Breeding Stock C

Distribution and abundance of humpback whales, *Megaptera novaeangliae*, off the coast of Mozambique, 2003

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ABSTRACT

Humpback whales within the southwestern Indian Ocean undertake annual migrations from summer Antarctic/Southern Ocean feeding grounds to winter breeding grounds in the tropical and sub-tropical coastal waters of Mozambique, Madagascar and the central Mozambique Channel Islands. Little is known of the inter-relationship of humpback whales on each of these wintering grounds, or the inter-relationship of these wintering grounds with the summer Antarctic feeding grounds.

A line-transect survey of cetacean species was carried out in Mozambique coastal waters between Cabo Inhaca (26°00'S, 33°05'E) and just north of Mozambique Island (14°26'S, 40°53'E) and between the 20 and 200m isobaths, over the period 26 August to 7 September 2003. The majority (98.1%) of 951.8 n.miles of search effort carried out on this survey was in passing mode due to the high densities of whales encountered. Humpback whales were the only large whales to be identified and the distribution of 691 sightings of an estimated 1,130 individual humpback whales and 132 sightings of an estimated 154 large unidentified whales show distribution throughout the survey region. Two sightings of individual small whales were made in the region of Inhambane.

In general, higher than expected sighting densities (based on survey effort) were recorded in the region between Cabo Inhaca and Xai-Xai, and in the region of the Pantaloon and David Shoals to the north east of Quelimane. Lower than expected sighting densities were recorded over the Sofala Banks. No distribution trends could be ascribed to environmental parameters, apart from whales being distributed in waters of higher salinities than expected, possibly due to turbidity associated with low salinity water arising from river input. Groups containing a cow and calf pair were distributed across the entire region surveyed.

Analyses of unstratified data result in a total abundance estimate of 6,808 (CV = 0.14) humpback and unidentified whales in the 14,029.5 n.mile2 area surveyed. As a result of the differences in width of the coastal shelf area along the coast of Mozambique, the line transect survey data were further analysed in four strata. Pooling of estimates over these four strata results in a total abundance of 6,664 whales (CV = 0.16), with highest densities in the southernmost stratum and the lowest densities in the narrow shelf region across the Sofala Banks. Similar analyses of humpback whales only resulted in abundance estimates of 5,930 (CV = 0.15) (unstratified data) and 5,965 whales (CV = 0.17) (data analysed by four strata). Although not directly comparable due to differing survey platforms, these estimates indicate the population to have increased since previous surveys in the early 1990s.

KEYWORDS: HUMPBACK WHALE; SOUTHERN HEMISPHERE; AREA-MOZAMBIQUE; ABUNDANCE; DISTRIBUTION

INTRODUCTION

The annual migrations of Southern Hemisphere humpback whales (*Megaptera novaeangliae*) from summer Antarctic or Southern Ocean feeding grounds to winter breeding grounds in shallow tropical and sub-tropical waters is known from the seasonality of whaling catches (Harmer, 1928; 1931; Mackintosh, 1942; Matthews, 1938; Olsen, 1914; Risting, 1912), from natural mark and tag returns (Chittleborough, 1965; Dawbin, 1956; 1966; Gill and Burton, 1995; Rayner, 1940) and from satellite telemetry studies (Zerbini *et al.*, 2006). Seven feeding grounds have been identified within the Southern Ocean (IWC, 1998; Mackintosh, 1942; Omura, 1973), each of which has been linked to a breeding ground in the coastal waters of South America, Africa (including Madagascar), Australia, New Zealand or the islands of the southwestern Pacific Ocean (IWC, 1998; Kellogg, 1929; Mackintosh, 1942; Rayner, 1940). En route between breeding and feeding grounds, humpback whales appear to utilise the coastal waters of Southern Hemisphere continents as migratory corridors, a factor which made them particularly susceptible to land-based whaling operations (Findlay, 2001). Historical catch records have indicated two general migration corridors in southern African waters. The west coast corridor takes whales as far north as breeding grounds off Gabon (Budker, 1954; Budker and Collignon, 1952; Townsend, 1935), although Tønnessen and Johnsen (1982) suggest that catches off Angola and Gabon arose from different stocks. The east coast corridor conveys whales to breeding grounds off Mozambique (Best, 1993; Findlay *et al.*, 1994; Olsen, 1914), Madagascar (Angot, 1951; Ersts and Rosenbaum, 2003) and the central Mozambique Channel Islands (Angot, 1951; Best *et al.*, 1998).

Populations of Southern Hemisphere humpback whales declined markedly during the 20th century as a result of severe modern whaling on both the Antarctic feeding and tropical breeding grounds (Findlay, 2001). Humpback whaling in South Africa started in 1908 in Durban (~30°S) and continued until October 1963. Catches were predominantly made prior to 1918, although subsequent to 1913 humpback whales no longer formed the major

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component of the Durban whaling ground catch (Best, 1994). Limited catches of presumably western Indian Ocean humpback whales were recorded off the southern Cape coast (Plettenberg Bay and Mossel Bay) between 1911 and 1916 (Best, 1994), and Best and Ross (1996) suggested that these animals migrate along the east coast of southern Africa. Modern whaling occurred in Mozambique waters between 1910 and 1923, with a floating factory operating off the Bazaruto Archipelago in 1910, a land station and two floating factories operating independently at Linga-linga (Inhambane) between 1911–1915 and 1912–1923 respectively, a land station operating in Delagoa Bay between 1912–1913, and floating factories operating at Quelimane in 1912 and at Angoche (16S) between 1911–1912 (Tønnessen and Johnsen, 1982). Humpback whales dominated this catch, although Tønnessen and Johnsen (1982) noted that only 3,360 whales were taken in the Mozambique whaling grounds in this era, with the highest catches recorded off Linga-linga, and catches to the north of Quelimane being generally poor.

Certain Southern Hemisphere populations of humpback whales appear to be undergoing considerable recovery from whaling in certain wintering grounds including those that migrate through the southwestern Indian Ocean. Although the time period of surveys was too limited to provide any estimate of population trend, the shore-based surveys carried out off Cape Vidal between 1988 and 1991 (Findlay and Best, 1996a; Findlay and Best, 1996b) suggest that the population has undergone some recovery since the cessation of humpback whaling in the region in October 1963. Assessments of humpback whale populations off the east and west coasts of Australia have shown population increase rates of about 10% per annum (Bannister *et al.*, 1991; Bryden *et al.*, 1990; Hedley *et al.*, 2011; Paton and Kniest, 2011), and based on preliminary results from shore-based surveys off Cape Vidal, South Africa, between 1988 and 2002 (Findlay and Best, 1996b) a similar increase is expected for the Mozambique population.

Migrations in the southwestern Indian Ocean being suggested by Best *et al.* (1998) comprise three principal migratory streams, including:

(a) an East African corridor taking whales to and from the coastal waters of Mozambique, hereafter termed the C1 ground after IWC (1998);
(b) a Madagascar Ridge corridor taking animals through Walters Shoal, to and from the coastal waters of Madagascar (termed the C3 ground); and
(c) a Central Mozambique Current corridor taking whales to and from the coastal waters of the central Mozambique Channel Islands of Aldabra, the Comores Islands and Mayotte, or to the coastal waters of Mozambique to the north of 18°S (termed the C2 ground).

However the complete migratory destinations and routes and inter-relationships between the three wintering grounds of Mozambique, Madagascar and the Central Mozambique Channel Islands are relatively unknown. Ersts *et al.* (2006) reported on movements of individual humpback whales between Antongil Bay, Madagascar and Mayotte. This paper reports on a cruise undertaken in Mozambican waters (Fig. 1) to estimate the abundance of humpback whales utilising the C1 breeding grounds, and to investigate their distribution. Little or no survey of humpback whales on their Mozambique breeding grounds has been carried out since 1991, when Findlay *et al.* (1994) surveyed the southern and central coastal waters of Mozambique. The survey reported

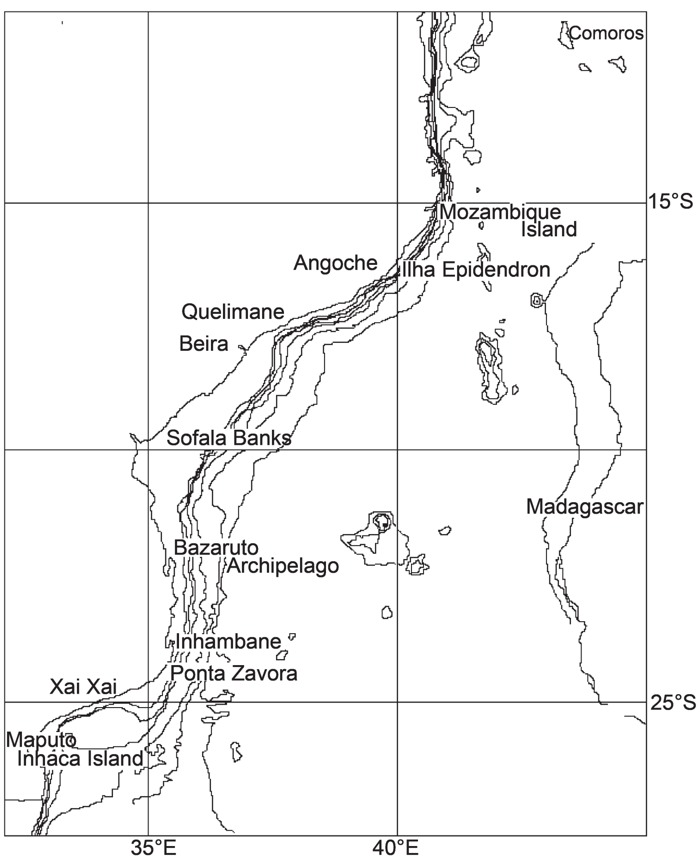

Fig. 1. The coastal waters of the Mozambique Channel showing localities referred to in the text.

here extends the coverage of Mozambique waters by some 300 n.miles north of the area surveyed by Findlay *et al*. (1994). Timing of the cruise was selected to coincide with maximum expected abundance of humpback whales within the study area.

METHODS AND MATERIALS

Field survey

Line-transect survey

A line-transect survey of all cetacean species was carried out between Cabo Inhaca (26°00'S, 33°05'E) and to the north of Mozambique Island (14°26'S, 40°53'E), between the 20 and 200m isobaths from 26 August to 7 September 2003. Limited search effort was also carried out both inshore and offshore of this area.

The survey was carried out between 0700 and 1700 each day in suitable weather conditions (i.e. adequate visual conditions with a clear visible horizon, sea conditions < Beaufort 5 and wind speed of <24 knots). All survey was on predetermined transects (Table 1) at a speed over ground of between 8 and 11 knots depending on current conditions. Searching was undertaken by two rotating teams (of a minimum of five seated observers each) from a specially constructed observation platform on the vessel's upper bridge at 12m above sea level. Searching was carried out using both wide-angle binoculars (7 × 35) and the naked eye. All searching activity was recorded as search effort and environmental conditions (wind speed and direction, cloud cover, Beaufort Sea State, swell height) were logged by observers during each hour of observation. An automated system recorded the vessel position, speed through the water, speed over the ground, heading and depth as well as environmental parameters (barometric pressure, wind speed and direction, sea surface temperature and salinity) on each minute of the cruise.

The survey was planned in both passing and closing modes. In closing mode, the vessel diverted from the survey trackline to intercept the observed cetacean groups to confirm group size and species identity. On completion of the interception the vessel resumed searching on a new trackline directly to the next way-point. All closing activity from the time of diversion until resumption of survey effort on the new trackline was considered as off survey effort and all sightings made during this time were considered secondary sightings. No diversions from the trackline were made in passing mode. However, the high densities of whales encountered resulted in almost all survey being carried out in passing mode, due to both the difficulty in tracking groups of whales in view during closing mode, and the high incidence of secondary sightings made during closing mode. Consequently observers carried out species identification and estimated group composition (i.e. the presence or absence of a calf) and group size from the trackline, usually at the closest distance when the whales were abeam of the vessel. Group size and composition were recorded as confirmed only when observers were certain of the size and composition of intercepted groups (or groups which passed close to the vessel in passing mode). In passing mode all sighted groups were tracked through the observation area by at least one observer, until they were abeam, so as to ensure that groups were not double counted.

Table 1

Positions and survey coverage of transects searched during the line transect component of the cruise.

				Total distance searched		
Leg	Start position	End position	Total planned distance	Passing mode	Closing mode	Total
1	26° 00 S, 33° 05 E	25° 28 S, 33° 09 E	32.20	29.3	0	29.3
2	25° 28 S, 33° 09 E	25° 22 S, 33° 43 E	31.29	21.48	0	21.48
3	25° 22 S, 33° 43 E	25° 01 S, 34° 12 E	33.61	0	0	0
4	25° 01 S, 34° 12 E	25° 30 S, 35° 01 E	52.96	0	0	0
4A	25° 37 S, 34° 12 E	24° 36 S, 35° 13 E	75.44	61.31	14.89	76.2
5	25° 30 S, 35° 01 E	24° 36 S, 35° 13 E	55.08	0	0	0
6	24° 36 S, 35° 13 E	24° 11 S, 35° 37 E	33.21	34.46	0	34.46
7	24° 11 S, 35° 37 E	23° 31 S, 35° 36 E	40.01	39.82	0	39.82
7A	23° 31 S, 35° 36 E	23° 31 S, 35° 29 E	6.42	7.7	0	7.7
8	23° 31 S, 35° 29 E	22° 59 S, 35° 42 E	34.16	33.95	0	33.95
9	22° 59 S, 35° 42 E	22° 28 S, 35° 34 E	31.87	31.02	0	31.02
10	22° 28 S, 35° 34 E	21° 56 S, 35° 36 E	32.05	30.68	0.4	31.08
11	21° 56 S, 35° 36 E	21° 31 S, 35° 32 E	25.27	26.68	0	26.68
12	21° 31 S, 35° 32 E	21° 00 S, 35° 41 E	32.11	31.36	0.16	31.52
13	21° 00 S, 35° 41 E	20° 34 S, 35° 26 E	29.54	29.52	0	29.52
14	20° 34 S, 35° 26 E	20° 13 S, 36° 07 E	43.79	35.11	0	35.11
15	20° 13 S, 36° 07 E	19° 33 S, 35° 34 E	50.63	45.01	2.14	47.15
16	19° 33 S, 35° 34 E	19° 40 S, 36° 39 E	61.63	50.22	0	50.22
17	19° 40 S, 36° 39 E	18° 50 S, 36° 30 E	50.72	51.35	0	51.35
18	18° 50 S, 36° 30 E	18° 38 S, 37° 16 E	45.19	44.82	0.19	45.01
19	18° 38 S, 37° 16 E	18° 00 S, 37° 10 E	38.42	36.13	0	36.13
20	18° 00 S, 37° 10 E	17° 51 S, 37° 50 E	39.11	20.87	0	20.87
21	17° 51 S, 37° 50 E	17° 25 S, 38° 07 E	30.63	29.41	0	29.41
22	17° 25 S, 38° 07 E	17° 25 S, 38° 42 E	33.40	34.58	0	34.58
23	17° 25 S, 38° 42 E	17° 04 S, 39° 12 E	35.52	38.07	0	38.07
24	17° 04 S, 39° 12 E	16° 46 S, 39° 40 E	32.27	23.47	0	23.47
25	16° 46 S, 39° 40 E	16° 24 S, 40° 02 E	30.47	29.71	0.16	29.87
26	16° 24 S, 40° 02 E	15° 58 S, 40° 24 E	33.50	33.52	0.04	33.56
27	15° 58 S, 40° 24 E	15° 32 S, 40° 39 E	29.74	28.06	0	28.06
28	15° 32 S, 40° 39 E	15° 00 S, 40° 53 E	34.73	34.33	0.02	34.35
29	15° 00 S, 40° 53 E	14° 26 S, 40° 53 E	34.00	21.87	0	21.87
Total			1,168.99	933.81	18.00	951.81

On making a sighting of any cetacean observers immediately estimated the radial distance to the sighting, and angle of the sighting from the bow of the ship. Angles were measured using angle boards (to the nearest degree), while radial distances were estimated using a photographic measurement of the group relative to the horizon (after Gordon, 1990). This required the horizon and target group to be immediately photographed after sighting with a fixed focal length lens (300mm) from the known upper bridge height. At the same time distances were estimated by eye using hand held reticules. Calibration of the reticule and the photographic techniques were carried out in a trial where measurements were made co-incidentally with radar measurements over a 5 n.mile approach to a radar-reflective small boat.

Analyses

All sightings of whales unidentified to species were assigned to species on a pro rata basis of sightings of identified whales. As humpback whales were the only large whale species recorded during the survey, all unidentified whales have been assigned as humpback whales. Absolute abundances are estimated for both humpback whales and humpback and unidentified whales combined.

Relative abundance

Effort (miles searched), frequency of observations and expected observation frequency were calculated by half degree square and by environmental parameter interval. Expected observation frequencies were calculated from the total number of whales sighted apportioned to the particular interval by the distance searched in that interval. Environmental parameters analysed included wind speed (in 5kt intervals), Beaufort Scale (1 to 5), and swell height (0 to 3m, in 0.5m intervals) (all of which possibly influence sighting probabilities), water depth intervals (0–20m, 20–50m, 50–100m, 100–200m and >200m intervals), sea surface temperature (20˚C to 26+˚C in 1C intervals), sea surface salinity (33.7ppt to 35.3ppt, in 0.1ppt intervals) and current speed (0kt to 6kt, in 1kt intervals). Problems at certain times throughout the survey with the automated depth-finder, resulted in depths being read after the survey from 1:300,000 bathymetric charts in 0–20m, 20–50m, 50–100m, 100–200m and >200m depth intervals. Malfunction of the thermo-salinograph from 1100 on 30 August to 1500 on 31 August meant that no sea surface temperature and salinity data were collected over this period. Current speeds were calculated as the absolute difference of vessel speed through the water and speed over the ground averaged by 10 minute interval.

Absolute abundance

Radial distances from the research vessel, the *FRS Algoa*, to each sighting were calculated using a modification of Gordon's (1990) photographic method. Distances between the horizon and the whale on an image taken with a 300mm focal length lens were used to calculate the dip angle between the horizon and the whale group and consequently the angle between the whale group and the vertical. (With the low swell heights recorded during this cruise, the angle between the vertical and the horizon is constant from any given height). Image distances were measured on a binocular microscope, and radial distances from the vessel to whale were computed (after Buckland *et al.*, 1993; Gordon, 1990) incorporating a correction factor derived from the radar calibration experiment.

Perpendicular distances of groups from the trackline were calculated for all sightings as d.sin(θ), where d and θ are the radial distance and the sighting angle respectively. The programme *Distance Version 5 Release 2* (Thomas *et al.*, 2006) was utilised to fit a hazard-rate model (Buckland *et al.*, 1993),

$$g(y) = 1 - \exp[-(y/a)^{1-b}]$$

to the perpendicular distances grouped into 0.2 n.mile intervals and truncated at 3.6 n.miles to give the probability density function $f(0)$ and its variance V[$f(0)$]. No measure of the group detectability on the trackline, $g(0)$, was made and it was assumed to be one (i.e. that every whale on the trackline was seen). The abundance estimate (N) of whales in the area surveyed (A) was given by

$$N = [A.n.s.f(0)]/[2L.g(0)]$$

where n is the total number of groups sighted on primary effort, s is the mean group size of confirmed groups, and L is the total length of the search track.

The variance on this estimate ($V(N/N^2)$) was calculated using the delta method,

$$V(N/N^2) = V[f(0)]/[f(0)]^2 + V[s]/s^2 + V[n_i/l_i]/[n/L]^2].$$

$V[ni/li]$ was the variance on transect sighting rates, where n_i and l_i were the number of sightings and the search effort of transect (i) respectively.

Inclement weather encountered on 26 August resulted in the initial survey effort (of 15.61 n.miles) on 27 August being carried out in deep water outside of the planned survey area and both this effort and its associated fifteen sightings have been excluded from the abundance estimation. The inshore and offshore limits of the area surveyed (A) were selected from the inshore and offshore transect way points, and intermediate points between them on the 20 (inshore) or 200m (offshore) isobaths, to provide the minimum area delineated by the survey transects.

On the basis of the relatively broad shelf area between Cabo Inhaca and Ponta Zavora, the narrow shelf area between Ponta Zavora and Cabo Bazaruto, the Sofala Banks between Cabo Bazaruto and Epidendron Island, and the relatively narrow shelf region between Epidendron Island and the northern limit of the survey, abundance estimation was also carried out on the data stratified into these four regions.

RESULTS

A total of 951.8 n.miles was searched during the line transect survey component of the cruise (Tables 1 and 3, Fig. 2). The weather encountered during the survey period was very good with only 18.6% of survey lost to inclement weather. High winds encountered off Xai Xai necessitated slight modification to the planned survey effort (Table 1), while all remaining transects were completed largely as planned. Although the survey was planned between the 20 and 200m isobaths, limited search effort was carried out in both shallower and deeper waters.

The high densities of humpback and unidentified large whales encountered during the survey effort resulted in only limited closing mode survey (18 n.miles) being carried out, and 933.8 n.miles of the survey were carried out in passing mode. Closing mode was compromised in that tracking of primary and secondary sightings was almost impossible once the vessel heading had altered. The total search effort of 951.8 n.miles covered 81.4% of the planned 1,170 n.miles of search effort. Mean vessel speed (measured as speed over ground by GPS logger each minute of the survey) during the survey was 9.90 (SD±1.12) kt. The majority of search effort

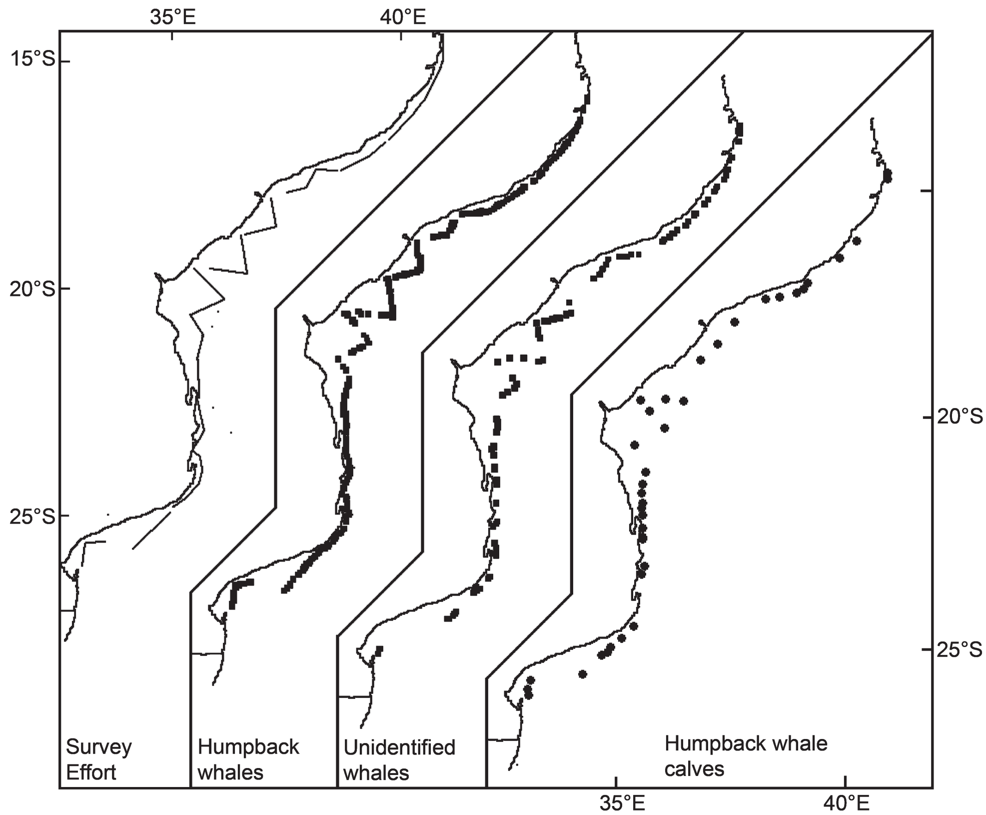

Fig. 2. The distribution of search effort carried out, and sightings of humpback whales, unidentified whales and humpback whale calves made during the line transect survey off Mozambique, 26 August to 7 September, 2003.

was carried out in excellent sighting conditions, in wind speeds of less than 15kt, swell heights of less than 1m and Beaufort Sea condition of 3 or less. The low correlation between wind speed and Beaufort Sea condition ($r^2 = 0.36$; $p > 0.05$; $n = 6{,}365$) possibly reflects Beaufort Sea condition being recorded on an hourly basis, rather than on a minute basis as for wind speed. Sea surface temperatures recorded during the survey ranged between 21° and 26°C (with an increasing northward cline in temperatures), while salinities were recorded between 33.7 and 35.2ppt, with lowest salinities being recorded over the Sofala Bank region, offshore of the Zambezi River Mouth. Current speeds recorded over the survey ranged between 0.03 and 5.78kt.

A total of 884 groups of an estimated 2,187 individual cetaceans of at least four species were recorded during the survey effort (Table 2). Sightings of large whales were recorded only on full search effort during passing and closing modes and during confirmation of groups during closing mode, as numbers of whales in the region were too high to record during off-effort periods. Few secondary sightings of large whales were recorded during interception of primary sightings during closing mode, and during periods of effort carried out when weather conditions were unacceptable for full search effort (on 26 August and 5 September). The majority of large whale sightings were cued by blows (Fig. 2), while all sightings of small cetaceans were cued by sight

Table 2

Cetaceans sighted during primary and secondary search effort during the line transect survey off Mozambique, 26 August to 7 September 2003. Secondary sightings are those made during confirmation of primary sightings or under effort in unacceptable weather conditions.

		Primary sightings		Secondary sightings	
Species	Group size confirmation	Groups	Individuals	Groups	Individuals
Humpback whales	Confirmed group size	258	503	20	28
	Un-confirmed group size	379	552	34	47
Unidentified large whales	Confirmed group size	–	–	–	–
	Un-confirmed group size	129	151	3	3
Unidentified small whales	Confirmed group size	1	1	–	–
	Un-confirmed group size	1	1	–	–
Bottlenose dolphin	Confirmed group size	3	13	1	4
	Un-confirmed group size	13	100	–	–
Spinner dolphin	Confirmed group size	4	121	3	62
	Un-confirmed group size	12	289	2	107
Risso's dolphin	Confirmed group size	1	2	–	–
	Un-confirmed group size	–	–	–	–
Unidentified dolphin	Confirmed group size	–	–	–	–
	Un-confirmed group size	18	197	2	6
Total		819	1,930	65	257

Table 3
Parameters analysed in estimation of abundance of humpback and large unidentified whales sighted during the line transect survey off Mozambique, 26 August to 7 September, 2003.

Stratum	Area (A)	Effort (total L)	Transects	Primary sightings (n)	f(0) (SE)	ESW (SE)	Density of groups (SE)	Mean group size (SE)	Density of whales (SE)	N (%CV)
Cabo Inhaca to 14°20.5'S	14,029	936.19	28	734	0.67416 (0.038)	1.4833 (0.083)	0.26428 (0.037)	1.8363 (0.060)	0.48528 (0.069)	6,808 (14.22)
Cabo Inhaca to Ponta Zavora	1,587.63	105.63	3	123	0.65770 (0.055)	1.5205 (0.127)	0.39537 (0.061)	1.9734 (0.156)	0.78024 (0.135)	1,239.0 (17.32)
Ponta Zavora to Cabo Bazaruto	1,243.64	204.41	7	180	0.48543 (0.033)	2.0600 (0.142)	0.22203 (0.067)	2.5050 (0.219)	0.55619 (0.175)	692.00 (31.44)
Cabo Bazaruto to Epidendron Island	10,001.94	455.26	12	293	0.74998 (0.086)	1.3334 (0.153)	0.25040 (0.059)	1.6254 (0.673)	0.40701 (0.097)	4,071.0 (23.97)
Epidendron Island to 14°20.5 S	1,196.26	170.89	6	115	0.89253 (0.122)	1.1204 (0.153)	0.30292 (0.094)	1.8291 (0.144)	0.55407 (0.177)	663.00 (31.98)
Pooled stratified estimate										6,664.0 (15.67)

of body or splashes. A total of 691 groups of humpback whales was sighted during the effort component of the line transect survey of which 637 groups were primary sightings (Table 2), while 132 groups of unidentified whales were sighted during the on effort component of the line transect survey, of which 129 groups were primary sightings. The distribution of these 691 sightings of an estimated 1,130 individual humpback whales and 132 sightings of an estimated 154 large unidentified whales show individuals to occur throughout the survey region (Fig. 2). Two sightings of two single unidentified small whales, were made in the region of Inhambane.

The high densities of whales encountered (mean of 8.87 groups per hour) necessitated that once sighted, groups were visually tracked through the observation area until they were abeam of the vessel, so as not to be recorded as new sightings. Diversion of the vessel from the trackline during closing mode resulted in confusion between previous primary sightings and new secondary sightings, and the survey was therefore carried out predominantly in passing mode. However, given the high densities of sightings, confirmations of group size could be carried out on a relatively large sample within acceptable distance ranges, usually as the group was at it's closest to the observation platform when abeam of the vessel. The sizes of 284 groups of humpback whales were confirmed (37%) providing a mean group size of 1.89 whales per group. Mean group sizes recorded during the 1991 survey (Findlay *et al.*, 1994) ranged by stratum between 1.80 and 2.16 whales per group. Species identity was carried out only on confirmation of the animal's body. Given that the only identified species of large whale on the survey were humpback whales, the assumption that all unidentified whales were humpback whales appears reasonable (the only other large whale species to be expected in the region, would be low densities of southern right whales in the extreme south of the survey area). Comparison of confirmed and unconfirmed group size estimates (Fig. 3) of humpback and unidentified large whales show the unconfirmed group sizes to be smaller ($\chi^2 = 388.7$; $df = 6$; $p < 0.0001$), possibly due to the underestimation of distant groups. Consequently only confirmed group sizes have been utilised in the calculation of the mean size of humpback whale groups of 1.90 (SD±1.09; $n = 284$) individuals. Group sizes of all sightings of unidentified whales remained unconfirmed. Age or sex composition of groups remained undetermined, although all groups containing calves were assumed to include a cow-calf pair. A total of 47 groups of humpback whales containing a calf were recorded throughout the survey area (Fig. 2). Thirty-eight of these calves were recorded within 278 groups of confirmed group size (13.7%), while a further nine calves were recorded in groups of unconfirmed group size.

The direction of travel of humpback whales was non-random over the four cardinal quadrants ($\chi^2 = 21.7$; $df = 3$; $p < 0.0007$), with fewer than expected whale groups observed travelling in a northwesterly direction (Fig. 3). Travel in a northwesterly direction was probably influenced by the orientation of the Mozambique coastline in a general northeasterly/southwesterly direction. Despite long-shore movement of animals, no directed northward or southward migration of animals were believed to bias encounter rates.

Relative abundance of humpback whales within the surveyed area

Expected densities of humpback whales were calculated as a function of search effort. Whales were not randomly distributed by half degree square ($\chi^2 = 145.0$; $df = 43$; $p < 0.0001$), with higher than expected sighting frequencies in the regions between Cabo Inhaca and Xai-Xai, between Ponta Zavora and Bazaruto and in the region of the Pantaloon Shoals to the north east of Quelimane, and lower than expected sighting frequencies over the Sofala Banks. The relative abundances of humpback whales and large unidentified whales were analysed by comparison of observed and expected densities across environmental parameters (Fig. 4). A significant difference ($\chi^2 = 10.4$; $df = 4$; $p < 0.035$) was found between the observed and expected frequencies of whale groups recorded by Beaufort Sea state (Fig. 4), although this is possibly a reflection of the sightability of whales in different sea states. Lower than expected frequencies were recorded in both Beaufort Sea state 1 and 4, and higher than expected frequencies were recorded in Beaufort Sea states 2 and 3, reflecting (as with wind speed) both the visibility of sighting cues and whale behaviour. Wind speed appeared to have a significant influence on sighting probability ($\chi^2 = 29.6$; $df = 6$; $p < 0.00005$) between observed and expected frequencies by wind speed (Fig. 4). Lower than expected frequencies were recorded during both light (<5knots) and strong winds (>15knots), with higher than expected frequencies recorded at intermediate wind speeds (5–10knots). The lower than expected sighting probabilities under light weather conditions is ascribed to both whale behaviour and the visibility of cues under such conditions.

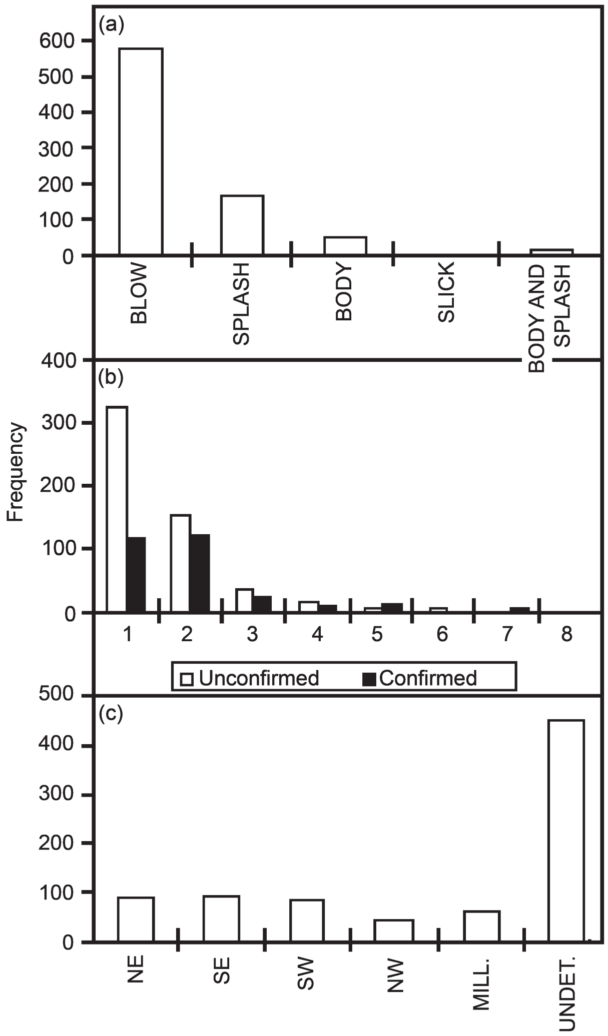

Fig. 3. Frequencies of sighting cues (A), confirmed and unconfirmed size estimates (B) and direction of travel (C) of groups of humpback and unidentified large whales sighted during the line transect survey.

No trend was evident in sighting rates by swell height (Fig. 4). Whales were observed at significantly different depths to those expected from a random distribution with respect to effort ($\chi^2 = 11.6$; $df = 4$; $p < 0.020$) (Fig. 4), with higher than expected frequencies recorded in the 100–200m depth interval and lower than expected densities recorded in both shallow and deeper water depth intervals. Although a significant difference ($\chi^2 = 12.2$; $df = 4$; $p < 0.02$) was found between observed and expected frequencies of whales by sea surface temperature interval (Fig. 4), no trend in distribution by sea surface temperature was evident. Humpback whale distribution was significantly related ($\chi^2 = 46.7$; $df = 15$; $p < 0.00004$) to sea surface salinity (Fig. 4), with possible avoidance of lower salinity waters. Although a significant difference between observed and expected sighting frequencies were recorded by current speed (distributed ($\chi^2 = 13.6$; $df = 55$; $p < 0.018$), whales were not distributed in faster or slower currents (Fig. 4).

Line transect survey

The relationship between photographically-determined distances to the small boat and radar measured distances recorded during the distance calibration experiment is shown in Fig. 5. Distances to 477 groups of whales were obtained from 579 photographs taken, the remaining 102 images being duplicates or blurred to the point that the group was indistinguishable within the image. Photographic distances were corrected for the error calculated from the radar calibrations ($y = 0.3462e^{0.8501x}$, $r^2 = 0.9725$, $p < 0.05$, $n = 35$, where x = photo distance and y = radar distance). Distances to the remaining 289 groups were determined from hand held reticule measurements converted to distance based on the results of the calibration experiment ($y = 2.9854e–^{03423x}$, $r^2 = 0.9602$, $p < 0.05$, $n = 35$, where x = reticule distance and y = radar distance, Fig. 6).

Unstratified data

HUMPBACK AND UNIDENTIFIED WHALES COMBINED

The 734 groups of humpback and unidentified whales sighted within 3.6 n.miles of the ship during the 936.19 n.miles of acceptable survey effort resulted in an encounter rate of 0.784 groups per n.mile (SE (*ni*/*li*) ± 0.099). The frequency of perpendicular distance estimates from the trackline is provided in Fig. 7. The hazard-rate model fitted to the perpendicular distances truncated at 3.6 n.miles resulted in an estimated sighting probability density function at zero $f(0)$ of 0.67416 (SE±0.038) (Table 3). On the assumption that $g(0) = 1$, this leads to an estimated density of 0.265 groups per square nautical mile and an estimate of 0.485 whales per square nautical mile. Such densities result in an abundance estimate of 6,808 whales (CV = 0.14) over the surveyed area of 14,029.49 n.miles^2 (Table 3).

HUMPBACK WHALES

A total of 618 groups of humpback whales were sighted within 3.6 n.miles of the trackline during 936.19 n.miles of acceptable on effort survey. Frequencies of groups sighted with distance from the trackline are shown in Fig. 9. On the assumption that $g(0)$ equals 1, the hazard rate model applied to these frequencies resulted in an estimated sighting probability density function at zero $f(0)$ of 0.69354 (SE ± 0.037) and an effective search width of 1.4419 (SE ± 0.078) (Table 4). Densities of encountered groups and whales were estimated at 0.22891 (SE ± 0.033) and 0.42268 (SE ± 0.062) per n.mile^2 respectively, leading to an abundance estimate of 5,930 (CV = 0.15) across the surveyed area of Mozambican waters (Table 4).

Data stratified by coastal region

HUMPBACK AND UNIDENTIFIED WHALES

Totals of 123, 180, 293 and 115 primary sightings of humpback and unidentified whales were made during 105.63, 204.41, 455.26 and 170.89 n.miles of search effort in Strata 1 to 4 respectively (Table 3). The frequencies of perpendicular distance estimates from the trackline of sightings in each stratum are provided in Fig. 8. Hazard rate models were fitted to the perpendicular distances truncated at 3.6 n.miles in each of these strata and resulted in the sighting probability density function values at zero shown in Table 3, along with other results of analyses of abundance estimation in each of these four strata. A significant difference was found in mean group size by stratum (Table 5, $F = 6.26$, $p < 0.005$, $n = 252$). A pooled total of 6,664 (CV = 0.16) whales was estimated in the area surveyed (Table 3), with highest densities in the southernmost stratum and the lowest densities across the Sofala Banks.

HUMPBACK WHALES

Totals of 113, 160, 253 and 92 primary sightings of humpback and unidentified whales were made within 3.6 n.miles of the trackline during 105.63, 204.41, 455.26 and 170.89 n.miles of search effort in Strata 1 to 4 respectively

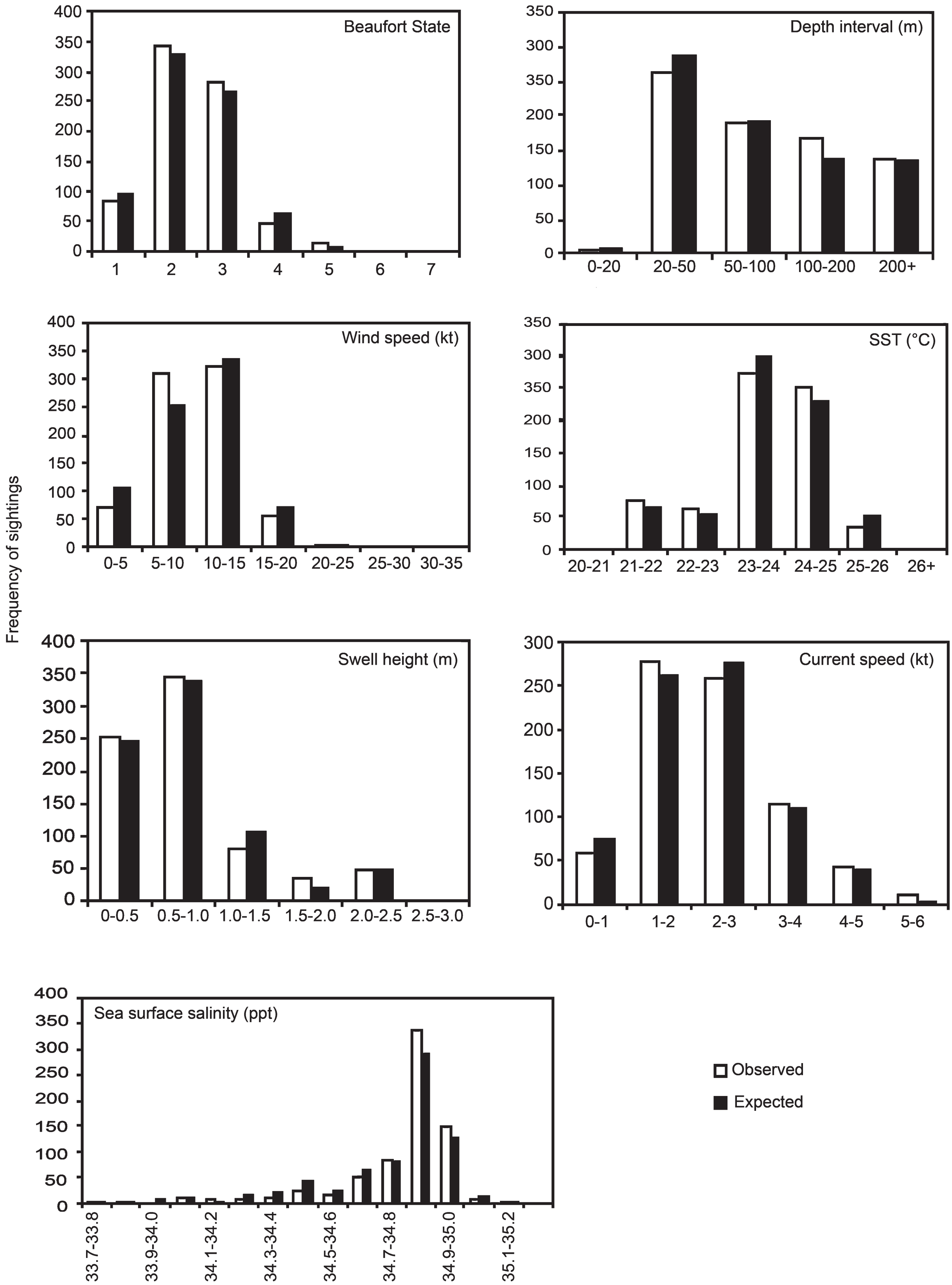

Fig. 4. Observed and expected numbers of humpback and large unidentified whale groups sighted by Beaufort State, wind speed, swell height, water depth, sea surface temperature, sea surface salinity and current speed interval during the line transect survey off Mozambique, 26 August to 7 September 2003. Expected numbers were calculated under the assumption that sighting densities are determined by relative search effort.

(Table 3). Frequencies of sightings with distance from the trackline (in 0.2 n.mile distance bins) are shown in Fig. 10. Application of the hazard rate model to these frequencies resulted in sighting probability density function values at zero, and on the assumption of $g(0)$ equalling 1 resulted in effective search widths of between 1.23 and 1.96 (see Table 4). Densities calculated in the four strata showed (as with the combined analyses of humpback and unidentified whales) densities to be lowest across the Sofala Banks and highest in the southern stratum between Inhaca and Ponta Zavora.

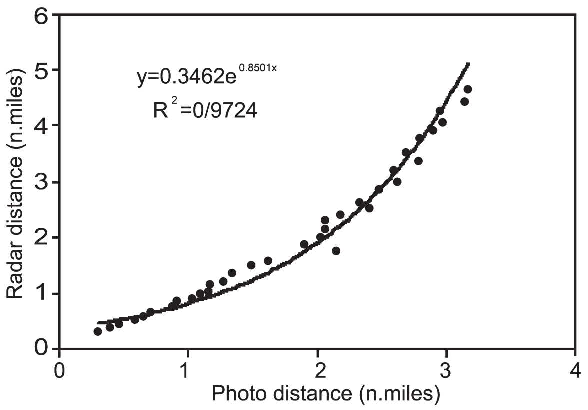

Fig. 5. Relationship between distance measurements to an inflatable small boat target measured by the photographic distance measurement (after Buckland *et al.*, 1993; Gordon, 1990) and by radar during the distance calibration experiment.

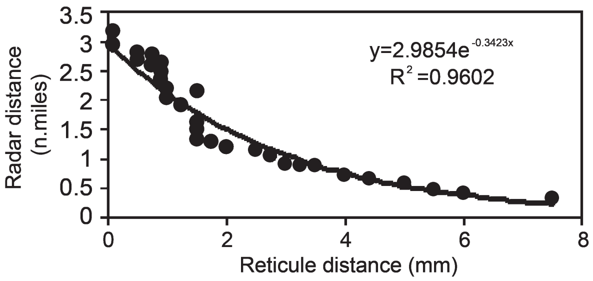

Fig. 6. Relationship between distances measured to an inflatable small boat by hand-held reticules and by radar during the distance calibration experiment.

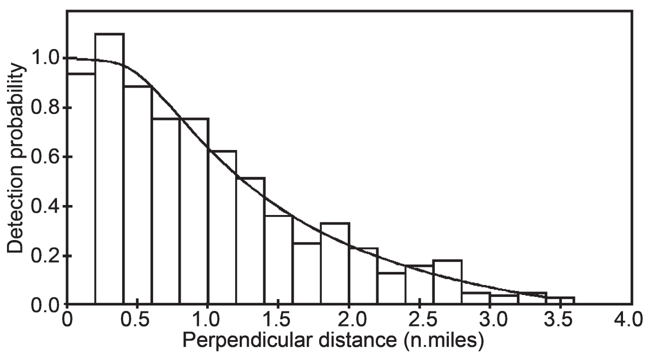

Fig. 7. Frequency of groups of humpback and unidentified whales sighted at perpendicular distances from the trackline during primary search effort over the line transect survey off Mozambique, 26 August to 7 September 2003.

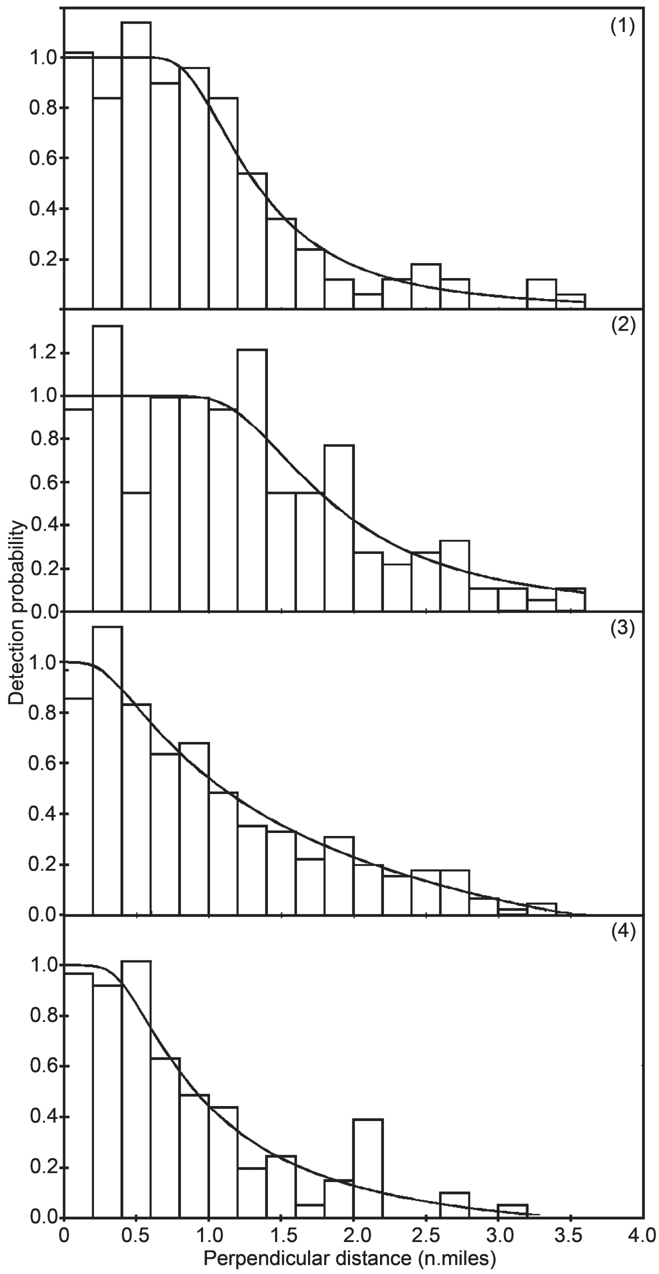

Fig. 8. Frequency of groups of humpback and unidentified whales sighted at perpendicular distances from the trackline in each of the four strata during primary search effort over the line transect survey off Mozambique, 26 August to 7 September 2003. (Stratum 1, Cabo Inhaca to Ponta Zavora; Stratum 2, Ponta Zavora to Cabo Bazaruto; Stratum 3, Cabo Bazaruto to Epidendron Island, and Stratum 4, Epidendron Island to 14°20.5'S).

Pooled stratum estimates resulted in an abundance estimate of 5,965 whales (CV = 0.17).

DISCUSSION

Townsend's (1935) charts of the positions of 19th Century open-boat whale-ships on days on which humpback whales were taken, show high catches in the region of 14°–15°S on the east coast of Africa, and few or no catches elsewhere on the Mozambican coast. Given that humpback whales migrate throughout coastal waters of this region, Findlay *et al.* (1994) believed this to be an error on Townsend's part in attributing catches from the coast of Mozambique to the town of Mozambique. However, Townsend's (1935) charts also show high localised catches in the region of Baie d'Antongil (15°30'S) in the north east of Madagascar, where Ersts and Rosenbaum (2003) have recently described a humpback wintering ground. Sightings recorded during the current survey were across the survey area and do not support the clumping of catches in the 14°–15°S region of the coast as indicated by Townsend (1935). Although such clumping may result from selection of anchorages or other logistic aspects, the availability of both sheltered sites and catches of other species indicated by Townsend (1935) elsewhere along this coast (for example, the catch of southern right whales on the Delagoa bay grounds off Maputo in southern Mozambique) suggest some anomaly in the distribution of catches shown by Townsend (1935). Rørvik (1980) and da Silva (in litt.)

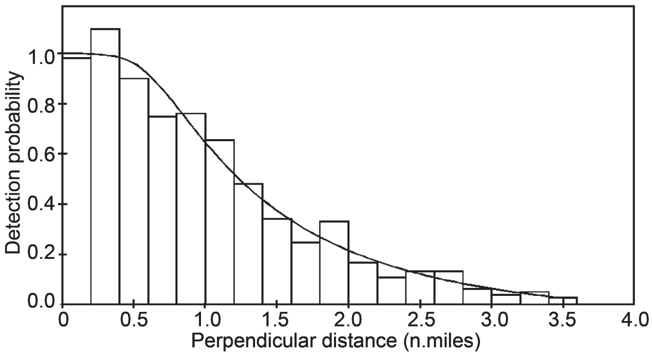

Fig. 9. Frequency of groups of humpback whales sighted at perpendicular distances from the trackline during primary search effort over the line transect survey off Mozambique, 26 August to 7 September 2003.

[see Findlay *et al.,* 1994] record sightings of humpback whales made in Mozambique waters, but neither sets of data have associated effort and no overall distribution patterns can be determined. However it should be noted that Rørvik (1980) recorded no sightings to the north of Angoche. Similarly, Tønnessen and Johnsen (1982) noted that catches to the north of Quelimane were generally poor. Despite few sightings within southern Tanzania, it was believed that the planned transects of this survey would extend beyond the northern limit of the wintering ground, and that sighting rates would decline in the north of the survey.

The timing of the 2003 survey was selected to maximise the abundance of humpback whales on the wintering ground. Olsen (1914) reported on the seasonality of humpback whale catches in the Durban whaling grounds over the period 1910 to 1912, and although Best *et al.* (1998) suggests that the 1912 data may be compromised, the seasonality of catches in both 1910 and 1911 show bimodal peaks in the last 10 days of July and in mid- to late September. Further bimodal seasonality of catches and sightings off Durban were reported by Matthews (1938) and Bannister and Gambell (1965) respectively. Sightings of humpback whales made by the Union Whaling Company's spotter aircraft in the Durban whaling grounds between 1972 and 1975 were too few to describe any seasonal abundance patterns (Findlay, 1989). Catches from Linga-linga, Mozambique, were unimodal in seasonal abundance with peak catches in August or July (Lea, 1919; Olsen, 1914). Bermond (1950) analysed catches off Madagascar in the 1938, 1939 and 1949 seasons by 10 day period and found a marked bimodal seasonality in 1938 and 1939 (peaks in July and late August/early September), but a less pronounced bimodal seasonality in 1949. Angot (1951) provided a more detailed analysis of the 1949 data and showed a bimodal seasonality with peaks in late July and early September (Table 1). Findlay (1994) and Findlay and Best (1996a; 1996b) provided the results of shore based monitoring of the migration of humpback whales off Cape Vidal, northern KwaZulu-Natal between 1988 and 1991, and found the northward migration to occur between July and August and the southward migration to occur in September and October. Although direction of movement of groups recorded during the 2003 survey was not random over the four cardinal quadrants of the compass (possibly due to the orientation of the coastline limiting movement in a north westerly direction), there was no difference in direction of movement between northerly and southerly direction which might have biased counts. Furthermore the southward migration is thought to commence in late August/early September so that any population movement would have been expected against the northward direction of the survey (thus limiting bias of the vessel following the migration).

Sighting conditions encountered during the cruise were generally very good with only 18.5% of survey lost to inclement weather. Relative sighting rates were marginally lower under calm conditions (wind speed of less than 5 knots or sea state of 1) probably as a result of reduced cues from less surface active behaviour under these conditions or from reduced visibility of blows against calm sea conditions. However, such calm conditions formed a relatively small component of the survey and relative differences are not believed to bias overall sighting rates. On the basis of observed versus expected frequencies of sightings, humpback and large unidentified whales were not randomly distributed by area, with lower than expected sighting frequencies over the Sofala Bank region. The most marked difference between the observed and expected sighting frequencies by environmental parameter was by sea surface salinity, where whales were distributed in higher salinities than expected. The lowest salinity waters were recorded in the Sofala Banks region (possibly corresponding to the outflow of the Save, Zambezi, and Pengue Rivers in this region). Avoidance of turbid waters by humpback whales has been noted during observations off Cape Vidal in South Africa and it is possible that turbid freshwater river outflow influenced whale distribution over the Sofala Banks.

A yacht-based survey of humpback whales carried out in Mozambique waters in 1991 (Findlay *et al.*, 1994), found

Table 4

Parameters analysed in estimation of abundance of identified humpback whales sighted duringthe line transect survey off Mozambique, 26 August to 7 September, 2003.

Stratum	Area (A)	Effort (total L)	Transects	Primary sightings (n)	f(0) (SE)	ESW (SE)	Density of groups (SE)	Mean group size (SE)	Density of whales (SE)	N (%CV)
Cabo Inhaca to 14°20.5'S	14,029	936.19	28	618	0.69354 (0.037)	1.4419 (0.078)	0.22891 (0.033)	1.8465 (0.060)	0.42268 (0.062)	5,930.0 (14.68)
Cabo Inhaca to Ponta Zavora	1,587.63	105.63	3	113	0.69726 (0.0613)	1.4342 (0.126)	0.37295 (0.069)	1.9795 (0.156)	0.73825 (0.148)	11,72.0 (20.14)
Ponta Zavora to Cabo Bazaruto	1,243.64	204.41	7	160	0.51120 (0.038)	1.9562 (0.146)	0.20006 (0.060)	2.4862 (0.217)	0.49738 (0.155)	619.00 (31.19)
Cabo Bazaruto to Epidendron Island)	10,001.94	455.26	12	253	0.81445 (0.088)	1.2278 (0.133)	0.22631 (0.056)	1.6341 (0.068)	0.36980 (0.093)	3699.0 (25.20)
Epidendron Island to 14° 20.5'S	1,196.26	170.89	6	92	0.80234 (0.097)	1.2464 (0.150)	0.21597 (0.064)	1.8398 (0.148)	0.39733 (0.122)	475.00 (30.75)
Pooled stratified estimate										5,965.0 (16.62)

Table 5
Mean group sizes of confirmed groups recorded by survey stratum off Mozambique, 26 August to 7 September 2003.

Stratum[1]	Average	SD	n
1	1.916667	1.126722	48
2	2.436364	1.607432	55
3	1.701754	0.739885	114
4	1.714286	0.825029\	35

[1]Stratum 1, Cabo Inhaca to Ponta Zavora; Stratum 2, Ponta Zavora to Cabo Bazaruto; Stratum 3, Cabo Bazaruto to Epidendron Island, and Stratum 4, Epidendron Island to 14° 20.5'S

whales distributed over the entire region surveyed, although whale densities were highest in the southern region between 33°E and 35°30'E (Maputo to Ponta Zavora) a region of shallow banks where the southerly Mozambique Current flowed further offshore. A high proportion of cow and calf pairs were sighted on the Sofala Banks during the 1991 survey (Findlay *et al.*, 1994), and compared favourably with proportions of cow and calf pairs sighted on other presumed calving grounds. As with the 1991 survey, highest densities of whales were recorded in the southern region between Cabo Inhaca and Ponta Zavora. Surprisingly however, cow calf groups were distributed throughout the survey area suggesting a possible expansion of the area utilised by lactating females.

The abundance of whales estimated from this survey ranged between 6,808 (CV = 0.14) humpback and unidentified whales and 5,930 humpback whales (un-stratified analyses) and 6,664 humpback and unidentified whales (CV = 0.16) and 5,965 humpback whales (CV = 0.17) (data analysed across the four coastal strata). The abundance estimate of 5,965 (CV = 0.17) whales is a marked increase over the estimate made in 1991 of 1,954 (CV = 0.38) by Findlay *et al.* (1994) or the estimate of 1,776 made during shore-based surveys on the northern KwaZulu Natal coast in 1991 (Findlay and Best, 1996b). However, comparison of these estimates requires considerable caution and no attempt has been made to estimate increase rates from these surveys. Firstly, the survey limits are not directly comparable in distribution or extent. The 1991 area surveyed by Findlay *et al.* (1994) extended from Maputo Bay (25°45'S) to 18°S and between the 10 and 100 fathom (or 18.3 and 183m isobaths) (a total area of 12,591 n.miles^2), while the current survey extended from Cabo Inhaca (26°00'S) and 14°20.5'S from inside the 20m isobath to immediately outside the 200m isobath (a total area of 14,029 n. miles^2). Although both the 1991 and the 2003 surveys assumed that all whales on the trackline were sighted (that $g(0)$ was 1) the distribution of sightings from the trackline may have differed between the two survey platforms, as the sighting probabilities of five observers at 12m above sea level on the more stable *FRS Algoa* platform would be expected to be considerably higher than those of two observers at 10m on a yacht mast.

Furthermore, the population abundance estimated during this survey must be considered minimal for the Mozambique population for a number of reasons.

(1) Although the timing of the survey was planned to coincide with maximal expected abundance on the Mozambique grounds, numerous sightings made in transit between Richard's Bay, South Africa and Cabo Inhaca suggest that a considerable proportion of the population was to the south of the surveyed area during the survey.

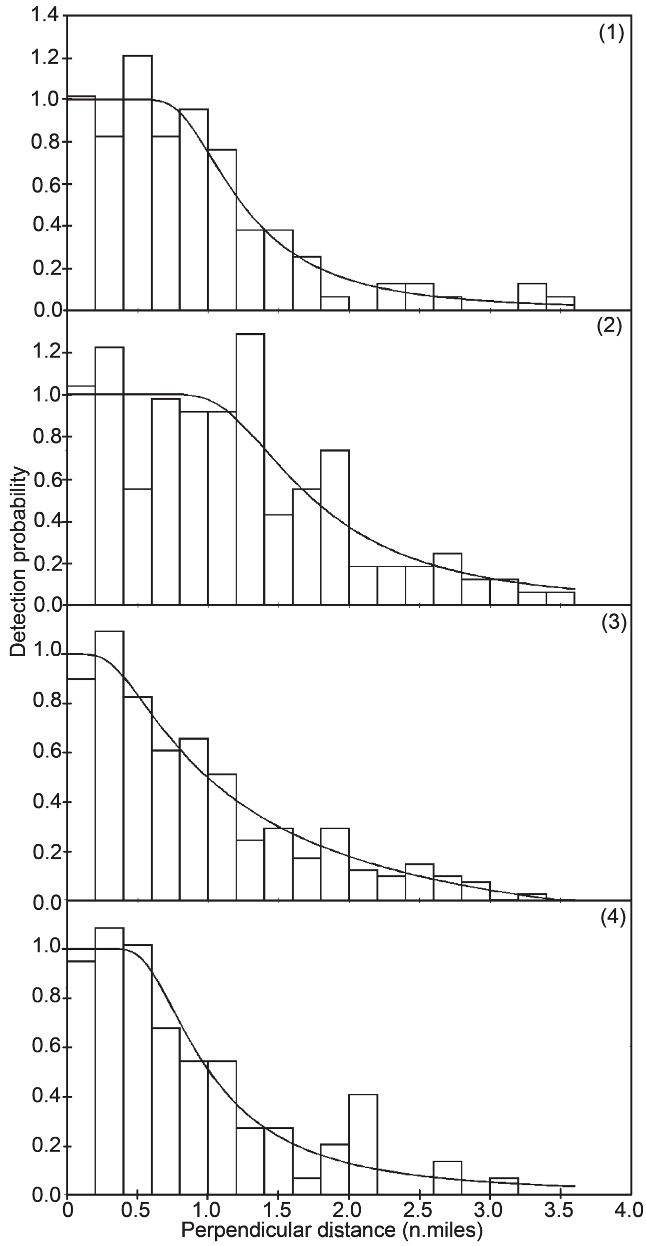

Fig. 10. Frequency of groups of humpback whales sighted at perpendicular distances from the trackline in each of the four strata during primary search effort over the line transect survey off Mozambique, 26 August to 7 September 2003. (Stratum 1, Cabo Inhaca to Ponta Zavora; Stratum 2, Ponta Zavora to Cabo Bazaruto; Stratum 3, Cabo Bazaruto to Epidendron Island, and Stratum 4, Epidendron Island to 14°20.5'S).

(2) The definition of the survey area between the 20 and 200m isobaths was selected on the basis of distributions and historical catches of humpback whales in coastal waters in breeding grounds across the Southern Hemisphere. However the sightings on this survey during limited effort in water depths of over 200m suggest that some unknown proportion of the population was offshore of the major area surveyed.
(3) The high encounter rates on the northernmost transects of the area surveyed suggest that it is probable that the northern limits of the breeding grounds were not surveyed.
(4) The assumption of $g(0)$ being one over all sighting conditions encountered likely biases the abundance estimate downwards.

Although not directly comparable to the yacht based survey of Mozambican waters carried out in 1991 (Findlay *et al.*,

1994) or shore based surveys off northern KwaZulu-Natal in 1990 and 1991 (Findlay and Best, 1996a) these estimates suggest the population of humpback whales off Mozambique has increased since the early 1990s. However, no increase rates have been calculated due to the marked differences in survey procedures, design and area.

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