

## Annex H

# Report of the Sub-Committee on Other Southern Hemisphere Whale Stocks

**Members:** Zerbini (Chair), Allison, An, Baba, Bannister, Bass, Berggren, Best, Bjørge, Borodin, Branch, Brandão, Brownell, Butterworth, Carlson, Charrassin, Childerhouse, Clapham, Clark, Dolman, Donovan, Engel, Ensor, Findlay, Galletti, Gedamke, Goto, Groch, Gunnlaugsson, Hakamada, Hammond, Hatanaka, Hedley, Hildebrand, Holloway, Huckle-Gaete, Hyugaji, Iñiguez, Ipatova, Ivashchenko, Jackson, Kanda, Kaschner, Kasuya, Kato, Kock, Lawrence, Leaper (Rebecca), Leslie, Martin, Mate, Matsuoka, Mattila, Miller, C., Miller, J., Miyashita, Mori, Morishita, Murase, Nakamura, Nishiwaki, Ohsumi, Øien, Okamura, Palazzo, Pastene, Peel, Polacheck, Ridoux, Robbins, Rosenbaum, Rowles, Senn, Simmonds, Skaug, Stachowitsch, Tanaka, Tominaga, Urbán, Vasquez, Van Waerebeek, Wade, Walløe, Weinrich, Williams, Yamakage, Yasokawa, Yoshida, Young.

### 1. INTRODUCTORY ITEMS

#### 1.1 Opening remarks

Zerbini, the Convenor, welcomed participants.

#### 1.2 Election of Chair

Zerbini was elected Chair. He noted that the sub-committee would have ten sessions in which to complete its work.

#### 1.3 Appointment of rapporteurs

Clapham, Findlay and Robbins undertook the duties of rapporteurs.

#### 1.4 Adoption of Agenda

The adopted Agenda is given in Appendix 1.

#### 1.5 Documents available

Documents identified as containing information relevant to the sub-committee included: SC/58/SH1-25, O2, O6, O16, O17, O22 and Williams *et al.* (2006). Documents submitted to the Southern Hemisphere humpback whale Comprehensive Assessment Workshop held in Hobart, Tasmania, in April 2006 were available to this meeting. A complete list of the Workshop documents is provided in Appendix 2.

### 2. IN-DEPTH ASSESSMENT OF SOUTHERN HEMISPHERE HUMPBACK WHALES

Last year, the Committee agreed that the completion of the Comprehensive Assessment of Southern Hemisphere humpback whales at the 2006 Annual meeting was a high priority (IWC, 2006a p.162) and that to achieve this would require holding an intersessional Workshop. The report of

the Workshop (SC/58/Rep5) is summarised below. The full Workshop report will be published in a future special issue of the Journal.

#### 2.1 Report of the intersessional Workshop on the Comprehensive Assessment of Southern Hemisphere humpback whales

SC/58/Rep5 reported the results of the Workshop held at the Australian Antarctic Division in Hobart, Tasmania, 4-7 April 2006. The Chair of the Workshop (Bannister) summarised the primary points of the report, beginning by noting the Terms of Reference. He noted that the Workshop agreed that issues of substructure on the breeding grounds should be dealt with on a case by case basis, and this was done. The Workshop reviewed in detail existing information for each breeding stock, including data on/from individual movements, natural marks and telemetry; in the light of these data, the Workshop examined what was known about genetic and demographic structure, seasonal distribution and migration. For convenience, summaries of the state of knowledge and current hypotheses about each breeding stock are given below.

##### *Breeding Stock A (BSA) summary*

At least based upon current knowledge (see SC/58/Rep5, table 2 and fig. 2), BSA has a relatively simple structure which links it to the feeding grounds of the western South Atlantic (i.e. part of Area II), notably South Georgia and the South Sandwich Islands. Thus, the situation for this region is that of a single breeding stock (A) connecting with a single feeding ground (Area II). There is no indication that animals feeding off the Antarctic Peninsula migrate up the eastern coast of South America.

##### *Breeding Stock B (BSB) summary*

There is some evidence for stock structure within BSB on the African west coast. Some genetic difference between whales from Gabon and Cabinda and off West South Africa exists. There is some recent evidence of breeding behaviour from Gabon, Angola, Cabinda, São Tome, Equatorial Guinea and Congo to the north of the Walvis Ridge, and recent evidence of feeding behaviour, but no breeding behaviour to the south of the Walvis Ridge. Townsend (1935) shows evidence of historical concentrations of humpback whales in the Gulf of Guinea in winter and off Walvis Bay (Namibia) in summer. Satellite telemetry has identified movement from Gabon further northwards to Nigeria and into the Gulf of Guinea as far as Ghana; two animals migrated, primarily offshore, southward to the Antarctic. Summer presence of feeding whales within the Benguela Upwelling System suggests use of this region as a

summer feeding ground. Catches of whales with full stomachs (clupeid prey) were made off West South Africa (Olsen, 1914). There is evidence of movement of two female whales (one nursing) from Gabon to West South Africa.

The Workshop **agreed** that, with a B1/B2 border in the vicinity of 18°S (where the Walvis Ridge meets the African coast and in the vicinity of the Angola Current-Benguela Current Front):

- (1) B1 is a breeding ground;
- (2) B2 is a feeding ground and migration corridor within the productive waters of the Benguela upwelling system.

Some of the whales feeding within B2 breed within B1. The Workshop also noted that it is unclear whether subdivisions exist within B1. There is equivocal evidence for at least two breeding stocks on the western coast of Africa, and one of these clearly breeds in an area (perhaps only a portion) of B1; whether the other breeding stock(s) exist within the bounds of B1 or elsewhere remains unclear. The observed genetic differences among females between B1 and B2 may be explained by the existence of a second breeding stock which is sampled on migration in B2, but this is currently unknown.

In discussion within the sub-committee of the summary of BSB, the statement that no breeding behaviour occurred south of the Walvis Ridge was challenged given that there are insufficient observations in this region. It was also suggested that hypotheses regarding population structure should include possible connections between B and C.

#### *Breeding Stock C (BSC) summary*

There is evidence of breeding in sub-region C1 from approximately 28°S to possibly as far north as Tanzania/Kenya, while a migratory corridor exists south of 28°S. Breeding also occurs off the Comoros Islands and Mayotte (C2) and in the coastal waters of Madagascar, although the relationship between whales on the east and west coasts of Madagascar is unknown. Recaptures of individuals provide potentially extensive connectivity between Mayotte (C2) and Antongil Bay (C3), and to a lesser extent (one individual) between the east coast of South Africa (1) and Antongil Bay. No evidence of connectivity exists for South Africa/Southern Mozambique (C1) and Mayotte (C2). One lost harpoon (Olsen, 1914) provides a link between East South Africa (Durban) and Southern Mozambique (Linga-linga). Genetic differentiation has been found between Antongil Bay (C3) and East South Africa/Southern Mozambique (C1), and between Mayotte (C2) and East South Africa/Southern Mozambique (C1), while no genetic differentiation is found between Mayotte (C2) and Antongil (C3).

On the basis of what is known of the stock structure of humpback whales off the East coast of Southern Africa, five potential sub-regions were identified:

- (1) C1 South (C1-S) including East South Africa and Mozambique as far north as Mozambique Island (15° S).
- (2) C1 North (C1-N) extending northwards from Mozambique Island to the northern limit of the range (Southern Tanzania possibly into Kenya).
- (3) C2 including Mayotte Island, the Comoros Islands and the Mozambique Channel;
- (4) C3 around Madagascar.
- (5) C4 extending across the Mascarene group of islands, including Mauritius and Reunion.

The Workshop agreed that the delineation between C1-S and C1-N may be a cline rather than a definite line, although given the current deficiency of data to the north of Mozambique Island the border can presently be considered a latitudinal line in the region of Mozambique Island (15°S). The links described above suggest that C2 and C3 may not be separate.

Seven models of stock structure were considered (SC/58/Rep5, fig. 4). The Workshop **agreed** that the most plausible was that linking C1-N and C1-S into one breeding sub-stock and the linking of C2 and C3 into another. The next most likely linked (1) C1-N and C1-S and (2) C2 and C3 while including some overlap between the C1-N and the combined C2/C3 sub-stocks.

In discussion within the sub-committee of the summary of BSC, the reliability of the hypothesised C4 as a discrete breeding stock was questioned. It was acknowledged that this was based upon relatively scant data.

#### *Breeding Stock X (BSX) summary*

The Workshop agreed that the evidence showed this to be an isolated population, resident in the Arabian Sea year-round; i.e. this is both a breeding and a feeding ground.

#### *Breeding Stock D (BSD) summary*

Recent information confirms earlier results, e.g. from Chittleborough (1965), with animals migrating northwards during winter from Antarctic Area IV along the west coast of Australia towards a current breeding ground destination as far north as 15°S (Jenner *et al.*, 2001) beyond North West Cape, Western Australia (*ca* 21°50'S, 114° 10'E). The southerly migration takes place in late winter/spring. A few early northward migrating animals may reach the coast in April, but the main northbound stream arrives in June. Recent aerial surveys for southern right whales along the south coast between Cape Leeuwin, Western Australia and Ceduna, South Australia have recorded animals moving westwards until August, from as far east as Esperance (33°52'S, 121°54'E), with some stragglers reaching the coast even further east in the Great Australian Bight (Bannister, pers. comm.) Catches off the south coast at Albany (35°01'E, 117°53'E) and off the west coast at Carnarvon (24°53'S, 113°40'E) and Point Cloates (22°43'S, 113°40'E), 1949-63 (Chittleborough, 1965; Dawbin, 1997), showed marked segregation during the northern migration, with sexually immature animals and mature females at the end of lactation in the vanguard, most adult males travelling in the middle of the period, pregnant females in the rear, and non-pregnant females being found throughout. On the southern migration, those first to arrive in warmer waters were the first to depart. Pregnant females, among the last to arrive from the south, having given birth were among the last to leave. Off North West Cape the highest numbers of animals, widely distributed, have recently been found at the time of transition between northern and southern migrations, in August (SC/A06/HW21). Off Perth, Western Australia (31°57'S, 115°51'E) southbound animals are found mostly in September and October, with cow-calf pairs most commonly seen in November (Burton, 1991); humpbacks are generally not seen off the south coast after August, i.e. during the southern migration. The Workshop concluded that the question of a possible sex bias in migrating animals still remains to be resolved. In the Antarctic, the area of greatest concentration recently has been east of the Kerguelen Plateau, between 80°-120°E (SC/A06/HW57). There may have been some habitat expansion from north to south in that area in recent years.

In discussion within the sub-committee of the summary of BSD, the question was raised regarding whether substructure within this stock had been investigated. In response, it was generally felt that current evidence is consistent with the idea that D represents a single BS without substructure.

#### *Breeding Stocks E and F (BSE and BSF) summary*

There was considerable uncertainty regarding population structure within and between BSE and BSF, and a number of scenarios were proposed; these are summarised in table 7 and fig. 6 of SC/58/Rep5.

#### *Breeding Stock G (BSG) summary*

Although the possibility of modelling the Magellan Strait feeding area as a separate stock was raised, given the lack of strong evidence for this and any information on a link to breeding grounds, the Workshop agreed that BSG should be modelled as a single stock.

Following the summaries of the breeding stocks given above, the Workshop report discussed overall population structuring, including linkages between breeding and feeding grounds. It was clear from discussions and data presented during the Workshop that the level of confidence associated with stock structure concepts varies considerably across the Southern Hemisphere. In some areas (e.g. BSA and Area II) the connections between breeding and feeding grounds and the structure within these are reasonably well understood; in such cases discussion focused largely on the extent to which boundaries should be expanded or contracted in variations of model runs. In others (e.g. Breeding Stocks B, C, E, F), there is considerable unresolved complexity and insufficient data to discriminate among a variety of stock structure hypotheses. There was much discussion of how the boundaries of each stock should be shifted, and accordingly of how the 'Core' and 'Fringe' areas for some of the stocks should be defined for the purpose of catch allocation.

The report also summarised the current status of data sources, including whaling data. The Workshop generally agreed that levels of catches prior to 1900 were low enough to validate the assumption that by 1900 populations had recovered. Various hypotheses for best and alternative catch/removal allocations were discussed.

#### *General discussion and conclusions*

After considering all the data, the overall conclusion of the Workshop was that modelling options and possible completion of the Comprehensive Assessment were possible for stocks A, D and G, but that there was insufficient information to resolve conflicting hypotheses and ideas regarding Breeding Stocks B, C, E and F. While the structure of BSX is relatively simple, an assessment cannot be conducted because there is no information on abundance and trends for this stock. Therefore, the primary focus of intersessional work and of the sub-committee at SC/58 should be on completion of assessments for stocks A, D and G.

Data on abundance, trends and biological parameters for these three stocks were summarised by the Workshop. The Workshop suggested that models continue to be run with priors for the annual intrinsic growth rate parameter ( $r$ ) bounded by 12.6%, but also with lower values to investigate sensitivity. A further review of biological parameters and maximum rate of increase was suggested, to be presented at SC/58 (see Item 2.2.1 below).

From the perspective of completing the assessment for the other areas, the highest priority research is for studies of stock structure and movements for Breeding Stocks B, C, E and F, particularly those that will allow appropriate allocation of catches from the feeding grounds to breeding stocks. Information from a variety of sources was recognised as important in this regard, especially genetic, photographic, telemetric and acoustic studies.

Recommendations arising from the Workshop are summarised in annex H of SC/58/Rep5. The sub-committee **endorsed** these recommendations.

## **2.2 Comprehensive Assessment of humpback whales**

### *2.2.1 Biological parameters*

SC/58/SH4 reviewed recent data on factors influencing rates of population growth in humpback whales, including survival, age at first parturition and calving rate. Ranges of observed values were summarised, and possible biases in each data set were highlighted. From this review, the authors calculated theoretical rates of increase at two levels: an average rate (AR) which used the means of observed values for these parameters, and a maximum possible rate (MPR) which used the extreme values reported from any population. The calculated rates of increase were: AR = 0.046 (4.7% per annum), MPR = 0.101 (10.6% per annum). They noted that it was possible that small populations recovering from severe depletion would have a somewhat higher MPR. However, in the absence of data indicating more extreme values for the three parameters concerned, they suggested that any empirical estimate of increase which exceeds 10.6% should be ignored for the purpose of the current Comprehensive Assessment of Southern Hemisphere humpback whales.

SC/58/SH24 also examined the question of maximum possible growth rates. The authors noted that the upper bound of 0.126 currently imposed upon age-aggregated assessment models was based upon an analysis that assumed steady age structure. They suggested that it was possible that transient age structure effects could permit greater population growth rates for short periods, and examined this through an age-structured model in which possible density dependent changes in pregnancy rate, age at first parturition and natural mortality were modelled explicitly, with allowance made for the possibility of senescence. The authors applied the model to BSD noting the point estimate of growth of 0.10 from surveys conducted between 1982 and 1994. Results based upon an estimate of abundance for this breeding population of 10,032 in 1999 suggested that 0.12 was the maximum feasible annual rate of increase for this stock during the period, assuming the population was closed. This result was based upon the same parameter choices that led to the earlier  $r = 0.126$  bound.

In discussion of SC/58/SH4 and SC/58/SH24, it was first noted that it was important to understand the terminology involved with this issue, notably the different ways in which growth rate is expressed. This terminology is summarised in Appendix 3.

With regard to the MPR of 10.6% proposed by SC/58/SH4, it was argued that this was based upon values for the three parameters derived from Northern Hemisphere populations, and therefore that application of this rate to the Southern Hemisphere was not appropriate. In response, the authors of SC/58/SH4 pointed out that the MPR was not a rate of increase taken from a specific Northern Hemisphere population, but rather was calculated based upon extreme values from three different populations that happened to be in the Northern Hemisphere; they had actually ignored data

from Southern Hemisphere populations giving less extreme values (which would have resulted in a lower rate of increase). The authors reiterated that a MPR higher than 10.6% was certainly possible, but that this would require values for survival, age at first parturition and birth rate that had not been observed anywhere in a variety of longitudinal and other studies in different areas. They had conducted the analyses using 5 years (rather than 5.9) as the age at first parturition, which was the earliest age at which any individual had been observed to give birth; however, this was excluded as unlikely to be representative of the individual variability in a population. Furthermore, use of the upper bounds of 95% confidence intervals for key parameters in rate of increase calculations was considered but not used because that gives values that are not biologically realistic when placed in the context of what is known of the biology of humpback whales and mammals in general. For example, use of a survival rate of 0.99 implies an average age of animals in the population of about 100 years. Thus, the CI approach was not used.

The sub-committee discussed the matter of inferences that could be drawn if point estimates from a time series of abundance estimates exceeded the theoretical maximum rate of population increase, calculated from demographic information for a closed population (as in SC/58/SH4). The sub-committee **agreed** that such an eventuality does not of itself necessarily imply that the information from such abundance estimates should be disregarded; the effect of sampling variability on abundance estimates from surveys about true population abundances leads to similar variation in associated estimates of trend, which consequently can exceed the demographic maximum. Information from such surveys can legitimately be included in assessments provided that these assessments also take due account of the bounds implied by demographics. However, if an appropriate confidence interval for any estimated rate of increase from the series of abundance estimates entirely exceeds the bound implied by demographics, this constitutes compelling evidence to not incorporate such information in assessments, pending evaluation of the possibilities of biases in the abundance estimates or their being influenced by immigration.

Current assessment models use a Pella-Tomlinson model, for which the maximum annual rate of increase is bounded at 12.6%. Based upon discussions surrounding SC/58/SH4, the sub-committee **agreed** that, on the basis of the best information currently available, the MPR of 10.6% was reasonable to adopt as an upper bound for this annual rate in assessments. However, it **recommended** further research to obtain data on parameters from Southern Hemisphere populations rather than relying on values drawn from elsewhere. In addition, it was suggested that the implications of dynamics different from the Pella-Tomlinson form should be explored. The sub-committee noted that MPR levels in that model apply to population sizes at very low levels and would not be expected in a population approaching  $K$ .

SC/58/SH3 was based upon the fact that in recent years, high rates of increase have been reported for some Southern Hemisphere humpback whale populations on either breeding grounds or in major migratory corridors. Although some of these estimates lie within the bounds of the possible, they require values for biological parameters that are towards the extreme end of a plausible range. SC/58/SH3 used the example of BSE to evaluate an alternative explanation: that the reported rates represent a combination of actual population growth as well as

immigration from other regions, driven by the strong tendency of this species to aggregate for mating during the winter breeding season. In this 'Social Aggregation Hypothesis' (SAH), the ubiquitous overexploitation by commercial whaling in the Southern Hemisphere diminished the density of humpback whales at major breeding grounds to the point where these were no longer viable; then, during subsequent population recovery, a critical mass was attained in certain areas which then drew in whales from elsewhere. The authors of SC/58/SH3 noted that, if the SAH were correct, it would not only explain high rates of increase in such 'hotspots' such as eastern Australia, but might also imply that formerly important areas (e.g. Fiji) host few whales today not because of a failure to recover, but because the whales concerned migrate to higher-density breeding grounds elsewhere. The paper showed through simple modelling that, in order to maintain the same rate of high growth observed off eastern Australia (referred to by the authors as the 'base population'), the contribution to that rate by immigration from a 'source' population would have to represent a larger and larger proportion of the source stock, and the demand for immigrants would eventually exceed the supply. The time to exhaustion of the source population varied depending on its initial size and growth rate relative to the base stock. In six scenarios examined by the authors, this time ranged from only two years (when both were growing at 4.7% and the source stock was initially very small) to 35 years (when both were growing at 7.7% and the source population was double that of the base in year zero). SC/58/SH3 concluded that, at least theoretically, the SAH could under certain scenarios account for the observed large rates of increase such as those reported since 1987 for BSE. However, in other scenarios it could not. The authors noted that it was difficult to believe that social aggregation would produce such consistency in the rates of increase actually observed off eastern Australia. However, given the social ecology and known distributional plasticity of humpback whales, they thought it is highly likely that some animals are indeed drawn into large breeding aggregations from elsewhere, but the contribution of this immigration to reported growth rates was unknowable without data on intrinsic rates of increase, population structure and the movements of individuals.

Some members felt that the SAH was entirely theoretical and speculative and that there was no evidence for it and further that rates of increase of 10% were not unreasonable and required no additional explanation. Others thought that the SAH was a reasonable concept given the mating system of this species, and pointed out that there were parallels in other taxa (e.g. northern elephant seals, for which rates of increase are thought to be artificially elevated by immigrants attracted to breeding aggregations).

SC/58/SH22 used mitochondrial DNA (mtDNA) diversity in a present-day population to provide a lower boundary on historical estimates of minimum population size ( $N_{min}$ ) for that population. As mtDNA is maternally inherited without recombination, the number of unique haplotypes in the current population must set the absolute lower limit of  $N_{min}$  for females in a population trajectory. Parameterising  $N_{min}$  is desirable in that it allows specification of a region of the logistic model which is generally left unconstrained, and which is prone to underestimating the true size of a bottleneck. The authors described four approaches to parameterising the lower bound of  $N_{min}$  and described preliminary results for three of these. In the first, they generated discovery curves of haplotypes numbers versus sample size in order to provide

an indicative estimate of the total haplotypes in a population. In the second, the authors calculated the number of haplotypes to be found in samples of various sizes when picked from a simulated pre-bottleneck neutral distribution of haplotypes. In their modelling, the authors chose the initial haplotype number input for a pre-bottleneck population by counting the total number of haplotypes observed across breeding populations E and F ( $n=77$ ). Other distributions ( $n=99$  and 121 haplotypes) were also calculated. Four different model types were explored. The potential loss of haplotypes over population trajectories was also explored using BOTTLESIM. Loss of haplotypes throughout the modelled trajectory was most marked for the highest  $r_{max}$  estimate (0.121), while loss of haplotypes subsequent to  $N_{min}$  was greatest for the trajectory for the smallest  $r_{max}$  (0.008). Current haplotype numbers also seemed to be robust to the initial haplotype frequency distribution used. The analysis was conducted for illustrative purposes only, but served to demonstrate the level of post- $N_{min}$  haplotype loss that could occur for a number of the calculated logistic trajectories. The major recommendation from the paper was that, for the purpose of establishing  $N_{min}$  in modelling, two values should be used: (i) two times the number of haplotypes seen in the population (the doubling accounts for males); and (ii) four times the number of observed haplotypes. The authors noted that the ultimate goal of the work was to establish a reasonable prior for  $N_{min}$  in modelling, but that this was contingent upon determining the frequency distribution of alleles at  $N_{min}$ .

The sub-committee welcomed this paper as it introduces an additional constraint on logistic model analyses and, as such, can better inform estimates of parameters such as  $r$ ,  $K$  and population recovery. However, it noted that these constraints (especially (i) above) were absolute lower bounds because the probability of detecting the haplotypes of all individuals in a population was very low. The sub-committee **agreed** that use of twice the number of observed haplotypes was too extreme; rather, use of 4x this number was more appropriate for an  $N_{min}$  value to bound assessments.

### 2.2.2 Modelling framework

SC/58/SH2 and SC/58/SH23 introduced the Bayesian stock assessment methodology to update the stock assessments of Breeding Stocks A, D and G. These assessments took into account the recently updated historic catch series, as well as the most recent estimates of current abundance and population trend information from the Hobart Workshop. These papers also discussed the effect of depensation at low abundance levels. Depensation is further treated in Appendix 2.

### 2.2.3 Assessments

#### 2.2.3.1 GENETIC INFORMATION

SC/58/SH25 investigated the genetic diversity of eastern Australian humpback whales, comparing mtDNA sequence data with those from breeding grounds across the South Pacific (New Caledonia, Tonga, the Cook Islands, French Polynesia and Colombia), as well as from western Australia. Eastern Australian haplotype and nucleotide diversities were similar to those from the compared breeding grounds, but haplotype diversity was significantly different from New Caledonia, the Cook Islands, French Polynesia and Colombia. The genetic differentiation observed in the study

and in previous analyses supported the proposed subdivision of BSE into three substocks, E1 (eastern Australia), E2 (New Caledonia) and E3 (Tonga).

In discussion, it was agreed that the work related to the recommendations for further genetic analyses agreed in the Hobart workshop (SC/58/Rep5) was required before the latter conclusion could be accepted. It was also noted that if separation of BSE into three substocks proved to be appropriate, this would require information on the relationship between these areas and the feeding grounds, in order that catches could be appropriately allocated. A variety of genetic analytical tools were available to assess mixing and allocate proportions of animals from breeding stocks (or substocks) onto feeding grounds. The utility of the genetic data in SC/58/SH25 to test the SAH (SC/58/SH3) was discussed; while microsatellite DNA might be used to detect individual movements, testing of the SAH probably required a broader temporal data set than was available.

#### 2.2.3.2 BREEDING STOCK A

##### 2.2.3.2.1 ABUNDANCE AND TRENDS

SC/58/SH14 presented estimates of population growth rates of humpback whales in the wintering grounds off the coast of Brazil. Sightings data and effort were collected from July to November in the Abrolhos Bank between 1992 and 1998 (Martins *et al.*, 2001). Only data from the period 1995-98, which was collected in a systematic, comparable fashion, was considered. Sighting per unit of effort was analysed using generalised linear models with Poisson and negative binomial error distributions. Parameters were estimated in a maximum likelihood framework. The best estimate of growth rate, 7.4% year<sup>-1</sup> (95% CI = 0.6-14.5% year<sup>-1</sup>), was obtained with a negative binomial model. This estimate is more precise than previously published estimates for this stock, and is consistent with observed growth rates in other humpback whale populations.

In discussion, it was noted that Poisson models gave smaller and more precise estimates of growth rate than negative binomial models, but that the latter were preferred in terms of the AIC<sub>c</sub> model selection criterion. SC/58/SH14 attributes this to overdispersion of observations compared to expectations under a Poisson model, which suggests that the results from the negative binomial models are legitimately preferred. Diagnostic plots of the residuals for the Poisson and negative binomial models with lower AIC<sub>c</sub> were provided and further supported this view. Examination of data in fig. 1 of SC/58/SH14 seemed to suggest that extreme values obtained during August and September might have had a strong effect on the results. Following analysis on a monthly basis, the sub-committee considered that while there were differences in the monthly trends, these were not sufficient to negate use of the estimate proposed in SC/58/SH14. It was therefore **agreed** that the trend estimated (7.4% year<sup>-1</sup>) with the negative binomial model should be used in the assessment of BSA. However, further investigation of the monthly trend would be worthwhile.

SC/58/SH15 was an updated version of SC/A06/HW2 as presented at the Hobart Workshop. The authors had reanalysed four years of line-transect sighting data from Brazil for the period 2002 to 2005 to produce an estimate of abundance of 6251 (CV=0.16) in 2005. In discussion, the question arose regarding the pooling of data across all years, whether an analysis involving individual years was possible, and whether observers were the same across all years. The authors replied that methodology and observers were the same across all years, and that detection functions therefore

may have not varied over the course of the study. The sub-committee **recommended** that these surveys continue in order that trend data could be obtained in the future.

SC/A06/HW6 presented estimates of abundance from circumpolar surveys that were also briefly presented at the Hobart Workshop. Estimates using standard line transect methods were available for three sets of circumpolar surveys: 1978/79-1983/84 (CPI), 1985/86-1990/91 (CPII), and 1991/92-2003/04 (CPIII). The surveys have now circled the Antarctic three times, on the most recent occasion covering 99.7% of the open-ocean area south of 60°S. The methods are little changed from those in Branch and Butterworth (2001), except that surveys from 1998/99 to 2003/04 are now included, completing the third circumpolar set of surveys (CPIII). Search half width and estimated school size increased over time in the surveys. Circumpolar estimates of abundance were 7,100 (CV=0.36), 10,200 (CV= 0.30) and 41,800 (CV=0.11). When adjusted to account for unsurveyed areas between the northern boundary of the survey and 60°S, the estimates for CPI and CPII increase somewhat and the circumpolar estimated rate of increase is 9.6% (with CI=5.8-13.4%). Estimates were also calculated for each survey, for each IWC Management Area and for feeding areas corresponding to breeding stocks (as linked to feeding areas by the Naïve catch model). Point estimates of the rate of increase were positive for all breeding stocks and significantly greater than zero for regions corresponding to Breeding Stocks D and E. The abundance estimates are negatively biased because it is assumed that all whales on the trackline are detected (although this bias is relatively small compared to Antarctic minke whales) and because some humpback whales remain north of 60°S, especially important for Breeding Stocks A and B. JARPA estimates, previously considered much higher than IDCR/SOWER, are now lower in Area IV and V, and in addition the IDCR/SOWER surveys in these two areas estimated high rates of increase similar to those from JARPA. Estimates from SC/A06/HW6 are given in Table 1.

Table 1

Estimates of abundance from IDCR/SOWER surveys for each breeding group of humpback whales, obtained from the feeding areas by assuming that the Naïve model is correct (SC/A06/HW6). Estimates of abundance for CPIII\* include a 10 degree longitudinal section from the 1998/99 survey that is also included in the CPIII estimate.

Breeding group	CP	Mid-year	Estimate		Comparable areas	
			N	CV	N	CV
A (50°W-20°W)	CPI	1981/82	98	0.96	45	0.88
	CPII	1986/87	336	0.55	259	0.62
	CPIII	1997/98	168	0.61	200	0.64
B (20°W-10°E)	CPI	1980/81	246	0.85	692	0.84
	CPII	1986/87	70	0.63	70	0.63
	CPIII	1995/96	595	0.51	595	0.51
C (10°E-60°E)	CPI	1979/80	720	0.53	1,043	0.62
	CPII	1987/88	700	0.46	926	0.57
	CPIII	1993/94	2,391	0.41	2,391	0.41
D (60°E-120°E)	CPI	1978/79	1,033	0.44	1,219	0.46
	CPII	1988/89	3,869	0.52	4,202	0.52
	CPIII	1997/98	17,959	0.17	17,959	0.17
	CPI	1980/81	995	0.58	1,913	0.60
E (120°E-170°W)	CPII	1985/86	622	0.50	622	0.50
	CPIII*	1992/93	2,012	0.43	3,484	0.33
	CPIII	2001/02	13,300	0.20	13,300	0.20
F (170°W-110°W)	CPI	1983/84	3,198	0.47	3,240	0.47
	CPII	1990/91	2,801	0.53	2,976	0.51
	CPIII	1997/98	3,852	0.22	3,852	0.22
G (110°W-50°W)	CPI	1982/83	683	0.63	1,452	0.65
	CPII	1989/90	1,505	0.34	2,817	0.38
	CPIII	1996/97	3,337	0.21	3,310	0.21

The sub-committee noted that the most recent estimates for Area II and BSA from CPIII was 1,178 (CV=0.39), and 168 (CV=0.64), respectively. Calculated rates of increase for Area II and BSA were 0.064 (95% CI=-0.021, 0.150) and 0.053 (95% CI=-0.069, 0.174). With regard to Breeding Stocks A and B, the sub-committee believed that these estimates of abundance were very likely to be negatively biased because of the occurrence of humpback whales in unsurveyed areas north of 60°S, where it is known from satellite telemetry that many whales feed (Zerbini *et al.*, 2006). Additional discussion of this paper, and the biases inherent in its abundance estimates, are contained in Item 2.2.4.1, below.

#### 2.2.3.2.2 ALLOCATION OF CATCHES

As noted in the Hobart Workshop, allocation of catches to BSA is relatively simple because of the straightforward connection with Area II. Details are given in SC/58/Rep5 (item 3.9, stock A). For the purpose of the assessment, SC/58/SH2 allocated catches for BSA according to the stock structure hypotheses defined in SC/58/Rep5 ('Core' and 'Fringe' in fig. 8) and also the 'Overlap' hypothesis defined by the IWC (1998). Uncertainty in the origin of whales taken in the Falkland Islands was also considered as suggested by IWC (2005).

#### 2.2.3.2.3 ASSESSMENT

SC/58/SH2 fitted a deterministic sex- and age-aggregated population dynamics model to modern whaling catch data, absolute estimates of abundance and indices of relative abundance, with the goal of estimating pre-exploitation population size ( $K$ ), the maximum net recruitment rate ( $r$ ), the maximum depletion level ( $N_{min}/K$ ), and other status indices. A Bayesian statistical method was used to calculate probability distributions for the model parameters and other quantities of interest. Prior distributions were set on  $r$  and on the population in 2005 (Uniform [ $\ln(550)$ ;  $\ln(20,000)$ ]). A total of 5,000 samples were used to compute the joint posterior distribution of the model parameters using the Sampling-Importance-Resampling (SIR) algorithm. The input data included in all models were the trend estimate presented in SC/58/SH14 (0.074, 95% CI=0.06-0.145) and the absolute abundance in 2005 provided in SC/58/SH15 (6,251, 95% CI=4,242-8,260). In addition, sensitivity analyses to various scenarios were conducted as follows (details in SC/58/SH2):

- (1) priors distributions on  $r$ : three priors were used, an uniform (0, 0.106), a normal prior corresponding to a meta-analysis of the growth rate of several recovering populations of baleen whales (mean = 0.067, SD = 0.04) (Branch *et al.*, 2004) and the posterior distribution from a previous assessment of Breeding Stocks D and E (median = 0.117, 95% credibility interval = 0.078-0.126) (Johnston and Butterworth, 2005);
- (2) choice of relative indices of abundance: three scenarios were investigated using (a) data from the feeding grounds associated to BSA (SC/A06/HW6), (b) data from the breeding grounds (SC/58/SH15) and (c) data from both of these regions combined;
- (3) catch allocation: six scenarios were considered using a combination of the distribution of catches specified in Item 2.2.3.2.3;
- (4) genetic constraint: a lower boundary on the historical minimal population size was set ( $N_{min} = 4 \times$  number of haplotypes in the population = 264);

- (5) depensation: four scenarios were investigated with depensation occurring at population sizes at 1%, 3%, 5% and 10% of  $K$ .

In discussion, it was noted that while some variation was observed in model outputs depending on the prior or the data used, consistency was observed in almost all scenarios. The catch series had the highest impact on the estimate of  $K$  and therefore misallocation of catches or underreporting should cause bias in the estimate of status parameters.

There was some discussion on the shape of the population trajectory output from the model regarding the effect of possible depensation and the delays in recovery to which this could lead.

It was **agreed** that new model runs would be conducted using the following data:

- (1) uniform prior distribution on  $r$  [0, 10.6%];
- (2) the 2005 absolute abundance of 6,251 (CV=0.16) (SC/58/SH15);
- (3) trend estimate of 7.4% year<sup>-1</sup> (CV = 0.48) (SC/58/SH14);
- (4) the feeding and breeding ground indices of abundance (SC/A06/HW6, SC/58/SH15);
- (5)  $N_{min} > 264$  (4x number of haplotypes in BSA, SC/A06/HW41).

These additional model runs included sensitivity analysis to Core (Table 2, Case A, Fig. 1) and Overlap (Table 2, Case B, Fig. 2) catch allocation hypotheses. In addition, sensitivity to a higher abundance estimate was explored (Table 2, Case C). The latter was arbitrarily set 25% higher than the current 2005 population size, had a CV of 0.20, and was included solely to evaluate sensitivity to a larger population size. Because of turn over of whales in the breeding grounds, it is believed that not all the population was accounted for in the aerial surveys. In addition, these surveys were corrected for availability bias, but not perception bias. Therefore, the absolute abundance estimate included in the assessment of breeding stock A may be underestimated.

In discussion of the results, it was noted that the long period at low population level could be explained by continued sporadic catches.

IDCR/SOWER estimates were used as an index of relative abundance in the model, but are known to be smaller than absolute abundance calculated from the breeding ground, possibly due to the fact that the surveys did not extend far enough north to fully cover populations at high latitude. This analysis therefore makes the assumption

that the trend in the subset of the population surveyed is representative of the overall feeding population. However, omitting these indices did not greatly affect the results.

The question arose in discussion whether an attempt was made to find and include missing catches from Brazilian land stations from 1929-46. It was clarified that an attempt had been made to acquire these data, but few records had been kept. While catches do not appear to have been very high compared to what was taken in South Georgia during the same period, it is not known the implications of these catches to the recovery of the population. A preliminary analysis showed that underreporting should result in an overestimation of current population status (e.g. Zerbini, 2004).

#### 2.2.3.2.4 CONCLUSIONS

Point estimates of current population status of BSA ranged from 27-34% of its pre-exploitation level (Table 2). Model parameter estimates were more sensitive to the differences in the catch allocation hypothesis. The sub-committee **agreed** that there has been an observed increase in the population in recent decades, but that the stock was estimated to remain well below initial population levels.

#### 2.2.3.3 BREEDING STOCK G

##### 2.2.3.3.1 ABUNDANCE AND TRENDS

In the Hobart Workshop (SC/58/Rep5), it was agreed that two BSG abundance estimates would be used in assessment modelling: one from the breeding ground (2,917, CV=0.19, SC/A06/HW13) and another from the feeding grounds (3,851, CV=0.02, SC/A06/HW56). However, the workshop also noted the latter required more detail to fully evaluate the method used to compute it, but no additional information had been made available in the short time since that workshop. The sub-committee also received recent IDCR/SOWER estimates of abundance from circumpolar surveys presented at the Hobart workshop (SC/A06/HW6). The most recent estimate for breeding stock G from CPIII was 3,337 (CV=0.21, approximate mid-year 1996/97, SC/A06/HW6). The calculated rate of increase was 4.6% (95% CI=-3.4, 12.6%).

No trend data were available for BSG. However, relative abundance trend estimates were available from IDCR/SOWER data for Area I (50°W-110°W), an area that was intermediary to the Core and Fringe areas of BSG (see below). These estimates are presented in Table 1. It was

Table 2

Selected BSA model parameter estimates. Posterior medians with the 5<sup>th</sup> and 95<sup>th</sup> percentiles (in brackets) are reported. In all scenarios an  $N_{min} > 264$  constraint is imposed.

	A	B	C
<b><math>r</math> prior:</b>	$r \sim U[0, 0.106]$	$r \sim U[0, 0.106]$	$r \sim U[0, 0.106]$
<b>Historic catch:</b>	Core	Overlap	Core
<b>Recent abundance:</b>	$N=6251$ , CV=0.16	$N=6251$ , CV=0.16	$N=7814$ , CV=0.2
<b>Trend information:</b>	7.4% yr <sup>-1</sup>	7.4% yr <sup>-1</sup>	7.4% yr <sup>-1</sup>
$r$	0.066 [0.019; 0.092]	0.066 [0.02; 0.092]	0.069 [0.022; 0.099]
$K$	24,691 [23,340; 29,593]	21,117 [19,894; 25,527]	24,566 [23,029; 29,380]
$N_{min}$	528 [273; 2,931]	602 [274; 3,058]	571 [277; 3,256]
$N_{2006}$	6,712 [4,848; 9,278]	6,770 [4,794; 9,369]	8,477 [5,747; 12,412]
$N_{min}/K$	0.021 [0.012; 0.099]	0.029 [0.014; 0.121]	0.023 [0.012; 0.11]
$N_{2006}/K$	0.268 [0.183; 0.382]	0.316 [0.213; 0.458]	0.342 [0.219; 0.516]
$N_{2020}/K$	0.587 [0.263; 0.848]	0.661 [0.305; 0.901]	0.711 [0.329; 0.943]
$N_{2040}/K$	0.963 [0.388; 0.998]	0.976 [0.444; 0.999]	0.984 [0.495; 1]

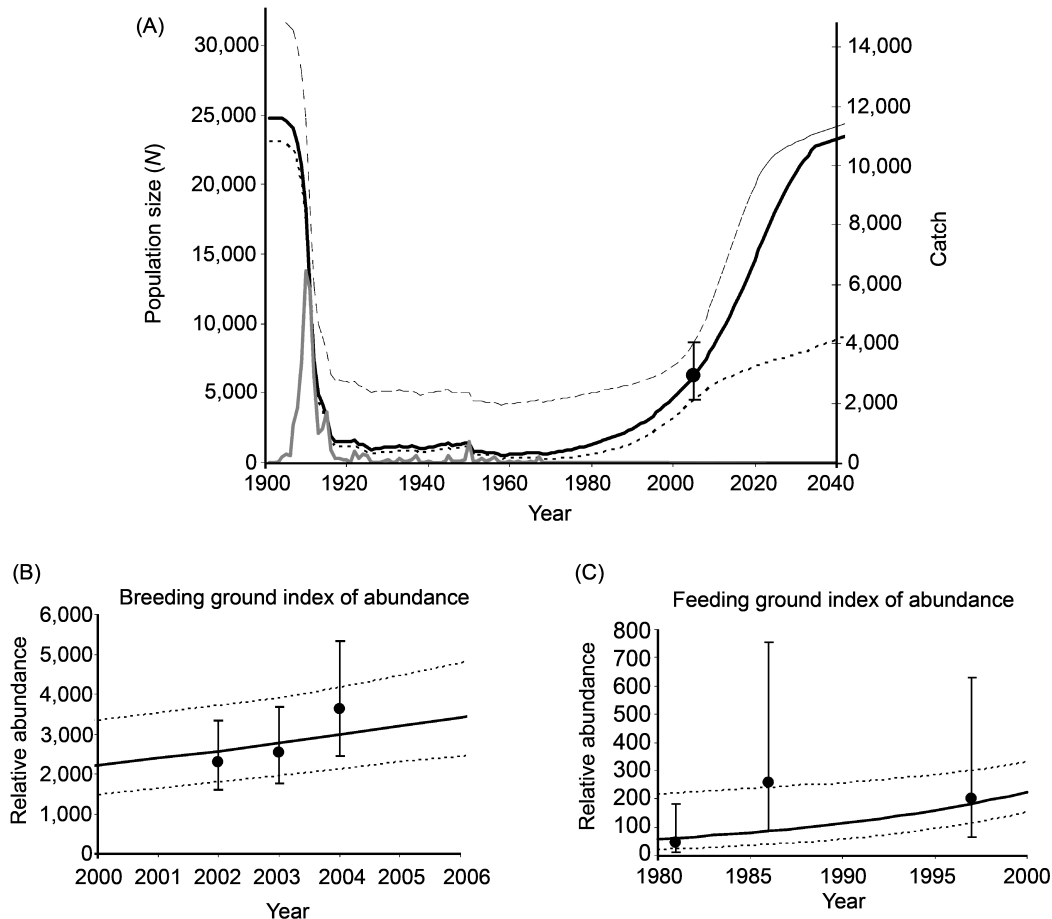


Fig. 1. A – Population trajectory of assessment modelling results for BSA in Case A, Table 2 (grey line = Core catches). B and C – model fit to the indices of relative abundance. Solid lines show the median trajectories and dashed lines correspond to the 5<sup>th</sup> and 95<sup>th</sup> percentiles. The single dots shows the abundance estimates with the 95% CI.

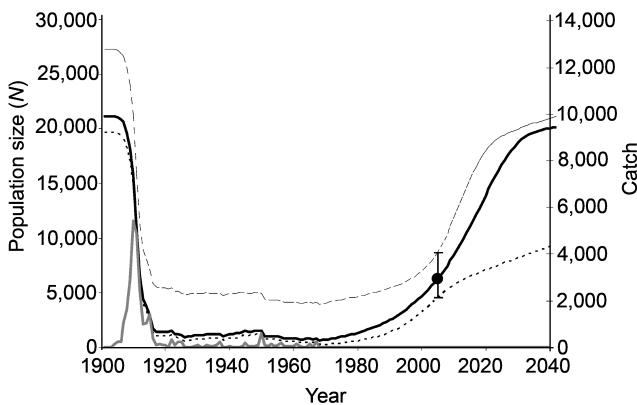


Fig. 2. Population trajectory of assessment modelling results for BSA in Case B, Table 2 (grey line = Overlap catches).

noted in discussion that there was less confidence in trend data for BSG because they resulted from surveys on the feeding ground where breeding stocks may mix.

#### 2.2.3.3.2 ALLOCATION OF CATCHES

Most of the catches occurred in the Antarctic Peninsula region and there is a relatively straightforward connection from there to Colombia and equatorial western South America (SC/58/Rep5). As noted in the Hobart Workshop report, the breeding location for animals feeding at Magellan Strait is unknown, but likely also lies within BSG. New information on the extension of feeding area to

northern Patagonia is presented in under Item 2.2.4.1. Catch allocation for the Core hypothesis therefore encompasses the area 50°W-100°W. The Fringe hypothesis area only extends west from the Core (50°W-130°W). These areas are shown in SC/58/Rep5, fig. 8. There is very little difference in total catch between Core and Fringe areas of BSG, making this a relatively unimportant distinction for this breeding stock.

#### 2.2.3.3.3 ASSESSMENT<sup>1</sup>

SC/58/SH23 presented a Bayesian stock assessment model incorporating updated historic catch series, current abundance and population trend information agreed in SC/58/Rep5. This sex- and age-aggregated production model was run with both Core and Fringe historic catch area hypotheses, as well as both the SC/A06/HW13 and SC/A06/HW56 recent abundance estimates. In the absence of trend data for this breeding stock, the prior distribution for  $r$  was obtained from a model fit to both Breeding Stocks D and E, allowing for mixing on the feeding grounds. Populations were projected into the future under a continuation of a zero harvesting strategy. Sensitivity analysis was performed on catch history values, the prior specified for  $r$  and the possibility of depensation. There was little sensitivity to the catch history used in the model and far greater sensitivity to the recent abundance estimate value. The use of the SC/A06/HW13 estimate in the reference case suggested BSG to be around 39% of  $K$  in

<sup>1</sup> see footnote on p.30 of this volume.



2006, while the use of the SC/A06/HW56 estimate produced a more optimistic result of 80% of  $K$ . An informative prior for  $r$  was considered to be important for this stock, because otherwise the median posterior for  $r$  was simply the average of 0-0.126. Depensation produced a smaller posterior  $r$  estimate (0.095) than to models run without it (0.117). The median  $N_{min}$  values were found to increase, as did the estimates of current abundance, both in absolute terms and relative to  $K$ . For the reference case, BSG was estimated to reach 94% of  $K$  (with the SC/A06/HW13 estimate) or 100% of  $K$  (with the SC/A06/HW56 estimate) by 2020.

The sub-committee discussed how much weight should be placed on the SC/A06/HW56 estimate. The sub-committee considered the CV of this estimate (0.02) to be unrealistically low and some methodological questions remained unresolved since the Hobart meeting. It was **agreed** that the conservative approach would be to focus the present assessment modelling on the SC/A06/HW13 estimate with the IDC/SOWER estimate (SC/A06/HW6) used as an alternative. However, it was **recommended** that the methodology of SC/A06/HW56 be presented and reviewed in greater detail next year.

It was **agreed** that new model runs would be conducted using the following data:

- (1) Core, Fringe and an Overlap catch hypothesis scenario (80% of catches from Naïve area G, plus 10% from Naïve A and Naïve F);
- (2) breeding ground estimate of abundance in 2003/04 ( $n=2,917$ ,  $CV=0.19$ ) from SC/A06/HW13;
- (3) feeding ground estimate of abundance in 1997 ( $n=3,337$ ,  $CV=0.21$ ) from IDC/SOWER (SC/A06/HW6);
- (4) relative abundance indices from IDC/SOWER data (SC/A06/HW6);
- (5)  $r \sim U[0, 0.106]$  and  $r$ -posterior (BSA);
- (6) genetic constraint of  $N_{min} > 108$  [4x number of haplotypes] (Olavarria and Baker, unpublished data – originally presented as Olavarria *et al.* (2003)).

Selected model outputs are presented in Table 3 and Fig. 3.

#### 2.2.3.3.4 CONCLUSIONS

Assessment modelling results for BSG proved to be insensitive to the selection of catch allocation hypotheses (Fig. 3). However, the results were particularly sensitive to recent abundance estimate assumptions. Fitting models with IDC/SOWER trend data (and an uninformative prior on  $r$ ) produced a median point estimate of current abundance of 0.39 relative to initial population size for the breeding

ground estimate of absolute abundance in 2003/04 (SC/A06/HW13) (Table 3, Case A) versus of 0.67 for IDC/SOWER abundance in 1997 (Table 3, Case B). When the IDC/SOWER trend data were omitted and the prior on  $r$  was taken from Stock A, the model using the breeding ground estimate of abundance produced a slightly more pessimistic result (0.30, Table 3, Case C). This was likely due to a smaller median  $r$  that was estimated with the  $r$ -posterior (Stock A).

Some considered Case A in Table 3 to be most plausible because it relied solely on data from the BSG and did not include feeding ground abundance estimates. Others felt that

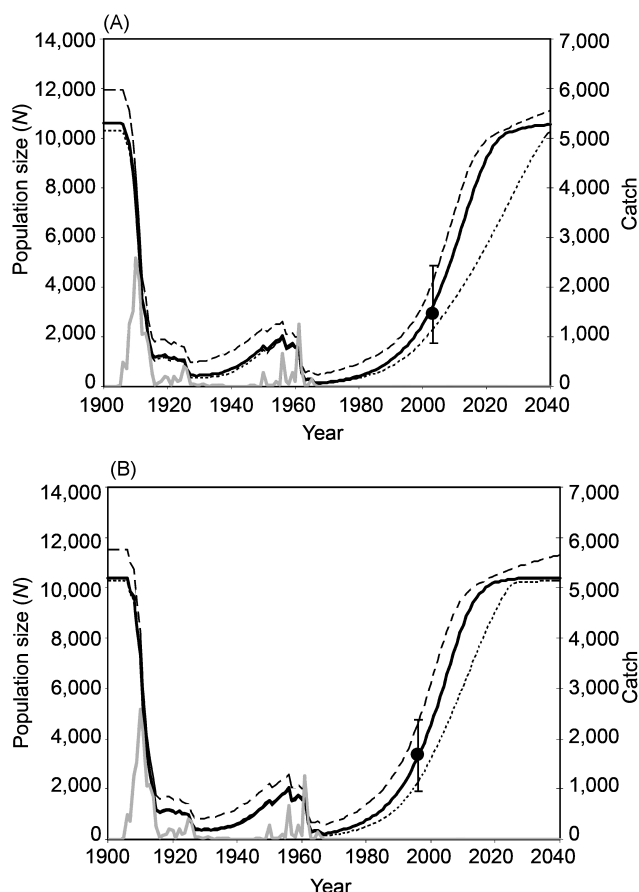


Fig. 3. Population trajectories of base case assessment modelling results for BSG. A – Case A, Table 3 and B – Case B, Table 3. The lines show the median population trajectories with the 5<sup>th</sup> and 95<sup>th</sup> percentiles. The single dot shows the abundance estimate with the 95% CI. The historic catch series is plotted in gray.

Table 3

Selected BSG model parameter estimates. Posterior medians with the 5<sup>th</sup> and 95<sup>th</sup> percentiles (in parentheses) are reported. In all scenarios an  $N_{min} > 108$  constraint is imposed.

	A	B	C
<b><math>r</math> prior:</b>	$r \sim U[0, 0.106]$	$r \sim U[0, 0.106]$	$r \sim \text{posterior}(\text{Stock A})$
<b>Historic catch:</b>	Fringe	Fringe	Fringe
<b>Recent abundance:</b>	$N=2,917$ ; $CV=0.19$	$N=3,337$ ; $CV=0.21$	$N=2,917$ ; $CV=0.19$
<b>Trend information:</b>	IDC/SOWER trend	IDC/SOWER trend	None
$r$	0.092 [0.045; 0.104]	0.100 [0.057; 0.107]	0.064 [0.022; 0.088]
$K$	10,594 [10,285; 11,947]	10,406 [10,260; 11,539]	11,482 [10,683; 14,001]
$N_{min}$	150 [120; 500]	251 [159; 629]	340 [146; 1241]
$N_{2006}$	4,102 [2,812; 5,367]	6,973 [4,845; 8,624]	3,464 [2,460; 4,801]
$N_{min}/K$	0.014 [0.012; 0.042]	0.024 [0.015; 0.054]	0.030 [0.014; 0.089]
$N_{2006}/K$	0.385 [0.238; 0.514]	0.668 [0.429; 0.833]	0.298 [0.191; 0.427]
$N_{2020}/K$	0.868 [0.466; 0.959]	0.982 [0.773; 0.995]	0.627 [0.278; 0.862]
$N_{2040}/K$	0.999 [0.849; 1.000]	1.000 [0.981; 1.000]	0.968 [0.428; 0.998]

there was not strong basis for discriminating between these alternatives at this time. The SC/A06/HW56 estimate was also based on breeding ground data and its use would result in a slightly more favourable breeding stock status, if further review deems the methodology acceptable. The sub-committee also reiterated that assessment results for BSG are considerably less reliable because of the absence of trend information from the breeding ground. The potential for bias due to mixing at high latitude, and therefore the reliability of IDCR/SOWER trend data for this purpose may be clarified by planned circumpolar genetic analysis of stock structure.

The sub-committee **agreed** that no firm conclusions could be drawn about the status of BSG given that point estimates of current abundance ranged from 30-70% of initial population size.

### 2.2.3.4 BREEDING STOCK D

#### 2.2.3.4.1 ABUNDANCE AND TRENDS

SC/A06/HW3 presented results of an aerial survey off Carnarvon, Western Australia in 2005 and a technique for using aerial and land-based results to obtain an estimate of  $g(0)$ . During the Hobart Workshop, it was determined that the 2005 estimate of abundance should not be used because of the potential problems identified by the authors. However, it was agreed that a revised estimate for 1999 accounting for  $g(0)$  (10,032; 95% CI=8,038-12,519) should be used for modelling purposes (SC/58/Rep5, item 5.2.1, Stock D).

Estimates of abundance from circumpolar surveys presented at the Hobart Workshop (SC/A06/HW6) were also reviewed for BSD. Methods were the same as those previously described (see Item 2.2.3.2.1). The most recent estimate from CPIII was 17,959 (CV=0.17). In addition, a feeding ground estimate of 31,750 (CV=0.11) was available from JARPA surveys (SC/A06/HW57).

Trend data were available from the breeding ground for the period spanning 1982-94 at 0.101 (IWC, 1996). For the feeding grounds, available trend data included JARPA (SC/A06/HW57) and IDCR/SOWER data (SC/A06/HW6). These data were summarised in table 3a of SC/58/SH23. The IDCR/SOWER feeding ground estimate of rate of increase for BSD was estimated at 0.144 (95% CI=0.096, 0.192, SC/A06/HW6). Sub-committee members recalled previous discussions on high rates of increase calculated from a time series of abundance estimates (Item 2.2.1). The rate of population increase on the feeding grounds for BSD exceeds the theoretical maximum for rate of increase, as calculated from demographic information for a closed population. It may therefore be worthwhile to investigate the possibility of movement between feeding grounds.

#### 2.2.3.4.2 ALLOCATION OF CATCHES

During the Hobart Workshop, it was agreed that BSD is most closely connected to Area IV, but that there is potential mixing with Areas III and V (SC/58/Rep5, item 3.9, Stock D). On the basis of *Discovery* mark data, the catch allocation areas for BSD were re-defined at the Workshop as 80°E-100°E (Core) and 50°E-130°E (Fringe). The bulk of the catches came from feeding areas and there were nearly twice as many in the Fringe as the Core area (SC/58/SH23).

#### 2.2.3.4.3 ASSESSMENT

SC/58/SH23 presented a Bayesian stock assessment model incorporating updated historic catch series, current abundance and population trend information agreed in SC/58/Rep5. This sex- and age-aggregated production

model considered both Core and Fringe historic catch areas. Recent abundance was modelled using the estimate provided by SC/A06/HW3, as well as recent feeding ground estimates from JARPA and IDCR/SOWER. All available feeding and breeding ground trends were used (see Item 2.2.3.4.1). Populations were projected into the future under a continuation of a zero harvesting strategy. Sensitivity analysis was performed on catch history values, the prior specified for  $r$  and the possibility of depensation. There was little sensitivity detected to historic catches. Use of the breeding ground trend data led to an estimate of present status that was high, whereas feeding ground trend series produced even higher results. The model was unable to match the high rate of increase indicated by JARPA and IDCR/SOWER data. However, there was relatively good agreement between the estimated and observed Catch Per Unit Effort (CPUE) trends for the model variant using the recent estimate of abundance SC/A06/HW3 combined with the breeding ground trend.

There was brief clarification given on how the IDCR/SOWER rate of increase information was taken into account in the model, given its wide time frame. Individual estimates were treated as relative rather than absolute. Only the SC/A06/HW3 abundance estimate was treated as absolute in the model.

The analyses presented in SC/58/SH23 were re-run with an upper bound on  $r$  of 0.106, as agreed in Item 2.2.1. Selected model outputs, using the Fringe and Core catch series, are presented in Table 4 and Fig. 4.

The Core catch allocation hypothesis produced a smaller  $K$  estimate, a similar current absolute abundance estimate and a somewhat more optimistic current abundance estimate relative to  $K$  (Table 4). The median population trajectories for the Core and Fringe hypotheses were similar for the 1960-2000 period (Fig. 4). Subsequent models focused on the Fringe hypothesis. Use of the abundance estimate provided in SC/A06/HW3 in conjunction with trend data from IDCR/SOWER or JARPA made little difference to the assessment results. However, these trend data produced slightly lower  $r$  estimates. The  $N_{min} > 204$  (SC/58/SH22) constraint was never invoked.

Table 4

Selected BSD model parameter estimates. Posterior medians with the 5<sup>th</sup> and 95<sup>th</sup> percentiles (in brackets) are reported.

	Reference case: Fringe	Reference case: Core
Catch history:		
$r$ prior:	$r \sim U[0; 0.106]$	$r \sim U[0; 0.106]$
Recent abundance:	$N=10,032$ ; CV=0.11	$N=10,332$ ; CV=0.11
Trend information:	IWC (1996)	IWC (1996)
$r$	0.091 [0.046; 0.105]	0.090 [0.044; 0.105]
$K$	22,690 [21,152; 29,892]	17,730 [16,380; 24,800]
$N_{min}$	721 [447; 2,189]	767 [470; 2,493]
$N_{2006}$	15,729 [12,496; 17,828]	14,311 [12,227; 15,650]
$N_{min}/K$	0.032 [0.021; 0.073]	0.043 [0.028; 0.101]
$N_{2006}/K$	0.689 [0.420; 0.812]	0.804 [0.503; 0.907]
$N_{2020}/K$	0.978 [0.686; 0.994]	0.990 [0.762; 0.998]
$N_{2040}/K$	1.000 [0.942; 1.000]	1.000 [0.961; 1.000]

In discussion it was noted that a simple model using JARPA data, a constant value of  $K$  and assuming a closed population was unable to reconcile the recovery trajectory with the catch data. Running the model with a time-varying  $K$  parameter and JARPA recent abundance and trend data improved the fit. However, some members questioned why this should be done for BSD and not other stocks as well.

It was noted in discussion that previous models that incorporated mixed stocks on the feeding ground, and using similar data, led to much lower estimates of current population size.

#### 2.2.3.4.4 CONCLUSIONS

Assessment model results for BSD were sensitive to catch allocation hypotheses and to recent absolute abundance estimates. By contrast, the choice of trend series fitted had little effect on model output. The sub-committee noted that absolute abundance estimates for JARPA feeding ground surveys will be subject to review over the coming year and this may improve information available to assessment. Furthermore, the sub-committee noted its continuing concern about the potential for exchange with BSE on the feeding ground. As noted above, previous models that incorporated mixed stocks on the feeding ground, and using similar data, led to much lower estimates.

The sub-committee **agreed** that in light of the above, the present assessment modelling results should be considered preliminary and should be re-evaluated in the future. This will first require clarifying stock structure of Oceania and Pacific Island populations and the extent of mixing at high latitudes. However, the sub-committee noted that the population has made a substantial increase since protection.

#### 2.2.3.5 GENERAL CONCLUSIONS

The sub-committee **agreed** that of the three stocks assessed, the most reliable results were those from BSA. This is because there was trend information from surveys on the breeding grounds and less uncertainty about catch allocation from the feeding grounds. For BSG, the only trend information available was for the feeding grounds and there was also uncertainty about possible stock structure within BSG. For BSD, although there is breeding ground trend information and an absolute estimate of abundance, catch allocation is less certain and perhaps influenced by mixing with BSE.

### 2.2.4 Information on other stocks

#### 2.2.4.1 FEEDING GROUNDS

SC/58/SH10 reported a new humpback whale feeding ground in northern Patagonia, Chile. An increasing number of humpback whales have been recorded during austral summer and autumn months in the Northern Chilean Patagonia, especially in the Corcovado Gulf (43°-44°S) and Moraleda Channel (44°-44°30'S). Between 2001 and 2006, a total of 145 humpback whale sightings, including at least 12 calves, were recorded from opportunistic platforms and through dedicated aerial and vessel surveys. During the 2005 and 2006 austral summer field seasons alone, a total of 107 humpback whales were observed from a land-based vantage point at the north end of Ascension Island, GUAITECAS Archipelago. Local knowledge of land-based whaling suggests the historic presence of humpback whales in the area and recent observations confirm feeding groups and mother-calf pairs. The Chiloé-Corcovado region could be regarded as the northern-most feeding ground for humpback whales in South America, extending the previous record (Carlos III Island, Magellan Strait) by some 1,081km. This possibly indicates a punctuated continuum in the feeding distribution of this species on predictably productive areas along the southwestern margin of South America to at least 42°S.

The author clarified that he had not yet submitted images to the Antarctic Humpback Whale Catalogue (AHWC), but would consider doing so in the future. In response to a question about historic whaling activities, he noted that there are three known coastal whaling stations, but no formal records of humpback whaling activities. However, a grandchild of a whaler remembers his father telling him about catches of 'long winged whales'. The author was also asked if this was likely new expansion of humpback whales into the area. He commented that evidence for historic whaling suggests against it, but that this was the first year that many humpback whales were seen, despite several previous years of field effort. It remains uncertain whether this is related to population resurgence, distribution or a question of sighting effort. He further noted that type of prey was unknown, but likely euphausiids. Oceanographic work is planned to address this question.

SC/58/SH17 described sightings of humpback whales feeding off the northwest end of Chiloé Island, Chile. Fieldwork was conducted from 3 February to 15 April from vessel and aerial surveys. Twelve vessel surveys were conducted within 22km of the coastline, 41°45'S-42°05'S. One aerial survey was conducted within 3-15km of the coast from a Chilean Navy aircraft and covered 200km of coastline, 40°57'S-42°37'S. Twelve groups, containing 17 humpback whales, were observed between 16 February and 1 March 2006. Groups consisted of one or two individuals and feeding and defecation were both observed. Eleven individuals were photographed by dorsal fin and fluke, when possible, including four juveniles and a mother-calf pair. Six individuals with fluke photographs were not successfully matched to the AHWC. The authors noted that these whales extend the Magellan Strait Feeding Area to at least 41°S. However, because of their low density these humpback whales may represent the northern limit of that area.

In response to a question, the authors clarified that one of the fluke photographs was from a calf, but that had not been accounted for. Therefore, the six flukes from non-calf individuals had a stable pigmentation pattern.

The sub-committee **recommended** that photo-identification and biopsy sampling efforts continue in this area to facilitate comparison to other areas. It also **recommended** extending surveys further north that 41°S along the coast of Chile to determine the northern extent of this population. Like the Magellan Strait population, the existence of feeding populations at this latitude in summer emphasises the importance of evaluating inference from Antarctic abundance estimates. The sub-committee recalled that the Hobart Workshop had concluded that a single stock was likely for BSG. Some sub-committee members questioned that assumption in light of new evidence for feeding grounds at mid-latitudes, including Southern Chile.

SC/58/SH13 discussed abundance estimates from the 1995 BROKE East and 2006 BROKE West surveys which covered areas within IWC areas III E and IV, respectively. The paper was provided as an update to SC/A06/HW37 and addressed a specific request by the Hobart Workshop for more detail on survey methodology and results.

The sub-committee welcomed this work and thanked the author for his prompt response to the workshop request. It was further discussed that these surveys were conducted opportunistically from a vessel engaged in krill surveys and the estimates should be evaluated in this light.

SC/58/SH6 examined whether abundance estimates for Southern Hemisphere humpback whales were biased due to the survey modes in JARPA. The results of Generalised

Linear Modelling revealed no significant effect of survey modes on abundance estimates. The results also supported estimates presented in SC/A06/HW57.

SC/58/SH21 reported updated distributions and abundance estimates of humpback whales in the Antarctic Areas IV (70°E-130°E) and V (130°E-170°W) in the waters south of 60°S, based on JARPA sighting data. In addition, information on JARPA sighting survey design is provided, which is important for interpreting results of distribution and abundance, and which was requested in the Hobart Workshop. Humpback whales were widely distributed in Areas IV and V. A distribution gap is observed around 130°E-140°E, which is possibly related to the hydrographic features. Further, it was found that humpback whales were concentrated between 90° and 120°E in northern and southern strata (eastern side of the Kerguelen Plateau), and were widely dispersed in other part of Area IV. Habitat expansion of humpback whale was observed in Area IV from the first half (1989/90-1996/97) to the later half of surveys (1997/98-2003/04). Abundance was estimated using the *DISTANCE* analysis program. Most recent abundance estimates were 31,750 (CV=0.11) in 2003/04 season in Area IV and 9,765 (CV=0.33) in 2004/05 season in Area V. JARPA estimates were not significantly different from SOWER estimates in Areas IV and V between 1989/90 and 2004/05 seasons, except the recent two estimates in Area IV. Only the recent two estimates in 2001/02 and 2003/04 seasons were larger than previous estimates. Design of JARPA sighting surveys was discussed. However, there was no difference in survey design before and after 2001. The orders of strata in 2001/02 and 2003/04 seasons were the same as 1999/2000 season. In other words, there are no effects of the survey design and potential sources of bias in these two high estimates. It was concluded that such design could not substantially bias the abundance estimates and trend of humpback whales in the Antarctic.

SC/58/SH6 and SC/58/SH21 provided information requested in the Hobart workshop with regards to JARPA survey methodology. Appreciation was expressed for the authors prompt response to these requests. Discussion of these papers is summarised in Annex G, item 4.

SC/A06/HW6 was submitted to the Hobart Workshop and summarises estimates of abundance for humpback whales in the austral summer based on IDCR/SOWER circumpolar (CP) sighting surveys. These have encircled Antarctica three times: 1978/79-1983/84 (CPI), 1985/86-1990/91 (CPII) and 1992/93-2003/04 (CPIII). Circumpolar estimates with approximate midpoints of 1980/81, 1987/88 and 1997/98 were 7,100 (CV=0.36), 10,200 (CV=0.30) and 41,800 (CV=0.11). There was considerable discussion of these estimates at the Hobart Workshop. Estimates were negatively biased because they assumed that all whales on the track line were sighted and because some humpback whales likely remained north of the surveyed area. Furthermore, only the third circumpolar survey surveyed the entire region south of 60°S.

The Scientific Committee has identified a number of potential concerns when comparing minke whale estimates from different IDCR/SOWER circumpolar survey sets. The sub-committee suggested that there needs to be a thorough review to see to what extent these concerns also apply to humpback whales when making quantitative comparisons. On this subject, Hatanaka stated that, unlike minke whales, humpback whales were not found in the Ross Sea or Prydz Bay during JARPA surveys. Furthermore, ice breakers did not report seeing humpback whales in pack ice areas. It was his opinion that the degree of ice extension would not have

had a great impact on humpback whale abundance estimates. With respect to the northern extent of the survey, SC/58/IA1 reported 149 groups of humpback whales (377 animals) during a systematic survey in January 2006 between 55°-61°S and 005°-020°E. There may be other factors that are of concern for humpback whales that were not considered for minke whales. The distribution of a feeding aggregation might shift from year to year, including farther south. Few data exist with which to evaluate the presence of humpback whales in the mid-latitudes and this was discussed further in Item 2.2.4.7.

#### 2.2.4.2 BREEDING STOCK B

SC/A06/HW10 contained information relevant to BSB and was available to the sub-committee. However, it was not presented or discussed at the meeting due to time constraints. The sub-committee thanked the authors for their efforts and **recommended** that the paper be considered in next year's meeting.

#### 2.2.4.3 BREEDING STOCK C

SC/58/O6 and SC/58/O13 provided new information on humpback whales from BSC2. Of particular interest was the new work from the Comoros Archipelago (SC/58/O6), which included the creation of a photo-identification catalogue of 153 individuals. The sub-committee acknowledged the submission of this work which addresses data gaps identified at the Hobart Workshop, and **recommended** the continuation of this work in the future.

SC/A06/HW9, SC/A06/HW12 and SC/A06/HW16 also contained information relevant to BSC. These papers were submitted to the Hobart workshop and were available to the sub-committee, but not presented or discussed due to meeting time constraints. The sub-committee thanked the authors for their efforts and **recommended** that the papers be considered at next year's meeting.

#### 2.2.4.4 BREEDING STOCK E

Several papers pertaining to BSE were submitted to the Hobart Workshop and available to the sub-committee, but were not presented or discussed due to time constraints. These included SC/A06/HW17, SC/A06/HW23, SC/A06/HW27, SC/A06/HW32, SC/A06/HW34, SC/A06/HW35, SC/A06/HW36 and SC/A06/HW51. The sub-committee thanked the authors for their efforts and **recommended** that the papers be considered at future meetings.

#### 2.2.4.5 BREEDING STOCK F

SC/58/SH5 described photo-identification and biopsy sampling at American Samoa. *Ad hoc* surveys were performed from a 7m vessel in the coastal waters of Tutuila on 27 days in late September-early October, 2003-05. The detection rate was consistently low, averaging 5.5 humpback whales per day in all three years. Observed behaviours were consistent with other low-density breeding grounds. Of the individuals that could potentially be re-identified, 20.7% ( $n=19$ ) were resighted on two or more days within a single season. The maximum interval between re-sightings was 14 days and the average was 2.8 days. Of 50 individuals with sufficient photo-documentation, none were re-sighted there between years. However, 11% ( $n=4$ ) of those photo-identified prior to 2005 were successfully matched to other breeding sites in Oceania. At a longitude of 170.5°, American Samoa lies near the boundary of Breeding

Stocks E and F. Three matches to date were made to the Cook Islands and French Polynesia (BSF) and the fourth was to Tonga (BSE). To date there have been no successful high latitude matches. In the future, molecular genetic analysis of skin samples from this area ( $n=45$ ) may help to clarify breeding stock structure and migratory destinations.

In response to a question, the author clarified that survey effort was non-systematic and limited to within three miles of the coastline for logistical reasons. Mattila added that surveys had not been conducted in waters deeper than 100 fathoms.

#### 2.2.4.6 BREEDING STOCK X

No new information was submitted on BSX.

#### 2.2.4.7 FUTURE ASSESSMENTS

At the Hobart Workshop, it was agreed that information on stock structure, catch, abundance and trends were sufficient to discuss and attempt to finalise assessment modelling for Breeding Stocks A, D and G. However, surveys for estimating abundance should continue for such stocks, for example in BSD. Recommendations were also made to address uncertainties for other stocks, notably B, C, E, F and X (SC/58/Rep5, annex H). However, some were general recommendations, no priority was established and no timeline was defined to finalise the proposed work.

The sub-committee **agreed** that Breeding Stocks B and C would be given the next priority and the following tasks would be undertaken at next year's meeting:

- (1) present and discuss abundance estimates;
- (2) examine potential to estimate trends from mark-recapture analysis;
- (3) update progress on stock structure hypothesis in the breeding grounds;
- (4) examine feeding ground/breeding ground differentiation and connectivity (for catch allocation);
- (5) examine stock structure of feeding grounds;
- (6) attempt to reach agreement on stock structure hypotheses, catch allocation, abundance estimates and trends in abundance;
- (7) attempt the completion of Assessment for Breeding Stocks B and C.

In the event that this work is not completed, it was **agreed** that Items 6 and 7 should be continued in 2008. However, new information on other breeding stocks would also be discussed during these two meetings.

The sub-committee also **recommended** that outstanding corrections to the revised 1948/49-1971/72 catch data be completed intersessionally, but indicated that the changes were unlikely to affect analyses that have already been performed.

It was previously noted (Item 2.2.4.1) that Japanese Scouting Vessel (JSV) data could potentially be used to gain insight into the relative number of whales found north of 60°S, but south of the breeding grounds, where they are missed by IDCR/SOWER survey effort. This could potentially be used to correct absolute feeding ground abundance estimates to account for animals north of typical feeding ground surveys. A similar exercise was previously done to extrapolate IDCR/SOWER estimates for all species south of 60°S, but more data are now available. It was noted, however, that it may be difficult to draw modern inference from JSV data because the data are not recent. Historic catch data could also potentially be used.

The sub-committee **recommended** that the JSV data be examined for this purpose and Matsuoka agreed to pursue this intersessionally.

The sub-committee discussed several potential areas for further work to advance assessment modelling efforts. It was reiterated that even the 4x form of  $N_{min}$  is quite conservative and priority should be placed on developing an approach (such as a prior distribution for  $N_{min}$ ) that is more realistic in light of the simple form of the model used. Furthermore, the possible roles of depensation, and differing decline and recovery dynamics, delaying stock recovery merits further investigation.

It was noted that work on  $N_{min}$  with a view to refining the estimate and developing a working prior on this parameter for use in logistic models is planned. It was **agreed** that although it may be premature to develop age structured models, it is possible to incorporate  $N_{min}$  into an age aggregated model framework in an *ad hoc* fashion. It was anticipated that work towards this goal will be conducted intersessionally. Mention was also made of the fact that  $N_{min}$  had not actually been an important factor in any of the assessments performed this year, likely due to the new lower prior on the maximum level of  $r$  combined with the low values for  $N_{min}$ .

Following this discussion, the sub-committee recognised that these are simple models but that  $N_{min}$  and depensation are important issues that require further examination and **recommended** that this work be done.

The sub-committee also discussed the potential value of developing multistock models to address situations in which stocks are mixing. This could be particularly important for the future assessment of breeding stocks E and F. Alternative specifications for density dependence (e.g. on the feeding ground rather than the breeding ground) will be important to consider in cases of mixed stock assessments.

#### 2.2.5 Antarctic humpback whale catalogue (AHWC)

SC/58/SH19 summarised the findings and advances in the AHWC over the past year. During the contract period, the AHWC catalogued 1,182 photo-identification images representing 823 humpback whales from Antarctic and Southern Hemisphere waters. Images were submitted by 28 individuals and research organisations. There were a total of 4,449 photographs of 2,594 individual whales. Of these, 183 individuals were identified in more than one year and 41 individuals were sighted 3 or more times in different areas or years. New between-area matches were made between the Antarctic Peninsula and Colombia ( $n=4$ ) and the Antarctic Peninsula and Ecuador ( $n=10$ ). Animals previously catalogued at the Antarctic Peninsula ( $n=61$ ) and Brazil ( $n=61$ ) were re-sighted in the same locations. The longest interval between re-sightings was 18 years for an individual sighted in 1986 and again in 2003. SOWER data from 2001 to 2006 will be analysed this year and made available, in accordance with IWC policy, in the public access catalogue by SC/59. Efforts continued to stimulate submission of opportunistic data from eco-tourism cruise ships in the Southern Ocean, as well as from research organisations and expeditions working throughout this region and in the Southern Hemisphere. The availability of this data has broadened our understanding of the exchange between areas and, in some cases, allowed for new discoveries. For example, an individual photographed by a cruise ship off South Georgia in 2004 was previously seen off Brazil, resulting in the first long-distance re-sighting of an individual from these areas. The

AHWC provides a unique clearinghouse for such data, making the photographs and analysis available to other researchers.

The sub-committee welcomed this report and **recommended** that this work continue.

#### 2.2.6 Other information

SC/58/SH11 examined the relevance of the JARPA II program to the objectives of the Comprehensive Assessment of Southern Hemisphere humpback whales. The authors considered the recommendations made by the Hobart Workshop and the methodological approaches that were identified. They concluded that JARPA II would contribute useful information on stock structure through biopsy sampling, and on distribution and abundance through sighting surveys. However, they felt that the lethal sampling of 50 humpback whales planned to begin in the 2007/2008 season would provide nothing of value to the Comprehensive Assessment (CA). Biological parameters could be obtained from longitudinal studies, with upper bounds for modelling set in theoretical terms (see SC/58/SH4). By contrast, further demonstration (through stomach content analysis) that humpback whales eat krill was considered unnecessary by the authors and irrelevant to the CA process. It was their view that studies of feeding ecology could be more reliably conducted using whales tagged with data loggers and concurrent oceanographic sampling. Finally, the authors stated that contaminant data are not a priority for the CA and could be obtained through biopsy sampling. Overall, the authors concluded that lethal sampling was unnecessary for advancing the objectives of the CA, and that well-established non-lethal techniques could provide all of the scientific requirements of the CA as well as those of JARPA II.

In response to SC/58/SH11, Ohsumi and Hatanaka expressed the opinion that lethal and non-lethal methods are both important research techniques. They believed that these should be applied in a comprehensive manner, taking advantage of the strengths of each. They called attention to the fact that while some information can be obtained by non-lethal techniques, such work can be time consuming and impractical in some cases. They drew attention to the question of age at sexual maturity, for which non-lethal techniques require more than a decade of continuous observations on individuals. By contrast, the age and reproductive status of many individual females can be established rapidly by lethal techniques. They also noted that diet, for example, can not be fully understood with available non-lethal techniques and that, when used in isolation, those techniques could lead to false conclusions. It was their view that JARPA II would contribute substantively to ecosystem research in the Antarctic as well as the Comprehensive Assessment of Southern Hemisphere humpback whales.

No consensus existed within the sub-committee on the subject of the JARPA II research proposal and its implications for the Comprehensive Assessment. Additional discussion on this subject can be found in sub-committee reports from this and previous meetings (see Annex O and Annex E).

#### 2.2.7 Future work

Plans for future work in regards to the assessment of Southern Hemisphere humpback whales are provided in the report of the Hobart Workshop (SC/58/Rep5) and above under Item 2.2.4.7.

### 3. IN-DEPTH ASSESSMENT OF SOUTHERN HEMISPHERE BLUE WHALES

#### 3.1 Comprehensive Assessment of Southern Hemisphere blue whales

##### 3.1.1. Distribution and movements

SC/58/SH1 presented a new analysis of blue whale and fin whale distributions in the Southern Ocean, in relation to sea surface temperature, extent of seasonal ice zone, and krill distribution. The summer spatial distribution of the whales was inferred from the monthly catch positions from the IWC whaling dataset between 1931 and 1966. Monthly sea ice climatology was obtained from satellite remote sensing from the early 1970s to 1994, while the Seasonal Ice Zone (SIZ) was defined as the area delimited by the winter maximum (September) and the summer minimum (February) sea ice extent. Krill biomass was extracted from historical densities of krill throughout the summers 1926-51. A general linear model was used to investigate the relationships of seasonal ice zone and krill densities with the longitudinal variability of whale abundance by sectors of 15° of longitude. The results indicated that:

- (1) most of the catches of blue (99%) and fin whales (93%) were located within the Seasonal Ice Zone;
- (2) the abundance of both species was heterogeneous around the Antarctic continent with a greater abundance in the Atlantic, West Indian sector, and to the north of the Ross Sea;
- (3) the blue whales were found exclusively in waters cooler than 2°C while the temperature range encountered by the fin whales was larger, indicating that blue whales were located closer to the ice edge;
- (4) except in the Antarctic Peninsula (south of South Georgia) area, where the seasonal ice zone is low but where the krill population is essentially driven by advection, the circumpolar abundances of the blue and fin whale are highly related to the extent of the seasonal ice zone – surprisingly, the correlation of whale abundance with krill densities was much lower, at the limit of the significance threshold.

SC/58/SH1 suggested that whales track the krill in relation to the sea ice habitat, and not exclusively in relation to the krill abundance. Blue and fin whales may preferentially target large seasonal ice zones providing predictable grounds of aggregated krill released through the rapid recession of sea ice.

SC/58/SH7 introduced blue whale distribution in the Antarctic Areas III-E, IV, V and VI-W in the waters south of 60°S, based on JARPA sighting data. Blue whales were encountered throughout the surveys and were widely distributed in the research area. No gaps in distribution were observed.

SC/58/SH9 described blue whale research undertaken during the 2006 field season in southern Chile by the NGO Blue Whale Centre and Universidad Austral de Chile. The main study area corresponds to the west of Chiloé Island, the Gulf of Corcovado and Chonos Archipelago (41°-44°S), particularly in the Gulf of Corcovado. This region is characterised by a complex system of inner seas, archipelagos, channels and fjords, and has been suggested to behave as a massive estuarine system that receives continental fresh water through the supply of mixed-regime river discharge and by the highest pluviosity in Chile (6,000 mm y<sup>-1</sup>). Satellite images of the study area appear to confirm that the Chiloé-Corcovado system corresponds to a

generation and dispersion centre for phytoplankton blooms as well as a retention area populated by abundant zooplankton. Results provided new information from the area from 2000 onwards, and included contributions to understanding blue whale distribution in Chile. During 2006 field season, a total of 57 sightings were made of 113 animals (group size mean=1.98 and range of 1-5), and including 10 mother-calf pairs. Development of photo-identification work, genetics analyses of biopsies, and satellite tagging has continued, along with preliminary recordings. Of particular interest in the results are some behavioural observations of possible reproductive behaviour when a pair of blue whales was approached by a third blue whale. In summary, Chile could be one of the few areas where important information on needed research about status, critical habitat, feeding preferences and sub specific identity might become available due to the logistic advantage of working close to the coast.

In response to a question on potential collaboration with a number of oceanographic research institutes in proximity to the research area, it was noted that such collaboration was currently being pursued.

It was noted that there was no presentation on the sub-species status of animals from the Chiloé Island region, and the availability of length estimates to answer the sub-specific status was questioned in light of similar offshore movements of pygmy blue whales off Western Australia. It was reported that while there were no direct length estimates, indirect evidence (length estimates in relation to the research vessel) suggested lengths in excess of 25m. It was noted that there are multiple lines of evidence to suggest differences between the Chilean blue whales and pygmy blue whales in the Indian Ocean and that caution should be applied in assigning the sub-specific status of the Chiloé whales. One certainty was that they differ from Antarctic or true blue whales (*B. musculus intermedia*).

It was reported that five blue whales were tagged with Argos satellite tags off southern Chile (43°S, 74°W) in January and February 2004. All tags sent data (from 47-203 days) for at least 25,932km of tracklines. Whales averaged 5,186 km of travel during 101 days of tracking with average speeds varying from 0.9-3.2km h<sup>-1</sup>. The longest track was 9,433 km in length in 124 days at the highest average speed. Speed and dive frequency were also recorded. The whales remained in the Chilean fjord (feeding) areas for longer than expected, and for the most part, during forays out of the fjords into the open ocean stayed close to shore. Such forays included trips both north and south before returning to the fjords. None of the whales moved to the Antarctic. Three whales migrated north in the fall, with two of them reaching the Nazca Ridge (25°S and 800km offshore), which may be a winter reproductive area. The underwater ridges typical to the area create semi-permanent topographic upwellings characterised by high productivity and thus this may be a region where blue whales continue to feed during the winter. These are the first movements to be reported for Southern Hemisphere blue whales. The suggestion of sub-tropical reproductive areas and summer feeding in mid-latitudes indicates that high latitude feeding may not be necessary for all blue whale populations and can result in short migrations. While sample size was small, these initial data and the duration of tag operation are encouraging enough to warrant further work in the future.

The hypothesis for the Nazca Ridge region being a breeding ground was questioned in light of the seasonality of movements and corresponding movements of individuals in the Northern Pacific and in the Costa Rica Dome region.

It was noted that the random movement of tagged individuals suggested that animals had terminated or suspended their migration in this region. The incidence of feeding in the Nazca Ridge region was questioned. Mate noted that this was inferred from evidence on the Costa Rica Dome where whales are distributed 'downstream' of upwelling productive areas. It was further noted that there may be differences in migration timing and residency of reproductive classes of whales in that it was suspected that pregnant females were in the vanguard of the migration and remain longest in the Nazca Ridge region.

The authors were congratulated on the results achieved, particularly as regards tag retention. In response to a question on including genetic comparisons in association with the satellite tagging studies, the authors noted that tagged whales had been biopsied so that, at minimum, the sex of tagged whales could be identified.

SC/58/SH17 reported on records of blue whales from the 2006 field season off the northwestern coast of Chiloé Island. Field work included twelve marine surveys (between 41°45'S and 42°05'S, within 22km from the coastline) and one aerial survey (covering 200km of coastline, from 40°57'S to 42°37'S, and between 3km and 15km offshore) on a Chilean Navy aircraft. Additionally, blue whales were sighted incidentally until 30 April, the end of the fishing season. At least 90 groups of 144 individuals were identified as blue whales between 11 February and 21 March 2006. As individual identifications were determined after photo identification interceptions, they do not include animals resighted on the same day. The presence of blue whales was recorded as far north as 40°58'11"S during the aerial survey. This record represents the current northern limit record for blue whales feeding in southern Chile. No significant differences in body length was observed within groups of individuals. The observations represent the third consecutive year that the study area was used by blue whales for feeding and social activities, and highlights the importance of continued research in the waters off the northwest coast of Chiloé Island to determine the spatial and seasonal distribution of blue whales in Chilean waters.

SC/58/SH18 reported on the results of photo-identification of blue whales off northwestern Chiloé Island between February and March, 2004 to 2006. Twenty-two marine surveys (totalling 114.05hrs) on board artisanal fishing vessels and Chilean navy vessels were conducted during which 97 sightings of 173 blue whales were recorded. Marine surveys usually were conducted off northwestern Chiloé Island, between 41°45'S and 42°12'S and within 22km from the coastline. However, during 2004, one marine survey was conducted around the Corcovado Gulf. Two catalogues, corresponding to left and right flanks including dorsal fins were established. Currently these catalogues consists of 70 right and 68 left flanks. Thirty-six individuals were photographed on both sides. The number of days individual whales were re-sighted, minimum residency time (the number of days between first and last sightings within the same season); and re-sighting rate (the proportion of individual whales identified on more than one day within the same season) were examined using the data. Resighting rate and minimum residency time were obtained for both left and right data sets and calculated from the 2005 and 2006 data. Data from 2004 included only two marine surveys in different areas and was not used in the analysis. Analyses of the 2005/2006 data set indicates a residency rate of 13.8% comparing left flank photographs and 14.7% comparing right flank photographs. The minimum residency

time of all re-sighted blue whales comparing right flanks ranged from 2 to 34 days, with a mean of 11.60 (SD=10.50) days and from 2 to 27 days comparing left flank photographs, with a mean of 11.20 (SD=9.44) days. Of the ten whales resighted within a season, one individual was identified on three occasions over a period of 34 days, in an area of 55km<sup>2</sup>. The results indicate that approximately 14% of all whales identified were sighted on multiple days within a season, with the majority of whales identified only on one occasion. The first between-year recapture of an individually photographed blue whale off Chiloé Island may indicate some level of site fidelity to the area. The authors state that these records confirm the importance of northwestern Chiloé Island for blue whales, and note that to accurately assess residency and movements patterns of blue whales and define their feeding grounds, it will be necessary to compare catalogues of photographed individuals from other nearby areas as well as along the entire South Pacific.

The sub-committee complimented the authors of the papers on research carried out in the Chiloé Island region to date and **recommended** continuation of this important work. It was recognised that a Marine Protected Area proposed in the region could provide an important framework for the continuation of this research.

It was noted that the close proximity of the two studies fosters opportunities for collaboration, particularly as regards photo-identification research and the generation of mark-recapture estimates of population abundance. Branch noted that preliminary data in SC/58/SH18 suggested the population to be in the order of 100's. The sub-committee **recommended** that abundance estimates be generated using data from these regions and other regions in the eastern South Pacific.

The sub-committee **recommended** further work to investigate the population structure of blue whales from the region. This work should include aspects of acoustic, photo-identification, genetic and morphological work.

SC/58/SH16 presented positional data for blue whales in the Southern Hemisphere and northern Indian Ocean, an area which encompasses the known range of Antarctic (true) and pygmy blue whales. Data were gathered from 169 published and unpublished papers, in addition to unpublished data contributed by many scientists. The resultant dataset included catch positions ( $n=303,239$ ), sightings (>6,728), strandings (105) and mark-recaptures from Discovery tags (96), with acoustic data to be added in the future. Solitary whales (69.6%) and pairs (21.3%) were most commonly sighted. Rough estimates of sighting rates (groups per 1,000km, obtained from a wide variety of platforms) were lowest off Brazil (0.003), South Africa (0.005), Somalia (0.19), the Eastern Tropical Pacific (0.30), Antarctic (0.17-0.52) and South Georgia (0.44); somewhat higher in the subAntarctic (0.56) and Peru (0.73-0.97); and highest around Indonesia (2.0), Sri Lanka (>1.6), Chile (4.9), southern Australia (7.4-18.6) and the Madagascar Plateau (36.0). Blue whales avoid the nutrient-poor central portions of the Indian, Pacific and Atlantic Oceans, and are more likely to be seen around the oceanic margins, especially in deep-water regions characterised by high chlorophyll-a levels. They are exceedingly rare in the Antarctic compared to historical catches, are no longer seen far from the pack ice in summer, and have almost vanished from the waters around South Georgia and south-west Africa, but are more concentrated south of Madagascar, around Sri Lanka, off western and southern Australia, and off the west coast of South America. Monthly data suggest

that blue whales (generally pygmy blue whales) from the more concentrated areas do not participate in the classical summer migration to feeding grounds in the Antarctic, and may therefore have avoided the worst effects of Antarctic whaling.

The large scope and broad study of this paper was acknowledged by the sub-committee and **recommended** that the work be completed.

It was suggested that inclusion of data from Mexico and the Costa Rica Dome were problematic due to their links with the Northern Hemisphere, and that inclusion of records from the northern Indian Ocean might be problematic due to their year round distribution in this region and unique call structure. Some discussion on sub-specific status of Northern Indian Ocean animals was held, particularly on the status of *B. m. indica* and results of further research on the stock structure and sub-specific status from this area was anticipated with interest. It was noted that both acoustic and satellite telemetry studies could be advantageous in establishing migration links. The use of remote acoustic recording devices in low latitudes was **recommended** by the sub-committee. A continuum identified between California and the Costa Rica Dome suggests that the similar continuum observed from northern Madagascar to the Arabian Sea, be regarded with caution as evidence of linkage. In conclusion Branch requested that any additional information on sightings, strandings or catches from sub-committee members be forwarded to him within the next three months.

Paper SC/58/O2 presented preliminary results of a study of large whale calls recorded at low latitudes in the southwestern Indian Ocean. Two triads of low frequency hydrophones were deployed within the framework of the International Monitoring System (in support of the Comprehensive Nuclear-Test-Ban Treaty) off the Crozet Archipelago in the Southern Indian Ocean. These hydrophones, deployed in the SOFAR sound channel, form part of a worldwide network to monitor the natural and artificial activity within the Ocean. Low frequency sounds (frequency lower than 100hz) have been recorded continuously since 2003 and the authors took this opportunity to initiate a monitoring study aimed at detecting the presence of large whales by investigating vocal signatures in the signal recorded. One year of data have been preliminarily analysed to date and the presence of blue whales, pygmy blue whales, and fin whale has been detected year round.

The sub-committee welcomed this submission and **recommended** continued analyses including detailed analyses of seasonal trends in vocalisations. In response, the authors of SC/58/O2 noted that in excess of 30 such systems were deployed worldwide and similar studies could be conducted in other parts of the Southern Hemisphere provided that access to the data is authorised.

SC/58/O16 described a sonobuoy survey in the Southern Ocean. During the large-scale BROKE West survey of Southern Ocean waters between 30 and 80° E longitude, the spatial distribution of marine mammals was examined with the systematic deployment of sonobuoys. As part of the survey, 142 DIFAR sonobuoys were deployed every 30' of latitude on north-south transects, and prior to CTD stations on the initial east-west transect. Underwater sound was analysed over 70 minute samples from each sonobuoy. An initial analysis indicates blue whales were the most commonly recorded species, occurring at 47 of the sonobuoy deployment sites, including 1 site with pygmy blue whale sounds. The results of the sonobuoy survey



provide a measure of each species' relative spatial distribution over the survey area based on acoustic detections.

### 3.1.2 Stock structure

SC/58/SH8 estimates the proportion of pygmy blue whales in the Antarctic from ovarian corpora. The maximum length of pygmy blue whales is 79ft (24.1m), and they reach sexual maturity at perhaps 63ft (19.2m), while Antarctic (true) blue whales can exceed 100ft (33m) and become sexually mature at 77-78ft (23.5-23.8m) on average. At lengths between approximately 72-79 ft pregnant females could be either old pygmy blue whales or shorter than usual Antarctic blue whales. Corpora lutea form in blue whale ovaries during ovulation, and then regress to form corpora albicantia. These ovarian corpora are persistent bodies that accumulate with age, thus at 72-79 ft pygmy blue whales would have high corpora counts while Antarctic blue whales would have zero or low corpora counts. Historical records of length-corpora counts were collated. Mean corpora count at length was fitted by a logistic equation, and the variability within each length by a negative binomial fit with over-dispersion proportional to the mean. A mixture model provided maximum likelihood estimates of proportion of pygmy blue whales in the Antarctic to be 0.4% (0.0-1.1%). As this was not significantly greater than zero, the possibility of zero pygmy blue whales in the Antarctic cannot be excluded. Closer examination revealed no evidence for an increase in this proportion from the 1930s to about 1950, during a period when Antarctic blue whales decreased threefold. In addition, Ichihara's (1966) proposal that the 'problematic' corpora in Laurie (1937) were actually pygmy blue whales, can be dismissed. The proportion of these corpora was too high, the geographic distribution randomly distributed within Antarctic catches, and a similar pattern of high corpora counts is also observed in short fin whales.

The sub-committee welcomed this novel approach and recommends that this project be completed. The sub-committee **agreed** that this was a useful addition to previous Scientific Committee conclusions that 'a small proportion, not more than 7%' of blue whales in the Antarctic would be pygmy blue whales (IWC, 2001).

### 3.1.3 Abundance and trends in abundance

SC/58/SH7 provided estimates of abundance of blue whales in the Antarctic Areas III-E, IV, V and VI-W in the waters south of 60°S, based on JARPA sighting data. Abundance of blue whale in these Areas was 1,300 (95% CI=690-2,440) in 2003/04 and 2004/05 seasons. There is no stock information of blue whales in the JARPA research area. Prior to exploitation, there were as many as 200,000 blue whales in the Antarctic, and abundance in 1996 was estimated at 1,700 by Branch *et al.* (2004). The authors suggest that the estimates of blue whales of 1,300 presented in SC/58/SH7 (in the half of Antarctic Management Area) is reasonable compared to other recent results.

### 3.1.4 Biological parameters

SC/58/SH17 reported on 'skinny' blue whales observed during seven marine surveys in 2006 at northwestern Chiloé Island for a second year. Analyses of photographs resulted in the establishment of three categories of skinny whales, based on respective depression of the lateral flank and exposure of vertebrae and ribs. In the skinny whales the dorsal processes of the vertebral column were clearly visible projecting along the back anterior to the dorsal fin with depressed tissue between the individual processes. Of 23

skinny blue whales in 17 groups, nine revealed depressed or concaved flanks and the outline of vertebrae, and the outline of the ribs could be seen under the blubber in one whale. There are at least three possible explanations for the skinny blue whales: (1) natural or human produced changes in prey availability or habitat quality; (2) physiological changes; or (3) disease. The authors believe the most likely cause of this condition is nutritional stress due to the lack of prey resources but the underlying reason(s) for this remain unknown.

A question was asked about the resighting rates of photographed 'skinny' blue whales in light of questions about the survivorship of skinny whales. It was noted that 'skinny' western gray whales had been linked to an alteration of reproductive cycles, while 'skinny' humpback whales generally showed low resighting rates.

### 3.1.5 Other information

SC/58/O17 described long term recordings that were used to examine the seasonal presence of blue and fin whales in the waters off East Antarctica. Long term acoustic records of underwater sound can be used to assess the timing of migrations, peak periods of relative abundance, and seasonality and overlap of different species' presence. Bottom mounted autonomous recording packages (ARPs) were deployed in the waters of eastern Antarctica from February 2005 through February 2006 recording low frequency (<250Hz) sound continuously over this period. Power spectral density (PSD) analyses of the frequency bands of blue and fin whale calls compared to surrounding frequencies was carried out. The preliminary results of these analyses show a higher acoustic presence of both these species from April through June with the strongest peak occurring in April-May. In addition, previously identified pygmy blue whale calls were detected on both of the instruments. This is likely the furthest south pygmy blue whale sounds have been recorded.

### 3.1.6 Future work

In identifying future work required to advance the Comprehensive Assessment of blue whales, it was suggested that priority areas be identified. One such area was the northern Indian Ocean where further genetic work is needed. Expanding on this, it was **recommended** that this and satellite tagging and acoustic surveys could play a valuable role in understanding blue whale migration and distribution, especially with regard to breeding grounds.

It was noted that a large proportion of true blue whale catches were from the southwestern Atlantic Ocean. A study to deploy bottom mounted autonomous recording packages was proposed, but the anticipated funding was not received. The sub-committee **recommended** the deployment of acoustic recorders within this region in the future.

The value of regional photo-identification studies was noted and the sub-committee **recommended** that existing photo-identification data from a number of regions be reviewed and analysed to provide mark recapture estimates where possible. It was noted that a research proposal had been submitted to SC/58 to initiate and further work on an Antarctic blue whale catalogue and that currently images from IDCR/SOWER cruises were being digitised.

A major component of the Comprehensive Assessment of Southern Hemisphere blue whales is the differentiation of true and pygmy blue whales. In response to a request for the establishment of a time line for this work, it was suggested that a synthesis document be compiled and gap analysis be carried out to identify the progress to date. It was noted that

the Comprehensive Assessment of Southern Hemisphere humpback whales had developed a summary table to assist in this regard, and that an intersessional Working Group had been established last year to undertake a similar synthesis for Southern Hemisphere blue whales (IWC, 2006b). The sub-committee welcomed this initial work and **recommended** the continuation of this intersessional Working Group which should meet for preliminary discussions during this meeting.

The sub-committee also noted and **endorsed** the recommendations for future work made at last year's meeting (IWC, 2006a p.162).

Ohsumi, noting the importance of blue whales within the Southern Hemisphere, suggested that recovery be monitored and noted the important contribution that the JARPA II surveys could play in international co-operation in this regard.

#### 4. OTHER INFORMATION

Williams *et al.* (2006) drew the sub-committee's attention to a recent study that collected data from Antarctic tourism ships, and used GAM-based spatial models to describe the density and distribution of minke, humpback and fin whales in the Scotia Sea and the South Atlantic sector of the Southern Ocean. Williams *et al.* (2006) recorded hundreds of sightings of these three species along more than 9,000km of trackline. The tourism industry has a strong presence in this region from November to March each year, and this allows the potential for expanding such analyses to spatio-temporal modelling, to assess timing of migration. Similarly, the dataset includes information on ice cover, which was thought to be of potential interest to members of the sub-committee. Williams welcomes the opportunity to collaborate with researchers interested in using these data to answer other questions of use to the IWC Scientific Committee.

SC/58/SH17 reported on sei whales recorded feeding off northwest Chiloé Island for the third consecutive year.

It was noted that no sightings of sei whales had been made on the recent SOWER cruise. In response to a question of records of sei whales in other regions of the southeast Pacific Ocean, it was noted that aggregations of sei whales had been made further south by IDCR/SOWER vessels in transit to and from the home port of Valparaiso. Findlay noted a record of an aggregation of sei whales made within the Beagle Channel in transit to Punta Arenas in 1990.

#### 5. WORK PLAN AND BUDGET REQUESTS

Last year, the sub-committee recognised that the completion of the assessment of Southern Hemisphere humpback whales had become a priority and that the assessment of blue whales should be initiated (IWC, 2006a). Recommendations for future work to be conducted in regards to the Comprehensive Assessment of humpback whales are provided in the report of the intersessional Workshop to in Hobart and in Item 2.2.4.7 above.

Although it was recognised that information from all stocks would be reviewed in future meetings, the sub-committee **agreed** that the assessment of Breeding Stocks B and C would be the highest priority for next year's meeting. Therefore, the sub-committee **recommended** that the following work be conducted:

- (1) review abundance estimates;
- (2) examine potential to estimate trends from mark-recapture analysis;
- (3) update progress on stock structure hypothesis in the breeding grounds;
- (4) examine feeding ground/breeding ground differentiation and connectivity (for catch allocation);
- (5) examine stock structure of feeding grounds;
- (6) attempt to reach agreement on stock structure hypotheses, catch allocation, abundance estimates and trends in abundance;
- (7) attempt the completion of assessment for Breeding Stocks B and C.

The sub-committee also recognised that the above tasks may not be finalised by next year and in the event that this work is not completed, it was **agreed** that it should be continued at the 2008 meeting.

The sub-committee also noted that additional work is necessary to improve the assessment of humpback whales and **recommended** that the following tasks be conducted:

- (1) finalise the correction of the revised 1948/9-1971/2 catch data series;
- (2) examine historic catch data and the JSV data be examined intersessionally to improve knowledge of humpback whale distribution at mid-latitudes;
- (3) further examination of issues of  $N_{min}$  and depensation for population modelling.

The sub-committee recognised that material presented in this meeting was an advance towards the Comprehensive Assessment of blue whales. However, it **agreed** that additional work needs to be done to produce the relevant information required for the assessment. It was **recommended** that:

- (1) the blue whale catch series be updated;
- (2) a synthesis document be compiled and gap analysis be carried out by the intersessional Working Group on Southern Hemisphere blue whales;
- (3) work identified in last year's work plan (IWC, 2006a p.162) be completed;
- (4) genetic, satellite tagging and acoustics work be done to elucidate migration and distribution, especially with regard to breeding grounds;
- (5) existing photo-identification data from a number of regions be reviewed and analysed to provide mark recapture estimates where possible.

Some of the items identified above will have budgetary implications. Another item with financial implications is the AHWC with a budget of £6,600.

The sub-committee noted a change in the procedure for applications for funds for intersessional work. A formal procedure exists for the submission and review of unsolicited proposals for IWC funding. However, in recent years, an increasing number of funding requests has been made during meetings related to sub-committee needs. There is not always a clear distinction between immediate requirements identified by the meeting and other components of the research proposed. It was noted that this difficulty had also occurred in other sub-committees and it was **recommended** that protocols be developed to review such proposals appropriately in this situation. The sub-committee also expressed the opinion that within-meeting proposals should be submitted only in direct response to needs that had been identified during sub-committee deliberations.

## 6. ADOPTION OF REPORT

The report was adopted at 23:20 on 2 June 2006. The Chair thanked the participants for all their hard work and expressed particular appreciation to the rapporteurs. The sub-committee thanked the Chair for the successful completion of a difficult task.

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## Appendix 1

### AGENDA

1. Introductory items
  - 1.1 Opening remarks
  - 1.2 Election of Chair
  - 1.3 Appointment of rapporteurs
  - 1.4 Adoption of Agenda
  - 1.5 Review of documents
2. In-depth Assessment of Southern Hemisphere humpback whale
  - 2.1 Report of the intersessional Workshop on the Comprehensive Assessment of Southern Hemisphere humpback whales
  - 2.2 Comprehensive Assessment of humpback whales
    - 2.2.1 Biological parameters
    - 2.2.2 Modelling framework
    - 2.2.3 Assessments
      - 2.2.3.1 Genetic information
      - 2.2.3.2 Breeding Stock A
      - 2.2.3.3 Breeding Stock G
      - 2.2.3.4 Breeding Stock D
      - 2.2.3.5 General conclusion
    - 2.2.4 Information on other stocks
      - 2.2.4.1 Feeding grounds
      - 2.2.4.2 Breeding Stock B
      - 2.2.4.3 Breeding Stock C
      - 2.2.4.4 Breeding Stock E
      - 2.2.4.5 Breeding Stock F
      - 2.2.4.6 Breeding Stock X
      - 2.2.4.7 Future assessments

- 2.2.5 Antarctic humpback whale catalogue (AHWC)
- 2.2.6 Other information
- 2.2.7 Future work
- 3. In-depth assessment of Southern Hemisphere blue whales
  - 3.1 Comprehensive Assessment of Southern Hemisphere blue whales
    - 3.1.1 Distribution and movements
    - 3.1.2 Stock structure
  - 3.1.3 Abundance and trends in abundance
  - 3.1.4 Biological parameters
  - 3.1.5 Other information
  - 3.1.6 Future work
- 4. Other information
- 5. Work plan and budget requests
- 6. Adoption of Report

## Appendix 2

### LIST OF DOCUMENTS FROM THE HOBART WORKSHOP, APRIL 2006

SC/A06/HW1 Alava, J.J. and Felix, F. Logistic population curves and vital rates of the Southeastern Pacific humpback whale stock off Ecuador.

SC/A06/HW2 Andriolo, A., Kinas, P.G., Engel, M.H. and Martins, C.C.A. Monitoring humpback whale (*Megaptera novaeangliae*) population in the Brazilian breeding ground, 2002 to 2005.

SC/A06/HW3 Paxton, C.G.M., Bannister, J.L. and Hedley, S.L. Group IV humpback whales: their status from aerial and land-based surveys off Western Australia, 2005.

SC/A06/HW4 Barendse, J., Best, P.B. and Thornton, M. Preliminary results of photo-identification of humpback whales on the west coast of South Africa.

SC/A06/HW5 Best, P. A note on the age at sexual maturity of humpback whales.

SC/A06/HW6 Branch, T. Humpback abundance south of 60°S from three completed sets of IDCR/SOWER circumpolar surveys.

SC/A06/HW8 Castro, C., Felix, F., Forestell, P., Haase, B., Kaufman, G. and Scheidat, M. Site fidelity of humpback whales *Megaptera novaeangliae* in Ecuador between 1991 and 2004, based on photo-identification.

SC/A06/HW9 Cerchio, S., Pomilla, C., Ersts, P., Razafindrakoto, Y., Leslie, M., Andrianrivo, N., Collins, T., Dushane, J., Murray, A., Weber, D., and Rosenbaum, H. Estimation of abundance of Breeding Stock C3 of humpback whales, assessed through photographic and genotypic mark-recapture data from Antongil Bay, Madagascar.

SC/A06/HW10 Collins, T., Cerchio, S., Pomilla, C., Ngouesso, S., Mbadinga, N., Dushane, J., Murray, A., Weber, D., Ersts, P. and Rosenboom, H.C. An estimate of abundance using mark recapture data for breeding stock B1: Gabon.

SC/A06/HW11 Engel, M.H., Fagundes, N.J.R., Rosenbaum, H.C., Ott, P.H., Schmitt, R., Secchi, E., Dalla Rosa, L. and Bonatto, S.L. Mitochondrial DNA variability and evaluation of the likely feeding grounds of the humpback whale (*Megaptera novaeangliae*) population of the Abrolhos bank, Bahia, Brazil.

SC/A06/HW12 Ersts, P.J., Pomilla, C., Rosenbaum, H.C., Kiszka, J. and Vely, M. Humpback whales identified in the territorial waters of Mayotte [C2] and matches to Madagascar [C3].

SC/A06/HW13 Felix, F., Castro, C., Haase, B., Forestell, P., Alava, J.J. and Scheidat, M. Estimates of the Southeastern Pacific humpback whale stock with mark-recapture models in Ecuador.

SC/A06/HW14 Felix, F., Muñoz, M. and Haase, B. Bycatch of humpback whales in artisanal fishing gear in Ecuador during 2005.

SC/A06/HW15 Felix, F., Palacios, D.M., Caballero, S., Haase, B. and Falconi, J. The 2005 Galápagos humpback whale expedition: a first attempt to assess and characterize the population in the archipelago.

SC/A06/HW16 Findlay, K.P. and Best, P.B. The migrations of humpback whales past Cape Vidal, South Africa, and a preliminary estimate of the population increase rate.

SC/A06/HW17 Forestell, P.H., Kaufman, G.D. and Chaloupka, M. Abundance estimate of humpback whales in Hervey Bay, Australia, based on CMR profiles, 1988-2002.

SC/A06/HW19 Garrigue, C., Olavarria, C., Baker, C.S., Steel, D., Dodemont, R., Constantine, R. and Russell, K. Demographic and genetic isolation of New Caledonia (E2) and Tonga (E3) breeding stocks.

SC/A06/HW20 Jenner, K.C.S., Jenner, M-N., Salgado Kent, C.P. and Brasseur, M. A preliminary analysis of sampling biases of sex ratio from two seasons of biopsy samples for breeding stock D.

SC/A06/HW21 Jenner, K.C.S., Jenner, M-N., Salgado Kent, C.P. and Sturrock, V.J. Recent trends in relative abundance of humpback whales in breeding stock D from aerial and vessel based surveys.

SC/A06/HW22 Johnston, S.J. and Butterworth, D.S. Updated assessments of various breeding populations of Southern Hemisphere Humpback whales.

SC/A06/HW23 Kaufman, G.D., Forestell, P.H., Malo, A. and Lehman, S. Calving rates and intervals for East Australia female humpback whales, based on individual photo-identifications: 1984-2005.

SC/A06/HW24 Kinas, P.G., Andriolo, A. and Engel, M. Integrating photo-identification and aerial surveys to estimate  $g(0)$  for humpback whales (*Megaptera novaeangliae*) in the Brazilian breeding ground.

SC/A06/HW25 Leaper, R., Peel, S., Peel, D., Bravington, M., Gales, N. Assessment of west and east Australian breeding stocks of humpback whales simulating different mixing and catch allocation on feeding grounds.

SC/A06/HW26 Loo, J., Pomilla, C., Best, P.B., Findlay, K.P. and Rosenbaum, H.C. Structure and diversity between feeding aggregations of humpback whales (*Megaptera novaeangliae*) using mitochondrial and nuclear DNA.

SC/A06/HW27 Noad, M.J., Paton, D. and Cato, D.H. Absolute and relative abundance estimates of Australian east coast humpback whales (*Megaptera novaeangliae*).

SC/A06/HW28 Noad, M.J., Paton, D.A., Gibbs, N.J. and Childerhouse, S.J. A combined visual and acoustic survey of humpback whales and other cetaceans of Samoa.

SC/A06/HW29 Olavarria, C., Aguayo, A., Acevedo, J., Medrano, L., Thiele, D. and Baker, C.S. Genetic differentiation between two feeding areas of the Eastern South Pacific humpback whale population: Update on SC/57/SH3.

SC/A06/HW31 Olavarria, C., Childerhouse, S., Gibbs, N. and Baker, C.S. Contemporary genetic diversity of New Zealand humpback whales and their genetic relationship with Breeding Stocks D, E, F and G.

SC/A06/HW32 Paton, D.A., Brooks, L., Burns, D., Franklin, T., Franklin, W., Harrison, P. and Baverstock, P. First abundance estimate of East Coast Australian humpback whales (*Megaptera novaeangliae*) utilizing mark-recapture analysis and multi-point sampling.

SC/A06/HW34 Gibbs, N., Paton, D., Childerhouse, S. and Clapham, P. Assessment of the current abundance of humpback whales in the Lomaiviti Island Group of Fiji and a comparison with historical data.

SC/A06/HW35 Paton, D.A. and Kniest, E. Analysis of data collected during humpback whale sighting surveys at Cape Byron, Eastern Australia, 1998 to 2004.

SC/A06/HW36 Paton, D.A., Oosterman, A., Whicker, M. and Kenny, I. Assessment of sighting survey data of humpback whales (*Megaptera novaeangliae*), Norfolk Island.

SC/A06/HW37 Peel, D. and Thiele, D. An estimate of abundance of humpback whales in Antarctic Area IV from the BROKE survey data.

SC/A06/HW38 Pomilla, C., Best, P.B., Findlay, K.P., Collins, T., Engel, M.H., Minton, G., Ersts, P., Barendse, J., Kotze, P.G.H., Razafindrakoto, Y., Ngouessono, S., Meyer, M., Thornton, M. and Rosenbaum, H.C. Population structure and sex-biased gene flow in humpback whales from Wintering Regions A, B, C and X based on nuclear microsatellite variation.

SC/A06/HW40 Pastene, L.A., Goto, M., Nishiwaki, S., Yoshida, H. and Kanda, N. Genetic characteristics and population structure of humpback whales in the Antarctic feeding ground as revealed by mitochondrial DNA control region sequencing and microsatellite analyses.

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### Appendix 3

#### CLARIFICATION REGARDING POPULATION GROWTH RATE PARAMETERS USED FOR SOUTHERN HEMISPHERE HUMPBACK WHALE ANALYSES

D.S. Butterworth

Papers on the dynamics of Southern Hemisphere humpback whales have described their growth rates in different ways. To attempt a simple summary, the following have been used (sometimes with different symbols to denote them or different forms of words to describe them):

$\delta$  : instantaneous growth rate (units  $\text{yr}^{-1}$ ) (sometimes indicated as  $r$ )

$\lambda$  : annual growth rate (units  $\text{yr}^{-1}$ )

$r$  : intrinsic growth rate (units  $\text{yr}^{-1}$ ) (sometimes indicated as  $r_{\text{max}}$ )

Relationships between these parameters are as follows. The instantaneous growth rate parameter  $\delta$  corresponds to the slope parameter in a log-linear regression of population estimates against time, and reflects a measure of exponential (Malthusian) growth. Computations of demographically imposed bounds on growth rates based on Leslie models assuming a steady age-structure have usually been quoted in these terms.  $\delta$  is related to  $\lambda$  by the formula:

$$\lambda = e^{\delta} - 1$$

where  $\lambda$  is the proportional amount by which the population will grow over the time unit in terms of which parameter values are quoted (here one year). The Table below shows some corresponding ( $\delta$ ,  $\lambda$ ) values – multiply by 100 to express either as a percentage.

$\delta$	$\lambda$
0	0
0.01	0.0101
0.05	0.0513
0.10	0.1052
0.126	0.1343

The intrinsic growth rate ( $r$ ) is (for purely compensatory population models) the highest growth rate that a population can attain, which is achieved in the limit of vanishing population size ( $N$ ). It pertains to either an instantaneous or an annual growth rate depending on whether a differential or a discrete (with annual time step) equation model is used to reflect the population dynamics.

Models used for Southern Hemisphere humpback whales have been of the latter type. Parameter values for  $r$  quoted for these models therefore relate to annual growth rates ( $\lambda$ ), rather than to instantaneous rates ( $\delta$ ).

Note that these models usually assume the purely compensatory density dependent formulation of the Pella-Tomlinson model:

$$r(N) = r [1 - (N/K)^{2.39}] \quad K = \text{carrying capacity}$$

so that at any population size  $N$  greater than zero, the annual growth rate will be less than  $r$ . 'Compensatory' means that  $r(N)$  is monotonically ('always') decreasing as  $N$  increases (because, if  $N$  is reduced, the population responds by increasing  $r(N)$  to 'compensate'). In contrast, depensation (the 'Allee effect') reflects a situation where as  $N$  decreases, below a certain (typically rather low) level  $r(N)$  starts to decrease. If below a certain level ( $N^*$ ),  $r(N)$  becomes negative, the situation is described as manifesting critical depensation, with  $N^*$  corresponding to the minimum viable population level.