MONITORING HUMPBACK WHALE (*Megaptera novaeangliae*) POPULATION IN THE BRAZILIAN BREEDING GROUND, 2002 TO 2005.

Artur Andriolo[1], Paul G. Kinas, P.G.[2], Márcia H. Engel[3], Cristiane C. Albuquerque Martins[3]

[1] *Departamento de Zoologia, Instituto de Ciências Biológicas, Universidade Federal de Juiz de Fora, Campus Universitário, 36036-900, Juiz de Fora, MG, Brasil. Phone: (032) 3229 32 15 E-mail: andriolo@icb.ufjf.br*
[2] *Fundação Universidade Federal do Rio Grande, Departamento de Matemática, Rio Grande, RS - Brasil. CEP: 96200-970. E-mail: dmtkinas@furg.br*
[3] *Projeto Baleia Jubarte/Instituto Baleia Jubarte, Rua Barão do Rio Branco, 26 - Caravelas, BA - Brasil. CEP: 45.900-000. E-mail: marcia.engel@baleiajubarte.com.br*

ABSTRACT

The potential impact of increasing vessel traffic and shoreline development has made the conservationists concerned about the future of the Brazilian humpback population. Our objective was to monitor the humpback whale abundance in the Brazilian coastal breeding ground in order to provide information to support future strategies for species conservation. A series of 4 years (2002-2005) to survey the humpback whale population was implemented at the Brazilian breeding ground. Abundance was estimated according to standard line-transect. Data analysis was undertaken with the software DISTANCE 5.0. Perpendicular sighting data were modeled with various models: using the uniform function with cosine and simple polynomial adjustments, half-normal function with cosine, and the hazard rate function with a cosine and with a simple polynomial series expansion. The model that best fitted the data was selected according to the Bayesian Information Criterion (BIC). We estimated the population off the Brazilian coast to be 6,251 (CV=0.16) individuals in 2005.

KEY WORDS: SURVEY-AERIAL, HUMPBACK WHALE, *Megaptera novaeangliae*, ABUNDANCE ESTIMATE, BREEDING GROUND, SOUTH AMERICA.

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) inhabit 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 (Dawbin, 1956; Mackintosh, 1965; Chittleborough, 1965). Its coastal habitat has made the humpback whale especially vulnerable to modern whaling methods. The species was heavily exploited in the Southern Hemisphere from both coastal stations and pelagic waters in all major ocean basins (e.g. Chittleborough, 1965; Gambell, 1973; Williamson, 1975; Tonessen and Johnsen, 1982; Best, 1994). About 200,000 whales were hunted since 1900, causing drastic declines of their populations (e.g. Gambell, 1973). The International Whaling Commission (IWC) has afforded the species virtually complete protection since 1966, and currently recognizes seven humpback whale breeding populations in the Southern Hemisphere (IWC, 1998). Despite the protection 7 humpback whales were captured in 1967 on the Brazilian coast (Paiva and Grangeiro, 1970). Breeding stock 'A' (BSA) is one of the least known and corresponds to whales wintering off Brazil.

Current information on the distribution of humpback whales show that the species is abundant in the Abrolhos Bank (16º40'-19º30'S), 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, Andriolo *et al*. accepted). Recent information about the routes and summering destination were documented by Zerbini *et al. (in press*) describing the migratory corridors and summer feeding grounds at South Georgia and in the South Sandwich Islands. Stevick *et al*. (*accepted)* described the first match in Shag Rocks, South Georgia Island, of a humpback whale previously photo-identified in the Abrolhos Bank. Marcovaldi *et al*. (2006) presented another three matches near South Sandwich Island, confirming the findings that part of the BSA migrates to South Georgia and South Sandwich waters.

The size of the population breeding in the Abrolhos Bank was estimated for 1995 as 1,634 individuals by using an empirical-Bayes closed mark-recapture model with photo-identification data (Kinas & Bethlem, 1998). Recently, abundance estimates of the whale population available to 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 (aprox. CV= 0.12) whales. Alternatively, an open population model suggested population increase over the study period and an estimated population size of 3,871 (CV= 0.18) whales in year 2000 (Freitas *et al.* 2004). The first estimate of humpback whale using line transects methodology, was performed off northeastern Brazil (Zerbini *et al.* 2004). The abundance for that region was estimated at 628 individuals (CV = 0.31). The results confirm that the humpback whales are regularly found in coastal waters, as far north as 5^{o}S along the northeastern coast of Brazil. In addition, a whale stranded in Ceará (3º43'S, 038º30'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 were reported for other areas of the coast, from Fernando de Noronha Archipelago (3ºS) to Rio de Janeiro (23ºS) (Lodi, 1994; Siciliano, 1997; Pizzorno *et al*., 1998).

Aerial surveys using fixed-wing aircraft associated with the line transect distance sampling methodology have been extensively used to study distribution and to estimate abundance of mammals (Burnham *et al.* 1980; Guenzel 1986, 1994; Firchow *et al.* 1990; Johnson *et al.* 1991; Andriolo *et al.* 2001, 2005; Secchi *et al.* 2001). This technique provides accurate estimates, which are corrected for animals that should have been detected using data obtained during each survey; provides confidence intervals and other measures to evaluate the reliability of estimates, and is generally less expensive and less time consuming than traditional trends counts (Guenzel 1994). The line-transect technique is useful to study humpback whales because they tend to be widely distributed throughout a large area along the coast.

The potential impact of increasing vessel traffic and shoreline development has made the conservationists concerned about the future of the Brazilian humpback population. Our objective was to monitor the humpback whale abundance in the Brazilian coastal breeding ground in order to provide information to support future strategies for species conservation.

METHODS

A series of 4 years to survey the humpback whale population was implemented at the Brazilian breeding ground. The total area covered was equal in 2002-2004, and was expanded in 2005. The sighting surveys were planed to take place at the yearly peak of humpback whale abundance off the Brazilian coast, between late August and early September. A fixed wing, bubble window, aircraft (Aerocommander) was used to survey the transect lines along the northern limit of the State of Bahia (12^{o} 10’S) until the southern limit of the State of Espírito Santo (20^{o} 42’S) in 2002-2004. In 2005 the area was expanded from 5^{o}S to 25 ^{o}S.

The study area was divided into 5 independent blocks in 2002-2004, and further expanded to 8 blocks in 2005. Table 1 summarizes the effort covering the sampled area in different years.

Table 1: Block division, transects established in the sampled area and the related effort and length considered for the abundance estimates analysis.

Year	Blocks	# of Transects	Effort (nm)	Area (km2)
2002-2004	A	29	511.35	10181.00
2002-2004	B	6	169.07	6858.90
2002-2004	C	20	655.36	28215.60
2002-2004	D	12	466.99	18134.80
2002-2004	E	10	322.50	17712.50
Total		77	2125.27	81102.80
2005	A1	60	1297.90	29906.00
2005	A	29	511.35	10181.00
2005	B	6	169.07	6858.90
2005	C	21	691.15	28215.60
2005	D	12	466.99	18134.80
2005	E	10	322.50	17712.50
2005	F	25	939.63	48995.10
Total		163	4398.59	160003.90

Parallel transects were systematically designed 25km apart covering the area from the coast until the 500m isobath (Fig. 1). Block F was expanded beyond the 500m isobath in order to cover an oil exploration area. Block G was added in order to investigate the south boundary of the breeding ground. It was set between the 23^{o} and 24^{o}S. The parallel design of the transects avoids the sub-sampling and over-sampling depending on the shape of the coast. But, in the northern region, corresponding to blocks A1 and A, transects were designed in a zigzag shape due to the shelf narrowness, to better cover the area and to maximize flying effort. Survey design and flights were planned using the software "GPS Trackmaker Pro".

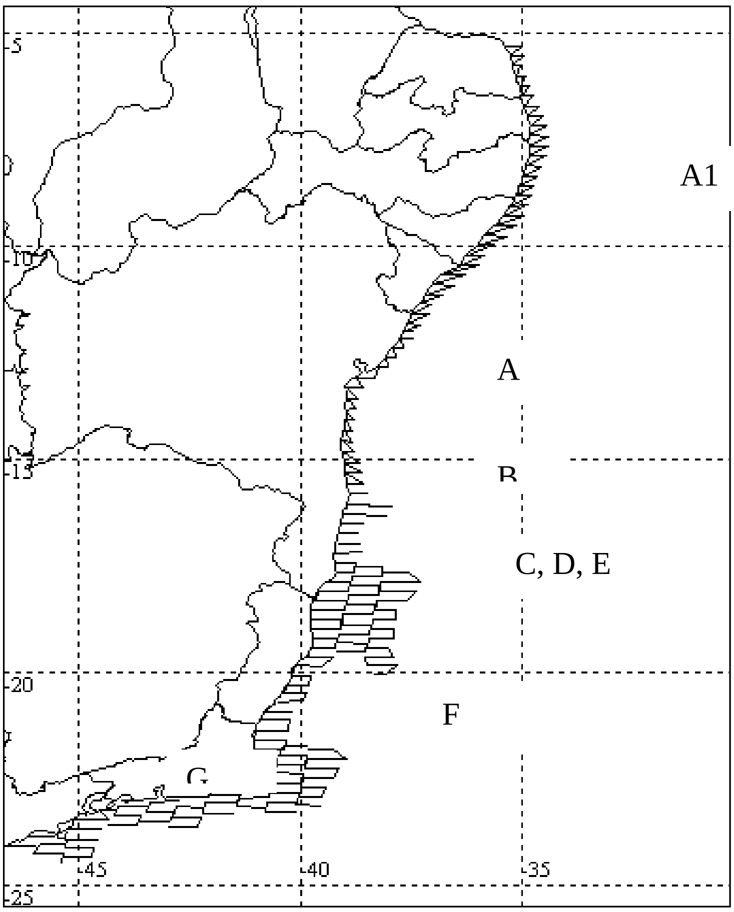

Figure 1: Transects established on the sampling area for the aerial surveys of humpback whale on the Brazilian breeding ground. The letters correspond to the blocks.

Survey protocol

The aircraft flew at a height of 500ft with a constant airspeed of 90kt. Transects were flown from 07:00 a.m. to 17:00 p.m. according to weather conditions. Planning meetings and training sessions were held three days before the survey started. Four observers participated in each flight, 3 on effort and 1 resting. They rotated approximately every 30min matching with the interval between transects, when search effort was suspended to circle before starting the next one. The two observers sat in front of the data recorder searching downwards and forward constantly and less often laterally, through a bubble window on each side of the aircraft. The observers had a hand-held clinometer each, and the declination angles (where 0^{o} is at the horizon and 90^{o} is directly below the aircraft) were called when the animal or group passed perpendicularly to the plane. The sighting position was registered in a GPS receiver, and all major information was written down on a data sheet by the data recorder. Species, group size and composition, and general comments were registered at sighting event. All sightings were recorded following line-transect methodology (Burnham *et al*. 1980; Buckland *et al*. 1993), assuming that the visibility decreases as a function of distance from the transect line.

Data Analysis

Perpendicular distances were calculated from the aircraft's altitude and the declination angle to the sighting.

We defined increasing width bands, as recommended by Guenzel, 1994 and Andriolo *et al*. 2005, which yield 8 intervals with cutpoints at distances of 0, 225, 494, 808, 1167, 1569, 2016, 2508, and 3,000 meters to accommodate clinometer reading errors. Truncation was applied discarding all observations beyond 3,000 meters. Block G confirmed southern limit at 23^{o}S and was excluded from the analysis.

Abundance was estimated according to standard line-transect (Burnham *et al.* 1980, Buckland *et al.* 1993). Data analysis was undertaken with the software DISTANCE 5.0 (Laake *et al.*, 1993). Perpendicular sighting data were modeled with various models: using the uniform function with cosine and simple polynomial adjustments, half-normal function with cosine, and the hazard-rate function with a cosine and with a simple polynomial series expansion. The model that best fit the data was selected according to the Bayesian Information Criterion (BIC). 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 [*f* (0)] was calculated using maximum likelihood estimation.

A pooled abundance estimate for each year was calculated as the sum over the estimates for blocks and the corresponding standard error as the square-root of the corresponding sum over squared standard errors.

Detection probability of g (0)

Since in aerial surveys the detection probability on the trackline, g (0), is less than 1, it had to be estimated from other sources. Based on breath-rate data collected around the Abrolhos bank, we used the estimate previously described in Andriolo *et al.* (2005), that is $\hat{g}(0) = 0.67$ (SE = 0.15).

RESULTS

The flights were scheduled in days with clear visibility of the sea surface, cloud cover ranged from 0-100%. The sea state varied most of the time (92%) between 1 and 5 (Beaufort scale).
The total number of humpback whale sightings and individuals observed on effort and considered in the analysis is summarized in Table 2.

Distribution
Whales were not regularly found along the survey area. There is an evident concentration of groups over the Abrolhos Bank. The survey of block G was essential to investigate the south boundary of the breeding ground. The south limit of the breeding ground was confirmed at the 23^{o}S corresponding to Arraial do Cabo area in the State of Rio de Janeiro (Fig. 2).

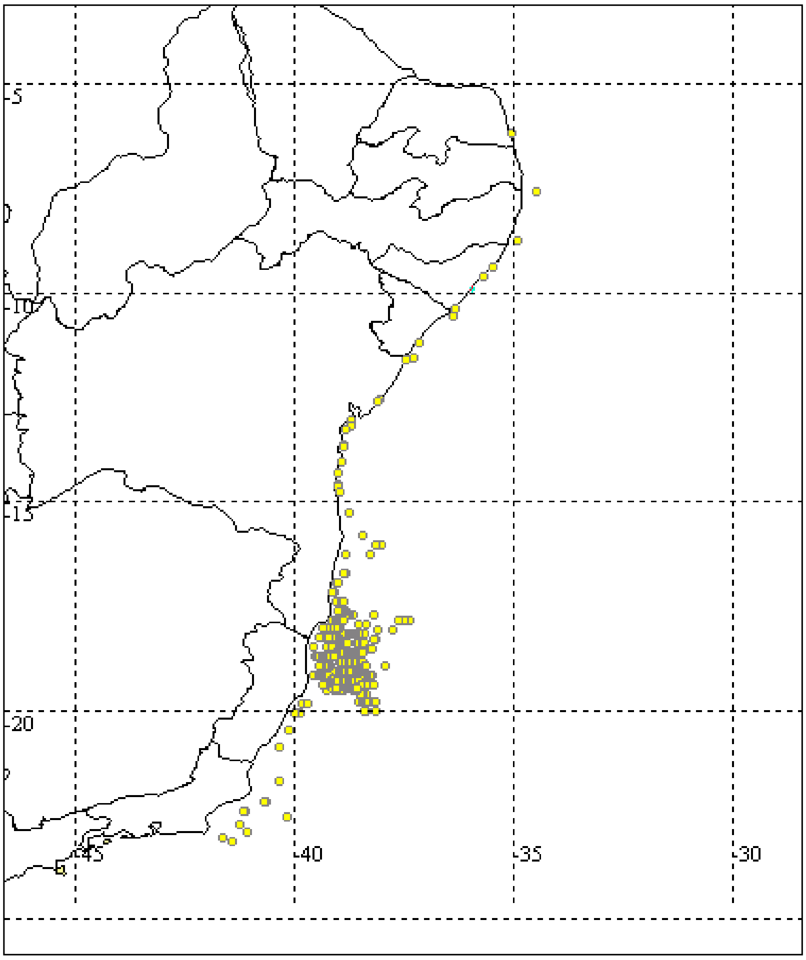

Fig.2. General distribution of humpback whales in 2005. The concentration area corresponds to the Abrolhos Bank.

Group size and composition
Group sizes of humpback whales ranged from 1 to 5. The average group size was 1.631 (CV=0.027). Calves were observed ranging between 7.2% and 13.7% of the total humpback whale sighted groups in different years (Table 2).

Table 2. Number of sightings, total number of individuals, and number of sightings that included one calf (calves), for different monitoring years of humpback whales on the Brazilian coast.

Year	Sightings	Individuals	Calves
2002	178	271	18
2003	211	378	29
2004	264	414	19
2005	334	539	32

Abundance

The model that best fit the perpendicular distance data, based on the minimum BIC criteria, was the hazard rate key without adjustments. Figure 3 presents the distribution of perpendicular distances and fit detection function. Estimated densities of each block and year are presented in Table 3 and displayed in Figure 4. Estimated abundances are given in Table 4. Pooled abundance was estimated for 2005 at 6,251 (CV=0.16).

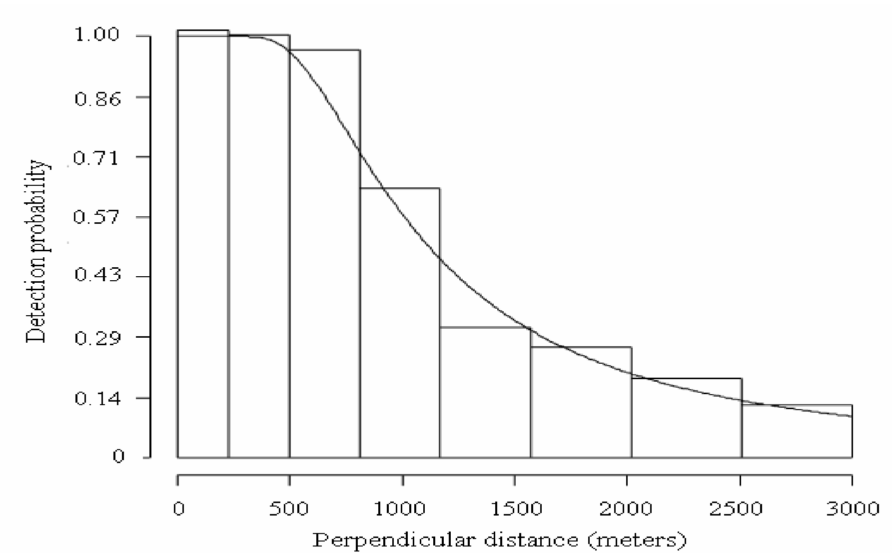

Figure 3. Perpendicular distances and fit detection function based on 964 sightings.

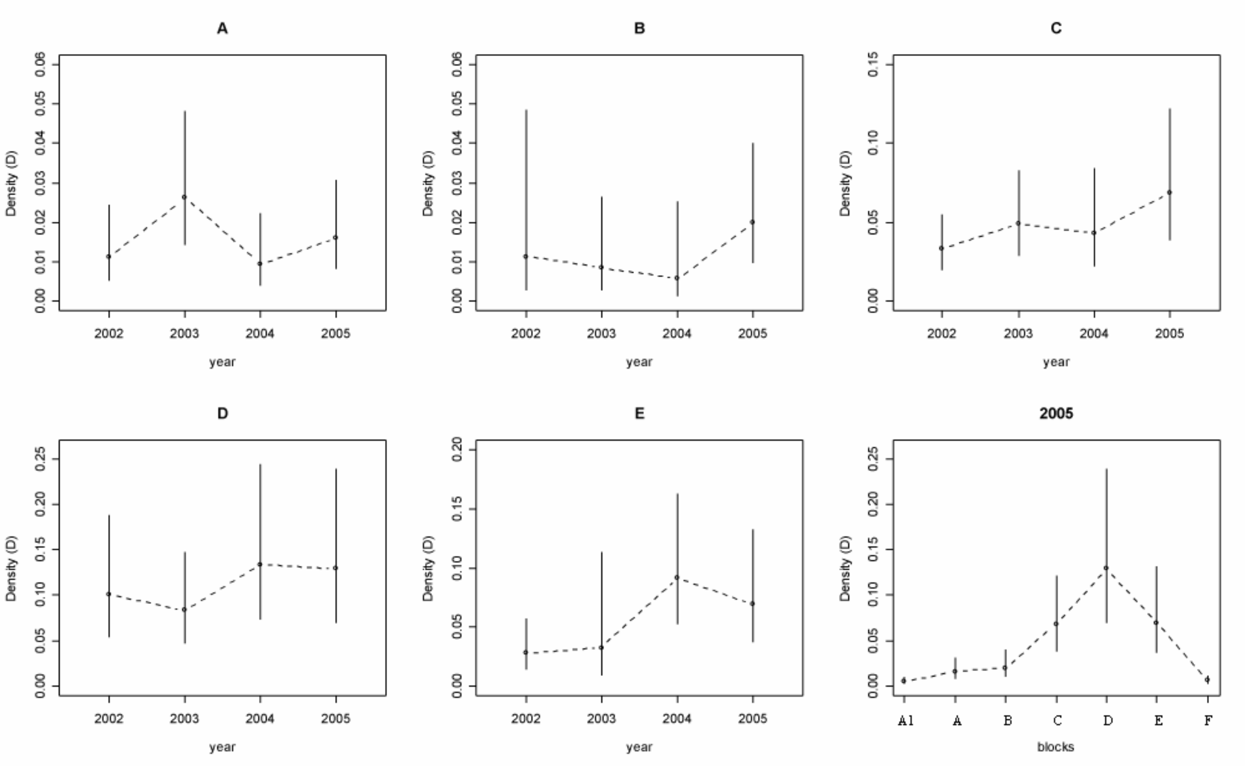

Figure 4. Density estimates and 95% confidence intervals for blocks A, B, C, D and E by year, and for blocks A1 to F in 2005.

Table 3. Humpback whales densities estimates in the different areas of the Brazilian breeding ground during the years 2002-2005.

Year	Block	Density	Estimate	%CV	95% CI	
2002	A	DS	0.0069	40.11	0.0032	0.0149
		D	0.0112	40.15	0.0052	0.0243
	B	DS	0.0069	66.57	0.0016	0.0299
		D	0.0113	66.60	0.0026	0.0487
	C	DS	0.0201	26.45	0.0121	0.0336
		D	0.0329	26.51	0.0197	0.0549
	D	DS	0.0616	31.88	0.0329	0.1152
		D	0.1004	31.93	0.0537	0.1880
	E	DS	0.0173	35.84	0.0085	0.0353
		D	0.0282	35.88	0.0138	0.0577
2003	A	DS	0.0161	31.59	0.0087	0.0296
		D	0.0262	31.63	0.0142	0.0483
	B	DS	0.0052	52.14	0.0017	0.0163
		D	0.0085	52.17	0.0027	0.0266
	C	DS	0.0300	27.20	0.0177	0.0508
		D	0.0489	27.25	0.0289	0.0829
	D	DS	0.0509	29.61	0.0285	0.0908
		D	0.0830	29.66	0.0465	0.1482
	E	DS	0.0200	62.42	0.0057	0.0699
		D	0.0326	62.45	0.0094	0.1140
2004	A	DS	0.0057	45.44	0.0024	0.0137
		D	0.0094	45.47	0.0039	0.0224
	B	DS	0.0035	68.13	0.0008	0.0154
		D	0.0057	68.15	0.0013	0.0252

	C	DS	0.0264	34.55	0.0135	0.0517
		D	0.0431	34.59	0.0220	0.0844
	D	DS	0.0817	30.83	0.0446	0.1495
		D	0.1332	30.88	0.0727	0.2440
	E	DS	0.0564	29.15	0.0319	0.0999
		D	0.0920	29.20	0.0519	0.1631
2005	A1	DS	0.0029	38.52	0.0014	0.0061
		D	0.0048	38.56	0.0023	0.0100
	A	DS	0.0098	33.96	0.0051	0.0188
		D	0.0159	34.00	0.0083	0.0307
	B	DS	0.0121	34.30	0.0060	0.0246
		D	0.0198	34.34	0.0098	0.0402
	C	DS	0.0420	29.72	0.0236	0.0748
		D	0.0686	29.77	0.0385	0.1221
	D	DS	0.0792	31.30	0.0428	0.1463
		D	0.1291	31.35	0.0698	0.2388
	E	DS	0.0428	32.45	0.0225	0.0813
		D	0.0697	32.50	0.0367	0.1327
	F	DS	0.0037	34.83	0.0019	0.0074
		D	0.0061	34.88	0.0031	0.0120

Table 4. Humpback whales abundance estimates in the different areas of the Brazilian breeding ground during the years 2002-2005, and pooled estimates for different years and the actual population size.

Year	Block	Estimate	%CV	95% CV	
2002	A	114	40.15	53	248
	B	78	66.60	18	334
	C	927	26.51	555	1549
	D	1821	31.93	973	3409
	E	499	35.88	244	1022
Pooled		3439	19.19	2146	4732
2003	A	267	31.63	145	492
	B	58	52.17	19	182
	C	1381	27.25	815	2340
	D	1505	29.66	843	2687
	E	578	62.45	166	2019
Pooled		3789	18.27	2432	5146
2004	A	95	45.47	40	228
	B	39	68.15	9	173
	C	1216	34.59	621	2382
	D	2416	30.88	1319	4425
	E	1630	29.20	920	2888
Pooled		5396	18.18	3473	7319
2005	A1	143	38.56	69	299
	A	162	34.00	84	312
	B	136	34.34	67	276
	C	1934	29.77	1086	3444
	D	2342	31.35	1266	4331
	E	1235	32.50	649	2350
	F	299	34.88	152	588
Pooled(A.B.C.D.E)		5809	17.53	3813	7805
Pooled		6251	16.40	4242	8260

DISCUSSION

Distribution

The present study showed that humpback whales are not equally distributed in coastal waters as far north as 12° 10'S in the State of Bahia until the southern limit of the State of Espírito Santo (20° 42'S). The estimated density varies among blocks (Table 3, Figure 4). The Abrolhos Bank is the preferential area of concentration, mainly the blocks C and D which have been recognized as a major calving/nursing area (Martins et al., 2001). Humpbacks tend to concentrate near islands and coral reef systems as proposed by Clapham & Mead (1999). A low density area was observed approximately between the parallels 13° 30'S to 16° 30'S.

Non-systematic sightings and strandings of humpback whales were reported for areas from Fernando de Noronha Archipelago (3ºS) to Rio de Janeiro (23ºS) (e.g. Lodi, 1994; Siciliano, 1997; Pizzorno *et al.*, 1998). So far, the southern limit for coastal distribution was mentioned based on strandings only. The aerial survey conducted in block G was the first systematic effort to confirm the southern limit considering the distribution of animals on the continental shelf. In concordance with this result is the documentation of the beginning of migration route (Zerbini, *in press*) where no animals were registered swimming southward following the coast after the Arraial do Cabo/Cabo Frio area in Rio de Janeiro (23°S).

Abundance

The assumption of no movement prior to detection is not met when whales respond negatively (move away from the observer) or positively (approach the observer) before detection. Evasive movements and positive responses result in underestimation and overestimation of abundance, respectively. We did not notice evident response of the animals related to the aircraft before sighting. Some sightings occurred when the animals were on the trackline staying on the water surface until the plane had passed.

The population was previously estimated by photo-identification data in the area of main occurrence of humpback whales off the Brazilian coast (roughly blocks C,D and E) at about 1,600 individuals (SD = 155.16) during 1995 in the Abrolhos Bank with an empirical Bayes closed mark recapture model (Kinas & Bethlem, 1998). Revised estimates based on data collected between 1996 and 2000 and using a variety of models estimate population sizes around 3,000 individuals (Freitas *et al*., 2004). For both studies data were collected within a fraction of the known stock range for this population. However, from information on density displayed in Figure 4, this unknown fraction is expected to be substantial.

The first aerial survey was performed in 2001 (Andriolo *et al*. in press) estimating the population as 2,229 (CV=0.31). The first use of line transects methodology to estimate humpback whales was performed on a vessel platform off northeastern Brazil (Zerbini *et al.* 2004). The abundance for the covered region was estimated at 628 individuals (CV = 0.311, 95% CI=366-1,091). The vessel platform provides good control of the g (0)=1 assumption because of low speed. In contrast, some other advantages are gathered using airplanes, such as size of the covered area per time. This would result in more sightings allowing for a better fit of the detection curve. Furthermore, it would give a detailed picture of the spatial distribution.

The fragility of aerial survey lays in the whales' detectability on the line. The assumption that all animals on the trackline are detected, g (0) = 1, is not appropriate for aerial surveys of humpback whales, since animals are not visible if they are not close enough to the surface. A true value of g (0) smaller than 1, when ignored, leads to visibility bias (Marsh & Sinclair, 1989) resulting in underestimated population abundance. A study developed to calculate the detection probability of harbor porpoise from aerial surveys (Laake *et al*. 1997) discusses the visibility problem for this species. In comparison, humpback whales are very conspicuous, facilitating the detection but not eliminating the problem completely. Visibility bias for marine mammals occur whenever animals are not close enough to the surface to be seen (availability bias) or when animals are visible but missed for a variety of other reasons like sun glare or observer fatigue (perception bias). To minimize perception bias, observers were trained previously to improve abilities to collect distance data and routinely switched positions during the flight.

Andriolo *et al*. (*in press*) proposed a correction factor calculated from land-based data collected at the Abrolhos Archipelago. The same estimate g (0) = 0.67, is also used here. Further improvement in this estimate is presently under investigation. However, preliminary results indicate that current g (0) might by biased upward. In the present study we estimated the population off Brazilian coast as 6,225 (CV=0.16) individuals in 2005, which is considered the most up-to-date estimate of humpback population size for the Brazilian breeding ground.

Conservation

We strongly suggest that aerial surveys, following distance sampling methodology, should be applied routinely as a tool for monitoring humpback whales in time. Once adequate and standardized protocols have been established, this methodology can be used to describe the population trend and growth rate. A consistent data collection protocol also permits the analysis on the spatial variations. These analyses can be performed with unknown correction factor g (0), as long as this factor can be assumed to be constant across estimates.

Even considering that the breeding stock A (BSA) humpback whale population is recovering and reoccupying historical areas, the total number of animals is still much smaller than the population sizes prior to whaling (Zerbini *et al*. this meeting). By registering the status and dynamic of the humpback whale population off the Brazilian coast, this study can help to identify new areas for whale watching and provide valuable information to evaluate the need for new protected areas.

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Contatc author:
Artur Andriolo
Departamento de Zoologia
Instituto de Ciências Biológicas, UFJF, Campus Universitário
36036-900, Juiz de Fora, MG, Brasil.
Phone: (032) 32293215
Fax: (032) 3229 3223
E-mail: andriolo@icb.ufjf.br