UNIVERSIDADE ESTADUAL DE SANTA CRUZ

PROGRAMA DE PÓS-GRADUAÇÃO EM ZOOLOGIA

GUILHERME AUGUSTO BORTOLOTTO DE OLIVEIRA

ESTIMATIVAS DE ABUNDÂNCIA E TAMANHO DE GRUPO DE BALEIAS-JUBARTE EM TRANSECTOS LINEARES NA COSTA BRASILEIRA

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Dissertação apresentada ao Programa de Pós-Graduação em Zoologia da Universidade Estadual de Santa Cruz, como parte dos requisitos para obtenção do título de mestre em Zoologia.

Área de concentração: Zoologia Aplicada

Orientador: Dr. Daniel Danilewicz Schiavon

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Ilhéus-BA, 27/03/2014

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Conheço-me!
Reconheço meus defeitos.
Alguns feitos, porém,
orgulham-me.
...
A busca pelo inevitável
se confunde com
a razão de existir
no momento em que
a dúvida me acompanha
ao partir.

Ivo Rasanti

SUMÁRIO

RESUMO

A população de baleias-jubarte que utiliza o litoral brasileiro como área de reprodução foi severamente reduzida pela caça, principalmente a partir do início do século XX. Estima-se que na década de 1950 teria restado apenas cerca de 2% do número de animais anterior a este período. No entanto, assim como a maioria das populações da espécie ao redor do mundo, o Estoque Reprodutivo A (BSA), como foi denominada pela Comissão Internacional da Baleia para fins de manejo, tem mostrado sinais de recuperação e está crescendo. É necessário caracterizar tal recuperação para avaliar possíveis tendências populacionais. Assim, densidade e abundância são os dois principais parâmetros de interesse. Com o objetivo de gerar as mais recentes estimativas de abundância para a população, dois cruzeiros de pesquisa (2008 e 2012) percorreram a área utilizada pela baleia-jubarte sobre a plataforma continental brasileira, seguindo o método de Amostragem de Distancias em transectos lineares. Foi, também, realizado um experimento para identificar possíveis erros cometidos por observadores a partir de embarcações sobre as estimativas dos tamanhos dos grupos da espécie, pois para a aplicação do método, o tamanho de cada grupo deve ser coletado o mais acurado o possível. Para tanto, um observador independente foi posicionado no mesmo navio, mas em uma plataforma mais alta do que a padrão/regular e com responsabilidade quase que exclusiva de estimar o tamanho dos grupos, tendo provável melhor condição de coleta para tal dado. Comparando suas estimativas com os tamanhos estimados para os mesmos grupos, mas coletadas por observadores em posições regulares, foi calculada a proporção dos erros destes últimos. Os resultados do experimento indicam que os observadores regulares subestimaram em 17,5% o tamanho dos grupos, mesmo em suas melhores estimativas, o que pode influenciar na estimativa de abundância na mesma proporção. No entanto, a grande imprecisão deste valor faz com que sua aplicação na estimativa de abundância final não seja estatisticamente diferente da estimada sem qualquer correção. Além disso, as melhores estimativas dos observadores regulares e as do observador regular também não diferiram. Concluiu-se que o observador independente conforme utilizado neste estudo não seria útil para corrigir os tamanhos dos grupos e que os observadores regulares coletam tamanhos de grupo relativamente acurados a partir de embarcações. Porém, para tanto, pode ser necessário um aumento de esforço de observação na posição regular. Isso reforça que a Amostragem de Distâncias para estimar a abundância de baleias-jubarte, quando realizada a partir de embarcação, permite obter resultados relativamente robustos. Desta forma, os cruzeiros de 2008 e 2012 resultaram nas estimativas de 16.774 (CV = 40,2, 95% CI = 9.290 – 30.294) e 19.809 (CV = 15,0, 95% CI = 15.405 - 25.479) baleias, respectivamente, para a população. No segundo ano, porém, apenas parte da área foi amostrada. Já a estimativa para 2008 foi a primeira a percorrer toda a área de ocorrência no Brasil utilizando uma embarcação para a Amostragem de Distâncias, sendo também a mais recente com o método. Comparando as estimativas para a área onde se tem dados em ambos os anos, calculou-se um crescimento populacional de 6,7%/ano durante o período. Ainda que esta possível taxa tenha sido obtida a partir de apenas duas estimativas, é bastante plausível e a BSA pode recuperar seu tamanho pré-1900 dentro das próximas duas décadas. Com o aumento do número de jubartes no litoral brasileiro e com a sobreposição da sua área de ocorrência com atividades antrópicas, se faz cada vez mais necessário o monitoramento contínuo da população para que estas informações possam servir de base em ações de manejo e conservação futuros.

APRESENTAÇÃO

Esta dissertação de mestrado tem por objetivo tratar de duas questões relativas à pesquisa de baleias-jubarte a partir de embarcações: (1) a ocorrência de erros nas estimativas de tamanho de grupo em amostragens de distâncias e (2) estimativas de abundância para a população que habita o litoral brasileiro a partir do mesmo método. Os dados utilizados no presente trabalho foram coletados em cruzeiros de pesquisa de um estudo de longo prazo da ecologia populacional de baleias-jubarte na área.

O documento apresenta no primeiro capítulo uma introdução geral, a fim de fornecer ao leitor um embasamento sobre aspectos básicos da biologia e ecologia da espécie estudada e sobre os métodos de pesquisa aplicados. Nos capítulos seguintes são apresentados dois manuscritos, os quais foram formatados de acordo com as normas dos periódicos *Marine Mammal Science* e *Marine Ecology Progress Series*, respectivamente:

Capítulo 2 – *Humpback whale group size estimation in line transect ship surveys: An evaluation of observer errors*;

Capítulo 3 – *Humpback whale abundance in the Brazilian breeding ground estimated by line transect ship survey*.

– CAPÍTULO 1 –

INTRODUÇÃO GERAL

1. *A baleia-jubarte*

Dentre as espécies de mamíferos que compõe a Infra-Ordem *Cetacea,* da Ordem *Cetartiodactyla*, a baleia-jubarte (*Megaptera novaeangliae* BOROWSKI, 1781) é a espécie melhor estudada entre as grandes baleias (REEVES et al., 2002). Isto se deve, além do seu hábito costeiro e ampla distribuição, à presença de marcas naturais em seu corpo, como o padrão de coloração da nadadeira caudal e formato da nadadeira dorsal, que permitem a diferenciação dos indivíduos (REEVES et al., 2002). São misticetos, portanto, da Superfamília *Mysticeti (PERRIN, 2013)*, cujos representantes apresentam cerdas filtradoras na boca, utilizadas para a retenção de alimento. Característica essa que os diferencia da Superfamília *Odontoceti (PERRIN, 2013)*, da qual fazem parte, por exemplo, as espécies de golfinhos (família *Delphinidae*), o cachalote (*Physeter macrocephalus*) e as baleias-bicudas (família *Ziphiidae*), todos possuindo dentes. As jubartes pertencem à família *Balaenopteridae*, juntamente a outros rorquais, ou baleias com pregas ventrais, como a baleia-azul (*Balaeonoptera musculus*), a baleia-fin (*Balaenoptera physalus*), a baleia-minke (*Balaenoptera acutorostrata*), a baleia-sei (*Balaenoptera borealis*) e a baleia-de-Bryde (*Balaenoptera edeni*) (PERRIN; BERND; THEWISSEN, 2009).

As longas nadadeiras peitorais (Figura 1), com comprimento equivalente a cerca de um terço do corpo, são a principal característica morfológico-diferencial da espécie. São também responsáveis pelo nome científico do gênero: do grego *mega* para "grande" e *pteron* para "asas". O nome específico, *novaeangliae*, é uma referência à Nova Inglaterra, Estados Unidos, local onde a espécie foi descrita (CLAPHAM; MEAD, 1999). Podendo medir até aproximadamente 17 metros de comprimento (CLAPHAM; MEAD, 1999) e pesar quase 40 toneladas (REEVES et al., 2002), o dimorfismo sexual da espécie é sutil, com as fêmeas ligeiramente maiores do que os machos. Já os filhotes nascem medindo entre 4 e 4,5 metros, após uma gestação de 11 a 12 meses, e podem permanecer junto às suas mães até seus dois anos de idade (CLAPHAM et al., 1993, 1999). No entanto, é comum que sua independência ocorra gradualmente dentro do primeiro ano de vida, conforme vai substituindo o leite materno por alimento sólido (CLAPHAM; MAYO, 1987).

Figura 1. Foto subaquática de um baleia-jubarte adulta e seu filhote. Notar o comprimento das nadadeiras peitorais, principal característica diferencial da espécie (Foto: Luciano Candisani - PMBS).

Para o Hemisfério Sul são considerados sete estoques reprodutivos de baleias-jubarte segundo a Comissão Internacional da Baleia (*International Whaling Commission*), sendo a população que habita o litoral brasileiro denominada de Estoque Reprodutivo A (*BSA - Breeding Stock A, IWC, 2006)*. De maneira geral, realizam grandes migrações anuais, com exceção da população que habita o mar da Arábia, nas imediações de Omã (Estoque Reprodutivo X, MIKHALEV, 1997). Esta migração se dá entre as áreas de alimentação em altas latitudes, próximas aos polos, e as áreas de reprodução, em baixas e médias latitudes em águas tropicais (REEVES et al., 2002).

O principal alimento das jubartes no Hemisfério Sul é um pequeno crustáceo chamado krill-antártico (*Euphausia superba*, Figura 2). O krill-antártico possui um ciclo de vida dependente do aumento da camada de gelo antártica, pois durante o inverno, quando a camada está em seu máximo de extensão, as larvas deste crustáceo se alimentam de algas que crescem sob o gelo (NICOL, 2006). No verão, completamente desenvolvidos, formam os enxames que são consumidos pelas baleias-jubarte durante a temporada de alimentação.

Assim, a presença das baleias na área coincide com a maior abundância sazonal de alimento (CORKERON; CONNOR, 1999).

Figura 2. Krill-antártico, principal alimento da baleia-jubarte no Hemisfério Sul (Disponível em: www.nutritionaloutlook.com).

A baleia-jubarte chama atenção também por alguns aspectos comportamentais característicos, como saltos e outros comportamentos aéreos. Também chamada de baleia-corcunda, dobra o corpo de maneira singular ao realizar um mergulho, expondo a pequena, porém evidente, nadadeira dorsal (Figura 3). Durante a temporada reprodutiva, os machos produzem complexas vocalizações, o que lhes confere outro nome comum, o de “baleia-cantora”. O canto da espécie foi primeiro descrito por Payne e McVay (1971) que reconheceram sua complexidade e semelhança à música, percebendo a divisão dos sons em frases e temas. Muitas evidências apontam para a hipótese de que este comportamento está ligado a questões reprodutivas (PARSONS; WRIGHT; GORE, 2008).

Figura 3. O salto (acima à esquerda) e a batida de nadadeira peitoral (acima à direita) são dois comportamentos aéreos da baleia-jubarte. Antes de um mergulho, ela expõe a nadadeira dorsal (abaixo à esquerda) e em sequência a nadadeira caudal (abaixo à direita).

Tanto em áreas de reprodução quanto em áreas de alimentação, as jubartes se organizam em grupos pequenos e instáveis. Grupos compostos por mãe e filhote são exceção, com os animais frequentemente permanecendo mais de seis meses juntos, devido à amamentação. Nas áreas de alimentação, as associações parecem ser determinadas pela distribuição e quantidade de alimento (CLAPHAM, 2009; DALLA ROSA et al., 2012). Nas áreas de reprodução, além de grupos compostos por mãe e filhote, com ou sem animais acompanhando-os, são também comuns os “grupos competitivos”. Nesse tipo de grupo, vários machos disputam a oportunidade de cópula com uma fêmea, inclusive com comportamentos agressivos na superfície (CLAPHAM, 2009; TYACK; WHITEHEAD, 1983).

Classificadas atualmente como espécie em estado de conservação de menor preocupação pela IUCN (REILLY et al., 2008), estima-se que a caça comercial de baleias tenha reduzido as populações de jubartes a uma pequena fração do seu tamanho pré-exploratório, especialmente no Hemisfério Sul, onde cerca de 200 mil foram capturadas desde 1900. Seu hábito relativamente costeiro lhes rendeu uma grande vulnerabilidade aos métodos modernos desta prática que, associados à expansão da caça para áreas de alimentação a partir do começo do século XX (ELLIS, 1991), permitiu um grande aumento nas capturas anuais. Desde a proteção mundial contra a caça de baleias-jubarte na década de 1960, a maioria das populações tem mostrado sinais de recuperação (e.g. FLEMMING; JACKSON, 2011; ZERBINI; CLAPHAM; WADE, 2010; ZERBINI et al., 2011).

2. A baleia-jubarte no litoral brasileiro

O litoral brasileiro, entre os estados do Rio Grande do Norte (~5°S) e do Rio de Janeiro (~23°S), é regularmente habitado por baleias-jubarte durante inverno e primavera (ANDRIOLO et al., 2006, 2010; ZERBINI et al., 2006) (Figura 4). O número crescente de registros em áreas fora destes limites, como no Arquipélago de Fernando de Noronha (LODI, 1994), no Arquipélago de São Pedro e São Paulo, (e.g. ZERBINI et al., 2011), na cadeia Vitória-Trindade (e.g. WEDEKIN, 2011) e nos litorais dos estados do Ceará (e.g. MEIRELLES et al., 2009), do Pará (e.g. PRETTO et al., 2009) e de Santa Catarina (e.g. CHEREM et al., 2004), sugere que a área de distribuição atual pode ser ainda maior e talvez um indício de que a população esteja reocupando áreas de ocorrência anteriores ao período de caça (MARTINS et al., 2001). No verão e outono, estes animais alimentam-se em áreas adjacentes às ilhas Geórgias do Sul e Sanduíches do Sul (~58°S, ~26°W). Chegam até lá utilizando rotas migratórias recentemente descritas por estudos de telemetria satelital (ZERBINI et al., 2006). Sua área de ocorrência regular durante a temporada reprodutiva está compreendida nas costas Nordeste e Leste do Brasil, segundo critérios geográficos (EKAU; KNOPPERS, 1999). O litoral Nordeste apresenta como característica uma estreita largura da plataforma continental, atingindo o mínimo (~10 km) em frente à cidade de Salvador, na Bahia. Já o Leste possui dois alargamentos abruptos da plataforma, caracterizados como bancos: o Banco de Royal Charlotte e o Banco dos Abrolhos. Este último, com até aproximadamente 220 km de largura, é tido como principal área utilizada para a reprodução da população e apresenta a maior densidade de animais durante o período de ocorrência no litoral brasileiro (ANDRIOLO et al., 2006, 2010; MARTINS et al., 2001, 2013). O banco dos Abrolhos apresenta a maior diversidade de corais do Atlântico Sul Ocidental (LEÃO, 1994) representando uma importante área para a conservação marinha. Além do Banco dos Abrolhos, a estreita plataforma caracteriza-se por um alargamento suave e gradativo em sentido sul, atingindo pouco mais de 100 km de largura em frente à cidade de Cabo Frio (Figura 4).

Figura 4. Área de ocorrência regular da baleia-jubarte no litoral brasileiro durante a temporada reprodutiva no inverno e primavera.

A indústria de caça de baleias no litoral brasileiro tem importância histórica, com diversas estações baleeiras, ou armações, sendo instaladas entre os litorais sul e nordeste a partir do século XVII (ELLIS, 1969; LODI, 1992). Após 1900, com as técnicas modernas de caça (e.g. canhão-arpão e navios a motor), a atividade despertou o interesse inclusive de europeus e japoneses. Estes últimos exploraram a área até a década de 1980 (LODI; BOROBIA, 2013), porém acredita-se que a última jubarte caçada em águas brasileiras tenha sido abatida na década de 1960 (PAIVA; GRANGEIRO, 1970).

Zerbini et al. (2011) estimaram que no final dos anos 1950, a população de baleias-jubarte que frequenta o litoral brasileiro foi reduzida a cerca de 2% do tamanho populacional anterior à caça moderna. No entanto, a partir da década seguinte já teria começado a mostrar sinais de recuperação e atualmente várias evidências sugerem que, após o fim da atividade baleeira, esta população está crescendo (ANDRIOLO et al., 2010; MEIRELLES et al., 2009; WARD et al., 2011; ZERBINI; CLAPHAM; WADE, 2010; ZERBINI et al., 2004, 2011).

Devido ao histórico de ameaça e a presença de atividades de interesse comercial na área de distribuição do Estoque Reprodutivo A, é necessário o monitoramento populacional contínuo. Portanto, estimativas de abundância para a população foram geradas, tanto pelo método de marcação-recaptura com técnicas de foto-identificação (FREITAS et al., 2004; KINAS; BETHLEM, 1998), quanto por amostragem de distâncias em transectos lineares (BUCKLAND et al., 2001) em levantamentos aéreos (ANDRIOLO et al., 2006, 2010; WEDEKIN, 2011) ou a partir de embarcação (ZERBINI et al., 2004). No entanto, nem todos os estudos amostraram sua área de ocorrência completa e podem não representar o tamanho populacional, mas uma fração desta.

Em 2000, Zerbini et al. (2004) realizaram o primeiro estudo utilizando a amostragem de distâncias para baleias-jubarte na costa brasileira a partir de uma embarcação, amostrando o litoral nordeste (5-12^{o}S), com uma estimativa de 628 animais (CV = 0,335, IC 95%= 327-1.157) para a região. Empregando aeronave como plataforma de observação, Andriolo et al. (2010) geraram a primeira estimativa para toda a área de ocorrência regular do Estoque A, inclusive, considerando diferentes cenários para a probabilidade de detecção sobre o transecto $g(0)$ (ver seção 3). O cenário considerado mais realista para o $g(0)$ forneceu uma estimativa de 6.404 animais (CV = 0,116, IC 95% = 5.084-8.068) para 2005. Mais tarde, Wedekin (2011), também a partir de levantamento aéreo, estimou uma abundância de 9.330 indivíduos (CV = 0,281, IC 95% = 4.857-20.229,) para a população em 2008.

3. A amostragem de distâncias em estudos com baleias

O tamanho populacional é um dos principais parâmetros de interesse em estudos de ecologia de espécies animais (HAMMOND, 2010). Em uma situação ideal, o censo, ou seja, a contagem de todos os indivíduos (objetos-alvos do estudo) dentro da área a ser pesquisada é a maneira mais acurada de se obter tal dado (SEBER; SCHWARZ, 1999). Porém, devido à impossibilidade desta prática, frequentemente por questões logístico-orçamentárias ou pela dificuldade de detecção de todos os objetos, os pesquisadores recorrem às estimativas por amostragens. As amostragens para estimativas de tamanho populacional são realizadas de forma a coletar dados em uma fração da área de estudo, portanto, com um esforço menor, para a subsequente extrapolação matemática para a área total. Uma maneira comum e bastante útil de amostragem em alguns casos é a contagem de todos os indivíduos dentro de “blocos amostrais” alocados na área de interesse. Extrapolando as contagens realizadas dentro dos blocos e considerando que a área total amostrada (somatório das áreas dos blocos) seja representativa da área de interesse, é possível que se faça inferências adequadas. Para isso, porém, é necessário que se conheça o tamanho de cada bloco e que todos os animais dentro destes sejam realmente detectados.

A amostragem de distâncias (*Distance Sampling*) é uma metodologia de coleta e análise de dados para estimativa de densidade e abundância bastante versátil, pois permite estimar o tamanho da área amostrada, sem a necessidade de detectar todos os objetos em uma área amostral pré-definida. A “área efetivamente amostrada” é estimada a partir das distâncias entre cada objeto, ou grupo de objetos, detectado e uma linha central (transecto) percorrida durante a amostragem (BUCKLAND et al., 2001). Sua utilização é particularmente importante em levantamentos de tamanho de populações animais, pois permite um aproveitamento ótimo do esforço, uma vez que todo objeto detectado pode ser incluído nas análises, Basicamente, o objetivo é amostrar uma área de tamanho a ser estimado, a fim de coletar dados de presença de objetos, ou de grupos de objetos, para posteriormente inferir sobre sua densidade e abundância na área de interesse.

A fórmula geral da estimativa de abundância por amostragem de distâncias em transecções lineares (*line transect distance sampling*) quando o objeto de estudo se organiza em grupos, é calculada como

$$\widehat{N} = \frac{A \cdot n \cdot E(s)}{2\hat{\mu} \cdot L}$$

onde $\widehat{N}$ = estimativa de abundância
A = área total de estudo
n = número de grupos observados
$E(s)$ = tamanho de grupo esperado
$2\hat{\mu}$ = largura efetiva (estimada a partir das distâncias de cada detecção)
L = comprimento total dos transectos percorridos

O principal desafio do método reside em estimar o parâmetro $\hat{\mu}$, que é modelado a partir de funções matemáticas (BUCKLAND et al., 2001) que descrevem a relação entre a probabilidade de detecção (*g(x)* = função de detecção) e as distâncias entre os objetos detectados e o transecto. Marques e Buckland (2003) desenvolveram a técnica atualmente utilizada para a inclusão de covariáveis (e.g. intensidade de sol, hora do dia, presença de chuva, método de detecção, idade do animal, tamanho de grupo) na modelagem de *g(x)*, uma vez que estas podem influenciar na detectabilidade dos objetos juntamente à distância.

A amostragem de distâncias é amplamente utilizada em estudos de diversos grupos animais, tais como moluscos (e.g. KATSANEVAKIS, 2007), peixes (e.g. TILLEY; STRINDBERG, 2013), aves (e.g. HYRENBACH et al., 2001), mamíferos terrestres (e.g. VARMAN; SUKUMAR, 1995, ANDRIOLO et al., 2005, NIELSON et al., 2006) e mamíferos marinhos (CALAMBOKIDIS; BARLOW, 2004; DANILEWICZ et al., 2010; EVANS et al., 2003; HOLT, 1984, 1987; MOORE et al., 2002; SCHWEDER, 1999; ZERBINI et al., 2006).

Para estudos envolvendo estimativas de abundância de cetáceos, existem duas principais maneiras de se empregar a amostragem de distâncias no que diz respeito à plataforma de observação: levantamentos aéreos e levantamentos a partir de embarcações. O primeiro possui a vantagem de cobrir grandes áreas, coletando dados suficientes para modelagem da função de detecção (i.e. $n > 70$), em pouco tempo. Também, minimiza a ocorrência de movimentos responsivos (i.e. movimentos dos animais em resposta ao deslocamento da plataforma), que são fontes de viés quando presentes (BUCKLAND et al., 2001; HAMMOND, 2010). Apesar das vantagens, o levantamento aéreo apresenta uma dificuldade em atender a principal premissa da metodologia, que é a detecção perfeita (100%) dos animais sobre o transecto, denominada *g(0) = 1* (probabilidade de detecção na distância zero igual a um). Isto ocorre principalmente devido a velocidade da plataforma de observação, incorrendo em *vieses de visibilidade* (MARSH; SINCLAIR, 1989) e que podem acarretar em subestimação (BARLOW, 1999). Assim, levantamentos a partir de embarcações apresentam maior possibilidade de movimentos responsivos, mas o uso deste tipo de plataforma para cetáceos frequentemente permite atender a premissa de *g(0) = 1*, principalmente para grandes baleias com corpo e borrifo evidentes (ZERBINI et al., 2006).

Devido ao fato de as baleia-jubarte se distribuírem de forma esparsa em suas áreas de ocorrência, o que torna alguns outros métodos logisticamente inviáveis, as estimativas de abundância através da amostragem de distâncias são empregadas com frequência (e.g. STEVICK et al., 2003; CALAMBOKIDIS; BARLOW 2004; ZERBINI et al. 2006; CALAMBOKIDIS et al. 2008; SECCHI et al. 2011).

Outra diferença entre a amostragem de distâncias a partir de aeronaves e a partir de embarcações para pesquisas com cetáceos, é que os observadores nesta última, estimam, de forma geral, um tamanho de grupo médio relativamente maior, como indicado por alguns estudos (GRÜNKORN; DIEDERICHS; NEHLS, 2006; ZERBINI et al., 2011). Ainda que observações a partir de embarcações tenham vantagens na estimativa do tamanho dos grupos devido a menor velocidade da plataforma, sua acurácia e a ocorrência de erros relacionados às estimativas de tamanho de grupo para baleias-jubarte permanecem desconhecidas.

Como apontado por Buckland et al. (2001) e Gerrodette e Perrin (1991), para animais que ocorrem em grupos, a estimativa correta do tamanho de grupo esperado $E(s)$ é uma necessidade, já que trata-se de um parâmetro da equação empregada para calcular N e, assim, afeta diretamente sua estimativa. A dificuldade que estudos que visam corrigir $E(s)$ enfrentam, reside na obtenção do "tamanho de grupo verdadeiro" (GERRODETTE; PERRIN, 1991). Gerrodette e Perrin (1991), Barlow et al. (1998) e Gerrodette et al. (2002) estudaram a acurácia e precisão entre diferentes observadores em estimar o tamanho de grupos de golfinhos oceânicos a partir de embarcações. Para isso, o tamanho real dos grupos foi obtido a partir de fotografias aéreas conforme o método de Gilpatrick Jr (1993). Barlow et al. (1998), por exemplo, estimaram um viés negativo de 7% nas estimativas dos observadores em relação às contagem utilizando as fotografias. Os mesmos autores ressaltam que alternativas com menor custo financeiro seriam preferíveis para fazer as correções, devido ao alto custo do método empregado em seu estudo. Da mesma forma, Zerbini et al. (2011) compararam o tamanho de grupo estimado para uma população de franciscanas (*Pontoporia blainvillei*) em uma baía no Sul do Brasil, em levantamentos aéreos e em levantamentos embarcados simultâneos, concluindo que a primeira abordagem pode apresentar tamanhos de grupos aproximadamente 30% menores que a segunda.

Da correta estimativa de abundância de uma espécie animal, pode depender a avaliação de seu estado de conservação e classificação em categoria de ameaça específica, por exemplo. Como estes fatores são usados de base para o planejamento de ações de conservação e manejo, todo o esforço possível na obtenção mais precisa e acurada das estimativas são necessários. Para isso é fundamental que se conheça os possíveis erros nos parâmetros que envolvem o seu cálculo. Assim, este trabalho pretende avançar no desenvolvimento do método de amostragem de distâncias, identificando os erros que observadores comentem na estimativa do tamanho dos grupos de baleias-jubarte a partir de embarcações, buscando estimativas de abundância mais robustas. Também nesse sentido, serão apresentadas as mais recentes estimativas de abundância para a população que habita a costa brasileira, e a primeira utilizando uma embarcação para aplicar a Amostragem de Distâncias em toda sua área de ocorrência.

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– CAPÍTULO 2 –

Humpback whale group size estimation in line transect ship surveys: An evaluation of observer errors

GUILHERME A. BORTOLOTTO ET AL.

ABSTRACT

For animals that occur in groups, abundance estimation by line transect distance sampling demands accurate mean group size collection. This is the first study evaluating the occurrence of errors in group size estimates during line transect surveys to estimate humpback whale abundance. Aboard a vessel sighting platform, we conducted an experiment and compared estimates made by regular observers and an independent observer. The independent observer was at a higher platform and had no responsibility of detecting new groups for abundance estimate as the remaining observers did. Besides the relative better sighting conditions of the independent observer, we found that the standard procedure of regular observer's self-correction, when the vessel travels along the line and groups became closer, was sufficient and the independent observer corrections did not improve group size estimates. Our results support that observers aboard vessels provide accurate group size estimates and aquatic platforms should be considered as the first choice for estimating humpback whale abundance by distance sampling methods, regarding other issues, such as operational costs.

Key words: cetacean, abundance, distance sampling, conservation, breeding stock A.

INTRODUCTION

Density (*D*) and abundance (*N*) are among the most essential parameters for studies concerning biological populations' conservation status (Hammond 2010). For threatened species, they are fundamental for understanding future trends and planning conservation and management efforts. One of the most often adopted approaches to estimate these key parameters for cetacean populations is the line transect distance sampling methodology (Buckland *et al.* 2001; Thomas *et al*. 2002). When target animals occur in groups, correct abundance estimates depend on accurate assessment of group sizes (Barlow *et al*. 1998; Gerrodette *et al*. 2002). Because expected group size *E(s)* is a component in the abundance calculation, and it can be estimated by average observed group size, bias in the estimation of this parameter may cause proportional error in the overall abundance estimation.

Line transect distance sampling has been used to estimate abundance of humpback whale (*Megaptera novaeangliae*, Borowski 1781) populations around the world (e.g. Calambokidis and Barlow 2004; Zerbini *et al.* 2004; Angliss and Outlaw 2005; Andriolo *et al.* 2006, 2010; Secchi *et al*. 2011; Johnston *et al.* 2012). The species is found in all major oceans and migrate annually between feeding grounds in high latitude cold waters, where the whales spend summer and autumn, and low latitude tropical waters, where they spend the winter and spring mating and calving during the breeding season (Clapham and Mead 1999; Reeves *et al*. 2002). An exception is the population inhabiting the coast of Oman that does not migrate (Mikhalev 1997). Their relatively coastal habits made them vulnerable to whaling, especially after 1900 when modern techniques were implemented. Since then, more than 200,000 animals were caught in the Southern Hemisphere (Findlay, 2001). The species is currently classified as "least concern" by IUCN, and most humpback whale populations show clear recovery signs after whaling activities have ceased (e.g. Barlow and Clapham 1997; Stevick *et al*. 2003; Angliss and Outlaw 2005; Calambokidis *et al*. 2008; Zerbini *et al*. 2010; Ward *et al.* 2011; Zerbini *et al*. 2011a). Nevertheless, continuous monitoring is needed to provide information for management plans elaboration.

The social organization of humpback whales is characterized by small, unstable but well defined groups, either on feeding or breeding grounds (Clapham 2009). Therefore, expected group size must be estimated in order to assess the abundance for humpback whale populations by distance sampling methods. Efforts to assess the errors in cetaceans' group size estimation from surface platforms have been made (Clark 1984; Scott *et al.* 1985; Gerrodette and Perrin 1991; Gilpatrick Jr 1993; Barlow *et al*. 2001; Gerrodette *et al*. 2002; Zerbini *et al.* 2011b). As denoted by Gerrodette and Perrin (1991), the difficulty of studies concerning the errors in *E(s)* relies on real group size assessment. Aiming to develop correction factors, Barlow *et al.* (1998) compared the accuracy and precision among observers in estimating oceanic dolphin group sizes from a ship, with aerial photogrammetry of the same groups, and their results indicated a negative bias of 7% on average. The authors also state that some less expensive alternative for correcting such parameter would be preferable. Likewise, Zerbini *et al.* (2011) compared franciscana dolphins group size estimated simultaneously through aerial and boat line transect surveys, revealing that aerial surveys may underestimate group size about 30%.

It is understandable that different platforms with distinct observation conditions should provide different group size estimates. Yet, little is known about the observer errors on group size estimates for large cetaceans. Aiming to assess the occurrence and magnitude of observer errors in humpback whale group size estimates in ship line transect survey, an independent observer experiment was carried out during a ship survey for humpback abundance off the Brazilian coast. This paper presents an evaluation of these errors and investigates how they may influence the humpback whale abundance estimates.

MATERIALS AND METHODS

Data Collection

Data were obtained during a survey to estimate humpback whale abundance off Brazilian coast (PMBS – *Projeto Monitoramento de Baleias por Satélite*) that took place on August-September of 2012, a period equivalent to the peak of abundance for the species in the area (Martins *et al*. 2001). The survey covered the continental shelf, from shore to the 500 meters isobath, between the coasts of Salvador (~13ºS), in Bahia State, and Cabo Frio (~23ºS), in Rio de Janeiro State, and included the Abrolhos Bank (~19ºS), an enlargement of the shelf where about 80% of the population is found every year (Andriolo *et al.* 2010). The observation platform was the oceanographic research vessel *Atlântico Sul* (*Universidade Federeal do Rio Grande*) that navigated along the lines at a constant speed of about 9 knots.

Animals were continuously searched from 5h30min to 17h00min. The research team consisted of nine trained observers which rotated every 30 minutes among three regular observer positions (*RO*), one independent observer (*IO*), one data recorder, and resting positions (2 hours minimum). The *RO* positions were port, center and starboard, all located on the flying deck at a 9.5 meters high platform. The regular observer in the central position was responsible for detecting animals between 10º from each side of the trackline, while lateral observers searched animals between 10º of the opposite side and 90º of its own side. This overlap of detection fields near the trackline was to ensure that the $g(0) = 1$ assumption was attended, which is essential to conventional distance sampling (Buckland *et al.* 2001). In the other hand, the *IO* was placed at a 12.6 meters high observation platform, located at the crow's nest. Each observer was equipped with a reticuled binocular 7x50 Fujinon, an angle board for bearing reading and a radio communicator.

Data relevant for estimation of abundance were collected by the *RO*s and recorded on Wincruz software (NOAA, USA) by the data recorder. Detections were made using the reticuled binoculars (80-90% of the time) and by naked eye (10-20% of the time). The reticules between the sighting and the horizon, and radial angles between the sighting and the trackline were collected right after the detection of each group. The radial distance r was obtained as described by (Lerczak and Hobbs 1998, erratum) and the perpendicular distance was calculated as $x = r \cdot sen(\theta)$, where θ is the radial angle of the group relative to the ship's bow. Group size estimates were first collected at the moment of detection and verification was usually made when the groups became closer as the ship travelled along the trackline.

Therefore, for some groups sighted by the *RO*s, there are a first estimate (*1RO*) and a last estimate (*2RO*) which confirmed or corrected the first one. When the survey crossed high density areas with several detections, off-effort observers were placed in the regular position platform adding effort to help tracking the already recorded groups and avoid double counting.

Experimental Design

The *IO* was acoustically isolated from the remaining observers (but not the data recorder) and had no information on the size of whale groups detected during the experiment. Immediately after a detection was called in by the *RO*, the data recorder relayed the information, except for the group size estimation, to the *IO*. This observer was then responsible for tracking the group until it passed abeam and to obtain and record independent estimates of group size. New relative positions, Beaufort sea state and a measure of confidence of the *IO* (high and low) on the identification of the group (i.e. that the *RO* and the *IO* were tracking the same group) were also recorded during the tracking. Records of a new group were only relayed to the *IO* when the recorder was informed that a previous tracking was finished. To ensure independence among estimates made by the *RO* and *IO*, a single radio channel was used for communication between the latter and the data recorder. Because of the higher observation platform (1.6 km of "horizon range" over the other) and the dedicated effort on group size estimation, with no responsibility of detecting new groups for abundance estimates, the independent observer could spend more time tracking each group and theoretically provide a more accurate estimate. Observers had no access to the records made in the independent position during the entire survey.

Data Analysis

In order to ensure that group size estimates recorded by the independent observer could be treated as *accurate estimates of group size*, groups were considered in the analysis only if they attended the following criteria: (1) groups with at least two sightings (re-sightings) made by the *IO* and (2) with high confidence on the correct group identification by the *IO*.

To evaluate the quality of the *IO* correction and the *RO*s self-corrections, three different approaches were used. The following ratios between the first (*1RO*) and the last (*2RO*) regular observer's group size estimates and the independent observer's estimate (*IOE*), were calculated:

C1 = $IOE_i/2RO_i$ = ratio between the independent observer's estimate and the last regular observer's estimate for group i;

C2 = $IOE_i/1RO_i$ = ratio between the independent observer's estimate and the first regular observer's estimate for group i;

C3 = $2RO_i/1RO_i$ = ratio between the last and the first regular observer's estimate for group i (*RO*'s self-correction).

Due to the non-normal distribution on the data, we compared the three ratio data sets with the Wilcoxon pairwise test ($\alpha = 0.05$), using software R (R Core Team 2013). The same test was used to compare group sizes estimates *IOE*, *1RO* and *2RO*. *C1* mean value was treated as a "abundance correction factor", which was applied as a multiplier in the abundance calculation in program Distance 6.1 (Thomas *et al.* 2010).

RESULTS

Group Size Estimates

The independent observer recorded 136 groups, with only 39 attending to the criteria of high confidence on correct identification and at least one re-sighting made by the *IO*. The modal estimate of *C1* (ratio of the *IO* estimate over the last/best estimate of the *RO*) was 1 (43.6%), and group size estimation by the *IO* was lower in 30.8% and higher in 25.6% of times, than the *RO*. The results of Wilcoxon pairwise test comparing group size estimates (*IOE*, *1RO* and *2RO*) and correction situations (*C1*, *C2* and *C3*) are presented in table 1.

When *C1* (1.175, SE = 0.83) was applied as a multiplier in the calculation of humpback whale abundance using program Distance 6.1, the estimated abundance increased from 16,983 (CV = 0.106, 95% CI = 13,123 – 21,987) (Chapter 3, this dissertation) to 19,955 (CV = 0.724, 95% CI = 4,091 – 97,340) whales. Histogram of the *C1* values is presented in figure 1.

Table 1. Wilcoxon pairwise test results comparing group size estimates (*IOE*, *2RO* and *1RO*) and correction situations (*C1*, *C2* and *C3*). *IOE* = independent observer estimate; *1RO* = regular observer's first estimate; *2RO* = regular observer's last estimate; *C1* = *IOE*/*2RO*; *C2* = *IOE*/*1OR*; *C3* = *2RO*/*1RO*. Significant values ($\alpha = 0.05$) are underlined.

		P-value (U-test)		
	Mean	***IOE***	***2RO***	***1RO***
IOE	1.897	–	0.874	0.004
2RO	1.923	–	–	0.001
1RO	1.308	–	–	–
-		***C1***	***C2***	***C3***
C1	1.175	–	0.001	0.127
C2	1.626	–	–	0.829
C3	1.603	–	–	–

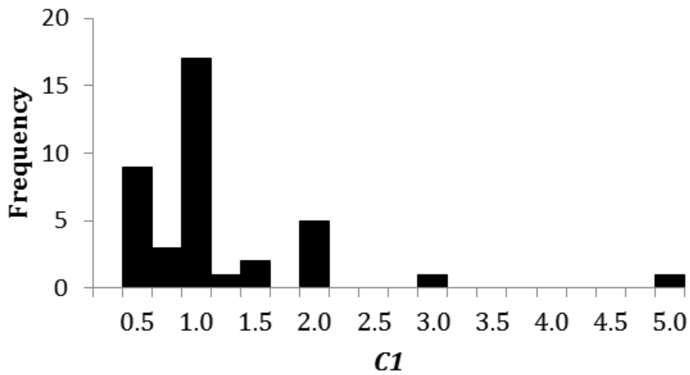

Figure 1. Histogram of *C1* values (n = 39). Values higher than 1 means *IOE* was higher than *2RO*. Values lower than 1 means *IOE* was lower than *2RO*. Note the modal value 1, which means high frequency of concordance between *IOE* and *2RO*.

DISCUSSION

Regarding the calculation of correction factors (*C1, C2* and *C3*), Scott *et al.* (1985) used a similar way to calculate the "relative error" of observers estimating dolphin group size, but their objective was to assess not just the error, but the variance among estimates of different observers. Their results demonstrated that the interpretation of observer estimates is problematic, and can be highly variable, with most observers tending to underestimate large groups, but overall, groups of dolphins are underestimated by 10-30%. The group size estimation difficulties for whales are slightly different than for dolphins, but field observation conditions are similar.

One of the main outcomes of the present work is that group sizes collected by the *IO* did not statistically differ from those collected by *RO* in their last estimates (*2RO*). *C2* (*IOE/1RO*) and *C3* (*2RO/1RO*) did not differ too, because the *IO* "corrects" the *RO*'s first group size estimate the same way that the *RO* corrects himself with his last estimate. This suggests that, despite advantages in sighting conditions and the presence of potential errors in *RO*'s estimates, *IO*'s corrections did not improve it. Also, the mode of *C1* is 1 (n = 18) indicates high frequency of concordance among *IOE* and *2RO* values. Hence, *C3* provides adequate correction on *1RO*, which means that *RO*'s correct their first estimates as good as the *IO* does. Although, the improvement of observation efforts made when off-effort observers were allocated in the regular platform, may be influencing the group size estimation accuracy, and be responsible for this quality on the RO's self-correction.

The comparison between abundance estimates without the multiplier *C1* (N = 16,983, CV = 0.106, 95% CI = 13,123 – 21,987) and applying it (N = 19,955, CV = 0.724, 95% CI = 4,091 – 97,340) do not show statistical differences, with the new estimate comprised by the 95% confidence interval of the former. Nevertheless the variance is considerably higher with the application of the multiplier due to the high standard error of *C1* (SE = 0.84), highlighting the low precision of this parameter. Hence, we concluded that corrections of the *IO* did not improve abundance estimate in this experiment. Although errors during group size estimates likely occur, overall they do not influence significantly the abundance estimates for humpback whales when ship platforms are used. Previous studies (Clark 1984; Gerrodette and Perrin 1991; Barlow *et al.* 1998; Gerrodette *et al.* 2002) demonstrated that estimates of cetacean group sizes may have high variance among different observers, even when made from the same ship. The main source of error in those cases was the observer's estimation particular characteristics, based on previous experience. Limited sample size precluded evaluation of such individual feature here.

The adequate *RO*'s self-correction is probably due to the improved effort of observer's team in tracking groups at areas of high density of detections. Off-effort observers, when placed in the regular observation platform, allow on-effort observer to focus on new detections. For example, the area of Abrolhos Bank presented an encounter rate of 1.3 animals/km, much higher than the average encounter rate (0.63 animals/km). In this sense, we strongly suggest that this "off-effort observers approach" is consistently implemented in line transect surveys when such areas are present. The independent observer as adopted here would be useful for that groups which the *RO* self-correction is not possible, e.g. groups with large perpendicular distances or groups that swimming direction is the opposite of the transection line, but the small set of data constrained its evaluation.

In conclusion, our results support that ship surveys provide reliable group size estimates for humpback whales, even more when compared to aerial survey, where estimates of group size show smaller values for the species and potential errors have never been studied for this issue. Comparing average group sizes estimated from aerial platforms by Andriolo *et al.* (2006), Andriolo *et al.* (2010) and Wedekin (2011) of 1.52, 1.63 and 1.59 respectively, with the estimated by Martins *et al.* (2001) and Zerbini *et al.* (2004) with 2.32 and 1.95 whales/group, respectively, from surface platform, we clearly see that aerial surveys provide smaller group sizes. However, these studies did not survey the same area, and mean group size is possibly influenced by distribution and time interval of the survey. In the study presented in Bortolotto *et al*. (Chapter 3, this dissertation), block 12 has mean group size observed for humpback whales of 1.93 in 2008 and 2.04 in 2012. The block comprises mainly the Abrolhos Bank, the same area surveyed by Martins *et al.* (2001), where pairs of mother-calf, or other reproductive groups with two or more animals, are more frequently sighted. One of the possible sources of differences between platforms, is when animals in a group may not be detected because they are underwater, likely the availably bias described by Marsh and Sinclair (1989), which is increased by the high speed of airplanes. This might explain the lower abundance estimate provided by Wedekin (2011) when compared to Bortolotto *et al.* (Chapter 3, this dissertation), both generated for 2008. Our findings support that ship surveys provide relative accurate abundance estimates and should be the first option for observation platform in distance sampling studies estimating the abundance of humpback whales. Although, when costs and time issues are considered, aerial surveys may have more advantages, if proper corrections are applied.

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– CAPÍTULO 3 –

Humpback whale abundance in the Brazilian breeding ground estimated by line transect ship survey

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ABSTRACT: The humpback whales population inhabiting Brazilian waters (BSA) was depleted to less than 3% of its size during modern whaling period. As coastal development and commercial activities in the area are increasing and pose potential threats for these animals, continuous monitoring is needed to support conservation strategies. To estimate the abundance of whales, line transect distance sampling methods are often used. Up to date, only aerial platforms were used to survey the whole area of BSA's distribution by this approach. The aim of this work is to present the first BSA abundance estimate by line transect distance sampling in a ship survey and a potential population increasing rate. Two research cruises were carried out, in 2008 and 2012, traveling from Natal (~5ºS) to Cabo Frio (~23ºS) during August-September, with 2,345km and 1,684km of effort, respectively. The area covered in 2012 was restricted to the coast from Salvador (~13ºS) to Cabo Frio, due to rough weather. The hazard rate model was selected as the best model describing the decrease of detection probability for both years. Abundance in 2008 was estimated in 16,774 (CV = 0.402) whales. For the 2012's restricted area, we estimated an abundance of 19,809 (CV = 0.149) animals. Comparing abundance for correspondent areas among years, we found an increasing rate of 6.1%/year. The 2008 abundance estimate for BSA may be considered as the most robust and recent, indicating that the population was between 60-76% of its original size. If BSA is increasing 6.1%/year, it should be recovered in numbers in the next two decades, and management together with conservation actions is needed.

KEY WORDS: Distance sampling · Rate of increase · Cetacean trends · Large whales · Breeding stock A

INTRODUCTION

As a cosmopolitan species, the humpback whale *Megaptera novaeangliae* occurs in all major oceans of the world. The species typically migrate between summer feeding grounds in high-latitude cold waters and winter breeding/calving grounds in tropical and sub-tropical waters (Clapham & Mead 1999). Whaling greatly depleted all populations (e.g. Best 1993, Clapham et al. 1999, Findlay 2001, Zerbini et al. 2011), with nearly 200,000 whales caught in the Southern Hemisphere alone (Findlay 2001). After protection from whaling warranted by the International Whaling Commission (IWC) in the late 1960's, most populations started showing signs of recovery (e.g. Barlow & Clapham 1997, Stevick et al. 2003, Angliss & Outlaw 2005, Calambokidis et al. 2008, Zerbini et al. 2010, Ward et al. 2011). The species was recently re-classified by IUCN, from "Vunerable" to "Least Concern", mainly due to increase in population sizes in areas where data are available (Reilly et al. 2008), but some populations remain listed, e.g. the Arabian Sea population (Willson et al. 2013) and the Oceania population (Childerhouse et al. 2008).

Currently, the IWC recognizes seven humpback whale breeding stocks in the Southern Hemisphere (IWC 1998, 2006) and Breeding Stock A (BSA) corresponds to the population inhabiting the Brazilian coast (Andriolo et al. 2010). BSA feeding grounds were recently described as an offshore area east of South Georgia and the South Sandwich Islands (Zerbini et al. 2006). Zerbini et al. (2011) estimated that by the mid-1950s this population was depleted to 2-3% of its pre-exploitation size, mainly due to extensive whaling activities in breeding and feeding areas, and migratory routes. Nevertheless, recent studies indicate that BSA has also been increasing (Freitas et al. 2004, Ward et al. 2011, Zerbini et al. 2011).

In the Brazilian breeding ground, the Abrolhos Bank (~18°30'S, 38°30'W) is considered the main breeding site of BSA, but its regular annual distribution comprises the continental shelf up to the 500m isobath, between Natal (~5°S) in Rio Grande do Norte State, and Cabo Frio (~23°S) in Rio de Janeiro State (Zerbini et al. 2006, Andriolo et al. 2010). Records beyond this range (e.g. Lodi 1994, Cherem et al. 2004, Meirelles et al. 2009, Pretto et al. 2009, Wedekin 2011) might be a sign that distribution may be even wider, but further research is needed to show if these areas constitute part of the typical range of the species. Because anthropogenic activities along the Brazilian coast, such as gas and oil exploration, intense traffic of ships, and presence of harbors overlap with the whales' distribution, they likely represent some risk to the population (Martins et al. 2013). Therefore, continuous monitoring is needed to provide information on population trends and to support conservation and management plans.

To date, BSA abundance estimates where performed either by mark-recapture methods using photo-identification data (Kinas & Bethlem 1998, Freitas et al. 2004), or by line transect distance sampling with aerial (Andriolo et al. 2006, 2010, Wedekin 2011) or ship surveys (e.g. Zerbini et al. 2004).

In 2000, Zerbini et al. (2004) conducted the first distance sampling study aiming to estimate humpback whale abundance in Brazil. These authors covered part of the northeastern coast of Brazil and estimated that the population from 5-12°S comprised 628 animals (CV = 0.335, 95% CI = 327-1,157) in 2000. The use of surface platforms in studies like this allows the main assumption of the distance sampling method to be more easily attended: the probability of detection over the transection line, i.e. at distance zero, must be of 100% (i.e. $g(0) = 1$; Buckland et al. 2001). Failure in meeting this assumption is common in cetacean studies and can lead to negative bias in estimates (Barlow 1999), but for large whales with evident cues, the magnitude of this bias is probably small (Zerbini, Waite, et al. 2006). The issue of "$g(0) = 1$" assumption is generally an advantage of surface over aerial platforms when conducting distance sampling surveys, which frequently have detection over the transect line less than 100% (*g(0)<1*) and therefore requires estimation of *g(0)* (Laake & Borchers 2004, Andriolo et al. 2006, 2010, Kinas et al. 2006). Up to date, distance sampling surveys over the whole area of distribution of the BSA were only made using aerial platforms. First by Andriolo et al. (2010), with BSA abundance estimated in 6,404 animals (CV = 0.116, 95% CI = 5,084-8,068) for 2005. Later, in 2008, Wedekin (2011) estimated 9,330 whales (CV = 0.281, 95% CI = 4,857-20,229). Both studies assumed the detection at distance zero to be less than 100% and applied the appropriate corrections. However, there are other differences when the two platforms are compared, with aerial ones often presenting smaller group sizes for cetaceans (Grünkorn et al. 2006, Zerbini, Danilewicz, et al. 2011). As the average group size observed is one of the parameters used in the distance sampling abundance estimation when target species occur in groups, effort is needed to access group sizes as accurate as possible (Gerrodette & Perrin 1991, Barlow et al. 1998, Buckland et al. 2001, Gerrodette et al. 2002) to avoid bias.

The objective of this work was to estimate abundance of humpback whales along the Brazilian coastal breeding ground using line transect data collected during a ship survey, and compare estimates across two years separated by a 4-year interval (2008 and 2012). A potential rate of increase is also presented and discussed.

METHODS

Survey design

Sighting data were collected during two research cruises, in 2008 and 2012. The cruises travelled along Brazilian coast from Cabo de São Roque (~5ºS) in Rio Grande do Norte State, to Cabo Frio (~23 ºS) in Rio de Janeiro State, surveying the continental shelf and shelf break up to the 500m isobath. The survey was conducted on board the oceanographic research vessel *Atlântico Sul* (*Universidade Federal do Rio Grande*) with constant speed (~9-10 knots). Sighting surveys were planned to take place at the seasonal peak of abundance for the animals in the breeding grounds (August and September, Martins et al. 2001).

In 2008, the study area was divided into 15 blocks (Fig. 1), in order for the zig-zag designed lines to be allocated in convex areas and guarantee uniform coverage probability (Strindberg & Buckland 2004). Due to rough weather conditions, the 2012 survey effort was restricted to the area between the cities of Salvador (~13ºS), in Bahia State, and Cabo Frio, corresponding to blocks 8 to 15 (Fig. 2), and the design did not follow that of 2008. In addition to the abundance data collection, the cruises had the objective of satellite tagging whales to monitor their movements, and the effort planned for 2008 was two times greater in blocks 1-9 than in blocks 10-15, due to the interest in spending more time for tagging whales in the former blocks.

Fig. 1. Survey blocks in the humpback whales' distribution area off the Brazilian continental shelf. Black line indicates the 500m isobath.

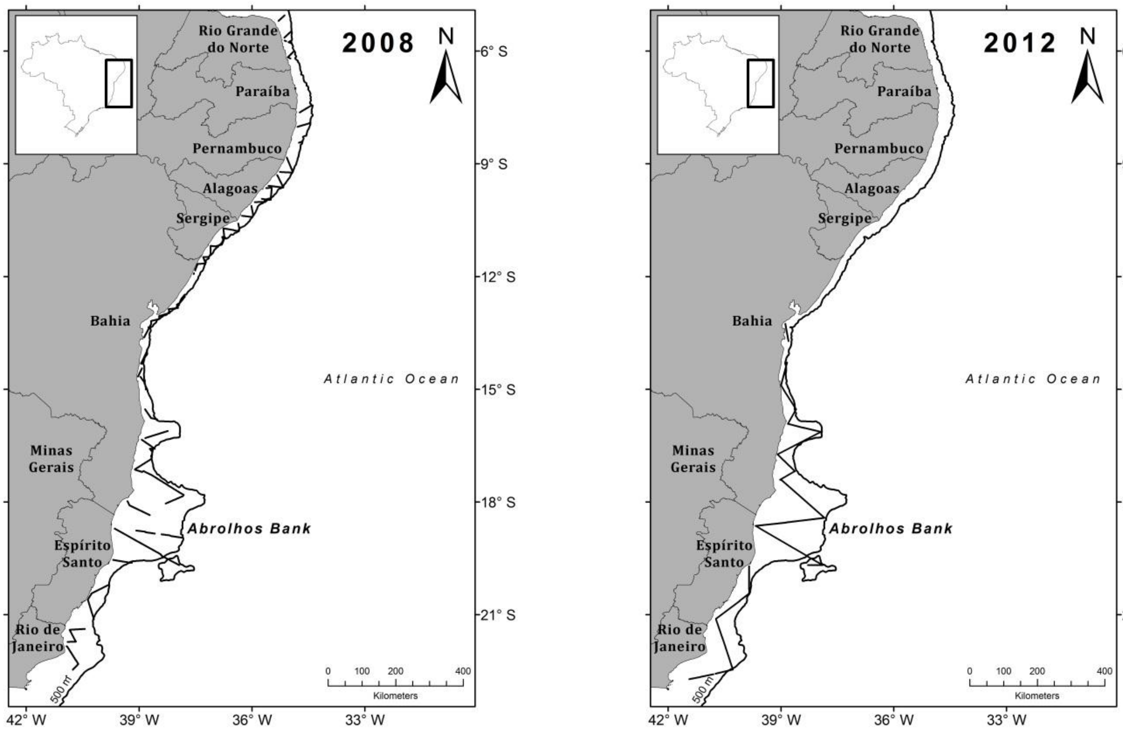

Fig. 2. Completed effort in years 2008 and 2012. Note that in 2012 only a portion of the area was surveyed due to rough weather.

Data collection

Data were collected following the line transect distance sampling methods (Buckland et al. 2001) in a passing mode approach (Hammond 2010). Animals were continuously searched from 5h30 to 17h00. During searching effort, trained observers rotated through three regular observer (RO) and data recorder position, every 30 minutes with a minimum of 2 hours of rest. The RO positions were port, center and starboard, all in the flying bridge at a 9.5 meters high platform. The RO in the central position was responsible for detecting animals between 10º from each side of the trackline, while the observer on port and starboard searched animals between 10º of the opposite side and 90º of its own side. The overlap of detection fields near the trackline was established to maximize detection in this region and to ensure that the $g(0) = 1$ assumption was not violated. In 2012, an independent observer was located at the crow's nest, 12.6 meters above the water level, to collect data for an experimental study on group size estimation errors described in Bortolotto et al. (Chapter 2, this dissertation). Each observer was equipped with a reticuled binocular 7x50 Fujinon, an angle board (for radial angle collection) and radio communicator.

Data for abundance estimation were collected only by regular observers. Sighting data (e.g. observer number, radial angle and reticle readings, species, group size, method and cue of detection) were recorded on Wincruz software (NOAA, USA) by the data recorder. Detections were made using the reticuled binoculars (80-90% of the time) and by naked eye (10-20% of the time). The reticules between the sighting and the horizon and the radial angle were estimated right after the detection of each group. The radial distance r was obtained by reticule readings as described by Lerczak & Hobbs (1998, erratum) and the perpendicular distance was calculated as $x = r \cdot sin(\theta)$, where θ is the radial angle of the group relative to the ship's bow. Group size estimates were collected at the moment of detection and re-estimates (or confirmed) of the former could be made as the ship travelled the trackline and groups became closer. In high-density areas, with many detections, off-effort observers helped ROs tracking groups to minimize double counting.

Data analysis

Analysis of the line transect data were performed using the software Distance 6.1 (Thomas et al. 2010). Analysis protocol followed Thomas et al. (2010) guidelines, with three steps: (1) exploratory analysis, (2) model selection, and (3) final analysis and inferences. Histograms of sighting frequencies in perpendicular distance classes were produced to verify possible truncation distances, which were decided by plotting preliminary models to identify distances such that detection probabilities were less than 0.15, as recommended by Buckland et al. (2001). Model selection was made in a stepwise approach, starting with simple models and including expansion series or covariates. "Half-normal" and "hazard-rate" models were tested, with expansion series (cosine or hermite polynomial, and cosine or simple polynomial, respectively), or with covariates (Table 1). The inclusion of covariates in the detection function model allows detection probabilities to be modeled, not only as a function of perpendicular distances, but also as a function of other covariates (e.g. group size, sighting cue, sea state conditions) (Marques & Buckland 2003). Before analysis, Beaufort sea state was divided into two categories, "calm" (including states 0-3), and "moderate" (states 4-6), because of the low frequency of sightings for states 1, 2 and 6. Detection functions were estimated with ungrouped data pooled across geographic strata. Density, encounter rate and group sizes were estimated by geographic stratum (i.e. blocks). Selection of the most supported models were made with *Akaike's Information Criterion* (Anderson 2008).

Due to the high frequency of unidentified whale sightings, their abundance was also estimated. As the number of sightings of other species of whales was insignificant when compared to the number of humpback sightings in both years (~1% or less), 100% of unidentified whales were considered as corresponding to humpback whales, and estimates of both were summed with variances calculated by the delta method (Buckland et al. 2001).

Table 1. Covariates tested in the model describing the decrease in the detection probability.

Covariate	Factor/Numeric	Levels
Geographic stratum	Factor	1 – 15
Beaufort sea state	Factor	calm (states 1, 2, and 3) and moderate (states 4, 5, and 6)
Cue	Factor	splash, body, blow and aerial behavior
Method of detection	Factor	binoculars and naked eye
Cluster size	Numeric	1 – 7

RESULTS

Effort completed was 2,345 km in 2008 and 1,684 km in 2012. Humpback and unidentified whales sightings in 2008 and 2012 are summarized in table 2.

Table 2. Sightings in the 15 blocks for 2008 and 2012. (L = effort completed, n = number of sighted groups, HW = humpback whales, UW = unidentified whales, n/L = groups encounter rate, S = average group size).

		2008						2012					
Block	**Area (km^2)**	**L**	**n HW**	**n UW**	**n/L HW**	**n/L UW**	**S HW**	**L**	**n HW**	**n UW**	**n/L HW**	**n/L UW**	**S HW**
1	2,360	97.4	0	0	0.000	0.000	0.00	0.0	-	-	-	-	
2	2,756	48.9	2	0	0.041	0.000	1.00	0.0	-	-	-	-	
3	5,348	43.8	3	1	0.069	0.023	1.67	0.0	-	-	-	-	
4	3,713	243.5	14	2	0.058	0.008	1.43	0.0	-	-	-	-	
5	3,802	302.1	44	8	0.146	0.026	1.55	0.0	-	-	-	-	
6	5,145	99.9	3	2	0.030	0.020	2.67	0.0	-	-	-	-	
7	5,681	112.3	12	2	0.107	0.018	1.42	0.0	-	-	-	-	
8	1,400	115.5	22	2	0.191	0.017	2.05	96.3	9	12	0.093	0.125	1.67
9	2,737	90.0	18	2	0.200	0.022	2.06	133.8	14	12	0.105	0.090	1.36
10	6,906	126.3	12	7	0.095	0.055	1.92	222.7	34	12	0.153	0.054	1.41
11	3,533	135.7	14	6	0.103	0.044	2.29	103.2	16	14	0.155	0.136	1.88
12	49,317	609.8	260	42	0.426	0.069	1.93	662.9	423	115	0.638	0.173	2.04
13	7,492	133.9	5	3	0.037	0.022	1.40	199.1	38	13	0.191	0.065	1.68
14	5,379	80.8	2	0	0.025	0.000	2.00	73.5	10	0	0.136	0.000	1.40
15	17,531	105.5	5	2	0.047	0.019	2.40	192.7	9	6	0.047	0.031	1.44
Total	**123,101**	**2,345**	**416**	**79**	**0.177**	**0.034**	**1.88**	**1,684**	**553**	**184**	**0.328**	**0.109**	**1.93**

Abundance estimates

Truncation distances for humpback and unidentified whales in 2008 and 2012 were defined analyzing each set of data individually (Fig. 3), following criteria described by Buckland et al. (2001) to withdraw observations that poorly contribute to the estimation of the detection function. This procedure reduced a little the sample sizes, with maximum perpendicular distances of 4km for humpbacks in both years and 2012's unidentified, and 5.5 km for 2008's unidentified whales.

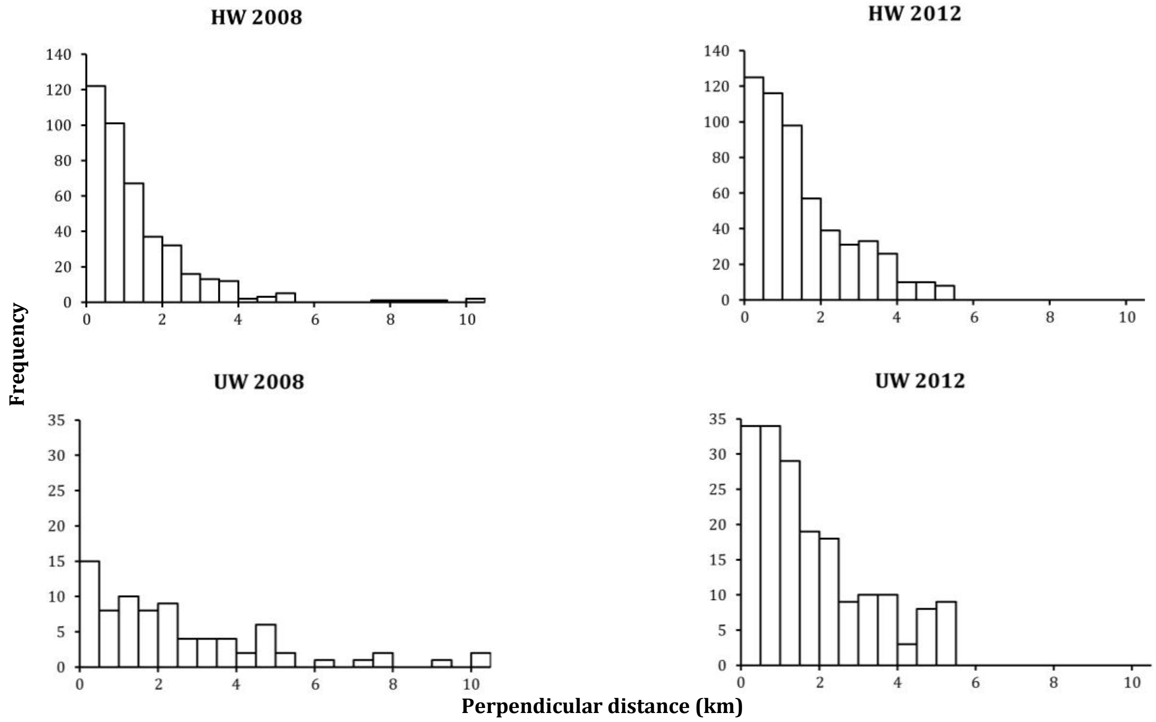

Fig. 3. Histograms of perpendicular distances observed for humpback whales (HW) and unidentified whales (UW) in 2008 and 2012.

The hazard rate model was selected for all sets of data with different covariate/adjustment term selected for each set. For humpback whale sightings, the covariate "method of detection" was selected in 2008, and "geographic stratum" in 2012. For unidentified whales, the 2012 model set included covariate "cue", with no adjustment terms for the 2008 model. The fit of the hazard rate models to perpendicular distance data are presented in Figure 4 and most supported models' details are summarized in Table 3. Abundance of humpback whales estimated were 15,710 (CV = 0.240, 95% CI = 8,726-28,285) in 2008 and 16,983 (CV = 0.106, 95% CI = 13,123-21,978) in 2012. Estimates for each block are presented in table 4.

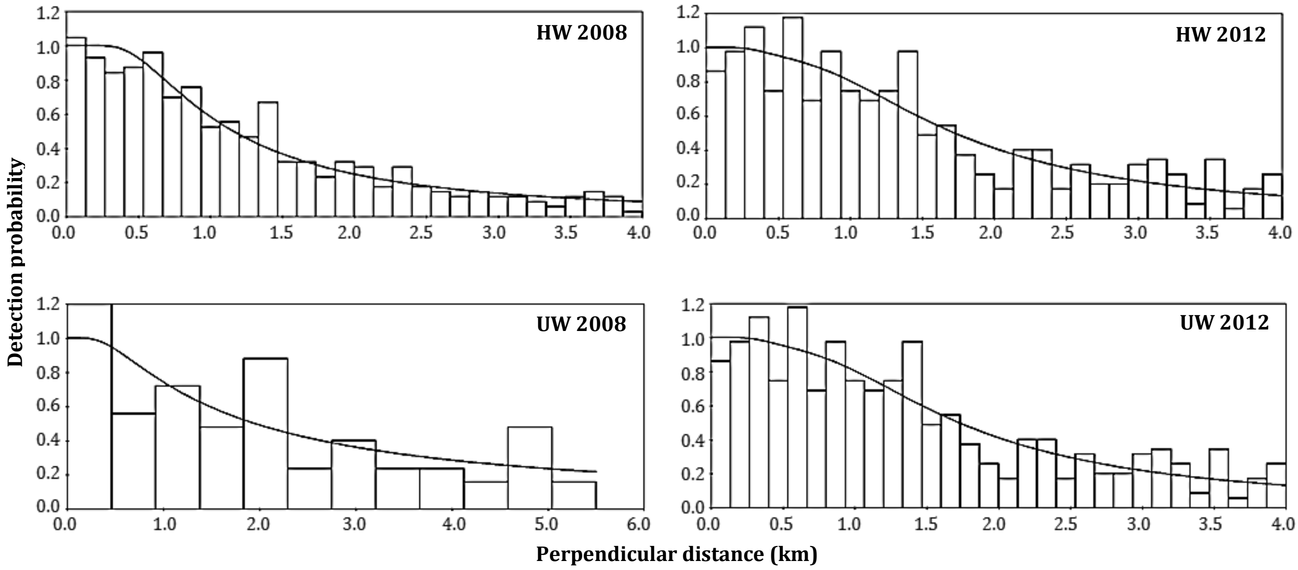

Fig. 4. Hazard rate models fitted to the histograms of sightings after truncation. (HW = humpback whale, UW = unidentified whale).

Table 3. Most supported models for each set of data. (Mn = humpback whale, Unid = unidentified whale, HZR = hazard rate model, meth = covariate method, strat = covariate geographic stratum, cue = covariate cue, ESW = effective half-strip width, P = mean probability of detection, D = density, N = abundance, IC L = lower 95% confidence interval limit, IC U = upper 95% confidence interval limit, CV = coefficient of variation, GOF K-S p = p-value for Kolmogorov-Smirnov goodness of fit test).

Year	Species	Name	ESW	P	D	N	N IC L	N IC U	N CV	GOF K-S p
2008	Mn	Mn_trunc4km_HZR+meth	1.55	0.39	0.128	15,710	8,726	28,285	0.240	0.862
2008	Unid	Unid_trunc5.5km_HZRnoAdjust	2.64	0.48	0.009	1,064	564	2,009	0.323	0.985
2012	Mn	Mn_trunc4km_HZR+strat	2.01	0.50	0.180	16,983	13,123	21,978	0.106	0.696
2012	Unid	Unid_trunc4km_HZR+cue	2.25	0.56	0.030	2,826	2,282	3,501	0.106	0.867

Table 4. Humpback and unidentified whales estimates in 2008 and 2012. (Legends in Table 3, Pooled = global estimate).

	2008					**2012**				
Humpback whale										
Block	**D**	**N**	**% CV**	**N IC L**	**N IC U**	**D**	**N**	**% CV**	**N IC L**	**N IC U**
1	0.000	0	-	-	-	-	-	-	-	-
2	0.013	36	34.6	1	2001	-	-	-	-	-
3	0.037	197	42.1	45	870	-	-	-	-	-
4	0.025	93	26.0	54	161	-	-	-	-	-
5	0.072	272	20.4	177	417	-	-	-	-	-
6	0.026	133	47.4	44	400	-	-	-	-	-
7	0.049	277	36.6	120	643	-	-	-	-	-
8	0.126	176	19.9	111	280	0.039	54	42.4	2	1228
9	0.097	265	29.3	124	565	0.035	97	31.1	33	283
10	0.059	406	34.3	113	1451	0.054	371	29.2	125	1097
11	0.076	269	37.3	109	662	0.072	256	15.0	174	375
12	0.258	12,730	29.2	6186	26198	0.306	15,075	11.7	11,277	20,153
13	0.017	126	97.5	5	3437	0.078	581	8.2	493	684
14	0.016	86	96.0	0	2,281,100	0.047	255	16.2	178	365
15	0.037	643	63.1	72	5719	0.017	294	53.8	2	43245
Pooled	**0.128**	**15,710**	**24.0**	**8,726**	**28,285**	**0.180**	**16,983**	**10.6**	**13,123**	**21,978**
Unidentified whale										
Block	**D**	**N**	**% CV**	**N IC L**	**N IC U**	**D**	**N**	**% CV**	**N IC L**	**N IC U**
1	0.000	0	-	-	-	-	-	-	-	-
2	0.000	0	-	-	-	-	-	-	-	-
3	0.009	46	60.0	2	1294	-	-	-	-	-
4	0.002	9	81.8	2	44	-	-	-	-	-
5	0.006	21	64.2	6	74	-	-	-	-	-
6	0.004	20	76.2	3	110	-	-	-	-	-
7	0.005	29	80.2	6	150	-	-	-	-	-
8	0.007	9	79.2	1	67	0.035	48	45.2	1	2449
9	0.004	12	51.5	4	36	0.020	54	65.2	4	671
10	0.017	114	42.4	46	283	0.013	89	27.1	41	196
11	0.008	30	34.0	15	60	0.030	106	1.4	33	345
12	0.014	690	38.2	318	1,497	0.047	2,310	11.3	1,835	2,908
13	0.003	21	99.2	1	497	0.016	117	30.6	18	740
14	0.000	0	-	-	-	0.000	0	-	-	-
15	0.004	63	65.9	9	466	0.006	101	79.3	0	539,400
Pooled	**0.009**	**1,064**	**32.3**	**564**	**2,009**	**0.030**	**2,826**	**10.6**	**2,282**	**3,501**

In order to compare with the 2012 surveyed area, abundance estimated for blocks 8-15 in 2008 was 14,701 (CV = 0.255, 95% CI = 7,851-27,529) humpback whales and 939 (CV = 0.337, 95% CI = 482-1,828) unidentified whales, resulting in a total of 15,640 (CV = 0.423, 95% CI = 8,333-29,357) whales. Summed estimates of humpback and unidentified whales for 2012 is 19,809 (CV = 0.150, 95% CI =15,405-25,479). The unidentified and humpback whale estimates are assumed to reliably represent the latter species because sightings of other whale species during both cruises represented less than 1.5% of the total sightings. We believe that the great majority of unidentified whales is probably represented by humpback whales in sighting conditions that did no permit accurate species identification, e.g. large distance of sighting and/or presence of sun glare. In this sense, when humpback and unidentified whales estimates are summed, 2008's total area abundance is 16,774 (CV = 0.402, 95% CI =9,290-30,294), and it is considered as representing the size of BSA for that year.

If we consider only the estimates for humpback whale sightings, we find a numeric increase from 14,701 (CV = 0.255, 95% CI = 7,851-27,529) whales, in 2008, to 16,983 (CV= 0.106, 95% CI = 13,123-21,978), for the area surveyed in 2012. This corresponds to a rate of annual increase of 3.7%. When unidentified whales estimates are summed to these values, the 4-year interval increase is from 15,640 (CV = 0.423, 95% CI = 8333-29357) to 19,809 (CV = 0.150, 95% CI =15,405-25,479), corresponding to an annual rate of 6.1%.

DISCUSSION

Abundance

The 2008 cruise covered the most representative area for the BSA, the same surveyed by airplane in the study of Andriolo et al. (2010), comprising the whole known distribution area of the population. Therefore, the estimate presented for this year can be considered the most recent for BSA abundance. However, increasing records in areas northward these bounds (Meirelles et al. 2009, Pretto et al, 2009), in oceanic islands such as Fernando de Noronha Archipelago (Lodi 1994) and Trindade Island (Wedekin 2011), indicate that the wintering range of the species may not be restricted to the surveyed area. Also, due to the migratory behavior of the species, there may be some fluctuation on the annual peak of abundance. Even though this peak is shown to occur in August-September (Martins et al. 2001), some animals might have started their migration back to the feeding grounds, while other animals might not have arrive yet when the survey was conducted. Another issue possibly causing underestimation of abundance is related to the assumption of $g(0) = 1$: when surface platforms are used to survey large whales with conspicuous cues, bias resulting from failing this assumption is probably small, but if the true *g(0)* of the study is not 1, abundance is underestimated (Barlow 1999). In the other hand, overestimation may be present if some of the sighted unidentified whales were other species than humpback whales.

Caution is necessary when comparing our BSA estimates with previous abundance estimates (Kinas & Bethlem 1998, Zerbini et al. 2004, Andriolo et al. 2006, 2010, Wedekin 2011), mainly due to either different methodologies, sighting platform employed or extent of surveyed area. The study of Andriolo et al. (2010) was the first to survey the whole recognized BSA breeding area applying the distance sampling methodology in 2005, with an aerial platform. Later, Wedekin (2011) also used an airplane to estimate BSA abundance for 2008. The aerial platform leads to a underestimation of group sizes when compared to vessel platforms surveying cetaceans (Grünkorn et al. 2006, Zerbini et al. 2011) and an evidence of that is shown in average group sizes of Andriolo et al. (2006), Andriolo et al. (2010) and Wedekin (2011) that estimated 1.52, 1.63 and 1.59

whales/group respectively, while Martins et al. (2001) and Zerbini et al. (2004) estimated 2.32 and 1.95 whales/group, respectively, from vessel platforms. However, these studies did not survey all the same area, and mean group size was possibly influenced by distribution and time interval of the surveys. In this study, block 12 had a mean group size of 1.93 humpback whales in 2008 and 2.04 in 2012. The block comprises mainly the Abrolhos Bank, the same area surveyed by Martins et al. (2001), where mother-calf pairs, or other reproductive clusters with two or more animals, are more frequently sighted. Overall, mean group sizes for the entire area in 2008 and 2012 were 1.88 and 1.93, respectively. While the low speed of vessel platforms provides some advantages, aerial platforms allow for larger and faster coverage of the survey area per unit of time, with adequate sample size for estimating the detection function obtained in less time. When corrected for the $g(0) < 1$ issue, aerial surveys provide reliable estimates. The IWC recommended the procedures of Andriolo et al. (2006) for this correction (IWC 2006).

The available abundances for the same area surveyed in 2008 and 2012 allowed the calculation of a potential increase rate for the BSA across comparable areas. Because the area surveyed in 2012 comprises the Abrolhos Bank (i.e. block 12) and it was responsible for 76% (n = 423) and 89% (N = 15,075) of total sightings and abundance in the year, respectively, the rate of increase is mainly describing the trend of this particular area. Blocks 1-7 correspond to the area not surveyed in 2012, and inferences on the trend for the whole area/population may require advanced methodological approaches, such as spatial modeling (Buckland et al. 2004). However, population increase rates of 3.7% and 6.1% are considered very plausible for the species (Zerbini et al. 2010) and the increase in the area not surveyed in 2012 (i.e. blocks 1-7) may be higher because the survey in this year was concentrated in core habitats. Because these regions tend to be occupied first, it is possible that the trend in more marginal habitats (not surveyed in 2012) is greater, which should result in a higher overall estimate of population trend. With the increase, the population may adjust its distribution as a function of environmental characteristics, such as preferential depths or areas of higher/lower density. Martins et al. (2001) and Ersts & Rosenbaum (2003), for example, found that groups presenting calves preferred shallower waters, possibly avoiding larger groups, such as competitive groups (Clapham 2000). Ward et al. (2011) estimated that BSA's rate of increase was 7.4%/year (95% CI = 0.6-14.5%/year) in the years 1995-98, using only data collected in the Abrolhos Bank, thus the qualitative estimate described here (3.7 and 6.1%/year) is consistent with their findings.

It must be noted that despite the positive qualitative trend, abundance estimates for 2008 and 2012 do not statistically differ, with each point estimate comprised by the 95% confidence interval of the other year. Therefore the trend reported here would not be significant if quantitatively computed.

Conservation

The 2008 estimate of 16,774 animals indicates that BSA was within 60-76% of its pre-exploitation abundance as estimated by Zerbini et al. (2011). Further, the 2012 estimated abundance of 19,809 animals, even if not comprising the whole distribution area, represents 70-90% of its pre-exploitation size, and suggests that the population may be approaching its pre-exploitation levels. Otherwise, in a conservative approach, we estimated 15,710 animals (i.e. 56-71% of the original size) for 2008 and 16,983 (60-77% of the original size) for 2012, considering only humpback whales, excluding the unidentified ones. In the same way, with a rate of annual increase of 3.7%/year, BSA must be totally recovered within years 2020 and 2026. Nevertheless, this prediction is based on the abundance generated for 2012 that did not cover the whole distribution area, and recovery might occur even earlier.

Besides the probable recovery and BSA's 'comfortable' conservation status, management is still needed and conservation actions are important to keep it abundant (Redford et al. 2013). As Jewell et al. (2012) indicate, repeated dedicated surveys specifically designed for the target species/region should be used to inform conservation and management, because it provides more robust results. Continuous monitoring of the Brazilian humpback whales population is necessary in the next years.

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CONCLUSÕES GERAIS

As principais conclusões do presente estudo são:

- As estimativas de tamanho de grupo de baleias-jubarte realizadas por um observador independente, com condições melhores de observação do que observadores regulares, não melhoram significativamente a estimativa destes últimos. Isto, desde que haja um aumento no esforço de observação, com observadores "fora de esforço" auxiliando no acompanhamento de grupos, quando altas densidades de observações estão presentes;

- As estimativas de tamanho de grupo de baleias-jubarte realizadas por observadores a partir de embarcações seguindo o método de amostragem de distâncias apresentaram evidências de serem acuradas;

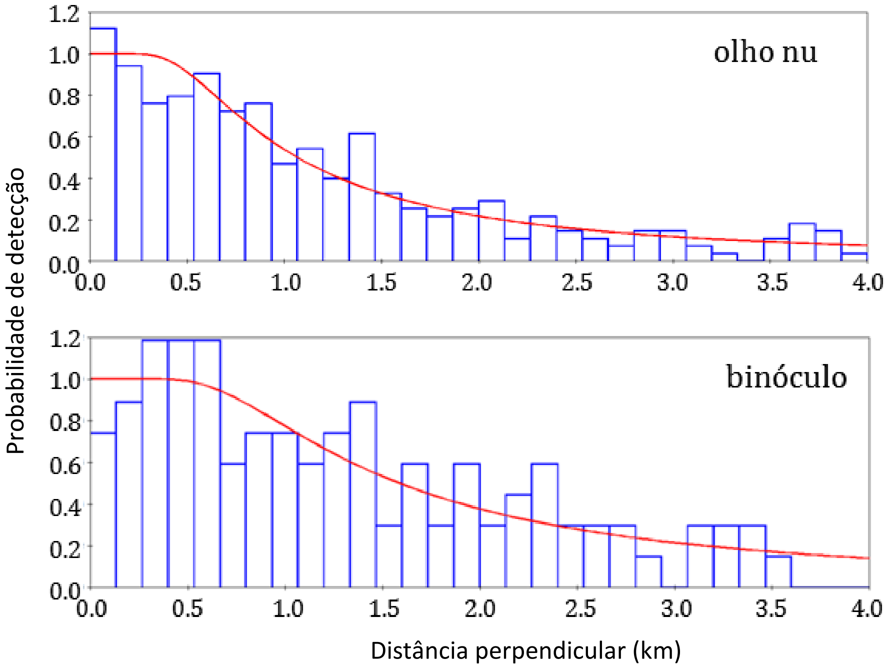
- A estimativa de abundância para as baleias-jubarte que frequentaram o litoral brasileiro em 2008 é de 16.774 indivíduos (CV = 40,2%, 95% IC =9.290-30.294). Esta é a mais recente estimativa para população e a primeira que utilizou uma embarcação para amostrar toda a área conhecida de sua distribuição no Brasil;

- Para o ano de 2012, foi estimado que 19.809 (CV = 15,0%, 95% IC = 15.405-25.479) baleias-jubarte frequentaram o litoral brasileiro entre Salvador e Cabo Frio. Mesmo que esta área não compreenda toda a distribuição da população durante a temporada de reprodução, este número representa entre 70 e 90% do tamanho populacional estimado para o início do século XX;

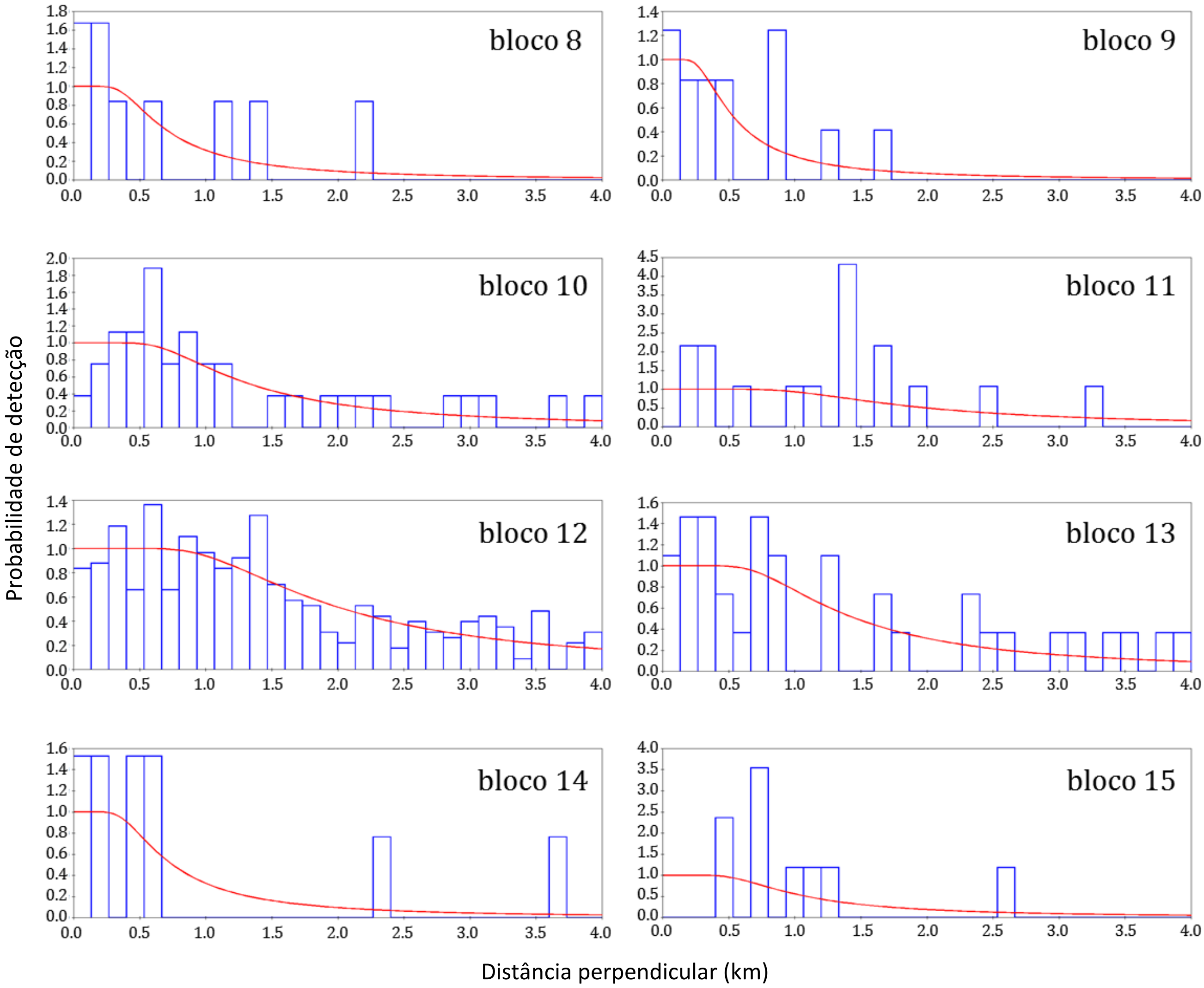
- A população de baleias-jubarte que frequenta o litoral brasileiro está bastante próxima de recuperar seu provável tamanho para o período anterior à caça moderna, podendo atingi-lo dentro das duas próximas décadas;

- A taxa de crescimento de 6,1%/ano estimada para a população de baleias-jubarte em águas brasileiras, apesar de bastante plausível, pode não representar a realidade, já que as estimativas de abundância para a mesma área em diferentes anos não diferiram significativamente e a área considerada não compreende toda sua área de distribuição.

APÊNDICE A – Funções de detecção para estimativa de abundância de baleias-jubarte no ano de 2008, para a covariável "método de detecção"



APÊNDICE B – Funções de detecção para estimativa de abundância de baleias-jubarte no ano de 2012, para a covariável “estrato geográfico” (bloco)



APÊNDICE C – Funções de detecção para estimativa de abundância de baleias não-identificadas no ano de 2012, para a covariável "pista de detecção"