The abundance of blue whales on the Madagascar Plateau, December 1996

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ABSTRACT

As part of the International Whaling Commission's SOWER blue whale research programme, two sighting vessels, the *Shonan Maru* and the *Shonan Maru No.2*, surveyed the Madagascar Plateau between 25° and 35°S, 40° and 45°E, in December 1996. A total of 95 sightings of 110 blue whales (assigned in the field as pygmy blue whales – see discussion), 14 sightings of 21 blue whales (subspecies undetermined) and 12 sightings of 13 'like blue' whales was made in 23 days. In the first half of the survey, the whole research area was covered in a mainly pre-determined zigzag search pattern, and the associated sightings and effort have been used to derive density estimates for blue whales for the area. Sightings in the second half of the survey, where effort was directed at blue whale concentrations, have only been used to provide supplementary data for calculation of the effective search half-width and mean school size. The resulting population estimate is 424 (CV = 0.42), or 472 (CV = 0.48) whales when 'like blue' sightings are included. Dive times and surfacing behaviour recorded in just over 21h of monitoring suggest that the assumption that all groups on the trackline were seen ($g(0) = 1$) is reasonable. As the geographical extent of the survey area was substantially less than that of past catches of blue whales in the region in December, this estimate must refer to only a portion (possibly about one third) of the total population. Some evidence of feeding on euphausiids in the region was detected, possibly as a consequence of a localised upwelling cell at the southern tip of Madagascar.

KEYWORDS: ABUNDANCE ESTIMATE; BLUE WHALE; INDIAN OCEAN; LINE TRANSECT; RESPIRATION; FEEDING

INTRODUCTION

In the Southern Hemisphere there are two generally recognised 'forms' of blue whales (*Balaenoptera musculus*), which have been taxonomically referred to the sub-species Antarctic blue whale *B. m. intermedia* and pygmy blue whale *B. m. brevicauda* (Rice, 1998). Pygmy blue whales were originally described as occurring mainly in the sub-Antarctic Zone of the Indian Ocean, between 0° and 80°E, especially in the waters round the Prince Edward Islands, Crozet and Kerguelen Islands (Ichihara, 1966). Subsequently Zemsky and Sazhinov (1982) described three independent sub-populations of pygmy blue whales in the Indian and South Atlantic Oceans:

(a) the Northwest Region, including the tropical and equatorial waters of the Arabian Sea, waters round the Laccadive Islands and the Maldives, and westward to Sri Lanka;
(b) the sub-Antarctic Region, including the tropical and subtropical waters of the east coast of South Africa and Madagascar, as well as the sub-Antarctic waters round the Crozet and Prince Edward Islands; and
(c) the Australian Region, including the tropical, subtropical and sub-Antarctic waters of the southeastern Indian Ocean and Tasman Sea.

The population of blue whales that inhabits the Peru Current, off the coasts of Peru and Chile, may also include pygmy blue whales (Aguayo L, 1974; Donovan, 1984).

Zemsky and Sazhinov (1982) believed that whales in the Northwest Region were largely non-migratory, owing to the high zooplankton productivity of the northwestern portion of the Arabian Sea. However, based on seasonal distributions they believed whales from the other two regions to be migratory. Whales from the sub-Antarctic Region were postulated to move south from the Seychelles and Amirante Islands through the Mozambique Channel past Madagascar and the Walters Shoal to the Crozet and Prince Edward Islands during spring/summer, and back again in the autumn. Whales from the Australian Region moved south from the Banda Sea along the western coast of Australia in spring/summer, then split into a group that went west to Amsterdam and St Paul, and a group that went east towards the Tasman Sea, returning again in autumn.

Mikhalev (2000) also concluded that the blue whales of the Northwest Indian Ocean were isolated from other populations in the Indian Ocean, but that they ranged as far south as 5°S, thereby including those found around the Seychelles. Foetal size composition data, however, suggested that whales from the Seychelles aggregation (unlike others from the Arabian Sea) experienced a Southern Hemisphere breeding season. This paper follows the distribution and migration links postulated by Zemsky and Sazhinov (1982; see Fig. 1).

In December/January 1996/97, the second cruise in the International Whaling Commission's Southern Ocean Whale and Ecosystem Research (SOWER) programme on Southern Hemisphere blue whales took place in the waters

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immediately south of Madagascar, and so presumably on the migration route of whales from the sub-Antarctic Region. Its objectives followed those of the SOWER programme, namely, to establish criteria for distinguishing between the two sub-species at sea and to develop techniques for assessing the current status of blue whales. Some of the results of the cruise are presented in this paper, and include an assessment of the number of blue whales and some description of their behaviour in the area. This is the first published research on the status of this population since the cessation of commercial whaling.

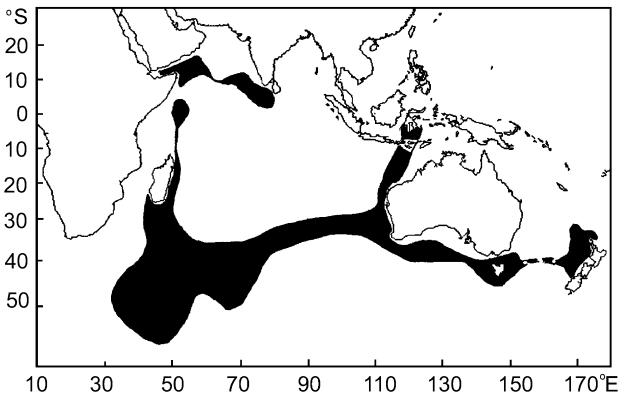

Fig. 1. Distribution of pygmy blue whales in the Indian Ocean, based largely on Soviet whaling operations (after Zemsky and Sazhinov, 1982; Mikhalev, 2000).

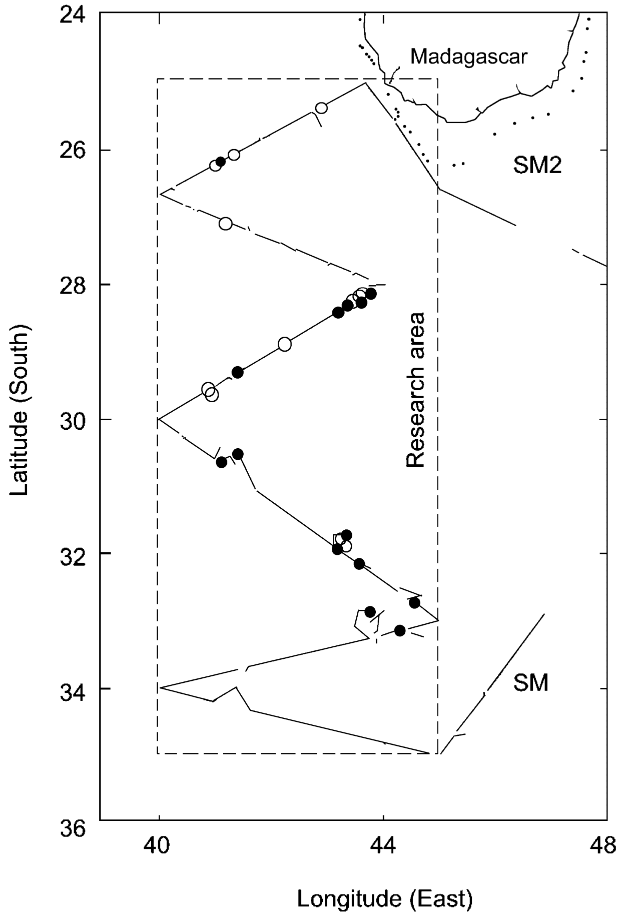

Fig. 2. Research area, cruise track and blue whale sightings (solid dot: primary, open dot: secondary) south of Madagascar, 7-18 December 1996.

MATERIAL AND METHODS

Cruise overview

The Japanese Government made two survey vessels, *Shonan Maru* (SM) and *Shonan Maru No. 2* (SM2), available for the survey. They were converted whale catchers, each 916 gross tons, 64.8m long, with a masthead lookout 20m above sea level and a further lookout position on the upper bridge 11m above sea level.

The research area, chosen largely on the basis of past sightings of blue whales from Japanese scouting vessels and catches by Soviet expeditions, was defined as between latitudes 25° and 35°S, and longitudes 40° and 45°E, or straddling the Madagascar Plateau (Fig. 2). This area was divided into northern (25°-30°S) and southern (30°-35°S) sectors. Both sectors were searched in the initial phase of the survey.

As the cruise track on this half of the cruise (7-18 December) was designed to cover the whole research area evenly, without reference to suspected blue whale concentrations, the search effort has been considered as essentially unbiased, and used in density estimation.

Based mainly on prevailing weather conditions and the distribution of past blue whale catches by the USSR, effort in the second half of the cruise was redirected to the southern half of the research area, but extended one degree of longitude to the east. In this sector of the cruise (21 to 29 December), blue whale concentrations were specifically sought out; consequently the associated effort cannot be used for density estimation. On the other hand, the methods of looking for whales were identical to those used in the first half of the cruise, so that the angle and distance data can be used in determining effective search half-widths, and group size information for determining mean school size, for each vessel.

Sighting protocol

The normal searching speed for each vessel was 11.5 knots. Two crewmembers kept a lookout from the masthead with three to five crewmembers or scientists from the upper bridge. Searching was carried out by naked eye or using 7×50 binoculars. When a sighting was made, the person making the sighting estimated its angle from the ship's track and its radial distance from the ship. This information was relayed to a recorder on the front bridge. If the description of the sighting suggested that it was a target species (e.g. a blue whale), or potentially could be a target species, the ship would turn immediately towards the sighting and approach close enough to make a positive identification and estimate of group size. Once the vessel had finished working with a sighting, it did not return directly to the trackline, but steered a course that converged at 45° with the track-line.

For each blue whale sighting, the observers on the masthead were to be interrogated regarding the criteria they used to make their identification as pygmy or Antarctic blue whale. The questions asked were:

(1) Relatively large head? Yes/No/Unknown.
(2) Relatively short tail (posterior end of dorsal fin to fluke notch)? Yes/No/Unknown.
(3) Dorsal fin/keel submerge almost simultaneously before long dive? Yes/No/Unknown.
(4) Relatively dark body colour? Yes/No/Unknown.

Surfacing rates of blue whales were investigated through visual observations. When a sighting of a large whale that might be a blue whale was made, it was approached only close enough to make a positive identification (usually within 0.5 to 1.0 n.mile). If a blue whale was identified, and while the ship drifted on acoustic watch (with engines off but other machinery running), continuous observations were made of the surfacing and blowing behaviour of the group. The times at which these observations began (and ended) were supposed to be independent of the surfacing behaviour of the group. Observers in the masthead or on the upper bridge assisted in calling out each surfacing, and the production and disappearance of each blow (as seen through polarised glasses) were also noted. The data were either recorded manually in real time using a digital stopwatch (SM), or spoken into a cassette-recorder and analysed later (SM2).

The following definitions were used in analysis.

(1) Blow intervals: the time between successive blows of the same group.
(2) Blow duration: the time that a blow, once produced, was visible to an observer wearing polarised glasses. The time of disappearance was, as far as possible, taken as that at which an observer scanning the sea (as opposed to the researcher who was aware of the blow's presence) would have failed to detect it.
(3) Surfacing time: the time between the production of the first and last blows of a sequence, when such a sequence was obvious. The last blow of a sequence was frequently indicated by an animal subsequently rounding out or even fluking.
(4) Dive time: the time between the production of the last blow of a surfacing sequence and the production of the first blow of the next sequence.
(5) Blows per surfacing: the number of visible blows produced in one surfacing sequence.
(6) Blow production rate: the number of blows produced per individual per unit time.

For all parameters apart from blow duration, only observation periods lasting 20mins or more were used in analysis. This was to reduce bias caused by the exclusion of longer dive times in very short periods of observation. For measurements of blow intervals and blow production rate, only observations involving single animals were used to avoid confusion. For measurements of surfacing times and dive times, only completed sequences were used. For estimation of blow production rate, however, the total monitoring period (including incomplete dive or surfacing sequences) was used, but experiments in which a number of cues were believed to have been missed were excluded. Blow durations were calculated from all available data.

Abundance estimation

Abundance estimation was carried out using the DISTANCE package (Buckland *et al.*, 1993). The basic formula for the abundance in a stratum is:

$$P = \frac{A \cdot \bar{s} \cdot n_s}{2 \cdot w_s \cdot L} \quad (1)$$

where:

P = uncorrected abundance (assumes all schools on the trackline are sighted);
A = open ocean area of stratum;
$\bar{s}$ = mean school size;
n_s = number of schools sighted during primary search mode;
w_s = effective search half-width for schools;
L = search effort (distance steamed in primary search mode).

All units of distance are in nautical miles. The components of this formula were evaluated as set out below.

Stratum areas (A)

For the analysis, the two strata within the overall area surveyed were divided at 29°30'S, corresponding to the sectors surveyed by each vessel. *A* refers to the open ocean area of each of these strata.

Search effort and sightings (L and n_s)

Search effort was classified according to the following codes:

BB = Full search effort on trackline, in closing mode for large whales only;
CO = Confirming sighting information;
BR = Full search effort, returning to trackline in closing mode at an angle of 45° (for large whales only);
TD = Steaming, on the constructed trackline, without full search effort;
TF = Steaming, off the constructed trackline, without full search effort;
BX = Begin experiment;
DR = Drifting.

Sightings were either primary (made while the vessel was on full searching effort, i.e. BB or BR codes) or secondary (made while the vessel was not on full searching effort, i.e. in all other codes). Only primary sightings (and the associated search effort in BB and BR modes) have been used for abundance estimation; n_s is the number of such primary sightings made of blue whale schools.

Sighting rates (n_s/L) and their CVs were estimated separately for the northern and the southern sectors. The variance estimate was obtained by treating days as the sampling units.

Distance and angle estimation bias

No experiment to identify and calibrate any biases in individual observer's estimation of angle and distance was carried out on the cruise, but the same vessels and crew participated in such experiments as part of the subsequent 1996/97 IWC-SOWER circumpolar Antarctic cruise. Consequently the latter correction factors were adopted for the distances and angles estimated by the same personnel on the blue whale cruise. These factors are listed in the files associated with the validated data for the SOWER surveys stored in DESS (Strindberg and Burt, 2000), specifically file C:/iwcdb/idcr/getdata/unbias.db.

Effective search half-width (w_s)

The estimated perpendicular distance distributions of schools in each sector were smeared using smearing parameter values of 3.24° (angle) and 0.29 (relative distance), these were the smearing values used for blue whales in Branch and Butterworth (2001a). Effective search half-width was then estimated by fitting the hazard-rate model to the data grouped into perpendicular distance intervals of 0.1 n.mile and truncated at 2 n.miles (i.e. discarding about 5% of the data, as recommended by Buckland *et al.*, 1993). Since the same methods of searching for whales were used in both halves of the cruise, the angle and distance data collected during both halves were used in determining effective search half-widths for each vessel.

M*ean school size* ($\bar{s}$)

A regression of *ln* (school size) against the detection function $g(y)$ was used to obtain a mean school size when the regression was significant at the 15% level; when the regression was not significant, average school size was used: this is the standard approach adopted by the IWC Scientific Committee for minke whale abundance estimation from the IDCR/SOWER surveys (Branch and Butterworth, 2001b). The data from both phases of the cruise were used to estimate mean school size in each sector and the sizes of all schools were assumed to have been confirmed.

General

Unless otherwise indicated, all values following a ± sign indicate one standard error of the mean.

RESULTS

Whales seen

The two vessels combined made a total of 95 sightings of 110 animals assigned in the field to pygmy blue whales, 14 sightings of 21 'unidentified' blue whales and 12 sightings of 13 'like' blue whales. There were no sightings classified as Antarctic blue whales.

The results of the crew questionnaire on SM were positive for the questions regarding large head, short tail and dorsal fin/keel exposure on 35 occasions, and negative or doubtful on none. For the question regarding a relatively dark colour, the reply was positive on 23 occasions and doubtful on 5 occasions; on another 7 occasions the reply was left blank but there were no negative responses. On SM2 there were positive responses on 4 occasions to all four questions (completion of the questionnaire was abandoned on 10 December). No attempts were made on either vessel to sketch the blowhole shape. Qualifying remarks were made on 6 occasions. These were:

9 December —'Spotting different from Antarctic blue —under dorsal fin spots are larger' (Boatswain, SM2); 'Darker than Antarctic blue' (Captain, SM2).
11 December —'95% confidence as 'pygmy' by Boatswain and Captain' (SM).
12 December —'Animals do not show body much. Show the head very briefly. Show the fin and keel only before longer dive. One animal [fluked] one time when *Shonan* approached to whales' (SM).
15 December —'Very large tadpole-like head' (SM).
23 December —'Fluke-up two times' (SM).
29 December —'85% pygmy blue' (SM).

Blue whale density estimates inside research area

Abundance estimates in each sector, and the values of the parameters used to compute these estimates, are presented in Table 1, with their associated CVs. Plots showing the fit of the hazard rate function to the perpendicular distance distributions for the sightings data are given in Fig. 3. The total population of pygmy blue whales in the research area is estimated to be 424 (CV = 0.419).

Only one 'like blue' sighting occurred in primary search mode during the first half of the cruise; when this sighting is included in the analysis, the abundance estimate increases to 472 (CV = 0.477), i.e. an increase of about 11%.

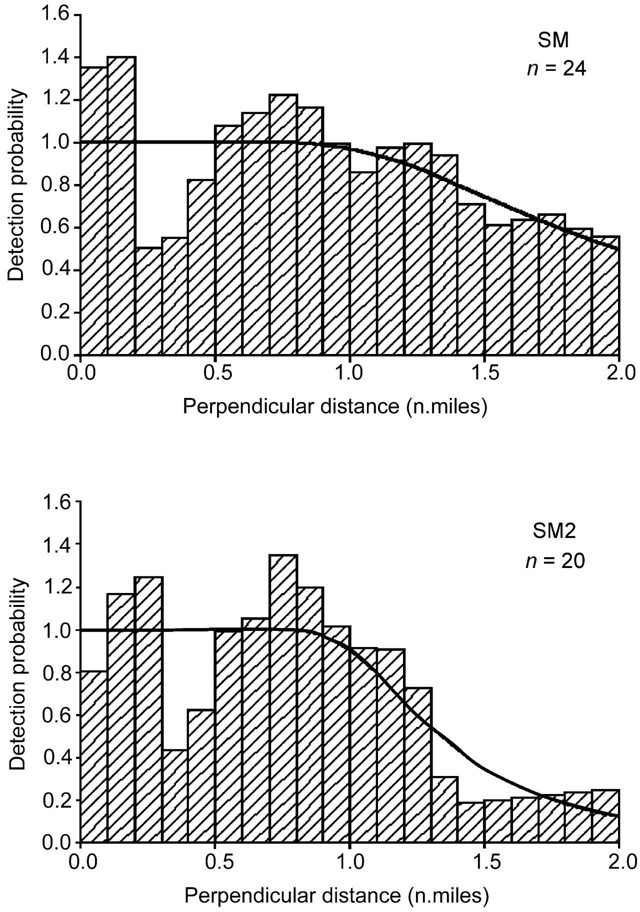

Fig. 3. Hazard rate model fits to smeared perpendicular distance distributions from blue whale sightings south of Madagascar, December 1996.

Blue whales outside the research area

When the boundaries of the research area were chosen, it was realised that they did not cover the entire range of the population at that time of year. The distribution of Soviet catches in the southwest Indian Ocean in December, for instance, showed that blue whales were taken between 10° and 44°S, and from 37° to 55°E , with only 373 (or 37%) of the catches occurring within the research area (Table 2).

This might suggest that the total population is of the order of three times the abundance estimates obtained here. However such an extrapolation factor could be biased if

Table 1

Abundance estimates and associated parameters for blue whales south of Madagascar; the figures in parenthesis are CVs. The criteria used to select the method of mean school size estimation opted for the average school size for the SM's, and for the regression method for the SM2's observations. Symbols are defined in the text (see equation 1), except that $D_s = P/A$ is the density of schools per unit area.

Year	Vessel	Sector	A (n.mile^2)	n_s*	L (n.mile)	n_s/L		w_s (n.mile)		$\bar{s}$		D_s (n.mile^{-2})		P		Total P	
96/97	SM	S	83,820	6	1,006.1	0.0067	(0.455)	1.74	(0.190)	1.24	(0.084)	0.0019	(0.493)	199	(0.500)	424	(0.419)
	SM2	N	71,410	4	538.1	0.0088	(0.632)	1.40	(0.164)	1.00	(0.030)	0.0032	(0.653)	226	(0.654)		

*After truncation at 2 n.miles.

Soviet catches were not spread uniformly over the distribution area of the population, and have high variance if there is large inter-annual variability in the whales' distribution pattern.

Estimated body lengths

Just before leaving each sighting, one of the crew in the masthead lookout would provide an estimate of the body length of all whales present. Such estimates are available for 95 blue whales, 38 from the SM and 57 from the SM2 (Fig. 4).

The estimated lengths ranged from 40 to 72ft, but those provided by the SM were smaller than those from the SM2 (medians = 62.5ft and 66ft respectively, Mann-Whitney T = 1235, $p < 0.0001$). This difference extended to the calves, which were estimated at 40-43ft long (n = 3) on the SM and 46-59ft (n = 5) on the SM2.

Incidence of calves

Of the 95 blue whales approached close enough to obtain estimates of size, 8 (8.4%) were classified as calves. Such a classification was based on both size and behaviour (associative with a larger individual).

Evidence of feeding

No direct observations of feeding behaviour were made, but faeces were seen produced on four occasions between 21 and 29 December, in the southern half of the research area. One of these instances occurred on 25 December at 32°49.1'S 43°02.6'E, and a second at 32°52.6'E 43°34.6'E on 28 December. A faecal sample was collected on 28 December and proved to contain digested euphausiid remains. Variation in the morphology of the mandibles and spermatophores present suggested three and two different species of euphausiid respectively, but none could be specifically identified (M. Gibbons, pers. comm.).

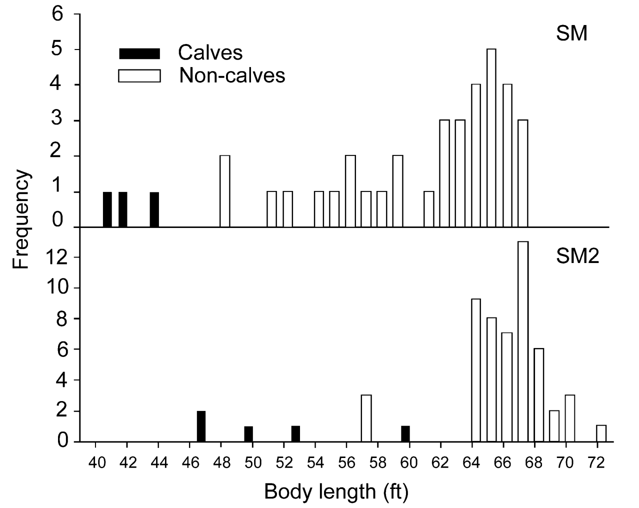

Fig. 4. Frequency distribution of estimated sizes of blue whales seen south of Madagascar, December 1996.

Surfacing behaviour

In total, 21h 14min of observations were available, from a total of 40 groups containing 47 whales (Table 3). Overall blow rates ranged from 0.5 to 1.4 per min, with an average of 0.95 ± 0.05 ($n = 20$) blows/min per individual. The distribution of surfacing intervals, however, was markedly bimodal (Fig. 5). Although short blow intervals (less than 40s apart) predominated, other intervals were markedly longer, ranging from about 180 to 660s with a mode at around 300-360s. This reflected a somewhat stereotyped respiratory cycle, in which surfacing sequences of several blows close together were separated by longer dives.

Average surfacing times for 27 single animals ranged from 47 to 222s, with a mean of 109 ± 8s, while for 7 pairs average surfacing times ranged from 59 to 115s, with a mean

Table 2

Soviet catches of pygmy blue whales in the southwestern Indian Ocean in December (box represents research area with a total catch of 377).

Latitude (°S)	Longitude (°E)																
	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	Total
10													21				21
11										3		3					6
12												25					25
14														1	22		23
15																8	8
18													4				4
24			4	70							4						78
25			28	13							1						42
26		9		22	25	4	3										63
27		7	5	14	6						1						33
28				8	8	2	2	2									22
29				3		15	3	2	7								30
30						37	2		2		3						44
31				15	11	33	47	1				2	5				114
32						23	4	25		2							54
33	1			2	5	66	71		2								147
34					1	15	32		6		7	6	2				69
35								1		6	5	38	17		4		71
36						18						15	10	6	21	20	90
37												35	17	1			53
38																	
39							2										2
40																	
41											4						4
43								7									7
Total	1	16	37	147	56	213	166	38	17	11	25	124	76	8	47	28	1,010

of 94 ± 7s. During these periods the average number of blows produced ranged from 4 to 13 (mean 8.0 ± 0.5) for single animals and 3.7 to 9.2 (mean 7.4 ± 0.7) for pairs.

The durations of 908 blows were recorded, being highly variable and ranging from 0.9 to 18.8s. Such variability is to be expected, given that the estimated duration is dependent not only on the strength of the initial expiration (which may be related to body size or behavioural state) but also on the prevailing meteorological conditions (with wind strength and back-lighting being perhaps the most important). The duration of blows produced in the first half of a surfacing sequence was more often longer than for those produced in the second half (38 vs 21, Chi-square = 4.898, $p < 0.05$). Mean blow durations calculated for the SM (4.7 ± 0.5s) and for the SM2 (6.2 ± 0.3s) were significantly different ($t = -2.29$, two-tailed $p = 0.03$), possibly indicating differences in observer criteria rather than animal behaviour.

Average dive times (or intervals between surfacing sequences) for 32 single whales ranged from 145 to 896s, with a mean of 428 ± 28s, while for 7 pairs, average dive times ranged from 340 to 606s, with a mean of 501 ± 36s.

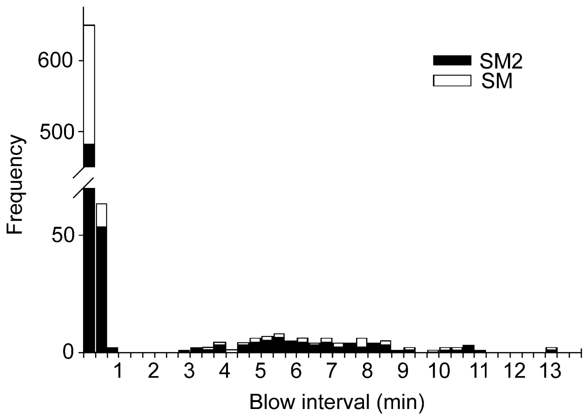

Fig. 5. Frequency distribution of blow intervals for blue whales south of Madagascar, December 1996.

DISCUSSION

The questionnaires completed regarding what characteristics of the whales were used in sub-species determination were fairly consistent in giving definite responses, suggesting that the observers were confident of their identifications. However, this confidence might have been somewhat misleading, as the sighting on 29 December that was classified as positive by SM for all four questions, was annotated that it was '85% pygmy blue', indicating that the crew were not totally confident of their identification. Some of this uncertainty may have arisen from the fact that the whales fluked up occasionally, a behaviour that the crew did not expect to see in pygmy blue whales (KS, pers. comm.). On the SM2 at least, there was the feeling that the way the questions were phrased was producing 'standard' answers, and that (combined with the lack of adequate interpretation) led to their discontinuation.

The estimated sizes of the blue whales from both ships were much smaller than those reported earlier for pygmy blue whales, where over 90% of the catch in 1959/60 exceeded 70ft in length (Ichihara, 1961). Although 70ft was the minimum legal length in operation at the time these catches were made, the size difference seems too great to be just the result of selection. Given the significant inter-vessel difference in length estimates (which might have been influenced by the fact that one bosun had much more experience in whaling for pygmy blue whales than the other −KS, pers. comm.), and the known difficulty in making such estimates at sea (Best, 1984), it seems likely that both vessels consistently underestimated the sizes of the blue whales they saw. The incidence of calves confirms that adult animals were present.

Ichihara (1966) reported monthly pregnancy rates for pygmy blue whales in the Antarctic of 35.6% for February, 23.1% for March and 6.9% for April, a trend that he attributed to the progressive emigration of pregnant females to the north. Consequently he felt the value for February (35.6%) should be regarded as the mean pregnancy rate for pygmy blue whales, which he considered extremely low compared to the figure of 49.4% for the Antarctic blue whale in February/March. Figures given by Mikhalev (2000) indicate an observed pregnancy rate of 41.3% for blue whales from the Northwest Region, but this is in a sample that only contained 1.3% lactating animals. Assuming that the proportion of lactating females should be roughly equivalent to the number of pregnant females, a 'corrected' pregnancy rate from these data would be $41.3/(100 + (41.3 - 1.3)) = 29.5\%$. Mikhalev also commented on the low reproductive capacity of these blue whales. Assuming an equal adult sex ratio, and that mature animals comprised about 56% of the population (Ichihara and Doi, 1964), then the pregnancy rate observed for the sub-Antarctic population would translate into an expected calving rate of $(35.6/2) \times 0.56 = 10\%$ of the total population. Given that this pregnancy rate value probably does not take selection against lactating females fully into account, the estimated calving rate compares well with an observed calf percentage of 8.4% during the IWC SOWER cruise.

Given (a) the small estimated sizes of the animals seen; (b) an incidence of calves suggesting that mature animals were fully represented; (c) the results of the questionnaires; and (d) the composition of historical catches in the region, there seems little doubt that most if not all the animals seen were pygmy rather than Antarctic blue whales.

Based upon catch age-composition and CPUE data, Ichihara and Doi (1964) estimated the initial (1960) population size (all ages) of pygmy blue whales in the region north of 54°S and from 0° to 80°E (equivalent to the sub-Antarctic Region) as 7,600 or 11,000. These alternatives depended on whether ages and mortality rates were calculated on the basis of one or two laminations being deposited annually in the ear plug. More recent work has supported an annual rather than biannual deposition rate in at least fin whales (Lockyer, 1984), so the initial population size is more likely to have been 7,600 animals. Ichihara and Doi estimated that this would have been reduced to 6,000 animals by the start of the 1963/64 season.

Zemsky and Sazhinov (1982) extended this assessment forward in time, using the initial population estimate of 7,600, a catch series that included previously unreported Soviet takes and assuming a net recruitment rate of 5%. They estimated that by the close of the 1971/72 season, this population had been further reduced to some 4,000 animals. The next season international observers were introduced to Antarctic fleets, at which time all hunting of pygmy blue whales ceased. In total, some 6,875 blue whales were removed from the sub-Antarctic population between 1960/61 and 1971/72 (Zemsky and Sazhinov, 1982).

The population estimate, albeit partial, of 424-472 blue whales obtained here is the first for the sub-Antarctic population since the close of commercial whaling.

Table 3

Details of monitoring blue whale surfacing behaviour, Madagascar, December 1996 (means are given ± one standard error, sample size in parentheses).

Date	Sighting no.	Group size	Surfacing times (*s*)	No. blows/ surfacing	Blow intervals* (*s*)	Dive times (*s*)	Blow duration (*s*)	Duration of observation	Blow rate/ min**
Shonan Maru									
11 Dec.	22	2	99 ± 39 (4)	8.3 ± 2.4 (4)	17.3 ± 2.6 (34)	606 ± 139 (5)	2.8 ± 1.4 (4)	59min 49s	
12 Dec.	15	2	115 (1)	8.0 (1)	16.9 ± 1.5 (16)	526 (1)	4.8 ± 0.9 (8)	31min 46s	
13 Dec.	6	1	-	-	13.3 ± 2.9 (11)	-	3.6 ± 1.6 (5)	2min 26s	
14 Dec.	3	2	92 ± 11 (3)	6.3 ± 0.3 (3)	16.5 ± 1.4 (19)	441 ± 44 (4)	6.7 ± 0.7 (18)	34min 44s	
15 Dec.	1	2	106 ± 3 (3)	7.7 ± 1.7 (3)	14.8 ± 1.3 (34)	579 ± 20 (4)	10.6 ± 1.0 (36)	45min 23s	
	2	1	148 (1)	10 (1)	17.2 ± 1.2 (21)	620 (1)	3.1 ± 0.6 (10)	40min 01s	
17 Dec.	1	1	78 ± 1 (2)	6.5 ± 1.5 (2)	13.9 ± 1.3 (15)	510 ± 25 (3)	5.6 ± 1.2 (10)	28min 58s	0.6
	4	1	86 ± 36 (3)	7.0 ± 2.3 (3)	14.9 ± 0.9 (24)	413 ± 55 (3)	4.7 ± 0.5 (10)	39min 37s	1.4
18 Dec.	7	1	47 ± 8 (5)	4.8 ± 1.0 (5)	12.1 ± 1.2 (20)	320 ± 34 (6)	5.3 ± 1.1 (10)	36min 5s	0.7
21 Dec.	1	1	112 ± 14 (5)	7.4 ± 0.7 (5)	13.4 ± 1.0 (34)	340 ± 26 (5)	3.2 ± 0.3 (29)	38min 9s	1.2
	9	1	49 ± 19 (2)	7.0 ± 3.0 (2)	8.1 ± 1.3 (12)	335 ± 25 (2)	-	12min 36s	
23 Dec.	3	1	74 ± 7 (6)	6.7 ± 0.9 (6)	12.9 ± 0.6 (41)	375 ± 41 (6)	1.6 ± 0.2 (9)	46min 18s	1.0
24 Dec.	1	1	-	-	13.8 ± 0.8 (13)	354 (1)	5.2 ± 0.5 (13)	8min 57s	
	7	1	94 (1)	5.0 (1)	23.5 ± 5.5 (4)	349 ± 8 (2)	-	13min 12s	
26 Dec.	2	1	88 ± 15 (2)	8.0 ± 1.0 (2)	12.5 ± 0.6 (14)	528 ± 59 (2)	4.0 ± 0.8 (8)	20min 40s	0.8
	3	1	-	-	-	688 (1)	-	13min 4s	
27 Dec.	4	1	-	-	36.7 ± 17.4 (6)	423 (1)	-	11min 43s	
28 Dec.	9	1	-	5.0 (1)	11.4 ± 1.3 (7)	288 ± 75 (2)	-	10min 56s	
	11	1	146 (1)	13.0 (1)	12.2 ± 0.8 (12)	258 ± 54 (2)	3.6 ± 0.4 (9)	11min 6s	
29 Dec.	1	1	91 (1)	5.0 (1)	18.3 ± 3.3 (9)	145 ± 47 (2)	5.4 ± 1.0 (5)	7min 36s	
	3	1	-	-	-	896 (1)	-	14min 56s	
Shonan Maru No. 2									
10 Dec.	3	1	121 ± 8 (5)	9.2 ± 0.7 (5)	15.0 ± 0.4 (41)	496 ± 21 (4)	6.4 ± 0.4 (45)	53min 17s	0.9
	2	2	59 ± 4 (3)	3.7 ± 0.3 (3)	22.2 ± 3.2 (8)	601 ± 90 (2)	5.8 ± 0.4 (11)	32min 17s	
12 Dec.	4	1	133 ± 4 (4)	11.0 ± 0.4 (4)	14.1 ± 0.4 (49)	689 ± 34 (4)	6.9 ± 0.2 (53)	64min 44s	0.8
16 Dec.	4	2	92 ± 8 (5)	9.2 ± 0.7 (5)	10.7 ± 0.8 (39)	340 ± 19 (4)	5.2 ± 0.4 (38)	43min 6s	
	7	1	134 ± 6 (4)	9.0 ± 0.7 (4)	16.6 ± 0.9 (40)	468 ± 22 (4)	4.9 ± 0.3 (43)	46min 32s	1.0
	11	1	222 ± 22 (3)	12.0 ± 0.6 (3)	20.0 ± 0.9 (41)	391 ± 22 (4)	7.2 ± 0.3 (45)	44min 5s	1.1
17 Dec.	2	1	190 ± 4 (3)	13.0 ± 0 (2)	16.0 ± 0.8 (25)	617 ± 7 (3)	7.9 ± 0.5 (35)	46min 26s	
19 Dec.	2	1	56 ± 8 (5)	6.2 ± 1.0 (5)	10.8 ± 0.7 (26)	393 ± 36 (4)	4.6 ± 0.2 (30)	38min 51s	0.8
22 Dec.	2 + 3	2	95 ± 9 (6)	8.3 ± 1.1 (6)	13.0 ± 1.1 (44)	460 ± 35 (5)	3.9 ± 0.4 (45)	58min 16s	
	6	1	91 ± 14 (4)	7.0 ± 0.7 (4)	14.7 ± 1.1 (22)	515 ± 6 (3)	7.1 ± 0.4 (26)	41min	0.7
23 Dec.	1	1	62 ± 7 (6)	6.2 ± 0.5 (6)	12.1 ± 0.6 (32)	256 ± 17 (6)	7.6 ± 0.6 (39)	38min 16s	1.0
24 Dec.	2	1	64 ± 6 (4)	4.0 ± 0 (4)	21.4 ± 3.6 (12)	329 ± 24 (3)	3.8 ± 0.3 (14)	30min 13s	0.5
	3	1	110 ± 35 (3)	8.0 ± 2.1 (3)	15.8 ± 0.5 (30)	513 ± 79 (3)	5.5 ± 0.5 (33)	36min 4s	1.0
25 Dec.	2	1	151 ± 22 (5)	9.8 ± 0.7 (5)	17.1 ± 0.9 (49)	358 ± 15 (5)	7.1 ± 0.4 (58)	52min 18s	1.1
	5	1	89 ± 7 (7)	8.1 ± 0.6 (7)	12.6 ± 0.4 (49)	259 ± 23 (7)	8.6 ± 0.3 (60)	46min 8s	1.3
	6	1	187 (1)	12 (1)	17.2 ± 0.9 (19)	334 ± 16 (2)	4.2 ± 0.3 (24)	16min 52s	
26 Dec.	1	1	133 ± 11 (3)	8.3 ± 0.7 (3)	18.2 ± 1.7 (22)	355 ± 16 (3)	7.1 ± 0.7 (30)	28min 53s	1.1
27 Dec.	38	1	101 ± 33 (4)	7.0 ± 1.7 (4)	16.9 ± 1.1 (24)	385 ± 64 (4)	6.6 ± 0.4 (28)	35min 33s	0.8
28 Dec.	6	1	93 ± 20 (6)	8.0 ± 1.3 (6)	12.8 ± 0.3 (56)	335 ± 19 (7)	6.0 ± 0.4 (64)	51min 18s	1.2

*Only for surfacing sequences. **Includes blows for which no duration estimated.

The data on dive times and surfacing behaviour can be used to examine whether it is reasonable to assume (as was done in calculating the above estimate) that all the schools on the trackline were seen. The distribution of dive times, for instance, can be compared with the radial distances at which primary sightings were made. At a searching speed of 11.5 knots, the vessels would have travelled 419/3,600(11.5) = 1.3 n.miles during the average dive of a single whale, or 896/3,600(11.5) = 2.9 n.miles during the longest recorded dive. Estimated radial distances at which primary sightings of blue whales were made during the cruise ranged from 0.6-5 n.miles with a mode at 2.5-2.9 n.miles ($n = 51$). This suggests that few if any dive intervals would have been long enough for the vessel to have passed the location of the whale (if it was on the trackline) before it underwent at least one surfacing period. Furthermore, during surfacing periods, which averaged 109 secs for single whales, an average of 8 blows would be produced, each lasting about 5 secs. This means that a sighting cue would be visible for about 40/109 or 37% of the time during a surfacing period. Overall, therefore, the assumption in the population estimate that all schools on the trackline were seen seems reasonable.

It should be mentioned, however, that dive times considerably longer than those recorded on the survey have been reported for blue whales (27 min —Donovan, 1984; 35 min —Tomilin, 1957; 50 min —Yablokov *et al.*, 1974). Most of the observation periods in this paper were too short to detect such dives. Nevertheless, results from the satellite-tagging of blue whales in the North Pacific (Lagerquist *et al.*, 2000) strongly suggest that the data obtained here are representative. Blow rates of the tagged whales averaged 1.0 per min, compared to 0.95 ± 0.23 per min south of Madagascar, while the longest of 2,007 dives recorded from the tagged whales was 18 mins, compared to 14.9 mins south of Madagascar.

The evidence of feeding in the region is consistent with the report of Gambell *et al.* (1975), who described defecations in two blue whales out of a total of 15 seen south and west of Madagascar in summer 1973/74. The two incidences occurred on 30 November 1973 at 27°52'S 48°24'E, and 13 January 1974 at 31°10'S 35°69'E (PBB field notes). Although very little is known of the oceanography in this region, a localised upwelling cell has recently been described inshore of the East Madagascar

Current where it diverges from the coast at the southern tip of Madagascar. This cell seems to be a very persistent phenomenon, being current- rather than wind-driven, and may be the source of filaments of biologically enriched water that are carried further south as part of the retroflection of the East Madagascar Current (Lutjeharms and Machu, 2000). Such conditions might create a predictable feeding ground for migrating blue whales of the sub-Antarctic Region, similar to those reported off southern Australia (Gill, 2002), and off the Channel Islands, California (Fiedler *et al.*, 1998).

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