AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS

Aquatic Conserv: Mar. Freshw. Ecosyst. (2014)

Published online in Wiley Online Library
(wileyonlinelibrary.com). DOI: 10.1002/aqc.2523

Potential ship strikes and density of humpback whales in the Abrolhos Bank breeding ground, Brazil

CAROLINA BEZAMAT[a,b,*], LEONARDO L. WEDEKIN[b,c] and PAULO C. SIMÕES-LOPES[a]

[a]*Laboratório de Mamíferos Aquáticos, Departamento de Ecologia e Zoologia, Centro Ciências Biológicas, Universidade Federal de Santa Catarina, Florianópolis, Brazil*

[b]*Instituto Baleia Jubarte, Caravelas, BA, Brazil*

[c]*Universidade de São Paulo, Instituto de Biociências, Departamento de Ecologia Geral, São Paulo, Brazil*

ABSTRACT

1. Ship strikes are one of the major threats to large whales worldwide. The potential impact from increasing vessel traffic therefore is a concern for the future of the Brazilian humpback whale (*Megaptera novaeangliae*) population.

2. In order to evaluate the risk of collision between large vessels and humpback whales along coastal shipping routes in the region of the Abrolhos Bank – the most important breeding ground for the species in the south-western Atlantic Ocean – commercial vessels were used as platforms of opportunity to monitor the coastal shipping routes.

3. Humpback whale density along coastal routes was estimated through multiple covariate line-transect 'distance sampling'. The number of potential collisions per year was estimated using a model based on vessel size and speed, track lengths, population density and the surfacing behaviour of whales.

4. During the peak of the 2011 breeding season, whale density on the coastal route between Belmonte and Caravelas was estimated to be 0.085 whales km^{-2} and between Caravelas and Barra do Riacho, 0.023 whales km^{-2}.

5. The three commercial vessels operating in coastal waters between Belmonte and Barra do Riacho had the potential to collide with 25 humpback whales in total, and kill 17 of these, during the 2011 breeding season.

6. As vessel traffic increases in the Abrolhos Bank region and humpback whale population grows, the likelihood of a vessel collision will increase.

7. A simple and effective framework to study how changes in whale density will affect their vulnerability to ship strikes, and ensure the suitability of alternative shipping routes is presented, while evaluating whether additional mitigation measures are necessary, such as speed limits in areas or periods with higher densities of whales.

Received 2 October 2013; Revised 16 June 2014; Accepted 18 August 2014

KEY WORDS: coastal; ocean; environmental impact assessment; modelling; mammals; shipping

*Correspondence to: C. Bezamat, Laboratório de Mamíferos Aquáticos, Departamento de Ecologia e Zoologia, Centro Ciências Biológicas, Universidade Federal de Santa Catarina. P.O. Box 5102, CEP 88040-970, Florianópolis, SC, Brazil. Email: carolinabezamat@gmail.com

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 disturb their behaviour, 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 favoured 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 have provided compilations of records of ship strikes involving large whales, however, many ship strikes probably go undetected or unreported (Laist *et al.*, 2001; Jensen and Silber, 2003; Van Waerebeek *et al.*, 2007; Van Waerebeek and Leaper, 2008). Cetacean carcasses do not necessarily strand along coastlines or remain afloat long enough to be detected at sea, and recovered carcasses are expected to represent only 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 (*Physeter macrocephalus*) whales (Laist *et al.*, 2001; Jensen and Silber, 2003; Van Waerebeek *et al.*, 2007; Van Waerebeek and Leaper, 2008). Higher vessel speed is an important factor in contributing to the severity of the strike (Laist *et al.*, 2001; Vanderlaan and Taggart, 2007; Conn and Silber, 2013). 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 co-occur (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 a major impediment to the recovery of the species (Fujiwara and Caswell, 2001; Kraus *et al.*, 2005). 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). The use of critical coastal habitats by these whales, its depleted population status, and the intense ship traffic led to dramatic population consequences, threatening the survival 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 south-western Atlantic Ocean (Andriolo *et al.*, 2010) – has led to concerns regarding the conservation of this population (breeding stock 'A', according to IWC, 1998, 2005). Migrating humpback whales aggregate to breed from July to November along the Brazilian coast from 5° to 24° S, but the highest density of whales was observed in the shallow waters of the Abrolhos Bank (0.137 whales km^{-2}; Andriolo *et al.*, 2010). Whale density decreases with increasing distance from the Abrolhos Bank (Andriolo *et al.*, 2010). The core density area within the Abrolhos Bank is found in the central waters of the bank, near the Abrolhos Marine National Park (Dutra *et al.*, 2012; Martins *et al.*, 2013), where groups containing female–calf pairs are the most frequent (Martins *et al.*, 2001; Morete *et al.*, 2003). Abundance of the breeding stock 'A' was estimated from an aerial survey to be 11 418 whales in 2011 (CI 95% = 10 276–12 559; Pavanato *et al.*, 2012), and it has been increasing (Andriolo *et al.*, 2010; Ward *et al.*, 2011). Some photographically identified individuals were observed using the Abrolhos Bank for up to 16 years, suggesting long-term site fidelity (Wedekin *et al.*, 2010).

In this study, the new coastal shipping routes were monitored to evaluate the impact of vessel traffic by: (1) estimating humpback whale density along the shipping routes, using the line-transect distance sampling methodology; and (2) estimating potentially fatal collisions with these vessels.

METHODS

Study area

The study area encompasses an area on the east coast of Brazil, from Belmonte (18°51′24″S–38°51′04″W) to Barra do Riacho (19°50′41″S–40°03′22″W), including the Royal Charlotte Bank and the Abrolhos Bank (Figure 1). Five small volcanic islands form the Abrolhos Archipelago, located 30 nautical miles (nm) offshore. The area is a mosaic of coral reefs, mud and calcareous algae bottoms with warm (winter average temperature = 24 °C) and shallow (average depth = 30 m) waters.

In 2003, two shipping routes were established in the area for transporting eucalyptus logs and bleached eucalyptus pulp. The Caravelas–Barra do Riacho coastal route (Route 1) was established based on humpback whale distribution and density data obtained from 3 years of aerial surveys (Andriolo *et al.*, 2006, 2010). While the Belmonte–Barra do Riacho offshore route, passing east of the Abrolhos Archipelago, was established without any previous study on cetacean distribution, based only on navigational priorities. The use of the latter was suspended in the same year and this route was replaced in 2005 by another one closer to the shoreline (Route 2). Routes 1 and 2 were the only regular shipping routes in the coastal region of the Abrolhos Bank during the study period. The vessels used on the routes are about 150 m long and travel at an average speed of 10–12 knots. Two vessels transport eucalyptus logs from Caravelas to Barra do Riacho, which takes 12 h, and one vessel transports bleached eucalyptus pulp from Belmonte to Barra do Riacho, which takes 24 h. These vessels operate 24 hours a day, all year round.

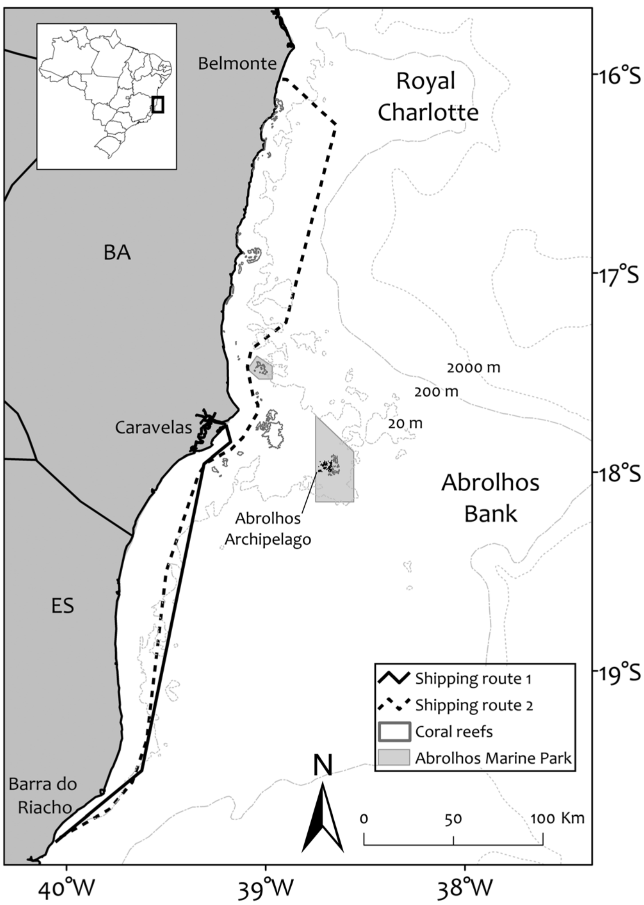

Figure 1. Coastal shipping routes in the Royal Charlotte Bank and the Abrolhos Bank, east coast of Brazil.

Data collection

Surveys were conducted aboard these 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, 2004, and 2005; and route 2 in 2011 (Figure 1). Data were collected following the line-transect distance sampling methodology (Buckland *et al.*, 2001).

Although surveys were non-systematic, search 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 × 50 reticulated binoculars and the naked eye from about 10° on the other side of the ship's bow to 90° on their side. Positions were switched every 30 min, to avoid directional or observer bias. For the 2011 survey, owing to limited space on the vessel, a single observer scanned about 120° centred 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 (i.e. trackline detection probability, g(0), was assumed to be 1), and to detect animals prior to any movement in response to the survey platform. Each uninterrupted sampling period (during daylight) was considered a transect line, with line transects ranging from 4.3 to 68.9 nm (mean = 27.4 nm). 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 periods of rain, Beaufort 5 or higher and/or when sighting conditions were considered poor by the observers.

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 the 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 were recorded.

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

Analysis

Density estimates

Data analysis was undertaken using the software DISTANCE 6.0 (Thomas *et al.*, 2010). Each survey was analysed 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 that can affect the detection probability (Marques and Buckland, 2003).

Perpendicular distance data were plotted as histograms and a suitable truncation distance, w, was selected. Size bias regression indicated that expected cluster size was not significantly different from mean cluster size ($P < 0.15$). Thus, the mean cluster size was used for analyses and a different group size truncation distance, w', where g(w') was in the range 0.6–0.8, was selected for estimating it (Buckland *et al.*, 2001). Multiple models of the detection function were 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.*, 2003); and (c) end: from October to mid-November. For the 2011 survey (Route 2), 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 1) and the 'Data Filter' was used to select and analyse 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 $\hat{D}$ is estimated by the Horvitz–Thompson-like estimator:

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

where si denotes the size of the ith 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 ith 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.

Collision risk

The number of potential ship strikes, that is, the number of whales at risk of being struck by a specific vessel, was estimated from the collision risk model developed by Tregenza *et al.* (2000). This spatial model assumes that: (i) the body of the whale can be represented on the sea surface as a line of the same length as the whale; (ii) the whale's orientation relative to the vessel's direction of travel is random; (iii) the whale does not tend to move into or out of the vessel's path; and (iv) vessels do not avoid whales.

The model was also modified by adding the probability of a strike being fatal as a function of vessel speed from a logistic regression analysis (Conn and Silber, 2013). Therefore, the estimated number of whales killed by ship strikes in a given period was given by:

$$\frac{(V+0.64W)*L*D*P*T}{1000*(1+exp^{-(-1.905+0.217S)})}$$

where V is the damaging width of the vessel, taken as the waterline width (m), W is the whale length (m), L is the length of the shipping route (km), D is the whale density in the survey area (no. of animals km^{-2}), P is the mean percentage of time that a whale spends at the surface, T is the number of trips by the vessel in a given period, and S is the vessel speed (knots).

The value of 14 m was used for humpback whale length (Clapham and Mead, 1999). The fraction of time spent at or near the surface was 30%, based on a study of blow rate developed at the Abrolhos Bank (Bezamat *et al.*, in prep). The hull of these commercial vessels was 20 m wide. The Caravelas–Barra do Riacho shipping route (Route 1) was 257.5 km long, and the Belmonte–Barra do Riacho route, close to the shoreline (Route 2), was 487 km long. Number of trips varied between years for each vessel. Estimates were made for three different vessel speeds: 12 knots (average vessel speed in this study); 10 knots (usual speed restriction); and 8.8 knots ($P_{lethal} = 50\%$, calculated from Conn and Silber's logistic regression analysis, 2013). The number of potentially fatal collisions 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 2, and then combined. Collision risk for route 1 in 2011 was calculated based on the density estimated for the southern portion of route 2.

RESULTS

Effort and sightings

During the study 11 626 nm were sampled along shipping routes in the Abrolhos and Royal Charlotte Banks. During the 2003–2005 and 2011 breeding seasons 1208 humpback whale groups were sighted comprising 2101 individuals, including 233 calves. Effort and number of humpback whale sightings are summarized in Table 1.

Along route 1, Caravelas–Barra do Riacho, whale distribution varied over time, but they were concentrated mainly between latitudes 18° and 19°S (Figure 2(a), (b), (c)). Along route 2, Belmonte–Barra do Riacho, more humpbacks were sighted in the northern portion (between Belmonte and Caravelas) than in the southern portion (between Caravelas and Barra do Riacho) (Figure 2(d)).

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

Year	Route	Survey period	Line transects	Effort (nm)	Sightings	Individuals	Calves
2003	1	18 July–15 Nov	126	4439.46	316	500	49
2004	1	03 July–14 Nov	94	2558.25	238	460	93
2005	1	01 Aug–15 Nov	64	1828.99	203	353	43
2011	2	29 Aug–13 Nov	141	2799.24	451	788	48

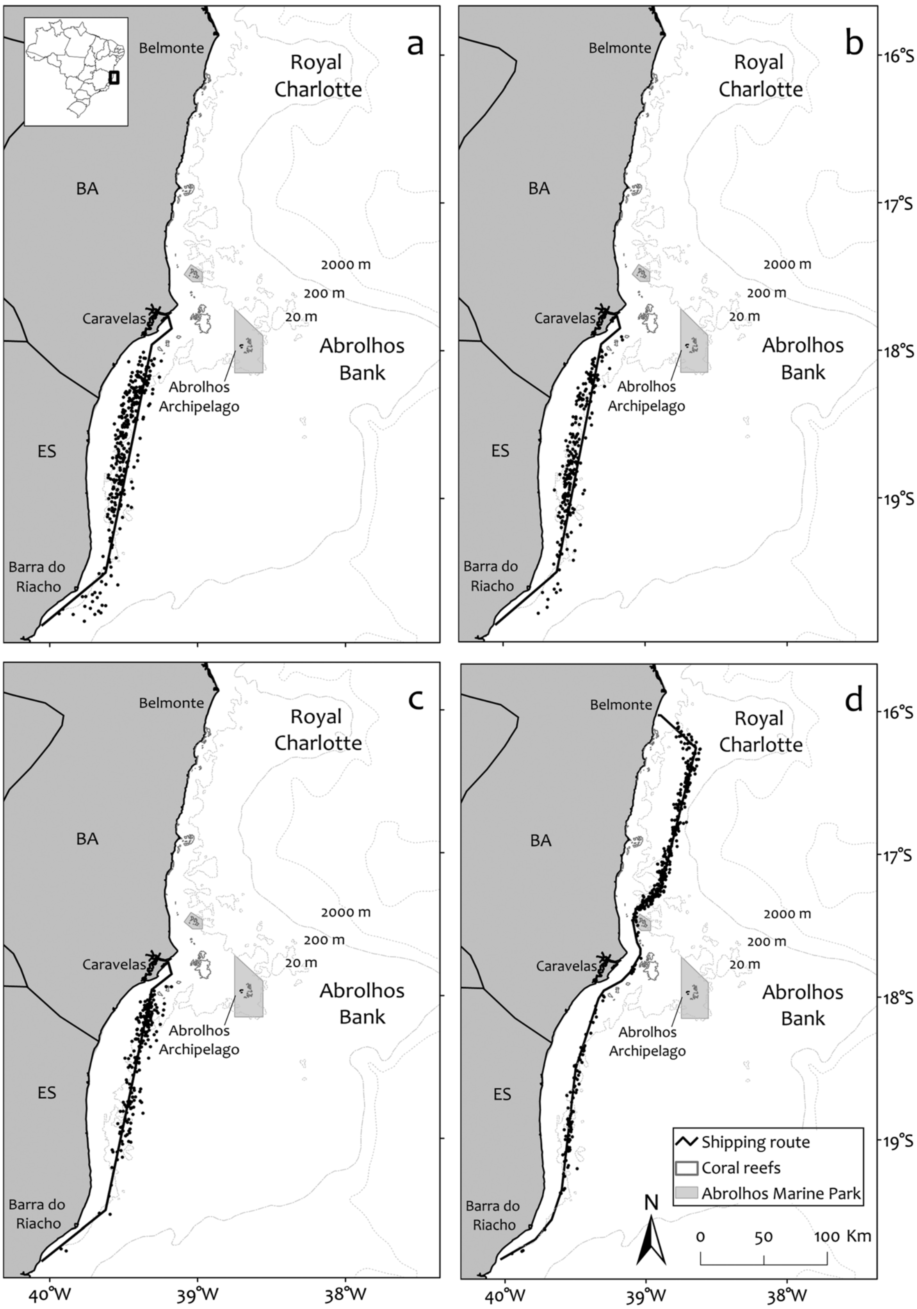

Figure 2. Humpback whale sightings (black dots) along (a) shipping route 1 in 2003, (b) 2004, (c) 2005, and (d) shipping route 2 in 2011.

Density estimates

The Caravelas–Barra do Riacho coastal route was monitored for 3 years, from 2003 to 2005. Surveys were analysed separately. Truncation distance and the best fit model were chosen based on distance data (Table 2). 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.

Humpback whale density along route 1 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 sightings nm^{-1}, 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).

The Belmonte–Barra do Riacho coastal route was monitored in 2011. Perpendicular sighting distances were truncated at 4 nm. The model that best fitted the resulting data was the half-normal with no adjustment and inclusion of the covariates: 'sighting cue', 'observer' and 'visibility' (Chi-sq GOF test P = 0.480). Effective strip half-width (esw) was estimated to be 1.23 nm (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 nm.

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 in the northern portion were more than three times higher than those in the southern portion. Encounter rate during the peak of the season was 0.264 on this route. The abundance estimate along the coastal shipping routes on the Belmonte–Barra do Riacho stretch was 382 whales (CV = 10.42%; 95%CI = 303–454), representing 3.3% of the estimated Brazilian humpback whale population (stock 'A') in 2011.

Collision risk

In 2005, the original Belmonte–Barra do Riacho offshore route was replaced by the coastal route (Route 2), and another vessel started operating on the Caravelas–Barra do Riacho route (Route 1). The number of trips increased each year as well as humpback whale density, and consequently so did the collision risk (Table 5; Figure 3).

The number of potential collisions along route 1 in 2011 was estimated to be five times higher than in 2003. The collision risk on the Caravelas–Barra do Riacho stretch (southern portion) was higher than on the Belmonte–Caravelas stretch (northern portion) owing to more intense vessel traffic, although density of whales was lower.

The three commercial vessels operating in 2011, on routes 1 and 2, had the potential to collide with at least 20 humpback whales in total (this estimate lacks the collision risk for the beginning of the season, which was not monitored). Considering the beginning of the season to be similar to the end, in numbers of whales, the model predicts 25 whales in total are at risk of being struck by any one of these commercial vessels in the Abrolhos Bank. With respect to density estimate confidence ranges, the model gives between 14 and 35 whales at risk of being struck in the 2011 breeding season.

The probability of a lethal whale strike for a vessel travelling at 12 knots, calculated from Conn

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

		Best fit model						
Year	w (nm)	Key function	Adjustment	Covariates	GOF Chi-p	esw (nm)	%CV	95%CI
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

CV: coefficient of variation; CI: confidence interval.

Table 3. Humpback whale density estimates and encounter rates on the Caravelas–Barra do Riacho shipping route during beginning, peak and end of the 2003, 2004, and 2005 breeding seasons

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			
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			

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 nm^{-1}); CV: coefficient of variation; CI: confidence interval.

and Silber's (2013) logistic regression analysis, is 67%. This resulted in an estimate of 17 humpback whales (confidence range: 10–24) being severely injured and killed by these commercial vessels during the 2011 breeding season. Chances of a lethal injury decline as vessel speed decreases but it is only at speeds below 8.8 knots that the chances of lethal injury drop below 50%.

DISCUSSION

Collision risk

Without intervention the problem of ship strikes is expected to increase 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

Table 4. Humpback whale density estimates and encounter rates on the Belmonte–Barra do Riacho shipping route, stratified in northern and southern portions, during peak and end of the 2011 breeding season

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			

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 nm^{-1}); CV: coefficient of variation; CI: confidence interval.

Table 5. Collision risk estimated for each coastal shipping route during each breeding season according to the number of vessels operating along each route, and the number of trips they made, for three different vessel speeds (probability of a lethal whale strike in brackets)

Year	Route	Vessels	Trips	Potential collisions	Potentially fatal collisions		
					12 knots (67%)	10 knots (57%)	8.8 knots (50%)
2003	1	1	73	2	2	2	1
2004	1	1	77	3	2	2	2
2005	1	2	116	5	4	3	3
2011	1	2	174	10*	7*	6*	5*
2011	2	1	59	15*	10*	9*	8*

Route 1: Caravelas–Barra do Riacho; Route 2: Belmonte–Barra do Riacho.
*Assuming that the collision risk at the beginning of the season (not sampled) is the same as at the end.

traffic. In Brazil, maritime traffic is expected to increase further in the next decades as a result of large investments in port infrastructure along the whole coast.

Parallel to this study, Andriolo *et al*. (2006, 2010) and Martins *et al*. (2013) confirmed the inappropriateness of the Belmonte–Barra do Riacho offshore shipping route, passing east of the Abrolhos Archipelago, as it is an important core area for humpback whales. As a result the shipping company changed the offshore route for a coastal route aiming to avoid these offshore areas where there is a high density of humpback whales (Dutra *et al*., 2012). Thus the coastal route, which showed an encounter rate four times lower than the original offshore route (Martins and Neves, 2004), has been used to date. However, other large vessels continue to cross the Abrolhos

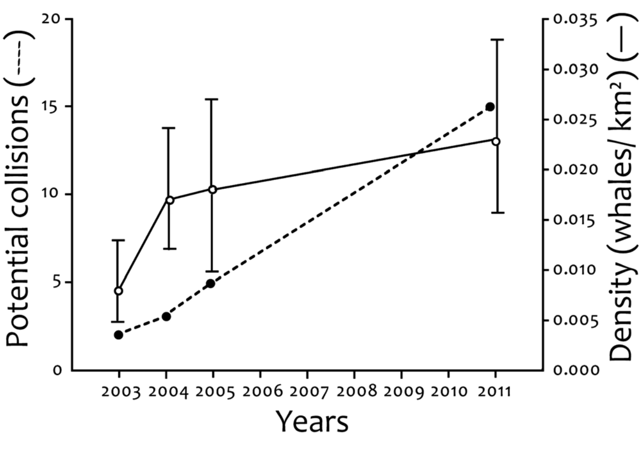

Figure 3. Estimates of potential collisions per year (black dots and dashed line) and humpback whale density at the peak of each breeding season (white dots and full line; whiskers represent 95% confidence intervals) in coastal waters on the stretch Caravelas–Barra do Riacho.

Bank, mainly from south-west to north-east, threatening whales in this important breeding ground (Martins *et al*., 2013). The collision risk persists and 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 (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 (Dutra *et al*., 2012; Martins *et al*., 2013), and this is evidence that the corridor that has been used for the coastal shipping routes is avoiding areas with the higher concentration of whales.

Various whale-conservation initiatives have been designed to reduce the threat of ship strike worldwide (Vanderlaan and Taggart, 2009; Silber *et al*., 2012; van der Hoop *et al*., 2012). Where alternatives such as shipping route 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 (Vanderlaan and Taggart, 2007; Silber *et al*., 2010; Wiley *et al*., 2011; Conn and Silber, 2013). A vessel speed reduction from 12 to 8.8 knots in the study area would decrease the probability of a strike being fatal by almost 20%. On the other hand, if one more vessel started operating on each of the two shipping routes, the collision risk in coastal waters would almost double.

However, the ship strike estimates presented here should be interpreted cautiously due to limitations of the model. Two potential biases that may overestimate the risk of ship strike are the behaviour of the vessel and the behaviour of the whales. By assuming the model's premise that 'vessels do not avoid whales' this might result in an overestimation of the collision risk. Species with a highly visible blow, such as humpback whales, might often be avoided by vessels in daylight but not during the night. In fact, during this monitoring, the captains of the vessels often changed their path when a whale was detected off the bow, although, sometimes they saw the animals near the bow but expected them to move. It is not known to what degree this avoidance behaviour by the captains was influenced by the fact that there were observers on board. Furthermore most of the time, these commercial vessels navigate on auto-pilot and captains make the most of this by carrying out other tasks on the navigation bridge, thus reducing the chances of sighting whales. Therefore, the presence of observers on board looking for whales is certainly important and probably is an effective mitigation measure.

Few data are available on avoidance reactions by whales. During this monitoring, occasionally it was possible to observe humpback whales showing different reactions to an approaching vessel, including diving shortly before the vessel reached them or remaining resting at the surface while the vessel passed nearby (Watkins, 1986). These different behaviours were not taken into account in the model and deserve further investigation. 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's mirror effect which reduces sound levels at the surface (Carey, 2009) where whales may remain while resting or feeding. 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). During this study, at least three near-collision events were witnessed opportunistically by a single observer in 2011, in which whales dived at the last moment to escape the collision. Not including this information in the model could result in overestimated collision rates for the studied shipping routes. But a late or shallow dive may not remove collision risk.

However, in terms of ship strike risk in the whole Abrolhos Bank, the results presented here probably represent just a small part of the real impact of vessel traffic. First, these were the only regular shipping routes in the coastal region of the Abrolhos Bank during the study, but other important shipping routes exist in this breeding ground, specially a large corridor that crosses the offshore waters of the Abrolhos Bank (Martins *et al.*, 2013). Thus, a much larger proportion of the population of humpback whales breeding off Brazil may be affected by ship collisions. Moreover, this collision risk assessment did not take into consideration other whale species that also occur in the area, such as the right whale. Notwithstanding the caveats described above, the proposed model is a useful decision-support tool designed to assess the impact of specific enterprises and how ship strike risk can change over time and among different areas, and with different mitigation measures (e.g. shipping route changes; vessel speed restrictions).

Further research is necessary to improve the model presented here. Owing to the dynamic nature of habitat use by humpback whales off Brazil and population growth, it is important to continue monitoring the collision risk along this shipping route and the whales' response to vessel traffic over time. No model can replace careful recording of actual collisions with ships, and extrapolating such rates to fleets and real traffic. However, crews of large vessels generally are unaware of collisions and typically notice the kill only when a whale becomes stuck on the bow (Jensen and Silber, 2003; Norman *et al.*, 2004; Félix and Van Waerebeek, 2005). The occasional occurrence of right whale in the area is also of great concern for several reasons: the species is one of the most frequently reported victims of vessel strikes (Van Waerebeek *et al.*, 2007), including records off Brazil (Greig *et al.*, 2001); the species occurs in coastal waters (Payne, 1986); the population off Brazil is increasing (Groch *et al.*, 2005) and reoccupying areas along the Brazilian coast in which they occurred before their exploitation (Santos *et al.*, 2001). Other improvements of this assessment and model include investigating other shipping routes crossing the Abrolhos Bank, and including the behaviour of the whales and the vessels in the model. Modelling the heterogeneity in the spatial distribution of humpback whales across a wider scale using explanatory spatial covariates (Williams *et al.*, 2006) is also recommended, so that a spatially explicit risk assessment can help identify areas of overlap between whales and shipping activity to guide appropriate mitigation measures (Williams and O'Hara, 2010). Finally, it would be interesting to use existing abundance estimates to assess potential mortality limits for this humpback whale breeding stock (Williams and O'Hara, 2010).

The ship strike risk in the Abrolhos Bank should be considered important since this is the main breeding and calving ground for the species in the south-western 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, since younger animals are highly vulnerable to collisions with vessels (Laist *et al.*, 2001; Lammers *et al.*, 2013). In general, young cetaceans typically suffer from a reduced physiological capacity to dive relative to older conspecifics, and therefore spend more time at the surface to breathe and dive shallower than their mothers (Würsig *et al.*, 1984; Papastavrou *et al.*, 1989; Szabo and Duffus, 2008; Tyson *et al.*, 2012). The collision risk model presented here can be used in the environmental impact assessments of port activities, as well as in the elaboration of conservation action plans for large cetaceans.

Ship strikes and the mortality of humpback 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 owing to advanced decomposition. These carcass-recovery counts, however, are opportunistic observations of either natural or anthropogenic causes of mortality. A recent study of 14 cetacean species in the northern Gulf of Mexico suggests that carcasses are recovered, on average, from only 2% of deaths (Williams *et al.*, 2011). Thus, the true death toll could be 50 times the number of carcasses recovered, given no additional information. Prado and colleagues (2013) found washed ashore only 7% of the tagged franciscana dolphins (*Pontoporia blainvillei*) incidentally killed by the coastal gillnet fisheries in southern Brazil. The probability of detecting the death of a marine mammal depends on a wide range of physical and biological factors, including behavioural responses prior to death, proximity of the carcass to the shore (or at-sea observers), scavenging and decomposition rates, 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 haemorrhaging) in stranded whales, propeller wounds (deep slashes or cuts into the blubber) and fluke/fin amputations on stranded or live whales (Wiley *et al.*, 1995). It should be noted that ship strikes do not always produce external 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 of skeletal abnormalities in humpback whales stranded from 2002 to 2011, Groch and colleagues (2012) observed traumatic lesions in four animals out of the 49 whales studied. The presence of osseous callus was observed in the ribs of three 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 Belmonte–Barra do Riacho coastal route had the potential to collide with 25 whales during the 2011 breeding season, potentially severely injuring and killing 17 of these (67%) if travelling at 12 knots. Whether the potential mortality represents a threat to the humpback whale breeding population off Brazil, remains unknown. The population affected by the coastal routes studied here represented only 3.3% of this breeding stock in 2011, with a negligible removal through ship collisions as suggested by the model, many other routes, however, remain unmonitored. Therefore, further assessments covering a wider geographical region and more detailed demographic analysis are necessary to answer this question.

CONCLUSIONS

The model of ship strikes to whales presented here can be used as an important tool to evaluate and mitigate the impacts of vessel traffic within cetacean habitats. Ship strikes are an important threat to large whales worldwide, and this is probably the first effort to estimate the collision risk along a shipping route for a cetacean species in the Southern Hemisphere. Vessels crossing the coastal waters of the Abrolhos Bank had the potential to hit and injure 25 humpback whales in 1 year (5 months of breeding season). This is probably an underestimate of the total number of collisions that may occur at the Abrolhos Bank, since other offshore shipping routes that cross the bank, overlapping important core areas for humpback whales, were not evaluated. Collision risk increased during our study due to whale population growth and increasing vessel traffic, and will probably continue to increase in the future. Therefore, the use and development of these tools are important to guide conservation and mitigation measures, such as vessel speed restrictions both in space and time and shipping route changes to avoid whale aggregation areas.

ACKNOWLEDGEMENTS

The work described here was completed in partial fulfillment of a Master of Science degree by the first author in the Department of Ecology and Zoology at Universidade Federal de Santa Catarina (UFSC), with funding provided by the Brazilian Ministry of Education (CAPES), and the Cetacean Society International. We wish to thank everybody involved in some way in this project: Projeto Baleia Jubarte's staff, observers who worked on data collection, Ariane Borges for helping with ArcGIS, and especially Cristiane Martins and Mariana Neves, responsible for this project in the early years; Projeto Baleia Jubarte's official sponsor – Petróleo Brasileiro S.A. (Petrobras); Fibria Celulose, Veracel Celulose and Companhia de Navegação Norsul for logistic and financial support; David Janiger for making several papers available; as well as John Baxter, Koen Van Waerebeek, Rob Williams, Fábio Daura-Jorge, Daniel Danilewicz, and Marta Cremer whose suggestions greatly improved our manuscript.

REFERENCES

Andriolo A, Martins CCA, Engel MH, Pizzorno JL, Más-Rosa S, Freitas AC, Morete ME, Kinas PG. 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**: 307–311.

Andriolo A, Kinas PG, Engel MH, Martins CCA, Rufino AM. 2010. Humpback whales within the Brazilian breeding ground: distribution and population size estimate. *Endangered Species Research* **11**: 233–243.

Bryant PJ, Lafferty CM, Lafferty SK. 1984. Reoccupation of Laguna Guerrero Negro, Baja California Sur, Mexico by gray whales. In *The Gray Whale*, Eschrichtius robustus, Jones ML, Swartz SL, Leatherwood JS (eds). Academic Press: Orlando; 375–387.

Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L. 2001. *Introduction to Distance Sampling: Estimating Abundance of Biological Populations.* Oxford University Press: Oxford.

Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L. 2004. *Advanced Distance Sampling: Estimating Abundance of Biological Populations.* Oxford University Press: Oxford.

Burnham KP, Anderson DR. 2002. *Model Selection and Multimodel Inference: a Practical Information-Theoretic Approach*, 2nd edn. Springer-Verlag: New York.

Carey WM. 2009. Lloyd's Mirror – Image Interference Effects. *Acoustics Today* **5**: 14–20.

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, 16.

Clapham PJ, Mead JG. 1999. *Megaptera novaeangliae*. *Mammalian Species* **604**: 1–9.

Conn PB, Silber GK. 2013. Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales. *Ecosphere* **4**: 43.

Dutra GF, Moura RL, Engel MH, Martins CCA, Wedekin LL, Neves MC, Paese A. 2012. SIG na linha de frente da conservação marinha: Gestão para a conservação da região dos Abrolhos. In *Conservação da Biodiversidade com SIG*, Paese A, Uezu A, Lorini ML, Cunha A (eds). Oficina de Textos: São Paulo; 71–88.

Epperly SP, Braun J, Chester AJ, Cross FA, Merriner JV, Tester PA, Churchill JH. 1996. Beach strandings as an indicator of at-sea mortality of sea turtles. *Bulletin of Marine Science* **59**: 289–297.

Félix F, Van Waerebeek K. 2005. Whale mortality from ship strikes in Ecuador and West Africa. *Latin American Journal of Aquatic Mammals* **4**: 55–60.

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

Greig AB, Secchi ER, Zerbini AN, Rosa LD. 2001. Stranding events of southern right whales, *Eubalaena australis*, in southern Brazil. *Journal of Cetacean Research and Management (Special Issue)* **2**: 157–160.

Groch KR, Palazzo Jr. JT, Flores PAC, Adler FR, Fabian ME. 2005. Recent rapid increases in the right whale (*Eubalaena australis*) population off southern Brazil. *Latin American Journal of Aquatic Mammals* **4**: 41–47.

Groch KR, Marcondes MCC, Colosio AC, Catão-Dias JL. 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. *Reports 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 AS, Silber GK. 2003. Large whale ship strike database. US Department of Commerce, NOAA Technical Memorandum. NMFS-OPR-25, 37.

Kraus SD, Brown MW, Caswell H, Clark CW, Fujiwara M, Hamilton PK, Kenney RD, Knowlton AR, Landry S, Mayo CA, *et al*. 2005. North Atlantic right whales in crisis. *Science* **309**: 561–562.

Laist DW, Knowlton AR, Mead JG, Collet AS, Podesta M. 2001. Collisions between ships and whales. *Marine Mammal Science* **17**: 35–75.

Lammers MO, Pack AA, Lyman EG, Espiritu L. 2013. Trends in collisions between-- vessels and North Pacific humpback whales (*Megaptera novaeangliae*) in Hawaiian waters (1975–2011). *Journal of Cetacean Research and Management* **13**: 73–80.

Lerczak JA, Hobbs RC. 1998. Calculating sighting distances from angular readings during shipboard, aerial, and shore-based marine mammal surveys. *Marine Mammal Science* **14**: 590–599. Errata in Marine Mammal Science 14: 903.

Marcondes MCC, Engel MH. 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 FFC, Buckland ST. 2003. Incorporating covariates into standard line transect analyses. *Biometrics* **59**: 924–935.

Martins CCA, Neves MC. 2004. Using platforms of opportunity to validate adequate routes for barge traffic in the breeding ground of humpback whales along the Brazilian coast. Paper SC/56/SH10 presented to the IWC Scientific Committee of the 56th Annual Meeting of the International Whaling Commission, Sorrento, Italy.

Martins CCA, Morete ME, Engel MH, Freitas AC, Secchi ER, Kinas PG. 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 CCA, Andriolo A, Engel MH, Kinas PG, Saito CH. 2013. Identifying priority areas for humpback whale conservation at Eastern Brazilian Coast. *Ocean and Coastal Management* **75**: 63–71.

Morete ME, Pace III RM, Martins CCA, Freitas AC, Engel MH. 2003. Indexing seasonal abundance of humpback whales around Abrolhos Archipelago, Bahia, Brazil. *Latin American Journal of Aquatic Mammals* **2**: 21–28.

Norman SA, Bowlby CE, Brancato MS, Calambokidis J, Duffield D, Gearin PJ, Gornall TA, Gosho ME, Hanson B, Hodder J, *et al*. 2004. Cetacean strandings in Oregon and Washington between 1930 and 2002. *Journal of Cetacean Research and Management* **6**:87–99.

Papastavrou V, Smith SC, Whitehead H. 1989. Diving behaviour of the sperm whale, *Physeter macrocephalus*, off the Galapagos Islands. *Canadian Journal of Zoology* **67**: 839–846.

Pavanato HJ, Wedekin LL, Engel MH, Kinas PG. 2012. Humpback whales abundance on the Brazilian breeding ground in 2011 using a hierarchical bayesian approach. Abstract presented on the 15ª Reunión de Trabajo de Expertos en Mamíferos Acuáticos de América del Sur y 9° Congreso SOLAMAC, Puerto Madryn, Argentina.

Payne R. 1986. Long term behavioral studies of the southern right whale, *Eubalaena australis*. *Reports of the International Whaling Commission (Special Issue)* **10**: 161–167.

Prado JHF, Secchi ER, Kinas PG. 2013. Mark-recapture of the endangered franciscana dolphin (*Pontoporia blainvillei*) killed in gillnet fisheries to estimate past bycatch from time series of stranded carcasses in southern Brazil. *Ecological Indicators* **32**: 35–41.

Richardson WJ, Greene CR, Malme CI, Thompson DH. 1995. *Marine Mammals and Noise*. Academic Press: New York.

Santos MCO, Siciliano S, de Souza SP, Pizzorno JLA. 2001. Occurrence of southern right whales (*Eubalaena australis*) along southeastern Brazil. *Journal of Cetacean Research and Management (Special Issue)* **2**: 153–156.

Silber GK, Slutsky J, Bettridge S. 2010. Hydrodynamics of a ship/whale collision. *Journal of Experimental Marine Biology and Ecology* **39**: 110–119.

Silber GK, Vanderlaan ASM, Arceredillo AT, Johnson L, Taggart CT, Brown MW, 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 EJ. 1979. *Whales*, 2nd edn. Cornell University Press: New York.

Sousa-Lima R, Clark CW. 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.

Szabo A, Duffus D. 2008. Mother-offspring association in the humpback whale, *Megaptera novaeangliae*: following behaviour in an aquatic mammal. *Animal Behaviour* **75**: 1085–1092.

Terhune JM, Verboom WC. 1999. Right whales and ship noises. *Marine Mammal Science* **15**: 256–258.

Thomas L, Buckland ST, Rexstad EA, Laake JL, Strindberg S, Hedley SL, Bishop JRB, Marques TA, Burnham KP. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* **47**: 5–14.

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; 195–197.

Tyson RB, Friedlaender AS, Ware C, Stimpert AK, Nowacek DP. 2012. Synchronous mother and calf foraging behavior in humpback whales *Megaptera novaeangliae*: insights from multi-sensor suction cup tags. *Marine Ecology Progress Series* **457**: 209–220.

van der Hoop JM, Vanderlaan ASM, Taggart CT. 2012. Absolute probability estimates of lethal vessel strikes to North Atlantic right whales in Roseway Basin, Scotian Shelf. *Ecological Applications* **22**: 2021–2033.

Van Waerebeek K, Leaper R. 2008. Second Report of the IWC Vessel Strike Standardisation Working Group. Report to the International Whaling Commission Scientific Committee 60th Annual Meeting, Santiago, Chile. Rep. No. SC/60/BC5; 8.

Van Waerebeek K, Baker AN, Felix F, Gedamke J, Iniguez M, Sanino GP, 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**: 43–69.

Vanderlaan ASM, Taggart CT. 2007. Vessel collisions with whales: the probability of lethal injury based on vessel speed. *Marine Mammal Science* **23**: 144–156.

Vanderlaan ASM, Taggart CT. 2009. Efficacy of a voluntary area to be avoided to reduce risk of lethal vessel strikes to endangered whales. *Conservation Biology* **23**: 1467–1474.

Vanderlaan ASM, Taggart CT, Serdynska AR, Kenney RD, Brown MW. 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.

Ward E, Zerbini AN, Kinas PG, Engel MH, 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.

Watkins WA. 1986. Whale reactions to human activities in Cape Cod waters. *Marine Mammal Science* **2**: 251–262.

Wedekin LL, Neves MC, Marcondes MCC, Baracho C, Rossi-Santos MR, Engel MH, Simões-Lopes PC. 2010. Site fidelity and movements of humpback whales (*Megaptera novaeangliae*) on the Brazilian breeding ground, southwestern Atlantic. *Marine Mammal Science* **26**: 787–802.

Wiley DN, Asmutis RA, Pitchford TD, Gannon DP. 1995. Stranding and mortality of humpback whales, *Megaptera novaeangliae*, in the mid-Atlantic and southeast United States, 1985–1992. *Fishery Bulletin* **93**: 196–205.

Wiley DN, Thompson M, Pace III RM, 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, O'Hara P. 2010. Modelling ship strike risk to fin, humpback and killer whales in British Columbia, Canada. *Journal of Cetacean Research and Management* **11**: 1–8.

Williams R, Hedley SL, Hammond PS. 2006. Modeling distribution and abundance of Antarctic baleen whales using ships of opportunity. *Ecology and Society* **11**: 28. http://ecologyandsociety.org/vol11/iss1/art1/

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

Würsig B, Dorsey EM, Fraker MA, Payne RS, Richardson WJ, Wells RS. 1984. Behavior of bowhead whales, *Balaena mysticetus*, summering in the Beaufort Sea: Surfacing, respiration and dive characteristics. *Canadian Journal of Zoology* **62**: 1910–1921.