The first aerial survey to estimate abundance of humpback whales (*Megaptera novaeangliae*) in the breeding ground off Brazil (Breeding Stock A)

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ABSTRACT

In the Southern Hemisphere, humpback whales (*Megaptera novaeangliae*) were heavily exploited from both coastal stations and in pelagic waters in all major ocean basins. About 200,000 whales were taken after 1900, causing declines of populations to small percentages of their pre-exploitation levels. The study presented here aimed to investigate humpback whale abundance in the Brazilian coastal breeding ground, in order to provide information to support further analysis of the population recovery. Between 25 August and 2 September 2001, a fixed wing, flat window, aircraft was used to survey transect lines along the northern limit of Bahia State (12°10'S), to the southern limit of Espírito Santo State (20°42'S). All on-effort sightings were recorded and abundance was estimated according to standard distance sampling methodology (Burnham *et al.*, 1980; Buckland *et al.*, 1993). Group sizes of humpback whales ranged between 1-5 and the mean group size was 1.52 (±0.06). The model that best fitted the perpendicular distance data, based on the minimum Akaike Information Criterion, was the hazard rate model. The population size estimated using uncorrected data was 1,493 (CV=0.21) whales. Surface time was used to correct the estimates for $\hat{g}(0)$, resulting in a correction factor of 0.67 (±0.15). The corrected analysis for each block and combined result, increased the population size estimate to 2,229 (CV=0.31) individuals. The data from this study could be used to identify new areas appropriate for whalewatching, to monitor the status and dynamics of the humpback whale population off the Brazilian coast and to provide information for the establishment of new protected areas.

KEYWORDS: SURVEY-AERIAL; HUMPBACK WHALE; ABUNDANCE ESTIMATE; BREEDING GROUND; SOUTH AMERICA; SOUTHERN HEMISPHERE

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) occur in all major oceans of the world. In the Southern Hemisphere they usually migrate from summer feeding grounds in the Antarctic to mating and calving grounds in tropical and subtropical regions (e.g. Mackintosh, 1965). Its coastal habitat has made the humpback whale especially vulnerable to modern whaling methods and the species was heavily exploited in the Southern Hemisphere from both coastal stations and in pelagic waters in all major ocean basins (e.g. Chittleborough, 1965; Gambell, 1973; Williamson, 1975; Tonnessen and Johnsen, 1982; Best, 1994). About 200,000 whales were taken after 1900, causing declines of populations to small percentages of their pre-exploitation levels (e.g. Gambell, 1973). The International Whaling Commission (IWC) has afforded the species virtually complete protection since 1966 and currently recognises seven humpback whale breeding populations in the Southern Hemisphere (IWC, 1998). Breeding stock 'A' is one of the least known and corresponds to whales wintering off Brazil.

Current information on the distribution of humpback whales shows that the species is abundant in the Abrolhos Bank (16°40'-19°30'S), possibly the main breeding area for the species in the western South Atlantic Ocean (e.g. Siciliano, 1997; Engel, 1996; Freitas *et al.*, 1998; Martins *et al.*, 2001). The size of the population breeding in the Abrolhos Bank has been estimated for 1995 as 1,634 individuals, using an empirical Bayes closed mark-recapture model with photo-identification data (Kinas and Bethlem, 1998). Recently, abundance estimates of the population of whales available for marking within the study area were obtained from across year mark-recapture data between 1996 and 2000. A closed population, multiple-recapture model resulted in an estimate of 2,393 whales (approx. CV=0.12). An alternative open population model suggested a population increase over the study period and an estimated population size of 3,871 (CV=0.18) whales in 2000 (Frietas *et al.*, 2004).

The first population estimate for humpback whales off part of northeastern Brazil using line transect methodology (628 individuals; CV=0.33) was for the year 2000 (Zerbini *et al.*, 2004). The study confirmed that humpback whales are regularly found in coastal waters, as far north as 5°S, along the northeastern coast of Brazil. In addition, a whale that stranded in Ceará (3°43'S, 38°30'W) (Furtado-Neto *et al.*, 1998), west of the northwestern tip of South America, suggests that humpback whales may be moving west along the northern coast of Brazil. Non-systematic sightings and strandings of humpback whales have been reported for other areas of the coast, from the Fernando de Noronha Archipelago (~3°S) to Rio de Janeiro (~23°S) (e.g. Lodi, 1994; Siciliano, 1997; Pizzorno *et al.*, 1998). Despite this information, humpback whale distribution and density are still poorly known for a large proportion of the Brazilian coast.

Surveys using fixed-wing aircraft and distance sampling methodology have been extensively used to study distribution and to estimate abundance of mammals (e.g.

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Burnham *et al.*, 1980; Guenzel, 1986; 1994; Firchow *et al.*, 1990; Johnson *et al.*, 1991; Andriolo *et al.*, 2001; Secchi *et al.*, 2001). This technique (including correction for missed animals) can provide reliable estimates with associated confidence intervals relatively inexpensively even when animals are widely distributed. It is useful for studying humpback whales because they are found throughout a large area along the Brazilian coast.

The potential impact of increasing vessel traffic and shoreline development has brought about concern for the future of the Brazilian humpback whale population. The objective of the study presented here was to investigate humpback whale abundance in the Brazilian coastal breeding ground in order to provide baseline information for the development and monitoring of future conservation measures.

METHODS

Study area and survey design

Between 25 August and 2 September 2001, a fixed wing, flat window, aircraft (Mitsubishi Marquese) was used to survey transect lines along the north limit of Bahia State (12°10'S) down to the southern limit of Espírito Santo State (20°42'S). It was not possible to obtain a plane with bubble windows (which enable observers to search directly under the plane and on the trackline). The sighting survey was planned such that it took place at the yearly peak of humpback whale abundance off the Brazilian coast (Paiva and Grangeiro, 1965; Paiva and Grangeiro, 1970; Williamson, 1975).

The study area was divided into five independent blocks (A-E). The total area covered was 25,139.1 n.miles^2. Seventy-seven parallel transects were systematically designed 25km apart, covering the area from the coast to the 500m isobath (Fig. 1). The parallel design of the transects avoids sub- and over-sampling depending on the shape of the coast. However, in the north of the Bahia State (A block), the transects were designed in a zig-zag shape due to the shelf narrowness in order to better cover the area and to maximise flying effort. The total length on effort was 2,125.25 n.miles, subdivided by block as follows: (1) A block – 511.35 n.miles; (2) B block – 294.35 n.miles; (3) C block – 530.08 n.miles; (4) D block – 384.02 n.miles; and (5) E block – 405.47 n.miles. Survey design and flights were planned using the software *GPS Trackmaker 11.4*.

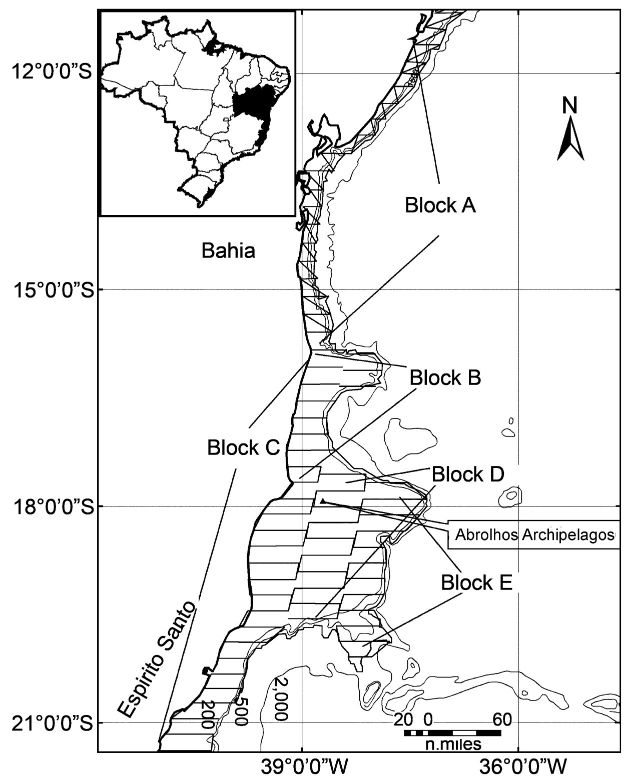

Fig. 1. Transects of aerial survey conducted along the Bahia and Espírito Santo States in late August and early September of 2001. The letters refer to areas used for analysis (Blocks A, B, C, D and E).

Survey protocol

Total time spent flying was 56hrs. The aircraft flew with a constant airspeed of 120kt at an altitude of 500ft (lower than normal for large whale surveys to enable sightings of small cetaceans as well). Flights occurred between 08:00hrs to 17:00hrs when conditions were suitable, i.e. Beaufort sea state 4 (they were usually 2-3) with a clear view of the sea surface (cloud cover ranged from 0-100%). Planning meetings and training sessions were held three days prior to the survey start. Five observers participated in each flight, three on effort and two resting. They rotated at approximately 30min intervals, which corresponded with the end of the transect. Search effort was suspended at the end of each line in order for the plane to circle, before beginning the next one. Species, group size and composition as well as general comments were recorded for each sighting. Two observers sat behind the data recorder, searching downwards and laterally through flat windows on each side of the aircraft. The observers used hand-held clinometers to record the declination angles (0° is at the horizon and 90° is directly below the aircraft) when the animal (or group) passed perpendicularly to the trackline. The sighting position was determined using Global Positioning System (GPS) and all major information was written down on a data sheet by the data recorder. All sightings were recorded following standard line-transect methodology (Burnham *et al.*, 1980; Buckland *et al.*, 1993).

Data analysis

Perpendicular distances were calculated using the aircraft's altitude and the declination angle to the sighting. The flat windows meant that animals could not be seen under the plane out to a declination angle of approximately 50°. A limit at 45° was imposed to assure data quality and this corresponds to a 152m offset on either side of the line. The blind spot distance from the measurements ($g(152)=1$) was subtracted and 3° bands were used, giving intervals corresponding to distances of 0, 11, 30, 49, 73, 100, 133, 173, 224, 289, 378, 506, 710, 1,085, 2,021 and 8,556m. Truncation was applied, discarding all observations beyond 4,000m.

Abundance was estimated in accordance with standard line-transect methodology (Burnham *et al.*, 1980; Buckland *et al.*, 1993). Data analysis was undertaken using the software *DISTANCE* (Laake *et al.*, 1993). Data were pooled across blocks to estimate the global detection function and the global expected group size. Various models were tested to the distances, including the uniform function with cosine and simple polynomial adjustments, half-normal function with cosine and the hazard rate function with cosine and simple polynomial adjustments. The model that best fitted the data was selected according to the Akaike Information Criterion (AIC) (Burnham and Anderson, 1992) as implemented by Laake *et al.* (1993). Abundance estimates were obtained by multiplying the density of whales (D) by the survey area (A). Variances of encounter rate (n/L) and group size were empirically estimated from the sample and variance of the probability density function [$\hat{f}(0)$] was calculated using maximum likelihood estimation.

Detection probability: *g*(0)

Line transect methods assume that all animals on the trackline will be seen. Since the detection probability on the trackline, $g(0)$, is not equal to 1 in aerial surveys the probability of detecting a humpback whale was estimated following the approach of Barlow *et al.* (1988):

$$\hat{g}(0) = \frac{s+t}{s+d}$$

where

s is the average time a humpback whale is at the surface;
d is the average time a humpback whale is submerged;
t is the time window during which the humpback whale is within the visual range of an observer.

The variance of $\hat{g}(0)$ was calculated by the delta method (Seber, 1982).

RESULTS

The total number of humpback whale sightings and individuals observed on effort and considered in the analyses are summarised in Table 1. Whales were not regularly found in the survey area. A concentration of groups is evident over the Abrolhos Bank (Fig. 2). The distribution and concentration of whales seems to be small in the northern portion of the study area and increases south of 18°S. Besides the humpback whales two southern right whales (*Eubalaena australis*), 14 unidentified large whales, 3 unidentified dolphins and 1 minke whale (*Balaenoptera sp.*) were seen.

Table 1

Number of groups and individuals registered in each block, and respective sighting rate considered in the analyses.

Block	Groups	Individuals	Calves	Area (n.miles^2)	Effort (n.miles)	Sighting rate
A	9	14	0	3,575.2	511.3	0.017
B	8	13	1	4,005.5	294.3	0.027
C	62	100	5	7,205.8	530.0	0.116
D	60	92	0	5,426.4	384.0	0.156
E	14	18	0	4,926.2	405.5	0.034
Total	153	237	6	25,139.1	2,125.3	0.074

Group size and composition

Group sizes of humpback whales ranged between 1-5 and mean group size was 1.52 (±0.07). Calves were observed only in six of the total humpback whale groups sighted (Table 1).

Abundance

The model that best fitted the perpendicular distance data was the hazard rate model, based on its minimum AIC value of 621.49. Fig. 3 presents the distributions of perpendicular distance and fitted detection function. Uncorrected abundance was estimated at 1,493 individuals (CV=0.21).

Detection probability – correction of *g*(0)

Solitary individuals accounted for 57% of sightings and the remaining 43% were of groups of two or more individuals. The detectability of groups will be higher than solitary animals. Twenty-seven groups of humpback whales (six solitary individuals and 21 cow-calf pairs) were consistently observed from a land base station at Santa Barbara island in the Abrolhos Archipelago, using continuous sampling methodology (Mann, 1999). The surface and dive times were calculated as proportions of the total observation time. When calculating the mean group size, solitary animals sightings were separated from group sightings and these values were used to calculate the final mean surface and dive times. Humpback whales were found to spend 66.46% of the time at the surface and 33.53% submerged. The time that an animals was visible from the aircraft's window (*t*), was estimated as 14.53sec (95% confidence interval (CI=±9.79). This measurement was directly made by recording the duration of visibility of any object at the surface of the sea. The estimate for $\hat{g}(0)$ as a correction factor was 0.67 (CI=±0.15). Table 2 presents the corrected analyses for each block and combined result, which increased the population size estimate to 2,229 individuals (CV=0.31).

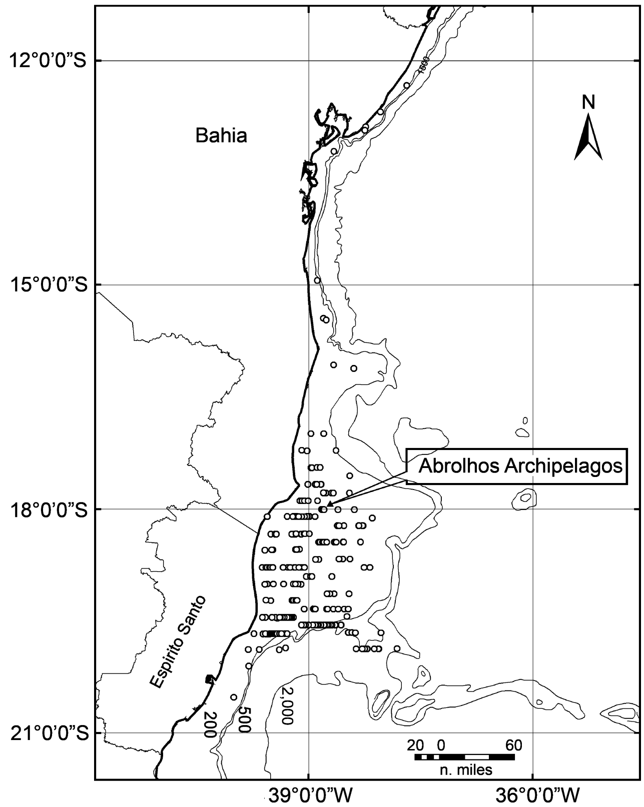

Fig. 2. Sightings recorded during the aerial survey of humpback whales at the Brazilian breeding ground. Isobaths are indicated in metres.

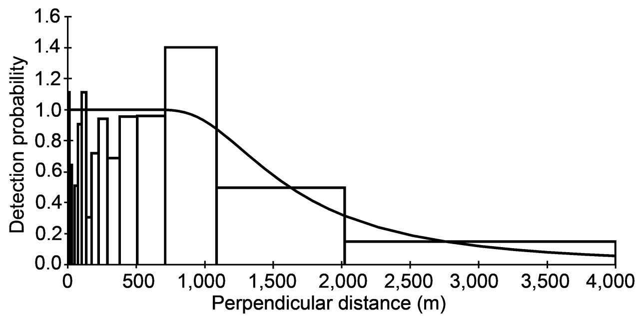

Fig. 3. Distribution of perpendicular distances and the fitted detection function.

Table 2

Parameters of estimated densities and population size of corrected data independently for each block and combining all blocks.
(DS=density of clusters; D=density of animals; N=number of animals).

	Estimate	%CV	95% Confidence interval	
Block A				
DS	0.0129	31.51	0.0571	0.0295
D	0.0192	32.17	0.0846	0.0440
N	69	32.17	30	157
Block B				
DS	0.0200	9.68	0.0069	0.0581
D	0.0298	9.81	0.0102	0.0863
N	119	9.81	41	346
Block C				
DS	0.0863	18.15	0.0414	0.1799
D	0.1282	18.75	0.0614	0.2677
N	924	18.75	443	1,929
Block D				
DS	0.1153	10.03	0.0457	0.2907
D	0.1713	10.22	0.0679	0.4320
N	930	10.22	369	2,344
Block E				
DS	0.0254	11.63	0.0081	0.0799
D	0.0378	11.75	0.0120	0.1187
N	187	11.75	59	585
Combined estimates				
DS	0.0596	29.57	0.0322	0.11052
D	0.0886	31.31	0.0477	0.16455
N	2,229	31.31	1,201	4,137

DISCUSSION

The flat windows of the plane, coupled with the possible inexperience of some observers, will have affected the distribution of the detection probability. One alternative approach to help reduce problems associated with imprecise measurements is grouping perpendicular distance data (Buckland *et al.*, 1993). This strategy was applied to the data set presented here.

Distribution

This study has shown that humpback whales are not equally distributed throughout coastal waters as far north as 12°10'S at Bahia State, to the southern limit of Espírito Santo State (20°42'S), which is evident from the different results for each block (Table 1). The Abrolhos Bank is the preferred area (mainly blocks C and D) as it had the highest number of sightings for both individuals and groups. A low density area was observed approximately between the parallels 13°30'S-16°30'S. It is thought that the whales tend to concentrate near islands and coral reef systems, which was proposed by Clapham and Mead (1999).

The area covered previously has been recognised as a major calving/nursing area (Martins *et al.*, 2001), however, during this study few calves were observed. A possible explanation is poor calf visibility, caused by the flat window. Calves are probably only visible when looking straight down, as their profile out of the water and any blow would be less visible than for an adult, and as they swim close to their mother. An improvement for future studies would be to use a slower aircraft, adapted with bubble windows, which would permit downward observations.

Abundance

The total abundance of the humpback whale stock wintering off Brazil is unknown. The 1995 population was previously estimated at about 1,600 individuals (SD=155.16) in the Abrolhos Bank, using photo-identification data and an empirical Bayes closed mark recapture model (Kinas and Bethlem, 1998). Freitas *et al.* (2004) presented new estimates also based on photo-identification data, collected from 1996-2000. However, these photo-identification data were collected in a relatively limited area when compared to the known stock range. The present study provides an estimate for this previously studied area, which can be used for comparison.

In 2000, line transect methodology was employed in northeastern Brazil for the first time to estimate the abundance of humpback whales (Zerbini *et al.*, 2004). The vessel covered an adjacent area north of the area surveyed in the present study and abundance was estimated at 628 individuals (CV=0.311, 95% CI=366-1091). Given the low speed of the vessel, an assumption that $g(0)=1$ is more reasonable. However, there are other advantages of conducting aerial surveys, including the ability to cover large areas in a shorter period of time. This should allow a better picture of spatial distribution. The main drawback of the present aerial survey was the absence of bubble windows preventing searching directly below the plane. Missing animals close to the trackline is inevitable given the diving behaviour of cetaceans (this is known as availability bias) and the correction factor used here tries to account for this. Even though humpback whales are relatively conspicuous, perception bias (due to observers missing animals that were at the surface) may occur, even though observers swapped positions during flights and were trained in collecting this type of data.

We recognise that the data used to estimate the correction factor used here are not ideal for a number of reasons. However, we believe the approach we adopted can be considered conservative, i.e. will probably result in an underestimate of the population size. Considering that this is the first aerial survey for humpback whales in Brazil and noting other difficulties, primarily the lack of bubble windows, we believe that taking a conservative approach is most appropriate from a conservation perspective. The survey covered the area at a time when the population density was expected to be at its highest and our abundance estimate for the area covered is about 2,300 (CV=0.31). As noted earlier, a vessel survey had also been carried out to the north of our region (5° and 10°S) at a similar time of year (Zerbini *et al.*, 2004). However, without further information on possible annual changes in distribution it is not appropriate at this time to add together these two estimates.

Conservation

The results presented here suggest that aerial surveys employing distance sampling techniques can be used to monitor humpback whale populations over time. This methodology can be used to estimate parameters such as the population growth rate; consistent data collection not only allows analysis of annual variation but allows trends to be considered without the use of a correction factor, if this factor can be assumed to be constant over the monitoring period.

Despite the fact that the humpback whale population is recovering and reoccupying its historical areas, the population is still small when compared with that prior to the commencement of whaling (Findlay *et al.*, 2000; Findlay and Johnston, 2001; Johnston *et al.*, 2001; Zerbini *et al.*, 2004). Information on the current status and dynamics of the humpback whale population off the Brazilian coast using data such as those presented here can help in clarifying appropriate mitigation measures to anthropogenic threats where necessary (e.g. protected areas) and provide information that might contribute to the local economy (e.g. identification of new areas for regulated whalewatching).

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