UNIVERSIDADE FEDERAL DE SANTA CATARINA
CENTRO DE CIÊNCIAS BIOLÓGICAS
DEPARTAMENTO DE ECOLOGIA E ZOOLOGIA
PROGRAMA DE PÓS GRADUAÇÃO EM ECOLOGIA

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RISCO POTENCIAL DE COLISÃO DE NAVIOS-BARCAÇA COM BALEIAS-JUBARTE EM UMA ÁREA DE REPRODUÇÃO

Dissertação apresentada ao Programa de Pós Graduação em Ecologia da Universidade Federal de Santa Catarina, para obtenção de título de mestre em Ecologia.
Área de concentração:
Ecossistemas Marinhos.

Orientador:
Dr. Paulo César Simões-Lopes
Co-orientador:
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Florianópolis
2013

Ficha de identificação da obra elaborada pelo autor, através
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Bezamat, Carolina
Risco potencial de colisão de navios-barcaça com baleias-jubarte em uma área de reprodução / Carolina Bezamat ; orientador, Paulo César de Azevedo Simões-Lopes; co-orientador, Leonardo Liberali Wedekin. - Florianópolis, SC, 2013.
66p.

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

Inclui referências

1. Ecologia. 2. Baleia jubarte. 3. Estimativa de densidade. 4. Risco de colisão. 5. Banco dos Abrolhos. I. Simões-Lopes, Paulo César de Azevedo. II. Wedekin, Leonardo Liberali. III. Universidade Federal de Santa Catarina. Programa de Pós-Graduação em Ecologia. IV. Título.

"Risco potencial de colisão de navios-barcaça com baleias jubarte em uma área de reprodução".

por

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Dissertação julgada e aprovada em sua forma final pelos membros titulares da Banca Examinadora (Port. 06/PPGECO/2013) do Programa de Pós-Graduação em Ecologia - UFSC, composta pelos Professores Doutores:

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Florianópolis, 04 de março de 2013.

Para Dadá

AGRADECIMENTOS

À minha família e amigos, por todo o amor e apoio ao longo dessa jornada em busca da realização dos meus sonhos.

Aos meus orientadores, Paulo e Leo, por todo o carinho e ensinamentos.

À banca examinadora, Fábio, Marta e Daniel, pelas valiosas contribuições.

A todos do Projeto Baleia Jubarte por mais esta oportunidade e todos os dias de felicidade plena, no mar e em terra. O Projeto Baleia Jubarte é patrocinado pela Petróleo Brasileiro S.A. (Petrobras).

À Fibria Celulose, Veracel Celulose e Companhia de Navegação Norsul pelo apoio logístico e financeiro para a realização deste trabalho.

Ao programa de Pós-Graduação em Ecologia da UFSC, todos os professores, funcionários e amigos, e à CAPES pela bolsa de mestrado.

À nossa querida Dadá, um anjo que Deus colocou em nossas vidas. Muito obrigada por amar a mim e meus irmãos como se fôssemos seus filhos. Descanse em paz, minha ‘mãe preta’. Te amo, mocréia!

“A distância não separa uma amiga”

RESUMO

Colisões com embarcações estão entre as principais ameaças às grandes baleias no mundo todo. Portanto, os potenciais impactos do crescente tráfego de embarcações são motivo de preocupação com relação ao futuro da população de baleias jubarte *Megaptera novaeangliae* que se reproduz na costa brasileira. Com o objetivo de avaliar o risco de colisão entre grandes embarcações e baleias jubarte no Banco dos Abrolhos – a mais importante área de reprodução para a espécie no Oceano Atlântico Sul Ocidental – nós usamos navios-barcaça como plataformas de oportunidade para monitorar suas rotas desde o sul da Bahia até o Espírito Santo. A densidade de baleias jubarte foi estimada através da metodologia de transecções lineares com amostragem de distâncias; e o risco de colisão foi estimado a partir de um modelo de duas dimensões, baseado no tamanho da embarcação, tamanho da rota, comprimento da baleia, densidade populacional e proporção do tempo que elas passam na superfície. O monitoramento ocorreu nas temporadas reprodutivas de 2003-2005 e 2011, quase 12 mil milhas náuticas foram amostradas e 1.456 grupos foram detectados. A rota Belmonte – Barra do Riacho que passava a leste do Arquipélago dos Abrolhos, por altas concentrações de baleias jubarte, foi suspensa logo após o monitoramento e substituída por uma rota mais próxima da costa. A taxa de encontro na rota externa foi cerca de 4 vezes maior do que na rota costeira. No pico da temporada de 2011, a densidade de baleias ao longo da rota no trecho Belmonte - Caravelas foi estimada em 0,085 baleias/km^2 e no trecho Caravelas - Barra do Riacho a estimativa foi de 0,023 baleias/km^2. O risco de colisão entre os navios-barcaça e baleias jubarte existe e vem aumentando com o aumento do tráfego de embarcações. Os três navios-barcaça operando no trecho entre Belmonte e Barra do Riacho tiveram o potencial de colidir com 25 baleias jubarte na temporada reprodutiva de 2011. Conforme o tráfego de embarcações aumenta no Banco dos Abrolhos e a população de baleias jubarte cresce, a probabilidade de colisão também deve aumentar. A continuação deste monitoramento é importante para que possamos avaliar como as baleias jubarte irão responder ao tráfego de embarcações.

Palavras-chave: *Megaptera novaeangliae*, amostragem de distâncias, plataforma de oportunidade, Banco dos Abrolhos, Brasil.

ABSTRACT

Ship strikes are among the major threats to large whales worldwide. Therefore, the potential impact of increasing vessel traffic is a concern regarding the future of the Brazilian humpback whale *Megaptera novaeangliae* population. Aiming to evaluate the risk of collision between large vessels and humpback whales in the Abrolhos Bank – the most important breeding and calving ground for the species in the Southwestern Atlantic Ocean - we used commercial vessels as platforms of opportunity to monitor their route from southern Bahia to Espírito Santo. Humpback whale density was estimated through multiple covariate line-transect Distance Sampling. Thereafter, maximum possible collision rates were estimated using a simple two dimensional model based on vessel size and track lengths, plus whale size, population density and mean surface time. Monitoring was carried out during the 2003-2005 and 2011 breeding seasons, we sampled almost 12,000 n.miles and sighted 1,456 groups. The shipping route Belmonte – Barra do Riacho, which used to pass by high concentrations of humpback whales, was suspended shortly after monitoring and replaced by another route closer to the shoreline. The encounter rate on the former route was about 4 times higher than the encounter rate on the coastal route. During the peak of the 2011 breeding season, whale density on the route along the stretch Belmonte – Caravelas was estimated to be 0.085 whales/km^2 and along the stretch Caravelas – Barra do Riacho, 0.023 whales/km^2. The risk of collision between commercial vessels and humpback whales has been increasing as vessel traffic increases. Our results showed that the three commercial vessels operating along the stretch Belmonte – Barra do Riacho had the potential to collide with 25 humpback whales during the 2011 breeding season. As vessel traffic increases in the Abrolhos Bank and the humpback whale population grows, the likelihood of a vessel collision may also increase. It is important to continue this monitoring to see how whales will respond to vessel traffic over time, and to ensure that this route keeps presenting a low risk of collision, while evaluating whether additional mitigation measures are necessary, such as speed limits in areas or periods of higher density of whales.

Keywords: *Megaptera novaeangliae*, distance sampling, platform of opportunity, Abrolhos Bank, Brazil.

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INTRODUÇÃO GERAL

A baleia jubarte, *Megaptera novaeangliae* Borowski, 1871, é uma espécie migratória e cosmopolita que ocorre em todos os oceanos (Clapham & Mead, 1999). Durante o verão ela se dirige para águas circumpolares para se alimentar e durante o inverno migra para águas tropicais e subtropicais para acasalar e dar à luz aos seus filhotes (Dawbin, 1966). As populações de baleia jubarte foram drasticamente reduzidas pela intensa caça comercial no século XX; estima-se que cerca de 200 mil jubartes foram mortas no Hemisfério Sul (Findlay, 2001) até sua proibição em nível internacional em 1966. De acordo com a Comissão Internacional da Baleia, existem sete estoques reprodutivos de baleias jubarte no Hemisfério Sul (IWC, 1998, 2005) com suas respectivas áreas de alimentação (Dawbin, 1966; Clapham & Mead, 1999). O estoque 'A' corresponde às baleias que migram anualmente para o Brasil. Informações atuais sobre a distribuição de baleias jubarte durante o período reprodutivo mostram que a espécie ocorre desde o Rio de Janeiro até o Rio Grande do Norte, e é abundante no Banco dos Abrolhos (16° 40' a 19° 30' S), a mais importante área de reprodução para a espécie no Oceano Atlântico Sul Ocidental (Andriolo et al., 2010; Wedekin, 2011).

O crescente tráfego de embarcações é uma potencial ameaça para grandes baleias no mundo todo (p.ex. Laist et al., 2001), incluindo a costa brasileira (Marcondes & Engel, 2009). A poluição sonora gerada pelo tráfego de embarcações se sobrepõe e mascara os sons de comunicação das baleias (Richardson et al., 1995) e pode perturbar seu comportamento, gerando preocupação quanto à potencial influência deste ruído no sucesso reprodutivo e crescimento das populações (Sousa-Lima & Clark, 2009). Os animais podem alterar padrões de uso do hábitat (Cartwright et al., 2012) ou abandonar áreas de uso, temporariamente ou permanentemente, em resposta ao aumento do tráfego ou atividade de embarcações (Bryant et al., 1984), degradando seu habitat ou reduzindo-o efetivamente.

Os grandes cetáceos também sofrem o risco de colisão com as embarcações. Inúmeros casos foram relatados (Laist et al., 2001; Jensen & Silber, 2003; Van Waerebeek et al., 2007; Van Waerebeek & Leaper, 2008), porém muitas colisões provavelmente não são detectadas ou relatadas. As vítimas mais frequentes são as baleias fin (*Balaenoptera physalus*), jubarte (*Megaptera novaeangliae*), franca (*Eubalaena glacialis* e *E. australis*) e cachalote (*Physeter macrocephalus*).

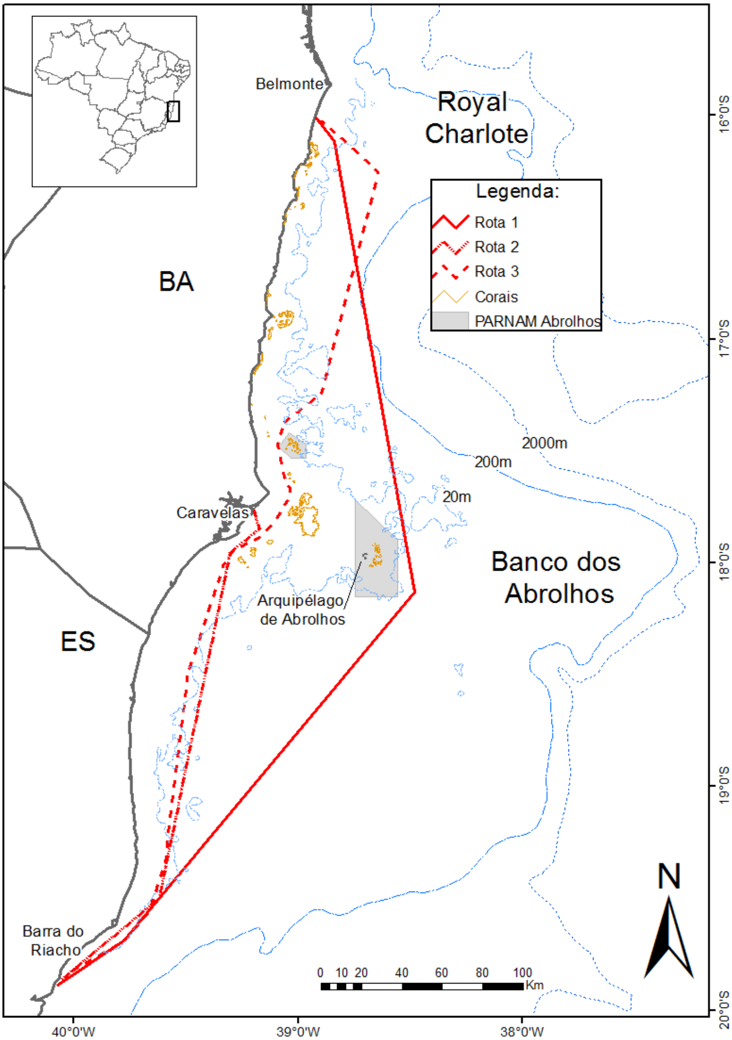

Figura 1. Banco Royal Charlote e Banco dos Abrolhos, leste do Brasil. Rotas dos navios-barcaça em vermelho. PARNAM: Parque Nacional Marinho.

A ocorrência e a gravidade de colisões com embarcações em várias regiões ao redor do mundo fizeram do risco de colisão uma questão de conservação emergente, especialmente em locais onde um tráfego intenso de embarcações e alta densidade de baleias coincidem

(Vanderlaan et al., 2008; Wiley et al., 2011; Silber et al., 2012). Para algumas espécies ameaçadas de extinção, como a baleia franca do Atlântico Norte, as colisões com embarcações são um impedimento à recuperação da espécie (Fujiwara & Caswell, 2001; Kraus et al., 2005).

A implementação de novas rotas mercantes cruzando o Banco dos Abrolhos (Fig. 1) é motivo de preocupação em relação ao futuro da população de baleias jubarte que se reproduz em águas brasileiras, por cruzarem hábitats-críticos da espécie. Em 2003, navios-barcaça começaram a transportar toras de eucalipto e celulose entre o sul da Bahia e o Espírito Santo. A rota Caravelas – Barra do Riacho foi traçada com o intuito de evitar áreas de maior densidade de baleias jubarte, tendo como base os dados de três anos de levantamentos aéreos na região (Andriolo et al., 2006, 2010). No entanto, a rota Belmonte – Barra do Riacho que passava a leste do Arquipélago de Abrolhos foi traçada sem nenhum estudo prévio sobre a distribuição e densidade de cetáceos na área. Esta rota passava por grandes concentrações de baleias jubarte, foi suspensa naquele mesmo ano, e substituída em 2005 por uma rota mais costeira. Os navios-barcaça (Fig. 2) possuem cerca de 150 m de comprimento e navegam a uma velocidade de 10-12 nós, em média.

Figura 2. Navio-barcaça que transporta toras de eucalipto e celulose entre o sul da Bahia e o Espírito Santo.

O objetivo deste estudo foi avaliar o impacto do tráfego de grandes embarcações no Banco dos Abrolhos, através do monitoramento de rotas mercantes utilizando os próprios navios-barcaça como plataformas de oportunidade. Nós estimamos a densidade de baleias jubarte seguindo a metodologia de transecções lineares com amostragem de distância (Buckland et al., 2001, 2004; Marques & Buckland, 2003), e estes dados foram incluídos em uma análise de risco de colisão (Tregenza et al., 2000) ao longo de cada rota. Além de avaliar a viabilidade destas embarcações como plataformas de observação, os resultados obtidos podem subsidiar futuras medidas de conservação e mitigação de impactos sobre a espécie.

Referências

Andriolo, A., Martins, C.C.A., Engel, M.H., Pizzorno, J.L., Más-Rosa, S., Freitas, A.C., Morete, M.E., Kinas, P.G., 2006. The first aerial survey to estimate abundance of humpback whales (*Megaptera novaeangliae*) in the breeding ground off Brazil (Breeding Stock A). Journal of Cetacean Research and Management 8(3), 307-311.

Andriolo, A., Kinas, P.G., Engel, M.H., Martins, C.C.A., Rufino, A.M., 2010. Humpback whales within the Brazilian breeding ground: distribution and population size estimate. Endangered Species Research 11, 233-243.

Bryant, P.J., Lafferty, C.M., Lafferty, S.K., 1984. Reoccupation of Laguna Guerrero Negro, Baja California Sur, Mexico by gray whales, in: Jones, M. L., Swartz, S.L., Leatherwood, J.S. (Eds.), The Gray Whale, *Eschrichtius robustus*. Academic Press, Orlando, pp. 375-387.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2001. Introduction to Distance Sampling: estimating abundance of biological populations. Oxford University Press, Oxford.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2004. Advanced distance sampling: estimating abundance of biological populations. Oxford University Press, Oxford.

Cartwright, R., Gillespie, B., Labonte, K., Mangold, T., Venema, A., Eden, K., Sullivan, M., 2012. Between a rock and a hard place: Habitat selection in female-calf humpback whale (*Megaptera novaeangliae*) pairs on the Hawaiian breeding grounds. Plos One 7(5) e38004, 16pp.

Clapham, P.J., Mead, J.G., 1999. *Megaptera novaeangliae*. Mammalian Species 604, 1-9.

Dawbin, W.H., 1966. The seasonal migratory cycle of humpback whales, in: Norris, K.S. (Ed.), Whales, Dolphins and Porpoises. University of California Press, Berkeley, pp 145-170.

Findlay, K.P., 2001. A review of humpback whale catches by modern whaling operations in the Southern Hemisphere. Memoirs of the Queensland Museum 47, 411-420.

Fujiwara M., Caswell, H., 2001. Demography of the endangered North Atlantic right whale. Nature 414, 537–541.

IWC (International Whaling Commission), 1998. Annex G - Report of the sub-committee on comprehensive assessment of Southern Hemisphere humpback whales. Report of the International Whaling Commission 48, 170-182.

IWC (International Whaling Commission), 2005. Report of the Scientific Committee, Annex H. Report of the sub-committee on other Southern Hemisphere whale stocks. Journal of Cetacean Research and Management 7 (Suppl.), 235-246.

Jensen, A.S., Silber, G.K., 2003. Large whale ship strike database. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-OPR-25, 37pp.

Kraus, S.D., Brown, M.W., Caswell, H., Clark C.W., Fujiwara M., Hamilton, P.K., Kenney, R.D., Knowlton, A.R., Landry, S., Mayo, C.A., McLellan, W.A., Moore, M.J., Nowacek, D.P., Pabst, D.A., Read, A.J., Rolland, R.M., 2005. North Atlantic right whales in crisis. Science 309, 561–562.

Laist, D.W., Knowlton, A.R., Mead, J.G., Collet, A.S., Podesta, M., 2001. Collisions between ships and whales. Marine Mammal Science 17(1), 35-75.

Marcondes, M.C.C., Engel, M.H., 2009. Ship strikes with humpback whales in Brazil. Trabalho SC/61/BC4 apresentado no Comitê Científico da 61ª Reunião Anual da Comissão Internacional Baleeira (IWC), Madeira, Portugal.

Marques, F.F.C., Buckland, S.T., 2003. Incorporating covariates into standard line transect analyses. Biometrics 59, 924-935.

Silber, G.K., Vanderlaan, A.S.M., Arceredillo, A.T., Johnson, L., Taggart, C.T., Brown, M.W., Bettridge, S., Sagarminaga, R., 2012. The role of the International Maritime Organization in reducing vessel threat to whales: Process, options, action and effectiveness. Marine Policy 36, 1221–1233.

Sousa-Lima, R., Clark, C.W., 2009. Whale sound recording technology as a tool for assessing the effects of boat noise in a Brazilian marine park. Park Science 26, 59-63.

Tregenza, N., Aguilar, N., Carrillo, M., Delgado, I., Diaz, F., Brito, A., Martin, V., 2000. Potential impact of fast ferries on whale populations a simple model with examples from the Canary Islands. Proceedings of the 14th Annual Conference of the European Cetacean Society. Cork, Ireland, 2-5 April.

Van Waerebeek, K., Baker, A.N., Felix, F., Gedamke, J., Iniguez, M., Sanino, G.P., Secchi, E., Sutaria, D., van Helden, A., Wang, Y., 2007. Vessel collisions with small cetaceans worldwide and with large whales in the Southern Hemisphere, an initial assessment. The Latin American Journal of Aquatic Mammals 6(1), 43-69.

Van Waerebeek, K., Leaper, R., 2008. Second Report of the IWC Vessel Strike Standardisation Working Group. Report to the International Whaling Commission Scientific Committe 60th Annual Meeting, Santiago, Chile, June 2008. Rep. No. SC/60/BC5.

Vanderlaan, A.S.M., Taggart, C.T., Serdynska, A.R., Kenney, R.D., Brown, M.W., 2008. Reducing the risk of lethal encounters: vessels and right whales in the Bay of Fundy and on the Scotian Shelf. Endangered Species Research 4, 283–297.

Wedekin, L.L., 2011. Ecologia populacional da baleia-jubarte (*Megaptera novaeangliae* Borowski, 1871) em sua área reprodutiva na costa do Brasil, Oceano Atlântico Sul. Tese de Doutorado. Universidade Federal do Paraná, Paraná. 144 pp.

Wiley, D.N., Thompson, M., Pace III, R.M., Levenson, J., 2011. Modeling speed restrictions to mitigate lethal collisions between ships and whales in the Stellwagen Bank National Marine Sanctuary, USA. Biological Conservation 144, 2377–2381.

Humpback whale density and potential ship strikes in the Brazilian breeding ground

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Abstract

Ship strikes are among the major threats to large whales worldwide. Therefore, the potential impact of increasing vessel traffic is a concern regarding the future of the Brazilian humpback whale *Megaptera novaeangliae* population. Aiming to evaluate the risk of collision between large vessels and humpback whales in the Abrolhos Bank – the most important breeding and calving ground for the species in the Southwestern Atlantic Ocean - we used commercial vessels as platforms of opportunity to monitor their route from southern Bahia to Espírito Santo. Humpback whale density was estimated through multiple covariate line-transect Distance Sampling. Thereafter, maximum possible collision rates were estimated using a simple two dimensional model based on vessel size and track lengths, plus whale size, population density and mean surface time. Monitoring was carried out during the 2003-2005 and 2011 breeding seasons, we sampled almost 12,000 n.miles and sighted 1,456 groups. The shipping route Belmonte – Barra do Riacho, which used to pass by high concentrations of humpback whales, was suspended shortly after monitoring and replaced by another route closer to the shoreline. The encounter rate on the former route was about 4 times higher than the encounter rate on the coastal route. During the peak of the 2011 breeding season, whale density on the route along the stretch Belmonte – Caravelas was estimated to be 0.085 whales/km^2 and along the stretch Caravelas – Barra do Riacho, 0.023 whales/km^2. The risk of collision between commercial vessels and humpback whales has been increasing as vessel traffic increases. Our results showed that the three commercial vessels operating along the stretch Belmonte – Barra do Riacho had the potential to collide with 25 humpback whales during the 2011 breeding season. As vessel traffic increases in the Abrolhos Bank and the humpback whale population grows, the likelihood of a vessel collision may also increase. It is important to continue this monitoring to see how whales will respond to vessel traffic over time, and to ensure that this route keeps presenting a low risk of collision, while evaluating whether additional mitigation measures are necessary, such as speed limits in areas or periods of higher density of whales.

Key words: *Megaptera novaeangliae*, distance sampling, platform of opportunity, Abrolhos Bank.

1. Introduction

The potential impact of increasing vessel traffic threatens large whales worldwide. Vessels produce loud sounds within the hearing and production range of large whales (Richardson et al., 1995) that can mask important aspects of their communication and disrupt their behavior, raising concerns about the potential influence of noise on reproductive success and population growth (Sousa-Lima and Clark, 2009). Animals may alter their patterns of habitat use (Cartwright et al., 2012), abandoning temporarily or permanently previously favored areas in response to increasing traffic or vessel activity (Bryant et al., 1984). This problem may ultimately lead to habitat degradation and loss. The health and lives of whales may also be threatened by ship strikes, leading to direct impacts on population parameters. Several reports provided summations of records of ship strikes involving large whales (Laist et al., 2001; Jensen and Silber, 2003; Van Waerebeek et al., 2007; Van Waerebeek and Leaper, 2008), however many ship strikes likely go undetected or unreported. Cetacean carcasses do not necessarily strand along coastlines or remain afloat long enough to be detected at sea. Actually, recovered carcasses are expected to represent a small fraction of cetacean deaths (Williams et al., 2011).

Vulnerability to ship strikes may vary among cetacean species. The most frequently reported victims of vessel strikes are fin (*Balaenoptera physalus*), humpback (*Megaptera novaeangliae*), right (*Eubalaena glacialis* and *E. australis*) and sperm whales (*Physeter macrocephalus*) (Laist et al., 2001; Jensen and Silber, 2003; Van Waerebeek et al., 2007; Van Waerebeek and Leaper, 2008). The occurrence and severity of ship strike to the whale population in a number of regions around the world has made strike threat an emerging conservation issue, particularly in those places where extensive vessel traffic and high whale density occurs (Vanderlaan et al., 2008; Wiley et al., 2011; Silber et al., 2012). For some endangered species, such as the North Atlantic right whale, vessel strikes are an impediment to the recovery of the species (Kraus et al., 2005; Fujiwara and Caswell, 2001). Mortality has increased, especially among breeding females, causing declines in population growth rate, life expectancy and the mean lifetime number of reproductive events (Fujiwara and Caswell, 2001). In this particular case, the use of coastal critical habitats by these whales, its depleted population status and the intense ship traffic in the North Atlantic lead to dramatic population consequences, threatening the persistence of this species.

The implementation of new shipping routes passing by the Abrolhos Bank, eastern Brazil – the main breeding and calving ground for humpback whales in the Southwestern Atlantic Ocean (Andriolo et al., 2010) – has led to concerns regarding the conservation of this population (breeding stock ‘A’, according to IWC, 1998, 2005). Humpback whale distribution along the Brazilian coast ranges from the States of Rio Grande do Norte to Rio de Janeiro (5° to 24° S), but their main concentration is in the shallow waters of the Abrolhos Bank, where groups containing female-calf pairs are the most frequent (Martins et al., 2001; Morete et al., 2007). Abundance of this stock was estimated from aerial survey to be 9,330 whales in 2008 (CI 95% = 4,857 – 20,299; Wedekin, 2011), and it has been increasing (Andriolo et al., 2010; Ward et al., 2011; Wedekin, 2011). Some photographically identified individuals were observed using the Abrolhos Bank for longer than 10 years, up to a maximum of 16 years, suggesting long term site fidelity (Wedekin et al., 2010). Different whales show distinct movement rates; some were observed using a large extent of the Abrolhos Bank region (Zerbini et al., 2006; Wedekin et al., 2010). Long-range movements within (>600 km) and between breeding seasons (>1,400 km) and genetic analysis suggest that one single breeding stock of humpback whales winters off the Brazilian coast (Wedekin et al., 2010; Cypriano-Souza et al., 2010).

In this study, we monitored these new coastal shipping routes aiming to evaluate the impact of vessel traffic by (1) estimating humpback whale density, using the line-transect distance sampling methodology; and (2) estimating potential collision rates along each vessel route.

2. Materials and methods

2.1 Study area

The study area encompasses the enlargement of the continental shelf on the east coast of Brazil, from Belmonte (Southern Bahia State) to Barra do Riacho (Espírito Santo State), including the Royal Charlotte Bank and the Abrolhos Bank (Fig. 1). Five small volcanic islands form the Abrolhos Archipelago, located 30 n. miles offshore. The area is a mosaic of coral reefs, mud and calcareous algae bottoms with warm (winter average temperature= 24^{o}C) and shallow (average depth= 30 m) waters.

In 2003, two shipping routes were implemented in the area for transporting eucalyptus logs and bleached eucalyptus pulp. The route Belmonte - Barra do Riacho, passing east of the Abrolhos Archipelago (Route 1), was established without any previous study on cetacean distribution, based only in navigation priorities. While the route Caravelas - Barra do Riacho (Route 2) was established based on humpback whale distribution and density data obtained from three years of aerial surveys (Andriolo et al., 2006, 2010). Route 1 was suspended in 2003 and replaced in 2005 by another one closer to the shoreline (Route 3). Routes 2 and 3 have been used to date. These commercial vessels are about 150 m long and travel at an average speed of 10-12 knots. Nowadays, there are three vessels operating 24 h a day, all year round. The trip Caravelas – Barra do Riacho lasts 12 h (Route 2) and the trip Belmonte – Barra do Riacho (Route 3) lasts 24 h.

2.2 Data collection

2.2.1 Surveys

Surveys were conducted aboard commercial vessels, which were used as platforms of opportunity for humpback whale observation, during the 2003, 2004, 2005 and 2011 breeding seasons. Route 1 was monitored in 2003; route 2 in 2003, 2004 and 2005; and route 3 in 2011 (Fig. 1). Data were collected following the line-transect distance sampling methodology (Buckland et al., 2001).

2.2.2 Effort

Although surveys were non-systematic, searching effort followed strict protocols while vessels were in transit during daylight. From 2003 to 2005, two trained observers, one on port and the other on starboard, scanned with 7 x 50 Tasco binoculars and the naked eye from about 10^{o} on the other side of the ship's bow to 90^{o} on their side. Positions were switched every 30 min, to avoid observation addictions. For the 2011 survey, due to limited space on the vessel, a single observer scanned about 120^{o} centered on the bow for 2 h followed by a 30 min rest period. Observers spent the majority of their time searching forward and near the line to ensure that animals on the transect line were detected with certainty (g(0) = 1) and to detect animals prior to any movement in response to the survey platform. Each sampling period was considered a transect line. A handheld GPS unit was used for recording position and length of transects.

At the beginning of each line transect and whenever conditions changed, factors that could affect sighting conditions were recorded: sun glare, cloud cover, Beaufort sea state, and a subjective visibility code (bad, moderate, good and excellent). Searching effort was carried out only under good conditions, that is, it was suspended during rainy days, Beaufort 5 or higher and/or when sighting conditions were considered poor by the observers.

2.2.3 Sightings

Data were collected from the highest accessible point of the vessels used in this study, ranging from 12 to 14 m above the sea. For each humpback whale group sighted we recorded: time, location, vessel's true heading, number of reticules (marks on binocular lenses that provide an estimate of the declination angle) from the horizon to the sighting, bearing to the sighting (recorded to the nearest degree using an angle board), cluster size, presence of calf, sighting cue (e.g. blow, breach) and observer identification.

Radial distance to each sighting was calculated from binocular reticle readings and platform height, taking into account the curvature of the earth (Lerczak and Hobbs, 1998, erratum). The location of each whale group was then estimated from the bearing and radial distance to the sighting and the ship's true heading at the moment of the sighting.

2.3 Analysis

2.3.1 Density estimates

Data analysis was undertaken using the software DISTANCE 6.0 (Thomas et al., 2010). Each survey was analyzed separately. Both Conventional Distance Sampling (CDS) and Multiple Covariate Distance Sampling (MCDS) approaches were used (Buckland et al., 2001, 2004; Marques and Buckland, 2003). MCDS incorporates covariates into the estimation of detection probability (Marques and Buckland, 2003).

Perpendicular distance data (calculated from the radial distance and the bearing to the sightings) were plotted as histograms and a suitable truncation distance, w, was selected. Size bias regression indicated that expected cluster size was not significantly different than mean cluster size ($p<0.15$). Thus, the mean cluster size was used for analyses and a different truncation distance, w', where $g(w')$ was in the range 0.6 - 0.8, was selected for estimating it (Buckland et al., 2001). A range of appropriate models of the detection function was fitted to the perpendicular distance data, grouped in distance intervals if necessary.

Stratification was carried out by time in the 2003, 2004 and 2005 surveys: (a) beginning of the breeding season: from July to mid-August; (b) peak: from mid-August to September (Martins et al., 2001; Morete et al., 2007); and (c) end: from October to mid-November. For the 2011 survey (Route 3), stratification was carried out by geographic region (northern portion: from Belmonte to Caravelas, and southern portion: from Caravelas to Barra do Riacho, which overlaps with Route 2) and the 'Data Filter' was used to select and analyze separately each time period, since the software supports only one level of stratification. The overall estimate of density was obtained as the mean of the stratum-specific estimates, weighted by the respective effort.

In the CDS approach, density $\hat{D}$ in the survey region was estimated as:

$$\hat{D} = \frac{n\,\hat{E}[s]\hat{f}(0)}{2L}$$

where n is the number of detected clusters (groups), $\hat{f}(0)$ is the estimated probability density function of the observed perpendicular distances evaluated at zero distance, $\hat{E}[s]$ is the estimated mean size of clusters in the study area, and L is the total length of the transect lines surveyed.

For some surveys, covariates were available and included in the analysis, such as: sun glare, cloud cover, sea state, visibility, sighting cue and observer identification. In the MCDS approach, density $\widehat{D}$ is estimated by the Horvitz-Thompson-like estimator:

$$\widehat{D}_{HT} = \sum_{i=1}^{n} \frac{si\ .\hat{f}i(0|zi)}{2L}$$

where *si* denotes the size of the *i*th detected cluster, $\hat{f}i(0|zi)$ is the estimated multivariate conditional probability density function of the observed perpendicular distances evaluated at zero distance given covariates *z* for the *i*th detected cluster, and *L* is the total length of the transect lines surveyed.

Density variance and confidence intervals were estimated by non-parametric bootstrap resampling, generating 999 resamples by sampling with replacement from the lines within the strata, so that independence between the lines was assumed.

The best model was selected by the Akaike Information Criterion (AIC), which provides a measure of model fit with a penalty term for the number of parameters in the model (Burnham and Anderson, 2002), and its adequacy was assessed using the chi-squared goodness of fit test.

2.3.2 Collision risk

Maximum possible collision rates were estimated by a simple two-dimensional model (Tregenza et al., 2000) that assumes:

1. The body of the whale can be represented on the sea surface as a line of the same length of the whale
2. The whale's orientation relative to the direction of travel of the vessel is random.
3. The whale does not tend to move into or out of the vessel's path.
4. Vessels do not avoid whales.

Parameters required for quantifying the number of cetaceans at risk from a specific vessel:

L whale length, m
T percentage of whale time at the surface
W damaging width of the vessel, taken as the waterline width, m
P whale density as animals per sq. km in the survey area
D length of shipping route, km
Y trips by the vessel each breeding season

A vessel will sweep a strip of sea as wide as the vessel, putting at risk all whales whose centers lie within that strip. In addition, the vessel may strike whales whose centers lie outside the strip defined by the width of the vessel. If whales are randomly orientated, they will present to the approaching vessel an average 'target size' of 0.64 * whale's length (0.64 being the mean value of cosines 0-90deg). Half of this may be added to each side of the strip defined by the width of the vessel to give a 'collision strip width'. From the length of the shipping route, a 'collision area' for each vessel trip can then be derived – (W + 0.64L) *D/1000 sq km. The mean number of whales in the collision area and at the surface will be T*P giving a total for annual collision risk of:

$$(W + 0.64L) * D * T * P * Y / 1000$$

The free program Collision.exe, a Windows 95 version of this calculator can be downloaded from http://www.chelonia.co.uk.

We have used the value of 14m for humpback whales length (Clapham and Mead, 1999). The fraction of time spent at or near the surface used is 30% (Bezamat et al. in prep). The hull of these commercial vessels is 20m wide. The shipping route Belmonte – Barra do Riacho, close to the shoreline (Route 3), is 487 km long and the route Caravelas – Barra do Riacho (Route 2) is 257.5 km long. Number of trips varied among years for each vessel. Risk of collision was calculated for each shipping route using densities estimated for the beginning, peak and end of each breeding season separately, as well as for northern and southern portions of route 3, and then combined. Collision risk for route 2 in 2011 was calculated based on the density estimated for the southern portion of route 3.

3. Results

3.1 Effort and sightings

Throughout the study we sampled 11,876.20 n.miles along shipping routes in the Abrolhos Bank and Royal Charlotte. During the 2003-2005 and 2011 breeding seasons we sighted 1,456 humpback whale groups: 2,441 individuals, including 243 calves. Effort and number of humpback whale sightings are summarized in Table 1.

The shipping route Belmonte - Barra do Riacho passing east of the Abrolhos Archipelago (Route 1) was effectively monitored for just four days in September 2003. This route was not fully sampled. Due to limited time of the observers abord the vessel, we could not sample part of the northern portion of the route, between Caravelas and Belmonte. Thus, the largest number of humpback whale sightings was in the central area of the Abrolhos Bank, from the surroundings of the Abrolhos Marine National Park to the south of the Bank (Fig. 1). Encounter rate (n/L) was high, 0.991, but humpback whale density along the route could not be estimated. This route was suspended shortly after the monitoring.

Along route 2, Caravelas – Barra do Riacho, whale distribution varied over time, but they were concentrated mainly between latitudes 18^o and 19^{o}S (Figs. 2, 3, 4). Along route 3, Belmonte – Barra do Riacho, we sighted more humpbacks on its northern portion (between Belmonte and Caravelas) than on its southern portion (between Caravelas and Barra do Riacho) (Fig. 5).

Table 1. Survey period, effort and number of humpback whale sightings for each shipping route monitoring in the Brazilian breeding ground. Route 1: Belmonte – Barra do Riacho passing east of the Abrolhos Archipelago; Route 2: Caravelas – Barra do Riacho; Route 3: Belmonte – Barra do Riacho, coastal route.

Year	Route	Survey period	Line transects	Effort (n.miles)	Sightings	Individuals	Calves
2003	1	18 Sep – 29 Sep	7	250.26	248	340	10
2003	2	18 July – 15 Nov	126	4,439.46	316	500	49
2004	2	03 July – 14 Nov	94	2,558.25	238	460	93
2005	2	01 Aug – 15 Nov	64	1,828.99	203	353	43
2011	3	29 Aug – 13 Nov	141	2,799.24	451	788	48

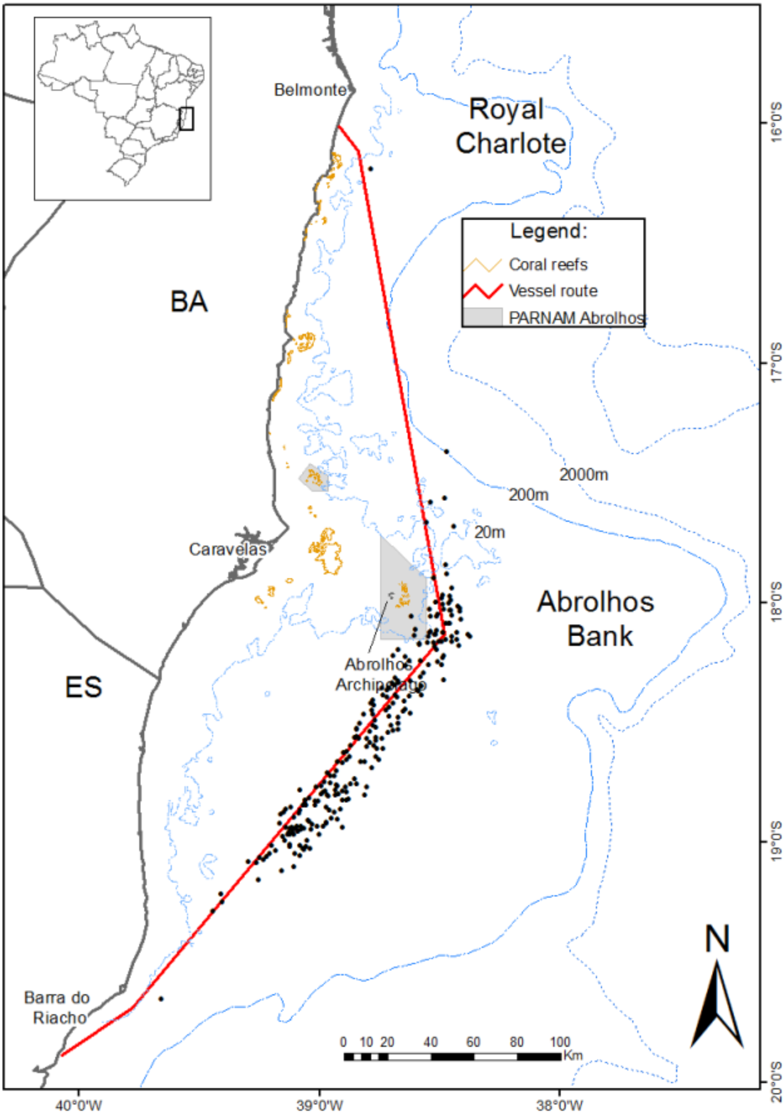

Figure 1. Humpback whale sightings (•) along Route 1 in 2003.

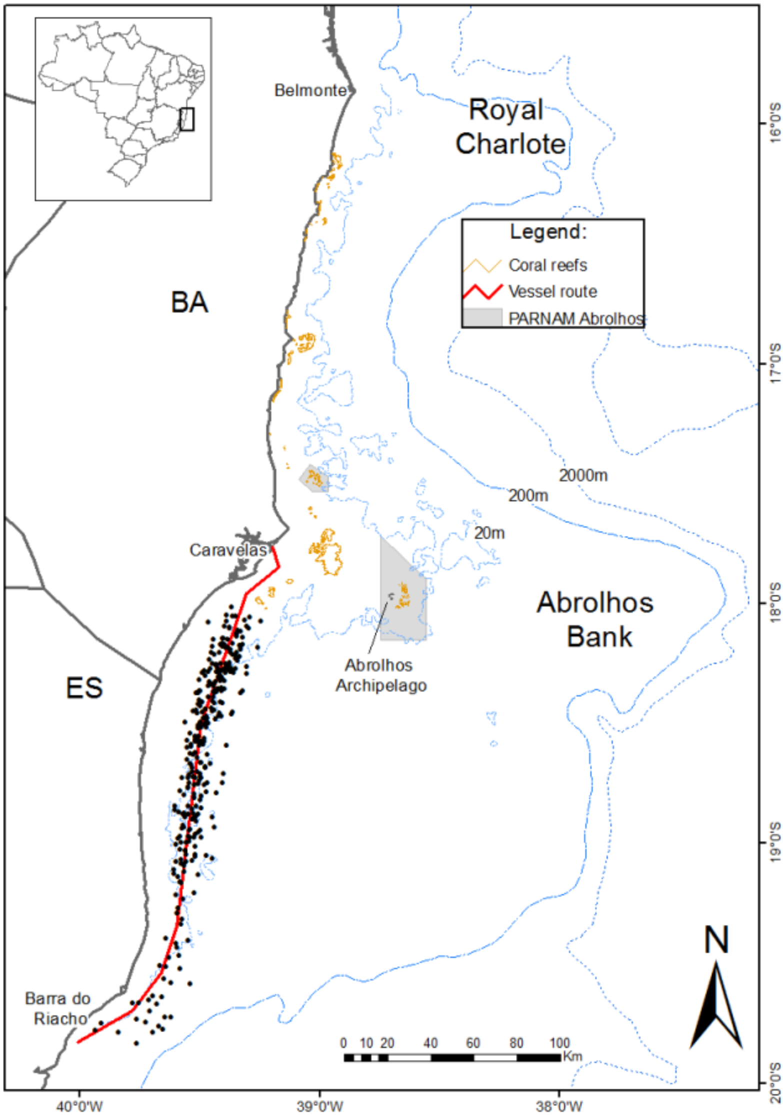

Figure 2. Humpback whale sightings (•) along Route 2 in 2003.

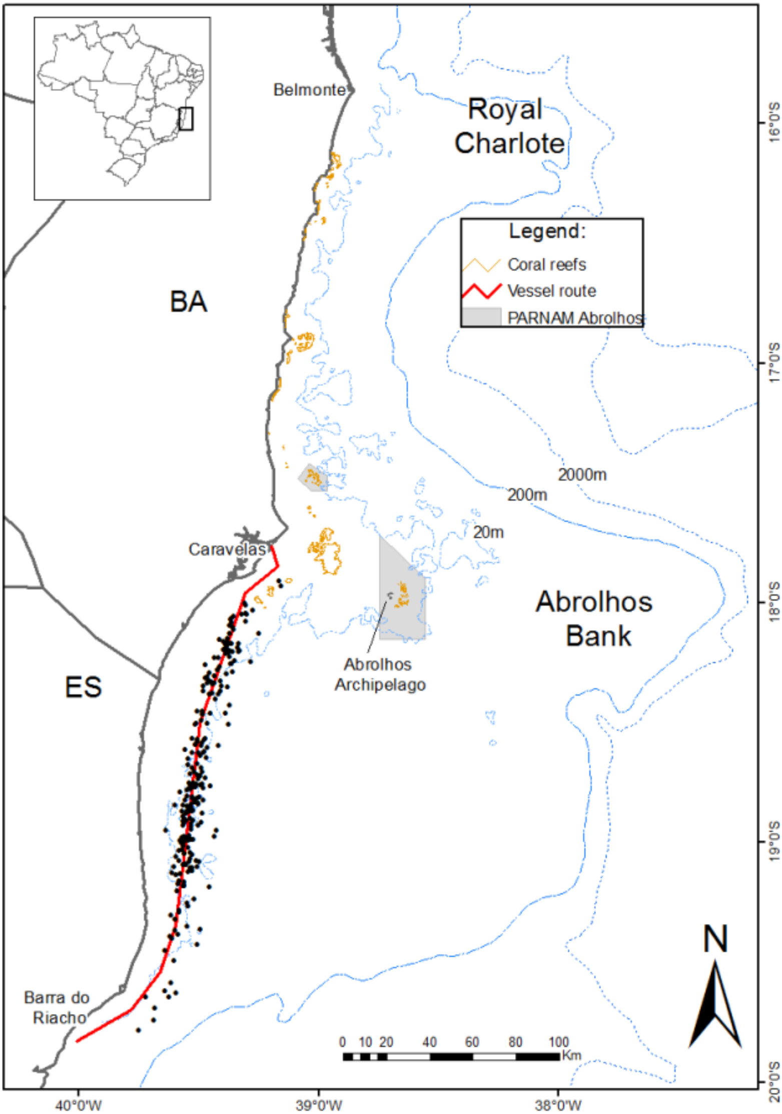

Figure 3. Humpback whale sightings (•) along Route 2 in 2004.

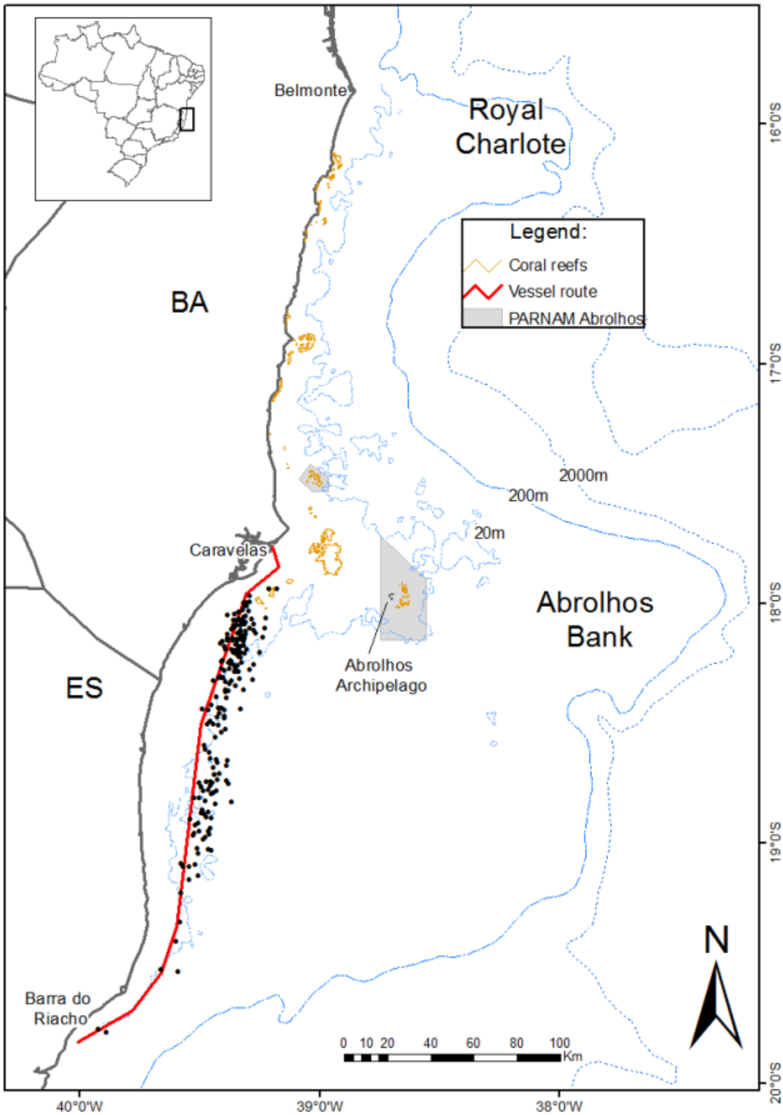

Figure 4. Humpback whale sightings (•) along Route 2 in 2005.

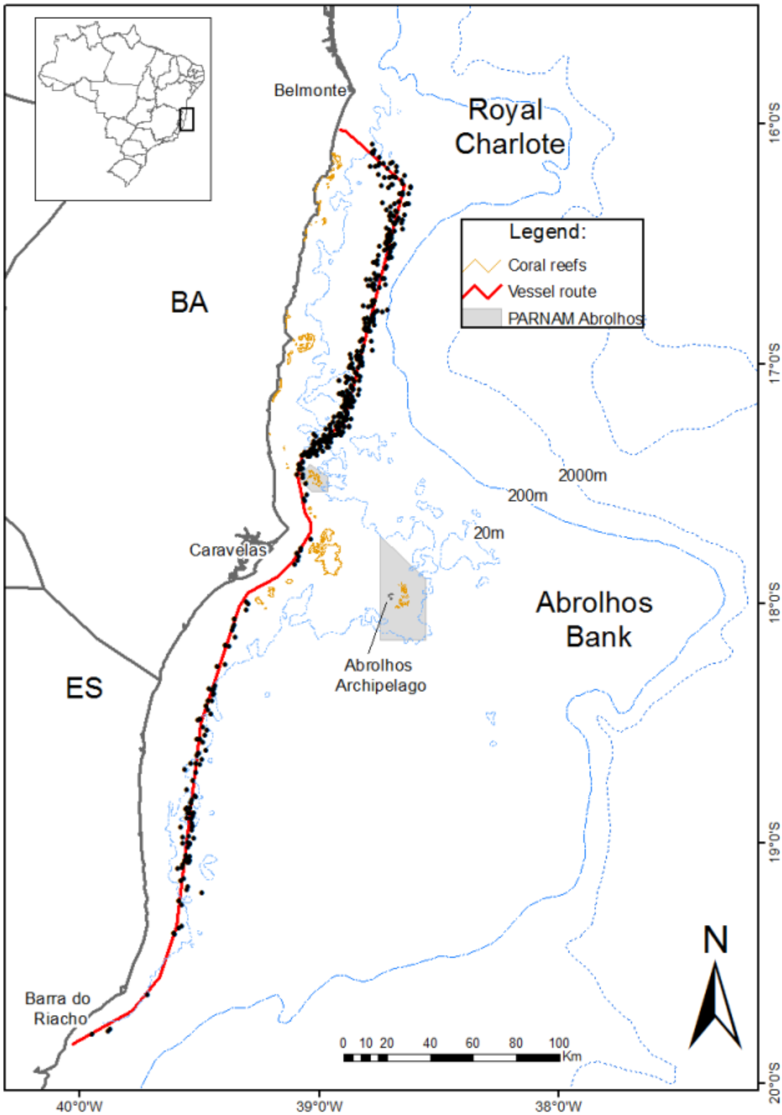

Figure 5. Humpback whale sightings (•) along Route 3 in 2011.

3.2 Density estimates

3.2.1 Route 2

The route Caravelas - Barra do Riacho was monitored for three years in a row, from 2003 to 2005. Surveys were analyzed separately. Truncation distance and the best fit model were chosen based on distance data (Table 2). Fig. 6 (a, b, c) presents the distribution of perpendicular distances and fitted detection functions. The 2003 survey was the only one whose data were grouped into distance intervals. Covariates 'visibility' and 'observer' influenced the scale of the detection function in 2005, affecting the rate at which detectability decreases with distance (Fig. 7). This rate increases as sighting conditions are less favorable; in more favorable conditions, more animals were detected further from the vessel. Observer 'B' detected only animals closer to the vessel, while the other observers detected animals at greater distances and showed similar curves.

Humpback whale density along this route was estimated to be 0.008; 0.017 and 0.018 whales/km^2 during the peak of the 2003, 2004 and 2005 breeding seasons, respectively (Table 3). Encounter rate, for the same period, was 0.081; 0.127 and 0.202, in 2003, 2004 and 2005, respectively. Table 3 shows density estimates and encounter rates for each time period (beginning, peak and end of breeding season) and each breeding season (pooled data).

Table 2. Truncation distance (*w*), selected model, probability for chi-square goodness-of-fit (GOF Chi-p) and effective strip half-width (*esw*) for each survey on the Caravelas – Barra do Riacho shipping route. CV: coefficient of variation; CI: confidence interval.

Year	*w* (n.miles)	Best fit model			GOF Chi-p	*esw* (n.miles)	%CV	95%CI
		Key function	Adjustment	Covariates				
2003	3.75	Uniform	Cosine	-	0.869	2.38	4.84	2.17 – 2.62
2004	4.50	Half-normal	-	-	0.856	2.14	5.07	1.94 – 2.36
2005	6.00	Half-normal	-	Visibility + Observer	0.336	2.71	5.67	2.42 – 3.03

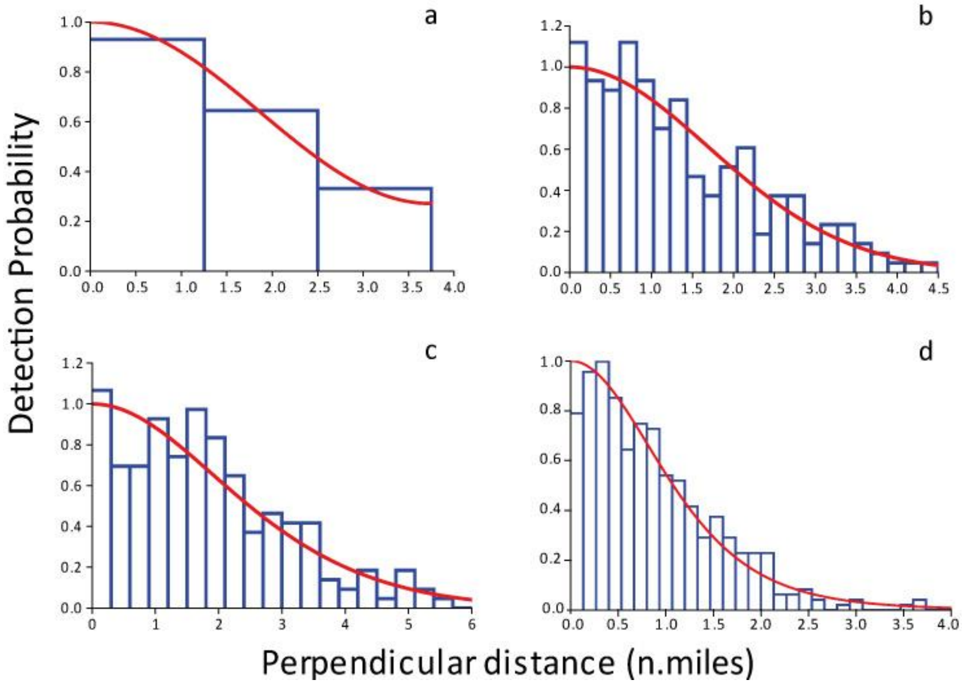

Figure 6. Distribution of perpendicular distances to humpback whale sightings on the shipping route Caravelas – Barra do Riacho in (a) 2003, (b) 2004 and (c) 2005, and (d) Belmonte – Barra do Riacho in 2011. The continuous curves represent the best fit detection functions.

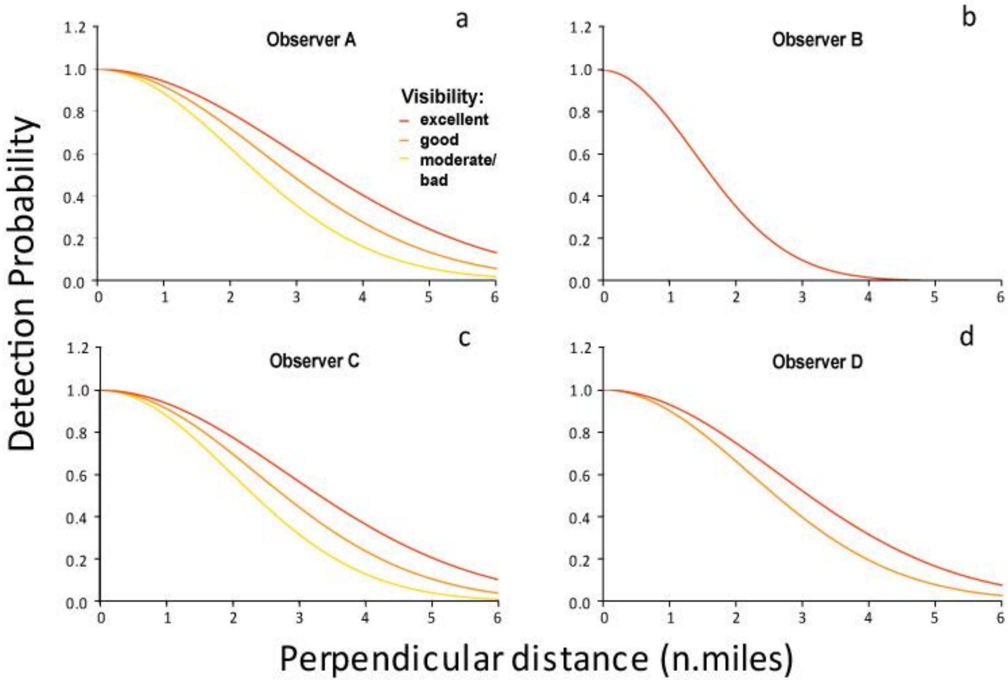

Figure 7. Influence of the covariates 'Visibility' and 'Observer' in the scale of the detection function of the 2005 survey on the shipping route Caravelas – Barra do Riacho.

Table 3. Humpback whale density estimates and encounter rates on the shipping route Caravelas - Barra do Riacho during beginning, peak and end of the 2003, 2004 and 2005 breeding seasons. DS: estimate of density of clusters (no. of clusters km^{-2}); D: estimate of density of animals (no. of animals km^{-2}); n/L: encounter rate (no. of sightings per total line length); CV: coefficient of variation; CI: confidence interval.

Year	Period	Density	Estimate	%CV	95% CI	n/L	%CV	95%CI
2003	Beginning	DS	0.002	20.49	0.001 – 0.003	0.039	19.78	0.026 – 0.059
		D	0.004	21.24	0.002 – 0.006			
	Peak	DS	0.005	24.05	0.003 – 0.007	0.081	20.89	0.053 – 0.122
		D	0.008	23.79	0.005 – 0.013			
	End	DS	0.004	25.41	0.002 – 0.007	0.072	24.12	0.045 – 0.116
		D	0.007	25.26	0.004 – 0.012			
	Pooled	DS	0.004	16.51	0.003 – 0.005			
		D	0.007	16.38	0.005 – 0.009			
2004	Beginning	DS	0.002	28.84	0.001 – 0.003	0.030	26.93	0.017 – 0.052
		D	0.004	28.89	0.002 – 0.006			
	Peak	DS	0.009	15.88	0.006 – 0.012	0.127	12.40	0.099 – 0.163
		D	0.017	18.20	0.012 – 0.024			
	End	DS	0.003	23.44	0.002 – 0.005	0.048	22.98	0.030 – 0.077
		D	0.006	24.24	0.003 – 0.009			
	Pooled	DS	0.005	13.18	0.004 – 0.006			
		D	0.009	15.23	0.007 – 0.012			

Year	Period	Density	Estimate	%CV	95% CI	n/L	%CV	95%CI
2005	Beginning	DS	0.009	26.33	0.005 – 0.014	0.174	25.02	0.102 – 0.298
		D	0.016	28.51	0.008 – 0.026			
	Peak	DS	0.010	25.22	0.005 – 0.016	0.202	26.75	0.115 – 0.356
		D	0.018	24.23	0.010 – 0.027			
	End	DS	0.002	23.49	0.001 – 0.002	0.031	23.04	0.020 – 0.050
		D	0.003	24.76	0.002 – 0.004			
	Pooled	DS	0.005	15.92	0.004 – 0.007			
		D	0.010	16.65	0.007 – 0.013			

3.2.2 Route 3

The current route Belmonte – Barra do Riacho, closer to the shoreline, was monitored in 2011. Perpendicular sighting distances were truncated at 4 n.miles. The model that fitted the resulting data best was the half-normal with no adjustment, and inclusion of the covariates: ‘sighting cue’; ‘observer’ and ‘visibility’ (Chi-sq GOF test p=0.480) (Fig. 8). The covariate ‘visibility’ influenced the detection function in the same way as previously described, with more animals being detected at greater distances when sighting conditions were more favorable. Observer ‘A’ detected animals at distances greater than observer ‘B’. ‘Sighting cue’ also affected the rate at which detectability decreases with distance: this rate was higher when the sighting cue was ‘body’, then ‘blow’ and finally ‘aerial behavior’. Effective strip half-width (*esw*) was estimated to be 1.23 n.miles (CV= 4.23%; 95%CI= 1.13 – 1.33). Mean cluster size was estimated to be 1.81 (CV= 3.43%; 95%CI= 1.69 – 1.92), discarding all observations beyond 1 n.mile.

Humpback whale density estimates for the entire route, and also for the northern and southern portions separately, are presented in Table 4, as well as encounter rates. Density estimates on the northern portion were more than three times higher than density on the southern portion. Encounter rate during the peak of the season was 0.264 on this route; almost four times lower than the encounter rate on the former route Belmonte – Barra do Riacho that used to pass east of the Abrolhos Archipelago, in September 2003.

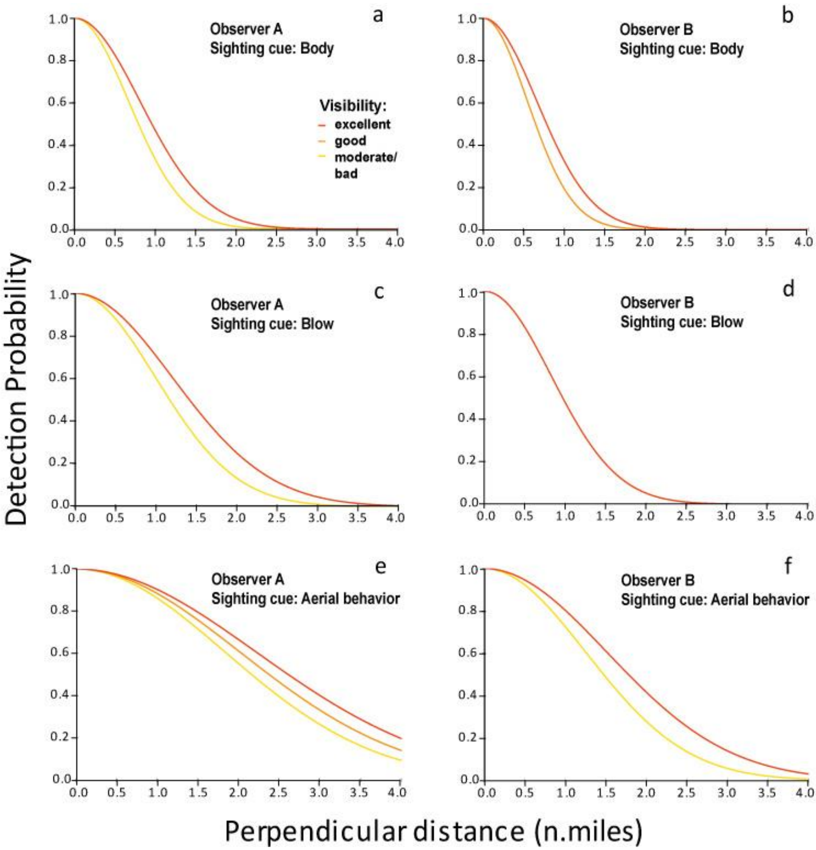

Figure 8. Influence of the covariates 'Sighting cue', 'Observer' and 'Visibility' in the scale of the detection function of the 2011 survey on the shipping route Belmonte – Barra do Riacho.

Table 4. Humpback whale density estimates and encounter rates on the shipping route Belmonte - Barra do Riacho, stratified in northern and southern portions, during peak and end of the 2011 breeding season. DS: estimate of density of clusters (no. of clusters km^{-2}); D: estimate of density of animals (no. of animals km^{-2}); n/L: encounter rate (no. of sightings per total line length); CV: coefficient of variation; CI: confidence interval.

Time	Portion	Density	Estimate	%CV	95%CI	n/L	%CV	95%CI
Peak	Northern	DS	0.047	11.51	0.037 – 0.058	0.425	11.51	0.337 – 0.537
		D	0.085	11.91	0.065 – 0.104			
	Southern	DS	0.013	21.93	0.007 – 0.018	0.113	21.96	0.073 – 0.176
		D	0.023	21.70	0.014 – 0.033			
	Pooled	DS	0.029	10.00	0.023 – 0.035	0.264	12.20	0.207 – 0.336
		D	0.053	10.42	0.042 – 0.063			
End	Northern	DS	0.016	22.92	0.009 – 0.023	0.099	18.31	0.068 – 0.143
		D	0.028	23.99	0.016 – 0.042			
	Southern	DS	0.005	28.63	0.002 – 0.008	0.031	25.51	0.019 – 0.051
		D	0.009	29.24	0.004 – 0.014			
	Pooled	DS	0.010	20.21	0.006 – 0.014			
		D	0.018	21.25	0.011 – 0.026			
Pooled	Pooled	DS	0.019	10.53	0.015 – 0.023			
		D	0.034	11.01	0.026 – 0.041			

3.3 Collision risk

We could not estimate the collision risk along the route Belmonte – Barra do Riacho, passing east of the Abrolhos Archipelago (route 1), due to lack of the whale density estimate. In 2005, this route was replaced by route 3, closer to the shoreline, and another vessel started operating on the route Caravelas – Barra do Riacho (route 2). The number of trips increased each year and so did the collision risk (Table 5). Collision risk along route 2 in 2011 was estimated to be four times higher than the collision risk in 2003. The collision risk is higher on the stretch Caravelas – Barra do Riacho than on the stretch Belmonte – Caravelas due to more intense vessel traffic, although density of whales is lower. The three commercial vessels operating in 2011, on routes 2 and 3, had the potential to collide with at least 20 humpback whales (this estimate lacks the collision risk for the beginning of the season, which we did not monitor and therefore do not have density estimates for). If we consider the beginning of the season similar to the end, in numbers of whales, the model gives 25 whales at risk of being struck by one of these commercial vessels in the Abrolhos Bank. With respect to density estimates confidence ranges, the model gives between 14 and 35 whales at risk of being struck in the 2011 breeding season.

Table 5. Collision risk per time period during each breeding season according to the number of vessels operating in each route, and the number of trips they made. NA: non-available; *: lacks the risk for the beginning of the season. Route 1: Belmonte – Barra do Riacho passing east of the Abrolhos Archipelago; Route 2: Caravelas – Barra do Riacho; Route 3: Caravelas – Barra do Riacho, coastal route.

Year	Route	Vessels	Trips	Collision risk			
				Beginning	Peak	End	Total
2003	2	1	73	0	1	1	2
2004	2	1	77	0	2	1	3
2005	2	2	116	1	3	1	5
2011	2	2	174	NA	6	2	8*
2011	3	1	59	NA	9	3	12*

4. Discussion

4.1 Collision risk

Without intervention the problem of ship strikes is expected to aggravate as already high levels of oceanic shipping continue to rise. Ship strikes could shortly constitute a major threat to whales congregating or migrating through areas of high traffic. In Brazil, maritime traffic will also have a tendency to increase in the next decades followed by large investments in port infrastructure along the whole coast.

During this study, our research group confirmed the inadequacy of the shipping route Belmonte – Barra do Riacho, passing east of the Abrolhos Archipelago, by important core areas for humpback whales (Andriolo et al., 2006, 2010; Wedekin, 2011; Martins et al., 2013), and recommended the shipping company to change it for a coastal route aiming to avoid these areas of high density of humpback whales (Dutra et al., 2012). They followed our recommendation and this coastal route, which showed an encounter rate four times lower, has been used to date. However, the risk of collision between commercial vessels and humpback whales still exists in the Abrolhos Bank and it has been increasing as vessel traffic and density of whales increase.

Annual species distribution has changed over the years, as observed from the aerial surveys between 2001 and 2008 (Dutra et al., 2012). However, although the location of high concentration areas varied over time, they did not overlap with the coastal route adopted. Humpback whale density appears to decrease with proximity to the coast (Wedekin, 2011), and this is evidence that the corridor that has been used by the coastal shipping routes is efficient in avoiding areas with higher concentration of whales.

Species with highly visible blow, such as humpback whales, might often be avoided by vessels in daylight, but not in darkness. In fact, some captains do change the path of these commercial vessels when they detect a whale off the bow, especially if there is an observer aboard to warn them about their presence. So, assuming the model's premise that "vessels do not avoid whales" we might be overestimating the risk of collision.

Assuming that "the whale does not tend to move into or out of the vessel's path" may also be a source of error. This is probably reasonable for high speed vessels or ferries because of the difficulty for a whale in estimating the track of a fast vessel even if it tried to do this and avoid it. Actually, little data are available on avoidance reactions by whales. During this monitoring, whales showed different reactions to the approaching vessel. For example, some whales which were right in the vessel's path dove shortly before the vessel pass them, and apparently it did not hit them. While other whales were swimming or resting close to the vessel's path and kept on doing that. Other whales were tailing-up (Morete et al., 2003), and dove or stayed at the surface while the vessel was passing, then went back to tailing-up.

The ability of whales to detect and avoid approaching vessels may be affected by the underwater pathways through which ship noises move. Terhune and Verboom (1999) suggest that the failure of right whales to react to vessel noise may be caused by, difficulty in locating approaching vessels due to underwater sound reflections, confusion from the sound of multiple vessels, hull blockage of engine and propeller noise in front of vessels, and the phenomenon known as the Lloyd mirror effect which reduces sound levels at the surface where resting or feeding whales may occur. The success of last-second flight responses may therefore depend in part on the swimming speed of whales relative to the speed of approaching ships. Right, bowhead, gray, humpback and sperm whales, however, are among the slowest swimming whales (Slijper, 1979).

Vessel speed is an important factor in contributing to the severity or lethality of the strike (Laist et al., 2001; Vanderlaan and Taggart, 2007). As the speed increases, the severity of injury increases. At the speed of 11.8 knots, the mean speed of the commercial vessels in this study, the chances of lethal injury are 50% (Vanderlaan and Taggart, 2007). Vanderlaan and Taggart (2007) found that the greatest rate of change in the probability of a lethal injury to a large whale occurs between vessel speeds of 8.6 and 15 knots. Across this speed range, chances of a lethal injury increase from approximately 20% at 8.6 knots to approximately 80% at 15 knots. Above 15 knots the chances asymptotically increase toward 100%.

Various whale-conservation initiatives have been designed to reduce the threat of ship strike worldwide (e.g. Silber et al., 2012, Vanderlaan et al., 2008). Where other alternatives such as vessel routing changes to avoid whale aggregation areas are not feasible, vessel speed restrictions are a meaningful management tool in reducing the threat of ship strikes to all large whale species (Laist et al., 2001; Vanderlaan and Taggart, 2007; Silber et al., 2010; Wiley et al., 2011). Eliminating or reducing the extent of vessel and whale coincidence in time and space is assured to reduce the likelihood of a vessel strike and thus it is preferable, where possible, to impose vessel-speed restrictions.

Due to the dynamic nature of habitat use by humpback whales off Brazil and population growth, it is important to continue monitoring the risk of collision along this shipping route and the whales' response to vessel traffic over time. The occasional occurrence of right whale in the area is also of great concern. The possibility of conflict of interests with artisanal fishing boats should also be considered. Fishermen have reported collisions and gear damage caused by the commercial vessels (Zambonim et al., 2009). It is also extremely important to investigate other shipping routes crossing the Abrolhos Bank and the intensity of vessel traffic in the area.

The risk of ship strike in the Abrolhos Bank should be considered since this is the main breeding and calving ground for the species in the Southwestern Atlantic Ocean (Andriolo et al., 2010). The high frequency of female-calf pairs observed in the area (Martins et al., 2001; Morete et al., 2003) could magnify the collision risk. As vessel traffic increases in the Abrolhos Bank and the humpback whale population grows, the likelihood of a vessel collision may also increase. The results of this study lead us to believe that partnerships between companies and research groups should be encouraged elsewhere. This partnership presented here provided important insights into the sustainable use and management of the Abrolhos Bank and its important natural resources.

4.2 Ship strikes: a possible explanation for the mortality of whales in the Abrolhos Bank

In the last decade, an average of 24 humpback whale strandings per year was recorded along the coast of Bahia and Espírito Santo States (Instituto Baleia Jubarte and Instituto Orca, unpubl. data), but often the cause of death could not be determined due to advanced decomposition. These carcass-recovery counts, however, are opportunistic observations of either natural or anthropogenic sources of mortality. A recent study suggests that carcasses are recovered, on average, from only 2% of cetacean deaths (Williams et al., 2011). Thus, the true death toll could be 50 times the number of carcasses recovered, given no additional information. The probability of detecting the death of a marine mammal depends on a wide range of physical and biological factors, including: behavioral responses prior to death, proximity of the carcass to the shore (or at-sea observers), decomposition rates and processes, water temperature, wind regime, and local currents (Epperly et al., 1996).

Ship strikes to humpback whales are typically identified by evidence of massive blunt trauma (fractures of heavy bones and/or hemorrhaging) in stranded whales, propeller wounds (deep slashes or cuts into the blubber) and fluke/fin amputations on stranded or live whales (e.g. Wiley et al., 1995). It should be noted that ship strikes do not always produce outward injuries and may therefore be underestimated for strandings that are not examined for internal injuries.

Evidence of collisions between vessels and humpback whales in the Brazilian breeding ground includes a live calf observed in the Abrolhos Bank in 1999 with two deep cuts near its dorsal fin, and half of its fluke's left lobe amputated. The calf's wounds appeared to be recent and were consistent with injuries caused by propellers (Marcondes and Engel, 2009). In a recent study about skeletal abnormalities in humpback whales stranded from 2002 to 2011, Groch and colleagues (2012) observed traumatic lesions in 4 animals. The presence of osseous callus was observed in the ribs of 3 whales, with evidence of fracture or fissure repair. One whale's rib showed severe osteomyelitis, possibly resulting from the infection of multiple fractures.

According to the models used in this study, the three commercial vessels operating on the coastal route Belmonte – Barra do Riacho had the potential to collide with 25 whales during the 2011 breeding season. This collision risk could be overestimated for this specific route due to model assumptions, as discussed above. However, it is definitely underestimated for the Abrolhos Bank, since we modeled the collision risk for this coastal route only, and did not take into account other routes, or other commercial vessels that also pass by the Abrolhos Bank, further from the shore, where whale density is higher. Undoubtedly, the collision risk between large vessels and humpback in the Abrolhos Bank should be much higher than we estimated here and thus, ship strikes could be the explanation for a considerable proportion of humpback whale deaths in the Brazilian breeding ground.

References

Andriolo, A., Martins, C.C.A., Engel, M.H., Pizzorno, J.L., Más-Rosa, S., Freitas, A.C., Morete, M.E., Kinas, P.G., 2006. The first aerial survey to estimate abundance of humpback whales (*Megaptera novaeangliae*) in the breeding ground off Brazil (Breeding Stock A). Journal of Cetacean Research and Management 8(3), 307-311.

Andriolo, A., Kinas, P.G., Engel, M.H., Martins, C.C.A., Rufino, A.M., 2010. Humpback whales within the Brazilian breeding ground: distribution and population size estimate. Endangered Species Research 11, 233-243.

Bryant, P.J., Lafferty, C.M., Lafferty, S.K., 1984. Reoccupation of Laguna Guerrero Negro, Baja California Sur, Mexico by gray whales, in: Jones, M. L., Swartz, S.L., Leatherwood, J.S. (Eds.), The Gray Whale, *Eschrichtius robustus*. Academic Press, Orlando, pp. 375-387.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2001. Introduction to Distance Sampling: estimating abundance of biological populations. Oxford University Press, Oxford.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2004. Advanced distance sampling: estimating abundance of biological populations. Oxford University Press, Oxford.

Burnham, K.P., Anderson, D.R. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer-Verlag, New York.

Cartwright, R., Gillespie, B., Labonte, K., Mangold, T., Venema, A., Eden, K., Sullivan, M., 2012. Between a rock and a hard place: Habitat selection in female-calf humpback whale (*Megaptera novaeangliae*) pairs on the Hawaiian breeding grounds. Plos One 7(5) e38004, 16pp.

Clapham, P.J., Mead, J.G., 1999. *Megaptera novaeangliae*. Mammalian Species 604, 1-9.

Cypriano-Souza, A.L., Fernández, G.P., Lima-Rosa, C.A.V., Engel, M.H., Bonatto, S.L., 2010. Microsatellite genetic characterization of the humpback whale (*Megaptera novaeangliae*) breeding ground off Brazil (breeding stock A). Journal of Heredity 101, 189-200.

Dawbin, W.H., 1966. The seasonal migratory cycle of humpback whales, in: Norris, K.S. (Ed.), Whales, Dolphins and Porpoises. University of California Press, Berkeley, pp 145-170.

Dutra, G.F., Moura, R.L., Engel, M.H., Martins, C.C.A., Wedekin, L.L., Neves, M.C., Paese, A., 2012. SIG na linha de frente da conservação marinha: Gestão para a conservação da região dos Abrolhos, in: Paese, A., Uezu, A., Lorini, M.L., Cunha, A. (Eds.), Conservação da Biodiversidade com SIG. Oficina de Textos, São Paulo, pp. 71-88.

Epperly, S.P., Braun, J., Chester, A.J., Cross, F.A., Merriner, J.V., Tester, P.A., Churchill, J.H., 1996. Beach strandings as an indicator of at-sea mortality of sea turtles. Bulletin of Marine Science 59 (2), 289–297.

Fujiwara M., Caswell, H., 2001. Demography of the endangered North Atlantic right whale. Nature 414, 537–541.

Groch, K.R., Marcondes, M.C.C., Colosio, A.C., Catão-Dias, J.L., 2012. Skeletal abnormalities in humpback whales *Megaptera novaeangliae* stranded in the Brazilian breeding ground. Diseases of Aquatic Organisms 101, 145-158.

IWC (International Whaling Commission), 1998. Annex G - Report of the sub-committee on comprehensive assessment of Southern Hemisphere humpback whales. Report of the International Whaling Commission 48, 170-182.

IWC (International Whaling Commission), 2005. Report of the Scientific Committee, Annex H. Report of the sub-committee on other Southern Hemisphere whale stocks. Journal of Cetacean Research and Management 7 (Suppl.), 235-246.

Jensen, A.S., Silber, G.K., 2003. Large whale ship strike database. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-OPR-25, 37pp.

Kraus, S.D., Brown, M.W., Caswell, H., Clark C.W., Fujiwara M., Hamilton, P.K., Kenney, R.D., Knowlton, A.R., Landry, S., Mayo, C.A., McLellan, W.A., Moore, M.J., Nowacek, D.P., Pabst, D.A., Read, A.J., Rolland, R.M., 2005. North Atlantic right whales in crisis. Science 309, 561–562.

Laist, D.W., Knowlton, A.R., Mead, J.G., Collet, A.S., Podesta, M., 2001. Collisions between ships and whales. Marine Mammal Science 17(1), 35-75.

Lerczak, J.A., Hobbs, R.C., 1998. Calculating sighting distances from angular readings during shipboard, aerial, and shore-based marine mammal surveys. Marine Mammal Science 14(3), 590-599.

Marcondes, M.C.C., Engel, M.H., 2009. Ship strikes with humpback whales in Brazil. Paper SC/61/BC4 presented to the IWC Scientific Committee of the 61st Annual Meeting of the International Whaling Commission, Madeira, Portugal.

Marques, F.F.C., Buckland, S.T., 2003. Incorporating covariates into standard line transect analyses. Biometrics 59, 924-935.

Martins, C.C.A., Morete, M.E., Engel, M.H., Freitas, A.C., Secchi E.R., Kinas, P.G., 2001. Aspects of habitat use patterns of humpback whales in the Abrolhos Bank, Brazil, breeding ground. Memoirs of the Queensland Museum 47, 563-570.

Martins, C.C.A., Andriolo, A., Engel, M.H., Kinas, P.G., Saito, C.H., 2013. Identifying priority areas for humpback whale conservation at Eastern Brazilian Coast. Ocean and Coastal Management 75, 63-71.

Morete, M.E., Freitas, A., Engel. M.H., Pace, R.M., Clapham. P.J., 2003. A novel behavior observed in humpback whales on wintering grounds at Abrolhos Bank (Brazil). Marine Mammal Science 19(4), 694-707.

Morete, M.E., Bisi, T.L., Rosso, S., 2007. Temporal pattern of humpback whale (*Megaptera novaeangliae*) group structure around Abrolhos Archipelago breeding region, Bahia, Brazil. Journal of the Marine Biological Association of the U.K. 87, 87-92.

Richardson, W.J., Greene, C.R., Malme, C.I., Thompson, D.H., 1995. Marine Mammals and Noise. Academic Press, New York.

Silber, G.K., Slutsky, J., Bettridge, S., 2010. Hydrodynamics of a ship/whale collision. Journal of Experimental Marine Biology and Ecology 39,110–19.

Silber, G.K., Vanderlaan, A.S.M., Arceredillo, A.T., Johnson, L., Taggart, C.T., Brown, M.W., Bettridge, S., Sagarminaga, R., 2012. The role of the International Maritime Organization in reducing vessel threat to whales: Process, options, action and effectiveness. Marine Policy 36, 1221–1233.

Slijper, E.J., 1979. Whales. Second Edition. Cornell University Press, New York.

Sousa-Lima, R., Clark, C.W., 2009. Whale sound recording technology as a tool for assessing the effects of boat noise in a Brazilian marine park. Park Science 26, 59-63.

Terhune, J.M., Verboom, W.C., 1999. Right whales and ship noises. Marine Mammal Science 15(1), 256-258.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R.B., Marques, T.A., Burnham, K.P., 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47, 5-14.

Tocchio, L.J., Marcondes, M.M, Wedekin, L.L., Le Pendu, Y., 2012. As carcaças de baleias-jubarte encontradas na costa brasileira representam a mortalidade ocorrida nos oceanos? 15ª Reunión de Trabajo de Expertos em Mamíferos Acuáticos de América del Sur y 9º Congreso SOLAMAC. Puerto Madryn, 16-20 September.

Tregenza, N., Aguilar, N., Carrillo, M., Delgado, I., Diaz, F., Brito, A., Martin, V., 2000. Potential impact of fast ferries on whale populations a simple model with examples from the Canary Islands. Proceedings of the 14th Annual Conference of the European Cetacean Society. Cork, Ireland, 2-5 April.

Van Waerebeek, K., Baker, A.N., Felix, F., Gedamke, J., Iniguez, M., Sanino, G.P., Secchi, E., Sutaria, D., van Helden, A., Wang, Y., 2007. Vessel collisions with small cetaceans worldwide and with large whales in the Southern Hemisphere, an initial assessment. The Latin American Journal of Aquatic Mammals 6(1), 43-69.

Van Waerebeek, K., Leaper, R., 2008. Second Report of the IWC Vessel Strike Standardisation Working Group. Report to the International Whaling Commission Scientific Committe 60th Annual Meeting, Santiago, Chile, June 2008. Rep. No. SC/60/BC5.

Vanderlaan, A.S.M., Taggart, C.T., 2007. Vessel collisions with whales: the probability of lethal injury based on vessel speed. Marine Mammal Science 23(1), 144-156.

Vanderlaan, A.S.M., Taggart, C.T., Serdynska, A.R., Kenney, R.D., Brown, M.W., 2008. Reducing the risk of lethal encounters: vessels and right whales in the Bay of Fundy and on the Scotian Shelf. Endangered Species Research 4, 283–297.

Vanderlaan, A.S.M., Corbett, J.J., Green, S.L., Callahan, J.A., Wang, C., Kenney, R.D., Taggart, C.T., Firestone, J., 2009. Probability and mitigation of vessel encounters with North Atlantic right whales. Endangered Species Research 6, 273–285.

Ward, E., Zerbini, A.N., Kinas, P.G., Engel, M.H., Andriolo, A., 2011. Estimates of population growth rates of humpback whales (*Megaptera novaeangliae*) in the wintering grounds off the coast of Brazil (Breeding Stock A). Journal of Cetacean Research and Management (Special Issue) 3, 145-149.

Wedekin, L.L., Neves, M.C., Marcondes, M.C.C., Baracho, C., Rossi-Santos, M.R., Engel, M.H, Simões-Lopes, P.C., 2010. Site fidelity and movements of humpback whales (*Megaptera novaeangliae*) on the Brazilian breeding ground, southwestern Atlantic. Marine Mammal Science 26(4), 787-802.

Wedekin, L.L., 2011. Ecologia populacional da baleia-jubarte (*Megaptera novaeangliae* Borowski, 1871) em sua área reprodutiva na costa do Brasil, Oceano Atlântico Sul. PhD Thesis. Universidade Federal do Paraná, Paraná. 144 pp.

Wiley, D.N., Asmutis, R.A., Pitchford, T.D., Gannon, D.P., 1995. Stranding and mortality of humpback whales, *Megaptera novaeangliae,* in the mid-Atlantic and southeast United States, 1985-1992. Fishery Bulletin 93 (1), 196-205.

Wiley, D.N., Thompson, M., Pace III, R.M., Levenson, J., 2011. Modeling speed restrictions to mitigate lethal collisions between ships and whales in the Stellwagen Bank National Marine Sanctuary, USA. Biological Conservation 144, 2377–2381.

Williams, R., Gero, S., Bejder, L., Calambokidis, J., Kraus, S.D., Lusseau, D., Read, A.J., Robbins, J., 2011. Underestimating the damage: interpreting cetacean carcass recoveries in the context of the *Deepwater Horizon*/BP incident. Conservation Letters 4, 228-233.

Zambonim, R., Wedekin, L.L., Farias, U.A. 2009. Comunidade de Pescadores de Caravelas, Sul da Bahia. Editora da Universidade Federal do Amazonas, Manaus.

Zerbini, A. N., Andriolo, A., Heide-Jorgensen, M. P., Pizzorno, J. L., Maia, Y. G., VanBlaricon, G. R., DeMaster, D. P., Simões-Lopes, P. C., Moreira, S., Bethlem, C., 2006. Satellite-monitored movements of humpback whales *Megaptera novaeangliae* in the Southwest Atlantic Ocean. Marine Ecology Progress Series 313, 295–304.

CONCLUSÕES GERAIS

A partir do monitoramento das rotas de navios-barcaça no Banco dos Abrolhos e Banco Royal Charlotte, área de reprodução de baleias jubarte, concluímos o seguinte:

1. A rota Belmonte – Barra do Riacho, passando a leste do Arquipélago dos Abrolhos, passava por altas concentrações de baleias jubarte na área central no Banco dos Abrolhos, desde os arredores do arquipélago até o sul do Banco;

2. Esta rota foi suspensa logo após o monitoramento e substituída por outra mais próxima à costa, onde a densidade de baleias jubarte é mais baixa;

3. A taxa de encontro na rota Belmonte – Barra do Riacho externa foi cerca de quatro vezes maior do que na rota costeira;

4. No pico da temporada de 2011, a densidade de baleias ao longo da rota no trecho Belmonte - Caravelas foi estimada em 0,085 baleias/km^2 e no trecho Caravelas - Barra do Riacho a estimativa foi de 0,023 baleias/km^2;

5. O risco de colisão entre os navios-barcaça e baleias jubarte existe e vem aumentando com o aumento do tráfego de embarcações, isto é, aumento do número de embarcações e de viagens por temporada;

6. Os três navios-barcaça operando no trecho entre Belmonte e Barra do Riacho tiveram o potencial de colidir com 25 baleias jubarte na temporada reprodutiva de 2011;

7. Conforme o tráfego de embarcações aumenta no Banco dos Abrolhos e a população de baleias jubarte cresce, a probabilidade de colisão também deve aumentar;

8. A continuação deste monitoramento é importante para que possamos avaliar como as baleias jubarte irão responder ao tráfego de embarcações; além disso, devemos investigar outras rotas e a intensidade do tráfego de grandes embarcações no Banco dos Abrolhos;

9. A parceria entre o nosso grupo de pesquisa e esta companhia de navegação gerou percepções importantes quanto ao uso sustentável e manejo do Banco dos Abrolhos e seus importantes recursos naturais. Parcerias como esta deveriam ser encorajadas em outros lugares.