Mammal Rev. 2007, Volume 37, No. 2, 116–175. *Printed in Singapore*.

Past and present distribution, densities and movements of blue whales *Balaenoptera musculus* in the Southern Hemisphere and northern Indian Ocean

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ABSTRACT

1. Blue whale locations in the Southern Hemisphere and northern Indian Ocean were obtained from catches (303 239), sightings (4383 records of ≥8058 whales), strandings (103), Discovery marks (2191) and recoveries (95), and acoustic recordings.

2. Sighting surveys included 7 480 450 km of effort plus 14 676 days with unmeasured effort. Groups usually consisted of solitary whales (65.2%) or pairs (24.6%); larger feeding aggregations of unassociated individuals were only rarely observed. Sighting rates (groups per 1000 km from many platform types) varied by four orders of magnitude and were lowest in the waters of Brazil, South Africa, the eastern tropical Pacific, Antarctica and South Georgia; higher in the Subantarctic and Peru; and highest around Indonesia, Sri Lanka, Chile, southern Australia and south of Madagascar.

3. Blue whales avoid the oligotrophic central gyres of the Indian, Pacific and Atlantic Oceans, but are more common where phytoplankton densities are high, and where there are dynamic oceanographic processes like upwelling and frontal meandering.

4. Compared with historical catches, the Antarctic ('true') subspecies is exceedingly rare and usually concentrated closer to the summer pack ice. In summer they are found throughout the Antarctic; in winter they migrate to southern Africa (although recent sightings there are rare) and to other northerly locations (based on acoustics), although some overwinter in the Antarctic.

5. Pygmy blue whales are found around the Indian Ocean and from southern Australia to New Zealand. At least four groupings are evident: northern Indian Ocean, from Madagascar to the Subantarctic, Indonesia to western and southern Australia, and from New Zealand northwards to the equator. Sighting rates are typically much higher than for Antarctic blue whales.

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6. South-east Pacific blue whales have a discrete distribution and high sighting rates compared with the Antarctic. Further work is needed to clarify their subspecific status given their distinctive genetics, acoustics and length frequencies.
7. Antarctic blue whales numbered 1700 (95% Bayesian interval 860–2900) in 1996 (less than 1% of original levels), but are increasing at 7.3% per annum (95% Bayesian interval 1.4–11.6%). The status of other populations in the Southern Hemisphere and northern Indian Ocean is unknown because few abundance estimates are available, but higher recent sighting rates suggest that they are less depleted than Antarctic blue whales.

Keywords: Antarctic blue whales, *Balaenoptera musculus brevicauda*, *Balaenoptera musculus indica*, *Balaenoptera musculus intermedia*, distribution, pygmy blue whales, true blue whales, whaling

Mammal Review (2007), **37**, 116–175
doi: 10.1111/j.1365-2907.2007.00106.x

INTRODUCTION

The blue whale *Balaenoptera musculus* is the largest of the mysticete (baleen) whales, with lengths exceeding 30 m. It was once abundant in the Southern Hemisphere, but was subject to intensive exploitation by whaling beginning in 1904 (Branch, Matsuoka & Miyashita, 2004); this was particularly true in the Antarctic, where blue whales congregated in summer to feed, primarily on krill *Euphausia superba*.

Despite being the largest animals ever to exist on Earth, surprisingly little is known about the distribution and migration of blue whales in the Southern Hemisphere and northern Indian Ocean. In this region, there are two recognized subspecies, the Antarctic (or true) blue whale *B. m. intermedia* and the pygmy blue whale *B. m. brevicauda* (Rice, 1998). Compared with pygmy blue whales, Antarctic blue whales attain greater maximum lengths (>30 m vs. 24.1 m), are longer at sexual maturity (23.7 m vs. 19.2 m) and have proportionately longer tail regions (Mackintosh & Wheeler, 1929; Ichihara, 1966). In the austral summer, Antarctic blue whales are generally found south of 55°S while pygmy blue whales are generally believed to remain north of 54°S (Ichihara, 1966; Kato, Miyashita & Shimada, 1995). Based on a combination of evidence from three long-term sightings series, Antarctic blue whales were depleted to very low levels before increasing to 1700 (95% Bayesian interval 860–2900) in 1996, but remain at less than 1% of their original abundance of 239 000 (95% Bayesian interval 202 000–311 000) (Branch *et al*., 2004). The status of pygmy blue whales is much more uncertain but their original abundance was probably an order of magnitude lower than that of Antarctic blue whales, and they are likely less depleted at present.

The distribution of blue whales in the Southern Hemisphere and northern Indian Ocean is poorly understood, except perhaps for the Antarctic during the austral summer. Some previous studies have assumed that they are distributed throughout this region (e.g. Gambell, 1979; Mizroch, Rice & Breiwick, 1984), presuming that gaps in their distribution are caused by lack of search and catch effort rather than a true absence of blue whales. However, data from Japanese Scouting Vessels (JSV, 1965–87) show that despite widespread effort, sightings were concentrated in the South Indian Ocean and largely absent from the South Pacific and South Atlantic Oceans (Miyashita, Kato & Kasuya, 1995). Plots interpolated from catches (Mikhalev, 2000; Best *et al*., 2003) are revealing but ignore information from sightings, strandings and acoustic detections. The best effort at drawing together data from different sources is that of Yochem & Leatherwood (1985), but their map did not include subsequent revelations of widespread illegal Soviet catches in the 1960s and 1970s (Yablokov, 1994; Mikhalev, 1997a;

Yablokov *et al*., 1998); it also interpolated between rare catches in some regions, and contained many question marks over the distribution of blue whales in other areas.

The classic theory of migration patterns for blue whales may also be in need of revision. It has long been assumed that Antarctic blue whales migrate to temperate mating and calving areas in the winter and then return to the Antarctic to feed in the summer. Early work by Mackintosh & Wheeler (1929) showed conclusively that the whales caught at South Georgia and at Saldanha Bay, South Africa, were morphologically similar, and that the timing of catches at the two locations was consistent with migration. Year-round voyages of the *Discovery II* showed a marked rise and fall of baleen whale numbers in the Antarctic also consistent with migration (Mackintosh, 1966). Finally, there is unequivocal evidence for this migration pattern in humpback whales *Megaptera novaeangliae* and some indications of a similar migration in fin whales *Balaenoptera physalus*; thus, it has been argued by analogy that the pattern holds also for blue whales (Mackintosh & Wheeler, 1929; Mackintosh, 1966).

More recent analyses of length frequencies (based on a database containing 82% of all catches between 1914 and 1973) have reinforced the conclusion that Antarctic blue whales migrate to South African and Namibian waters in winter (Best, 1998; Branch *et al*., 2007). Additionally, acoustic recordings (from the 1990s onwards) have detected brief periods of Antarctic-type calls in the austral autumn and winter (peaking in July) in the eastern tropical Pacific and central Indian Ocean, and off south-west Australia and northern New Zealand (Stafford *et al*., 2004; McDonald, 2006).

However, not all evidence supports the migration hypothesis: some Antarctic blue whales remain behind during the winter. At South Georgia, blue whales were present year-round (Hinton, 1915; Risting, 1928). There were also year-round acoustic detections of blue whales in the West Antarctic Peninsula (Širović *et al*., 2004) and East Antarctic (McKay, Širović & Thiele, 2005), although these were greatly reduced in winter.

It is also well-known that pygmy blue whales do not generally migrate to the Antarctic in summer. Pygmy blue whales in the northern Indian Ocean form a resident population (Yochem & Leatherwood, 1985; Mikhalev, 2000; Anderson, 2005), and the abundance of pygmy blue whales around Australia (Gill, 2002), south of Madagascar (Best *et al*., 2003) and in the southern Indian Ocean (Zemsky & Sazhinov, 1982; Miyashita *et al*., 1995) peaks in the summer months. Blue whale catches and sightings in the south-east Pacific are also more common in summer than in winter (Clarke, Aguayo & Basulto, 1978; Hucke-Gaete *et al*., 2003).

To provide updated maps of blue whale distribution, to address questions about the classical migration theory for blue whales and to compare densities in different regions, we compiled available data for catches, sightings, strandings, acoustic recordings and Discovery mark recoveries from a variety of published and unpublished sources. The resulting data were compared with maps of bathymetry, thermal fronts and phytoplankton biomass to better understand their association with blue whale distribution. Finally, the whale data were examined for monthly patterns suggesting migration.

METHODS

The study area is defined to be the entire Southern Hemisphere in addition to the northern Indian Ocean, because this covers the known distribution of Antarctic and pygmy blue whales. In the eastern tropical Pacific, sightings between the equator and 5°N are also included, because extensive surveys there (e.g. Reilly & Thayer, 1990) show that there is a gap (~3–7°N) between blue whale sightings near the Costa Rica Dome that are from the California/Mexico population (Mate, Lagerquist & Calambokidis, 1999), and those closer to the equator that probably come from the south-east Pacific population. Data were collected on bathymetry, thermal fronts and phytoplankton biomass to relate these environmental factors to blue whale distribution. The study focused on positional information from catches, sightings, strandings, mark-recaptures (using Discovery marks) and acoustic detections, but did not include data from several satellite tagging and photo-identification studies since these had not yet been published. Positional data were separated into whaling (≤1973) and post-whaling (>1973) eras to assess whether the occurrence and distribution of blue whales was affected by whaling.

Historical catches

Catch positions were provided by the International Whaling Commission (IWC) Secretariat and include an up-to-date account of catches by the USSR in the 1950s to 1970s, correcting for USSR misreporting and illegal whaling (Yablokov, 1994; Mikhalev, 1997a; Yablokov *et al*., 1998). Catch positions were recorded to the nearest degree for many earlier catches, but to the nearest minute for later catches. The positions associated with land station catches were usually fixed and did not represent the actual catch positions, except in later years. Finally, the catch database does not have a fully comprehensive set of individual positions, especially for the early part of the 20th century and during World Wars I and II.

Nearly all whaling on blue whales was conducted in the Antarctic, providing little information on blue whale distribution outside this area. However, Soviet vessels travelled widely outside the Antarctic during the 1950s to 1973, catching whales without regard to closed seasons, closed areas and forbidden species. Revised data on their catches are available from 1958 to 1973. For this period of time, a proxy of Soviet effort was obtained by comparing the catches of blue whales with those of all whales for each 2° × 2° square.

Sightings

Sightings were obtained from a wide variety of published papers, technical reports and unpublished IWC Scientific Committee documents, in addition to unpublished data from the authors of this paper and other sources listed in the acknowledgements (Appendix 2). Potential sources were restricted to a manageable number by including only sources that listed blue whale sightings. Because effort associated with surveys with zero sightings was excluded, total estimated effort is negatively biased. Where the number of groups of whales was recorded, this may have referred to schools (stable groups of whales that usually travel together and are often related) or to feeding aggregations (unstable groups aggregating around an ephemeral food source). Where later papers referred to the same sightings obtained from another more primary source, the earlier source was preferred. Less effort was expended in collating sightings prior to 1973 while catches were still being taken. For example, no effort was made to extract data from logbooks of 19th century American whaling boats except for those collated by Wray & Martin (1983). Four particularly extensive datasets are described in more detail below.

IDCR/SOWER database

Antarctic surveys were conducted under the auspices of the IWC from 1978/79 to 2005/06, under the auspices of the International Decade of Cetacean Research (IDCR), and Southern Ocean Whale and Ecosystem Research (SOWER) programmes (Branch & Butterworth, 2001a; Matsuoka *et al*., 2003). Sightings were obtained from the IWC's database DESS 3.42 (Database-Estimation Software System, Strindberg & Burt, 2004) for 1978/79–2004/05. Details from each survey can be obtained from the individual cruise reports (e.g. Ensor *et al*., 1999, 2000, 2004). At the time of submission, sightings had not been encoded from the 2005/06 survey (33 groups, 63 whales) (Ensor *et al*., 2006).

JARPA database
The Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) has so far operated from 1989/90 to 2005/06. Blue whale abundance estimates have been calculated up to the 2004/05 season (Matsuoka *et al.*, 2006), and sightings from 1989/90 to 2004/05 are included in this paper. Effort was widespread south of 60°S and from 35°E eastwards to 145°W. Additional effort was recorded in much of the region north of 60°S during transits and during surveys between 57°S and 60°S.

JSV database
Japanese Scouting Vessels (JSV) recorded noon-day positions, total blue whales sighted on that day, and daily search effort from 1965/66 to 1988/89 (Miyashita, Shigemune & Kato, 1994; Miyashita *et al.*, 1995). However, from the 1978/79 season onwards, some of these vessels were also used in the IDCR/SOWER surveys, resulting in potential record duplication in the two databases. Since the IDCR/SOWER records contained more accurate positions these were preferred, reducing JSV records from 2520 blue whales (recorded on 833 vessel-days) to 2410 whales (799 vessel-days). JSV recorded the number of groups and number of whales in most years, but in some years the number of groups was not recorded.

SWFSC surveys in the eastern tropical Pacific
The Southwest Fisheries Science Center (SWFSC) of the U.S. National Marine Fisheries Service conducted a series of marine mammal surveys in the eastern tropical Pacific between 1986 and 2006 (e.g. Holt & Sexton, 1987; Hill, Rasmussen & Gerrodette, 1991; Mangels & Gerrodette, 1994; Kinzey *et al.*, 2001; Jackson *et al.*, 2004). The surveys extended eastwards from Hawaii to California and Mexico and southwards to about 15°S. Previous blue whale sightings around the Costa Rica Dome (Wade & Friedrichsen, 1979; Reilly & Thayer, 1990) have been linked through satellite tagging to the Mexico/California population of northern blue whales, *B. m. musculus* (Mate *et al.*, 1999). For this reason, only the effort and sightings south of 5°N were included in this study, as these sightings were considered more likely to be from the south-east Pacific grouping of blue whales.

Effort assessment
Where reported, the effort associated with each survey was recorded. Where multiple surveys were conducted in a study, the total effort for all surveys was reported even if blue whales were not sighted on many individual surveys. However, the effort associated with a very large number of studies that reported zero blue whale sightings was excluded. Effort was reported in a variety of ways: days, hours, kilometres or nautical miles. The total effort was estimated by assuming that 10 hours of effort equalled 1 day and by converting measurements from nautical miles to kilometres. For sighting rates, where the number of groups was not consistently recorded (e.g. JSV), the number of whales was converted to number of groups using the mean group size from all other records.

Strandings
'Strandings' included both live strandings and washed up and floating carcasses. Sources (listed in Appendix 3) included published and unpublished reports, and relied heavily upon previous collations of sightings, e.g. James & Soundararajan (1979), De Silva (1987) and Sathasivam (2000). Identification was usually clear, as evidenced by a published description by a cetacean expert, a maximum length exceeding that of other species in the region, completely black baleen plates or other diagnostic features. Reports identified as *B. indica*

(originating from Blyth, 1859) (the Great Indian Fin Whale or Great Indian Rorqual) were considered to be a synonym for *B. musculus* (Rice, 1998). Although care was taken to include only strandings verified to be blue whales, in many cases, particularly in the northern Indian Ocean, the published descriptions did not provide full details of how the species identification was made. Original records of older strandings could not always be obtained as they were often published in obscure and inaccessible journals. In such cases, the closest summary in time was used and the oldest known reference noted. The reliability of length measurements varies. Older records probably measured maximum total length which is appreciably longer than the accepted standard catch measurement from the 'tip of the snout to the notch of the tail flukes' (Mackintosh & Wheeler, 1929); thus, older measurements are probably biased high. In the majority of cases, the name of the stranding location was given but not the exact latitude and longitude. In these cases, the place was located using Google Earth software (http://www.earth.google.com) to find the most accurate position. This was particularly difficult for Indian place names where variant spellings and name changes were common.

Mark-recaptures and movements

The only source of mark-recapture data included in this paper are Discovery marks, but a brief outline of known work on photo-identification and satellite tags is summarized at the end of this section.

Mark and recapture data from the Discovery marking program and the International Marking Scheme were obtained from the IWC Secretariat and are listed in Appendix 4. Marks consisted of a metal tube stamped with a unique serial number that was fired into the muscle of the whales, and recovered during whaling (Brown, 1954, 1962). The mark-recaptures included three (no. 25601, no. 25608, no. 25619) from Soviet expeditions (Mikhalev & Tormosov, 1997) not currently in the IWC database, and excluded German mark G00706, which had a missing recapture location. There is some doubt about the mark positions and species identity (fin or blue whale) of Soviet marks no. 1294 and no. 1298 reported in Ivashin (1971); thus, these were excluded. There were nine instances where two marks were recaptured from a single whale. In each instance, both marks had been placed on the same day and almost identical location; thus, the numerically higher mark was excluded from analyses of the Discovery marks.

Photo-identification studies include those from Sri Lanka (Alling, Dorsey & Gordon, 1991), and studies in progress in Perth Canyon in Western Australia (K. C. S. Jenner, M.-N. M. Jenner & V. J. Sturrock, unpublished data), Bonney Upwelling, southern Australia (P. C. Gill & M. G. Morrice, unpublished data), Geographe Bay, Western Australia (C. Burton, unpublished data), Chile (Hucke-Gaete, Viddi & Bello, 2005; Cabrera *et al.*, 2006), Indonesia (B. Kahn, unpublished data) and the Southern Ocean (P. Olson, personal communication).

Satellite tagging has been conducted around Australia (N. Gales, K. C. S. Jenner & P. C. Gill, unpublished data), Indonesia (Kahn, 2005) and Chile (Hucke-Gaete *et al.*, 2005).

Acoustic detections

Acoustic recordings of Southern Hemisphere blue whales were obtained from a variety of sources based on bottom-moored or sound channel-moored hydrophones, dipping hydrophones and sonobuoys (Appendix 5). Sonobuoys record data over relatively short time frames (hours), whereas moored hydrophones are capable of collecting year-round datasets. Sonobuoys were deployed during seven SOWER cruises (1996–2006) both in the

Antarctic and in pygmy blue whale habitat during the austral summer. The distance at which calls can be detected depends on many factors including bottom topography type, ambient noise levels, instrument type, and depth of the vocalizing whale and receiver. Since these factors were seldom recorded in our sources, it is generally not possible to estimate how far away the calling whales were. Širović (2006) does estimate that Antarctic-type calls from the Antarctic Peninsula were detected up to 200 km away from bottom-mounted instruments in October and November, but we believe the distance to be much less for most of the other studies cited.

Reliability of data

The catch database covers 83.6% of known catches of blue whales in the study area. Similarly, the set of mark-recaptures examined is comprehensive and differs little from previous extensive analyses (Rayner, 1940; Brown, 1954, 1962). Strandings are more commonly reported from areas of high human population density and where there are cetacean experts, which explains why strandings were reported in such high numbers from India, Sri Lanka, Australia, New Zealand and Chile. The absence of any strandings around Africa, despite high catches from the south-west coast, is at least partly due to low monitoring effort. The sightings data were often from surveys in restricted areas, except for major efforts like JSV, JARPA and IDCR/SOWER. Many areas were never surveyed while other areas were intensively studied. Since sighting effort was not included from publications recording zero blue whales, the study-wide sighting rate estimate will be biased high. Finally, sighting rates are obviously difficult to compare from one study to another because the sighting platform, number of observers, vessel speed, sighting conditions and many other factors vary. Nevertheless, blue whales produce highly visible and relatively frequent blows so that we assumed that sighting rates varying by an order of magnitude or more would reflect real differences in densities. Acoustic data provide reliable presence-absence information but were often obtained incidental to other studies and did not include concurrent visual sightings of blue whales. Although relative densities can be inferred from the number of calls recorded, it is unknown what proportion of blue whales produces calls and therefore acoustic data cannot be used to estimate the number of individuals in range of the acoustic instrument.

Bathymetry, thermal fronts and phytoplankton chlorophyll-*a* concentrations

To better understand the possible environmental correlates of blue whale distribution, large-scale positions of bathymetry, thermal fronts and phytoplankton biomass were obtained from digital sources. Bathymetry for the study area was obtained from version 8.2 (November 2000) of the dataset described in Smith & Sandwell (1997), and was downloaded from the website of the Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography (http://topex.ucsc.edu/). These data come from a combination of depth soundings and satellite gravity measurements and have a nominal resolution of about 4 km.

Following the representation of Moore & Abbott (2000), we obtained the mean annual position of the major fronts in the Southern Ocean. These include, from north to south: the North Subtropical Front, the Agulhas Current Front, the South Subtropical Front, the Subantarctic Front, the Southern Antarctic Circumpolar Current Front, and the Antarctic Polar Front. For the more northern regions, we considered the annual mean location of the Costa Rica Dome in the eastern tropical Pacific (~9°N 90°W), as outlined by the 20°C isotherm depth at 35 m (Fiedler, 2002), and the location of the 25°C isotherm at the surface, which marks the position of the seasonal Equatorial Front in the eastern equatorial Pacific and eastern equatorial Atlantic. The surface manifestation of the 25°C isotherm also describes the extent of south-west monsoon-induced upwelling in the western Indian Ocean. The mean position of the 25°C isotherm was obtained from a satellite-derived sea-surface temperature climatology for the month of August from NOAA's National Oceanographic Data Center (http://www.nodc.noaa.gov/sog/pathfinder4km/) (sensor: AVHRR, grid resolution: 4 km, base period: 1985–2001; see Casey & Cornillon (1999) for details of an earlier version of this product).

Long-term annual and seasonal mean phytoplankton chlorophyll-*a* concentrations, a proxy for biomass, were obtained in $mg.m^{-3}$ from satellite measurements (sensor: SeaWiFS, grid resolution: 9 km, base period: 4 September 1997 to 30 September 2006; http://oceancolor.gsfc.nasa.gov/). One caveat is that these measurements are from surface waters and may not reflect phytoplankton biomass associated with the deep chlorophyll maximum.

RESULTS

Catches

The IWC catch database includes catch positions for 303 329 blue whales (and individual data for 311 948 whales in all) in the study area, i.e. 83.6% of the estimated 362 879 blue whales caught in this region (Branch *et al*., 2004). Figure 1 shows the distribution of the catch and the major environmental features of the study area, although treatment of the association between the latter and blue whale distribution is left for the Discussion section. Catches covered the Antarctic densely. The major concentrations of catches in the Antarctic shifted southwards from October–December to January–March (Fig. 2). In the South Pacific, there were widespread catches along the west coast of South America north of 44°S off Chile, Peru and Ecuador and from Peru to the Galapagos Islands, but no other catches north of 59°S in the waters stretching west to 180°. In the South Atlantic, there were isolated catches off Argentina, Uruguay and Brazil. However, the identification of one of the two Brazilian catches is questionable given that it was recorded as either a 'bowhead or blue' whale, neither of which is very likely. There were substantial catches off Angola, Namibia and the west coast of South Africa and a single catch off Congo. Catches were common off Durban (South Africa), from south of Madagascar to Australia, around the south and west coasts of mainland Australia and Tasmania, in the north-western Indian Ocean, and north-west of New Zealand. Pelagic catches in the Indian Ocean were limited to the 1959/60–1963/64 Japanese expeditions and 1962/63–1972/73 USSR expeditions capitalizing on the discovery of pygmy blue whales (Ichihara, 1961).

The pattern of Soviet catches (1958–73) of all large cetacean species is revealing (Fig. 3). In some areas, Soviet blue whale catches were very scarce despite considerable catches of other large cetaceans, particularly in the South Atlantic, central Indian Ocean, south of South America and in the Tasman Sea.

Sightings

The sightings database included 4383 records comprising at least 8058 individual whales (Appendix 2), of which 3691 records of at least 6019 whales were recorded after 1973. Sightings largely mirrored the catch distribution, except for scattered sightings in the South Pacific and South Atlantic, broad areas south and south-west of Australia, in Indonesia and north of New Zealand to the equator (Fig. 4). In the Antarctic, all sightings were clustered close to the continent in a much more restricted range than the catches. Where individual group sizes were recorded ($n = 3346$; mean = 1.56; S.E. = 0.026; range = 1–60), the great majority comprised one (65.2%) or two whales (24.6%), and groups exceeding five whales were rare (1.1%) (Table 1). The total estimated effort where recorded was ~14 676 days (624

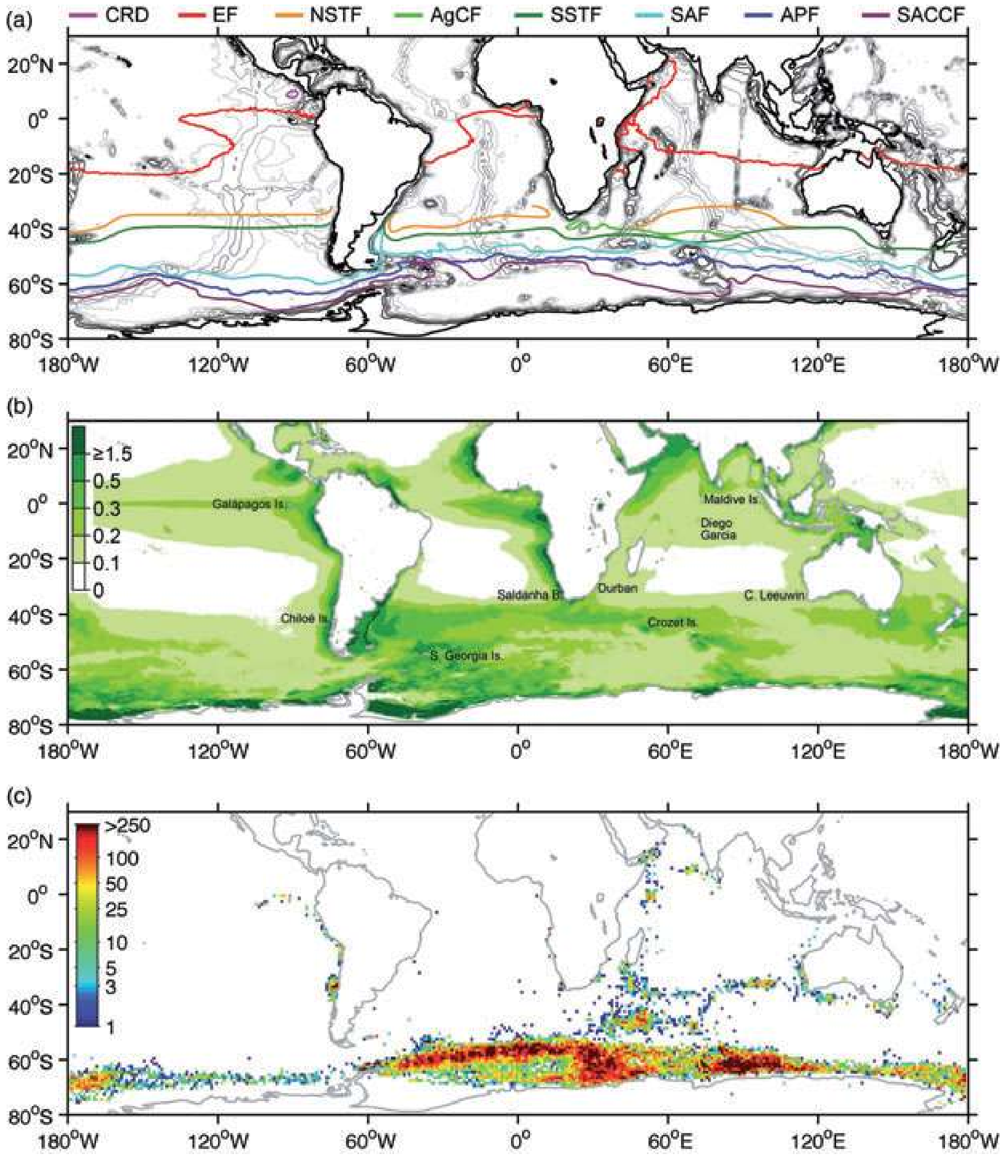

Fig. 1. (a) Bathymetry and mean location of major oceanographic features in the study area (see text for details). From north to south: CRD, Costa Rica Dome; EF, Equatorial Front; NSTF, North Subtropical Front; AgCF, Agulhas Current Front; SSTF, South Subtropical Front; SAF, Subantarctic Front; APF, Antarctic Polar Front; SACCF, Southern Antarctic Circumpolar Current Front. (b) Annual mean phytoplankton chlorophyll-*a* concentrations in $mg.m^{-3}$ from SeaWiFS (4 September 1997–30 September 2006). (c) Catches of blue whales in the International Whaling Commission database grouped into $1° \times 1°$ squares. Catches from land stations were generally all assigned to the same square.

groups) plus ~7 480 450 km (3365 groups). Overall sighting rates were therefore approximately 0.04 per day or 0.45 per 1000 km (one group every 2200 km), but are obviously biased upwards because most studies focused on high-density blue whale areas and many studies that reported no blue whales were excluded. For large-scale surveys with dedicated cetacean effort and good sighting platforms, sighting rates varied by more than four orders of mag-

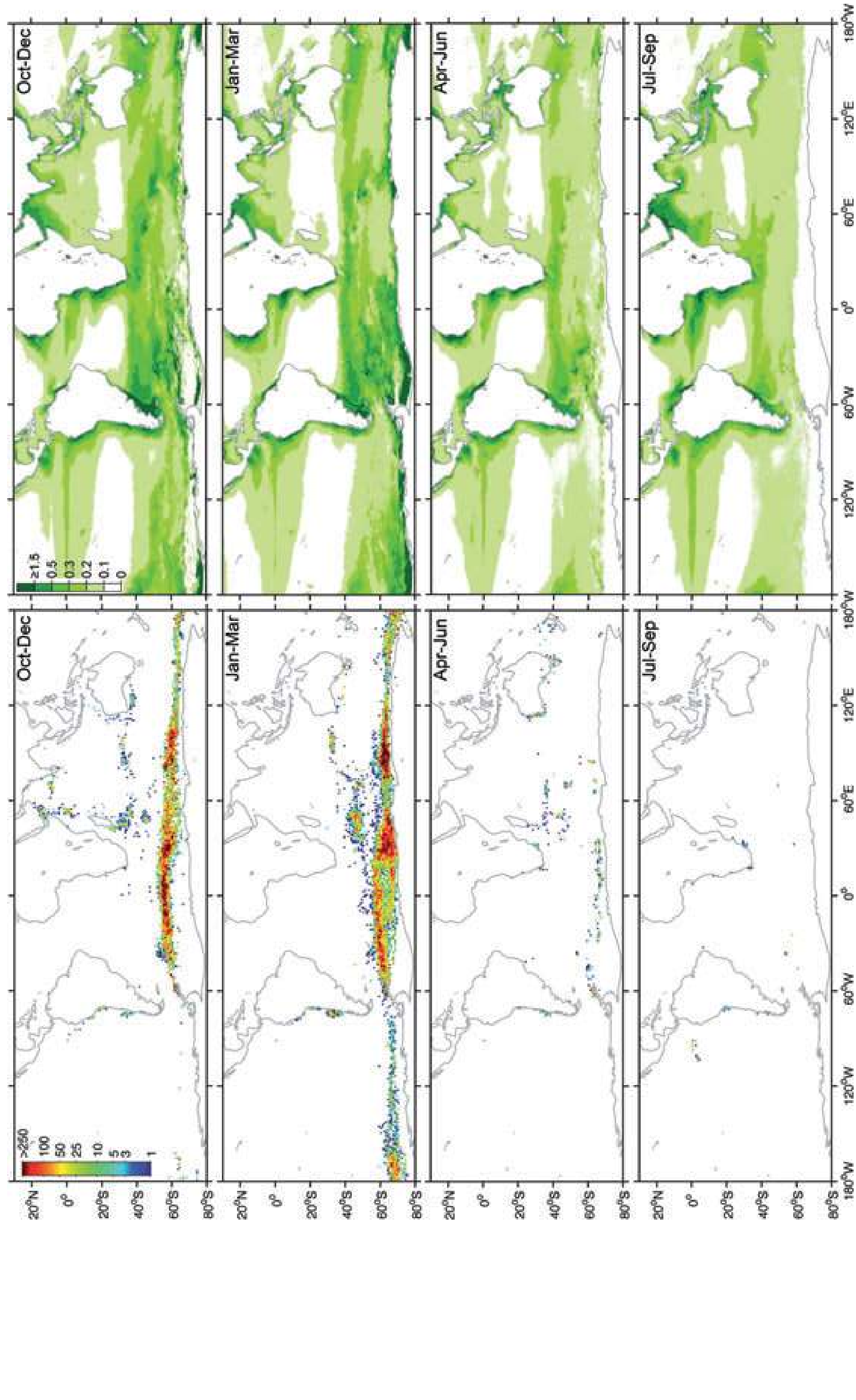

Fig. 2. Three-monthly seasonal patterns in catches (grouped into 1° × 1° squares) and mean seasonal phytoplankton chlorophyll-*a* concentrations in $mg.m^{-3}$. Sources are the same as Fig. 1.

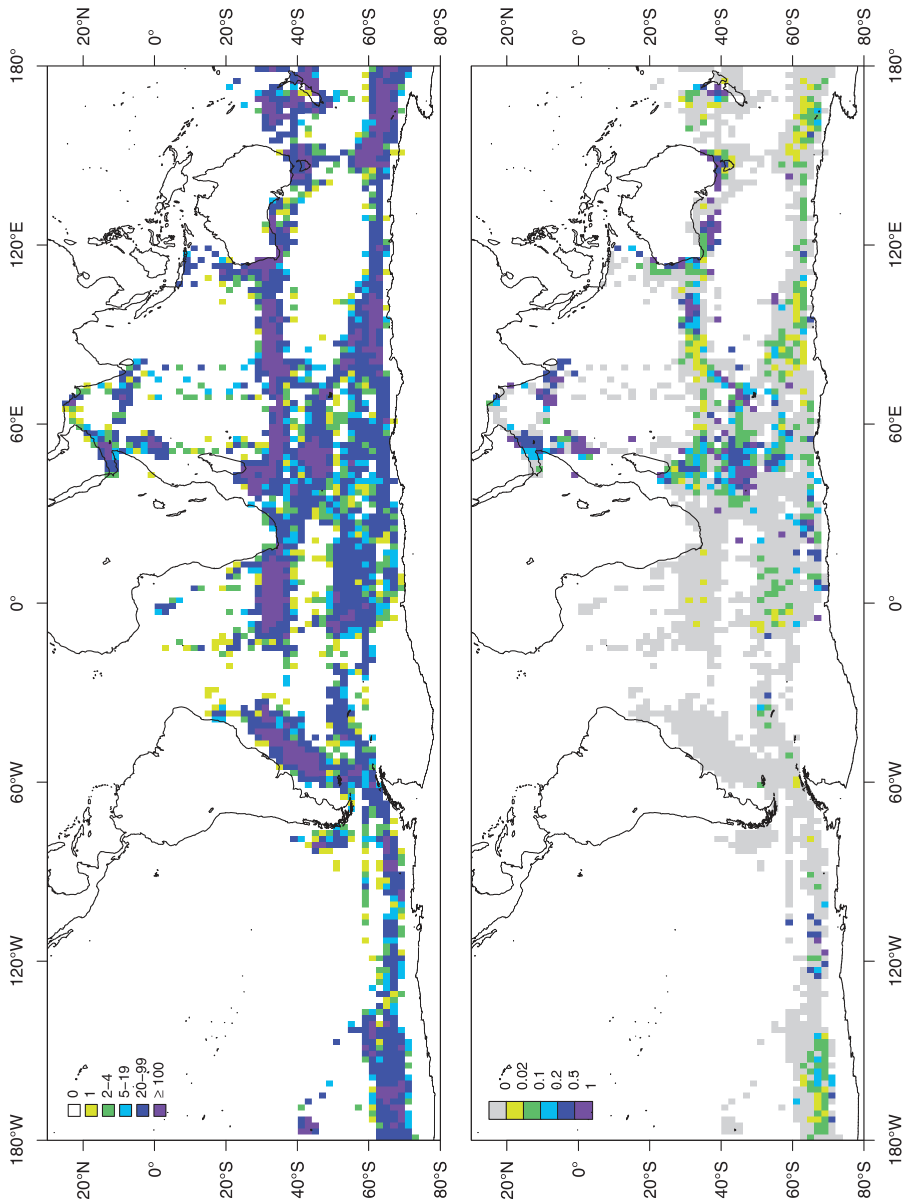

Fig. 3. Soviet catches during 1958–73 in the study area. Top panel: number of catches of all large cetaceans in each 2° × 2° square (a rough measure of total catch effort). Bottom panel: proportion of large cetacean catches in each 2° × 2° square that were blue whales.

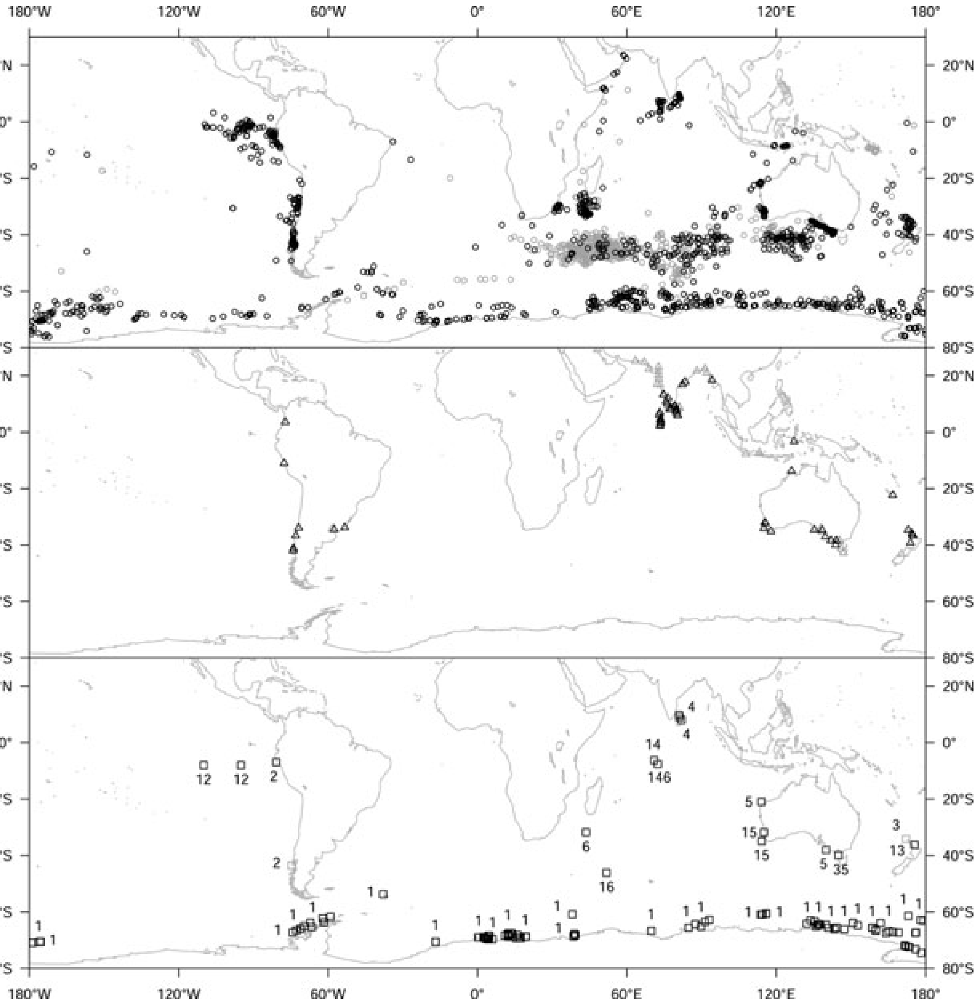

Fig. 4. Positional information from (top to bottom) sightings (○); strandings (△); and acoustic recordings (□). Grey is used for positions ≤1973 and black for >1973. Acoustic locations are annotated with the call type using numbers: Antarctic (1), South-east Pacific (2), New Zealand (3), Sri Lanka (4), Australia (5) and Madagascar (6); these numbers are concatenated if two or more call types were recorded at a single location.

nitude from region to region. When ordered, these sighting rates (groups per 1000 km) are as follows: off Costinha, Brazil, 0.003 (da Rocha, 1983); off Durban, South Africa, 0.005 from spotter planes (P. B. Best, unpublished data); around Somalia, 0.19 (Small & Small, 1991); around the Galapagos Islands, 0.25 (Palacios, 1999a); Oman, 0.32 (Oman Whale and Dolphin Group, unpublished data); Antarctica south of 55°S, 0.17 (JSV), 0.34 (JARPA, Matsuoka *et al*., 2006) and 0.52 (IDCR/SOWER); South Georgia, 0.44 (Moore *et al*., 1999); in the eastern tropical Pacific, 0.45 (SWFSC surveys); off Peru, 0.73 (Donovan, 1984a) and 0.97 (Valdivia *et al*., 1983; Ramirez, 1985); around Komodo and Solor-Alor, Indonesia, 2.0 (Kahn, 2000, 2002, 2005; B. Kahn, unpublished data); Maldives, 2.4 (Ballance *et al*., 2001); southern Indian Ocean 35–50°S 30–100°E, 2.9 (JSV); east Sri Lanka, ~6 assuming vessel speed of 5 knots (Alling *et al*., 1991) and north-west Sri Lanka, 1.6 (A. D. Ilangakoon,

Group size	Frequency	Percentage
1	2183	65.2
2	822	24.6
3	205	6.1
4	62	1.9
5	37	1.1
6	15	0.4
7	6	0.2
8	6	0.2
9	4	0.1
≥10	6	0.2
Total	3346	100.0

Table 1. Distribution of group sizes in sightings data, based on reports where group sizes were recorded. Groups may have been either schools or feeding aggregations, depending on the source. The largest groups were 10, 12, 15, 18, 20 and 60.

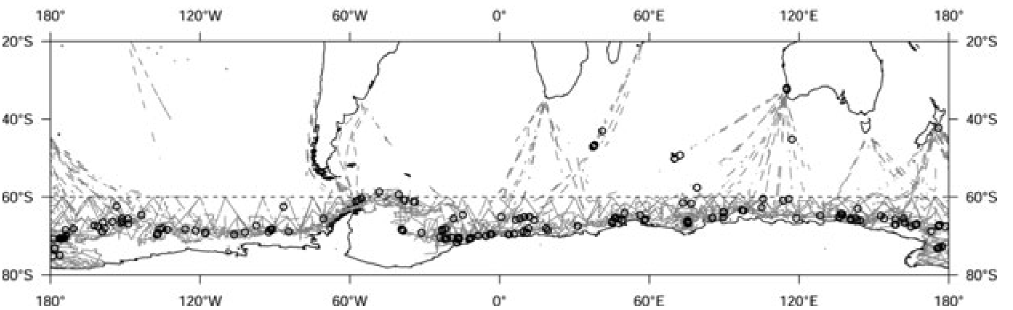

Fig. 5. IDCR/SOWER vessel tracks (lines) and blue whale sightings (○) between 1978 and 2005. Only primary search effort is plotted, but blue whales sighted both on-effort and off-effort are plotted. The intended surveys were generally conducted south of 60°S (dashed line) but additional primary effort was recorded further north during transits to the survey areas. IDCR, International Decade of Cetacean Research; SOWER, Southern Ocean Whale and Ecosystem Research.

unpublished data); off southern Australia, 7.4 (Gill, 2002; P. C. Gill & M. G. Morrice, unpublished data); off western Australia, 18.5 (K. C. S. Jenner, M.-N. M. Jenner & V. J. Sturrock, unpublished data) and 18.6 (J. L. Bannister & C. L. K. Burton, unpublished data); on the Madagascar Plateau, 36.0 (Best *et al*., 2003); and off Chile, 4.9 from a ship survey (Findlay *et al*., 1998) and 52.4 from aerial surveys north-west of Chiloé Island (Galletti Vernazzani, Carlson & Cabrera, 2005; Galletti Vernazzani *et al*., 2006).

Nearly all of the sightings on the IDCR/SOWER surveys were near the southern boundary of the survey region despite substantial effort northwards of the pack ice to 60°S (Fig. 5). Furthermore, during transits to the Antarctic, sightings were recorded only in the southern Indian Ocean, and never during transits south of South Africa, South America, Tasmania, or New Zealand despite substantial search effort.

The JSV database included 4 827 370 km of search effort throughout the study region (Fig. 6), but sightings per 1000 km varied dramatically from region to region. The highest sighting rates were recorded between 40°S and 55°S in the southern Indian Ocean and south of Australia. Dramatically lower sighting rates were recorded in the South Atlantic, central Indian Ocean, Tasman Sea and southern Pacific Ocean. In the Antarctic, blue whales were generally recorded only in a few of the most southern 2° × 2° squares.

Sightings from the SWFSC surveys in the eastern tropical Pacific were grouped into those off Mexico, those on or near the Costa Rica Dome and those near to or south of the equator (Fig. 7). Only sightings from the last grouping were analysed further in this paper.

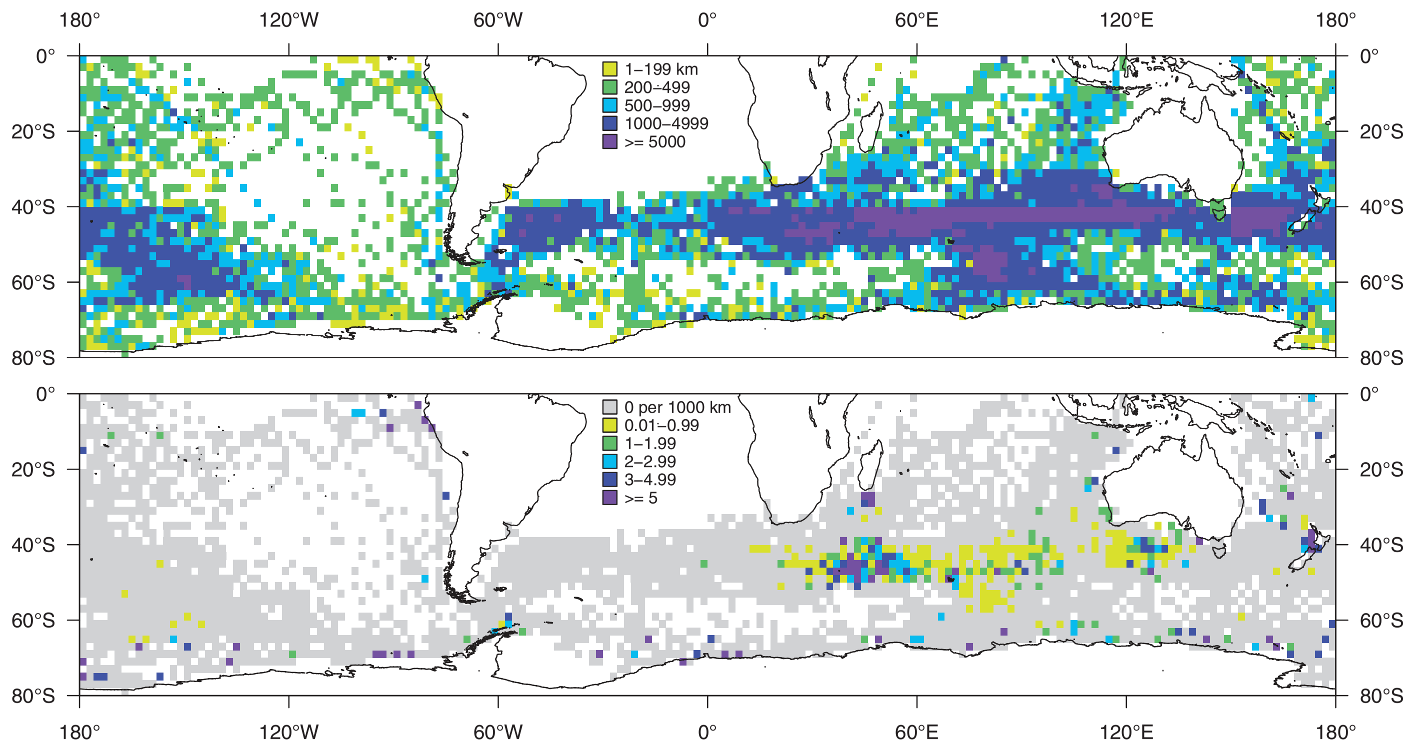

Fig. 6. Japanese Scouting Vessels (JSV) effort in km (top panel), and sightings per unit effort (bottom panel) in each 2° × 2° sector in the Southern Hemisphere. The JSV database covers the period from 1965 to 1987 but does not include effort and sightings for the northern Indian Ocean.

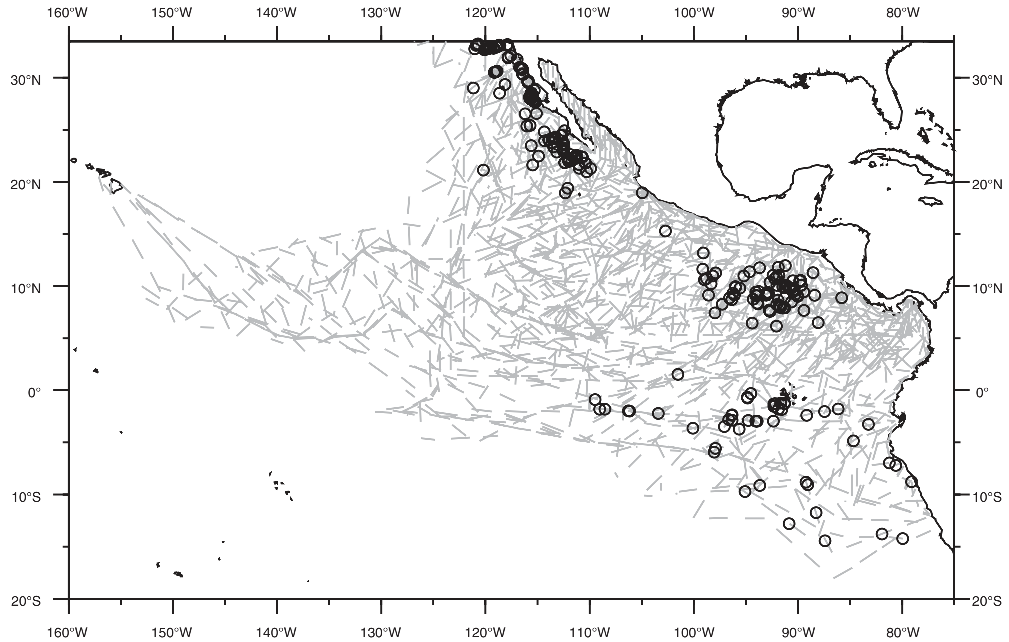

Fig. 7. Southwest Fisheries Science Center surveys between 1986 and 2006 in the eastern tropical Pacific. Grey lines indicate primary search effort, while circles show both on-effort and off-effort sightings of blue whales. Only sightings and effort south of 5°N were included in the analyses presented in this paper.

Strandings

We found records of 103 strandings in the study area (Appendix 3). Most of the strandings were reported from the south-east Pacific, in the northern Indian Ocean (Pakistan, India, Sri Lanka, Bangladesh, the Maldives), on the south and south-west coasts of Australia, and in north-west New Zealand (Fig. 4). Isolated strandings were also reported from Uruguay, New Caledonia, northern Australia and Indonesia, but none were reported from any African country. All strandings were of solitary individuals, although a notable stranding on 23 January 1946 in Trincomalee Harbour, Sri Lanka, was of a pregnant female that gave birth in the harbour the following day and was then towed to safety (Deraniyagala, 1948). Reported lengths ranged from 6.35 m to 29.3 m but most blue whales measured in recent times (after 1927) were shorter than the maximum pygmy blue whale length of 24.1 m (Ichihara, 1966), except for a 27.4 m whale reported at Orewa, New Zealand in 1978 (A. N. Baker unpublished data). In addition, bones from a 24.0 m blue whale stranded near Busselton, Western Australia & in 1898 reveal that it was a physically immature Antarctic blue whale (Bannister, Burton & Hedley, 2005), and the skeleton still exists of a properly measured 26.5 m blue whale stranded on 8 February 1908 north of Okarito, New Zealand (Waite, 1912; Stollman *et al.*, 2005).

Mark-recaptures

There were 104 Discovery marks recovered from 95 individual whales (Appendix 4) and an additional 2191 Discovery marks that were not recovered (Fig. 8). Some blue whales were caught far from the mark position, but there was no obvious increase in the distance between marks and recoveries with increased time except that recoveries in the same season were usually closer to the mark position than recoveries after one season or more (Figs 8 and 9).

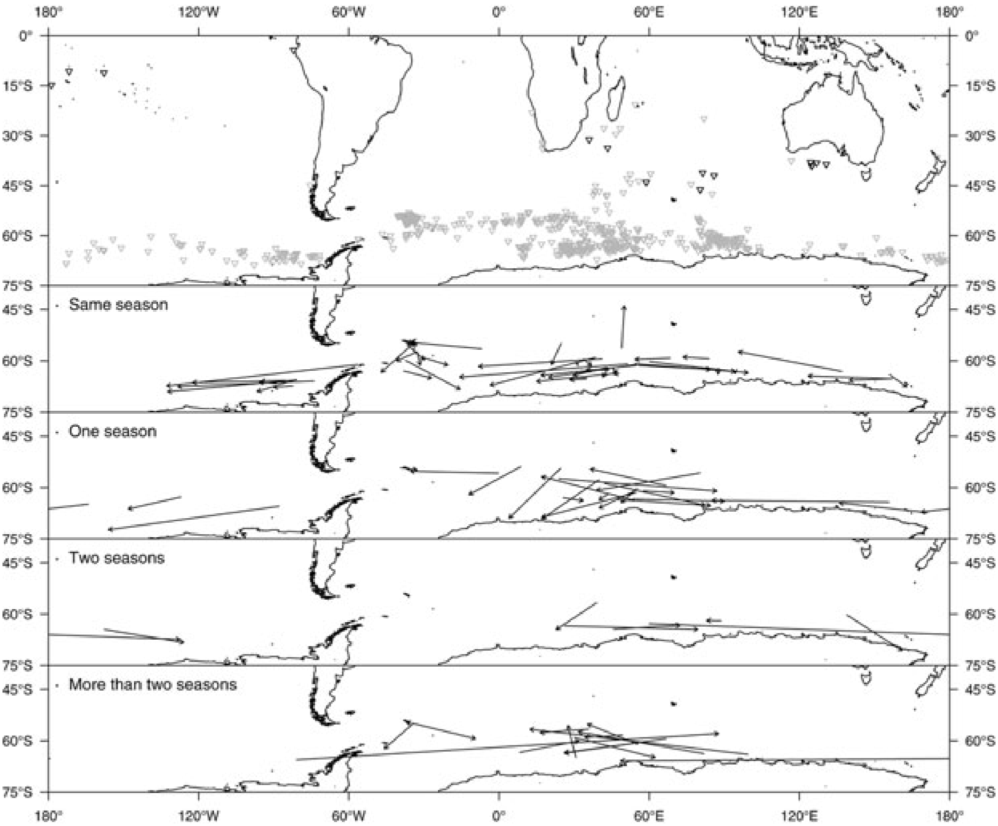

Fig. 8. Discovery mark placement (triangles, top panel) and recoveries of Discovery marks (arrows, other panels) of blue whales. The top panel shows the positions of all marks (grey ≤1973, black >1973), panels below zoom into a narrower latitudinal range to show all mark-recaptures. Mark-recapture pairs are split between those recovered in the same season, the following season, two seasons later and more than two seasons after the mark. The shortest mark-recapture path sometimes crosses the international dateline. Only the same-season recovery at 43°55′S 50°02′E was identified as a pygmy blue whale.

Most marked blue whales (n = 54) were caught in the same season, but 15 were caught more than two seasons later and one evaded capture for 13 years 10 months and 12 days. With one exception, mark-recapture pairs were all south of 53°55′S and between October and March and can be presumed to be Antarctic blue whales. The single exception was a blue whale marked at 56°15′S 49°03′E on 1 December 1962 that was identified as a pygmy blue whale when caught at 43°55′S 50°02′E on 4 April 1963 (Ichihara, 1966).

Acoustics

Acoustic recordings were distributed widely around the Antarctic, around the Indian Ocean, off northern New Zealand and in the south-east Pacific (Fig. 4). The earliest Southern Hemisphere acoustic recordings in the presence of blue whales were off Chile in 1970 (Cummings & Thompson, 1971). They described long (10–30 seconds), low-frequency (10–40 Hz), multi-unit sounds; all subsequent recordings of blue whales share these characteristics, but are also geographically distinct both within and between ocean basins. Distinct call types have been described in the literature associated with the following regions: the Antarctic,

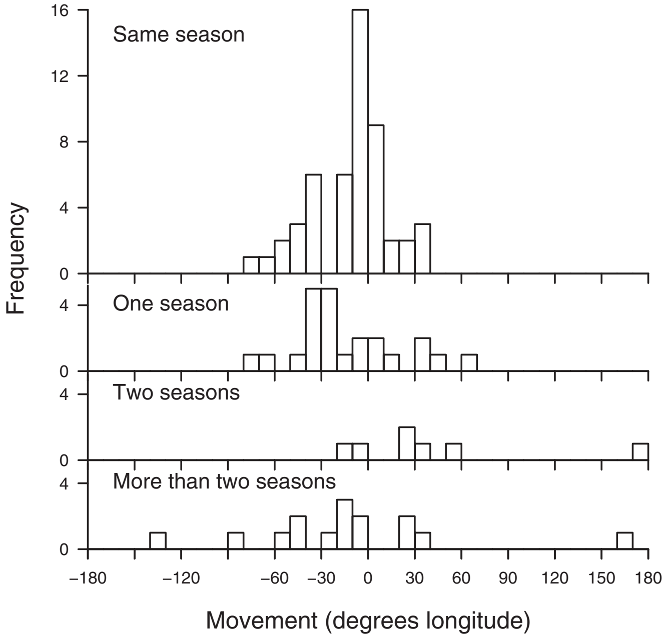

Fig. 9. Longitudinal movement between marks and recoveries of blue whales in the same season, after 1 year, 2 years and more than 2 years. Positive numbers indicate eastward movement and negative numbers westward movement.

south-east Pacific, Madagascar, Australia, Sri Lanka and off northern New Zealand (e.g. Stafford, Nieukirk & Fox, 1999; McCauley *et al.*, 2001; Stafford *et al.*, 2004; McDonald, 2006; reviewed by McDonald, Hildebrand & Mesnick, 2006).

In all Antarctic regions, a unique call type sometimes referred to as the '28-Hz pulse' or '28-Hz tone' has been recorded together with the low-frequency downsweeps common to blue whales worldwide (Fig. 4) (Ljungblad, Clark & Shimada, 1998; Stafford *et al.*, 1999; Clark & Fowler, 2001; Širović *et al.*, 2004; Stafford *et al.*, 2004; McKay *et al.*, 2005; Rankin *et al.*, 2005; Ensor *et al.*, 2006). This 28-Hz tone is now considered diagnostic of the Antarctic subspecies (Rankin *et al.*, 2005) and has been recorded from sonobuoys on SOWER cruises (December–February) coincident with blue whale sightings or at night when blue whales had been seen during the day (Ljungblad *et al.*, 1998; Clark & Fowler, 2001; Rankin *et al.*, 2005; Ensor *et al.*, 2006). Short recordings of Antarctic-type calls were also recorded 4–6 April 2004 near South Georgia (C. W. Clark & A. R. Martin, personal communication) which represents the furthest north they have been recorded in the Atlantic Ocean.

The seasonal occurrence of Antarctic blue whale calls can be obtained from moored instruments. Distinctive 28-Hz tones were recorded on instruments moored to the west and north of the Antarctic Peninsula in all months with strong seasonal peaks in February–May and October–November, and low numbers of calls during June–August during high ice concentration cover (Širović *et al.*, 2004). These 28-Hz tones were also recorded year-round from an instrument moored at 66°44′S 69°48′E with peaks in April–June, October–November and a dearth of calls in December–March, although this analysis is preliminary (McKay *et al.*, 2005). Additionally, there are limited records of 28-Hz tones in mid and low latitudes during May to September in the Pacific and Indian Oceans, suggesting that at least some Antarctic blue whales migrate northwards in the austral winter (McCauley *et al*., 2004; Stafford *et al*., 2004; McDonald, 2006). In the eastern tropical Pacific, these calls were recorded in low numbers from May to September, with peak number of calls in July at 8°S 95°W and 8°S 110°W (Stafford *et al*., 1999). Near northern New Zealand (36°22′S 175°54′E), 28-Hz tones were recorded in May to July (McDonald, 2006). Off south-western Australia (~34°54′S 114°06′W) they were recorded from May to November (peak in July) (McCauley *et al*., 2004; Stafford *et al*., 2005), and near Diego Garcia (~7°S 72°E) from May–August 2002 (peak in July) (Stafford *et al*., 2004). Finally, 28-Hz tones were recorded near Crozet Island at 46°10′S 51°48′E but no seasonal information was provided (Samaran *et al*., 2006).

None of the other five blue whale call types have been recorded in the Antarctic south of 60°S. These other call types have usually been labelled as 'pygmy' blue whales and differ according to ocean basin. Three distinct call types have been recorded from the Indian Ocean (Alling *et al*., 1991; Ljungblad *et al*., 1998; McCauley *et al*., 2001), one from the south-east Pacific (Cummings & Thompson, 1971; Stafford *et al*., 1999), and one likely pygmy blue whale call type from the south-west Pacific (Kibblewhite, Denham & Barnes, 1967; McDonald, 2006), but no pygmy-type call has yet been recorded from the Atlantic Ocean.

The first of the three distinct Indian Ocean call types was recorded in the presence of blue whales off north-east Sri Lanka in February–April 1984 (Alling *et al*., 1991), and has since been recorded on bottom-mounted instruments near Diego Garcia in all months except February–April and July (Stafford *et al*., 2005). The second call type was recorded in late December 1996 on the Madagascar Plateau in the presence of nominal pygmy blue whales (Ljungblad *et al*., 1998). It has also been recorded at Diego Garcia in May–July (Stafford *et al*., 2005) and off Crozet Island (Samaran *et al*., 2006). The third call type, first described by McCauley *et al*. (2001) from moored hydrophones, has been recorded in south-western Australian waters during November–June (McCauley *et al*., 2004; Stafford *et al*., 2005), along the West Australian coast off Exmouth (21°S) in June–July and November–December (R. D. McCauley, unpublished data) and along southern Australia from Bass Strait westwards to south-western Australia (R. D. McCauley, unpublished data).

The south-east Pacific blue whale call type was first recorded on 30–31 May 1970 at 43°36′S 74°40′W off Chile (Cummings & Thompson, 1971), and has been recorded year-round on a hydrophone array in the eastern tropical Pacific, primarily at 8°S 95°W, with peak calling from March–September (Stafford *et al*., 1999). These calls were also recorded off Peru at 6°54′S 80°50′W in November 2000 (T. Norris, unpublished data). In addition to this 'normal' call type, a different call type was recorded during biopsy approaches off Chile during the 1997–98 IWC survey, apparently in reaction to the rapid approach of the survey vessel (Ljungblad & Clark, 1998).

The northern New Zealand call type consists of a single instance of these calls in the 1960s (Kibblewhite *et al*., 1967) together with four records in 1997 (McDonald, 2006).

Combined distribution from all sources

Where blue whales were present, this was often confirmed by multiple sources (Fig. 10). For example, although there were only rare detections of blue whales off northern New Zealand, these records included catches, sightings, strandings and acoustic detections.

Monthly distribution

Most positional data were recorded during the austral summer season between October and April (Fig. 11). During summer, records were nearly circumpolar especially between November and March. The Antarctic region between 160°W and 70°W was hardly exploited before

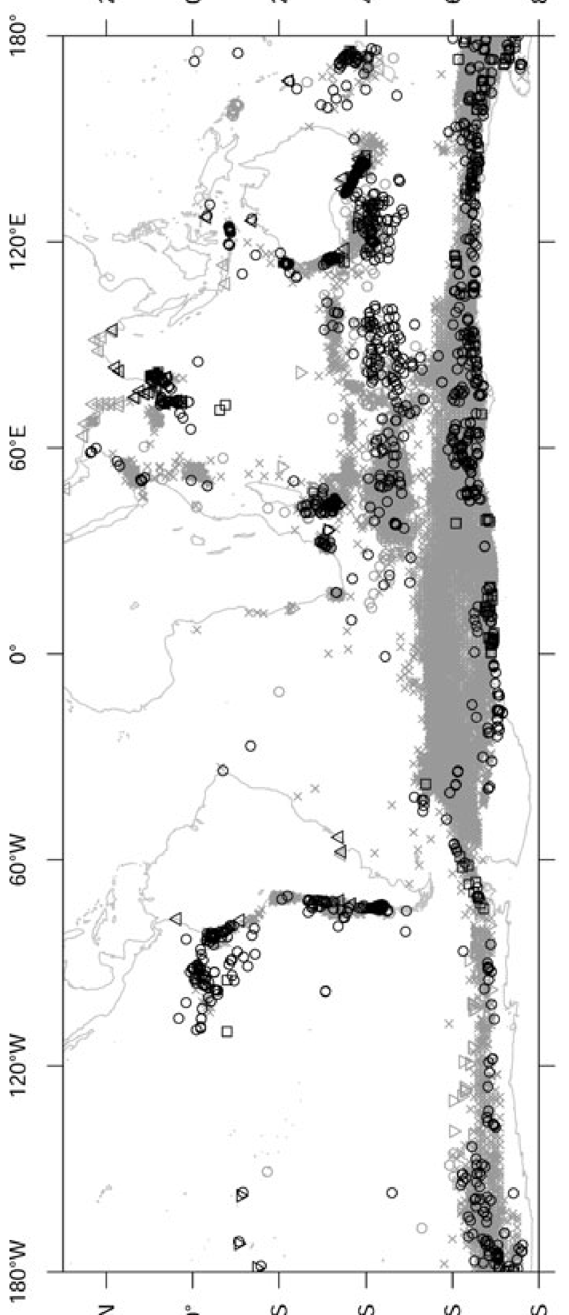

Fig. 10. Distribution of blue whales in all months based on catches (×), sightings (○), strandings (△), acoustic records (□) and Discovery mark positions (▽). Grey is used for positions ≤1973 and black for >1973.

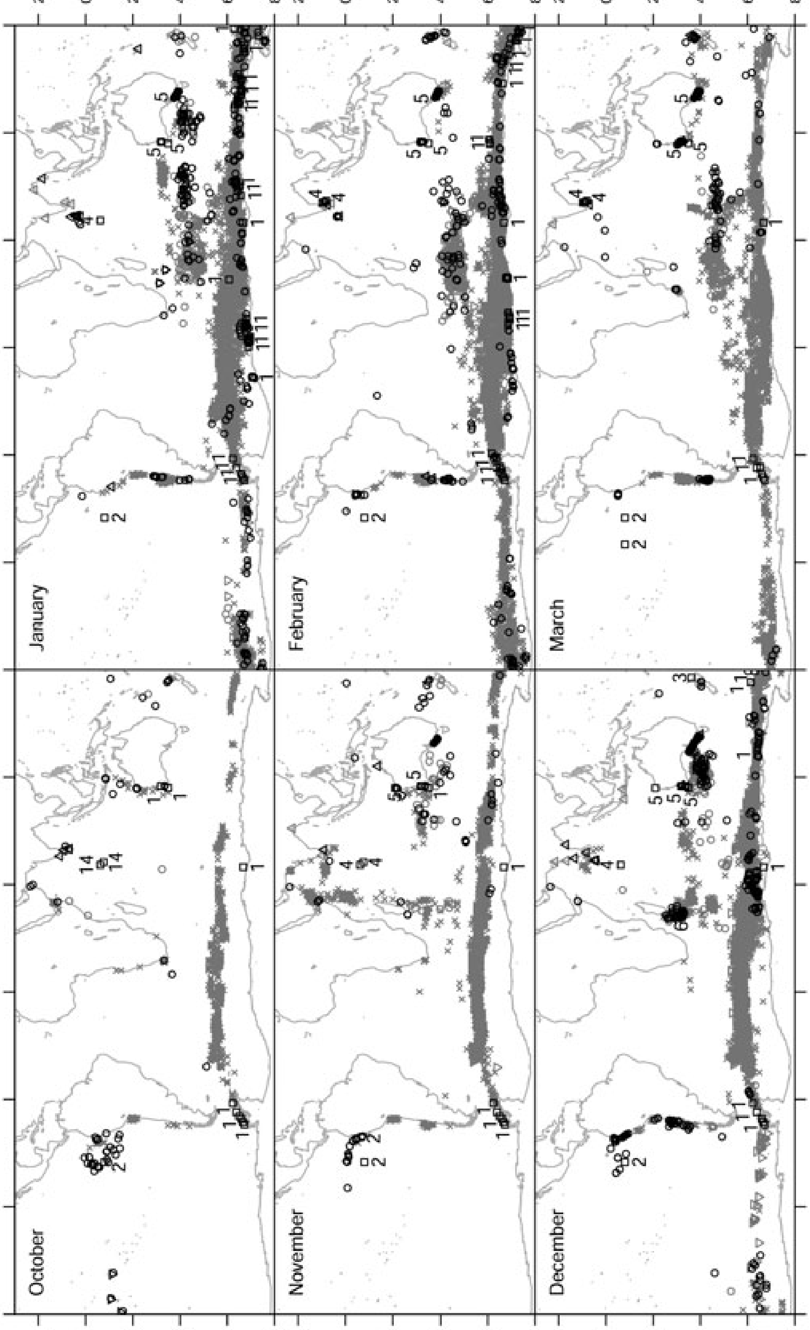

Fig. 11. Monthly distribution of blue whales during October to March based on catches (×), sightings (○), strandings (△), acoustic records (□) and Discovery mark positions (▽). Grey is used for positions ≤1973 and black for >1973. Acoustic locations are annotated with the call type using numbers: Antarctic (1), South-east Pacific (2), New Zealand (3), Sri Lanka (4), Australia (5) and Madagascar (6); these numbers are concatenated when two or more call types were recorded at a single location.

World War II, and was proclaimed a sanctuary from 1938/39 to 1954/55, after which catches were legal between January and March only, explaining the near-absence of catches in this region outside those months. During summer, blue whales were commonly recorded in temperate latitudes off the west coast of South America, in the northern Indian Ocean, in the Subantarctic, around southern Australia and in north-west New Zealand, but were largely absent from African waters. In winter months (April–September), high catches were reported off south-west Africa (especially Saldanha Bay), and Durban (Fig. 12). In these months, sightings and strandings continued in other areas. It is also notable that catches were reported in every month of the year at South Georgia, although numbers (and catch effort) decreased greatly in the winter months.

DISCUSSION

The dataset assembled here allows for an updated examination of blue whale distribution and its association with environmental factors, migration patterns and the relative status of different populations of blue whales in the study area.

Distribution

Blue whales feed on euphausiids and other crustacean meso-zooplankton (e.g. Mackintosh & Wheeler, 1929; Yochem & Leatherwood, 1985). To maintain their great energetic demands, they search out the densest patches of their prey (Croll *et al.*, 2005). It has previously been accepted that blue whales in the study area (particularly Antarctic blue whales) feed in the austral summer but fast during the winter breeding season (e.g. Mackintosh & Wheeler, 1929; Mackintosh, 1966). However, as detailed below, we found that their distribution year-round is linked to areas with known or inferred high densities of euphausiids, suggesting that their winter distribution also may be influenced by feeding opportunities (cf. Reilly & Thayer, 1990; Croll *et al.*, 2005).

Blue whale distribution in the study area is strongly linked to latitude. Close to the Antarctic, blue whales were recorded along bands stretching across entire ocean basins, but at lower latitudes they are progressively more clustered, localized and compressed along the continental margins (Fig. 10). This pattern probably reflects euphausiid biogeography, with large Antarctic krill *Euphausia superba* at the highest latitudes, mid-sized *Euphausia* species in the mid latitudes and smaller *Nyctiphanes* species in coastal upwelling systems in the mid and low latitudes (see maps in Brinton *et al.*, 2000). However, until better region-wide data become available, we must rely on environmental proxies for euphausiid aggregation such as bathymetry, frontal processes and phytoplankton biomass (Atkinson *et al.*, 2004; Siegel, 2005).

Patterns of blue whale distribution in relation to environmental features are best summarized in Figs 1 and 10. At the largest scale, blue whales generally occurred in regions with high phytoplankton densities such as the productive Antarctic and Subantarctic waters, and in the upwelling systems of the Arabian Sea and the west coasts of South America and Africa. A major exception to this pattern is in the 35–45°S band between South America and Africa, and extending into the Agulhas Retroflection south of Africa, where few blue whales were reported despite high chlorophyll-*a* concentrations. Conversely, annual mean chlorophyll-*a* levels were intermediate to low south of Madagascar and around Australia, where blue whale sightings were numerous. These areas, however, undergo seasonal blooming (Fig. 2), and are thus under-represented in the annual mean. Blue whales were virtually absent year-round from the mid-latitude central gyres with lowest chlorophyll-*a* concentrations.

Blue whales were generally associated with waters deeper than the continental shelves. Shallow-water records were typically from regions with narrow continental shelves, but blue

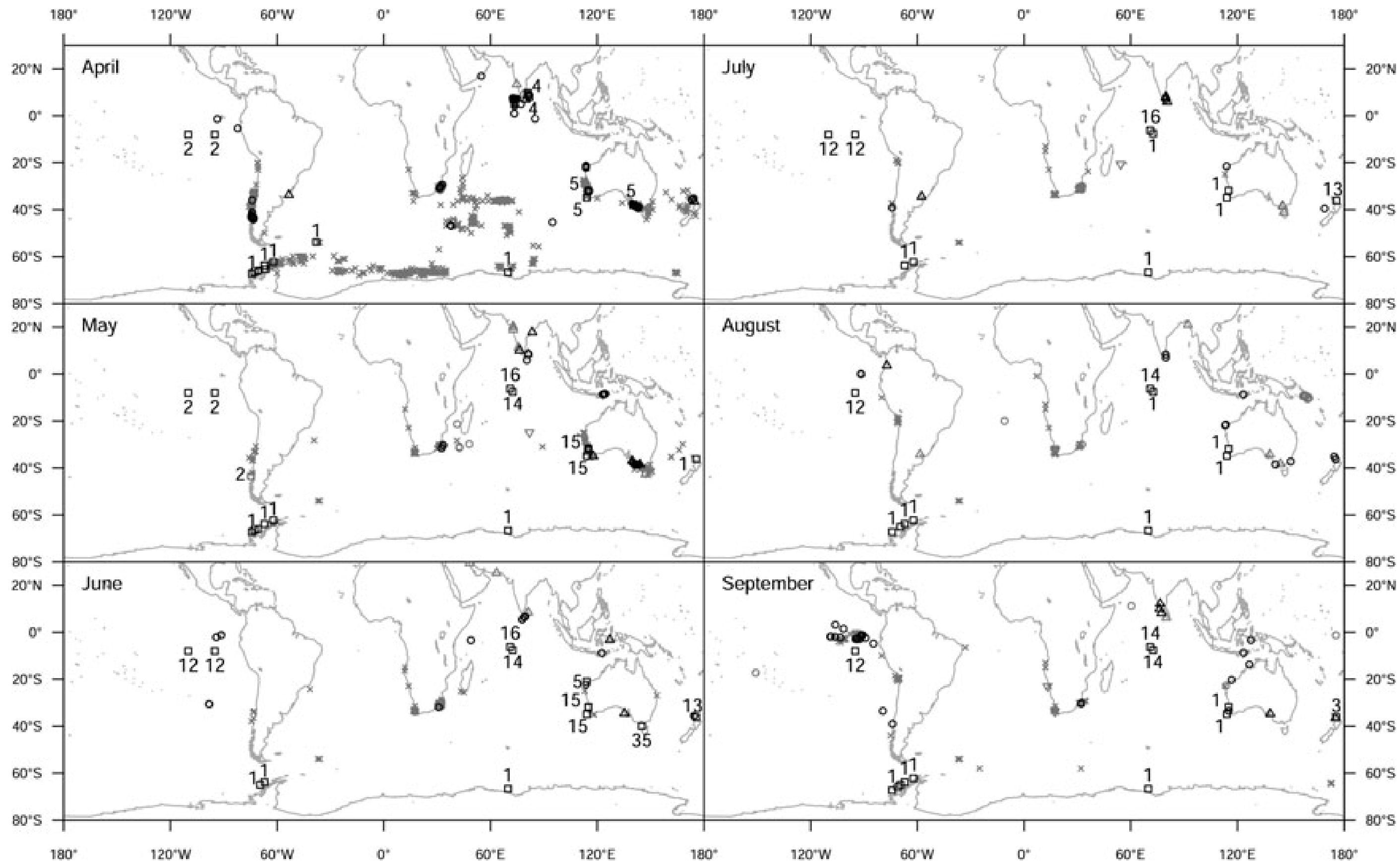

Fig. 12. Monthly distribution of blue whales during April to September based on catches (×), sightings (○), strandings (△), acoustic records (□) and Discovery mark positions (▽). Grey is used for positions ≤1973 and black for >1973. Acoustic locations are annotated with the call type using numbers: Antarctic (1), South-east Pacific (2), New Zealand (3), Sri Lanka (4), Australia (5) and Madagascar (6); these numbers are concatenated when two or more call types were recorded at a single location.

whales were virtually absent from the wide continental shelves off south-east Argentina, northern Australia and south-east New Zealand. In the Antarctic, they were most common on deep continental slopes (Kasamatsu, Matsuoka & Hakamada, 2000). Frequent sightings and strandings have been reported from Trincomalee Harbour, Sri Lanka, in waters shallower than 200 m, but deeper water (>500 m) is found near to this harbour (Alling *et al.*, 1991). Blue whales also move through waters less than 50 m depth in Geographe Bay, Australia (C. Burton, unpublished data), around Chiloé Island, Chile (Hucke-Gaete *et al.*, 2003), and in the Bonney Upwelling of south-east Australia, where the mean depth of 920 sightings was 93 m (P. Gill & M. Morrice, unpublished data).

Blue whale occurrence matched large-scale fronts closely in some regions, but not in others. Frontal regions define water masses with distinct physical properties and production regimes, which influence euphausiid biogeography (e.g. Longhurst, 1998). In addition, enhanced frontal dynamics, such as interaction with bathymetric features, cross-frontal exchange, splitting and merging, meandering, and eddy shedding, often result in front-associated phytoplankton blooms (Moore & Abbott, 2000, 2002). Antarctic catches were bounded to the north by the Antarctic Polar Front, and pygmy blue whale distribution in the Subantarctic was fairly well bounded by the Subantarctic Front and the North and South Subtropical Fronts (Fig. 1). Off the west coasts of South America and Africa, distribution extended from upwelling regions to the Equatorial Front. Blue whales south of Madagascar may be supported by biological enrichment from the interaction of the North Subtropical Front with the steep bathymetry of the Madagascar Plateau; interactions of this front with the Broken Plateau may similarly support aggregations west of Australia. However, there were no links with any fronts for concentrations of blue whales in the northern Indian Ocean, coastal Australia and around New Zealand.

The above discussion examined large-scale patterns of blue whale distribution in the study area. There are also regional particularities that deserve additional consideration. We therefore focus in more depth on 10 regions of special interest.

Antarctic

It can safely be assumed from a variety of sources that nearly all blue whales in the Antarctic are from the Antarctic (true) subspecies. First, based on the lengths of sexually mature females, nearly all (99.2%) catches taken south of 52°S were Antarctic blue whales (Branch *et al.*, 2007). Second, genetic evidence shows a significant separation between samples taken south of 60°S (Antarctic blue whales) and samples from the Indian Ocean (pygmy blue whales) (Conway, 2005; LeDuc *et al.*, in press). Third, acoustic data south of 60°S from SOWER cruises (austral summer) and moored instruments (year-round) have consistently recorded the distinctive Antarctic-type 28-Hz tones (Ljungblad *et al.*, 1998; Clark & Fowler, 2001; Širović *et al.*, 2004; Stafford *et al.*, 2004; McKay *et al.*, 2005; Rankin *et al.*, 2005; Ensor *et al.*, 2006). To date, none of the other blue whale call types have been recorded south of 60°S.

Antarctic blue whales have a continuous circumpolar distribution, although catches were lower between 70°W and 160°W. Prior to 1938/39, little whaling was conducted in 70–160°W, presumably because there were few blue whales there. From 1938/39 to 1954/55, this region was proclaimed a sanctuary; thus, the majority of whaling in this region was conducted after 1954/55. The continuous circumpolar distribution of Antarctic blue whales is reinforced by recoveries of Discovery marks showing that they sometimes disperse over time widely around the Antarctic, as noted by previous authors (Brown, 1954, 1962). While they may show some fidelity to particular IWC Management Areas (the IWC divides the Antarctic into six roughly equal Areas for management purposes), they also cross the borders between Management

Areas and have been caught on several occasions more than 100 degrees of longitude from their marking position. Circumpolar-wide acoustic records of 28-Hz tones further support their continuous distribution (Ljungblad *et al.*, 1998; Clark & Fowler, 2001; Širović *et al.*, 2004; Stafford *et al.*, 2004; McKay *et al.*, 2005; Rankin *et al.*, 2005; Ensor *et al.*, 2006).

Nearly all blue whale catches in the Antarctic were between October and April (Figs 2 and 12). While Tynan (1998) found that highest krill densities and highest whale catches are aligned with the Southern Boundary of the Antarctic Circumpolar Current (not shown here), we found that the Antarctic Polar Front was a more useful indicator of the northern boundary of the Antarctic catches. Where the Antarctic Polar Front was farther south (70–130°W), the catches were more southerly, and where it was further north (50°W–60°E), catches were more northerly. Antarctic krill presence is not associated with any one oceanographic feature, but is determined by the presence of abundant phytoplankton near ice edges, continental shelves and dynamic frontal regions (Atkinson *et al.*, 2004; Siegel, 2005).

It is striking that recent Antarctic sightings are in a much narrower ring close to the pack ice and the continental shelves (Figs 4 and 5), while most catches were further north. In part, this may be explained by greater sighting effort (from the IDCR/SOWER surveys) south of 60°S. Additionally, the Antarctic pack ice has retreated since the 1960s (de la Mare, 1997; Cotté & Guinet, 2007), although this conclusion is disputed by Ackley *et al.* (2003). As an alternative, their narrower present-day distribution may be explained by the 'basin model' of MacCall (1990): at higher densities, the Antarctic blue whales may have occupied a wider habitat range, but now that they are depleted to <1% of their original abundance (Branch *et al.*, 2004), they are more concentrated close to the ice edge where krill is most abundant.

Central ocean basins

Blue whales are largely absent from the central portions of each of the major ocean basins in the study area, which are notable biological deserts, as evidenced by the very low chlorophyll-*a* concentrations in these regions (Fig. 1; McClain, Signorini & Christian, 2004).

In the central South Pacific, two Soviet cruises in 1973/74 and 1974/75 found no blue whales between 40°S and 60°S (Mikhalev, 1978), and the JSV database also recorded no sightings in the South Pacific (20–50°S 90–150°W) despite 42 335 km of search effort.

Few blue whales were recorded from the central South Atlantic. Large-scale studies based on ship reports reinforce this conclusion (Brown, 1958; Slijper, van Utrecht & Naaktegeboren, 1964): sightings of rorquals (not identified to species) were nearly absent in the central region while higher sighting rates were recorded close to the African coast and in the 30–40°S latitude strip. However, these high rorqual sighting rates in 30–40°S in the South Atlantic probably did not include any blue whales, given that in the JSV database only three blue whales were sighted in 35–50°S, 10°E–65°W during 352 554 km of effort (0.005 groups per 1000 km assuming mean group size of 1.56). Furthermore, few Soviet blue whale catches were taken in this band despite large catches of other cetacean species (Fig. 3; Yablokov *et al.*, 1998).

In the south-central Indian Ocean, blue whale records were completely absent although numerous sightings and catches were recorded along the Australian coast, in the northern Indian Ocean and south of about 35°S. Rorqual sightings from large-scale ship studies matched the patterns observed in this paper: low sighting rates in the central Indian Ocean contrasted with high sighting rates on the oceanic periphery (Brown, 1957; Slijper *et al.*, 1964). Soviet catch data show a similar pattern (Mikhalev, 2000), including zero blue whale catches in the central Indian Ocean despite some catches of other species there (Fig. 3; Yablokov *et al.*, 1998).

South-west Atlantic (Brazil, Uruguay and Argentina)

The lowest sighting rate in the study area was from Costinha, Brazil where only three sightings were recorded during 46 273 hours of effort (da Rocha, 1983), to add to two Brazilian catches (one of which was originally recorded as being either a bowhead or a blue, and whose identity is thus questionable) and one stranding (Dalla Rosa & Secchi, 1997). A thorough review concluded that blue whales are nearly absent from Brazil (Zerbini *et al.*, 1997). Isolated strandings were reported from Uruguay (Praderi, 1985) and Argentina (Burmeister, 1871, 1872), and in October 1993 the jawbones from a long-forgotten blue whale stranding were discovered in central Patagonia (Reyes, 2006). Most likely these few blue whales off eastern South America are Antarctic blue whales, although the Brazilian stranding could not be assigned unambiguously to either the Antarctic or pygmy subspecies (Dalla Rosa & Secchi, 1997). It is a mystery why there are so few blue whale records from this region despite intensive whaling and sighting effort (Figs 3 and 6; da Rocha, 1983), especially given its extensive use by other large cetaceans (Zerbini *et al.*, 1997; Croxall & Wood, 2002; Reyes, 2006) and areas of high chlorophyll-*a* concentrations (Fig. 1b; Romero *et al.*, 2006). However, it is worth noting that the high chlorophyll-*a* concentrations are over the broad continental shelf (Fig. 1a), which is probably shallower than the depths preferred by blue whales.

South-western Africa

Large catches were recorded from Saldanha Bay (South Africa) ($n = 7969$), Namibia ($n = 1665$), Angola ($n = 1917$) and Congo ($n = 1$). Saldanha Bay in particular was known to be a place frequented by a high percentage of immature blue whales in addition to some very large females (Mackintosh & Wheeler, 1929; Mackintosh, 1942). These catches occurred throughout the highly productive upwelling system of the Benguela Current (Carr & Kearns, 2003). Despite large historical catches, only two sightings of blue whales have been recorded from the entire west coast of Africa since 1973, suggesting that these blue whales were nearly extirpated by whaling. Recently, no sightings were recorded in 3644 hours of survey effort between March 2004 and September 2005 off central and northern Angola in deep waters (C. Weir, personal communication). No strandings have ever been reported from this coast, perhaps because it is sparsely inhabited. These blue whales are most likely to be Antarctic blue whales because (i) Antarctic blue whales were severely depleted by whaling (Branch & Butterworth, 2001b; Branch *et al.*, 2004); (ii) an estimated >90% of sexually mature females caught were Antarctic blue whales (Branch *et al.*, 2007); and (iii) a detailed study found that they were morphologically similar to Antarctic blue whales caught at South Georgia (Mackintosh & Wheeler, 1929).

South-eastern Africa

Catches with positional data in this region were recorded only at Durban, South Africa, and consisted of a mixture of immature and adult blue whales. In total, 2986 blue whales were caught off Durban. Additional catches (positions not available) were taken in south-east South Africa ($n = 417$) and Mozambique ($n = 14$) during 1911–16. Evidence from a variety of sources suggests that most catches here were originally Antarctic blue whales but by the end of the whaling period most catches and sightings were probably pygmy blue whales (Branch *et al.*, 2007). This is not surprising given the close proximity to known pygmy blue whale grounds south of Madagascar (Best *et al.*, 2003), and a pygmy blue whale reported caught at Durban (Gambell, 1964). Sightings during 1968–75 were rare and concentrated in March–May, while earlier catches peaked in May–July (Bannister & Gambell, 1965).

Madagascar and Subantarctic (southern Indian Ocean)

This region of numerous sightings and catches is known to be primary pygmy blue whale habitat in the summer. One of the highest sighting rates recorded was on the Madagascar Plateau: 36 groups per 1000 km (Best *et al.*, 2003), while 1607 whales were recorded in the JSV database in the Subantarctic (2.9 groups per 1000 km in 35–50°S 30–100°E). These sighting rates are 500 times greater than in the South Atlantic and South Pacific and an order of magnitude greater than in the Antarctic. Calls recorded here in the presence of pygmy blue whales are distinctive (Ljungblad *et al.*, 1998) and have also been recorded north-east of Madagascar near Diego Garcia (Stafford *et al.*, 2005) and in the Subantarctic near Crozet Island (Samaran *et al.*, 2006). South of Madagascar, localized wind-driven upwelling occurs in winter (Ho, Zheng & Kuo, 2004), and the East Madagascar Current regularly sheds energetic eddies that feed into the Agulhas Current off south-eastern Africa (Quartly *et al.*, 2006). Sightings and catches extended over a broad area from Africa to Australia, and were just south of a band of high eddy variability extending from Madagascar to Australia (Palastanga *et al.*, 2007).

Australia and Indonesia

Sighting rates off southern and western Australia were among the highest recorded (7.4–18.6 groups per 1000 km). These areas were also where Soviet whalers took large catches of pygmy blue whales, and where relatively many strandings have been recorded. Given the near continuous distribution of records from Tasmania to Indonesia, it is likely that these blue whales form one population. Recordings of blue whales off western Australia include Australia-specific calls, presumably from pygmy blue whales, which peak from February to May, and limited numbers of Antarctic-type calls from May to October (Ljungblad *et al.*, 1997; McCauley *et al.*, 2004; Stafford *et al.*, 2004). Additionally, the 1898 stranding off south-west Australia was of a physically immature Antarctic blue whale, 24.0 m in length (Bannister *et al.*, 2005). Thus, while the great majority of blue whales in this region are probably pygmy blue whales, a few Antarctic blue whales migrate here in the austral winter. Environmental factors driving biological enrichment and enhanced blue whale foraging in this region include upwelling, eddy shedding and current meandering. Upwelling is most evident along the southern coasts of Java and Sumbawa Islands, Indonesia (Hendiarti, Siegel & Ohde, 2004), in the eastern Great Australian Bight (McClatchie, Middleton & Ward, 2006) including the Bonney Upwelling region (Gill, 2002), and at Perth Canyon, Western Australia, where a strong subsurface chlorophyll maximum (i.e. not evident in satellite imagery) supports seasonal blue whale foraging (Rennie, McCauley & Pattiaratchi, 2006). Eddy shedding is evident in the Leeuwin Current (Fang & Morrow, 2003), and current meandering interacts with upwelling around Halmahere Island, Indonesia (Christian *et al.*, 2004).

Northern Indian Ocean

Numerous catches were recorded off Oman and Somalia, and around the Maldives and Sri Lanka. Sightings and strandings were recorded year-round in high productivity portions of the northern Indian Ocean, especially off Somalia (Small & Small, 1991), the Maldives (Anderson, 2005) and Sri Lanka (Alling *et al.*, 1991). Strandings were also reported from a much wider area (Bangladesh, Burma, India and Pakistan) than sightings and catches. Sighting rates were generally higher than in the Antarctic, except off Oman where sightings were rare. Calls recorded from Sri Lanka (Alling *et al.*, 1991) are distinct from those recorded off Madagascar, Australia and around the Antarctic but have also been recorded south of the equator at Diego Garcia (Stafford *et al.*, 2005). This region encompasses the Arabian Sea, a productive upwelling region during the south-west monsoon (Longhurst, 1998). Localized upwelling also occurs between the southern tip of India and Sri Lanka (Rao *et al*., 2006), where blue whales are known to feed.

It has been suggested that northern Indian Ocean blue whales are a separate subspecies, *B. m. indica* (Blyth, 1859). While this name is accepted as valid, and has nomenclatural priority over both *brevicauda* (Ichihara, 1966) and *intermedia* (Burmeister, 1871), the distinguishing features (if any) of northern Indian Ocean blue whales are poorly known (Rice, 1998). It seems more likely that northern Indian Ocean and pygmy blue whales belong to the same subspecies, based on Soviet catches, where the mean length of sexually mature females from the northern Indian Ocean is 69 ft (21.0 m), nearly identical to that for pygmy blue whales from the southern Indian Ocean, and in contrast to the ~84 ft (25.6 m) from Antarctic catches (Branch *et al*., 2007). On the other hand, their geographical distribution is fairly discrete (Fig. 10), and their breeding cycle is 6 months out of phase with those in the southern Indian Ocean (Mikhalev, 2000, p. 151). It is noteworthy that a resident population of humpback whales in the northern Indian Ocean (particularly the Arabian Sea) also has a reproductive cycle shifted by 6 months compared with the Southern Hemisphere (Mikhalev, 1997b).

South-east Pacific (Chile, Peru, Ecuador)

Sightings, strandings and catches were recorded throughout the waters of Chile, Peru, Ecuador and the Galapagos in a nearly continuous distribution bounded to the south by the South Subtropical Front and to the north by the Equatorial Front. This population is supported by the rich upwellings along the extent of the Humboldt Current (Carr & Kearns, 2003), and by topographic and equatorial upwelling processes near the Galapagos (Palacios, 2004). Recent sighting rates from an offshore survey (Findlay *et al*., 1998) and from the inshore Chiloé Island-Corcovado region (e.g. Hucke-Gaete *et al*., 2003; Galletti Vernazzani *et al*., 2006) are one to two orders of magnitude higher than those recorded in the Antarctic (from the IDCR/SOWER, JARPA and JSV surveys).

Several lines of evidence confirm that blue whales in Chilean waters are not from the same population as those in the Antarctic. First, hundreds of blue whales were caught annually in Chile in the 1960s (Clarke *et al*., 1978) at a time when Antarctic blue whales numbered less than a thousand (Branch *et al*., 2004). Second, a feeding and nursing aggregation of blue whales was discovered in southern Chilean waters during the summer when Antarctic blue whales should be in polar waters (Hucke-Gaete *et al*., 2003). Finally, there was a distinct gap between the southernmost sightings at 44°S and the northernmost Antarctic records at 64°S, corresponding to the region between the South Subtropical Front and the Antarctic Polar Front (Fig. 10).

Acoustic data include a call type unique to the south-east Pacific (Cummings & Thompson, 1971; Stafford *et al*., 1999; T. Norris, unpublished data). In the eastern tropical Pacific, this call type was paired with the Antarctic call type during June–September although the Antarctic calls were recorded much more rarely (Stafford *et al*., 1999; Stafford *et al*., 2004).

The subspecific status of south-east Pacific blue whales remains a topic open for debate. The gap of 20° latitude between their southernmost distribution and the northernmost Antarctic records, and their high density peaking in summer months in Chile are evidence that they are not Antarctic blue whales. Aguayo (1974) asserts that 10 out of 168 examined Chilean catches were pygmy blue whales (but provides no details), and an examination of a stranded individual (Van Waerebeek *et al*., 1997) suggested more affinity to Antarctic blue whales than to pygmy blue whales. South-east Pacific blue whales have a unique acoustic call type (Cummings & Thompson, 1971; Stafford *et al*., 1999; T. Norris, unpublished data). Genetic evidence has suggested similar levels of divergences between Antarctic samples, Indian Ocean samples and those from the south-east Pacific (LeDuc *et al.*, 2007). The mean length of sexually mature blue whales from Chile (23.5 m) is intermediate between pygmy (21.0 m) and Antarctic (25.6 m) blue whales (Branch *et al.*, 2007). These lines of evidence led Branch *et al.* (2007) to hypothesize that these blue whales may belong to a separate as-yet undescribed subspecies, although this remains to be demonstrated.

New Zealand and south-west Pacific islands

A distinct grouping of catches, sightings and strandings was recorded from New Zealand, separated by the 155°E longitude line from blue whales recorded around Tasmania. In the JSV database, no sightings were recorded in the Tasman Sea despite high search effort. It seems reasonable to conclude that these blue whales are linked to those recorded directly north of New Zealand. This area is influenced by frontal dynamics at the Subtropical Front to the south and the Tasman Front to the north, and by upwelling at several sites along the coast of New Zealand (Longhurst, 1998). Sounds produced off northern New Zealand differ from those produced by pygmy blue whales from the Indian Ocean (McDonald, 2006; McDonald *et al.*, 2006); however, these sounds were only recorded four times during a full year of monitoring and just once from acoustic data monitored in the early 1960s (Kibblewhite *et al.*, 1967; McDonald, 2006). Two carefully measured New Zealand strandings are too long to have been pygmy blue whales: a 26.5 m individual in February 1908 (Waite, 1912), and a 27.4 m blue whale in April 1978 (A. N. Baker, unpublished data). Matters are complicated further in that reported Soviet catches in this area do not include length data but were considered to be pygmy blue whales (Mikhalev, 2000) and because Antarctic calls have been recorded from this area in the winter months (McDonald, 2006). The available evidence suggests that blue whales recorded here in austral summer months are probably a separate population of pygmy blue whales but further work on morphology, acoustics and genetics is needed to clarify their relationship to the described subspecies.

Migration

Antarctic blue whales

The classic theory for Antarctic blue whales holds that they migrate to the Antarctic in the austral summer to feed, and then migrate to a variety of more northerly locations in the winter to calve and mate (Mackintosh, 1966). Good supporting evidence is available for the winter migration of Antarctic blue whales to the west coast of South Africa, Namibia and Angola (e.g. Best, 1998). First, large females were recorded in south-west African locales with similar morphology to blue whales at South Georgia (Mackintosh & Wheeler, 1929). Second, Antarctic catches peaked in the austral summer, and south-west African catches peaked in the austral winter. Third, south-west African catches plummeted to near zero with identical timing to the substantial depletion in the Antarctic. Fourth, only two sightings have been recorded in the region since whaling ceased (although effort is limited), implying that blue whales off south-west Africa remain substantially depleted.

Similar evidence links Durban with Antarctic blue whales: size distribution, seasonal distribution of catches and a plummeting catch per unit effort (Best, 2003). However, later catches and sightings off Durban were primarily in March–May instead of the earlier catch peak in June–July; catch per unit effort decreased to 3% (Best, 2003) instead of the 0.3% levels expected (Branch *et al.*, 2004); a pygmy blue whale was caught there in September 1963 (Gambell, 1964); and four out of 12 pregnant blue whales caught at Durban were shorter than 75 ft (IWC catch database). These data suggest that in later years most blue whales encountered at Durban were pygmy blue whales.

In areas other than southern Africa, the main evidence for migration comes from acoustic detections of the characteristic 28-Hz Antarctic call type and occasional strandings of Antarctic-length blue whales. Antarctic blue whale calls have been recorded in winter months in a variety of locations: the eastern tropical Pacific, the central Indian Ocean, south-west Australia and northern New Zealand (Stafford *et al.*, 1999; McCauley *et al.*, 2004; Stafford *et al.*, 2004; Stafford *et al.*, 2005; McDonald, 2006). These call detections are generally infrequent, suggesting small numbers of calling blue whales. Strandings might be expected to shed light on migration patterns but few unambiguous Antarctic blue whales have stranded and been examined: notably a 24.0 m physically immature blue whale in Australia in 1898 (Bannister *et al.*, 2005), a 26.5 m female in New Zealand in February 1908 (Waite, 1912), and a 27.4 m individual in New Zealand in April 1978 (A. N. Baker, unpublished data).

While the acoustic detections provide evidence that Antarctic blue whales migrate to northerly locations in winter, it is still unknown what proportion migrate. Moored acoustic devices along the Western Antarctic Peninsula (Širović *et al.*, 2004) and in East Antarctica (67°S 70°E) (McKay *et al.*, 2005) detected Antarctic blue whales year-round. Admittedly, these acoustic detections were greatly reduced in winter months, but it is likely that this reduction was partly due to the encroachment of heavy ice cover over the acoustic devices (Širović *et al.*, 2004), forcing the blue whales northwards. At South Georgia, although few vessels attempted whaling in the winter months, Risting (1928, p. 20) reported that 559 blue whales were taken during July–September in 1914–18, i.e. 5.0% of the 11 114 blue whales taken in those years (source: IWC). Hinton (1915, p. 155) also records that while humpbacks were present only between October and March around South Georgia, 'finback and blue whale are to be found around the island at all times'. Thus, at least some Antarctic blue whales do not migrate northwards in winter. No information is available from Discovery marks since these were recovered only in the Antarctic ($n = 103$) and Subantarctic ($n = 1$) during summer months. Overall, the available evidence suggests that Antarctic blue whales generally do migrate to northerly locations in winter, although some overwinter in the Antarctic.

Pygmy blue whales

The migration patterns of pygmy blue whales are poorly known. High densities observed during summer months in the northern Indian Ocean, off southern Madagascar and Australia and around New Zealand provide evidence that these blue whales do not migrate to the Antarctic (Ichihara, 1966; Kato *et al.*, 1995; Mikhalev, 2000; Gill, 2002; Best *et al.*, 2003).

In the northern Indian Ocean, blue whales are present around Sri Lanka and India in all months of the year and seasonally around the Maldives (Alling *et al.*, 1991; Anderson, 2005). The call type recorded off Sri Lanka from February to April was recorded from Diego Garcia from May to December (except July), suggesting some movement between these two areas on a seasonal basis. A more fine-scale analysis of seasonal movements within the northern Indian Ocean is ongoing and will be reported separately.

The pygmy blue whales recorded south of Madagascar appear to move southwards and spread longitudinally in the southern Indian Ocean in the summer. In January through March, pygmy blue whales are distributed almost continuously in the Subantarctic between Africa and Australia (Fig. 11). The call type recorded south of Madagascar in December was recorded in Diego Garcia (6°18′S 71°E) in May–July (Stafford *et al.*, 2005), suggesting a northern migration in winter.

Around Australia and Indonesia, the monthly data suggest a migratory link between Australia and Indonesia around the western coast of Australia. As shown in Figs 11 and 12, blue whales have been recorded in Indonesian waters during May to November while high concentrations are reported from the southern coast of Australia mostly during the austral summer (November to May). Acoustic detections off West Australia (21°S) record blue whales apparently migrating northwards in June–July and southwards in November–December (R. D. McCauley, unpublished data). In July–October the acoustic detections from Cape Leeuwin, Australia (35°S 114°E) included Antarctic blue whales only, but from November to June Australian call types were often recorded there (McCauley *et al*., 2004; Stafford *et al*., 2004).

Off north-western New Zealand there is little evidence for migration, although it seems reasonable to hypothesize that some blue whales migrate from New Zealand northwards to the Pacific islands in winter. These blue whales were described as pygmy blue whales in Soviet catches (Mikhalev, 2000), although length data are not available for confirmation.

South-east Pacific blue whales

In the south-east Pacific, sightings and catches of blue whales peak in the summer months, while in August to November there are numerous records off Peru and the Galapagos. These data can be used to infer a migration from southern Chilean waters in summer to more northerly regions in winter, although the data also show that some blue whales remain in each of these regions all year.

Population status

Since the type and amount of effort differ substantially from region to region, the resulting sighting rates are only a qualitative measure of the status of the blue whale populations discussed here. For Antarctic blue whales, sightings remain rare in the Antarctic (0.17–0.52 per 1000 km) despite considerable effort during dedicated sightings surveys. Sightings are also concentrated at the edge of the pack ice, whereas historical catches were more broadly distributed, especially in the summer months. Recorded sightings are also rare (only two since the 1960s) off south-west Africa where large catches of Antarctic blue whales were taken in the 20th century (C. Allison, IWC catch database). This pattern is consistent with substantial depletion of Antarctic blue whales to a low point of 0.07–0.29% of pre-exploitation levels in 1973 (Branch *et al*., 2004). Until recently, there was little evidence for recovery in this subspecies, but Branch *et al*. (2004) showed statistical evidence that they are increasing at 7.3% per year (95% interval 1.4–11.6%), while remaining below 1% of their original levels.

Within the known distribution range of pygmy blue whales (Indian Ocean including Indonesian waters, south of Australia and north of New Zealand), there are areas with sighting rates one to two orders of magnitude higher than in the Antarctic. This is of particular interest because of the intensive effort associated with Antarctic sighting surveys compared with the lower effective effort in many pygmy blue whale areas. This may reflect a higher density and perhaps abundance of pygmy blue whales compared with Antarctic blue whales, although this may only apply to specific regions where survey effort has been directed. Given that catches of pygmy blue whales were much lower than Antarctic blue whales (~13 000 vs. >330 000; Branch *et al*., 2004), and current densities in at least some places are higher, it is clear that pygmy blue whales are less depleted at present than Antarctic blue whales, although their status remains highly uncertain. Relatively high numbers of recent sightings and strandings of south-east Pacific blue whales, and a lack of decline in catches in the 1960s, suggest that this population is also less depleted than in the Antarctic, although, again, their status remains uncertain.

ACKNOWLEDGEMENTS

We are grateful for sightings and strandings contributed, and assistance received in many different ways, from the following sources: A. Alling, J. Barendse, L. Bedriñana, C. W. Clark, R. Constantine, J. Cotton, B. M. Dyer, P. Ensor, K. Evans, B. Haase, S. Heinrich, D. Hyrenbach, T. A. Jefferson, C. Kemper, F. Kennedy, S. Kromann, R. G. LeDuc, A. R. Martin, M. A. McDonald, S. A. Mizroch, M. J. Moore, S. Ohsumi, P. Olson, V. Peddemors, R. L. Pitman, R. Praderi, S. Reilly, D. Rice, H. Shigemune, A. Širović, E. Sullivan, P. Taylor, C. T. Tynan, R. Veit, I. Visser, C. Weir, A. N. Zerbini, members of the Oman Whale and Dolphin Research Group (R. Baldwin, T. Collins, L. Ponnampalam, F. Kennedy and G. Minton) and the New Zealand Department of Conservation. Frontal paths in the Southern Ocean were provided by I. M. Belkin, J. K. Moore and A. H. Orsi and the Costa Rica Dome by P. C. Fiedler. Chlorophyll-*a* data were obtained from the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE. Helpful comments on the manuscript were received from R. R. Reeves, P. J. Clapham and an anonymous reviewer. D.M.P. was supported by award No. N00014-05-1-0045 from the U.S. National Oceanographic Partnership Program. T.A.B. is very grateful for funding from the IWC and the South African National Antarctic Programme, without which this project would never have been attempted.

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Submitted 8 December 2006; returned for revision 28 February 2007; revision accepted 26 March 2007
Editor: PC

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APPENDIX 2

List of sources used to obtain sightings data together with the number of associated records, the listed number of groups sighted and the number of whales sighted, alphabetized by source name. A 'group' could be either a school or feeding aggregation depending on the source. Listed sightings are those with associated positions, many papers noted additional sightings without positions. Latitudes and longitudes are given in whole degrees and rounded to encompass the study region. Where sources are 'unpubl.' this means 'unpublished data'. For totals, each record contains ≥1 group and ≥1 whale. Mean group size is based on all records containing both the number of groups and number of whales. Total effort in days is based on the assumption that 10 hours of effort equals 1 day. For records from the eastern tropical Pacific only the sightings and effort south of 5°N were included.

Source	Region	Dates	Effort	Records	Groups	Whales	Ave group size
Aguayo (1974)	Coastal Chile 43–46°S	Mar, Dec 1966	Not recorded	2	2	9	3.67
Aguayo *et al.* (1998)	SE Pacific 26–34°S 91–111°W	Sep 1994, Jun 1995	770.5 hours	3	3	6	2.00
Alling *et al.* (1991)	East coast, Sri Lanka	Jan–Apr 1983–84	890 hours (49 sightings)	138	–	138	–
Anderson (2005), R. C. Anderson unpubl.	Maldives	Nov–Apr 1999–2004	161 days (11 sightings)	14	14	15	1.07
Anonymous (1987a)	Oman	28 Oct 1985	Opportunistic	1	1	2	2.00
A. N. Baker, unpubl.	New Zealand 171–177°E 33–42°S	1981, 1984, 1998–2004	Opportunistic	31	31	40	1.29
Ballance *et al.* (1996), Ballance & Pitman (1998)	Indian Ocean	Mar–Jul 1995	92 days; 403.9 hours; 9783.9 km	17	17	27	1.59
Ballance *et al.* (2001)	Maldives 3–8°N 72–74°E	Apr 1998	20 days; 155.5 hours; 1700 km	4	4	4	1.00
Best *et al.* (2003)	Madagascar Plateau 25–35°S 40–45°E	Dec 1996	23 days; 2859.9 km	103	103	131	1.27
P. B. Best, unpubl.	Saldanha Bay, South Africa	1964–2003	Opportunistic	4	4	4	1.00
P. B. Best, unpubl.	Durban, South Africa	Mar–Sep 1968–75	5545 boat days + 1592 385 aerial km	62	62	71	1.15
Blokhin (1981)	Southern Australia 29–45°S 113–148°E	2–28 Mar 1979	5839 km	7	7	23	3.29
Borsa & Hoarau (2004)	New Caledonia, 22°S 167°E	29 Dec 2001–27 Jan 2002	Opportunistic	1	1	1	1.00
P. Borsa, unpubl.	Kerguelen Is., 48°S 71°E	Mar 1985	Opportunistic	1	1	1	1.00

P. Borsa, unpubl.	Indonesia, 2°N–11°S 122–137°E	1995–2004	270 hours	2	2	7	3.50
Bowles *et al.* (1994)	Heard Island 53–54°S 74–75°E	19 Jan–3 Feb 1991	162.75 hours; 2412 km	2	2	2	1.00
C. L. K. Burton, unpubl.	Geographe Bay, Australia 34°S 115°E	Sep–Dec 1994–2005	750 days; ~2600 hours (372 whales)	126	126	270	2.14
J. L. Bannister & C. L. K. Burton, unpubl.	Western Australia 31–33°S 115°E	Nov–May 2000–05	12 209.2 aerial km (227 sightings)	252	252	282	1.12
Cabrera, Carlson & Galletti Vernazzani (2005), Galletti Vernazzani *et al.* (2005, 2006)	NW Chiloé Island, Chile 40–43°S 73–75°W	Feb–Apr 2004–06	108.3 hours; 1714.2 km (138 sightings)	184	184	321	1.74
Cawthorn (1983)	New Zealand 38°S 141°E	Feb 1982	Opportunistic	1	1	1	1.00
Cawthorn (1988)	New Zealand 40°S 139°E	Jul–Aug 1986	Opportunistic	1	3	21	7.00
Chittleborough (1953)	Western Australia 23°S 114°E	Sep–Oct 1952	Not recorded	1	1	1	1.00
Clarke & Ruud (1954)	Antarctic 53–62°S 47°W–15°E	Nov–Dec 1953	27 days	12	–	35	–
Clarke *et al.* (1978)	Chile 28–37°S	Nov–Dec 1964	3876 km	3	3	4	1.33
Corbett (1994)	S Indian Ocean, Mauritius	Jul 1991–Jul 1992	16 days	8	8	9	1.13
Cummings & Thompson (1971)	Guafo Island, Chile 44°S 74°W	30–31 May 1970	Opportunistic	1	–	4	–
da Rocha (1983)	Costinha, Brazil	1966–1981	2771 days; 46 273 hours; ~943 000 km	3	3	–	–
de Boer (2000)	Antarctic, Indian Ocean	Nov 1999–Jan 2000	22 920 km	1	5	10	2.00
Donovan (1984a,b)	Peru 10°S–10°N 78–110°W	Nov–Dec 1982	16 437 km	12	12	16	1.33
B. M. Dyer, pers. comm.	Marion Island 47°S 38°E	Apr 2005	Opportunistic	3	3	8	2.67
Eyre (1995)	Sydney, Australia to Suez Canal	May–Jul 1993	45 days; 16 974 km	4	4	4	1.00
Eyre (2000)	Mauritius to Singapore	Apr 2000	15 days; 6130 km	1	1	1	1.00
Findlay *et al.* (1998)	Chile 18–53°S	Dec 1997–Jan 1998	389 hours 58 minutes; 8248.6 km	40	40	48	1.20
Gambell, Best & Rice (1975)	SW Indian Ocean 20–42°S 30–67°E	Nov 1973–Feb 1974	13 271 km	7	7	15	2.14

Table A2. (*Continued*)

Source	Region	Dates	Effort	Records	Groups	Whales	Ave group size
Gill (2002), P. C. Gill, unpubl.	Victoria, Australia 37–40°S 139–144°E	Feb 1998–May 2002	38 996 aerial km (290 sightings)	358	358	532	1.49
P. C. Gill & M. G. Morrice, unpubl.	Victoria, Australia 35–40°S 134–144°E	Dec 2002–Feb 2006	Unknown	729	729	1013	1.39
Gordon, Papastavrou & Alling (1986)	Trincomalee Bay, Sri Lanka 8°N 81°E	Mar 1984	Opportunistic	6	–	6	–
Gunaratna, Obeyesekera & Hahn (1985)	SW Sri Lanka 5–7°N 79–81°E	May 1985	6 days	1	1	2	2.00
B. Haase, pers. comm.	Galapagos Islands	28 Feb 2003	Opportunistic	1	1	1	1.00
Hucke-Gaete (2004), Hucke-Gaete *et al.* (2003, 2005, 2006), R. Hucke-Gaete, unpubl.	Coastal Chile 29–53°S	Jan–Dec 1998, 2001–2006; but mostly Jan–Apr	15.72 aerial hours (23 sightings); 625.36 boat hours (118 sightings)	158	158	429	2.72
D. Hyrenbach, pers. comm.	S Indian Ocean 47°S 67°E	Feb 2004	Opportunistic	2	2	2	1.00
IDCR/SOWER, IWC unpubl.	Surveys south of 60°S, plus transits	Dec–Mar 1978–2005	237 988.1 km (124 sightings)	242	242	490	2.01
A. D. Ilangakoon, unpubl.	North-west Sri Lanka 6–9°N 79–82°E	1987, 1994, 2003–05	63 hours 49 minutes; 617.2 km (1 sighting)	15	15	25	1.67
JARPA, Matsuoka *et al.* (2006), K. Matsuoka & S. Nishiwaki, unpubl.	Antarctic and S Indian Ocean, 40°E–180°–140°W, mostly S of 60°S	Nov–Mar 1989–2005	423 928 km (143 sightings)	253	253	432	1.71
K. C. S. Jenner, M.-N. M. Jenner & V. J. Sturrock, unpubl.	Western Australia, 20–33°S 113–117°E	1993, Feb 2000–Apr 2005	1612 hours; 24 572 km	455	455	548	1.20

M. Joergensen, unpubl.	Chile 43–44°S, 49°S	Feb 2004	1 day	10	10	15	1.50
JSV, Miyashita *et al.* (1995), T. Miyashita, unpubl.	Southern Hemisphere	Dec 1965–Feb 1987	4 827 370 km (2520 whales)	799	–	2410	–
Kahn (2000, 2002)	Komodo, Indonesia	Sep–Oct 2000, Oct 2001	227.25 hours; 4430.7 km	3	3	3	1.00
Kahn (2005)	Solor-Alor, Indonesia	Apr–May 2005	79.75 hours; 1162.9 km	8	8	–	–
Kasuya & Wada (1991)	Equatorial Indian Ocean	Mar 1982	4295 km	2	–	8	–
Kato *et al.* (1996)	Southern Australia 31–45°S 113–149°E	Dec–Jan 1996	~44 days	52	52	60	1.15
Leatherwood (1986)	Antarctic, S. Indian	1874, 1979	Opportunistic	14	–	–	–
Leatherwood *et al.* (1984)	Northern Indian Ocean; Sri Lanka	Apr 1983; 3 May 1983	4023 km (1 sighting); 4 hours (9 sightings)	9	9	9	1.00
A. R. Martin, pers. comm.	West of South Georgia	10 Feb 2006	Opportunistic	2	–	16	–
B. Maughan, unpubl.	South Atlantic 0–70°S	Oct–Apr 1997–2001	Opportunistic	4	4	–	–
Moore *et al.* (1999)	Falkland to S Georgia 51–55°S 34–58°W	Jan–Feb 1997	2266 km	1	1	2	2.00
Ohsumi & Shigemune (1993)	Pacific 36°N–30°S 141°E–145°W	Aug–Oct 1957	13 479 km (in Southern Hemisphere)	23	23	44	1.91
Oman Whale and Dolphin Research Group, unpubl.	Oman 16–24°N 54–59°E	Oct–Apr 1996–2005	12 417 km (4 sightings)	7	7	11	1.57
Palacios (1999a,b), D. M. Palacios, unpubl.	Galapagos 3°N–3°S 90–107°W	1978–1995	190 days; 31 390 km (8 sightings)	17	17	36	2.11
Parker (1978)	Melbourne, Australia to Mawson, Antarctica	Dec 1976, Feb–Mar 1977	34 days; ~136 hours	1	–	2	–
V. Peddemors, pers. comm.	Indian Ocean 37°S 10°E	20 Oct 1987	Opportunistic	1	1	2	2.00
R. L. Pitman, pers. comm.	Peru; South Georgia	Mar 1982, Dec 1985; Jan 2003	Opportunistic	17	17	52	3.06
Puddicombe (1986)	New South Wales, Australia 37°S 150°E	16 Aug 1984	Opportunistic	1	1	1	1.00

Table A2. (*Continued*)

Source	Region	Dates	Effort	Records	Groups	Whales	Ave group size
Ramirez (1985)	Peru, 3–6°S 81–84°E	Oct–Dec 1983	3014.6 hours (852.2 searching)	10	–	79	–
Rudolph, Smeenk & Leatherwood (1997)	Indonesian archipelago	Jun–Sep 1990–93	Opportunistic	3	3	6	2.00
Slijper (1962)	Indian Ocean 11°N 60°E	23 Sep 1953	Opportunistic	1	–	40	–
Small & Small (1991)	Somalia 10–14°N 44–52°E	Aug 1985–May 1987	2615 hours; 32 062.9 km	6	6	–	–
SWFSC cruises, T. Gerrodette, unpubl.	Eastern tropical Pacific	Aug–Nov 1986–1990, 1992, 1998–2000, 2003, 2006	104 691.9 km (47 sightings)	57	57	120	2.11
Thiele (2005)	North-west Australia 13–16°S 123–130°E	Sep 2004	125 hours	1	1	1	1.00
D. Thiele, unpubl.	Australia to Antarctic	Jul 1995–Dec 2004	~1244 days	25	25	54	2.16
Tynan (1996)	Southern Indian Ocean 82–115°E	Dec 1994–Jan 1995	50 days	2	2	2	1.00
Valdivia *et al*. (1983)	Peru 3–8°S 80–86°W	Feb–Mar 1982	3400 km	14	14	–	–
Van Waerebeek *et al*. (1997)	Chile 36–44°S 74–75°W	1970, 1982, 1983, 1995	Opportunistic	4	4	9	2.25
Wade & Friedrichsen (1979)	Eastern tropical Pacific	Jan–May 1971, 1975–76	Unknown	1	1	1	1.00
Wheeler (1946)	Central Atlantic 20°S	Aug–Sep 1943	15 days	1	1	1	1.00
Whitehead *et al*. (1983)	Sri Lanka and Maldives	Oct–Dec 1983	40 days	1	1	1	1.00
Wray & Martin (1983)	Indian Ocean 45°S–7°N 42–96°E	Oct–May 1836–1888	Opportunistic	15	15	–	–
Total				4383	≥4389	≥8058	1.56

APPENDIX 3

Blue whale strandings in the Southern Hemisphere and northern Indian Ocean, ordered by date of stranding. The source is the reference from which the information was obtained; if this was not the original reference, then the original reference is also listed. Where species identity was uncertain the stranding was generally excluded from this list, unless later authors confirmed that it was a blue whale. Most locations were obtained by reading the position from Google Earth, and were typically accurate to at most two decimal places; however, four decimal places are given to account for strandings with more detailed information and to avoid strandings being placed on land. Negative latitudes are south of the equator; negative longitudes are west of the Greenwich meridian.

Source	Date	Sex	Length (m)	Latitude	Longitude	Position name	Notes
Guiler (1978) from Hobart Town Gazette	6/5/1825		29.3	–42.7833	147.0667	New Norfolk, Derwent River, Tasmania, Australia	
Blyth (1859)	15/8/1842		27.4	21.0000	92.1833	Chittagong coast about 21°N, Bangladesh	ID uncertain, length ‘as alleged’
Blyth (1859)	1851		25.6	18.7833	93.9667	Juggu/Amherst Is., S of Ramri, E of Cheduba on Arakan coast, Burma (Myanmar)	Skeleton in Indian Museum, Calcutta (Jones, 1953); according to Rice (1998) some authors erroneously recorded location as Sondip or Sordip
Blyth (1859)	c.1858		27.4	8.8833	76.5667	Quilon, India	ID uncertain
Dixon & Frigo (1994) and M’Coy (1867)	Aug 1866		27.4	–38.3333	144.3000	Jan Juc, outside Port Phillip Heads, Victoria, Australia	Total length recorded, baleen black
Burmeister (1871, 1872)	14/8/1866	Female	17.7	–34.3000	–58.4500	Mouth of Río Luján, near Buenos Aires, Argentina	Type specimen for *B. m. intermedia*
Anonymous (1874)	25/7/1874		26.5	–41.0927	146.0921	West side of Leven Estuary (Ulverstone), Tasmania, Australia	Length exclusive of tail, weight estimated 100–150 tons
Moses (1947)	1874		14.4	12.8333	74.8333	Mangalore, India	Skeleton in Madras Museum, ID confirmed in Gibson-Hill (1950)
Anderson (1878)	~Nov 1874			22.5000	91.4167	Sandwip (formerly Sondip) Island, Bangladesh	Young whale
De Silva (1987) from Murray (1884)	1879			24.8000	67.0167	Clifton beach, Pakistan	
R. M. Warneke, unpubl.	27/7/1887		19.2	–38.3333	145.4167	West of Warrnambool, Victoria, Australia	

Table A3. (*Continued*)

Source	Date	Sex	Length (m)	Latitude	Longitude	Position name	Notes
De Silva (1987) from Haly (1894)	Sep 1894		19.8	6.2333	80.0500	Ambalangoda, Sri Lanka	Skeleton in Colombo Museum
Bannister *et al.* (2005)	1898		24.0	–33.6500	115.3167	Near Busselton, Western Australia	Physically immature Antarctic blue whale, skeleton in WA Museum
Pillay (1926) and James & Soundararajan (1979)	1901		~22	8.1000	77.4000	Rajakamangalam, 5 miles south of Muttum lighthouse between Colachel and Cape Comorin, India	Total length estimated from jaw bone lengths of 5.56 m each, lower jawbone at Travancore Museum
Waite (1912)	8/2/1908	Female	26.5	–43.1333	170.2333	Near Commissioner's Point, 10.5 km north of Okarito, New Zealand	Length from tip of snout to notch of tail, 30.2 m over curves of back; skeleton at the Canterbury Museum, Christchurch (Stollman *et al.*, 2005)
Kinnear (1915)	Jan 1911		21.3	16.9667	72.2833	Viziadrug, Ratnagiri District, India	Measured from nose to tip of tail in straight line, blue-black baleen
Prater (1915)	11/12/1914	Male	12.5	16.8000	73.3167	Dhabool, 155 km south of Bombay, India	Measured from tip of snout to tip of flukes, ID uncertain
Reuter (1919)	Dec 1916		27.28	–7.7000	107.7500	Pameungpeuk, between Tjilauteureun and Tjikelet, Java, Indonesia	Length from extremities of flukes to tip of lower jaw, skeleton in zoology museum in Bogor
R. M. Warneke, unpubl.	4/7/1923	Male	22.6	–38.6667	145.5833	'The wreck', Wonthaggi, Victoria, Australia	
A. N. Baker, unpubl.	1/1/1925	Female	30	–36.5667	174.7167	Orewa, New Zealand	
Waite (1926)	5/8/1925		7.42	–34.2500	138.2167	Head of Gulf St Vincent, South Australia, Australia	Juvenile, carefully measured
Moses (1947)	Nov 1927		28.7	9.9667	76.2333	Cherai, Cochin, India	Skeleton at St. Aloysius College, Mangalore, India
Rudolph *et al.* (1997) from Delsman (1932)	Dec 1931		17	–7.2167	113.2333	Sampang, Madura Island, Indonesia	
De Silva (1987) from Pearson (1932)*	26/5/1932	Male		8.5333	81.1500	Tamblegam Bay, Trincomalee, Sri Lanka	

De Silva (1987) from Pearson (1932)*	30/6/1932		20.1	8.4667	81.2167	Koddiyar Bay, Trincomalee, Sri Lanka	
Deraniyagala (1960)	6/2/1934		15.14	5.9333	80.5333	Polhena, Matara (S.P), Sri Lanka	Described as fin whale but uniform black colour and all-black baleen; photo in De Silva (1987)
Jones (1953)	Jan/Feb 1934			21.6833	88.1667	Jambudwip, Bengal coast, India	Decomposition advanced
McCann (1934)	7/5/1934		15.8 or ~21.3	18.9000	72.8000	Colaba Reclamation, Mumbai, India	Exact location difficult to determine
Deraniyagala (1965)	10/1/1939		~19.5	6.0833	80.1333	Dodanduwa (S.P), Sri Lanka	Length estimate uncertain
Moses (1940)	21/3/1939	Female	24.1	22.4000	68.9500	Mulvel, Okhamandel, India	
Deraniyagala (1948)	23/1/1946	Female	18.3	8.5667	81.2167	Trincomalee Harbour, Sri Lanka	Gave birth the next day in the harbour, towed to safety
Deraniyagala (1960)	8/4/1949			6.8833	79.8500	Bambalapitiya (W.P.) Colombo, Sri Lanka	
Chari (1951)	14/5/1951		20.7	20.2000	72.7500	Umargam, 160 km from Bombay, India	Decomposition advanced, 20.7 m from tip of snout to centre of flukes, some later sources erroneously reported as 22.6 m
Wakefield (1967)	Apr 1955		18	–38.4167	144. 1833	Anglesea, 50 miles SW of Melbourne, Victoria, Australia	Approximate length
Wakefield (1967)	*c*. 1957		18.3	–38.2667	141.8500	Fitzroy River mouth, Portland Bay, Victoria, Australia	
Kewalramani (1969)	27/12/1960	Female	23.8	21.5333	72.6833	Soonvai Creek near village Ganeshghan in Bhal area of Vallabhipur Taluka, Bhavsagar Dt., Gujarat, India	Location uncertain, some later sources erroneously reported as 23.4 m on 7/12/1960
Daniel (1963)	23/2/1963		20.28	23.0667	72.7167	Village Gavier, near Magdalla Port, 11 km from Surat, Gujarat, India	
Al-Robaae (1974)	6/6/1963			29.3333	48.1167	In muddy area, 'Kadguma', Kuwait; location uncertain	Skeleton at Natural History Museum, Shuaikh Secondary School, Kuwait
Nagabhushanam & Dhulkhed (1964)	21/4/1964		15.76	13.4167	74.6750	Muloor village, India	Decomposition advanced, length from tip of lower jaw to fluke notch

Table A3. (*Continued*)

Source	Date	Sex	Length (m)	Latitude	Longitude	Position name	Notes
Siddiqi (1968)	1965			25.2667	63.4833	Juddi near Pasni, Mekran coast, Pakistan	Location of 'Juddi' not known, lower jaw 3.0 m, skeleton in Zoological Survey Museum, Karachi, Pakistan
De Silva (1987)	3/4/1965			6.8833	79.8500	Wellawatte (W.P.), Sri Lanka	
De Silva (1987)	14/4/1965			9.0000	80.9500	Kokkilai near Pulmoddai (E.P.), Sri Lanka	
James & Soundararajan (1979)	5/2/1966		13.65	9.2833	79.1167	Mandapam (Palk Bay), India	Putrefied specimen
Venkataraman & Girijavallabhan, 1966)	25/5/1996		13.51	11.2500	75.7667	Kannanparambu, 1 km south of South Beach, Calicut, India	Calicut = Kozhikode, flipper:TL 1:8.6, baleen missing, ID uncertain
R. M. Warneke, unpubl.	6/2/1967		18.3	–41.1167	146.1333	Three Sisters Island, Tasmania, Australia	Approximate length
Siddiqi (1968)	Jun 1967		18.3	25.2167	63.4000	5 miles west of Pasni, Makran coast, Pakistan	Lower jaw 5.5 m, in Zoological Survey Museum, Karachi, Pakistan
Bensam, Vincent & Mahadevan Pillai (1972)	2/4/1969	Female	11.26	8.7833	78.1667	Tuticorin, Gulf of Mannar, India	Juvenile, alive but shot and killed before brought to shore; ID uncertain
IWC catch database, Bannister *et al.* (2005)	May 1973	Female		–35.0500	117.8833	Princess Royal Harbour, Albany, Australia	Processed, yielded 118 barrels
Al-Robaae (1974)	Unknown			23.61671	58.6000	Entangled in submarine telegraph cable Muscat, Oman	Location named as Masket, Arabia, in original
Bannister *et al.* (2005)	May 1974			–35.0667	117.8667	Princess Royal Harbour, Albany, WA, Australia	
Cawthorn (1978)	1975			–39.1167	173.9500	Onetai Beach, Taranaki, New Zealand	
De Silva (1987)	Mar 1976	Female		6.9333	79.8500	Galle Face, Colombo (W.P.), Sri Lanka	Mother and calf
R. M. Warneke, unpubl. and Leatherwood (1986)	5/4/1976	Male	17.5	–38.3833	142.0500	Levy's Point, Victoria, Australia	
Marichamy, Rajapandian & Srinivasan (1984)	20/12/1976	Female	6.35	8.2667	77.9000	Near Ovari, Gulf of Mannar, India	Immature female

James & Soundararajan (1979)	4/10/1977	Female	10–12	9.2833	79.1833	Pamban, Palk Bay, India	Entangled live in gillnet
A. N. Baker, unpubl.	30/4/1978		27.4	–36.5667	174.7167	Orewa, New Zealand	
Leatherwood (1986) from Fernando (1981)*	9/2/1981			7.5833	79.7833	Chilaw, Sri Lanka	
Praderi (1985)	9/7/1983		18.3	–34.4333	–57.6000	Uruguay	
Venkataramanujam, Paulraj & Ramadhas (1984)	11/9/1983		11.67	8.2000	77.1667	Erayumanthurai near Thengapattinam, Tamil Nadu, India	Black baleen plates, advanced decomposition
Anderson, Shaan & Waheed (1999)	1984		19	7.0167	73.2500	H.A. Dhidhoo, floating at sea, Maldives	
Van Waerebeek *et al*. (1997)	24/2/1984		23	–36.6167	–72.9500	Coliumo Bay, near Tome, Chile	
Anderson *et al*. (1999)	30/1/1985		22	3.5167	73.5667	V. Thinadhoo, floating off V. Maadhiggaru, Maldives	Approximate length
Anderson *et al*. (1999)	16/2/1985		21	2.5000	73.3167	Th. Vilufushi, floating near reef, rotten, Maldives	Approximate length
Somasekharan & Jayaprakash (1987)	31/9/1985	Male	10.3	9.9667	76.2333	Chappa Beach, Narakkal, Cochin, India	Date may be 31/8/1985; total length 7.7 times flipper length, identification uncertain.
A. D. Ilangakoon, unpubl.	11/7/1986		18.9	7.5807	79.8047	Chilaw (north-west coast) Sri Lanka	
Anonymous (1987b)	18/10/1986		13	10.9000	75.8833	Tirur beach, India	Photograph provided
Smith *et al*. (1997)	19/1/1987		21.9	18.3333	94.3333	One mile from shore, Andrew Bay (Thabyugyaing), Myanmar (Burma)	Skeleton 17.4 m long, now in Yangon Zoological Gardens
Rudolph *et al*. (1997)	22/6/1987		23.5	–3.2667	127.1167	Namlea, Buru Island, Indonesia	Skeleton in Ambon Museum
Lal Mohan (1992)	29/9/1988	Female	19.2	12.1667	76.5000	Paravana, near Calicut, India	Flippers 2.5 m, 1/7 total length; 80 throat grooves
Nammalwar *et al*. (1989)	10/12/1988	Male	15.16	16.9167	82.3167	Motupally, near Ramachandrapuram, Andhra Pradesh, Prakasam District, India	Measured from tip of upper jaw to notch of caudal fluke
C. Kemper, South Australian Museum, pers. comm.	19/9/1989	Female		–34.7300	138.5000	Gulf St. Vincent, Australia	
R. M. Warneke, unpubl.	4/12/1991	Male	20	–39.9500	143.8500	British Admiral Beach, King Island, Tasmania, Australia	Approximate length
A. N. Baker, unpubl.	1/3/1992	Female	16.4	–35.8167	174.5333	Whangarei harbour, New Zealand	

Table A3. (*Continued*)

Source	Date	Sex	Length (m)	Latitude	Longitude	Position name	Notes
Dalla Rosa & Secchi (1997)	29/4/1992	Female	23.1	–33.7500	–53.3800	2 km from Chui Bar southern Brazil, near border with Uruguay	Genetic sample held by L. Pastene
Dixon & Frigo (1994)	5/5/1992	Male	18.17	–38.4833	144.0167	Cathedral Rock, 5 km NE of Lorne, Victoria, Australia	
Bannister *et al.* (2005)	Mar 1993			–32.2000	115.6667	Garden Island, WA, Australia	
James, Menon & Pillai (1993)	2/5/1993		26	9.9667	76.2333	Chellanam, Cochin, India	Carcasse putrefied, length approximate
LeDuc *et al.* (1997)	14/6/1993			–34.5167	135.3167	Australia	
Van Waerebeek *et al.* (1997)	30/8/1993		12.5	3.6048	–77.2042	Periquillo beach, Colombia	
Mohanraj, Somaraju & Seshagiri Rao (1995)	9/5/1994	Male	11.73	17.8333	83.4167	Off Mangamaripeta, 12 km north of Visakhapatnam, India	Live male caught in drift gillnet, length from tip of upper jaw to notch of caudal fluke, some later sources erroneously list date as 9/5/1995
A. N. Baker, unpubl.	11/9/1994	Male	20.6	–36.5667	175.0333	Hauraki Gulf, New Zealand	Hit by ship, identified as pygmy blue
Lipton *et al.* (1995)	25/11/1994		13.3	9.1833	79.4000	Dhanushkodi, India	Measured from snout to notch of caudal fluke
Van Waerebeek *et al.* (1997)	7/2/1995	Female	18	–33.9000	–71.8333	300 m north of mouth of Rapel River, Chile	Decomposing
LeDuc *et al.* (1997)	9/5/1995			–36.9833	139.7000	Australia	
Van Waerebeek *et al.* (1997)	3/1/1997	Female	20.44	–11.0393	–77.6597	Isla don Martin, Peru	
R. C. Anderson, unpubl.	5/1/1997		16	3.2500	73.5000	V. Rakeedhoo, Maldives	Floating at sea. Mandibles (longest 482 cm) and scapula on island
Anderson *et al.* (1999)	20/1/1997		18	2.2500	73.3000	Th. Guraidhoo, floating in Veimandhoo Kandu, Maldives	Approximate length
Van Waerebeek *et al.* (1997)	20/3/1997		23	–41.1667	–73.9050	Near Llico Bajo, X Region, Chile	
Anderson *et al.* (1999)	3/1/1999		19	6.2000	73.0333	Sh. Medukumburudhoo, washed on beach, Maldives	

A. D. Ilangakoon, unpubl.	21/7/1999	Female	21.9–23.8	5.9612	80.4288	Kaparatota/Weligama (south coast) Sri Lanka	
McCauley *et al*. (2004)	6/11/2000		21	–13.7500	126.1330	Troughton Island, Kimberleys, Australia	
A. N. Baker, unpubl.	14/11/2001	Female	15.2	–34.6333	173.0167	Henderson Bay, New Zealand	Pygmy blue?
McCauley *et al*. (2004), K. C. S. Jenner, unpubl.	9/12/2001		22.3	–34.0881	114.9989	Cape Freycinet, Western Australia, Australia	ID as pygmy blue whale; location incorrectly reported as Margaret River
Borsa & Hoarau (2004), Borsa (2006)	29/1/2002	Male	16.5	–22.3333	166.8167	Baie de la Somme, New Caledonia	
R. C. Anderson, unpubl.	9/12/2002		15	4.1667	73.5167	SW outer reef, K. Malé, Maldives	Rotten, most of head missing, vertebral epiphyses not fully fused
Krishnan *et al*. (2004)	21/12/2001		12.3	13.3000	74.7000	Beach of Guijerbettu, Udupi district, Karnataka, India	Dorsal fin 1% of total length
A. D. Ilangakoon, unpubl.	15/10/2003	Female	20.1	6.9103	79.8492	Bambalapitiya/Colombo (west coast) Sri Lanka	
A. D. Ilangakoon, unpubl.	2/4/2004	Male	19.8–21.3	6.9418	79.8597	Colombo Harbor (west coast) Sri Lanka	
A. D. Ilangakoon, unpubl.	11/7/2004		18	8.1377	79.7005	Thalawila (north-west coast) Sri Lanka	
R. C. Anderson, unpubl.	6/1/2005		23	4.2500	73.5500	On outer reef, K. Furana, Maldives	Rotten, tail and part of head missing, photos held at MRC
Hucke-Gaete *et al*. (2005); B. Galletti Vernazzani, unpubl.	29/3/2005	Male	23 or 24.38	–41.9861	–74.0333	Pumillahue Bay, NW Chiloé Island, Chile	
Bannister *et al*. (2005)	16/12/2005	Female	20.8	–32.0167	115.4686	Strickland Bay, Rottnest Island, Western Australia	Tail-anus/total length = 0.24, therefore likely a pygmy blue whale
R. C. Anderson, unpubl.	19/12/2005		20	4.6833	73.4333	K. Olhahahi, Maldives	Photos held at MRC

*Details of original reference have not been obtained or were not listed in citing paper.

APPENDIX 4

Details of blue whales marked and recaptured in the Southern Hemisphere, ordered by Discovery tag number. When two marks were recovered from one whale, they were both fired on the same day and at the same location, except for two instances detailed in the footnotes. Where the notes indicate 'uncertain', and probably in instances where length and sex were not recorded, the mark was recovered from the cooker, digester, boiler or stored meat. In such cases, a range of possible recapture locations and dates was often recorded and the central such position and date reported here. Code prefix 'G' indicates a German mark and 'USSR' a Soviet mark.

Code	Marked latitude	Marked longitude	Marked date	Recaptured latitude	Recaptured longitude	Recaptured date	Sex	Length at capture (m)	Distance (km)	Duration (days)	Notes
656/1229*	–54.7167	–33.9833	26/12/1934	–54.5000	–34.3167	29/12/1934	Female	24.1	32	3	
700	–54.2500	–33.9667	06/12/1934	–54.1833	–34.8333	11/12/1934	Male	23.8	57	5	
825/853	–54.9167	–35.2333	30/11/1934	–55.1333	–34.5333	30/11/1934	Male	23.5	51	0	
859	–54.9000	–35.2333	30/12/1934	–54.5000	–37.0000	28/11/1946	–	–	122	4351	
903	–54.0167	–38.8500	12/01/1935	–55.4000	–33.7833	19/01/1935	Female	23.9	360	7	
1123/1125	–55.0000	–34.3333	29/12/1934	–62.3333	–45.8333	12/01/1939	Female	25.3	1048	1475	
1245	–54.8833	–34.5667	27/12/1934	–59.3833	–9.3667	30/12/1939	–	–	1589	1829	
2026	–57.4333	23.8333	14/12/1935	–61.0000	87.0000	16/12/1936	–	–	3473	368	
2525	–56.6667	39.0000	05/12/1934	–64.5500	22.8333	01/02/1937	Female	22.9	1236	789	
2537	–56.6000	35.7500	04/12/1934	–57.6167	16.4667	22/12/1938	Female	25.5	1165	1479	
2548	–58.3500	49.2667	08/12/1934	–59.0000	34.2500	02/12/1937	Male	24.4	869	1090	
2816	–63.3500	53.5333	17/01/1935	–64.0000	90.0000	09/03/1936	–	–	1774	417	
2892	–63.5333	47.2833	22/01/1935	–65.2833	84.5000	26/02/1936	Male	25.9	1770	400	
2902	–63.5333	47.9500	22/01/1935	–66.0000	15.0000	12/03/1935	–	–	1566	49	
2903	–63.5333	47.9500	22/01/1935	–63.9333	45.9333	26/01/1935	Male	26.2	109	4	
2910	–62.7500	46.3667	24/01/1935	–63.4167	45.9333	26/01/1935	Female	21	77	2	
2960/2965	–62.7667	43.0833	26/01/1935	–64.7667	41.4167	31/01/1935	Female	22.1	237	5	
2963	–62.6500	43.9667	26/01/1935	–62.6500	34.8833	08/02/1935	Female	25.9	463	13	
3013	–61.9167	43.2833	28/01/1935	–64.2333	29.7500	27/03/1935	Female	22.9	726	58	

3023	–62.0167	43.3500	28/01/1935	–63.6167	39.9000	09/01/1936	–	–	250	346	
3528	–63.4333	26.1833	28/02/1935	–64.4500	79.4500	17/01/1937	Female	22.6	2526	689	
3598	–63.3833	8.3000	08/03/1935	–60.0000	32.0000	20/01/1948	–	–	1296	4701	
3771	–54.1833	–39.2500	04/12/1935	–54.8667	–32.6833	14/11/1936	Male	24.2	430	346	
3853	–56.1333	–36.0167	11/12/1935	–63.3667	–47.1167	07/03/1936	Female	22.6	1013	87	
4122	–57.2833	–33.9167	27/12/1935	–54.5667	–33.7000	30/12/1935	–	–	302	3	
4563	–55.3167	–36.6500	02/01/1936	–59.7333	–29.7667	02/02/1936	Male	22.9	639	31	
4843	–54.8667	–33.7333	18/01/1936	–55.2333	–34.2500	22/01/1936	–	–	52	4	
5245	–62.1333	87.6167	01/02/1936	–63.9167	87.4667	08/02/1936	Female	26.8	198	7	
5261	–61.9333	88.7000	01/02/1936	–61.8667	82.9500	02/01/1938	Female	25.9	301	701	
5456	–63.9500	99.3167	13/02/1936	–56.6333	12.3500	09/01/1948	Female	27.7	4474	4348	Pregnant
5525	–63.2500	94.3167	16/02/1936	–63.7333	94.4167	17/02/1936	Female	25.3	54	1	
5632	–63.7500	81.8500	22/02/1936	–57.3833	31.6667	20/12/1947	Female	–	2751	4319	Pregnant
5728	–63.8167	54.4000	02/03/1936	–56.8000	17.0333	08/01/1937	–	–	2161	312	
5800	–64.4000	45.8167	08/03/1936	–63.2333	72.3667	03/01/1938	Female	23.5	1299	666	
7705	–54.9000	24.8167	13/12/1936	–61.1167	20.8333	09/02/1937	Female	24.4	729	58	
8743	–64.8667	30.7000	13/02/1937	–55.5000	27.5000	15/12/1947	–	–	1055	3957	Uncertain
10427/10431	–55.8167	–0.2333	17/12/1937	–55.2000	–35.4000	24/02/1939	Female	22.1	2190	434	
10638	–58.8000	–31.3667	01/01/1938	–61.2500	–20.3500	09/01/1938	Male	22.9	668	8	
11354	–61.5000	54.8333	07/01/1953	–68.6333	17.2833	18/03/1954	–	–	1890	435	
12186	–56.4667	–6.9500	29/11/1953	–54.5000	–37.0000	23/03/1954	–	–	1889	114	
12362	–57.3667	–32.6000	23/12/1953	–60.0000	–41.0000	20/01/1954	–	–	566	28	Uncertain
12363	–57.6333	–32.7000	23/12/1953	–61.3000	–31.4333	16/02/1954	Male	23.2	414	55	
12391	–59.8833	–37.2500	10/12/1953	–68.3333	–15.5000	12/03/1954	Male	23.2	1399	92	
12438	–53.9167	8.6667	29/11/1954	–62.1000	–12.0000	21/02/1956	–	–	1508	449	
12770	–58.7833	42.2500	03/11/1955	–65.1833	82.3667	03/03/1957	Female	24.1	2168	486	
12777	–57.7667	39.9167	04/11/1955	–69.2167	17.0000	09/03/1957	–	–	1686	491	Uncertain
12826	–54.4000	24.5667	10/11/1955	–69.0000	4.0000	14/02/1957	–	–	1930	462	Uncertain
13147	–62.9500	–38.0333	16/11/1955	–65.0500	–26.8667	18/02/1956	–	–	591	94	
13400	–60.3167	55.2000	02/12/1957	–64.4000	48.8167	03/02/1959	Female	24.7	560	428	

Table A4. (*Continued*)

Code	Marked latitude	Marked longitude	Marked date	Recaptured latitude	Recaptured longitude	Recaptured date	Sex	Length at capture (m)	Distance (km)	Duration (days)	Notes
14645	–64.5000	–157.6833	05/01/1956	–68.2833	–125.8833	07/02/1958	Male	23.2	1458	764	Uncertain
14661	–62.7667	–127.0833	09/12/1955	–66.2667	–148.1167	17/02/1957	Female	22.9	1072	436	CL 0 EP 7
14730	–62.7833	60.0000	17/12/1955	–67.4000	–127.4167	22/02/1958	Male	22.3	5523	798	
15216	–59.4000	41.2167	02/11/1955	–61.6167	–8.1500	17/02/1956	Male	21.3	2646	107	
17406	–60.2500	139.0000	01/01/1957	–70.7167	161.1333	12/03/1959	Female	21.3	1529	800	
17629	–67.3000	–82.3333	22/12/1956	–67.7333	–89.9833	02/02/1957	Female	23.5	328	42	
17644	–65.7000	–85.3333	23/12/1956	–66.3333	–122.4167	02/02/1957	Female	23.2	1652	41	CL 0 EP7
17645	–65.4667	–87.8333	23/12/1956	–72.3333	–156.0000	18/02/1958	–	–	2665	422	
17745	–66.6500	–89.0667	03/01/1957	–66.2000	–95.7833	01/02/1957	Male	25	303	29	
17866	–65.8500	–92.6333	20/12/1956	–66.0000	–95.0000	01/02/1957	Male	24.7	109	43	
18027	–65.2000	–179.3167	02/12/1957	–65.8667	48.5667	22/03/1962	–	–	4943	1571	Uncertain
18085	–64.8833	–164.0667	04/12/1957	–67.1667	168.5833	14/02/1959	Female	25.6	1250	437	CL 19
18155/18194†	–65.5500	–80.8000	23/12/1957	–69.0167	–132.4000	08/02/1958	Female	21.9	2179	47	
18163	–65.5500	–80.8000	23/12/1957	–57.9000	87.7500	27/02/1962	Male	24.1	6250	1527	EP 12
18166	–65.4333	–81.0000	23/12/1957	–69.0000	–96.6333	23/02/1958	Male	22.3	778	62	
18235	–65.8833	–73.8667	02/01/1957	–67.5000	–128.3333	09/02/1957	–	–	2324	38	
18318	–64.2667	155.7333	30/12/1957	–63.7667	85.0667	12/02/1959	Male	21.9	3262	409	
18323	–64.0333	156.0333	30/12/1957	–67.6167	162.9167	09/02/1958	Male	22.9	506	41	
18981	–61.0833	–56.3333	20/12/1956	–67.3167	–132.7833	04/02/1957	Female	21.6	3516	46	CL 0
19705/19719	–60.2333	60.1667	21/12/1957	–63.5000	99.5000	15/02/1958	Female	20.7	2058	56	
19720/19728	–60.9500	57.8333	21/12/1957	–61.5167	70.0000	05/02/1959	Male	23.5	653	411	
19754	–61.3167	54.8333	22/12/1957	–64.2333	16.7667	02/02/1958	Female	–	1932	42	
19762	–60.8667	54.5000	24/12/1957	–66.0000	40.0000	15/02/1959	–	–	915	418	
19766	–60.9000	51.3667	23/12/1957	–64.7500	–15.7500	25/02/1958	–	–	3270	64	Uncertain

19768	−60.8667	54.5000	24/12/1957	−63.1167	94.4833	13/02/1958	Male	21.9	2067	51	
19772	−60.8500	54.4667	24/12/1957	−62.5000	84.5000	15/02/1958	–	–	1579	53	Uncertain
19792	−60.9833	55.2667	24/12/1957	−64.8500	19.8000	06/02/1958	Female	21.3	1819	44	
19798	−61.3167	55.6333	24/12/1957	−62.5000	84.5000	15/02/1958	–	–	1503	53	Uncertain
19799	−60.9833	55.4000	24/12/1957	−55.0833	35.3500	20/03/1962	–	–	1342	1547	
19834	−67.3000	171.1333	15/12/1957	−64.5000	136.0000	20/02/1959	Male	22.9	1601	432	
20512	−65.2000	157.0833	19/12/1958	−65.6667	139.8333	08/02/1959	Male	23.8	796	51	
20515	−65.2333	157.0333	19/12/1958	−64.4167	123.5000	13/02/1959	Female	23.8	1569	56	EP 7
22321	−63.0667	137.0167	16/12/1959	−57.3333	95.6667	04/02/1960	Male	22.9	2325	50	EP 11
22543	−59.3333	83.7667	22/12/1959	−58.8500	73.5333	04/02/1960	Male	21.9	586	44	EP 11
24027	−55.7667	80.2167	15/12/1960	−60.8500	38.9167	>05/03/1962	–	–	2432	>445	'1961/62'
24535	−58.9667	38.6000	19/12/1960	−67.1333	−3.5833	21/02/1961	Female	24.7	2254	64	
25576	−56.2500	49.0500	01/12/1962	−43.9167	50.0333	04/04/1963	Male	21.5	1372	124	Pygmy, testes 16.0 kg, 14.5 kg
25605/25607	−59.3833	66.7667	23/11/1962	−54.5833	36.4333	05/03/1964	Female	24.2	1894	468	CL0EP10
G01111	−63.0000	25.7500	18/02/1939	−63.8333	33.6667	12/01/1940	Male	19.5	404	328	
G01201	−59.0000	30.0000	07/12/1938	−64.9000	62.3833	02/01/1951	Female	27.4	1790	4409	Pregnant
G01305	−60.8333	31.8333	31/12/1938	−60.4000	30.5167	02/01/1939	–	–	86	2	
G01306	−65.0000	35.0000	09/02/1939	−65.4500	28.1500	06/03/1939	–	–	323	25	
G01309	−59.4167	33.8333	06/12/1938	−61.4000	36.9000	20/12/1938	Female	25.3	277	14	
G01370	−65.2333	35.0000	26/02/1939	−65.4500	28.4833	06/03/1939	–	–	303	8	
USSR-25601	−59.3833	66.7667	23/11/1962	−63.5000	26.0833	02/01/1967	Male		2170	1501	
USSR-25608	−59.3833	66.7667	23/11/1962	−63.6167	26.1667	02/01/1967	Female		2164	1501	
USSR-25619	−59.1333	68.3333	23/11/1962	−59.6000	54.3667	10/01/1963	Female		791	48	

*Mark latitude of 1229 was −54.6500.
†Mark longitude of 18194 was −80.8333.
CL, corpora lutea count; EP, ear plug laminae.

APPENDIX 5

List of sources for acoustic detections of blue whales in the study region. The reference, region (positions rounded to whole degrees), call type, recording method and dates are listed. Where sources are 'unpubl.' this is shorthand for 'unpublished data'.

Source	Region	Call type	Recording method	Recording duration	Dates calls recorded
Alling *et al*. (1991)	East coast, Sri Lanka	Sri Lanka	Dipping hydrophone	Feb–Apr 1984	Feb–Apr 1984
C. W. Clark & A. R. Martin, pers. comm.	South Georgia 54°S 38°W	Antarctic	Moored instrument	4–5 Apr 2004	4–5 Apr 2004
Cummings & Thompson (1971)	Guafo Island, Chile	South-east Pacific	Dipping hydrophone	30–31 May 1970	30–31 May 1970
Ensor *et al*. (1999), Clark & Fowler (2001)	Antarctica Areas III, IV	Antarctic	Sonobuoy	Jan–Feb 1999	10, 15, 25 Jan; 4, 9, 21 Feb 1999
Ensor *et al*. (2000), D. Ljungblad, unpubl.	Antarctica Area I 67–71°W	Antarctic	Sonobuoy	Jan–Feb 2000	26 Jan; 11 Feb 2000
Ensor *et al*. (2004)	Antarctica Area V 175°W–175°E	Antarctic	Sonobuoy	Jan–Feb 2004	19 Jan; 7–21 Feb 2004
Ensor *et al*. (2006)	Antarctica Area III 0–20°E	Antarctic	Sonobuoy	18 Jan–13 Feb 2006	18 Jan–13 Feb 2006
Kibblewhite *et al*. (1967)	Three Kings Island, New Zealand	New Zealand	Moored instrument	1 day; date unknown	Unknown
Ljungblad *et al*. (1998)	Antarctic area II	Antarctic	Sonobuoy	7 Jan–26 Feb 1997	29–30 Jan 1997
Ljungblad *et al*. (1998)	Madagascar Plateau 25–35°S 40–45°E	Madagascar	Sonobuoy	7–28 Dec 1996	28 Dec 1996
McCauley *et al*. (2004)	Cape Leeuwin, Australia	Antarctic	Moored instrument	Oct 2002–Jul 2004	May–Oct 2002–04
McCauley *et al*. (2004)	Cape Leeuwin, Australia	Australian	Moored instrument	Oct 2002–Jul 2004	Nov–Jun 2002–04
R. D. McCauley, unpubl.	Bass Strait 40°S 145°E	New Zealand	Moored instrument	Mar–Aug 2002	Jun 2002
R. D. McCauley, unpubl.	Bass Strait 40°S 145°E	Australian	Moored instrument	Mar–Aug 2002	Jun 2002
R. D. McCauley, unpubl.	Robe, South Australia 37°S 140°E	Australian	Moored instrument	Nov 2004–Jun 2005; Nov 2005–Jun 2006	Jan–Apr 2005–06
R. D. McCauley, unpubl.	Perth Canyon, Australia 32°S 115°E	Australian	Moored instrument	Jan 2000–Dec 2005	Nov–Jun, 2000–05
R. D. McCauley, unpubl.	Exmouth, Australia 21°S 114°E	Australian	Moored instrument	Oct 2003–Oct 2004	Nov–Dec 2003, Jun 2004
McKay *et al*. (2005)	East Antarctica 67°S 70°E	Antarctic	Moored instrument	Feb 2003–Jan 2004	Year-round but peaks Apr–Jun, Nov
McDonald (2006)	North Island, New Zealand	Antarctic	Moored instrument	Jan–Dec 1997	May–Jul 1997

McDonald (2006)	North Island, New Zealand	New Zealand	Moored instrument	Jan–Dec 1997	Once each in Jun, Jul, Sep, Dec 1997
T. F. Norris, unpubl.	Islas Lobos De La Fuera, Peru	South-east Pacific	Sonobuoy	2–3 Nov 2000	2–3 Nov 2000
Rankin *et al*. (2005)	Antarctic area V 150°E–170°W	Antarctic	Sonobuoy	6–8, 21, 29, 31 Jan 2002	6–8, 21, 29, 31 Jan 2002
Rankin *et al*. (2005)	Antarctic area V 130°E–150°E	Antarctic	Sonobuoy	23–24 Jan 2003	23–24 Jan 2003
Samaran *et al*. (2006)	Crozet Island	Antarctic	Moored instrument	May 2003–Apr 2004	Unknown
Samaran *et al*. (2006)	Crozet Island	Madagascar	Moored instrument	May 2003–Apr 2004	Unknown
Širović *et al*. (2004)	Western Antarctic Peninsula	Antarctic	Moored array	Mar 2001–Feb 2003	Year-round but peaks Mar–Apr, Oct–Nov
Stafford *et al*. (1999)	Eastern tropical Pacific 8°S 95°W	South-east Pacific	Moored instrument	May 1996–May 1997	Year-round but peaks Mar–Aug
Stafford *et al*. (1999)	Eastern tropical Pacific 8°S 95°W	Antarctic	Moored instrument	May 1996–May 1997	Jul 1996
Stafford *et al*. (2004)	Eastern tropical Pacific 8°S 95°W	Antarctic	Moored instrument	May 1996–Nov 2002	Jun–Sep, peaks in Jul
Stafford *et al*. (2004)	Indian Ocean Diego Garcia	Antarctic	Moored instrument	Jan 2002–Apr 2003	May–Aug, peaks in Jul
Stafford *et al*. (2004)	Indian Ocean Cape Leeuwin	Antarctic	Moored instrument	Jan 2002–Apr 2003	May–Nov, peaks in Jul
Stafford *et al*. (2005)	Indian Ocean Diego Garcia	Madagascar	Moored instrument	Jan 2002–Apr 2003	May–Jul, peak in Jul
Stafford *et al*. (2005)	Indian Ocean Diego Garcia	Sri Lanka	Moored instrument	Jan 2002–Apr 2003	May–Jan
Stafford *et al*. (2005)	Indian Ocean Cape Leeuwin	Australia	Moored instrument	Jan 2002–Apr 2003	Dec–Jun