined using the Euclidean Distance tool of the ArcGIS program.

Effect of environmental, spatial and temporal variables on bottlenose dolphin distribution

Exploratory data analyses were conducted following Zuur et al. (2007, 2009, 2010) to check for outliers, collinearity, heterogeneity and other potential problems of the response and explanatory variables that could affect model fitting (Table 1). Temporal variations in dolphin and net densities were investigated considering cold (May to October) and warm (November to April) periods, which were defined according to mean sea surface temperature (sst) obtained during the surveys. Spearman correlation tests and variance inflation factors (VIF) were used to assess the collinearity of the explanatory variables considering a threshold of VIF = 3 (Zuur et al. 2010). The explanatory variables which showed a significant correlation (r > 0.80) and a high VIF value (VIF > 3) were not used together in the same model. Due to differences in spatial and environmental characteristics (e.g. depth, wave exposure, gradients in temperature and salinity) as well as sampling design between the estuary and the adjacent coast, models were fitted separately, considering the area (estuary and coast).

Generalized additive models (GAMs)

The environmental, temporal and spatial explanatory variables that described the distribution patterns of bottlenose dolphins (number of dolphins per km²) were investigated using GAMs. GAMs are extensions of generalized linear models which use a nonlinear link function to model the relationship

Table 1. Variables used in the exploratory analyses of bottlenose dolphin Tursiops truncatus distribution in the Patos Lagoon estuary and adjacent coast of southern Brazil. Δ : difference between surface and bottom values; CM: coastal areas; EM: estuary areas

Variables	Models	Unit	Abbreviations of variables
Environmental			
Temperature (surface; bottom; Δ)	EM, CM	Continuous (°C)	sst; sbt; dift
Salinity (surface; bottom; A)	EM, CM	Continuous (%)	ssal; bsal; difsal
Transparency	EM, CM	Continuous (m)	tran
Spatial			
Distance from the estuary mouth	EM, CM	Continuous (m)	dem
Distance to coast	CM	Continuous (m)	dcoast
Area	CM	Factor (south, north) ar
Depth	EM, CM	Continuous (m)	dep
Stope	EM, CM	Continuous (")	slp
Temporal			
Period	EM, CM	Factor (warm, cold)	peri

between the response and explanatory variables without imposing parametric constraints (Hastie & Tibshirani 1990, Venables & Dichmont 2004). The models were built using the mgcv package in R version 3.1.2 (R Development Core Team 2014). A quasi-Poisson family, to account for overdispersion (McCullagh & Nelder 1989, Venables & Dichmont 2004), and a logarithmic link function were used in the models. The area of each grid was used as an offset of the number of dolphins because not all grids had the same area.

Model selection

The spatially adaptive local smoothing algorithm (SALSA) was used for model selection through the MRSea package (Scott-Hayward et al. 2013). SALSA automatically chooses the location and number of knots in the spline regression model, based on the fit criteria and maximum Pearson residuals, respectively (Walker et al. 2011). Bayesian information criterion score for over-dispersed data (QBIC) was used for the model selection fit criteria, which is based on a likelihood function to compare nonnested models by penalizing for the number of parameters and sample size (Redfern et al. 2006). During the process using the 'runSALSA1D_with removal' function, k-fold cross-validation was also used to choose between models with covariates as a smoother-based term, linear term or omitting each term altogether. Once the model reached the best fit, some variables in the models were replaced, one at a time, by another variable that had been correlated in the data exploration and SALSA was run again. Factor and interaction between variables were tested manually by ANOVA function using F-test in car package (Fox & Weisberg 2011). The procedure was repeated until the model with the lowest QBIC score was obtained after testing all the possibilities.

Model assessment was verified by creating 1000 over-dispersed Poisson data sets (simulated data) generated using this study data set. The models selected by SALSA were then fitted to these simulated data sets and plotted to graphs to compare the observed and simulated data mean variance relationship, residuals and pseudo- R^2 (squared correlation between observed and fitted values under the selected model). The mean-variance relationship was assessed using the ggplot2 package (Wickham 2009) and the residual independence using the 'acf' function (stats package in R). A histogram using the function 'hist' (graphics package in R) was generated to verify pseudo- R^2 for all simulated models and those obtained by the real data set.

Overlap between dolphins and artisanal gillnet fishery

The relative density of dolphins and buoys and/or flags was estimated considering the number of individuals per area covered, which was calculated according to the effort of each survey. Non-parametric Mann-Whitney U-tests and Kruskal-Wallis H-tests were used to verify for differences in mean densities of dolphins and nets between sampling time periods and areas, respectively.

A fixed kernel density was estimated to compare dolphin and fishing net distribution areas in warm and cold periods. This density estimator takes the sighting position into account within a searching area and considers the number of individuals or nets in each position. The influence of sightings in nearby areas decreases as distance increases following a normal distribution. Through this method the area near the sightings with larger numbers of individuals or fishing nets had higher density values than distant areas (ESRI 2001).

Representative areas (RAs) used by dolphins and fisheries were delimited by contour lines representing the boundary of the area which contains a percentage of a probability density distribution. The area was considered representative if it contained on average 90% of the sighting positions which were used to generate the estimated kernel density. These areas were obtained through the Hawths tools extension for the ArcGIS (ESRI, version 9.2). RAs were determined for the warm and cold periods. Areas of overlap between dolphins and fishing nets were established according to the intersection of their representative areas for both warm and cold periods.

The percent area overlap (PAO) was determined following Atwood & Weeks (2003):

$$PAO = \left(\frac{Ad, f}{Ad} \times \frac{Ad, f}{Af}\right)^{0.5}$$
(1)

where Ad, f is the overlap representative area between dolphins and fisheries, Ad is the representative area for dolphins and Af is the representative areas for fisheries.

All statistical analyses were performed using R and BioStat (version 5.3, Ayres et al. 2007). A significance level of 5% was adopted for all tests.

RESULTS

Between September 2006 and July 2009, 134 groups of bottlenose dolphins and 187 gillnets were encountered in 69 surveys totaling 2980.9 km² of observation effort. The number of surveys varied among areas (25 were carried out inside the estuary, and 18 and 26 in the north and south coastal areas, respectively), time periods (28 were conducted during cold and 41 in warm periods) and years (6 in 2006, 25 in 2007, 21 in 2008 and 17 in 2009) (Table 2). Table 2. Number of surveys carried out, and numbers of hottlenose dolphin groups and individuals sighted in cold (May to October) and warm (November to April) periods between September 2006 and July 2009 in Patos Lagoon estuary and adjacent coastal areas of southern Brazil Table 3. Environmental, temporal and spatial explanatory variables used in the Generalized Additive Models (GAMs) to describe the distribution patterns of bottlenose dolphins *Tursiops truncatus* in estuary and coastal areas. Variables separated by slashes (/) were tested in different models due to collinearity. A: difference between surface and bottom values

Area/Period		2006	2007	2008	2009	Total
Coastal						
Warm	Surveys	1	11	12	6	30
	Groups	0	18	19	14	51
	Individuals	0	142	126	100	368
Cold	Surveys	1	5	3	5	14
	Groups	3	15	12	13	43
	Individuals	16	95	55	113	279
Estuary						
Warm	Surveys	2	3	3	3	11
	Groups	5	5	4	7	21
	Individuals	45	23	19	48	135
Cold	Surveys	2	6	3	3	14
	Groups	6	4	. 5	4	19
	Individuals	27	40	21	19	107

Effects of environmental, spatial and temporal variables on bottlenose dolphin distribution

The explanatory variables considered in the estuary and coastal models are listed in Table 3. The best models selected for both areas did not show significant non-linear relationships of dolphin density with all the explanatory variables (Tables 4 & 5). Model assessment for both areas showed mean-variance relationship and a reasonable pseudo-R² value when compared to the simulations (Figs. 2 & 3) and there was no evidence of residual correlation of both models (Figs. 4 & 5). The variables retained in the estuary model were distance to the estuary mouth (dem), surface water salinity (ssal) and temperature (sst) (Fig. 4). The smooth curves showed that bottlenose dolphins were more likely to be found in areas closer to the estuary mouth and occurred at all ranges of surface salinity and temperature (Fig. 4A-C). For the coastal area, dolphin relative density increased as distance to shore and to the estuary mouth decreased (Fig. 5A,B). The interaction between area and period showed that there was a lower relative density of dolphins in the south area on the warm period compared to the intercept; however, this was not significant (Table 5). No environmental variables were retained in this coastal model.

Overlap between dolphins and artisanal gillnet fishery

In general, there were no significant differences between the number of nets found in the study area

Variables	Variance inflation factor (VIF)
Estuary area	
Surface temperature /	1.40 / 1.24 / 1.73
A temperature / penod	1.72
Surface salinity / bottom salinity	1.61/1.95
Δ salinity	1.61
Transparency	1.14
Distance from estuary mouth	1,57
Depth	2.16
Slope	1,76
Coastal area	
Surface temperature / bottom temperature / period	1.99 / 1.79 / 1.64
∆ temperature	1.36
Surface salinity / bottom salinity	1.65 / 1.50
Δ salinity	1.57
Transparency	1.21
Distance from estuary mouth	1.08
Distance to coast	1.02
Area	1.05

Table 4. Results of the generalized additives models (GAMs) selected for bottlenose dolphin (*Tursiops truncatus*) density in the estuary area. *F*-values, *t*-values, *p*-values (Pr) and degrees of freedom (df) are given for the explanatory variables. The pseudo-R² value (the square of the correlation between observed and filted values) is also shown, sst: sea surface temperature; dem: distance from the estuary mouth; ssal: surface solimity

Explanatory variable	Model results (estuary area)			
Intercept	Estimate t Pr(>it!)	1.84 1.30 0.19		
sst	Estimate F Pr(>P) dI	-2.06 1.66 0.17 3		
dem	Estimate F Pr(>F) df	5.11 36.18 2×10^{-16} 3		
ssal	Estimate F Pr(>F) df	1.62 2.89 0.035 3		
Pseudo-R ²	0.47			

Table 5. Results of GAMs selected for bottlenose dolphin (Tarsiops truncatus) density in the coastal area. F-values, tvalues, p-values (Pr) and degrees of freedom (df) are given for the explanatory variables. The pseudo-R² value is also shown, peri (warm): warm period; ar (south): south coastal area, dem: distance from the estuary mouth, dcoast: distance from the coast; peri (warm)'area (south): interaction term between warm period and south coastal area

Explanatory variable	Model results (coastal area)		
Intercept	Estimate t Pr(>itl)	5.79 7.798 1.07 × 10 ⁻¹⁴	
peri (warm)	Estimate F Pr(>P) df	0.13 2.39 0.12 1	
ar (south)	Estimate F Pr(>P) df	0.37 0.27 0.6 1	
dem	Estimate F Pr(>P) df	-6.07 19.42 1.19 × 10 ⁻¹⁴ 4	
dcoast	Estimate F Pr(>F) df	-1.52 129.20 2.2×10^{-16} 1	
peti (warm)*area (south)	Estimate F Pr(>F) df	-084 3.35 0.06 1	
Pseudo-R ²	0.1		

between time periods, when the adjacent coastal areas (north and south) and estuary were compared and between time periods inside the estuary (Fig. 6). In the warm period, relative net density to the south was higher than in the north area (H = 7.0912, p = 0.03) and when compared to the same area (south) in the cold period (U = 37.5, p = 0.03) (Fig. 6).

The RAs used by dolphins and fisheries in warm months were approximately 74.5 and 117 km², respectively (Fig. 7A,B). During the cold period, the RA used by dolphins was similar to warm months (66.2 km²) (Fig. 7B). On the other hand, the artisanal gillnet fishery used less than half the area in cold months (59.6 km²) compared to warm months (Fig. 7B). The overlap of RAs between dolphins and fisheries was twice as large (45.4 km²) in warm months as in cold months (21.2 km²), representing 48.6% and 33.8% of the dolphin usage areas, respectively (Fig. 8). Regardless of the time periods, there was an overlap between dolphins and fisheries in the area close to the estuary mouth inside the estuary and in the coastal area near the jetties.

DISCUSSION

Effects of environmental, spatial and temporal variables on bottlenose dolphin distribution

The aim of this study was to describe the distribution patterns of dolphins in the PLE and adjacent marine coast. Common biases in analyzing small-



Fig. 2. Estuary area model assessment. (A) Mean variances of simulated models (black lines) generated using data set from this study assuming over-dispersed Poisson distribution. The red line shows the value obtained for the estuary model selected using the spatially adaptive local smoothing algorithm (SALSA). (B) Histogram of frequency of pseudo-R² values (the square of the correlation between observed and fitted values) for simulated models compared to the value obtained for the selected model (red dashed line)



Fig. 3. Coastal area model assessment. (A) Mean variances of simulated models (black lines) generated using data set from this study assuming over-dispersed Poisson distribution. The red line shows the value obtained for the estuary model selected using SALSA. (B) Histogram of frequency of pseudo-R² values for simulated models compared to the value obtained for the selected model (red dashed line)



Fig. 4. Density of bottlenose dolphins *Tursiops truncatus* in the estuary area modeled as a smooth function of (A) distance from the estuary mouth (dem), (B) superficial salinity (ssal) and (C) sea surface temperature (sst). Dot-dashed lines represent 95% confidence intervals. A rug plot indicating sampled values is shown along the x-axis. (D) Autocorrelation function (ACF) plot used to assess model residual independence. Dashed lines indicate statistically significant boundaries



scale cetacean distribution with GAMs are a high number of zeros, spatial and temporal autocorrelations, collinearity of variables, outliers in the data and differences in survey effort. In our study, sampling effort was high (n = 69 surveys over 3 yt) and evenly distributed over areas and time periods, and collinearity was investigated and eliminated from the models. In addition, the use of distributions of the quasi-Poisson family was opted to minimize over dispersion caused by zero-inflation and outliers in the data.

The distribution pattern of bottlenose dolphins inhabiting the PLE and adjacent marine coast varied seasonally and was influenced mainly by spatial variables. Bottlenose dolphins were observed in the estuary throughout the year and higher densities occurred closer to the estuary mouth, which was similar to results from previous studies (Castello & Pinedo 1977, Mattos et al. 2007). This region is characterized by dense populations of a few fish species (Vieira & Musick 1994, Garcia et al. 2012), and thus supplies high quantities of food to the dolphins. Mattos et al. (2007) frequently observed dolphins foraging near the estuary mouth. This area in the lower estuary, close to its mouth, is characterized by deeper waters (-18 m) and steep slopes compared to the upper estuary. Areas close to the estuary mouth are subject to higher variations in current speed and direction,



Fig. 5. Density of bottlenose dolphins Tursiops truncatus in the coastal area modeled as a smooth function of (A) distance from the coastline (dcoast), (B) distance from the estuary mouth (dem). Dashed lines represent 95% confidence intervals. A rug plot indicating sampled values is shown along the x-axis. (C) Autocorrelation function (ACF) plot used to assess model residual independence. Dashed lines indicate statistically significant boundaries

which changes the water salinity, temperature and their gradients according to the interaction of water discharge and strength of north-easterlies and southwesterlies (Möller et al. 2001, Castelão & Möller 2003). Such variability induced by seasonal forcing affects many estuarine-dependent fish species that are abundant in the estuary and adjacent coast (e.g. Garcia et al. 2012, Rodrigues & Vieira 2013), and thus



Fig. 6. Mean density of fishing nets (nets km⁻²) (black diamonds; vertical black lines show SE) and sampling effort (km²) (grey bars) in each area (estuary, north coast, south coast) and period (warm, cold) surveyed in the Patos Lagoon estuary and adjacent coastal areas of southern Brazil



Fig. 7. Representative areas (RAs) used by bottlenose dolphins *Tursiops truncatus* in (A) warm and (B) cold periods, and by artisanal fisheries in (C) warm and (D) cold periods between September 2007 and July 2009 in the Patos Lagoon estuary and adjacent coastal areas of southern Brazil. Black dots are sighting locations

the North Atlantic (e.g. Robinson et al. 2007); possibly these conditions facilitate prey capture.

The estuarine-dependent fish species whitemouth croaker, Brazilian flounder *Paralichthys orbignyanus* and the mullet *Mugil liza* are the main prey for these dolphins (Pinedo 1982, Lopez 2013). During periods of higher precipitation, as occurs during El Niño

may change the prey distribution and availability for dolphins. In other estuaries worldwide, areas where dolphins concentrate are also related to foraging sites (Ballance 1992, Hastie et al. 2003, 2004). A preference for areas with steep slopes and strong currents has been also observed in other estuaries (e.g. Ingram & Rogan 2002) as well as in coastal waters of



Fig. 8. Areas of overlap between bottlenose dolphins *Tursiops truncatus* and artisanal fishery activity in (A) warm and (B) cold periods in the Patos Lagoon estuary and adjacent coastal areas of southern Brazil

years, freshwater predominates and salinity remains low. This affects the distribution and diversity of all estuarine-dependent species, which in turn leads to higher densities in the adjacent coastal area (Garcia et al. 2003). In addition, Vieira et al. (2008) suggest that during periods with less saline water intrusion into the estuary, schools of mullet that would aggregate for the reproductive migration remain dispersed. These variations in the occurrence of potential prey for bottlenose dolphins might directly affect their distribution and may explain the relationship between dolphin relative density and water temperature and salinity observed in this study.

The spatial distribution pattern on the marine coast area showed that relative density of dolphins decreased as the distance from the estuary mouth and shore increased. Although there have been long movements reported for individuals of this community in waters ca. 250 km south of our study area (Laporta 2009) and for other coastal bottlenose dolphins around the world (Wells et al. 1999, Robinson et al. 2012), these dolphins are often closely associated with estuaries and productive bays (e.g. Ballance 1990, Simões-Lopes & Fabián 1999, Ingram & Rogan 2002). Fish species that are commonly captured by artisanal fisheries in these shallow, nearshore waters and adjacent to the estuary mouth (Klippel et al. 2005, Leal & Bemvenuti 2006, Rodrigues & Vieira 2013), such as banded croaker Paralonchurus brasiliensis, cutless fish Trichiurus lepturus and southern king croaker Menticirrhus sp., are also prey of this bottlenose dolphin community (Lopez 2013).

The lower relative density of dolphins in the south area during the warm period could be due to dolphins avoiding the increased human-related disturbance during the late spring and especially austral summer months. Specifically, Cassino beach, located 6 km south of the PLE, attracts about 200 000 tourists during summer, which contrasts with the ~20000 local residents. In this period, fishing activities as well as swimmers, recreational boats, jet skis and a high volume of traffic moving along the sand beach (Fig. 9A,B) are likely to increase underwater noise considerably, which might disturb either the dolphins or their prey. These jet skis and boats concentrate within 1 km of shore and around the estuary entrance. The effort of artisanal gillnet fisheries targeting white croaker is higher in spring and summer (Fig. 9A) (Reis et al. 1994, Kalikoski & Vasconcellos 2012) and occasional illegal gillnet fishing for the Brazilian guitarfish Rhinobatos horkelli (S. Estima pers. comm.) also take place during summer. It has been noted that some bottlenose dolphin populations can change their preferred habitats to avoid areas of major shipping traffic (Lusseau 2005) or temporally leave areas affected by intense noises caused by anthropogenic activities (Brandt et al. 2011, Pirotta et al. 2013). Allen & Read (2000) suggested that movement of vessels indirectly affects dolphins' habitat selection by interfering with prey availability. Longterm studies are needed to confirm this pattern of distribution and the potential effect of noise on dolphin habitat selection.

Distribution overlap between dolphins and fisheries

During the present study, the spatial distributions of dolphins and fishing activities were obtained simultaneously and, therefore, the areas of higher bycatch risk were identified. The results showed clearly that the artisanal fisheries expanded their effort to the coastal areas in the warm period, resulting in a considerable increase in the overlap area with bottlenose dolphins. Fruet et al. (2012) investigated trends in mortality of bottlenose dolphins along the southern portion of Rio Grande do Sul State coast from 1969 to 2006. They found an increased number of stranded carcasses with clear signs of bycatch in areas adjacent to the PLE after 2002, and a marked seasonal pattern of mortality (during spring and summer). This information together with the findings of this study reinforces that this dolphin mortality pattern is related to the artisanal fishing activities during the warm period in the areas adjacent to the estuary.

The fact that prey species consumed by dolphins and targeted by the artisanal coastal fisheries are the same probably promotes the overlap in their distributions. Only 11 bottlenose dolphins were found washed ashore during the period of this study (September 2006 to July 2009; ECOMEGA, unpubl. data), a low number when compared to the 49 carcasses found washed ashore between 2002 and 2006 (Fruet et al. 2012). Events such as El Niño and La Niña influence rainfall and salinity in this area, causing changes in the distribution, abundance and recruitment of fish stocks and shrimp in this region (D'Incao et al. 2002, Garcia et al. 2003, Möller et al. 2009). During years of poor shrimp harvests, fishermen increases gillnet fishing effort targeting white croaker, squirrel hake Urophycis brasiliencis and blue crab Callinectes sapidus to offset economic losses (Fruet et al. 2012). During the austral summer 2006-2007 El Niño was weak, with low precipitation rates allowing for the intrusion of salt water and shrimp larvae, which resulted in a good shrimp harvest (Pereira 2010). According to technical reports of artisanal fishery landings provided by the local governmental environ-







Fig. 9. (A) Artisanal fishing boats in the Patos Lagoon estuary mouth. (B) Tourists during summer on Cassino Beach. (C) Fishing exclusion area suggested based on the results of this study

mental agency (CEPERG/IBAMA, www.icmbio.gov. br/ceperg/publicacoes.html), the 2006–2007 shrimp harvest was followed by a marked decline in subsequent years, reaching minimal values in 2009–2010. Therefore, artisanal gillnet fishing effort was probably much higher during the warm period of 2008– 2009 and the following years of continued low shrimp harvest. As mentioned earlier, the period of increased fishing effort in the coastal area coincides with the harvest of white croaker, which is an important economic resource for the artisanal fishery in this region (Reis & D'Incao 2000, Kalikoski & Vasconcellos 2012).

Establishment of a dolphin protected area in 2012

In order to reduce mortality among this small dolphin community, the results of this study were used as a framework to design a fishing exclusion area, which was discussed with local stakeholders. In August 2012, the Ministry of Fisheries and Aquiculture and the Ministry of Environment jointly created a resolution to regulate the gillnet fisheries in the southern and southeastern states of Brazil (Brasil 2012). This resolution prohibits gillnet fishing within the first 5 km inside the estuary, around the jetties and the adjacent marine coast. Along the marine coast this no-gillnet zone extends 1 nautical mile (1.8 km) from shore and 20 km south and north of the Patos Lagoon entrance (Fig. 9C). It is unlikely that this regulation will cause drastic changes in the local fishing dynamic or in fishermen's incomes, as they will need to move only a very short distance from their previous main fishing sites. When artisanal fishermen leave the estuary they have to bypass the jetties that extend up to 4 km into the ocean. Thus, when they reach the marine coast they are already outside the fishing exclusion area, except in areas around the end of the jetties. In fact, they would have to navigate back towards the coast to set the nets within the protected area.

Despite the relatively short period of this study, the distribution of bottlenose dolphins was consistent with results of previous studies (e.g. Mattos et al. 2007). Since the boundaries of the protected area were designed in accordance with the results of the present study and the distribution of the dolphins has not changed over the years, this no-take zone for gillnetting can be expected to be effective in avoiding bycatch. Unfortunately, our marine coast surveys were spatially limited to 20 km north and south from the jetties (for logistical reasons we could not survey more distant areas along the coast) and, therefore, may not be sufficient to reduce bycatch in areas along the coast outside the protected area. Although the results showed higher dolphin densities near the estuary mouth, where feeding, breeding and calving take place, movements further away along the coast are known to occur (Laporta 2009). In addition, other dolphin communities roam along the adjacent marine coast (Genoves 2013) and are also susceptible to bycatch. All these bottlenose dolphin communities present very low levels of genetic diversity (Fruet et al. 2014). A recent population viability analysis has demonstrated that the removal of 1 mature female per year due to bycatch would result in a high probability of decline of the small PLE dolphin community (Fruet 2014). Reducing non-natural mortality by protecting the core and adjacent areas used by this small dolphin community can help reduce risks of decline and, most importantly, promote population growth. The latter would enhance connectivity and increase gene flow with the adjacent communities, which is desirable for increasing the long-term viability of bottlenose dolphins in southern Brazil. Nevertheless, it is recommended that systematic surveys are maintained in order to detect potential changes in bottlenose dolphin distribution patterns and to assess whether or not this gillnet fishery regulation is being followed, is effective in reducing bycatch, and allows for an economically viable fishery.

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