Winter distribution and abundance of humpback whales (*Megaptera novaeangliae*) off Northeastern Brazil

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ABSTRACT

The Brazilian coast is recognised as a Southern Hemisphere humpback whale (*Megaptera novaeangliae*) wintering ground (IWC breeding stock 'A'). The northeastern coast of Brazil was an important whaling ground in the 20th century. Shipboard sighting surveys were conducted in this area to evaluate large whales' distribution and density in 1999 and 2000. Humpback whale sightings ($n = 81$, 153 individuals) were recorded using line transect methodology. Data from the 2000 survey were used to estimate abundance over the continental shelf from 5 to 12°S (20,040km^2). A total of 872.1km were surveyed on effort. Humpback whales were distributed from nearshore to the 800m isobath, but 93.5% of sightings were recorded shoreward of the 300m isobath. The relatively high density off northeastern Brazil suggests that the species is reoccupying historical areas of distribution and the presence of newborn individuals indicates that calving and nursing occur in the area. The hazard rate model best fit perpendicular distance data. Abundance was estimated at 628 individuals (CV = 0.335, 95% CI = 327-1,157). This estimate probably corresponds to only a portion of the breeding population. Therefore, additional studies must be conducted to estimate the total size of the humpback whale population wintering off Brazil.

KEYWORDS: HUMPBACK WHALE; DISTRIBUTION; BREEDING GROUNDS; ABUNDANCE ESTIMATE; SURVEY-VESSEL; SOUTHERN HEMISPHERE; SOUTH AMERICA

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) occur in all major oceans from polar and sub-polar regions to the Equator. In the Southern Hemisphere they migrate from summer feeding grounds in the Antarctic to mating and calving grounds in tropical and subtropical regions (e.g. Dawbin, 1956; Chittleborough, 1965; Mackintosh, 1965), where they tend to concentrate near islands and coral reef systems (e.g. Clapham and Mead, 1999). 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; Tønnessen and Johnsen, 1982; Best, 1994). About 200,000 whales were taken both in the Antarctic and the breeding grounds after 1900 (Findlay, 2001), causing declines of populations to small percentages of their pre-exploitation levels (Gambell, 1973).

The International Whaling Commission (IWC) 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. Historically, this population was believed (e.g. Slijper and Utrecht, 1959; Slijper, 1962; 1965; IWC, 1998) to migrate to feeding grounds in IWC Management Areas I (the Antarctic Peninsula) and II (the South Georgia Islands). Recent studies, however, have not provided clear evidence that whales breeding off Brazil

indeed migrate to these areas. Moore *et al.* (1999) recorded a notably small number of humpback whales around the South Georgia Islands within a period of 10 years and suggested that this population has not recovered after being exploited in the region. This contrasts with the apparent growth of the humpback whale population off the coast of Brazil (Siciliano, 1997) and may suggest that these whales migrate somewhere else in the Antarctic Ocean. In addition, photo-identification studies, analysis of fluke colouration patterns and molecular genetic data indicated that whales feeding near the Antarctic Peninsula were linked to breeding grounds in the eastern South Pacific (breeding stock 'G') and that whales from the coast of Brazil are possibly linked to populations in Africa and Oceania (e.g. Rosenbaum *et al.*, 1995; 2000; Muñoz *et al.*, 1998; Engel *et al.*, 1999; Olavarría *et al.*, 2000; Dalla-Rosa *et al.*, 2001).

Humpback whales were harvested by open boat whalers off the southern and central coast of Brazil between the 16th and the early 20th centuries (e.g. Ellis, 1969; Lodi, 1992). Modern whaling operations took humpback whales off the coast of Cabo Frio (~23°S) from 1960 to 1963 and off the coast of Costinha (~7°S) from 1910 to 1964 (Paiva and Grangeiro, 1965; 1970; Williamson, 1975). Additional whales may have been taken illegally off the central coast of Brazil by the former Soviet Union fleet, after the species was protected in the middle 1960s (see Yablokov *et al.*, 1998). The total number of whales caught is unknown. Bureau of International Whaling Statistics (BIWS) catch data account

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for about 1,600 individuals, but this figure does not consider individuals taken by open boat fishers or by the modern whaling industry from 1929 to 1946.

Current information on the distribution of humpback whales shows that the species is abundant at Abrolhos Bank, 15°-18°S (e.g. Siciliano, 1995; Bethlem *et al.*, 1996; Martins *et al.*, 2001). Occasional sightings and strandings have been reported for the Fernando de Noronha Archipelago (~3°S) and in southern and southeastern Brazil (e.g. Lodi, 1994; Siciliano, 1997; Pizzorno *et al.*, 1998). However, distribution and density are still poorly known for a great portion of the Brazilian coast. Population size estimates are available only for the Abrolhos Bank area (Kinas and Bethlem, 1998).

From 1998 to 2001, cetacean surveys were conducted off the northeastern coast of Brazil. The survey area included the former whaling ground off Costinha (~7°S), Paraíba State, where a substantial number of large whales were captured in the past. The objective of this study was to verify the winter distribution and density of large whales in the former whaling area. In this paper, only data on humpback whales collected during the 1999 and 2000 cruises are presented. Information on other species is summarised in da Rocha *et al.* (1999), Siciliano *et al.* (2000), Zerbini *et al.* (2000) and Andriolo *et al.* (2001).

METHODS

Planning the surveys, research area and track design

Surveys were planned to take place at the peak of abundance of large whales off northeastern (NE) Brazil (August-November, Paiva and Grangeiro, 1965; 1970;

Williamson, 1975) and were scheduled according to ship availability. Cruises were conducted on board the Brazilian Navy ship *Almirante Graça Aranha* on 6-27 September 1999 and from 14 August to 1 September 2000. Planning meetings to discuss survey design and protocols were held three days before the cruises started.

The study area included the former whaling grounds off NE Brazil and is illustrated in Fig. 1. The 1999 study was limited to the 5° and 10°S parallels and the coastline and the 33°W meridian. Given the spatial differences in large whale distribution observed in 1999, the 2000 cruise was stratified into two blocks: an oceanic block that covered the same study area as the 1999 survey, except that its western boundary was moved to the 500m isobath; and a coastal block that comprised the continental shelf (as far offshore as the 500m isobath[1]) that was extended further south to 12°S parallel (Fig. 1). This block was relatively long (740km) and narrow (22-50km) compared to the oceanic stratum. A saw-tooth transect design was adopted in all surveys (Fig. 2).

Survey protocol

The cruises were divided into two phases: training and actual line transect survey. The former took place at the beginning of each cruise and the objectives were to train observers and simulate the sampling routine adopted during the surveys. The 'flying deck' was used as the observation platform and was located 13.8m above the surface. Cetaceans were continuously searched from 05:30hs to 17:00-17:15hs. Eight

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[1] The offshore limit of the continental shelf was considered the 500m isobath to assure that sightings recorded near the shelf break (usually the 200m isobath) were included in the analysis.
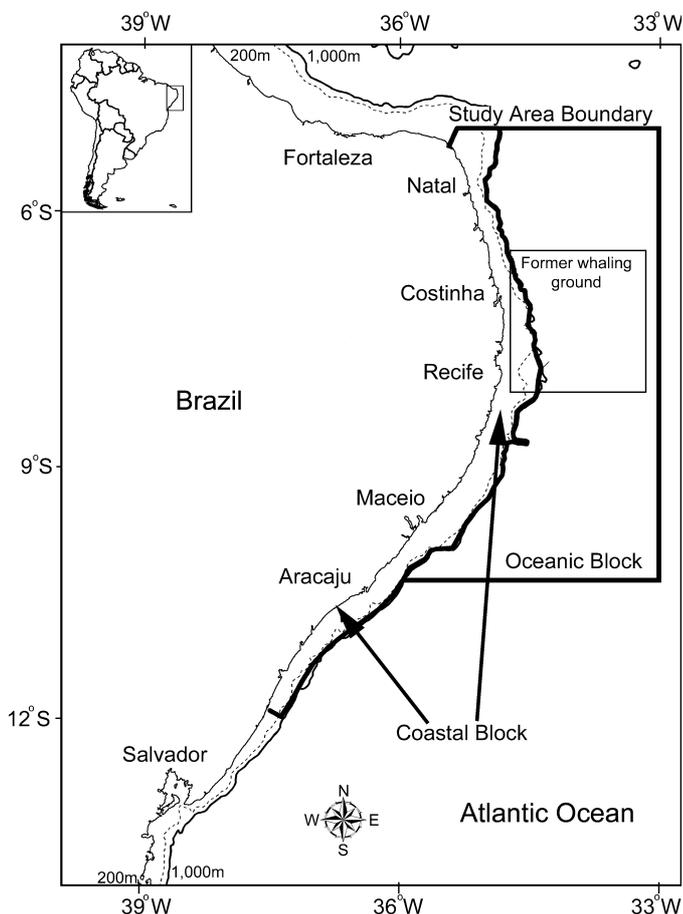

Fig. 1. Study area and blocks of the cetacean sighting surveys conducted off NE Brazil in 1999 and 2000.
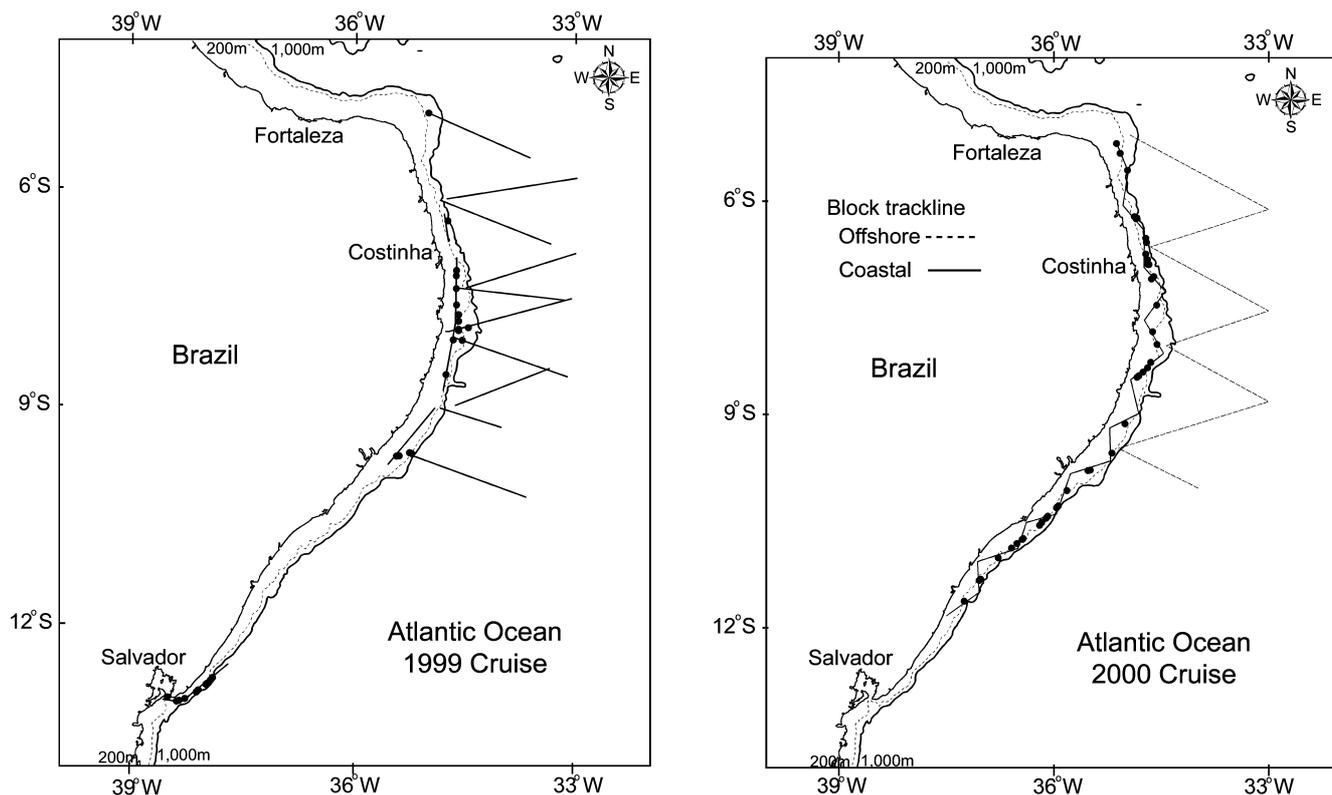
Fig. 2. Trackline design and humpback whale sightings during the 1999 and 2000 cruises conducted off NE Brazil.

(1999) or nine (2000) scientists rotated through four observation positions. A full observation period lasted two hours (30 minutes in each position) and was followed by a two-hour resting period. One scientist at port and another at starboard searched from 0° (the bow) to 90° while the other two observers searched a narrower sector, between 40° port and 40° starboard of the trackline. A fifth observer acted as data recorder and was not involved in searching, but aided the observer team in identifying species, tracking detected groups and estimating group size and composition. The team of observers was randomly selected for each day of survey.

Cetaceans were searched for using reticuled binoculars (80-90% of the time) and by naked eye (10-20% of the time). Immediately after a sighting was detected, the number of reticules between the horizon and the sighting and the radial angle between the group sighted and the ship's track were recorded on a standard data form. Environmental variables such as cloud cover, wind strength and direction, sea state (Beaufort scale) and sea surface temperature were also recorded. Sightings made while the observer team was on-watch were considered 'on effort'. Those recorded by the ship's crew, during training days, during the night or during off-watch periods were considered 'off effort'. Search was abandoned when the weather and visibility conditions were poor and sea state was above Beaufort 5. The 1999 and 2000 surveys were conducted in closing and passing mode, respectively (e.g. see Matsuoka *et al.*, 2003, p.179).

Data analysis
Distribution and group characteristics
The distribution of humpback whales was studied by pooling data from the two years. Sightings collected during training and actual survey, as well as *en route* to and from the ports were included in this analysis. Differences in latitudinal distribution were investigated only with data collected

during the 2000 cruise. The sighting rate of whales seen within 1.5km of the trackline was considered an index of density. The study area was then divided into four equally spaced latitudinal intervals and the expected and observed number of whales in each interval was compared. The expected number of whales was assumed to be uniform and was calculated by multiplying the overall encounter rate by the survey effort in that interval. A chi-square test was used to investigate significant differences in relative density.

Abundance
Abundance was derived using line transect methods (Buckland *et al.*, 2001) with data from the coastal block (area = 20,040km^2) of the 2000 cruise because it was designed to uniformly cover the continental shelf. Nineteen transects were surveyed in this block at a speed of 9-11 knots, resulting in a total trackline of 872.1km.

Radial distance of each sighting was calculated using the 'approximation 2' suggested by Lerczak and Hobbs (1998, erratum).

Sightings recorded as 'confirmed humpback whales' and 'probable humpback whales' were included in the analysis. It is reasonable to pool these records since the only other large whale species sighted in the coastal block, the Antarctic minke whale (*Balaenoptera bonaerensis*) and the dwarf minke whale (*B. acutorostrata*), present behaviour and blow characteristics distinctive from humpback whales.

Abundance was estimated as:

$$\hat{N} = \frac{A \cdot n \cdot \bar{s}}{2 \cdot L \cdot ESW \cdot \hat{g}(0)}$$

where:
A   is the survey area;
n   is the number of sightings recorded 'on effort';

$\bar{s}$ is the mean group size;
L is the total trackline length surveyed;
ESW is the effective strip width;
$\hat{g}(0)$ is the estimated probability of detection on the trackline (assumed to be equal to 1 here).

Data analysis was undertaken with the software *Distance 3.5* (Thomas *et al.*, 1998). Perpendicular distance data were truncated at 3km and *ESW* was estimated by modelling ungrouped data using the half normal and hazard rate functions. Cosine and hermite polynomial series expansions (for half normal function) and cosine and simple polynomial adjustments (for hazard rate) were also considered in the set of candidate models. Model selection uncertainty was incorporated in the analysis by running 999 bootstrap replicates and letting the Akaike Information Criterion (AIC) (Akaike, 1973) select the best model for each bootstrap replicate. Variance and confidence intervals were also obtained from the bootstrap replicates.

RESULTS

The total number of humpback whale sightings and individuals observed in 1999 and 2000 is summarised in Table 1.

Table 1

Humpback whales sighted off NE Brazil in 1999 and 2000.

Year	On effort		Off effort		Total	
	No. of sightings	No. of indiv.	No. of sightings	No. of indiv.	No. of sightings	No. of indiv.
1999	13	25	18	31	31	56
2000	42	80	8	17	50	97
Total	55	105	26	48	81	153

Distribution

Whales were regularly found along the survey area (from 5° to 12°S, Fig. 2) from close to shore to depths of up to 750m. Most groups sighted were observed within the 200m isobath and those with calves tended to occur in shallower waters than groups without calves (Fig. 3). No sightings in deeper, oceanic waters were observed. There was no significant difference in the relative density of whales across the study area (Table 2, $\chi^2 = 2.71$, df = 3, $p = 0.439$).

Group size and composition

Group sizes of humpback whales ranged from 1-4 in 1999 and 1-6 in 2000; the modal group size was two in both years. Group composition is presented in Table 3. Overall, calves were observed in 29.5% of the humpback whale groups sighted. The proportion of calves/group was smaller in 1999 (20.7%, $n = 31$) than in 2000 (35.6%, $n = 45$), but this difference was not statistically significant ($\chi^2 = 1.66$, df = 1, $p = 0.198$). Newborn individuals were observed in 80% of the triads, 50% of the groups with four individuals and 37.5% of the groups with two whales.

Abundance

The hazard rate model with no adjustment best fitted perpendicular distance data. Abundance was estimated at 628 individuals (CV = 0.335, 95% CI = 327-1,157). Table 4 summarises encounter rate, average group size and model parameters. Fig. 4 presents the distribution of perpendicular distances and fitted detection function.
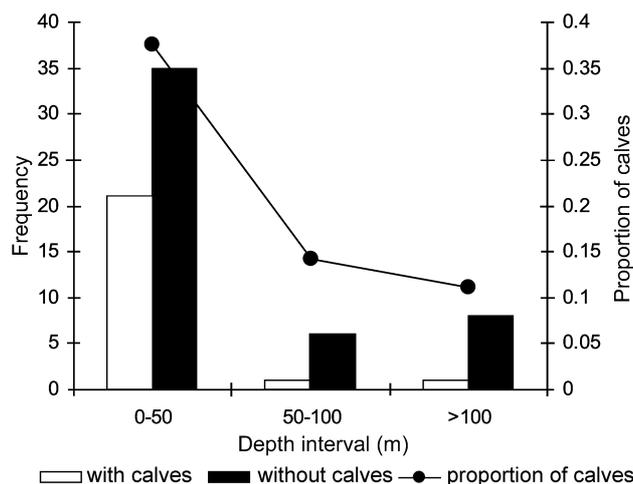

Fig. 3. Depth distribution of humpback whale groups off NE Brazil, and proportion of calves per depth interval.

Table 2

Observed and expected number of humpback whales per latitudinal interval off NE Brazil.

Interval	Observed	Expected	χ^2 value
5-6°45'S	5	6.4	0.30
6°45'-8°30'S	6	6.9	0.12
8°30'-10°15'S	7	8.7	0.33
10°15'-12°S	12	8.0	1.96
Total	30		$\chi^2 = 2.71$

Table 3

Group composition of humpback whales recorded off NE Brazil in 1999 and 2000.

Group composition	1999	2000	Total
Group of one	11	16	27
Mother/calf	6	9	15
Group of two (no calf)	10	12	22
Mother/calf/escort	0	6	6
Competitive group	2	1	3
Competitive group with a calf	0	1	1
Undefined	2	5	7
Total	31	50	81

DISCUSSION

Distribution

The current winter distribution of humpback whales in the southwestern Atlantic Ocean has been better understood in recent years. Whales have long been regularly found at Abrolhos Bank, ~ 15-18°S (Siciliano, 1995; Freitas *et al.*, 1998), but more recent records have shown that the species is more widely distributed along the South American coast. Sightings have been reported from São Paulo (24°S), southeastern Brazil, to the northern coast of Bahia, 12°S (Siciliano *et al.*, 1999) and strandings were reported as far south as Rio Grande do Sul, 34°S (Siciliano, 1997). Some records have been reported for oceanic islands such as the Archipelagos of Fernando de Noronha (3°51'S) and Trindade and Martin Vaz (20°30'S) (Lodi, 1994; Siciliano *et al.*, 1999). The present study shows that humpback whales

Table 4

Estimated model parameters, density and abundance of humpback whales off NE Brazil.

Parameter	Point estimate	% CV	95% CI
$f(0)$	0.719	22.8	0.456-1.135
p	0.464	22.8	0.294-0.731
ESW (km)	1.39	22.8	0.881-2.194
Encounter rate (n/L)	0.045	23.31	0.024-0.066
Density of groups (groups/km^2)	0.016	32.60	0.008-0.029
Average group size (s)	1.95	8.83	1.63-2.32
Density of individuals (ind/km^2)	0.031	32.78	0.016-0.059
Abundance	628	33.46	327-1,157
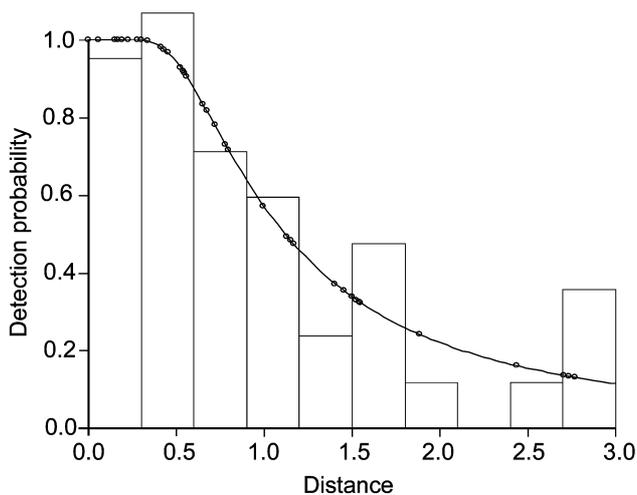
Fig. 4. Hazard rate model fit to humpback whale perpendicular distance (dots represent expected detection probability for individual sightings).

are regularly found in coastal waters as far north as 5°S along the northeastern coast of Brazil. In addition, a whale stranded in Ceará (3°43'S, 38°30'W), west of the northwestern tip of South America (Furtado-Neto *et al.*, 1998), suggests that humpback whales may be moving west along the northern coast of Brazil.

Although the distribution of humpback whales is better known, the extent of the calving grounds is not yet clear. Given its shallow and relatively protected waters, the Abrolhos Bank has been recognised as a major calving/nursing area. Siciliano (1997) reported that females with calves corresponded to 33 and 49% of the groups in the area during the breeding seasons of 1989 and 1990 respectively. The present study shows that newborn individuals are also present in a high portion of the groups observed off NE Brazil, indicating that this region has also been used as a calving ground. The proportion of groups containing newborns (20.7-35.6%) was not as high as observed for the Abrolhos Bank, but was higher than other Southern Hemisphere humpback whale breeding grounds such as Mozambique (14.8%; Findlay *et al.*, 1994) and Ecuador (17%; Scheidat *et al.*, 2000). The high proportion of newborn whales off NE Brazil, contrasts with data collected during the whaling period (1914-1985). They indicate that few whales taken in Costinha were pregnant or were accompanied by calves. In addition, biological inspection of the whales captured from 1947 to 1963 found only one pregnant individual among the 76 females taken (data from Bureau of International Whaling Statistics [BIWS]/IWC). In

addition, calves were observed in only three out of 46 groups sighted during whaling operations from 1979 to 1984. The proportion of females with calves was not as high or is unknown for other areas of the Brazilian coast. Lodi (1994) reported that two out of 11 groups (18%) observed in Fernando de Noronha from 1989 to 1993 included calves. However, humpback whales are not regularly seen in the area (F. Camargo, pers. comm.). Newborn individuals have also been recorded south of Abrolhos Bank suggesting that births also take place there. Sightings of females with calves have been regularly reported by local inhabitants or boat operators cruising the coast of Espírito Santo and northern Rio de Janeiro (Pizzorno, unpublished data). In addition, a relatively high proportion of the incidental catches recorded in this area corresponded to calves (Siciliano, 1997; Zerbini and Kotas, 1998). Recently recorded distributional data therefore indicate that the humpback whale calving grounds range from about 5 to 21°S in the western South Atlantic Ocean.

Humpback whales were captured off NE Brazil since early in the 20th century. Whaling statistics revealed that an annual average of 150 whales was taken in the period 1911-1914/1924-1928 (BIWS/IWC; Williamson, 1975). This number dropped to about 12 individuals per year from 1947 to 1963, clearly reflecting the overexploitation of the stock (see also Pinedo, 1985). Whaling operations continued in the area up to 1985 and sightings recorded by the catcher boat from 1979 to 1984 (Antonelli *et al.*, 1987; Siciliano, 1997) revealed that humpback whales were rare in the area by the end of the whaling period. Despite the high observation effort (the season was five months long and the catcher operated almost every day), an average of only eight sightings per season was recorded at that time. Current data show that abundance is greater off NE Brazil, indicating the species has reoccupied this historical area of distribution.

It is most likely that whales moving to the northeastern coast of Brazil are passing through the Abrolhos Bank on their way north. Freitas *et al.* (1998) reported that a whale photographed off Salvador (12°S) was previously recorded off Abrolhos in the same season. This suggests that there is some degree of movement between the two areas. However, alternative migration routes (e.g. whales migrating through offshore waters) cannot be ruled out. The lack of photo-identification effort precludes any conclusion regarding movements of whales visiting NE Brazil. Such studies should be initiated in the area.

Abundance estimates

The abundance estimate reported in this paper corresponds to a fraction of the stock size of whales wintering off the coast of Brazil. The surveys covered the northern portion of

the humpback whale area of distribution (5-12°S) during the breeding season. During this period, whales are known to be found as far south as about 21°S (Pizzorno, unpublished data). The 2000 cruise, from which estimated abundance was obtained, was carried out in late August to early September, approximately the peak of abundance of humpback whales off Brazil. Whaling statistics indicate that catches off Costinha peaked in August (data from the BIWS/IWC) while sighting frequency off Abrolhos Bank peaked in early September (Siciliano, 1997). This suggests that the cruise covered the area when density was expected to be the greatest.

In the present study, probability of detecting whales on the trackline [$g(0)$] was considered to be unity (as assumed by line transect theory), but this assumption could lead to a slight downward bias in the abundance estimation because some whales might have been undetected. This problem was possibly minimised by allocating more effort to the trackline. In addition, it is believed that in general, $g(0)$ for humpback whales is very close to one. Barlow and Gerrodette (1996) and Barlow (1997) estimated that $g(0)$ for groups ranging from 1-3 individuals was 0.9 and for groups with more than four whales was one.

The total size of the stock breeding along the coast of Brazil is unknown. Kinas and Bethlem (1998) estimated that about 1,600 individuals occurred in the Abrolhos Bank in the mid 1990s using an empirical Bayes closed mark-recapture model. The present work provides an estimate for a previously unsurveyed area, but the two estimates cannot be combined because sampling periods were relatively far apart and because sampling conditions and assumptions are different. In addition, it is possible that an unknown proportion of whales heading to or from NE Brazil may move through the Abrolhos Bank and hence may have been captured in the photo-identification surveys.

Total stock size is necessary for any population assessment work, and it is recommended that both line transect and mark recapture survey efforts be expanded to estimate population size and trends of humpback whales off Brazil.

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