Density and abundance of the humpback whale in the Brazilian breeding ground (stock A): aerial survey, 2008.

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ABSTRACT

Population monitoring is crucial for defining the status of a species and its conservation strategies. In order to access the density and abundance of the breeding stock A of the humpback whales (*Megaptera novaeangliae*), an aerial survey was done in 2008 covering the Brazilian coast until the 500m isobath, from 5º to 24ºS. Abundance and density were estimated through multiple covariate line-transect distance sampling. More than 2,700nm were covered (84 line transects), and 308 groups of humpback whales were observed. The model that fitted better to the distance data, based on the minimum AIC, was the half-normal with the inclusion of two covariates (sighting cue and observer). The abundance of whales for the Brazilian coast in 2008, considering a g(0)=0.68, was estimated to be 9,330 whales (95%CI=7,185-13,214; %CV=16.13). Alternative estimates are provided based on different strategies of bias correction. Comparing to previous aerial surveys (2001-2005), this stock is undergoing a steady growth. The results presented here provide important subsidies for the conservation of the species in the Brazilian coast.

Keywords: aerial survey, distance sampling, covariate, humpback whale, *Megaptera novaeangliae*, abundance, breeding ground

INTRODUCTION

The humpback whale (*Megaptera novaeangliae*) populations worldwide were severely depleted by the commercial whaling in the last century (Clapham *et al.*, 1999). Recently, the species was reclassified as “Least Concern” by the IUCN (IUCN, 2008). Seven breeding stocks (A to G) are recognized for the species in the Southern Hemisphere (IWC, 2005). The breeding stock A winters in the eastern and northeastern Brazilian coast (Martins *et al.*, 2001; Zerbini *et al.*, 2004; Andriolo *et al.*, 2006), and spends the summer feeding near the South Georgia and South Sandwich islands (Stevick *et al.*, 2006; Zerbini *et al.*, 2006; Engel *et al.*, 2008; Engel & Martin, 2009).

Population studies concerning the breeding stock A have provided much information about the species, which include: abundance estimates through photo-identification and mark-recapture models (Kinas & Bethlem, 1998; Freitas *et al.*, 2004); abundance estimates through line transects and distance sampling (Zerbini *et al.*, 2004; Andriolo *et al.*, 2006; 2010); growth rates (Ward *et al.*, in press); and population dynamics (Zerbini *et al.*, in press). The more recent abundance estimate available to the breeding stock A was 6,404 whales in 2005 (95%CI= 5,085–8,068; %CV=11.6) (Andriolo *et al.*, 2010). The population was estimated to grow 7.4% per year (95%CI=0.6–14.5%) (Ward *et al.*, in press). The rate of growth of this breeding stock was estimated through inferences from relative abundance collected from boat surveys in the main breeding ground (Abrolhos Bank) from 1994-1998. Pre-whaling abundance estimate suggests that the population is still below its pre-exploitation size of 24,500 whales (Zerbini *et al.*, in press). Abundance, rate of growth and other population parameters are important to define the conservation status of a species, and are input parameters in population assessment models (Zerbini *et al.*, in press).

Distance sampling is a robust approach to obtain density and abundance estimates for a myriad of living organisms, such as plants and animals of different taxa (Buckland et al. 2001). For the humpback whales in the Brazilian coast it has been used for providing density and abundance estimates through aerial surveys in the scale of the breeding range of the species (Andriolo *et al.*, 2006; 2010). As a part of an ongoing long-term monitoring of the breeding stock A of the humpback whales, an aerial survey was conducted in the Brazilian coast in the winter of 2008. This article brings an updated population abundance estimate for the species within the winter breeding ground in Brazil, three years after the last survey of 2005.

MATERIAL AND METHODS

Study area

The study area covered the coastal waters of eight Brazilian States from 5°S to 24°S (Fig. 1). With the exception of the offshore oceanic islands, the areas surveyed covered the known distribution of humpback whales in Brazil. Moreover, the study area was extended further north and south to investigate the limits of the breeding ground of the stock A. Based on previous knowledge about the habitat use patterns of the species, the study area was limited by the 500m isobath.

The study area was divided in eight strata, covering a total area of more than 174,000km² (Tab. 1). Zig-zag and parallel line transects were designed depending on the continental shelf wideness to maximize flying effort (Fig. 1). The line transects of the strata A1 and A were placed in zig-zag shape due to the continental shelf narrowness. The southernmost stratum (G) was excluded from the analysis because no whales were observed in that region.

Table 1: Survey effort (total and per stratum) of the aerial survey in 2008.

Stratum	Brazilian States	Line transects (n)	Line transects (km)	Area (km²)
A1	RN, PB, PE, AL, SE	32	1,846	29,906
A	BA	15	623	10,181
B	BA	4	224	6,859
C	BA, ES	9	562	28,216
D	BA, ES	6	433	18,135
E	BA, ES	5	367	17,713
F	RJ	9	717	48,995
G	RJ	4	316	14,151
TOTAL		84	5,088	174,156

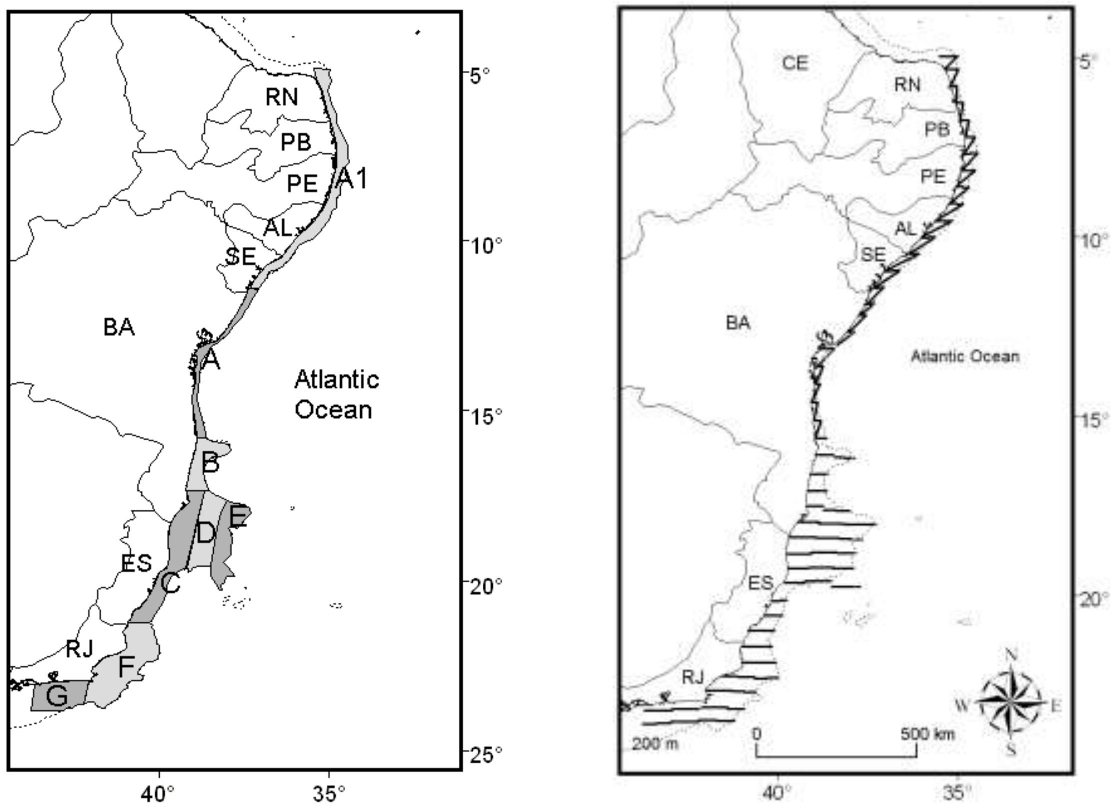

Figure 1: Strata (left) and line transects (right) of the aerial survey in 2008.

Data collection

Data were collected with a double engine aircraft (Aerocommander) equipped with bubble windows on both sides. The aircraft flew at 1,000ft of height and 90kn of speed. Four researchers alternated among four positions in the aircraft: two observers (on each side of the aircraft), data recorder and resting. Observers were oriented to search mainly ahead and below the aircraft, in order to accomplish the assumption of complete detection in the line transect. The horizon was scanned eventually in order to assure that the detection function did not fall steeply (see Buckland *et al.*, 2001). Line transects lasted approximately half an hour, after which researchers rotated the positions, always alternating an observation and the resting or data recording position.

At the beginning of each line transect or whenever conditions changed, the following sighting conditions were assigned by the observers: sun glare (%), cloud cover (%), Beaufort sea state, and a subjective sightability code (bad, regular, good and excellent). When a group of whales was observed, the vertical angle to the line transect was measured using a hand-held clinometer. The vertical angle was then transformed to the perpendicular distance using the appropriate trigonometric formula, considering the height of the aircraft. Group size, presence of calf, geographical position (GPS) and sighting cue (e.g. blow, breach, submerged, back) were also recorded for each sighting.

Data analysis

Data analysis was performed through 'multiple covariate distance sampling' - MCDS (Marques & Buckland, 2003; 2004) and the Distance software, version 6.0 (Thomas *et al.*, 2002; 2009; 2010). Perpendicular distance data was analyzed as ungrouped. Different combinations of 'key' functions (hazard-rate and half-normal) with and without series adjustments (cosine, hermite and simple polynomial) were fitted to the perpendicular distance data. The function was selected based on the minimum AIC (Akaike's Information Criterion). Suitability of the model chosen according to the AIC was judged by the Chi-square GOF, Cramer-von Misses and Kolmogorov-Smirnov tests, and the Q-Q plot (see Thomas *et al.*, 2009).

The following covariates were considered in the detection function model: individual observer; sun glare (%); cloud cover (%); Beaufort sea state (as a factor: 1-2, 3 and 4-5); sightability code (as a factor: bad-regular, good-excellent); geographic stratum; and sighting cue (grouped as: body, aerial behavior and blow). To choose the best model with covariates we adopted the stepwise approach described by Marques & Buckland (2003). The first step is to estimate *f*(0) without covariates. Then, each covariate is included separately in the model. If a model containing a covariate is selected (based on the smallest AIC), the remaining covariates are again separately added in the model with the covariate initially chosen. This procedure is repeated until no new covariates are added.

We estimated the detection function at multiple levels, fitting a global detection function with covariates, but calculated a different detection function for each stratum, depending on the covariate values (see Thomas *et al.*, 2009). This was a reasonable approach because there was not enough data to fit a separate detection function for each stratum and covariates may vary depending on the region. For example, aerial behaviors may be more common in certain areas and thus affect the detection distances accordingly. Density and abundance were calculated for each stratum and then combined to produce estimates for the whole study area. Variance for each stratum estimate was calculated with the estimator S2 for systematic sampling design following a poststratification scheme (Fewster *et al.*, 2009). Variance for the global abundance estimate was calculated using the bootstrap method.

Sources of bias

Considering that whales spend much of their time submerged, g(0) was considered to be less than 1. The method described by Barlow *et al.* (1988) was used to estimate g(0), considering the proportion of time that the whales are submerged or near the surface. The breathing rates of humpback whales around the Abrolhos Archipelago were used to infer about the average proportion of time in which a whale was submerged (Petta, 2002). The estimated g(0) was slightly higher than previously calculated for the aerial surveys of humpback whales in Brazil (Andriolo *et al.*, 2006; 2010). This change was due to the higher altitude of the aircraft in 2008 (1,000ft), which increased the mean time that an object is visible in the window from 37s to 84s. This change resulted in a negligible increase in the g(0) of 0.67 (2002 to 2005), to 0.68 (2008). Another approach, proposed by Kinas *et al.* (2006) was also considered as an alternative value of g(0)=0.432. This alternative approach was obtained based on the ratio between a population size estimate from distance sampling and an independent population size estimate based on mark-recapture methods. This alternative approach may greatly change the abundance estimate for the humpback whales, and we consider it useful because depending on the breathing rate study, the value of g(0) by the Barlow method may vary (see Discussion).

Another potential source of bias was the group size, which may be underestimated due to the high altitude and speed of the airplane. The group size estimated in the aerial survey was 1.61 whales (SD=0.11), which is substantially below and less variable than the group size estimated through boat cruises during the same period in the Abrolhos Bank (mean group size=2.33 whales; SD=0.99). Different studies suggest that the mean group size of the humpback along its breeding distribution does not vary (Zerbini *et al.*, 2004; Rossi-Santos *et al.*, 2008; this study). There is evidence that the presence of calves is also underestimated through aerial surveys. A proposed alternative to deal with this bias was to analyze the data as object (without considering the cluster size) and use a multiplier with the mean group size collected during boat cruises in the same period of the aerial survey. For this approach, we considered the g(0) calculated through de Barlow method.

RESULTS

The aerial survey was done in the peak of the breeding season, from 6 September to 3 October 2008, and was completed after 10 non-consecutive sampling days. Adverse climatic conditions precluded the conclusion of the survey earlier in September. Stratum G and the five last tracklines of the Stratum F were concluded on the beginning of October.

The survey plan designed (with 84 line transects) was fully completed, with more than 2,700nm or 5,080km traversed. A total of 308 groups of humpback whales were observed on-effort, with 4% containing a calf (*n*=12). The average group size was 1.6 whales (SD=0.11; mode=1).

Distance data was truncated after 3,500m from the aircraft (*n*=281 groups after truncation). The half-normal with no adjustments and the inclusion of two covariates (sighting cue and observer) was selected among the other models. Q-Q plot, Kolmogorov-Smirnov goodness-of-fit ($p>0.05$) and Cramer-von Misses tests ($p>0.05$) suggested an adequate fit of the distance data to the model selected. The Chi-square GOF test was significant ($p<0.05$), suggesting a poor fit of the data, but the classes with significant deviance from expected were the furthest from the trackline. The effective strip width (ESW) was 1,526m (95%CI=1,376-1,692). The estimated mean detection probability ($\hat{p}$) was 0.44 (%CV=5.25).

The effect of the sighting cue in the detection distances was evident, and based on the minimum AIC, all the models including this covariate were selected based on a ΔAIC>20. Aerial behaviors and blows were detected at further distances than the body of the whale submerged or on the surface (Figure 2). Individual observer also affected the detection distances and were included as a covariate (ΔAIC>3).

A total of 9,330 whales was estimated for the Brazilian coast (stock A) in 2008 ($\%CV_{bootstrap}$=16.13; $95\%CI_{bootstrap}$=7,185–13,214; Table 2). Density for the whole study area was estimated to be 0.058 whales/km^2 (95% $CI_{bootstrap}$=0.045–0.083). Density varied across different strata, being highest in the strata that cover the Abrolhos Bank (C, D, E), and decreasing gradually with distance from the bank.

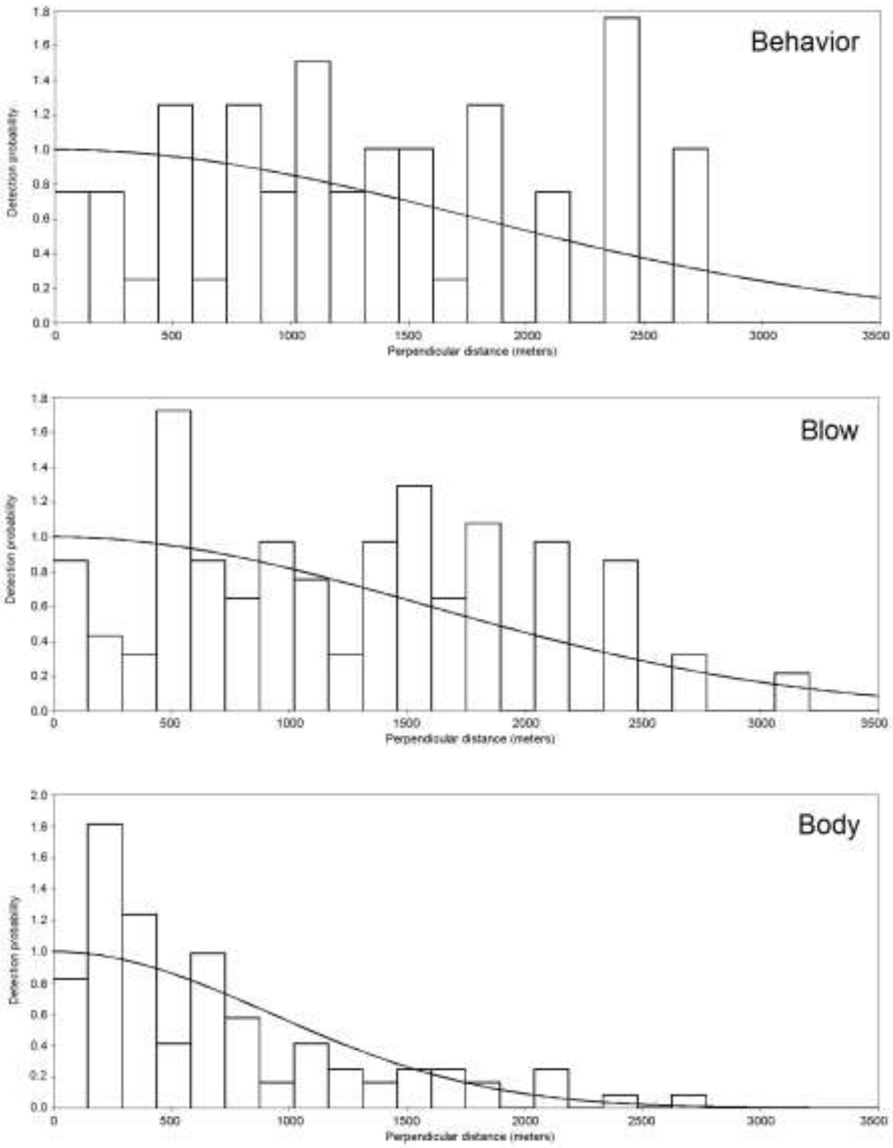

Figure 2: Fitted detection probabilities (half-normal curve) for different sighting cues of the humpback whale in the Brazilian coast during the aerial survey of 2008.

Table 3: Density and abundance of the humpback whale in different strata surveyed in the Brazilian coast through the aerial survey in 2008.

Stratum	*Density (whales/km²)*	*CI 95%*	*Abundance*	*95%CI*	*%CV*
A1	0.011	0.006–0.022	334	173–643	34.06
A	0.024	0.010–0.058	248	104–593	44.60
B	0.042	0.016–0.111	291	111–762	45.74
C	0.105	0.058–0.191	2,962	1,629–5,386	30.25
D	0.185	0.089–0.386	3,360	1,611–7,006	34.74
E	0.094	0.050–0.179	1,670	877–3,179	32.08
F	0.009	0.003–0.029	465	151–1,433	58.11
TOTAL	0.058	0.045–0.083	9,330	7,185–13,214	16.13

Alternative abundance estimates were calculated considering different approaches and bias correction. All the approaches resulted in higher abundance estimates than the approach used in previous years (Andriolo *et al.*, 2006; 2010) and above. The population abundance estimates for the breeding stock A varied from a minimum of 9,330 to 15,128 (Tab. 4).

Table 4: Alternative abundance estimates for the humpback whale in the Brazilian coast through the aerial survey in 2008, considering different bias correction approaches.

Bias correction approach	*Point estimate*	*95%CI*
Aerial group size + g(0) = 0.68	9,330	7,185–13,214
Boat group size + g(0) = 0.68	12,404	8,108–16,210
Aerial group size + g(0) = 0.43	15,128	11,379–22,294

DISCUSSION

Assumptions

Three main assumptions are necessary for reliable estimates based on distance sampling (Buckland *et al.*, 2001): (1) objects on the line are detected with certainty; (2) objects are detected at their initial location; and (3) perpendicular distance measurements are exact. The exploratory histograms of the distance data indicate that the first assumption was met. The histogram showed that no considerable underdetection occurred in the first classes, and a wide shoulder was evident. Responsive movements were unlikely to be caused by the airplane, even when animals were close to the trackline. Finally, the clinometer angles near the horizon include a wider range of perpendicular distances, and thus some rounding was common in the further classes of distance. Q-Q plots, however, showed no pronounced steps at any distance, indicating that the rounding would not require the distance data to be grouped for analysis.

Marsh & Sinclair (1989) defined two types of bias: perception bias (missed animals that were potentially visible to observers but were not seen) and availability bias (missed animals that were not available because they were out of sight, such as a submerged whale). Submerged animals, underestimation of group size, and groups missed by the observers are all potential bias that lead to the underestimation of the point abundance estimate, and contribute to its uncertainty. The problem of missed animals in aerial surveys is a matter of great concern for studies on cetacean population ecology (Laake *et al.*, 1997; Hiby & Lovell, 1998; Hain *et al.*, 1999; Paxton *et al.*, 2006).

We used the Barlow *et al.* (1998) method for g(0) correction as a default to allow comparisons with the earlier aerial surveys (Andriolo *et al.*, 2006; 2010). This method considers the proportion of time in which a whale is submerged, and thus, unavailable for the observer. However, uncertainties related to this method in the present case should be highlighted. Depending on the study used to describe humpback whales' breathing behavior in the Brazilian breeding ground, different values for g(0) may be obtained. At least three alternative studies have been conducted in the area so far. Petta (2002) observed 120 groups of humpback whales from a land-based station in the Abrolhos Bank (see Morete *et al.*, 2008), with a total observation time of 245h. To allow comparisons with earlier aerial surveys, this study was considered in the present abundance estimates. According to Petta (2002), whales spent an average of 34% of their time submerged. Peres (2006) used the same data set, but filtered the groups which were observed for more than 20min, considering in the analyses 73 groups, observed for more than 97h. Peres (2006) also considered different definitions of diving, based on a minimum interval between two consecutive blows. It is a reasonable rationale because when observing from the sky, a whale can still be detected when it is submerged, but near the surface. This author's estimations of average proportion of time submerged varied between 44 and 57%, depending on the definition of diving used. Finally, Abreu (2009) analyzed data collected from boat surveys in the Abrolhos Bank, and followed 212 groups of whales, during 122h of observation. Depending on the definition of diving, the average proportion of time submerged varied between 18 and 30%. Values for g(0) through the Barlow method may vary from 0.42 to 0.85, according to the study considered. This uncertainty is crucial when the parameter of interest is the abundance, such as this case. Therefore, we recommend further studies concerning the diving behavior of the humpback whales or, preferably, other approaches for the estimation of g(0), such as double platforms or other experiments (*e.g.*, Laake & Borchers, 2004; Paxton *et al.*, 2006).

Covariates

Many covariates may affect the perpendicular distance of detection of cetaceans (Barlow *et al.*, 2001). Andriolo *et al.* (2010) have included the Beaufort sea state and geographic strata as covariates on the detection function of the aerial surveys of humpback whales from 2002 to 2005. Beaufort sea state also influenced detection probabilities during boat-based surveys of cetaceans in the eastern tropical Pacific (Barlow *et al.*, 2001). In the present work, models including Beaufort sea state and geographic strata as covariates were not supported, suggesting a negligible effect on the detection probabilities.

Sighting cue had a significant effect on the detection function. Other studies also suggested that this covariate may affect detection probabilities (Barlow *et al.*, 2001; Thomas & Buckland, 2003). As expected, the body of the whale was detected nearer to the trackline than blows or aerial behaviors. Furthermore, aerial behaviors were detected at larger distances than blows. The inclusion of this covariate resulted in considerably higher abundance estimate and lower detection probability than the model with no covariates.

The inclusion of the observer effect as a covariate also resulted in a better model of detection probability. Barlow *et al.* (2001) found a significant effect of the observer in the detection probabilities in a boat-based cetacean survey. Each person may observe and search for animals through different manners, despite training sessions conducted prior to the survey. The effect of this covariate was not as strong as the sighting cue, but models including it were supported by the smallest AIC. Subtly higher abundance estimate and lower detection probability was obtained with the inclusion of the observer in the model.

Abundance estimates

Different approaches for bias correction of the abundance estimates of the humpback whale in the Brazilian coast resulted in point estimates ranging from 9,330 to 15,128 whales. Based on a previous boat-based estimate through distance sampling in the northeastern Brazil, which correspond to our Stratum A1, it is also possible to infer about the magnitude of the bias in the aerial surveys. A total of 628 whales (95%CI=327-1,157; %CV=33.5) was estimated for the area in the year 2000 (Zerbini *et al.*, 2004). The point estimates to the same area (Stratum A1) obtained from the aerial surveys in 2005 and 2008 were 147 and 334 whales, respectively (Andriolo *et al.*, 2010; this work). Considering that a boat platform offers a good control of g(0), and projecting the estimated population growth (7.4% - Ward *et al.*, in press), we may obtain the proportion of detected animals through the aerial surveys. Grossly, this proportion was 0.16 for 2005 and 0.30 for 2008, suggesting a significant underestimation of the abundance in this Stratum and possibly the whole aerial survey. Therefore, the highest and alternative abundance estimate of 15,128 whales is also plausible. Without further studies in order to elucidate the uncertainty of the g(0), the more conservative abundance estimation of 9,330 whales should be considered. Comparing the actual estimate with the previous abundance estimate (6,404 whales in 2005), the Brazilian breeding population is undergoing a steady growth.

Conclusions

The aerial surveys to estimate the density and abundance of humpback whales in the Brazilian coast are important for providing a snap shot of the whole breeding range of the stock A. The abundance in 2008 was estimated to be 9,330 whales (95%CI=7,185–13,214; %CV=16.13). Comparing to previous aerial surveys (2001-2005), the breeding population of Brazil is increasing. Alternative bias correction approaches suggested that abundance of the Brazilian population is underestimated, and thus, further studies are necessary for reducing uncertainties associated with g(0) estimation and other potential sources of bias.

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