Report of review group of data sources on odontocetes in the Southern Ocean in preparation for IWC/CCAMLR workshop in August 2008

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INTRODUCTION

One of the steps identified in preparing for the joint IWC-CCAMLR workshop to review input data required for the development of ecosystem models for the Antarctic marine ecosystem was to summarise available data on odontocetes. The steering group identified the following types of data as relevant to models

(a) population - biomass/numbers in different regions of the Southern Ocean, trends in abundance, population structure, including age/size/spatial structure;

(b) habitat utilisation ï movement, key habitats and environmental variables (drivers of key population processes), foraging areas;

(c) population growth rates ï growth of individuals, reproductive output, recruitment, mortality rates, density-dependent processes;

(d) foraging activities ï diet, foraging success, consumption rate, competition;

(e) catch ï biomass/numbers taken and size structure in different regions over time.

There is generally less information on the odontocetes of the Southern Ocean than the baleen whales. For example with respect to obtaining abundance estimates from visual surveys, for a number of species, analyses are made more complex because the behaviour of the animals violates the assumption that all animals directly on the trackline will be detected (e.g. due to the long dive times and often inconspicuous surface behaviour of beaked whales and sperm whales) and by the likelihood that some species (e.g. hourglass dolphins) may show considerable responsive movement.

In a systematic review of odontocetes of the Southern Ocean, Van Waerebeek *et al.* (2004) identified 28 species as occurring with 22 species showing a regular, apparently year-round, presence. Based on this review and the frequencies of sightings, a list of species that appear potentially ecologically important south of the CCAMLR boundary (between 45^{o}S and 60^{o}S depending on longitude) would be:

Sperm whale *Physeter macrocephalus*
Killer whale *Orcinus orca*
Southern long-finned pilot whale *Globicephala melas edwardii*
Hourglass dolphin *Lagenorhynchus cruciger*
Southern bottlenose whale *Hyperoodon planifrons*
Arnouxôs beaked whale *Berardius arnuxii*
Strap-toothed beaked whale *Mesoplodon layardii*
Grayôs beaked whale *Mesoplodon grayi*

All of these have a circumpolar distribution although with some longitudinal gaps in the case of pilot whale and hourglass dolphin, and very limited data for Arnouxôs, strap-toothed and Grayôs beaked whales. This list was compiled on the basis of overall numbers of reported sightings. Species whose distribution is concentrated in areas which tend to have poor sightings conditions or that are relatively inconspicuous, will be under-represented. For example, the spectacled porpoise *Phocoena dioptrica,* appears to have a particularly low probability of being seen.

In revising Van Waerebeek *et al.* (2004) for publication, data collected from the IWC IDCR SOWER cruises will be taken fully into account. An example distribution map is given as Fig. 1. It is hoped that the revised version of the paper will be available for the CAMMLR/IWC Workshop.

ABUNDANCE, TRENDS AND DISTRIBUTION DATA

The IDCR/SOWER data set is one of the most comprehensive sets of surveys in the region and a potential source of abundance estimates and possibly also trends. Some circumpolar abundance estimates for odontocetes have been generated using these data (Kasamatsu and Joyce, 1995; Branch and Butterworth, 2001a). However, both papers note a number of caveats to their estimates. The most recent IDCR/SOWER estimates are given in Table 1 from (Branch and Butterworth, 2000; 2001a). The recent discussions of Antarctic minke whale estimates have also highlighted further issues that may need to be considered (summarised in Branch, 2007).

A general issue is whether an estimate for the whole population is required or whether the estimate is just used as an indication of numbers within a specified area at a certain time of the year. For some species, estimates of summer abundance in Antarctic waters may represent close to the entire population whereas for others it would only be a small fraction. The sperm whale is perhaps the most extreme case with generally only large males occurring south of the Polar Front. The degree to which this is important will depend on the nature of the modelling exercise envisaged.

In addition to completed analyses, there are a number of datasets that are relevant to abundance and distribution that could be analysed further. These include IDCR/SOWER (Table 2), JARPA (Table 3), IWC/CCAMLR krill survey in 2000, Southern Ocean Cetacean Ecosystem Program, IWC-Southern Ocean Collaboration, and systematic observations from platforms of opportunity. Tables 4 and 5 are taken from Van Waerebeek *et al*. (2004) and list Southern Ocean Cetacean Ecosystem Program and IWC-Southern Ocean Collaboration cruises respectively. Table 6 lists passive acoustic surveys for sperm whales and identifies where these have generated density estimates. Smith *et al.* (2005) note the efficiency of acoustic surveys for sperm whales and that these are likely to become the norm in the future. This is particularly the case in the Southern Ocean where complications related to large groups do not arise and visual sighting conditions are often difficult. Ongoing studies to evaluate the efficiency of acoustic methods for beaked whales may also allow acoustic surveys for these species in the future. Van Waerebeek *et al*. (2004) reviewed estimates of sperm whale density and abundance from a number of sources (Whitehead, 2002; Branch and Butterworth, 2001a; Gillespie, 1997; Leaper *et al*., 2001) and found them all to be broadly consistent, with regional estimates of sperm whale density between 0.13 and 0.73 sperm whales per 1,000km^2 and mean circumpolar estimates between 0.29 and 0.65 sperm whales per 1,000km^2 (if corrections are made for g(0)). The Whitehead (2002) estimates were based on densities from a variety of different abundance surveys, extrapolated to larger areas including an estimate of current sperm whale numbers worldwide.

Considerations for estimates from IDCR/SOWER

Based on previous analyses and Branch (2007), the following is a draft list of factors that would need to be considered prior to further analyses of IDCR/SOWER data for generating estimates of odontocete abundance or trends for use in ecosystem models relevant to the IWC/CCAMLR workshop.

Uncertainty in the proportion of animals directly on the trackline that are detected, g(0)

The assumption of *g*(0)=1 is clearly not valid for many odontocete species but particularly the deep diving species whose dive duration can exceed the time for which they may be in detection range (particularly sperm and beaked whales. Kasamatsu and Joyce (1995) used a model of diving behaviour to estimate *g*(0) for sperm whales (0.32), beaked whales (0.27), killer whales (0.96) and pilot whales (0.93). These estimates are probably unreliable to some extent, given that *g*(0) for Antarctic minke whales is estimated to be 0.91 using the same method (Kasamatsu, 2000), but current *g*(0) estimates for minke whales are 0.61 (CV = 0.11) (Okamura *et al*., 2005). Although there may be some potential to account for perception bias (the proportion of animals that are available that are not detected) in the IDCR/SOWER dataset, there is no way of accounting for availability bias (animals which do not come to the surface within the detection range) directly from the data. Although considerably more data have been gathered on sperm whale and beaked whale diving behaviour over the last decade, there have been few studies in the Southern Ocean and there seems limited scope for much refinement of the Kasamatsu and Joyce estimates of *g*(0). However, there have been methodological developments (e.g. Okamura, 2003). Nevertheless, this method still requires an estimate of mean surfacing rate that is independent of the line transect survey. All estimates will be sensitive to temporal and spatial variation in diving behaviour.

Identification to species level

This is primarily relevant to beaked whale species. Branch and Butterworth (2001a) note that in the three sets of circumpolar only 5%, 60% and 71% respectively of the beaked whale sightings were identified to species level. The changes in the attention given to species identification of beaked whales will have particular importance for estimates of the less common species. Branch and Butterworth (2001a) just produced estimates for southern bottlenose whales whereas Kasamatsu (2000) pooled all ziphiids into one group. Other species that have been identified include Arnouxθs, Cuvierθs, Grayθs and Layardθs beaked whales, but average sighting rates for each of these species are around one group a year or less. Again, depending on the nature of the modelling exercise envisaged, a number of approaches could be considered. For example, one possibility is to obtain estimates for all ziphiids combined, and then divide these among each species in proportion to the sighting rates seen for each species (Branch and Butterworth 2001a). This, of course, implies that the relative proportions of the species have remained constant over time. Other possibilities could also be developed depending on the modelling requirements.

Group size estimation
Whilst this potentially affects all odontocetes, it is probably a minor issue for the sperm whale. Previous analyses showed that minke whale school size estimates in passing mode were negatively biased compared to closing mode by about 30% (Branch, 2007). For less frequently sighted species that can occur in large schools, schooling behaviour will have a large effect on the variance of estimates. Changes between protocols for passing mode and closing mode should be investigated and comparison with similar surveys elsewhere that have investigated schools size estimation issues more closely for the smaller cetaceans may be valuable.

Responsive movement
Hourglass dolphins frequently show attraction to vessels (R. Leaper, pers. obs). This could potentially result in large positive biases in abundance. Similar issues have been found in other waters (e.g. common dolphins in the northeastern Atlantic (Canadas *et al,* 2007) who found that estimates ignoring responsive movement were positively biased by a factor of 5). Other species may potentially respond by coming to the surface (also causing positive bias in relation to model based g(0) estimates) or by avoiding vessels (causing negative bias). It may be possible to examine this at least qualitatively for certain species by examining the information on swimming direction recorded at the time of the sighting where available or by comparison with other surveys where appropriate data have been collected.

Mixed schools
Codes for mixed schools were used up until 1993/94 and mainly affect sightings of killer whales and hourglass dolphin (7.2 and 8.3% of sightings respectively). On subsequent surveys, mixed schools were recorded as separate sightings (Branch and Butterworth, 2001a). This is a minor issue for sperm whales.

Timing of surveys
The timing of surveys from 1994/95 to 2000/01 was later than in earlier years (Branch, 2007). Kasamatsu and Joyce (1995) suggested that most odontocetesô occurrence peaked in January apart from the hourglass dolphin whose occurrence appeared to be still increasing in February.

Changes in latitudinal coverage
The first (CPI) and second (CPII) surveys did not cover the full latitudinal range from the ice edge north to 60°S (Branch and Butterworth 2001b, Matsuoka *et al*. 2003). Comparisons of distribution and abundance between circumpolar series would need to be considered on a species by species basis, taking into account the gaps in survey coverage and what is known about distribution patterns.

Changes in the location of the ice edge and the proportion of animals south of the ice edge
This issue appears to particularly affect killer whales in CPI in that one vessel followed the ice edge in that year. This may explain why the killer whale estimates in Branch and Butterworth (2001a) were more than three times higher for CPI than for CPII and CPIII. An additionally complexity related to this issue (and indeed some other issues such as school size estimation) and killer whale abundance estimates is the existence of three types of killer whales in the Antarctic, which appear to respectively specialize on minke whales, other marine mammals and fish (Pitman and Ensor, 2003). The smaller, fish-eating form most closely associated with the pack ice is found in huge schools, unlike the other two types.

Analyses of odontocetes could draw on some of the investigations of changes in ice edge that have been conducted with regard to the Antarctic minke whale estimates.

Considerations for estimates from JARPA

The JARPA (the Japanese Whale Research Program under Special Permit in the Antarctic) program provides a long-term data set from primarily the Indo-Pacific region (35ºE-145ºW) of the Antarctic (south of 60ºS). The data have been used to obtain abundance estimates and trends for sperm and beaked whales as well as estimates of biomass (Matsuoka *et al*., 1998a, b and Matsuoka *et al*., 2005). JARPA has been conducted in the Indian sector (35ºE-130ºE) and the Pacific sector (130ºE-145ºW) in alternate years since 1987/88 season, and thus in principle the data set can be used to investigate trends in abundance in those regions. The sighting survey methods of JARPA are almost the same as in the IDCR/SOWER, the same consideration referred to above with respect to the IWC IDCR/SOWER datasets are relevant to interpretation of abundance and trend estimates from JARPA; in addition, the Scientific Committee has identified certain JARPA-specific caveats. These are summarised below.

Uncertainty in the proportion of animals detected directly on the trackline , g(0)
Matsuoka *et al*., 1998(a ,b), and Matsuoka *et al.* (2005) used the same assumption of g(0) as Kasamatsu and Joyce (1995). The limitations of this have been discussed in the context of the IDCR/SOWER dataset.

Identification to species level
Matsuoka *et al*., 1998(a, b) pooled all ziphiids into one group as did Kasamatsu (2000).

Group size estimation
The limitations of this have been discussed in the context of the IDCR/SOWER dataset.

Responsive movement
The limitations of this have been discussed in the context of the IDCR/SOWER dataset.

Mixed schools
No mixed schools were reported in Matsuoka *et al*., 1998(a, b) and Matsuoka *et al*. (2005)

Timing of surveys
The JARPA sighting surveys were mainly conducted in January and February and thus the general effects of the timing of the survey on abundance estimation should not be substantial although timing of surveys within the survey area (e.g. timing surveys among strata) was slightly different from year to year. The level of any effect these latter changes may have on the estimation of abundance trends of Antarctic minke whales has been discussed but not resolved yet by the Scientific Committee (e.g. IWC, 2008). This issue is also of relevance to estimates of odontocete abundance trends.

Changes in the location of the ice-edge and the proportion of animals south of the ice-edge
The limitations of this have been discussed in the context of the IDCR/SOWER dataset.

Japanese Scouting Vessel (JSV) data
The seasonal and geographical distribution maps of two toothed whales (sperm and killer whales) using the JSV data were presented in Miyashita *et al.* (1995). Data were presented as number of individuals per 10,000 n.miles sighting effort at a scale of 5 by 5 latitudinal-longitudinal grid size. The JSV data in the Southern Hemisphere were collected by the National Research Institute of Far Seas Fisheries (NRIFSF). The JSV data consist of data obtained from Japanese Scouting Vessels (Japanese whaling fleet scouting vessels from 1965/66 to 1975/76, and from systematic sighting surveys from 1976/77 to 1987/88 including IWC/IDCR cruises (from 1978/79 to 1987/88). Data collection by Japanese whaling fleet scouting vessels started in the 1965/66 Antarctic seasons (Miyashita *et al.*, 1994; Ohsumi and Yamamura, 1982), and ended in March 1988 because of the pause of commercial whaling. The survey areas of these cruises were decided by fleet commanders. Areas with expectation of high density of target species of commercial whaling were usually selected. The vessels were usually allowed to modify their tracklines according to the observed oceanography and whale distribution. These sighting data are recorded to each daily noon position. Primary and secondary sightings are not recorded separately. No sighting distance and the angle are available. Systematic sighting survey started in the 1976/77. In principle, vessels in systematic sighting survey steamed on tracklines predetermined by the scientists, but the line transect method of IWC/IDCR southern hemisphere minke whale assessment cruise has been fully implemented since 1982 (Hiby and Hammond, 1989). The JSV data can be used to extrapolate abundance estimates north 60^{o}S where little survey effort has been conducted in recent years. For example, Butterworth *et al.* (1992) used the JSV data for abundance estimation of large baleen whales by using sightings rates from JSV as an index of relative density, adjusted for absolute density using IDCR/SOWER data where the two data sets covered a comparable area.

Other data from localised studies and platforms of opportunity
Other data sets with visual observations of odontocetes include a sequence of cruises by Greenpeace vessels described in Pierpoint *et al*. (1997), SC/52/O9 and SC/53/SM8. Systematic observations have been made in more recent years including 2008 but have not yet been analysed (L. Goncalves, unpublished data).

Line transect surveys were conducted in a limited area around Heard Island (53°S, 74°E) in Jan-Feb 1991 as part of monitoring related to ATOC experiments (Bowles *et al*., 1994). Observations were also made on passages from Fremantle to Heard Island and from Heard Island to Cape Town (Ann Bowles, unpublished data).

There are also sequences of cruises with systematic observations as part of a number of national Antarctic research programmes. This has included surveys by British Antarctic Survey vessels around South Georgia (Leaper *et al*., 1999; Reid *et al*., 1999) and from the German RV Polarstern around the Antarctic Peninsula (Pankow and Kock, 2000). Williams *et al*. (2006) also reports on a sequence of cruises from Antarctic cruise ships that included observations of odontocetes.

Killer whales were reviewed at the 2007 Scientific Committee meeting (IWC, 2008). During the review, information from the Southern Ocean was provided for Macquarie island (Morrice, 2007), Possession Island (Crozet archipelago) (Roche *et al*., 2007), Terra Nova Bay in the Ross Sea (Fortuna *et al*., 2007), the Antarctic Peninsula (Dalla Rosa *et al.,* 2007) and on a wider scale using ships of opportunity (Visser *et al*., 2007).

POPULATION MODELS AND LIFE HISTORY DATA

The only Southern Ocean odontocete species for which life history data are available are the southern bottlenose whale, the killer whale and the sperm whale. Some aspects of biology of southern bottlenose whale were examined by Zemskii and Budylenko (1970). During the 2007 review, the Scientific Committee conducted noted that in general little is known about the life history of killer whales in the Southern Ocean (IWC, 2008) although some information was available from Soviet catches (Mikhalev, 1981).

Southern Hemisphere sperm whales have not been examined by the Scientific Committee since the early 1980s. Inputs to population models for sperm whales were reviewed at the International Cachalot Assessment Research Planning Workshop (Smith *et al*., 2005). It was noted that the old model used by the SC based on a required ratio of 2 males to 15 females to maintain pregnancy rates failed to match observed trends in pregnancy rates, either qualitatively or quantitatively. Thus it remains an open question how the greater depletion of males by commercial whaling should be treated in population models. Other discussions at the workshop on studies showing large inter-reader variability in growth layer groups (GLG) in sperm whale teeth, suggested that used of age data from GLG counts must take this into account.

FEEDING ECOLOGY

Odontocete feeding ecology in the Southern Ocean is more complex than for krill specialists, in that it involves a greater variety of prey species, many of which are poorly known. Van Waerebeek *et al.* (2004) briefly review what is known about diet on a species by species basis. With the exception of the killer whale, the overall diet of odontocetes in the Southern Ocean is dominated by squid. However, hourglass dolphins and sperm whale are known also to prey on fish species. Kock *et al.* (2005) note that sperm whales feed on Patagonian toothfish (*Dissostichus eleginoides*) north and south of the Southern Polar Frontal Zone and Antarctic toothfish (*Dissostichus mawsoni*) have also been described being taken by sperm whales. Pitman and Ensor (2003) suggest three different eco-types of killer whales specialising on different prey (minke whales, other marine mammals or fish. Abundance estimates cannot be generated separately for each ecotype at the present since nearly all of the surveys did not distinguish between the subspecies. Some initial attempts are made in Branch and Williams (2006) but these are quite crude. Recent mtDNA evidence suggests these ecotypes are genetically distinct (LeDuc *et al.* 2008).

Clarke *et al.* (1981) suggested that sperm whales play a significant role in the feeding ecology of albatrosses, particularly wandering albatross (*Diomedea exulans*), by regurgitating deep water squid which then become available at the surface.

Several studies have attempted to estimate prey consumption for some odontocete species in the Southern Ocean. For example, Kasamatsu and Joyce (1995) estimated that on a circumpolar basis, beaked whales accounted for 67% of odontocete consumption of squid and sperm whales 22%, although they recognised the considerable uncertainty inherent in their analysis. However, the range of values estimated by Santos *et al*. (2001) for sperm (3.4-9.2 million tons) and beaked whales (1.6 - 5.3 million tons) overlapped, but with sperm whales having the higher values. Hindell *et al*. (2003) provide some comparisons of consumption of cephalopods by pinnipeds with that consumed by odontocetes. Rodhouse (1997) included sperm whale, southern bottlenose whale and long-finned pilot whale as significant cephalopod predators when considering the potential fishery for an ommastrephid squid *Martialia hyadesi* in the SW Atlantic. All these studies note limitations in both abundance estimates and data on diet. Other issue that require further consideration include seasonal differences in consumption rates and whether energy is stored during periods of high feeding intensity.

Further details on the feeding ecology of sperm whales, long-finned pilot whales

EXPLOITATION

Sperm whales were systematically exploited in the Southern Ocean during the 20th Century. Van Waerebeek *et al*. (2004) note that prior to 1933, annual takes were less than 100 animals. However, catches rose quickly and by 1939 annual catches were around 2,500. After a reduction in catches in the early 1940s due to the war, whaling increased again in the 1950s with average annual takes around 6,000 sperm whales up until zero catch limits were introduced in the Southern Hemisphere from the 1981/82 season. The available 20th century catch data are included in the IWC catch database and are believed largely to be complete (Smith *et al.* 2005). Although some mis-reporting and falsification of catches have occurred, Southern Hemisphere catch records have largely been corrected in the database. The total true Soviet catch of sperm whales in the Southern Hemisphere was 89,493 compared to a reported figure of 74,834 (Yablokov *et al*. 1998, Clapham and Baker 2002). The total estimated 20th century catch for the Southern Hemisphere including the revised Soviet data was estimated by Clapham and Baker (2002) at 395,000 sperm whales.

Some other odontocete species were exploited, particularly southern bottlenose whale, and Arnoux¢s beaked whale (often collectively referred to as ôbottlenose whalesö) but takes were relatively small and largely opportunistic. Killer whales were also taken although they were not a primary target for pelagic whaling fleets in the Southern Ocean. Soviet takes increased substantially in 1979/80. The USSR reported a total of 906 killer whales (447 males and 459 females) taken between 18 January 1980 and 21 March 1980 (USSR, 1981) compared to a total take of 738 between 1953/54 and 1978/79 (Mikhalev *et al*., 1981). The killer whales were taken between140°E-60°E. In 1981, the Scientific Committee recommended that catch limits for Antarctic killer whale stocks be zero due to a lack of knowledge about their abundance and dynamics (IWC, 1981).

DISCUSSION AND RECOMMENDATIONS

The main aim of this paper was to summarise sources of data and associated caveats. In addition it is hoped to promote discussion at the 2008 SC meeting for steps that could be taken to provide the most useful input to the IWC-CCAMLR workshop. Further analysis of IDCR/SOWER data have been identified as potentially valuable and it is hoped that the Committee can provide some guidance on the best approach taking into account discussions regarding minke whale estimates over the last few years. JARPA is another data source, especially in Indo-Pacific region (35ºE-145ºW) of the Antarctic, because these surveys have been conducted in Indian sector and the Pacific sector in alternate years since the 1987/88 season, For specific modelling purposes there may be a need to generate regional abundance estimates and these would benefit from agreement on a consistent approach. Updating odontocete estimates from the IDCR/SOWER cruises including beaked whales by species and hourglass dolphin would also be an obvious next step.

The Committee also made some recommendations with regard to killer whales in 2007 including the recommendation that the Secretariat contacts CCAMLR and requests a compilation of data on killer whale occurrence and fisheries interactions from their observer reports and supply those for consideration to the IWC (IWC/59/Rep1).

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Table 1. Circumpolar odontocete abundance estimates and associated 95% CI, and density estimates and their associated 95% CI for the IDCR-SOWER surveys. All figures from Branch and Butterworth (2001a) except for hourglass dolphin which are from Branch and Butterworth (2000) but were excluded from the resulting published paper due to concerns about their validity. Estimates are given for the surveyed areas described in Branch and Butterworth (2001a).

Species	CP set	N	CV	N CI lower	N CI upper	Area (km^2)	Density ($N.km^{-2}$)	D CI lower	D CI upper	Notes
Sperm whales	CPI	5,367	0.38	2,600	11,100	5,365,172	0.00100	0.00048	0.00207	
Sperm whales	CPII	10,450	0.15	7,800	14,000	6,293,587	0.00166	0.00124	0.00222	
Sperm whales	CPIII	8,329	0.16	6,100	11,400	8,126,611	0.00102	0.00075	0.00140	CPIII only to 1997/98
Killer whales	CPI	91,310	0.34	48,000	175,000	5,365,172	0.01702	0.00895	0.03262	
Killer whales	CPII	27,168	0.26	16,600	44,400	6,293,587	0.00432	0.00264	0.00705	
Killer whales	CPIII	24,790	0.23	15,900	38,700	8,126,611	0.00305	0.00196	0.00476	CPIII only to 1997/98
Southern bottlenose whales	CPI	NA	NA	NA	NA	5,365,172	NA	NA	NA	Not identified to species
Southern bottlenose whales	CPII	71,560	0.13	56,000	91,400	6,293,587	0.01137	0.00890	0.01452	
Southern bottlenose whales	CPIII	53,743	0.12	42,400	68,100	8,126,611	0.00661	0.00522	0.00838	CPIII only to 1997/98
Hourglass dolphins	CPI	52,959	0.82	13,000	215,000	5,365,172	0.00987	0.00242	0.04007	
Hourglass dolphins	CPII	110,065	0.56	40,000	305,000	6,293,587	0.01749	0.00636	0.04846	
Hourglass dolphins	CPIII	51,646	0.54	19,000	139,000	8,126,611	0.00636	0.00234	0.01710	CPIII only to 1997/98

Table 2. Summary of IDCR/SOWER cruises from 1978/79 to 2006/2007.

Survey	Season	IWC Area	Longitude	Cruise dates		Days	Vessels
CPI	1978/79	IV	70E-130E	1978/12/12	1979/2/14	65	2
CPI	1979/80	III	0-70E	1979/12/20	1980/2/21	64	2
CPI	1980/81	V	130E-170W	1980/12/17	1981/2/12	58	3
CPI	1981/82	II	60W-0	1981/12/19	1982/2/14	58	3
CPI	1982/83	I	120W-80W	1982/12/30	1983/2/26	59	3
CPI	1983/84	VI	170W-120W	1983/12/29	1984/3/1	64	4
	1984/85	IV	70E-130E	1984/12/21	1985/3/1	71	4
CPII	1985/86	V	130E-170W	1985/12/18	1986/2/24	69	4
CPII	1986/87	II	60W-0	1986/12/27	1987/2/20	56	4
CPII	1987/88	III	0-70E	1987/12/11	1988/2/8	60	2
CPII	1988/89	IV	70E-130E	1988/12/21	1989/2/20	62	2
CPII	1989/90	I	120W-80W	1989/12/26	1990/2/19	56	2
CPII	1990/91	VI	170W-120W	1990/12/29	1991/2/23	57	2
CPIII	1991/92	V	130E-170W	1991/12/21	1992/2/17	59	2
CPIII	1992/93	IIIW	0-40E	1992/12/17	1993/2/16	62	2
CPIII	1993/94	I	110W-80W	1993/12/23	1994/2/21	61	2
CPIII	1994/95	IIIE, IV W	40E-80E	1995/1/5	1995/3/6	61	2
CPIII	1995/96	VIW	170W-140W	1996/1/6	1996/3/4	59	2
CPIII	1996/97	IIE	30W-0	1997/1/7	1997/2/26	51	2
CPIII	1997/98	IIW	60W-25W	1998/1/14	1998/2/26	44	2
	1998/99	IV	80E-130E	1998/12/31	1999/3/1	61	2
	1999/00	IE, IIW	80W-55W	2000/1/6	2000/2/18	44	2
	2000/01	VIE, IW	140W-110W	2001/1/5	2001/3/5	60	2
	2001/02	VW	130E-150E	2001/12/20	2002/2/18	60	2
	2002/03	VE, VW	150E-170W	2002/12/17	2003/3/3	77	2
	2003/04	VE	170E-170W	2003/12/19	2004/3/8	81	2
	2004/05	III	0-70E	2004/1/4	2005/3/9	64	2
	2005/06	IIIW	0-20E	2005/12/22	2006/2/25	66	1
	2006/07	IIIW	0-20E	2006/12/21	2007/2/23	65	1

Surveys grouped together as CPI, CPII and CPIII refer to abundance estimates in Table 1. The areas south of 60°S covered by the surveys was 65%, 81% and 68% for CPI, CPII and CPIII respectively. Subsequent analyses using later surveys as part of CPIII apply to 100% of the area south of 60°S.

Table 3. Summary of JARPA cruises from 1987/1988 to 2004/2005. The survey is still on going after 2004/2005. All surveys were conducted south of 60ºS.

Season	Surveyed area	Research period	Research days	# of sighting vessels
1987/1988	70E-130E	Jan-Mar	70	2
1988/1989	130E-165W	Jan-Mar	79	3
1989/1990	70E-130E	Dec-Mar	97	3
1990/1991	130E-165W	Dec-Mar	94	3
1991/1992	70E-130E	Dec-Mar	112	3
1992/1993	130E-165W	Dec-Mar	112	3
1993/1994	70E-130E	Dec-Mar	107	3
1994/1995	130E-165W	Dec-Mar	109	3
1995/1996	35E-130E	Nov-Mar	118	4
1996/1997	130E-145W	Nov-Mar	103	4
1997/1998	130E-145W	Dec-Mar	98	4
1998/1999	130E-145W	Jan-Mar	78	4
1999/2000	130E-145W	Dec-Mar	97	4
2000/2001	130E-145W	Dec-Mar	100	4
2001/2002	130E-145W	Nov-Mar	100	4
2002/2003	130E-145W	Dec-Mar	97	4
2003/2004	130E-145W	Nov-Mar	95	4
2004/2005	130E-145W	Dec-Mar	92	4

Table 4. SOCEP (Southern Ocean Cetacean Ecosytem Program) East Antarctica collaborative cruises 1995/96 ï 2003/04 and tourist vessel cruises with experienced observer on board (From Van Waerebeek *et al*., 2004).

Vessel/cruise acronym	**Cruise dates**	**Purpose**
V7 2003/04 *Aurora Australis*	17 Feb ï 12 March 2003	Casey resupply and passive acoustic mooring pick-up
V3 2003/04 *Aurora Australis*	2 ï 16 Dec 2003 and 26 Feb ï 6 March 2004	Heard Island transits
V4 2002/03 *Aurora Australis*	3 Jan ï 18 March 2003	Fine scale krill survey
V7 2001/02 *Aurora Australis*	26 Jan 2002 ï 8 March 2003	Amery Ice Shelf sea ice and oceanographic study
V6 2000/01 *Aurora Australis*	1 Jan 2001 ï 8 March 2001	Fine scale krill survey
V6 1999/00 *Aurora Australis*	18 Feb 2000 ï 29 March 2000	Opportunistic survey
V4 1999/00 *Aurora Australis*	22 Nov 1999 ï 21 Jan 2000	APIS survey
V1 1999/00 *Aurora Australis*	13 July ï 7 Sept 1999	Winter polynya study Mertz Polynya
V1 1998/99 *Aurora Australis*	15 July ï 31 July 1998	Winter polynya study Mertz Polynya
V2 1998/99 *Aurora Australis*	Oct ober 1998	Survey and base resupply
V3 1998/99 *Aurora Australis*	November 1998	Survey and base resupply
V5.1 1998/99 *Polar Queen*	18 Feb ï 19 March 1999	Survey and base resupply
1998/99 *Kapitan Klebnikov*	January 1999	Tourist vessel (PC Gill observer)
V1,V2,V5,V6,V7 1997/98 *Aurora Australis*	Sept ï Nov 1997 and 3 April ï 22 May 1998	Various Antarctic and sub-Antarctic
1997/98 *Kapitan Klebnikov*	January 1998	Tourist vessel (PC Gill observer)
V4 1995/96 *Aurora Australis*	19 Jan 1996 ï 31 March 1996	Large scale multidisciplinary krill and oceanographic survey
V1 1995/96 *Aurora Australis*	17 July ï 2 September 1995	Winter sea ice study

Table 5. IWC-Southern Ocean Collaboration (SOC) cruises 2001/02 ï 2003/04. (From Van Waerebeek *et al*., 2004)

Vessel/cruise acronym	**Cruise dates**	**Purpose**
R/V Laurence M. Gould/LMG 0103	18 March ï 13 April 2001	Mooring cruise (initial deployments)
RV Polarstern/AntXVIII5b	14 April ï 7 May 2001	Survey and ice/krill process cruise
RVIB Nathaniel B. Palmer/NBP 0103	24 April ï 5 June 2001	Survey cruise
RVIB Nathaniel B. Palmer/NBP 0104	24 July ï 31 Aug 2001	Survey cruise
R/V Laurence M. Gould/LMG 0201A	6 Feb ï 3 March 2002	Mooring cruise (retrieve and deploy)
R/V Laurence M. Gould/LMG 0203	7 April ï 21 May 2002	Process cruise
RVIB Nathaniel B. Palmer/NBP 0202	9 April ï 21 May 2002	Survey cruise
RVIB Nathaniel B. Palmer/NBP 0204	31 July ï 18 Sept 2002	Survey cruise
R/V Laurence M. Gould/LMG 0302	12 Feb ï 17 March 2003	Final mooring cruise (retrieval)
RVIB Nathaniel B. Palmer	23 Feb ï 10 April 2004	Ross Sea ANSLOPE oceanography
RV Polarstern/AntXXI	27 March ï 7 May 2004	Weddell Sea SO GLOBEC

Table 6. Sperm whale acoustic surveys

Date	Area	Description	Reference
10 Jan ï 27 Feb 2006	East Antarctica 30-80°E	142 sonobuoys were deployed on a systematic grid pattern and sperm whales were detected on 44 of these. No estimate of detection range.	Gedamke *et al*. 2006
14 Jan ï 12 Feb 2000	Scotia Sea and west Antarctic Peninsula 20°W ï 70°W, 50°S-70°S	Density estimate based on acoustic Distance type analysis (0.19 whales per 1000 km^2)	Leaper *et al*., 2000
18 Dec 1998 ï 10 Jan 1999	South Georgia and surrounding area within 40°S-60°S, 30°W-60°W	Density estimate based on acoustic Distance type analysis (0.13 whales per 1000 km^2)	Leaper *et al*., 2000
Nov ï Dec 1996	Antarctic Peninsula/Drake Passage	Insufficient detections for Density estimate	Leaper and Scheidat (1998)
Feb ï Mar 1996	East Antarctica 62°S-66°S 80°E-125°E,	Density estimate based on ôCartwheelsô analysis (0.50-0.73 whales per 1000 km^2)	Gillespie (1997)
Dec 1994- Mar 1995	Pacific sector of Southern Ocean	Combined visual and acoustic data	Pierpoint *et al*. (1997)

Fig. 1. Example map from the IDCR/SOWER database. Confirmed sightings of southern bottlenose whales from 1978/79 to 2004/2005 (n=2138)

Table 7. Metadata table of sperm whale prey consumption estimates

CETACEAN PREY CONSUMPTION ESTIMATES	
Species or ecotype	Sperm whale (only larger males in Antarctic)
Diet composition	Santos et al. (2001) list squid (*Kondakovia, Moroteuthis, Mesonychoteuthis*) based on Clarke (1980; 1983). Kock et al. (2005) note that sperm whales may feed on Patagonian toothfish (*Dissostichus eleginoides*) north and south of the Southern Polar Frontal Zone and Antarctic toothfish (*Dissostichus mawsoni*) have also been described being taken by sperm whales.
Body mass	30-40 tonnes used by Santos et al. (2001) for mature males Kasamatsu and Joyce (1995) used 27.4 tonnes based on Lockyer (1981) for mature males Laws (1977) assumed 27 tonnes.
Seasonal feeding patterns and storage of energy	Laws (1977) assumed that sperm whales increase body mass by 20% (compared to 50% for baleen whales) on the feeding grounds, but notes there are no data to support this.
Time spent in Southern Ocean	Santos et al. (2001) assume 122 days
Consumption estimates	Laws (1977) does not give details of calculation but for an abundance of 43,000 and a total biomass of 1,161,000 tonnes, squid consumption was estimated at 4,632,000 tonnes and fish at 244,000 tonnes (these figures correspond approximately to consumption of 4% of body mass a day for 90 days). Kasamatsu and Joyce (1995) scale the consumption estimate of Laws (1977) to a sperm whale abundance of 28,100 giving estimated consumption of 3,100,000 tonnes. Santos et al. (2001) assume 3.3% of body mass per day.

Table 8. Metadata table of southern bottlenose whale prey consumption estimates

CETACEAN PREY CONSUMPTION ESTIMATES	
Species or ecotype	Southern bottlenose whale
Diet composition	Santos et al. (2001) list squid (*Kondakovia, Mesonychoteuthis, Gonatus*). Stomach contents analyses (squid species) are reported by Sekiguchi *et al.* (1993) and Slip *et al*. (1995).

Body mass	Kasamatsu and Joyce (1995) assume 4.5 tonnes for all beaked whales. Santos et al. (2001) assume 3.7 tonnes for all beaked whales.
Seasonal feeding patterns and storage of energy	
Time spent in Southern Ocean	Kasamatsu and Joyce (1995) assume 90 days Santos et al. (2001) assume 60-122 days
Consumption estimates	Kasamatsu and Joyce (1995) assume prey consumption of 4% of body mass per day in the Antarctic Santos et al. (2001) assume 3.3% of body mass per day.

Table 9. Metadata table of killer whale prey consumption estimates

CETACEAN PREY CONSUMPTION ESTIMATES	
Species or ecotype	Killer whale (three ecotypes described A,B,C see Pitman and Ensor (2003))
Diet composition	Pitman and Ensor (2003) suggest the following Type A ï apparently feeds mainly on minke whales south of 50^{o}S but also pinnipeds dolphins and fish in warmer waters (Branch and Williams, 2006). These authors estimated an annual diet of 40% minke, 20% pinniped, 20% dolphin and 20% fish (but note caveats to these estimates). Type B ï known to feed on pinnipeds, possibly also whales and penguins Type C ï appears to prey mainly on fish
Body mass	Kasamatsu and Joyce (1995) assume 4.0 tonnes for all ecotypes combined Williams et al (2006) suggest 4.7t and 2.8t for typical mature male and female respectively in North Pacific. Type A appear most similar in size to killer whales elsewhere with adult females in the range 7.5-7.8m (Mikhalev et al., 1981). Probable adult female type B whales taken by Soviet fleet reached lengths of 6.4-6.5m (Pitman and Ensor, 2003) suggesting a likely body mass of 60% of type A (corresponding to 1.7t based on the figures used by Williams et al. (2006)).
Seasonal feeding patterns and storage of energy	Type A ï apparently migrates to lower latitudes during winter Type B, C ï may be migratory but also known to over-winter in ice
Time spent in Southern Ocean	Kasamatsu and Joyce (1995) assume 70 days
Consumption estimates	Kasamatsu and Joyce (1995) assume prey consumption of 4% of body mass per day in the Antarctic Branch and Williams (2006) use estimates of energy requirements from Williams et al (2004) to estimate (type A) adult males requiring 287,331 kcal/day and females 193,211 kcal per day based on the same body masses as Williams et al (2006). These estimates correspond to 115kg and 77kg of whale meat or 78kg and 48kg of blubber for males and females respectively. These estimates of energy consumption are based on estimates of FMR which are 6 times the BMR estimated from the Kleiber formula. This is a subject of ongoing debate. See for example Leaper and Lavigne (2007).

Table 10. Metadata table of long-finned pilot whale prey consumption estimates

CETACEAN PREY CONSUMPTION ESTIMATES	
Species or ecotype	Long-finned pilot whale
Diet composition	Some discussion on possible prey in Rodhouse (1997) who notes an absence of data.
Body mass	Kasamatsu and Joyce (1995) assume 0.8 tonnes.
Seasonal feeding patterns and storage of energy	
Time spent in Southern Ocean	Kasamatsu and Joyce (1995) assume 70 days
Consumption estimates	Kasamatsu and Joyce (1995) assume prey consumption of 4.7% of body mass per day in the Antarctic

Table 11. Metadata table of hourglass dolphin prey consumption estimates

CETACEAN PREY CONSUMPTION ESTIMATES	
Species or ecotype	Hourglass dolphin
Diet composition	Some information from a limited number of specimens in Goodall *et al.* (1997)
Body mass	Kasamatsu and Joyce (1995) assume 0.1 tonnes. Goodall *et al.* (1997) report weights of 74-94kg
Seasonal feeding patterns and storage of energy	
Time spent in Southern Ocean	Kasamatsu and Joyce (1995) assume 60 days
Consumption estimates	Kasamatsu and Joyce (1995) assume prey consumption of 8% of body mass per day in the Antarctic