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INTERNATIONAL WHALING COMMISSION

In-depth assessment of an eastern Indian and a western South Pacific stocks of Antarctic minke whale from 2001 to 2014: A synthesis and summary（DRAFT）

(EDITED BY THE INTERSESSIONAL CORRESPONDENCE GROUP)

HIROTO MURASE[1] (CONVENOR), HIDEHIRO KATO[2], TOSHIHIDE KITAKADO[2], KOJI MATSUOKA[3], DEBRA PALKA[4], LUIS PASTENE[3] AND ANDRE PUNT[5]

[1]National Research Institute of Far Seas Fisheries, Japan Fisheries Research and Education Agency, 2-12-4 Fukuura, Kanazawa, Yokohama, Kanagawa 236-8648, Japan
[2]Tokyo University of Marine Science and Technology, 4-5-7 Konan, Minato-ku, Tokyo 108-8477, Japan
[3]The Institute of Cetacean Research, 4-5 Toyomi-cho, Chuo-ku, Tokyo 104-0055, Japan
[4]NOAA Fisheries, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, Massachusetts, 02543, USA
[5]School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195-5020, USA

ABSTRACT

In-depth assessment of an eastern Indian and a western South Pacific stocks of Antarctic minke whale was carried out from 2001 to 2014 by the Scientific Committee of the International Whaling Commission (IWC/SC). The assessment covered a wide range of topics including systematics, commercial and research catches, abundance estimates, spatial distribution patterns, stock structure, biological information, population dynamics, food habit and energetic, pollutants and marine debris, and species interactions. This document is s a synthesis and summary of the assessment over 13 years. The results of the Statistical Catch-at-age Analysis (SCAA) revealed that (1) abundance increased from 1930 until the mid-1970, and declined over the period the mid-1970s until 1988 and (2) trends in abundance over the most recent 20 years are relatively flat. Although the primary focus at the start of this assessment was trying to understand the abundance trends during observed in abundance surveys conducted during 1984 – 2004, but expanded to increasing our knowledge on life history of this species which would contribute the management. The assessment also advanced many aspects of analytical methods in the course of discussion in the IWC/SC.

KEYWORDS: ENVIRONMENT, FEEDING, POPULATION ASSESSMENT, POPULATION PARAMETERS, SOUTHERN HEMISPHERE, STOCK IDENTITY, REPRODUCTION

INTRODUCTION

The Antarctic minke whale (*Balaenoptera bonaerensis* Burmeister, 1867) resides in the Southern Hemisphere, spending the southern summer feeding in waters all around the Antarctic and wintering between about 7° and 35°S where breeding occurs. Observations of whales between 35° – 50°S suggested that the major proportion of animals from the breeding grounds migrated south from October onwards to feeding areas in the Antarctic to arrive by January. When feeding in the Antarctic the highest densities are along the ice edge with some animals within the pack ice.

In 1990 the last Comprehensive Review of Southern Hemisphere minke whales was completed. This review focused on minke whales south of 60°S (IWC, 1990), which now is considered to be the Antarctic minke whale. The effect of historical catches was evaluated in two ways: by comparing the total catches to the then current abundance estimate and by HITTER, a computer program that evaluates effects of catches on a stock. At that time, it was assumed there was a single stock in all six IWC Management Areas (Table 1) because results for different approaches using samples from the commercial catch that were mostly from near the ice edge failed to identify unambiguously isolated stocks within the Antarctic minke whales. Though the assessment evaluated the effects of historical catches of minke whales within each the six Management Areas I−VI. Negatively biases abundance was estimated for each Area using IDCR sighting survey data collected during 1979/80 – 1988/89. In addition, Japanese scouting vessel data, mark-recapture, and catch per unit effort data were also considered as data to estimate abundance. Demographic parameter values used in HITTER included age at recruitment=7, age at sexual maturity=7.5, and the natural mortality rate=0.105. Maximum sustainable yield (MSY) level was evaluated at 60% and 80%. MSY rate was evaluated at 0, 1, 2, 3, and 4%. Those members who considered the HITTER model appropriate, interpreted the results as, if the carrying capacity had been constant before 1972, for most stocks the exploited female component of the stock was at the high end of the range 50-100% of carrying capacity. Those members who considered that the only useful indication of the status of the stocks came from a comparison of the ‘current’ stock estimated with the total cumulative catch concluded that the abundance of minke whales in Areas V and VI (i.e., the major part of the Pacific sector) had been little changed by those catches. Also the abundance in Area I (the eastern sector of the Pacific) and Area II (in the South Atlantic) will not have been affected to an extent which would raise questions as to whether the historic rates of exploitation had been too high. However, they believed that Areas III and IV (covering the South Atlantic and Indian Ocean sectors) have experienced catches that raise the question of whether lower rates of exploitation would have been desirable. They added that there had been a tendency for catching to concentrate on the Area III/Area IV boundary. Such catches could have led to greater depletion in the boundary region if it did not in fact divide two stocks which mix fully and rapidly within the greater areas of the putative stock divisions.

In 2000 the Scientific Committee agreed to update this review and start an in-depth assessment that would evaluate the status of the minke whales involving an examination of current stock size, recent population trends, carrying capacity and productivity (IWC, 2001a). In particular, it was considered urgent to address trend-related issues to provide up-to-date estimates of minke whale abundance. At that time, it was noted that while the estimates of the minke population sizes accepted in the Comprehensive Assessment in 1990, which totalled 760,000 and were obtained using IWC/IDCR data from 1982/83 to 1989/90, were the best available at the time of the years surveyed, these estimates were no longer appropriate estimates of current minke whale abundance. This was because some initial crude extrapolations of the incomplete third circumpolar set of surveys led to a point estimate that was appreciably lower than the total of the previously agreed point estimates by Area from the Comprehensive Assessment.

At that time, there was a long list of plausible hypotheses that may explain the apparent decline and it was not possible to know the implications of this trend to the management of Antarctic minke whales and to their ecosystem (IWC, 2003). That list of plausible hypotheses consisted of:

- Factors related to the population surveyed (e.g., changes in survey spatial-temporal coverage over years; changes in the location of the ice edge; or changes in the animal's distribution within the survey area and outside (within the ice and north of 60S).
- Factors related to survey process (e.g., changes over the years in the proportion of schools classified as 'like-minke', probability of observing animals on the track line [g(0)], bias of Closing versus independent observer modes, or analysis options).
- Factors that could cause a real decline in abundance (e.g., increase in natural mortality or decrease in recruitment rate due to say increase in killer whales, pollution or disease; mortality due to commercial and scientific whaling; incidental mortality from bycatch and ship strikes; overshooting carrying capacity; decrease in carrying capacity due to lower krill populations or competition from other predators; or changes in climatic conditions).

It took until 2014 to deal with all the issues, develop new methods, incorporate more recent data and put them together into an updated assessment of the status of the minke whales and update the state of knowledge of how the minke whales relate to their environment. This document summarizes the state of knowledge of the minke whales as related to systematics, commercial and research catches, abundance estimates (from IDCR/SOWER, JARPA/JARPAII, and joint icebreaker/aerial surveys), spatial distribution patterns, stock structure, biological information (including age, growth, morphology, maturity, and reproduction), population dynamics (using virtual population analysis (VPA) and statistical catch-at-age (SCAA) techniques), food habit and energetics (including consumption and body condition trends), pollutants and marine debris, and species interactions. This document focus on an eastern Indian and a western South Pacific stocks of Antarctic minke whale which are distributed from Area III East to Area VI West (Table 2). In-depth assessment of Antarctic minke whale in the rest of the Antarctic was not completed in that period because of scarcity of data (IWC, 2015b). In the context of the IWC/SC, in-depth assessment or comprehensive assessment can be considered as an in-depth evaluation of the status of all whale stocks in the light of management objectives and procedures (IWC, 1987). It would include the examination of current stock size, recent population trends, carrying capacity and productivity.

SYSTEMATICS

Until recently, only one species of minke whale was thought to exist, *Balaenoptera acutorostrata* Lacèpéde, 1804, however Rice (1998) reviewed both morphological (e.g. Williamson, 1959; van Utrecht and van der Spoel, 1962; Kasuya and Ichihara, 1965; Omura, 1975; Best, 1985) and genetic (e.g. Wada *et al*., 1991; Arnason *et al*., 1993; Pastene *et al*., 1994) data collected from extant minke whale populations and re-specified two species, the Antarctic minke whale *B. bonaerensis* Burmeister, 1867, which is restricted to the Southern Hemisphere, and the common minke whale *B. acutorostrata* Lacèpéde, 1804, which is distributed globally. Furthermore, he recognized three sub-species of the common minke whale, one in the North Pacific, one in the North Atlantic and one in the Southern Hemisphere (see below). In the Southern Hemisphere, the common minke whale is referred to as the 'dwarf' or 'diminutive' minke whale (Best, 1985; Arnold *et al*., 1987; Kato and Fujise, 2000; Kato *et al*, 2015). The two species in the Southern Hemisphere have not been confused during the sighting survey with closing mode because of the distinctive morphological features of the dwarf minke whales reported by those authors.

The Scientific Committee of the International Whaling Commission (IWC) accepted the recognition of these two species but deferred a decision on other nominal taxa until the completion of a worldwide review of genetic and non-genetics information of minke whales (IWC, 2001b).

Subsequent worldwide genetic analyses of minke whales based on mitochondrial DNA sequences provided further evidences for the separation of the two species, *B. bonaerensis* and *B. acutorostrata*, and at least three sub-species of the common minke whale as recognized by Rice (1998) (Fig.1, Pastene *et al*., 2010). It has been hypothesized that the two-species diverged in the Southern Hemisphere less than 5 million years ago and that the current sub-species of *B. acutorostrata* diverged after the Pliocene some 1.5 million years ago (Pastene *et al*., 2007).

Genetic analyses based on microsatellites also provided evidence for the separation of species and sub-species of minke whale (Glover *et al*., 2013). As noted above, *B. bonaerensis* distributes in the Southern Hemisphere however recent genetic studies provided evidence of migration of individuals of this species to the Arctic Northeast Atlantic (Glover *et al*., 2010; 2013). Whether these migrations represent contemporary events, or have occurred at a low frequency over many years, remain open.

The body length at physical maturity for North Pacific common minke whale was estimated in 7.5m for males and 8.0m for females (Kato, 1992); for North Atlantic common minke whale it was estimated in 8.2m for males and 8.8m for females (Jonsgard, 1951); for dwarf minke whale it was estimated in 6.6m for males and 7.0m for females (Kato and Fujise, 2000; Kato *et al*., 2015); and for Antarctic minke whale, it was estimated in 8.5m for males and 9.2m for females (Bando, personal communication). A report is available on variation in the color pattern of white patch on the flippers between North Pacific and North Atlantic common minke whales (Nakamura *et al*., 2014) and other authors have reported on differences in external appearance, body length and proportion, osteological features and other biological aspects among minke whale species and sub-species (Kato and Fujise, 2000; Kato *et al*., 2015).

The Committee of Taxonomy of the Society for Marine Mammalogy listed the following species and sub-species of minke whale (Committee on Taxonomy, 2016):

Balaenoptera acutorostrata Lacèpéde, 1804. Common minke whale

B. a. acutorostrata Lacèpéde, 1804. North Atlantic minke whale

B. a. scammoni Deméré, 1986. North Pacific minke whale

B. a. un-named subsp. Dwarf minke whale

Balaenoptera bonaerensis Burmeister, 1867. Antarctic minke whale

For the Antarctic minke whale which is the main target of this review, Perrin and Brownell (2009) provided a brief description of the morphological characteristics of the Antarctic minke whales. The rostrum is very narrow and pointed and there is a single ridge on the head. The dorsal fin is relatively tall and falcate and is located relatively far forward on the posterior one-third of the body (Fig. 2). Baleen plates are black on the left beyond the first few plates and on the right, they are white in the first third and black in the rear two-thirds of the row.

While further genetic and morphological/morphometric studies are required to elucidate further the taxonomic status within *B. acutorostrata*, including the dwarf minke whale, there is agreement among scientists on the taxonomic status of *B. bonaerensis*, the species targeted for the *in-depth assessment* by the Scientific Committee of the IWC.

CATCH BY COMMERCIAL AND SCIENTIFIC EXPEDITIONS

Catch data for this in-depth assessment were extracted from the IWC individual catch database (IWC, 2005). Number of Antarctic minke whales taken by commercial and scientific expeditions in the Indo-Pacific sector of the Antarctic (35°E-145°W) from 1956/57 to 2014/15 and their geographic positions are shown in Figs. 3 and 4. Data for these figures are extracted from the latest version of the database (Allison, 2016) at the time of the publication of this paper. The first catch in this sector was recorded in 1956. UK took 3 individuals from 1956/57 to 1959/60 but vast majority of them were taken by USSR and Japan throughout the rest of period. Commercial whaling targeting on this species has been suspended since 1986/87 after the IWC moratorium adoption in 1982. Scientific sampling of this species has been conducted since 1987/88 (see below for more details). Maximum number of catch in the period was recoded as 5,941inidividuals in 1976/77.

SURVEYS

IDCR/SOWER

The IWC Southern Hemisphere minke whale assessment cruises (IDCR: International Decade of Cetacean Research and SOWER: Southern Ocean Whale and Ecosystem Research) have been conducted since 1978/79 in the Antarctic regions of all six IWC management Areas for baleen whales (covering all, or more recently, part, of one Area each season). In total, 32 shipborne surveys including the total of 4,340 ship-days, the total of 70 vessels, and the total of 240 international researchers from 15 nations have been completed, which fall into three circumpolar sets: 1978/79-1983/84 (the first circumpolar survey; CPI), 1985/86-1990/91 (the second circumpolar survey; CPII) and 1991/92-2003/04 (the third circumpolar survey; CPIII), and experiment cruises from 2004/05 to 2009/10. The 1984/85 and 2004/05-2009/10 surveys were devoted mostly to experiments and were excluded when estimating abundance for this in-depth assessment. Although the primary aim of the surveys has been to estimate minke whale abundance, all cetacean sightings are recorded, which makes it possible to estimate abundance for species other than minke whales. The survey methodologies up to 2000/01 were reviewed by Matsuoka *et al.* (2003).

Over the years, there have been two major and some minor modifications to the survey design as a result of the development of survey procedures. These developments represent the best possible compromise between statistical needs and logistics. From 1985/86, the beginning of the second circumpolar set of cruises, the programme (initially a combination of Discovery marking and sightings) became essentially a dedicated line-transect systematic sightings cruise only. Passing mode with independent observer (IO mode) was introduced on an experimental basis in 1985/86 and routinely covered half of the planned trackline from 1986/87. Prior to 1985/86, the surveys were conducted only in Closing mode in principle. During IO mode, a primary observer was stationed in the independent observer platform (IOP) in addition to two primary observers in the barrel. IO mode was introduced to provide data for the estimation of the probability that a school on the trackline is sighted (g(0)). Modification of the survey design from the third circumpolar set of cruises (from 1991/92), to cover the whole region south of 60°S in the Antarctic resulted in a change in emphasis of the latitudinal coverage, especially in Areas I, II, III and V.

A series of experiments was carried out from 2004/05 to 2009/10 to address problems encountered with the analysis of previous cruises. These included Bucland-Turnock survey method (Bucland and Turnock, 1992), school size estimation experiments (terms as SS-II and SS-III) and visual dive time experiment. Cooperative surveys with Japanese ice breaker and Australian aircraft were also conducted during this period (see below for more details).

The sightings data from CPI to CPIII were encoded and validated and were contained in a database package DESS 3.5 (IWC Database-Estimation Software System v 3.5, Strindberg and Burt, 2004). A standard data set was extracted from DESS for abundance estimation (Burt, 2004).

The programme has also enabled collection of biopsy, photo-identification, oceanographic and acoustic samples. It is concluded that the programme has developed and established standard sighting procedures and has also improved the precision of whale identification standards in the Southern Ocean. This seems appropriate, given the quantity of data available and information on their overall distribution in the Southern Ocean during the survey period (Matsuoka et al., 2003).

JARPA/JARPAII

Government of Japan conducted the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) from 1987/88 to 2004/05 under the Article VIII of the International Convention for Regulation of Whaling (ICRW). There were two original objectives: (1) estimation of biological parameters to improve the stock management of the Southern Hemisphere minke whale (this included age-specific natural mortality coefficient and reproductive parameters such as age at sexual maturity and their changes) and (2) elucidation of the role of whales in the Antarctic marine ecosystem (Government of Japan 1987; 1989). To address objective 1, age-specific natural mortality coefficient and reproductive parameters such as age at sexual maturity and their changes were examined. The abundance of each whale species and the diet of the Antarctic minke whale were examined to address objective 2. The third objective, (3) elucidation of the effect of environmental change on cetaceans, was added in 1995/96 in response to the Commission’s resolution regarding to environment and pollution (Government of Japan 1995). The fourth objective, (4) elucidation of the stock structure of the Southern Hemisphere minke whales to improve stock management was added in 1996/97 (Government of Japan 1996). Initially, the surveys were conducted each year in alternating Areas IV and V. The survey area was expanded to include Area III East and Area VI West from the 1995/96 to improve the study on stock structure of Antarctic minke whales which related to the fourth objective. Subsequently, Areas III East + IV and Areas V + VI West were surveyed alternately each season. Two or three sighting and sampling vessels (SSVs) conducted sighting and sampling survey. A dedicated sighting vessel (SV) was introduced from 1991/92 season. Sampled Antarctic minke whales were examined on a research base vessel. General survey methodology was reviewed by Nishiwaki *et al.* (2006). Data and results from the JARPA were reviewed in two specialist workshops held by the IWC: an Intersessional working group meetings held in May 1997 (IWC JARPA mid-term review) (IWC, 1998) and the final intersessional workshop held in December 2006 (IWC JARPA final review) (IWC, 2008).

Government of Japan conducted the Japanese Whale Research Program under Special Permit in the Antarctic —Phase II (JARPAII) from 2005/06 to 2013/14 under the Article VIII of the ICRW. There were four objectives of JARPAII: (1) monitoring of the Antarctic ecosystem, (2) modelling competition among whale species and future management objectives, (3) elucidation of temporal and spatial changes in stock structure and (4) Improving the management procedure for Antarctic Minke whale stocks. Areas III East + IV and Areas V + VI West were surveyed alternately each season. Two or three SSVs conducted sighting and sampling survey while one or two SVs were conducted sighting survey. Sampled Antarctic minke whales were examined on a research base vessel. General survey methodology was reviewed by Nishiwaki *et al.* (2014). Data and results from the JARPAII from 2005/06 to 2010/11 were reviewed in a specialist workshop held by the IWC (IWC, 2015a).

Icebreaker/Aerial surveys
Sighting data obtained by several icebreaker surveys were considered in the period of in-depth assessment. These were platforms of opportunity (PoP) surveys rather than dedicated sighting surveys. A PoP survey was carried from US icebreaker, the *Nathaniel B. Palmer*, between 150°W and 70°W in February-March in 1994 (Ainley *et al.*, 2007). Cetacean sighting data were recorded in sea ice field between 77°50'E and 150°50'E in November-December in 1999 by Australian icebreaker, the *Aurora Australis*, as a part of the Antarctic Pack Ice Seal (APIS) circum-Antarctic surveys and the Southern Ocean Cetacean Ecosystem Program (SOCEP) (collective termed as APIS/SOCEP) (Thiele *et al*., 2002). Cetacean sighting data collected in the Ross Sea by the *Nathaniel B. Palmer* in 2004 as a part of the US Antarctic Slope (AnSlope) experiment were also presented to the IWC/SC (Thiele *et al*., 2005). Cetacean sighting surveys in sea ice field between 40°E and 150°E was conducted by Japanese icebreaker, the *Sirase*, in 2004/05 (Shimada and Kato, 2005). The survey was conducted collaboratively with IDCR/SOWER (Ensor *et al.*, 2005). Three helicopter surveys with approximately 2 hours flight for each were also conducted from the *Sirase*.

Dedicated cetacean sighing surveys using Australian fixed-wing aircraft were conducted between 93°E and 113°E in 2008/09 (Kelly *et al*., 2009) and 2009/10 (Kelly *et al*., 2010) following a trial survey in 2007/08 (Kelly *et al*., 2008). These surveys were conducted collaboratively with IDCR/SOWER (Ensor *et al*., 2008; 2009; Sekiguchi *et al*., 2010).

ABUNDANCE

IDCR/SOWER

IWC standard methodology
Abundance estimates of Antarctic minke whales from the 1978/79 to 1997/98 were presented to 53 IWC/SC based on the IWC standard methodology (Branch and Butterworth, 2001). which was developed by the IWC/SC over years (IWC, 2002). The results brought a number of methodological issues to be considered. These included school size estimation (Brandão *et al.*, 2001), data pooling by vessel and/or strata to estimate effective search half-width (esw) and mean school size (Burt and Hughes, 2002; Hakamada and Matsuoka, 2002; Matsuoka and Hakamada, 2002), like minke sightings (Mori *et al.*, 2003), closing-IO mode correction factor (Brandão and Butterworth, 2002), overlap area covered by more than one survey in CPIII (Branch and Ensor, 2004; Branch 2005). These points were addressed in the analysis when abundance was estimated using three completed circumpolar sets of surveys from 1978/79 to 2003/2004 (Branch, 2006). Abundance estimated by the standard methodology was negatively biased because it was assumed that all schools on the trackline were sighted (g(0)=1).

Potential covariates for estimation
Effect of observer efficiency was investigated (Butterworth *et. al.*, 2001; Mori *et al.*, 2003) but it was concluded that the effect contributes less to differences in g(0) than school size does (IWC, 2003). the effects of sighting conditions (school size, sighting cue, latitude and sea state) on Antarctic minke whale abundance estimation parameters (effective search half-width, sighting forward distance and mean school size) were investigated (Murase *et al.*, 2004) and such factors were considered further in abundance estimation models taking account of g(0). Mori *et al.* (2002) demonstrated strong evidence that g(0) depended on school size. New methods to

incorporate covariates information into estimation of school size and esw were also presented (Borchers and Burt, 2002; Rademeyer and Butterworth, 2001).

Models taking account of g(0)

Three new abundance estimation methods which can take account of g(0) were initially presented by Bravington (2002), Cooke (2002) and Okamura et al. (2002) at 54 IWC/SC. Later, these models were called as IM (integrated model), SPLINTR (spatial line transect) method and OK (Okamura-Kitakado) method, respectively. SPLINTR was also termed as BBM (big beautiful model) and BHWP (Bravington, Hedley, Wood and Peel) method in the course of the development. OK method adopted a design-based approach using a hazard probability model while SPLINTR adopted a two-stage spatial modelling using a point independence detection function model. IM used a hazard probability model with a spatial model based on Fourier series for density. A simulation data set were prepared to investigate performance and robustness of these new methods (Palka and Smith, 2003). OK method outperformed SPLINTR for simple simulation scenarios, whereas SPLINTR outperformed OK for simulation scenarios with complex spatial effects. An intersessional group was established in 55 IWC/SC to improve these new methods along with the simulation data (IWC, 2004). Five Intersessional workshops were also held (IWC, 2009; 2010; 2012; 2013a). After 10 years of discussions, agreed abundance estimates for CPII and CPIII were finally produced in 64 IWC/SC based on OK method with some bias corrections about spatial effects from SPLINTR outputs (Table 3; IWC, 2013b). Additional variance (or process error) had also been considered since 55 IWC/SC (IWC, 2004) and it was incorporated in the agreed estimates. Two sets of estimates are given, survey-once and CNB (Common Northern Boundary) because the northern extent of the surveyed regions differs between CPII and CPIII. The survey-once estimates cover all of the surveyed regions in each CP series. The CNB estimates exclude part of the surveyed regions in each series to ensure a consistent northern limit. The CNB estimates are the most appropriate estimates for a comparison of abundance estimates between CPII and CPIII. The CNB estimates are the basis for the Additional Variance (AV) calculations. The CV internal in the table shows the uncertainty associated with the abundance estimate of whales in the surveyed region at the time of the survey. The CV with AV shows the uncertainty associated with the average number of whales present in the surveyed region across the whole of that CP series. The CV with AV is more useful for most subsequent analyses. Only one set of CVs are presented in the table because they are approximately the same for survey-once as for CNB.Estimate for CPI was not considered in these new methods because no IO mode data was available from CPI to take account of g(0). Abundance estimates in Areas III East, IV, V and VI West which were used in the population dynamic model (see below for details) are shown in Table 4.

JARPA/JARPAII

Abundance for each stratum were estimated by school size based on 1987/88 and 1988/89JARPA data (Kasamatsu *et al.*, 1990; 1991) in order to obtain unbiased biological information such as age composition and segregation for the minke whales (Kato *et al.*, 1990; 1991) using approach in Kishino *et al.* (1991), given that the minke whales were sampled under multi-stage stratified random sampling.

At the intersessional working group to review data and results special permit research on minke whales in the Antarctic in 1997 (IWC, 1998), sighting survey procedure during JARPA and abundance estimate in Areas IV and V based on the sighting surveys from 1989/90-1995/96 were provided by Nishiwaki *et al.* (1997). The review meeting recommended that more research was required to develop a reliable method for adjusting for negative bias in abundance estimates induced by under-sampling of high density areas resulting from the JARPA survey design. The working group agreed that more research was required to develop a reliable method for adjusting for the higher-density-under-surveying future of the JARPA survey design. Once this had been achieved, the resultant abundance estimates should be useful both as absolute and relative indices (IWC, 1998).

At the intersessional workshop to review data and results from special permit research on minke whales in the Antarctic in 2006 (IWC, 2008), Burt and Paxton (2006) review spatial modelling applied to JARPA data to adjust the underestimate of abundance raised at the working group in 1997. The workshop noted potential difficulties in correcting for skip effects by applying spatial models to estimate abundance, and agreed that standard design-based estimates were best at this stage even if those need some sorts of correction as put forward using spatial modelling approach. Hakamada *et al.* (2006) presents updated abundance estimates for Antarctic minke whale based on JARPA sighting data using IWC 'standard' methodology and the inter-mode calibration method of Haw (1991), including consideration of the recommendation above. All estimates assumed g(0)=1. They also conducted sensitivity analysis to consider unsurveyed area due to for example ice-edge movement and saw-tooth tracklines that seemed parallel to ice-edge in response to recommendations at SC58 meeting (IWC, 2007). The estimates of abundance in Areas IV and V presented were 44,564 (CV=0.291) in 2003/04 and 72,087 (CV=0.146) (in 2004/05), respectively. The estimated annual rates of increase and their 95% CIs in Areas IV and V were -

0.42% [-4.02%; 4.59%] (1989/90-2003/04) and -1.54% [-4.91; 2.18%] (1990/91-2004/05), respectively, which suggested no significant increase or decrease in abundance trend were detected.

Recommendations were made at the workshop (IWC, 2008; Hakamada *et al.*, 2013). Some recommendations were related to improve abundance and trend estimate and their precisions and others are related to factors that may affected abundance trend and variance estimation. They are (1) re-estimation of detection functions in cases where the number of schools detected is small; (2) investigation of sensitivities to pooling across vessels to estimate effective search half width and mean school size; (3) investigation of a possible 'shoulder' in the detection function; (4) variance estimation for surveys by the Sampling and Sighting Vessels (SSVs) data taking correlation among tracklines into account; (5) undertaking of sensitivity analyses to examine the effect of portions of the trackline following contours of the ice edge; (6) abundance estimation taking the whale density in the gaps between the two main survey strata to be zero; (7) extrapolation of density to the unsurveyed area within a stratum; (8) consideration of changes over time in order in which strata were surveyed; (9) estimation of 'additional variance'; and (10) revision of estimates of the annual rates of increase in abundance and their CVs following suggestions (1)–(9).

Analyses of the IDCRSOWER surveys results by Okamura and Kitakado (2012) and by Bravington and Hedley (2012) have pointed to values of g(0) being less than 1 for minke whales and shown that possible changes in g(0) over time can be important in estimating trends in abundance. Because independent observer mode was not conducted during JARPA.

Hakamada *et al.* (2013) revised abundance and trend estimate in Areas IV and V, respectively, taking these recommendations into account. Log-linear models are used to adjust for different strata being surveyed at different times of year over the duration of JARPA, with model selection being based on AICc. Effects on changes in g(0) over time is investigated for the JARPA abundance estimates by the application of a regression model, developed from the results of the OK method to estimate Antarctic minke whale abundance from the IDCR/SOWER surveys, which provides estimates of g(0) from the statistics of the minke whale school size distribution in a stratum. Abundance estimates for Area IV range from 16,562 (CV = 0.542) in 1997/98 to 44,945 (CV = 0.338) in 1999/00, while those for Area V. range from 74,144 (CV = 0.329) in 2004/05 to 151,828 (CV = 0.322) in 2002/03. Estimates of the annual rates of increase in abundance are 1.8% with a 95% CI of [–2.5%, 6.0%] for Area IV and 1.9% with a 95% CI of [–3.0%, 6.9%] for Area V. Abundance estimate and trend were robust to the effects related to the recommendations (3), (5), (6), (7) and (8) above. With adjustment to allow g(0) < 1 derived from the regression model, abundance estimates increase by an average of 32,333 (106%) for Area IV and 89,245 (86%) for Area V, while the estimates of annual rates of increase and their 95% CIs change slightly to 2.6% [–1.5%,6.9%] for Area IV and 1.6% [–3.4%,6.7%] for Area V.

At the JARPAII review workshop (IWC, 2015a), approach in Hakamada *et al.* (2013) was applied to JARPA and JARPNII data in Areas III East, IV, V and VI West (170°-145°W) between 1989/90 and 2008/09 (Hakamada et al., 2014). Abundance estimate in Areas III East, IV, V and VI West with and without taking into account model error were shown in Table 5. For the estimates that took the model error into consideration the annual rates of increase in abundance were 1.1% with a 95% CI of [-2.3%, 4.5%] for Area III East +IV and 0.6% with a 95% CI of [-2.2%, 3.3%] for Area V+VI West. Estimates are robust the effect related to the recommendations (3), (5), (6), (7) and (8) above.

Sea ice field

It has long been known that Antarctic minke whales are distributed in sea ice field (Ainley, *et al*., 2007; Ensor, 1989; Naito, 1982; Ribic, *et al*., 1991; Scheidat, *et al*., 2011; Taylor, 1957; Thiele and Gill, 1999). However, no shipboard sighting survey data to the south of ice edge was available from IDCR/SOWER and JARPA/JARPAII because the vessels could not navigate in there. In these surveys, ice edge was defined by a level of ice cover that prevented the survey from being conducted at nominal survey speed of about 11.5 knots (Matsuoka *et al*., 2003). There was a number of attempts to estimate abundance to the south of ice edge in Areas III, IV, V and VI at the time of these surveys (Murase and Kitakado, 2013; Murase and Shimada, 2004; Murase *et al*. 2005; Shimada and Burt, 2007; Shimada and Murase, 2002; Shimada and Murase, 2003; Shimada *et al*., 2001; Shimada *et al*., 2002). Main objective of these studies was not to produce absolute abundance but to investigate magnitude of potential numbers taking simple relationship between abundance and sea ice concentrations derived from satellite. Relationship between abundance in survey area and sea ice extent was also investigated (Matsuoka *et al*., 2006; Matsuoka *et al*., 2008; Matsuoka *et al*. 2009; Murase and Shimada, 2004; Murase, 2010; Shimada and Murase, 2006). Abundance in sea ice field in portions of Area III (40°E-50°E) and Area IV (70°E-82°E) was tentatively estimated by using data obtained by Japanese icebreaker, Shirase in 2004/2005 (Shimada and Kato, 2006; Shimada and Kato, 2007). Abundance in sea ice field in portions of Area IV (93°E-110°E) was tentatively estimated by using data obtained by Australian aerial surveys in 2008/2009 and 2009/2010 (Kelly *et al*., 2014).

The Joint Symposium on High Latitude Sea Ice Environments was held as a pre-meeting of 57 IWC/SC to review information on sea ice environments in the Arctic and Antarctic, and to develop means of incorporating sea ice and similar data into analyses and models used by the Scientific Committee in its work on abundance estimation, determining variance, resolving issues of habitat use and the implications of seasonal, interannual and decadal variability in sea ice on cetacean populations and habitat (IWC, 2007). Methods and data for estimation of abundance in sea ice field was evaluated by Kelly *et al* (2012) while technical aspect of see ice data derived from satellite were reviewed by Murase *et al*. (2012).

These studies revealed that considerable number of Antarctic minke whales were distributed in sea ice field of this sector. However, absolute number could not be obtained in the period of the in-depth assessment. It is recommended that aerial survey should be sighting surveys in sea ice field bearing mind points raised in Kelly *et al*. (2012).

SPATIAL DISTRIBUTION

Prior to this in-depth assessment, spatial distribution of Antarcitc minke whales in the Indo-Pacific sector was investigated qualitatively either using overlay maps (Ichii, 1990; Matsuoka *et al*., 2003; Murase *et al*.,2002) or simple statistical correlation (e.g. Kasamatsu *et al*., 2000). Results of spatial distribution studies using generalized additive models which applied to data obtained by line transect surveys were presented in the period of assessment after such a method was proposed (e.g. Hedley, 1999). The circumpolar spatial distribution of Antarctic minke whales during CPII and CPIII cruises was estimated using (GAMs) (Murase *et al*., submitted). Geographical features (bathymetry and distance to upper slope) and climatological data at the surface (water temperature, sea surface height, salinity, and chlorophyll, silicate, nitrate and oxygen concentrations) as well as longitude and latitude, were used as explanatory variables in the model while number of individuals aggregated in 30 × 30 km grid cells was used as response variable. The results revealed that Antarctic minke whales were distributed throughout the indo-Pacific sector of CPII and CPIII but their regions of high density appeared to be reduced from CPII to CPIII (Fig. 5). High densities were observed in the souther part of the sector especially around the Ross Sea (south of 69°S between 160°E and 160°W). The relationship between the circumpolar spatial distribution of Antarctic minke whales and their environment was also investigated with GAMs using CPI, II and III data sets (Beekmans *et al*., 2010), but with maps of estimated spatial distribution only included for the Weddell and Ross Sea regions. Spatial distribution of Antarctic minke whales in the Ross was investigated using JARPA data taking account of spatial distribution of krill (Murase *et al*., 2013).

STOCK STRUCTURE

Background

The Antarctic minke whale, like all the other Southern Hemisphere baleen whales species apart from the Bryde’s whale (*B. edeni*), was managed by the IWC on the basis of six geographical ‘Areas’. The IWC established these Areas from the 1974/75 austral summer season, based mainly upon information from Mackintosh (1942; 1966) on distribution of catches of blue, fin and humpback whales (see review by Donovan, 1991). These Areas were used by the IWC for the implementation of the New Management Procedure (NMP) on baleen whale species. However, biological evidences for the particular boundaries are weak, especially for those species such as the Antarctic minke whale, whose data were not considered when the original management Areas were established. In this regard, important questions were formulated originally by Hoelzel and Dover (1989): ‘Are the Antarctic minke whales found in two geographically distinct management Areas from two different genetic stocks?’ or ‘Are individuals from more than one genetic stock present in a particular management Area? If so, what level of interchange may have occurred between different genetic stocks?’ Several approaches were used in the past to identify genetic stocks of this species in the Antarctic feeding grounds and to determine to what extent genetic stocks and IWC management Areas coincide.

Studies on stock structure of the Antarctic minke whale started at the end of the decade of the 1970’s and results of genetic and non-genetic analyses were revised by the IWC Scientific Committee (IWC SC) during the comprehensive assessment (CA) of the species in 1990. All the analyses presented at the CA were based on samples and data from commercial pelagic whaling in the Antarctic. Genetic studies were based mainly on allozyme although studies based on mitochondrial and nuclear DNA were also conducted, and most of the analyses involved small sample sizes from only Areas IV and V. Non-genetic studies revised in the 1990’s CA involved morphology, catch and sighting distribution pattern, analysis of Discovery marks and ecological markers. Results from the different approaches failed to identify unambiguously any isolated stock in the Antarctic (IWC, 1991).

Studies on stock structure under the JARPA started after the CA. It was considered that samples taken by JARPA were more useful for studies on stock structure than the commercial samples given the wider geographical covering of the surveys, and because whales were taken along track-lines in a random mode design in contrast to the commercial whaling samples analyzed in the 1990's CA, which were taken mainly from areas of high density near the ice-edge (Pastene, 2006). Initially the JARPA genetic studies on stock structure were based on mtDNA Restriction Fragment Length Polymorphism (RFLP), and a considerable genetic heterogeneity in Areas IV and V was found (Pastene *et al.*, 1993; 1996).

Results of stock structure analyses under the JARPA

The rationale for the analyses on stock structure under the JARPA was as follow. Analyses of Japanese sighting data obtained during 1976-1987 in low latitudinal waters of the Indian and western South Pacific Oceans suggested that there were two areas of high density of Antarctic minke whale, one in the eastern Indian Ocean (west of Australia) and the other in the western South Pacific (east of Australia) (Fig. 6), which were proposed as possible breeding grounds of this species (Kasamatsu *et al.*, 1995). The Australian continent can be considered a natural barrier to gene flow for some large baleen whale species during the winter reproductive period. For example, humpback whales (*Megaptera novaeangliae*) from western and eastern Australia are genetically differentiated for both mitochondrial and nuclear DNA (Schmitt *et al.*, 2012). The genetic differences between western and eastern Australian humpback whale stocks can also be detected in the Antarctic feeding grounds south of Australia, probably reflecting site fidelity of stocks to particular feeding areas in the Antarctic during the summer season (Kanda *et al.*, 2014).

In the case of the Antarctic minke whale, no genetic samples are available from low-latitude areas of the eastern Indian Ocean and western South Pacific that could be enable an investigation of the stock structure of this species. However, if whales from those two low-latitude localities are differentiated genetically, and they move directly to the south during their spring/summer migration to particular feeding areas in the Antarctic, then it would be possible to study the stock structure of Antarctic minke whale based on JARPA/JARPAII samples collected in the feeding grounds, as the stocks would be distinguishable genetically even during the feeding season (Fig. 6).

Results of the genetic and non-genetic analyses on stock structure under the JARPA were presented to the JARPA final review workshop (IWC, 2008). The main analytical procedure was hypothesis testing under the null hypothesis of panmixia. Different approaches were used such as mtDNA RFLP (12 six-base restriction enzymes), microsatellite DNA (six loci), morphometric (10 external measurements), and mean length of physical maturity. Details of the laboratory and analytical approaches as well as a synthesis of the results were presented by Pastene (2006). Whales in the eastern and western sectors of the research area were more differentiated than they were to whales in the central sectors, and this result was common for most of the approaches used. Therefore the author concluded that the single stock scenario cannot be applied to Antarctic minke whales in the feeding grounds of Areas III East-VI West. He concluded that the results were consistent with the occurrence of at least two genetic stocks in the research area, which are probably related with the proposed breeding areas in the eastern Indian Ocean and western South Pacific (Fig. 6). The following names were proposed for these stocks: Eastern Indian Ocean Stock (I-Stock) and Western South Pacific Ocean Stock (P-Stock) (Pastene, 2006).

The JARPA final review workshop agreed that there were at least two stocks of Antarctic minke whales present in the research area and that the data do not support the current IWC management Areas. The workshop also agreed that the data suggest an area of transition in the region around 150-165°E across which there is an as yet undetermined level and range of mixing (IWC, 2008). During the workshop several recommendations were made to refine the analyses conducted on stock structure. One of them was that the transitional area be studied by fitting model where the fraction of whales belonging to one putative population is a function of the longitude at which it was sampled. This could be a simple logistic regression model coupled with two-product multinomial models describing the allele frequencies in the two putative stocks either side of the transition area. It was noted that this approach could also be extended beyond two populations, and incorporate both genetic and morphometric data (IWC, 2008). This approach was taken into consideration when the analyses on stock structure were refined under the JARPAII.

Refinement of the analyses on stock structure under the JARPAII

JARPAII was conducted during the austral summer seasons 2005/06/-2013/14 in the same research area covered by JARPA. The analyses on stock structure were refined in two ways, the first implied additional laboratory work for additional genetic markers, and the second the application of a new analytical approach following a recommendation from the JARPA final review workshop.

All the Antarctic minke whales taken by JARPAII between 2005/06 and 2010/11 were sequenced for a 340bp-segment of the control region of the mtDNA (instead of the mtDNA RFLP used in JARPA) and genotyped using twelve microsatellite loci (instead of the six used in JARPA). Results of the heterogeneity test for both markers showed significant genetic differences between whales in two sectors, western (35-130°E) and eastern

(165°E-145°W), confirming that different stocks inhabit the Indian and Pacific sectors of the Antarctic (I and P stocks). Microsatellite DNA analyses showed more dispersal in males than females, and also some degree of annual variation (Pastene and Goto, 2016).

In response to a recommendation from the JARPA final review workshop Schweder *et al.*, (2011) developed an integrated approach for estimating longitudinal segregation of two stocks using different sources of data: morphometric, microsatellite and mtDNA data. Under this approach the soft boundary (or transition area) suggested previously was allowed to vary by year and sex. A joint likelihood function was defined for the estimation of mixing proportions and statistical tests without assuming any baseline populations. The approach was originally applied to the JARPA data (Schweder *et al.*., 2011) and subsequently to JARPA and JARPAII data (Kitakado *et al.*, 2014).

The results of this new analytical approach confirmed the occurrence of at least two stocks (I and P stocks) in the JARPA/JARPAII research area. Furthermore the results indicated that the spatial distribution of the two stocks has a soft boundary in Area IVE (100-130°E) and VW (130-165°E), which change by year. Results also suggested possible sex differences in the pattern of distribution of the two stocks (Kitakado *et al.*, 2014).

Therefore the structure of Antarctic minke whale in Areas III East-VI West appears to be more complex than originally thought: at least two stocks with a wider mixing area, which change by year and sex (Fig. 7).

BIOLOGICAL INFORMATION

Age

Age of Antarctic minke whales is traditionally estimated by counting growth layer groups (GLGs) accumulated in the earplug, assuming an annual deposition of growth layers (i.e. one pair of dark and pale laminae accumulated per year) (Lockyer, 1984). Earplug age reading has been conducted from the beginning of exploitation of this species in 1970s. Age reading error, i.e. the extent of bias and inter-reader variability among readers have been discussed in the SC and a statistical model for quantifying age reading error was developed by Kitakado *et al.* (2013) and results were incorporated in SCAA (Punt *et al.*, 2013).

Another ageing method is the estimation by ratio of aspartic acid racemization in eye lens. This method was developed for other baleen whale species such as fin (Nerini, 1983) and bowhead (George, *et al.*, 1999) whales and applied to Antarctic minke whales (Yasunaga, *et al.*, 2014).

Growth

Growth curve of I-stock and P-stock Antarctic minke whales were estimated by Bando *et al.* (2006) from JARPA samples (Table. 6). Mean body length increased rapidly until around 7 years old and the growth ceased at around 15-20 years old. Estimated asymptotic length was about 20cm larger in I-stock than P-stock, 8.63m and 8.45m for I-stock and P-stock males and 9.17m and 8.93m for both stocks of females.

Physical maturity was determined based on the examination of the vertebral epiphysis of 6th dorsal vertebra stained by 0.25% toluidine blue-O solution. Cartilage between epiphyses and centrum was observed by naked eye or stereoscopic microscope and whales of which the epiphyses fused to the centrum were defined as physically mature. The estimated age at 50% physical maturity of male was younger than female for both stocks (Table. 6). As in the case of asymptotic length, the body length at 50% physical maturity of I-stock was larger than P-stock (Table. 6).

Morphology

Some morphological and morphometric studies were conducted on the Antarctic minke whale in the past using data obtained during commercial pelagic operations (Doroshenko, 1979; Wada and Numachi, 1979; Bushuev, 1990). However, results of these analyses provided no evidence of unambiguous genetic differences between Areas in the Antarctic.

Morphological and morphometric analyses are useful tools to examine questions on stock structure as demonstrated in the case of the North Atlantic common minke whale (Christensen *et al.*, 1990). Fujise (1995) conducted a preliminary morphometric analysis based on 16 external measurement of 1989/90 JARPA samples (*n*=326) in Area IV using Analysis of Covariance (ANCOVA), Principal Component Analysis (PCA) and Canonical Discriminant Analysis (CDA).

For investigation of stock structure using non-genetic marker, Hakamada (2006) conducted morphometric analysis using JARPA surveys in Areas III East, IV, V and VI West between 1987/88 and 2004/05. In the analyses, ANCOVA and cluster analysis were applied to 10 external measurements from 2,629 male and 1,803 female mature Antarctic minke whales. Results were broadly consistent with those in Fujise (1996) and those using genetic marker (Pastene *et al.*, 2006).

Schweder *et al.* (2011) developed an integrated approach for estimating longitudinal segregation of two stocks using different sources of data: morphometric, microsatellite and mtDNA data. The approach dealt with soft boundary between two stocks. The approach was originally applied to the JARPA data (Schweder *et al.*, 2011) and subsequently to JARPA and JARPAII data (Kitakado et al., 2014).

Kato and Fujise (2000) conducted analysis on morphometric variation among dwarf minke, Antarctic minke and western North Pacific common minke whales using ANCOVA and CDA. Analysis revealed significant difference in external body proportion and skull measurements among three forms of the minke whales.

Maturity

Sexual maturity of male is determined by examination of testis histological samples. Sexual maturity for females is determined by the presence of corpora luteum or albicans in both ovaries. Three method has been developed to estimate age and body length at sexual maturity of Antarctic minke whales (Kato, 1987).

tm50%, *Lm50%*: Age/length at 50% of animals attained sexual maturity

tmov, *Lmov*: Mean age/length of females with first ovulation

tmp: Mean age estimated from transition phase in earplug

Tm50%/*Lm50%* and *tmov*/*Lmov* were estimated from JARPA samples based on two stocks (Table. 6, Bando *et al.*, 2006). The estimated body length at sexual maturity of I-stock animals was 10-20cm larger than P-stock for both sexes.

The long trajectory of *tmp* based on cohort was examined by several authors by using commercial whaling and JARPA/JARPAII samples (Kato and Sakuramoto, 1991; Thomson *et al.*, 1999; Zenitani and Kato, 2006; Bando *et al.*, 2014). The *tmp* declined from 14years in 1940s to 7years in 1960s and remained constant at 7-8years till 1990s cohorts.

Reproduction

Bando *et al.* (2006) reported several biological parameters related to reproduction estimated by JARPA samples (Table. 6). Proportion of pregnant in matured female (PPF) was estimated as 92.9% and 85.4% for I-stock and P-stock, respectively. The PPF during JARPAII period remained high and no significant trend was detected for both stocks (Bando and Hakamada, 2014). Annual ovulation rate, which is a maximum value of true pregnancy rate, was 0.98 and 1.01 for both stocks, which might indicate high true pregnancy rate for Antarctic minke whales (Bando *et al.*, 2006). Foetal male ratio was 51.8% and 46.8%, which did not differ from parity. Multiples was rare for this species, only 8 among 1,142 and 9 among 717 cases of twin were observed for I-stock and P-stock, respectively (Bando *et al.*, 2006).

POPULATION DYNAMICS

Background

The data for Antarctic minke whales have been analyzed using population dynamics models for over 40 years, although the focus for population dynamics research for Antarctic minke whales has changed over time. The earliest analyses aimed to provide a basis for setting catch limits and to explore whether the extensive exploitation of other baleen whale species led to the creation of a "krill surplus" and hence whether Antarctic minke whales were increasing prior to the start of substantial exploitation in the early 1970s. The subsequent set of analysis aimed to assess whether population dynamics models, along with data collected by the "Japanese Whale Research Programme under Special Permit in the Antarctic" (or JARPA), could allow estimation of age-specific natural mortality (M), as inferences regarding changes over time in minke whale abundance are sensitive to assumptions regarding the value for M (Fig 1. of Punt, 2014). The most recent analyses have focused on directly estimating changes over time in carrying capacity and recruitment, and over age in natural mortality, and hence exploring the possibility that the decline in recruitment is related to competition and other population dynamic-related factors (IWC, 2005).

The initial population models based on cohort analysis (e.g. Sakuramoto and Tanaka 1985, 1986) were applied to data for Antarctic Areas III and IV, treating the data for each Area separately. Subsequent analyses based on ADAPT-VPA (Gavaris, 1988) considered the minke whales in Antarctic Areas IV and V as separate populations (Butterworth and Punt, 1990; Bergh, 1991a,b; Butterworth *et al*., 1996, 1999, 2002; Mori *et al*., 2007). However, the assumption that each Antarctic Area contains a separate stock was shown to be untenable based on genetic (mtDNA and microsatellite) and non-genetic (morphometric, biological parameters) analyses (IWC, 2008; Pastene, 2006). This led to the development of population dynamics models based on Statistical Catch-at-age Analysis (SCAA) that can simultaneously model multiple stocks (e.g. Punt and Polacheck, 2005, 2006; Punt *et al*. 2014) and extension of the assessed area from Antarctic Areas IV and V to Areas III East, IV, V and VI West. However, even the most recent assessments fail to allow for mixing of stocks in the assessed area, despite evidence that such variation occurs (Kitakado *et al*., 2014)

The VPA and SCAA were modified over time in response to review by the Scientific Committee. Thus, the following sections focus on the "final" versions of the two methods (Butterworth *et al.* (2002) and Punt *et al*. (2014) respectively).

Virtual Population Analysis

In common with all VPA-type methods, the VPA developed for Antarctic minke whales assumed that the catches-at-age were measured without error and projected cohort numbers backwards from either the most recent year or the oldest age. Initially, the VPA analyses were based on grouping and analyzing the catch-at-age data on a 3-age-3-year basis to overcome small sample size problems for the statistical distribution underlying the estimator used at that stage, although subsequently analyses were also conducted on a 1-age-1year basis. The analyses by Butterworth *et al*. (2002) followed the methodology applied by Butterworth *et al*. (1999) and estimated age-specific natural mortality, a fishing mortality scalar for the last year with data (2001 for Antarctic Area IV and 1998 for Antarctic Area IV), and selectivity for the JAPRA surveys and the commercial catches. The VPA was fitted to the JARPA indices of relative abundance, the IDCR estimates (taken to be estimates of absolute abundance), and the commercial and scientific catches-at-age.

The estimates of recruitment (and hence 1+ abundance) were estimated using the VPA to have increased over time (from at least the 1940s) and peaked at the end of the 1960s and then declined and stabilized (Fig. 8). This result was robust to whether the model is based on a 1-age-1-year or 3-age-3-year basis, as well as to the choice of the plus-group for the catch-at-age data component of the likelihood function. The estimates of (age-independent) natural mortality were 0.07yr-1 (90% CI 0.036-0.093) (Area IV) and 0.049 yr-1 (90% CI 0.011-0.095) (Area V).

Statistical Catch-at-Age Analysis

Statistical catch-at-age analysis (Fournier and Archibald, 1982) involves developing a population dynamics model and fitting it to the available data by maximizing an objective function. Punt and Polacheck (2005) noted that there were several potential concerns with the ADAPT-VPA approach as implemented at that time that could be addressed within the context of statistical catch-at-age analysis: (a) the catch age-composition data were assumed to be known exactly when constructing the numbers-at-age matrix, (b) it was not possible to estimate the numbers-at-age for some of the oldest ages in the earliest years for which commercial age-composition data were available directly using back-projection, and (c) one of the key objectives of the past assessments of minke whales in Areas IV and V was to estimate the Maximum Sustainable Yield rate (MSYR), but the VPA could not do this directly.

The most recent version of the SCAA (Punt *et al.*, 2014) is sex-specific, can model multiple stocks simultaneously, and allows for multiple fleets and regions, permits carrying capacity, the deviations in calf numbers about the expected number of births, the growth curve, vulnerability, and the proportion of each stock in each region to change over time. It includes multiple options for modelling time-dependence in natural mortality and sex- and length-specific vulnerability. The model allows some of its parameters (such as the age-specificity of natural mortality and the resilience of the stock-recruitment relationship) to be shared among stocks. The model can be fitted to estimates of absolute and relative abundance, catch length-composition data, and conditional age-at-length data. The model is nominally fitted to the total catches by sex, but given the weight assigned to the associated likelihood component, the fit is almost exact. The model can also be fitted to catch-at-age data, but this was not needed for the implementation for Antarctic minke whales. Punt (in review) concluded that this is the most complex stock assessment for any cetacean population. The objective function minimized includes the likelihoods for each data type and penalties on time-variation in births, vulnerability, growth, carrying capacity, and area-proportion deviations.

The application to Antarctic minke whales assumes that there are two stocks in Areas III East to IV West, with the I (Indian) stock – assumed to be found in Areas III West, IV, and V West, and the P (Pacific) stock –

assumed to be found in Areas V East and VI West. The model includes 15 'fleets' consisting of three whaling types (Japan before 1987/88, Japan from 1987/88, and ex-Soviet Union) in each of the five areas considered in the model. Two Japanese whaling types are considered so that the data for commercial and Scientific Permit catches can be treated separately. The SCAA ignored the length-frequency data for the ex-Soviet Union fleet because of concerns regarding the reliability of these data (there are no age-composition data for this fleet) and vulnerability for the ex-Soviet Union and the Japanese fleet were assumed to be the same. This latter assumption was made given information on possible misreporting of catch length distributions by the ex-Soviet Union (IWC, 2011).

The SCAA was able to mimic the available data well, although this was due in part to the large number of parameters and the allowance for both overdispersion and age reading error. The results from the SCAA analysis (now for Stocks I and P, and with data until the 2012/13 austral summer) were qualitatively similar to those from the VPA (Figs 8 and 9). Specifically, the SCAA inferred that Antarctic minke whales in the assessed area increased from 1930 until the mid-1970, and declined over the period the mid-1970s until 1988. The increase rate for total abundance size was estimated to be 1.9% (SE 0.7%) annually for stock I and 2.1% (SE 1.1%) for stock P. The extent of increase from 1945 to 1968 was estimated to be higher for stock P than for stock I. Although stocks I and P do not match Antarctic Areas IV and V exactly, the results from the SCAA are more precise and the trend for stock P exhibits a continuing decline compared to the VPA. The increase in abundance was estimated to be due primarily to an increase in recruitment owing to an increase in carrying capacity. However, carrying capacity was estimated to have declined following a peak for both stocks, but the effect of this on recruitment and hence total population size was much smaller for stock P than for stock I. The estimates of the recruitment (right panels of Fig. 9) suggest that there have been periods of good and poor recruitment.

Natural mortality is a piecewise linear function of age (Fig. 10). The estimates of natural mortality indicate that natural mortality is highest for the youngest and (particularly) oldest animals, with the estimate of natural mortality for age 15 0.048yr^{-1} (SE 0.005) for Stock I and 0.046yr^{-1} (SE 0.005) for stock P, which are lower than the estimates from the VPA (Fig. C).

The SCAA can be used to estimate MSYR1+. The reference case SCAA estimates of MSYR1+ were generally very high (>0.2), but some of the sensitivity tests led to estimates of MSYR1+ which are essentially zero. A primary reason for the inability to estimate MSYR1+ is that the stocks were estimated to be close to carrying capacity throughout the assessment period for most of the SCAA analyses (Fig. 3 of Punt *et al*., 2014).

The results are generally insensitive to changes to specifications of the SCAA reference case analysis. However, not allowing for time-varying growth led to a markedly faster estimated rate of increase for stock P and also to higher estimates of natural mortality for very young animals for both stocks, while the rate of increase was lower over the initial years of the projection period when carrying capacity was assumed to be constant.

An original aim for developing the SCAA was to determine the reason or reasons for the decline in abundance of Antarctic minke whales. The SCAA does not provide definitive conclusions in this regard. However, the results point to the possibility that carrying capacity has changed over time (first increasing then decreasing). However, "carrying capacity" in the model relates to trends in at least four processes: pregnancy rates, infant survival rates, age-0 survival rates and changes in maturity – the data included in the SCAA do not allow these processes to be distinguished.

Next steps

Although the SCAA-based assessment is "mature" in that it was under development for almost a decade and had been refined through the suggestions and advice of the Scientific Committee, there remain areas for future work as highlighted by Punt *et al*. (2014): (a) consideration of other stock structure hypothesis, including a soft boundary in Areas IV-E and V-W, which depends on year and sex (Kitakado *et al*., 2014), (b) evaluating the performance of the estimation method using simulations, (c) application of the model to broader range of areas within the Antarctic, and (d) analyzing the estimates of deviations in calf survival rate to identify the likelihood of possibly causal mechanisms for the changes in recruitment over time.

FOOD HABIT AND ENERGETICS

Food habits and consumption

The Antarctic minke whale, which grows up to 10m (Horwood, 1990), is the most abundant balaenopterid species in the Southern Ocean with abundance estimated at 515,000 animals south of 60°S in austral summer (95% CI:360,000–730,000). These estimates were based on sighting data collected between the 1992/93 and 2003/04 seasons (IWC, 2013). Like other balaenopterid species (except the Bryde's whale), the Antarctic minke whale spends its breeding season at lower latitudes in austral winter and migrates to the Southern Ocean to feed in austral summer (Horwood, 1990; Kasamatsu *et al.*, 1995). The Antarctic minke whale feeds mainly on Antarctic krill (*Euphausia superba*) in offshore waters (Kawamura, 1980; Bushuev, 1986; Ichii and Kato, 1991), and on ice krill (*E. crystallorophias*) on the coastal shelf along such areas as the Ross Sea and Prydz Bay (Bushuev, 1986; Tamura and Konishi, 2009). Previous studies estimated the daily prey consumption by Antarctic minke whales in the Southern Ocean on the basis of energy-requirement calculations (Lockyer, 1981; Armstrong and Siegfried, 1991; Reilly *et al*., 2004).

Based on the Japanese Whale Research Program (JARPA) research from 1987/88 to 2004/05 seasons, the maximum weight of stomach contents were 125.7kg (3.1% of body weight) and 156.0kg (3.4% of body weight) for immature male and female, respectively and 343.8kg (4.2% of body weight) and 321.2kg (3.6% of body weight) for mature male and female, respectively. The mean weight of fresh or lightly digested stomach contents were 30.9±23.5kg (1.0% of body weight) and 43.0±31.5kg (1.0% of body weight) for immature male and female, respectively and 74.2±50.1kg (1.1% of body weight) and 76.3±54.6kg (1.0% of body weight) for mature male and female, respectively.

The daily prey consumption by the whales in each reproductive status group was estimated using energy-requirement and energy deposition. The daily prey consumptions during feeding season were 31.5×10^4 and 68.3×10^4 kJ for immature and mature male, and 52.1×10^4 and 122.3×10^4 kJ for immature and mature female, respectively. When the mean energy value of prey of 4 473kJ kg-1 and the assimilation efficiency of 84 % were considered, the daily prey consumptions during feeding season were 83.7 and 181.7kg for immature and mature male, and 138.7 and 325.5kg for immature and mature female, respectively. These values were equivalent to 2.9 and 2.7 % of body weight for immature and mature male, and 3.7 and 4.0 % of body weight for immature and mature female, respectively. The total prey consumptions per capita during feeding season were 7.5 and 16.4 tons for immature and mature male, and 12.5 and 39.1 tons for immature and mature female, respectively (Tamura and Konishi, 2009).

As next step, the uncertainty in several components involved in estimating the amounts and types of prey consumed by whales was assisted by a recent review by Leaper and Lavigne (2007) and Tamura *et al.* (2009). The several uncertainties (*e.g.* allometric relationships, body weight of whales, energy values of prey species, assimilation efficiency and length of feeding period) in the estimations of prey consumption associated to the relevant parameters will be treated by Monte Carlo simulations. Recently, development of individual-based models of cetacean foraging are progressing using the multi-sensor movement tag and telemetry data (Friedlaender *et al.*, 2008, 2011, 2016). It is useful for understanding of the species-specific energetic costs of feeding by Antarctic minke whales.

Body condition and the annual trend in energy storage

Whales generally accumulate energy as lipid in the blubber during the summer feeding period at high latitudes and migrate to low latitude areas (Næss *et al.*, 1998) spending the energy for reproduction and migration. The proxy of fat reserves in blubber have been used as an indication of body condition in whale studies (*e.g.* Lockyer . 1985, 1986; Lockyer and Waters 1986; Vikingsson, 1995; Koopman, 1998; Ichii *et al.*, 1998; Haug *et al.*, 2002). Blubber thicknesses, blubber weight and girth have been used as the indices of previous studies and found to increase through the feeding season (Lockyer, 1987; Vikingsson, 1995; Næss *et al.*, 1998; Konishi *et al.*, 2008). The measurements of blubber thickness positively correlates with lipid content in the whole body fat and proven to be dependable proxy for energy storage in whales by Lockyer *et al.* (1985). In the 18 years JARPA period, annual trend in energy storage in the Antarctic minke whale was examined using minke catch data. This regression analyses clearly showed that blubber thickness, girth and fat weight had been decreasing for this period. The decrease per year is estimated at approximately 0.02 cm for mid-lateral blubber thickness and 17 kg for fat weight, corresponding to 9% for both measurements over the 18-year period (Konishi *et al.*, 2008). The IWC/SC agreed that a decline in blubber thickness and in fat weight that was statistically significant at the 5% level had occurred in JARPA period (IWC, 2015b; Konishi and Walloe, 2015). As next step, several body condition analyses for the Antarctic minke whales will be developed based on scientific permit researches by Japan.

POLLUTANTS AND MARINE DEBRIS

Honda *et al.* (1987) had proposed the hypothesis that 'yearly changes of age accumulation patterns of hepatic mercury (Hg) in Antarctic minke whales suggest possible environment changes such as changes of food availability' based on no observation of usual age-related accumulation of hepatic mercury in minke whales taken during a period of early 1980's, and Fujise *et al.* (1997), Watanabe *et al.* (1998) and Honda *et al.* (2006) reported that the phenomenon continued until 1990's due to a greater availability of food. Yasunaga *et al.* (2006a) reported using sample taken until 2005 that Hg intake in young minke whales (1-15 years) significantly decreased with sampling years, while that of individuals over 16 years old was stable, and Yasunaga *et al.*

(2014a) reported using sample taken until 2013 that hepatic Hg levels of minke whales of all age groups in Area IV decreased significantly with research years and that of 15-26 year old whales in Area V increased significantly. It is suggested that food availability of Antarctic minke whales in 2000's may be change to those in 1980' and 1990'.

Levels of polychlorinated biphenyls (PCBs), dichlorodiphenyl trichloroethanes and metabolites (DDTs), hexachlorocyclohexane isomers (HCHs), hexachlorobenzene (HCB) and chlordane compounds (CHLs) in blubber of minke whales taken from Areas V and VI in a period from 1988/89 to 2004/2005 extremely slowly decreased or maintained a steady state, while those of HCHs were drastically decrease in the period (Yasunaga *et al.*, 2006b; Yasunaga *et al.*, 2015). In comparison of those from Area V between from 1988/1989 to 2004/2005 and in 2010/2011, Levels of DDTs, HCHs, HCB and CHLs in Area V decreased significantly with year, while the yearly trend of PCBs did not change significantly. HCHs levels in minke whales in 2010/2011 were similar to those in the JARPA period from 1996/1997 to 2004/2005 however they were lower than those in the JARPA period from 1988/89 to 1996/1997 (Yasunaga *et al.*, 2014b). These results suggested that levels of HCHs in the Antarctic Ocean have varied from slightly decreasing to a steady state in the middle 1990s.

Isoda *et al.* (2014) summarized marine debris records in the JARPA and JARPA II for the period 1987/88 to 2010/11. In sighting records of research vessels, buoys made of plastic were the most abundant debris (69% of all marine debris recorded) in Areas III East, IV, V and VI West. The highest density was recorded in Area V (DI: 0.15) (DI: number of marine debris observed per 100 n. miles), followed by Area IV (DI: 0.12). DI of buoys in Area IV and V suddenly increased after the 2005/06 austral summer season. The increase of buoy debris coincides with an increase of long-line fishery operations in this area. The stomachs of a total of 10,041 Antarctic minke whales was examined for debris. The number of occurrence of marine debris and objects other than prey in the fore and main stomachs per 100 Antarctic minke whales examined was estimated at 0.35. Four cases of entanglement in a total of 10,041 Antarctic minke whales examined were found. Those involved fishing hook, monofilament fishing line, rope and packing band.

SPECIES INTERACTIONS

It has been documented that killer whales feed on Antarctic minke whales (see Pitman and Ensor, 2003 for review). Likely effect of predation by killer whales on change of abundance estimates of Antarctic minke whales between CPII and CPIII were considered but it was concluded that predation by killer whales didn't have considerable effect on Antarctic minke whales given estimated consumption rates of killer whales and their estimated abundance (Branch and Williams, 2003) although the relationship in the Indo-Pacific sector was not investigated explicitly.

Interaction with other baleen whales was suspected because number of baleen whales other than Antarctic minke whales in this sector was increased from 1978/79 to 2008/09 as indicated by IDCR/SOWER and JARPA/JARPAII estimates (e.g. Branch 2007; 2010; Hakamada and Matsuoka, 2014; Matsuoka and Hakamada 2014). the population size of breeding stock D (BSD) of humpback whales which utilizes Area IV as there feeding ground reached 90% of pre-exploitation in 2012 (IWC, 2015b). Changes in spatial distribution of large baleen whales (southern right, fin, sei and humpback whales) in relation to Antarctic minke whales were examined in Area IV and V-W using data obtained in IDCR/SOWER CPII and CPIII (Murase *et al*., 2011). Change in spatial distribution of humpback whales in relation to Antarctic minke whales was examined in Area IV using JARPA/JARPAII data (Murase *et al*., 2014). These studies revealed that spatial distribution of large whales expanded as their number increased while that of Antarctic shrank toward south although improvement of these models were recommended before making the conclusion (e.g. IWC, 2015a).

Attempts were made to construct multi-species ecosystem models in the period of the in-depth assessment. Mori and Butterworth (2004) constructed a multi-species production model to model interactions among krill, Antarctic minke and blue whales at a circumpolar scale. Additional species (fin and humpback whales, and Antarctic fur and crabeater seals) were included in their expanded model (Mori and Butterworth, 2006). There were two modelled areas (the Indian and Atlantic sector consisted of Area II, III and IV, and the Pacific sector consisted of I, V and IV) in the expanded model. Further refinement was attempted by Kitakado *et al.* (2014) targeting Area IV though the results was preliminary at the time of the presentation. A preliminary attempt to model ecosystem of Area was also made by using a whole-ecosystem model, Ecopath (Kitakado *et al.*, 2014).

SUMMARY OF CONCLUSIONS, FUTURE WORK AND DISCUSSION

After many years of working towards an in-depth assessment of Antarctic minke whales, we have now reached a point where we can summarize what has been achieved, provide conclusions and determine what outstanding issues are feasible and/or worthwhile to address in the future. This exercise started out trying to understand the abundance trends during observed in abundance surveys conducted during 1984 – 2004, but expanded to increasing our knowledge on the population dynamics, biological characteristics (stock structure, abundance estimates, …)

and environmental interactions of the Antarctic minke whale. Conclusions from each of these types of data will be summarized and outstanding issues to be addressed in the future will be discussed.

Population dynamics

Results from VPA and SCAA population dynamic analyses were used to provide an overall assessment of the status of the Antarctic minke whales. The SCAA analysis was refined to account for more issues than could be dealt with in the VPA framework; thus the SCAA has provided the final results of the assessment. Both of these analytical techniques required information on population structure, the degree of mixing among the stocks, age-specific catches from the commercial and research programs, and a series of abundance estimates. The most recent version of the SCAA was also sex-specific, modelled multiple stocks simultaneously allowing some factors to be shared by both stocks, allowed for multiple catch fleets and regions, allowed for estimates of absolute and relative abundance, and allowed for in each region changes over time in respect to carrying capacity, deviation in calf numbers about the expected number of births, growth curves, sex- and length-specific vulnerability, and the proportion of each stock in each region.

As a result of the 10-year development, the SCAA analysis in one of the most complex stock assessments for any cetacean population. It finally focused on directly estimating changes over time in carrying capacity and recruitment, and over age in natural mortality, and hence explored the possibility that the decline in recruitment is related to competition and other population dynamic-related factors. Given that carrying capacity for minke whales was estimated to have changed over time, usual assessment measures such as population size relative to the (current) carrying capacity were not immediately straightforward to interpret. However, the results of the SCAA model can be interpreted in the context of trends in abundance. The model implied that the total 1+ population size increased annually by 1.9% (SE 0.50) for stock I and 2.1% (SE 0.70) for stock P per annum between 1945 and 1968. The number of 1+ animals was then estimated to have declined by 54% (stock I) and 35% (stock P) from 1968 to 2001. In addition, natural mortality was able to be estimated for age groups. However MSYR for 1+ animals was not able to be reliably estimated, primarily because the model estimated the stock was close to carrying capacity throughout the assessment period. The SCAA was also not able to definitive conclude on the reason(s) for the abundance decline. However, the results point to the possibility that carrying capacity changed over time. Though which biological reflexion of carrying capacity (pregnancy rates, infant survival rates, or changes in maturity) was related to the abundance change was not able to be distinguished. Reliability of conclusions from the SCAA as recorded in IWC (2014) are shown in Table 7

Remaining areas for future work on the SCAA include: (a) consideration of other stock structure hypothesis, including a soft boundary in Areas IV-E and V-W, which depends on year and sex (Kitakado *et al*., 2014), (b) evaluating the performance of the SCAA estimation method using simulations, (c) application of the model to broader range of areas within the Antarctic, and (d) analyzing the estimates of deviations in calf survival rate to identify the likelihood of possibly causal mechanisms for the changes in recruitment over time.

Stock structure

An essential piece of information needed in any stock assessment is the stock structure and degree of mixing. The Antarctic minke whale's stock structure has been investigated using genetic studies (mitochondrial and nuclear DNA) and non-genetic studies (morphology, catch and sighting distribution patterns, and patterns derived from Discovery marks and ecological markers). The 1990 Comprehensive Assessment assumed there was a single stock. After the 1990 Comprehensive Assessment, using samples collected from JARPA research catches that started in 1987/88, genetic and non-genetic analyses revelled the single stock scenario was incorrect in the feeding grounds of Management Areas III East – VI West. There appeared to be at least two stocks that were probably related with the proposed breeding areas in the eastern Indian Ocean (I-stock) and western South Pacific (P-stock) with an area of transition in the region around 150 – 165°E. Refining the laboratory using samples collected under JARPA (1987/88 – 2004/05) and JARPA II (2005/06 – 2013/14) confirmed the two stocks and showed more dispersal in males than females and also some degree of annual variability. Refining the analytical methods by developing an integrated approach using morphometric, microsatellite and mtDNA data suggested the transition area (soft boundary) varied by year and sex and the soft boundary was from 100 – 130°E in Area IV East and in 130 – 165°E in Area V West. Therefore, the structure of Antarctic minke whale in Areas III East-VI West appears to be more complex than originally thought: at least two stocks with a wider mixing area, which change by year and sex.

Kato and Fujise (2000) conducted an analysis on morphometric variation among dwarf minke, Antarctic minke and western North Pacific common minke whales using ANCOVA and CDA. Analysis revealed significant difference in external body proportion and skull measurements among three forms of the minke whales.

Abundance and distribution

Another essential piece of information needed in any stock assessment is an estimate of abundance, or preferable a time series of abundance estimates. The 1990 Comprehensive Assessment only had available one set of abundance estimates for each Management Area. In contrast, the SCAA assessment analysis was able to utilize two sets of absolute estimates from the IWC/IDCR sighting dedicated line transect survey from the last two circumpolar sets: 1985/86-1990/91 (the second circumpolar survey; CPII) and 1991/92-2003/04 (the third circumpolar survey; CPIII) and relative estimates derived from the JARPA/JARPA II program from 1989/90 to 2008/09 that were in Areas III East to VI West (35°E – 145°W, south of 60°S). The first circumpolar survey (CPI) was not able to be used because it was not possible to correct for the biases due to the non-standard survey design and to correct for the lack of data to estimate g(0).

After 10 years of discussion, abundance estimates for the IWC/IDCR/SOWER CPII and CPIII and their associated additional variance (i.e., process error) were agreed upon in 2012. These estimates were the result of developing/improving three independent analysis methods [IM (integrated model developed by Cooke, SPLINTR (spatial line transect) developed by Bravington and Hedley, and OK (Okamura-Kitakado) developed by Okamura and Kitakado] and evaluating the performance and robustness of different versions of these three analysis methods using simulated datasets. The final agreed upon estimates were derived from the evolved OK method with adjustments from the SPLINTR method.

After 6 years of discussion, abundance estimates derived from the JARPA/JARPA II data were corrected for the non-standard survey design, changing g(0), school size bias, un-surveyed areas, and use of multiple survey vessels at different times within the season.

Though the SCAA only used the Antarctic minke whale sightings data, the CP series surveys also collected sightings data on all cetaceans and the programme also included the collection of biopsy, photo-identification, oceanographic and acoustic samples.

In addition, experiment cruises from 2004/05 to 2009/10 were devoted mostly to experiments to address problems encountered with the analysis of previous cruises. The experiments included the Buckland-Turnock survey method that estimates g(0) and accounts for responsive animal behavior, school size estimation experiments, and visual dive time experiments. These experiments were instrumental in developing the final agreed upon abundance estimates for the minke whales.

Another type of experiment cruise were the cooperative surveys with ice breakers (Australian *Aurora Australis* in 1999, US *Nathaniel B. Palmer* in 1994 and 2004, and Japanese *Sirase* in 2004/05), helicopter surveys from the *Sirase*, and Australian fixed-wing aircraft in 2007/08 – 2009/10. The objective of these experiments were to investigate the minke whales that were distributed in the sea ice and so were not available to be counted during the IWC/IDCR/SOWER and JARPA/JARPA II abundance surveys. These cooperative surveys in the sea ice revealed that considerable numbers of Antarctic minke whales. However, absolute numbers could not be obtained for the previous time periods of the CPI – CPIII series of abundance surveys.

Remaining areas of future work related to abundance estimates includes conducting surveys in the sea ice most practically via aerial surveys, if more complete abundance estimates are needed.

<u>Biological information</u>

The biological information used by the SCAA included the length, age and sex of the commercial and research catch, age-length relationships and age reading error (the extent of bias and inter-reader variability among readers).

The age of minke whales were traditionally estimated by counting growth layers in the earplug (Lockyer 1984), though the method using the ratio of aspartic acid racemization in eye lens was also explored (Yasunaga et al. 2014). A statistical model quantifying age reading error was developed by Kitakado *et al.* (2013).

Growth curves (length – age relationships) were derived for the I- and P-stocks using JARPA samples (Bando et al. 2006). Physical maturity was determined based on the examination of the vertebral epiphysis of 6th dorsal vertebra stained by 0.25% toluidine blue-O solution and used to estimate the age at 50% physical maturity. Sexual maturity was determined by male testis histological samples and presence of corpora luteum or albicans in females. This resulted in an estimated asymptotic length of about 20cm larger in I-stock than P-stock, 8.63m and 8.45m for I-stock and P-stock males and 9.17m and 8.93m for both stocks of females. The mean body length increased rapidly until about 7 years old and stops at around 15 – 20 years old. The estimated age at 50% physical maturity of males were younger than female for both stocks and the body length at 50% physical maturity of I-stock was larger than P-stock. The estimated body length at sexual maturity of I-stock animals was 10-20cm larger than P-stock for both sexes. The mean age of sexual maturity estimated from transition phase in earplugs declined from 14 years in 1940s to 7 years in 1960s and remained constant at 7-8 years till the 1990s cohorts. Using JARPA samples, the proportion of pregnant in matured female was estimated as 92.9% and 85.4% for I-stock and P-stock, respectively and there was no significant trend going into the JARPA II time period.

Remaining areas of future work related to estimating biological parameters is (a) to examine past yearly changes of biological parameters for each stock, (b) to examine whether there is an age-dependent changes for reproductive parameter and (c) to detect possible future changes.

Food habits and energetics

The Antarctic minke whale feeds mainly on Antarctic krill (*Euphausia superba*) in offshore waters (Kawamura, 1980; Bushuev, 1986; Ichii and Kato, 1991), and on ice krill (*E. crystallorophias*) on the coastal shelf along such areas as the Ross Sea and Prydz Bay (Bushuev, 1986; Tamura and Konishi, 2009). The daily prey consumption by the whales in each reproductive status group was estimated using energy-requirement and energy deposition. The daily prey consumptions during feeding season values were equivalent to 2.9 and 2.7 % of body weight for immature and mature male, and 3.7 and 4.0 % of body weight for immature and mature female, respectively. The total prey consumptions per capita during feeding season were 7.5 and 16.4 tons for immature and mature male, and 12.5 and 39.1 tons for immature and mature female, respectively (Tamura and Konishi, 2009).

Remaining areas of future work involve investigating several uncertainties (*e.g.* allometric relationships, body weight of whales, energy values of prey species, assimilation efficiency and length of feeding period) in the estimations of prey consumption associated to the relevant parameters that can be treated by Monte Carlo simulations. Recently, development of individual-based models of cetacean foraging are progressing using the multi-sensor movement tag and telemetry data (Friedlaender *et al.*, 2008, 2011, 2016).

In the 18 years JARPA period, a regression analysis of the annual trend in energy storage in the Antarctic minke whale showed that blubber thickness, girth and fat weight had been decreasing for this period. The decrease per year is estimated at approximately 0.02 cm for mid-lateral blubber thickness and 17 kg for fat weight, corresponding to 9% for both measurements over the 18-year period (Konishi *et al.*, 2008). The Scientific Committee agreed that a decline in blubber thickness and in fat weight that was statistically significant at the 5% level had occurred in JARPA period (IWC, 2015b; Konishi and Walloe, 2015). Remaining areas of future work include several body condition analyses for the Antarctic minke whales based on scientific permit research catches.

Environmental aspects

The Antarctic minke whale is part of a larger physical and biological changing ecosystem. Antarctic minke whales are both predator and prey and they also have to share the ocean with other predators. All of these factors influence their distribution and density patterns. As noted earlier, high density areas of minke whales were commonly found at the sea ice edge especially in and around the Ross Sea, and the abundance of minke whales has declined since the 1970s. The large scale distribution patterns over all years appears to be at least partially related to the presence of sea ice (Ichii, 1990; Kasamuatsu *et al.*, 2000; Matsuoka *et al.*, 2003; Murase *et al.*, 2002) and other transition zones such as the continental shelf break (Beekmans *et al.*, 2010; Murase *et al.*, submitted). These transition zones are known to be regions that aggregate krill, the minke whale's prey. At a smaller scale presence of krill has been shown to be associated with minke whale distribution (Friedlaender *et al.*, 2008; 2011; 2016). Though it has been documented that killer whales feed on Antarctic minke whales (Pitman and Ensor, 2003) and the numbers of killer whales are increasing in the Antarctic, it does not appear that killer whales have been a driving factor in the broad scale declining abundance trend since the 1970s (IWC, 2015b). In contrast, since the 1970s, as the distribution and abundance patterns of minke whales shrank and concentrated in the south near the ice edge, the patterns of other baleen whales (southern right, blue, fin, and humpback whales) expanded (Branch 2007; 2010; Hakamada and Matsuoka 2014; Matsuoka and Hakamada 2014; Murase *et al.*, 2014). Attempts to model the multi-species relationships between krill, Antarctic minke whales and other whale species have been attempted using multi-species production models (Mori and Butterworth, 2004; 2006; Kitakado *et al.*, 2014) and the whole-ecosystem Ecopath model (Kitakado *et al.*, 2014).

Effects of humans relative to the Antarctic minke whale have also been changing. Trends of pollutants levels of PCBs, DDTs, HCHs, HCB, CHLs show different patterns depending on which part of the Antarctic the minke whale resides in. This reflects not only the Antarctic environment but also the more northern breeding areas where the minke whales spend the rest of the year. Minke whales in Areas V and VI showed extremely slowly decreasing or a steady state patterns during 1988/89 – 2005/05. In contrast, levels in minke whales from decreased significantly (Yasunaga *et al.*, 2006b; 2014b; 2015). In addition, accumulation patterns of hepatic mercury varied over years differently for young minke whales (1 – 15 years old) as compared to older animals. This suggested that food availability in the 2000s changed compared to the 1980s and 1990s (Honda *et al.*, 1987; Fujise *et al.*, 1997; Watanabe *et al.*, 1998, Honda *et al.*, 2006; Yasunaga *et al.*, 2006a, 2014a). The sighting surveys have also documented the locations of marine debris since 1987/88. In general levels of marine debris were low, with plastic buoys being the most common item (Isoda *et al.*, 2014). The number of buoys in Area IV and V suddenly increased after the 2005/06 austral summer season which coincides with the increase of long-line fishing. This same general pattern was seen in the 10,041 Antarctic minke whale stomachs that were examined for debris.

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REFERENCES

Ainley, D.G., Dugger, K.M., Toniolo, V. and Gaffney, I. 2007. Cetacean occurrence patterns in the Amundsen and southern Bellingshausen sea sector, Southern Ocean. *Mar. Mamm. Sci.* 23: 287-305. (submitted to the IWC/SC as SC/59/ForInfo7)

Allison, C. IWC individual catch database Version 6.1; Date: 18 July 2016 (available from the International Whaling Commission)

Amante, C., Eakins, B.W. 2009. ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24.

Armstrong, A. J., and Siegfried, W. R. 1991. Consumption of Antarctic krill by minke whales. *Antarct. Sci.* 3:13-8.

Arnason, U., Gullberg, A. and Widegren, B. 1993. Cetacean mitochondrial DNA control region: sequences of all extant baleen whales and two sperm whale species. *Mol Biol Evol* 10: 960-70.

Arnold, P., Marsh, H. And Heinsohn, G. 1987. The occurrence of two forms of minke whales in east Australian waters with a description of external characters and skeleton of the diminutive or dwarf form. *Sci Rep Whal Res Inst* Tokyo 38:1-46.

Bando, T. and Hakamada, T. 2014. Yearly trend in the proportion of pregnant animals among mature female Antarctic minke whales in the JARPA and JARPAII period. Paper SC/F14/J09 presented to the Expert Workshop to Review the Japanese JARPAII Special Permit Research programme, Tokyo, February 2014 (unpublished). 6pp.

Bando, T., Zenitani, R., Fujise, Y., Hakamada, T. and Kato, H. 2006. Biological parameters of the Antarctic minke whale based on materials collected by the JARPA survey in 1987/88 to 2004/05. Paper SC/D06/J17 presented to the JARPA Review Workshop, Tokyo, December 2006 (unpublished). 28pp.

Bando, T., Kishiro, T. and Kato, H. 2014. Yearly trend in the age at sexual maturity of Antarctic minke whales examined by transition phase in earplugs collected during JARPA and JARPA II surveys. Paper SC/F14/J08 presented to the Expert Workshop to Review the Japanese JARPAII Special Permit Research programme, Tokyo, February 2014 (unpublished). 10pp.

Beekmans, B.W.P.M., Forcada, J.F., Murphy, E.J., de Baar, H.J.W., Bathmann, U.V. and Fleming, A.H. 2010. Generalised additive models to investigate environmental drivers of Antarctic minke whale (*Balaenoptera bonaerensis*) spatial density in austral summer. J. Cetacean Res. Manage. 11: 115-29.

Bergh, M.O., Butterworth, D.S. and Punt, A.E. 1991a. Further examination of the potential information content of age-structure data from Antarctic minke whale research catches. *Rep. int. Whal. Commn* 410:349–61.

Bergh, M.O., Butterworth, D.S., and Punt, A.E. 1991b. Initial evaluations of the information content of catch-age data using the 'Appendix 3' protocol. Paper SC/43/O16 presented to the IWC Scientific Committee, May 1991 (unpublished) 14pp.

Best, P.B. 1985. External characters of southern minke whales and the existence of a diminutive form. *Sci Rep Whal Res Inst* Tokyo 36:1-33.

Borchers, D. and Burt, L. 2002. Generalised regression methods for estimating school size from line transect data. Paper SC/54/IA23 presented to the IWC Scientific Committee, April-May 2002 (unpublished). 10pp.

Branch, T.A. 2005. Combining estimates from the third circumpolar set of surveys. *J. Cetacean Res. Manage.* (Suppl.) 7:231-233.

Branch, T.A. 2006. Abundance estimates for Antarctic minke whales from three completed circumpolar sets of surveys, 1978/79 to 2003/04. Paper SC/58/IA8 presented to the the IWC Scientific Committee, May-June 2006 (unpublished) 14pp. 28pp.

Branch, T.A. 2007. Abundance of Antarctic blue whales south of 60°S from three complete circumpolar sets of surveys. *J. Cetacean Res. Manage.* 9: 253-62.

Branch, T.A. 2011. Humpback whale abudance south of 60ºS from three completed sets of IDCR/SOWER circumpolar surveys. *J. Cetacean Res. Manage.* Special issue 3: 53-69.

Branch, T.A. and Butterworth, D.S. 2001. Southern Hemisphere minke whales: standardised abundance estimates from the 1978/79 to 1997/98 IDCR-SOWER surveys. J. Cetacean Res. Manage. 3: 143-74. (submitted as SC/53/ForInfo7)

Brandão, A. and Butterworth, D.S. 2002. Further results concerning the closing:IO mode density ratio, R, for the IDCR-SOWER surveys. Paper SC/54/IA26 presented to the IWC Scientific Committee, April-May 2002 (unpublished). 13pp.

Branch, T.A., and P. Ensor. 2004. Combining estimates from the third circumpolar set of surveys. *J. Cetacean Res. Manage.* (Suppl.) 6:239-240.

Branch, T.A. and Williams, T, M. 2006. Legacy of Industrial Whaling: Could Killer Whales Be Responsible for Declines of Sea Lions, Elephant Seals, and Minke Whales in the Southern Hemisphere? pp.262-78, Whales, Whaling, and Ocean Ecosystems, 1 ed. University of California Press

Brandão, A., Rademeyer, R.A. and Butterworth, D.S. 2001. Estimation of mean school size for minke whales from IWC/IDCR-SOWER surveys.Paper SC/53/IA26 presented to theI WC Scientific Committee, July 2001 (unpublished). 21pp.

Bravington, M.V. 2002. Spatial analyses of Southern Hemisphere minke whale data, allowing for size bias and sightability. Paper SC/54/IA21 presented to the IWC Scientific Committee, April-May 2002 (unpublished). 18pp.

Bravington, M.V. and Hedley, S.L. 2012. Abundance estimates of Antarctic minke whales from the IWC IDCR/SOWER surveys, 1986–2002. Paper SC/64/IA13 presented to the IWC Scientific Committee, June 2012, Panama City (unpublished). 17pp.

Buckland, S.T. and Turnock, B.J. 1992. A robust line transect method. Biometrics 48: 901-9.

Burt, M.L. 2004. Overview of the standard dataset of IDCR/SOWER data. Paper SC/56/IA2 presented to the IWC Scientific Committee, July 2004, Sorrento, Italy (unpublished). 3pp.

Burt, M.L. and Hughes, M.S. 2002. A note on using different analysis options on abundance estimates using IWC-SOWER 1998/99 survey as an example. Paper SC/54/IA5 presented to the IWC Scientific Committee, April-May 2002 (unpublished). 12pp.

Burt, M.L. and Paxton, C.G.M. 2006. Review of density surface modeling applied to JARPA survey data. Paper SC/D06/J4 presented to the Intersessional Workshop to review data and results from special permit research on minke whales in the Antarctic, Tokyo, December 2006. (unpublished). 5pp.

Bushuev, S. G. 1986. Feeding of minke whales, *Balaenoptera acutorostrata*, in the Antarctic. *Rep int Whal Commn* 36:241-5.

Bushuev, S. G. 1990. A study of the population structure of the southern minke whale (Balaenoptera acutorostrata Lacépède) based on morphological and ecological variability. *Rep. int. Whal. Commn* 40: 317-324.

Butterworth, D.S. and Punt. A.E. 1990. Some preliminary examinations of the potential information content of age-structure data from Antarctic minke whale research catches. *Rep. int. Whal. Commn* 40:301–15.

Butterworth, D.S., Punt, A.E., Geromont, H.F., Kato, H. and Miyashita T. 1996. An ADAPT approach to the analysis of catch-at-age information for Southern Hemisphere minke whales. *Rep. int. Whal. Commn* 46:349–59.

Butterworth, D.S., Punt, A.E., Geromont, H.F., Kato, H. and Fujise, Y. 1999. Inferences on the dynamics of Southern Hemisphere minke whales from ADAPT analyses of catch-at-age information. *J. Cetacean Res. Manage.* 1:11–32.

Butterworth, D.S., Punt, A.E., Branch, T.A., Fujise, Y., Zenitani, R. and Kato, H. 2002. Updated ADAPT VPA recruitment and abundance trend estimates for Southern Hemisphere minke whales in Areas IV and V. Paper SC/54/IA25 presented to the IWC Scientific Committee, June 2002 (unpublished) 18pp.

Butterworth, D.S., Rademeyer, R.A. and Brandão, A. 2001. First attempts to quantify some factors that potentially confound temporal comparisons of minke whale abundance estimates from the IWC/IDCR-SOWER surveys. Paper SC/53/IA27 presented to the IWC Scientific Committee, July 2001 (unpublished). 21pp.

Christensen, I., Haug, T. and Wiig, O. 1990. Morphmetoric comparison of minke whales *Balaenoptera acutorostrata* from different areas of the North Atlantic. *Mar. Mam. Sci.* 6:327-38.

Committee on Taxonomy. 2016. List of marine mammal species and subspecies. Society for Marine Mammalogy, www.marinemammalscience.org, consulted on on 11 March, 2017.

Cooke, J.G. 2002. Progress report on analysis of IDCR/SOWER data. Paper SC/54/IA1 presented to the IWC Scientific Committee, April-May 2002 (unpublished). XXpp.

Donovan, G.P. 1991. A review of IWC stock boundaries. *Rep. int. Whal. Commn* (special issue 13):39-68.

Doroshenko, N.V. 1979. Populations of minke whales in the southern hemisphere. *Rep. int. Whal. Commn.* 29: 361-4.

Ensor, P. H. 1989. Mike whales in the pack ice zone, east Antarctica, during the period of maximum annual ice extent. *Rep. Int. Whal. Commn* 39:219-225.

Ensor, P., Findlay, K., Friedrichsen, G., Hirose, K., Komiya, H., Morse, L., Olson, P., Sekiguchi, K., Van Waerebeek, K. and Yoshimura, I. 2004-2005 International Whaling Commission-Southern Ocean Whale and Ecosystem Research (IWC-SOWER) cruise, Area III Paper SC/57/IA1, presented to the IWC Scientific Committee, May 2005 (unpublished). 85pp.

Ensor, P., Komiya, H., Kumagai, S., Kuningas, S., Olson, P. and Tsuda, Y. 2009. 2008-2009 International Whaling Commission-Southern Ocean Whale and Ecosystem Research (IWC-SOWER) Cruise. Paper SC/61/IA19 presented to the 61st IWC Scientific Committee, May 2009 (unpublished). 55pp.

Ensor, P., Minami, K., Morse, L., Olson P. and Sekiguchi, K. 2008. 2007-2008 International Whaling Commission-Southern Ocean Whale and Ecosystem Research (IWC-SOWER) cruise. Paper SC/60/IA1 presented to the IWC Scientific Committee, May 2008 (unpublished). 51pp.

Fournier, D. and Archibald, C.P. 1982. A general theory for analyzing catch at age data. *Can. J. Fish. Aquat. Sci.* 39:1195–207.

Friedlaender, A. S., Lawson, G. L. and Halpin, P. N. 2008. Evidence of resource partitioning between humpback and minke whales in the Antarctic. *Mar. Mamm. Sci.* 25:402-12

Friedlaender, A. S., Johnston, D. W., Fraser, W. R., Burns, J., Halpin, P. N. and Costa, D. P. 2011. Ecological niche modeling of sympatric krill predators around Marguerite Bay, Western Antarctic Peninsula. *Deep Sea Res. II.* 58:1729-40.

Friedlaender, A. S., Johnston, D. W., Goldbogen, J. A., Tyson, R. B., Stimpert, A. K., Hazen, E. L., Kaltenberg, A. and Nowacek, D. P. 2016. Two-step decisions in a marine central-place forager. *R. Soc. Open Sci.* 3: 160043.

Fujise, Y. 1995. A preliminary morphometric study in minke whales from Antarctic Area IV using data from the 1989/90 JARPA Survey. Paper SC/47/SH7 presented to the IWC Scientific Committee, May 1995 (unpublished). 15pp

Fujise, Y., Honda, K., Yamamoto, Y., Kato, H., Zenitani, R. and Tatsukawa, R. 1997. Changes of hepatic mercury accumulations of southern minke whales in past fifteen years. Paper SC/M97/20 presented to the IWC Intercessional Working Group to Review Data and Results from Special Permit Research on minke whales in the Antarctic, May 1997 (unpublished). 16pp.

Gavaris, S. 1988. An adaptive framework for the estimation of population size. Res. Doc. Can. Atl. Fish. scient. Adv. Commn (CAFSAC) 88/29:12pp (mimeo).

Glover, K.A., Kanda, N., Haug, T., Pastene, L.A., Oien, N., Goto, M., Seliussen, B.B. and Skaug, H.J. 2010. Migration of Antarctic minke whales to the Arctic. *PlosOne* 5:e15197.

Glover, K.A., Kanda, N., Haug, T., Pastene, L.A., Oien, N., Seliusen, B.B., Sorvik, A.G.E. and Skaug, H.J. 2013. Hybrids between common and Antarctic minke whales are fertile and can back-cross. *BMC Genetics* 14:25.

Government of Japan 1987. The program for research on the Southern Hemisphere minke whale and for preliminary research on the marine ecosystem in the Antarctic. Paper SC/39/O4 presented to the IWC Scientific Committee, June 1987 (unpublished). 60pp.

Government of Japan 1989. The research plan in 1989/90 season in conjunction with note for 'The program for research on the Southern Hemisphere minke whale and for preliminary research on the marine ecosystem in the Antarctic (SC/39/O4)'. Paper SC/41/SHMi13 presented to the IWC Scientific Committee, 1989 (unpublished). 21pp.

Government of Japan 1995. The 1995/96 research plan for the Japanese Whale Research Program under Special Permit in the Antarctic. Paper SC/47/SH3 presented to the IWC Scientific Committee, May 1995 (unpublished). 8pp.

Hakamada, T. 2006. Morphometric analysis on stock structure in the Antarctic minke whale based on JARPA samples. Paper SC/D06/J10 presented to the Intersessional Workshop to Review Data and Results from Special Permit Research on Minke Whales in the Antarctic, Tokyo December 2006. (unpublished) 8pp.

Hakamada, T. and Matsuoka, K. 2002. An examination of the effect of alternative pooling strata in the estimation of abundance in the Antarctic minke whale. Paper SC/54/IA13 presented to the IWC Scientific Committee, April-May2002 (unpublished). 27pp.

Hakamada, T. and Matsuoka, K. Estimates of abundance and abundance trend of the humpback whale in Areas IIIE-VIW, south of 60°S, based on JARPA and JARPA II sighting data (1989/90-2008/09). Paper SC/F14/J04 presented to the JARPA II Special Permit Review Workshop, February 2014 (unpublished). 36pp.

Hakamada, T. and Matsuoka, K. 2014. Estimates of abundance and abundance trend of the Antarctic minke whale in Areas IIIE-VIW, south of 60ºS, based on JARPA and JARPAII sighting data (1989/90-2008/09). Paper SC/F14/J03 presented to the expert workshop to review the Japanese JARPA II special permit research programme, Tokyo, February 2014. (unpublished). 41pp.

Hakamada, T., Matsuoka, K. and Nishiwaki, S. 2006. An update of Antarctic minke whales abundance estimate based on JARPA data. Paper SC/D06/J6 presented to the Intersessional Workshop to review data and results from special permit research on minke whales in the Antarctic, Tokyo, December 2006. (unpublished). 34pp.

Hakamada, T., Matsuoka, K., Nishiwaki, S. and Kitakado, T. 2013. Abundance estimates and trends for Antarctic minke whales (*Balaenoptera bonaerensis*) in Antarctic Areas IV and V for the period 1989/90–2004/05. J. Cetacean Res. Manage. 13: 123-51.

Haug, T., Lindstrøm, U. and Nilssen, K.T. 2002. Variations in minke whale (*Balaenoptera acutorostrata*) diet and body condition in response to ecosystem changes in the Barents Sea. *Sarsia* 87: 409-22.

Haw, H.D. 1991. Haw, M.D. 1991. An investigation into the differences in minke whale school density estimates from passing mode and closing mode survey in IDCR Antarctic assessment cruises. *Rep. int. Whal. Commn.* 41: 313–30.

Hedley, S.L., Buckland, S.T. and Borchers, D.L. 1999. Spatial modelling from line transect data. *J. Cetacean Res. Manage.* 1: 255-64.

Hoelzel, A.R. and Dover, G.A. 1989. Molecular techniques for examining genetic variation and stock identity in cetacean species. *Rep. int. Whal. Commn* (special issue 11):81-120.

Honda, K., Aoki, M. and Fujise, Y. 2006. Ecochemical approach using mercury accumulation of Antarctic minke whale, *Balaenoptera bonaerensis,* as tracer of historical change of Antarctic marine ecosystem during 1980-1999. *Bull. Environ. Contam. Toxicol.* 76:140-7.

Honda, K., Yamamoto, Y., Kato, H. and Tatsukawa, R. 1987. Heavy metal accumulations and their recent changes in southern minke whales *Balaenoptera acutorostrata*. *Arch. Environ. Contam. Toxicol.* 16:209-216.

Horwood, J. 1990. Biology and exploitation of the minke whale. CRC Press, Inc., Boca Ration Florida. 238p.

Ichii, T. 1990. Distribution of Antarctic krill concentrations exploited by Japanese krill trawlers and minke whales. *Proc. NIPR Symp. Polar Biol.* 3:34–45.

Ichii, T., and H. Kato, H. 1991. Food and daily food consumption of southern minke whales in the Antarctic. *Polar Biol.* 11:479-87.

IWC. 1987. Report of the special meeting of the Scientific Committee on planning for a comprehensive assessment of whale stocks. *Rep. Int. Whal. Commn.* 37: 147-57.

International Whaling Commission. 1991. Report of the Scientific Committee, Annex E. Report of the Sub-Committee on Southern Hemisphere Minke Whales. *Rep. int. Whal. Commn* 41: 113-31.

International Whaling Commission 1998a. Report of the Intersessional Working Group to review data and results from special permit research on minke whales in the Antarctic, Tokyo, 12-16 May 1997. *Rep. Int. Whal. Commn* 48: 377-412.

International Whaling Commission. 2001a Report of the Scientific Committee. *J. Cetacean Res Manage* 3 (Supplement): 1-76.

International Whaling Commission. 2001b Report of the working group on nomenclature. *J. Cetacean Res Manage* 3 (Supplement):363.

International Whaling Commission. 2002. Summary of historical changes to the 'standard methodology'. *J. Cetacean Res Manage* 4 (Supplement):218.

International Whaling Commission 2003. Report of the Scientific Committee, Annex G. Report of the Sub-Committee on the Comprehensive Assessment of Whale Stocks – In Depth Assessments. *J. Cetacean. Res. Manage.* (Suppl.): 5:248–92.

International Whaling Commission 2004. Report of the Scientific Committee, Annex G. Report of the Sub-Committee on the Comprehensive Assessment of Whale Stocks – In Depth Assessments. *J. Cetacean. Res. Manage.* (Suppl.): 6:248–92.

International Whaling Commission 2005. Report of the Scientific Committee, Annex G. Report of the Sub-Committee on the Comprehensive Assessment of Whale Stocks – In Depth Assessments. *J. Cetacean. Res. Manage.* (Suppl.): 7:224–45.

International Whaling Commission. 2006. Report of the Joint Symposium on High Latitude Sea Ice Environments: Effects on Cetacean Abundance, Distribution and Ecology. *J. Cetacean Res. Manage.* (Suppl.) 8:367–83.

International Whaling Commission. 2007. Report of the Scientific Committee. *J. Cetacean Res. Manage.* 9 (Suppl.): 1-73.

International Whaling Commission. 2008. Report of the Intersessional Workshop to Review Data and Results from Special Permit Research on Minke Whales in the Antarctic, Tokyo, 4–8 December 2006. *J. Cetacean Res. Manage.* (Suppl.) 10:411–45.

International Whaling Commission. 2009. Report of the SOWER Abundance Workshop. *J. Cetacean Res. Manage.* (Suppl. 1) 11:455–63.

International Whaling Commission. 2010. Report of the SOWER Abundance Workshop. *J. Cetacean Res. Manage.* (Suppl. 2) 11:509–19.

International Whaling Commission. 2012. Report of the Intersessional IA Workshop on Estimating Abundance of Antarctic Minke Whales. *J. Cetacean Res. Manage.* (Suppl.) 13:363–68.

International Whaling Commission. 2013a. Report of the 2012 Intersessional IA Workshop on Estimating Abundance of Antarctic Minke Whales. J. Cetacean Res. Manage. (Suppl.) 13:387–91.

International Whaling Commission. 2013b. Report of the Scientific Committee. *J. Cetacean Res. Manage.* (Suppl.) 13:1–86

International Whaling Commission. 2014. Report of the Scientific Committee. Annex G. Report of the Sub-Committee on In-Depth Assessment (IA). J. Cetacean Res. Manage. (Suppl.) 15:233–49

International Whaling Commission. 2015a. Report of the Expert Workshop to Review the Japanese JARPAII Special Permit Research Programme. *J. Cetacean Res. Manage.* 16 (Suppl.):369-409.

International Whaling Commission. 2015b. Report of the Scientific Committee. *J. Cetacean Res. Manage.* 16 (Suppl.):1-87.

Isoda, T., Tamura, T., Nishiwaki, S and Pastene, L.A. 2014. Observation of marine debris in the Antarctic based on JARPA and JARPAII data. Paper SC/F14/J22 presented to the JARPA II Special Permit Review Workshop, February 2014 (unpublished). 11pp.

Jonsgard, Å.1951. Studies on the little piked whale or minke whale (*Balaenoptera acuto-rostrata Lecepede*). *Norsk Hvalfangst-Tidende* 5:209-232.

Kanda, N., Goto, M. and Pastene, L.A. 2014. Update of stock structure of humpback whales in the Antarctic feeding grounds as revealed by microsatellite DNA data (SC/F14/J31rev). Paper SC/65b/SD2 presented to the IWC Scientific Committee, May 2014 (unpublished). 6pp.

Kasamatsu, F., Kishino, H. and Hiroyama, H. 1990. Estimation of the number of minke whale (*Balaenoptera acutorostrata*) schools and individuals based on the 1987/88 Japanese feasibility study data. *Rep. int. Whal. Commn.* 40: 239–47.

Kasamatsu, F., Kishino, H. and Taga, Y. 1991. Estimation of southern minke whale abundance and school size composition based on the 1988/89 feasibility study data. *Rep. int. Whal. Commn.* 41: 313–30.

Kasamatsu, F., Matsuoka, K. and Hakamada, T. 2000. Interspecific relationships in density among the whale community in the Antarctic. *Polar Biol.* 23:466–473.

Kasamatsu, F., Nishiwaki, S. and Ishikawa, H. 1995. Breeding areas and southbound migrations of southern minke whales, *Balaenoptera acutorostrata*. *Mar. Ecol. Prog.* Ser. 119:1-10.

Kasamatsu, F., Nishiwaki, S. and Ishikawa, H. 1995. Breeding areas and southbound migrations of southern minke whales *Balaenoptera acutorostrata*. *Mar. Ecol. Prog. Ser.* 119:1-10.

Kasuya, T. and Ichihara, T. 1965. Some information on minke whales from the Antarctic. *Sci Rep Whal Res Inst* Tokyo 19:37-43.

Kato, H. 1987. Density dependent changes in growth parameters of the southern minke whale. *Sci. Rep. Whales Res. Inst*. 38: 47-73.

Kato, H. 1992. Body Length, reproduction and stock separation of minke whales off Northern Japan. *Rep. int. Whal. Commn,* 42:443-53.

Kato, H. and Fujise, Y. 2000. Dwarf minke whales; Morphology, growth and life history with some analyses on morphometric variation among the different forms and regions. Paper SC/52/OS3 presented to the Scientific Committee. June 2000 (unpublished).30pp.

Kato, H., Fujise, Y. and Kishino, H. 1991. Age structure and segregation of southern minke whales by the data obtained during Japanese research take in 1988/89. Rep. int. Whal. Commn. 41: 287–92.

Kato, H., Fujise, Y., Nakamura, G., Pastene, L. A., Hakamada, T. and Best, P. B. 2015. Marked Morphological and Morphometric Differentiation between Dwarf minke and Antarctic and Common minke whales. Abstract. Bay 03 A7. 21st Biennial Conference on the biology of marine mammals. Society of Marine Mammalogy. 13-18 December 2015. San Francisco.

Kato, H., Kishino, H. and Fujise, Y. 1990. Some analyses on age composition and segregation of southern minke whales using samples obtained from the Japanese feasibility study in 1987/88. Rep. int. Whal. Commn. 40: 249–56.

Kato, H. and Sakuramoto, K. 1991. Age at sexual maturity of southern minke whales: a review and some additional analysis. *Rep. int Whal. Commn* 41: 331-337.

Kawamura, A. 1980. A review of food of Balaenopterid whales. *Sci Rep Whales Res Inst.* 32:155-97.

Kelly, N., Murase, H., Kitakado, T., Kock, K-H., Williams, R., Feindtherr, H. and Walløe, L. 2012. Appraisal of methods and data to estimate abundance of Antarctic minke whales within sea ice covered areas of the Southern Ocean. Paper SC/64/IA10 presented to the IWC Scientific Committee, June 2012 (unpublished). 16pp.

Kelly, N., Peel, D. Bravington, M. V. 2014. Distribution and abundance of Antarctic minke whales in sea ice regions of East Antarctica: a summary of results. Paper SC/65b/IA15 presented to the IWC Scientific Committee, May 2014 (unpublished). 7pp.

Kelly, N., Peel, D., Pike, D., Bravington, M. and Gales, N. 2008. Aerial survey of minke whales off East Antarctica: report on 2007/08 test survey and future plan. Paper SC/60/IA4 presented to the 60th IWC Scientific Committee, May 2008 (unpublished). 8pp.

Kelly, N., Peel, D., Pike, D., Bravington, M. and Gales, N. 2009. An aerial survey for Antarctic minke whales in sea ice off east Antarctica: a pilot study. Paper SC/61/IA3 presented to the IWC Scientific Committee, May 2009 (unpublished). 14pp.

Kelly, N., Peel, D., Bravington, M. V. and Gales. N. 2010. Aerial survey of minke whales off East Antarctica: Report on 2009/10 Survey. Paper SC/62/IA8 presented to the IWC Scientific Committee, May 2010 (unpublished). 24 pp.

Kishino, H., Kato, H., Kasamatsu, F. and Fujise, Y. 1991. Detection of heterogeneity and estimation of population characteristics from the field survey data: 1987/88 Japanese feasibility study of the Southern Hemisphere minke whales. Annals of the Institute of Statistical Mathematic. 43: 435-53.

Kitakado, T., Murase, H., Tamura, T. and Yonezaki, S. 2014. An attempt to ecosystem modelling for species in Area IV in the Antarctic Ocean using JARPA and JARPAII data. Paper SC/F14/J26 presented to the JARPA II special permit expert panel review workshop, Tokyo, February 2014 (unpublished) 15pp.

Kitakado, T., Lockyer, C. and Punt, A. E. 2013. A statistical model for quantifying age-reading errors and its application to the Antarctic minke whales. *J. Cetacean Res. Manage*. 13: 181-90.

Kitakado, T., Schweder, T., Kanda, N., Pastene, L.A. and Walløe, L. 2014. Dynamic population segregation by genetics and morphometrics in Antarctic minke whales (SC/F14/J29rev). Paper SC/65b/IA13 presented to the IWC Scientific Committee, May 2014 (unpublished). 25pp.

Konishi, K., Tamura, T., Zenitani, R., Bando, T., Kato, H., and Walløe, L. 2008. Decline in energy storage in the Antarctic minke whale (*Balaenoptera bonaerensis*) in the Southern Ocean. *Polar Biol.* 31:1509–20.

Konishi, K. and Walloe, L. 2015. Substantial decline in energy storage and stomach fullness in Antarctic minke whales (*Balaenoptera bonaerensis*) during the 1990's. *J. Cetacean Res. Manage.* 15:77-92.

Koopman, H. N. 1998. Topographical distribution of the blubber of harbor porpoises (*Phocoena phocoena*). *J. Mamm.* 79:260–70.

Leaper, R. and Lavigne, D. 2007. How much do large whale eat? *J. Cetacean Res. Manege.* 9:179-88.

Lockyer, C. 1981. Estimation of the energy costs of growth, maintenance and reproduction in the female minke whale, (*Balaenoptera acutorostrata*), from the southern hemisphere. *Rep int Whal Commn* 31:337-43.

Lockyer, C. 1984. Age determination by means of earplugs in baleen whales. *Rep. int. Whal. Commn* 34: 692-696.

Lockyer. C. 1986. Body fat condition in Northeast Atlantic fin whales, *Balaenoptera physalus*, and its relationship with reproduction and food resource. *Can. J. Fish. Aquat. Sci.* 43:142–7.

Lockyer C., McConnell, L. C., and Waters, T. D. 1985. Body condition in terms of anatomical and biochemical assessment of body fat in North Atlantic fin and sei whales. *Can. J. Zool.* 63:2328–38.

Mackintosh, N.A. 1942. The southern stocks of whalebone whales. *Disc. Rep.* 22:197-300.

Mackintosh, N.A. 1966. The distribution of southern blue and fin whales. pp.125-44. In: K.S. Norris (ed.) Whales, Dolphins and Porpoises. University of California Press, Berkeley and Los Angeles. xv+789pp.

Matsuoka, K., Ensor, P., Hakamada, T., Shimada, H., Nishiwaki, S., Kasamatsu, F. and Kato, H. 2003. Overview of minke whale sightings surveys conducted on IWC/IDCR and SOWER Antarctic cruises from 1978/79 to 2000/01. *J. Cetacean Res. Manage.* 5:173-201.

Matsuoka, K. and Hakamada, T. 2002 Applying alternative approach to Antarctic minke whale abundance estimation with an example for the part of Area IV using IWC/SOWER 1998/99 data. Paper SC/54/IA15 presented to the IWC Scientific Committee, April 2002 (unpublished). 18pp.

Matsuoka, K. and Hakamada, T. 2014. Estimates of abundance and abundance trend of the blue, fin and southern right whales in Areas IIIE-VIW, south of 60°S, based on JARPA and JARPA II sighting data (1989/90-2008/09). Paper SC/F14/J05 presented to the JARPA II Special Permit Review Workshop, February 2014 (unpublished). 27pp.

Matsuoka, K., Hakamada, T., Kimura, K. and Okada, Y. 2009. Influence of sea ice concentration on Antarctic minke whale abundance estimation in the Ross Sea. Paper SC/61/IA16 presented to the IWC Scientific Committee, May 2009 (unpublished). 7pp.

Matsuoka, K., Kiwada, H. and Hakamada, T. 2006. The relationships between sea ice extension and trends in sighting parameters of Antarctic minke whales based on IDCR-SOWER data from CPII to CPIII. Paper SC/58/IA17, presented to the IWC Scientific Committee, June 2006 (unpublished). 7pp.

Matsuoka, K., Nishiwaki, S., Murase, H., Kanda, N., Kumagai, S. and Hatanaka, H. 2008. Influence of sea ice concentration in the research area on IDCR-SOWER abundance estimation. Paper SC/60/IA12 presented to the IWC Scientific Committee, May 2008 (unpublished). 9pp.

Matsuoka, K., Watanabe, T., Ichii, T., Shimada, H. and Nishiwaki, S. 2003. Large whale distributions (south of 60°S, 35°E–130°E) in relation to the southern boundary of the Antarctic Circumpolar Current. In: Antarctic Biology in a Global Context. A.H.L. Huiskes, W.W.C. Gieskes, J. Rozema, R.M.L. Schorno, S.M. van der Vies & W.J. Wolff (eds) Leiden: Backhuys Publishers, pp. 26–30.

Mori, M. and Butterworth, D.S. 2004. Consideration of multispecies interactions in the Antarctic: a preliminary model of the minke whale – blue whale – krill interaction. *Afr. J. Mar. Sci.* 26: 245-59.

Mori, M. and Butterworth, D.S. 2006. A first step towards modelling the krill-predator dynamics of the Antarctic ecosystem. *CCAMLR Sci.* 13: 217-77.

Mori, M., Butterworth, D.S., Brandao, A., Rademeyer-Rebecca, A., Okamura, H. and Matsuda, H. 2003. Observer experience and Antarctic minke whale sighting ability in IWC/IDCR -SOWER surveys. *J. Cetacean Res. Manage. 5: 1-11.*

Mori, M., Butterworth, D.S. and Kitkado, T. 2007. Further progress on application of ADAPT-VPA to Antarctic minke. Paper SC/59/IA13 presented to the IWC Scientific Committee, June 2007 (unpublished) 32pp.

Mori, M., Butterworth, D. and Matsuda, H. 2002. Comparison of duplicate sighting rate for Southern Hemisphere whales between the 2nd and 3rd circumpolar surveys of IWC/IDCR-SOWER. Paper SC/54/IA16 presented to the IWC Scientific Committee, April 2002 (unpublished). 18pp.

Murase, H. 2010. January sea ice trends during period of three IWC IDCR/SOWER circumpolar surveys (1978-2004). Paper SC/62/IA5, presented to the IWC Scientific Committee, May 2010 (unpublished). 15pp.

Murase, H. and Kitakado, T. 2013. Consideration of an abundance estimation method of Antarctic minke whales within sea ice field using the IWC IDCR-SOWER data. Paper SC/65a/IA11 presented to the IWC Scientific Committee, June 2013 (unpublished). 12pp.

Murase, H., Kitakado, T., Hakamada, T., Matsuoka, K., Nishiwaki, S. and Naganobu, M. 2013. Spatial distribution of Antarctic minke whales (*Balaenoptera bonaerensis*) in relation to spatial distributions of krill in the Ross Sea, Antarctica. *Fish. Oceanogr.* 22:154-73.

Murase, H., Kelly, N., Kitakado, T., Kock, K-H., Williams, R. and Walløe, L. 2012. Review of technical aspects of sea ice data which will be used to bound or estimate the abundance of Antarctic minke whales in the south of the ice edge during the period of IWC IDCR/SOWER. Paper SC/64/IA3 presented to the IWC Scientific Committee, June 2012 (unpublished). 13pp.

Murase, H., Matsuoka, K. and Kitakado, T. (submitted) Changes in circumpolar spatial distributions of baleen whales in the Antarctic in the period of the IWC IDCR/SOWER CPII and CPIII (1984 – 2004) *J. Cetacean. Res. Manage.* (spec. issue)

Murase, H., Matsuoka, K., Hakamada, T., Nishiwaki, S., Wada, A. and Kitakado, T. 2011. Open sea area in the south of the ice edge in IDCR/SOWER CPII and CPIII. Paper SC/63/IA9 presented to the IWC Scientific Committee, May 2011 (unpublished). 16pp.

Murase, H., Matsuoka, K., Ichii, T. and Nishiwaki, S. 2002. Relationship between the distribution of euphausiids and baleen whales in the Antarctic (35°E–145°W). *Polar Biol.* 25:135–45.

Murase, H., Matsuoka, K., Nishiwaki, S., Hakamada, T. and Mori, M. 2004. Effects of observed covariates (school size, sighting cue, latetude and sea state) on the Antarctic minke whale abundance estimation parameters in the IWC/IDCR-SOWER surveys. *J. Cetacean Res. Manage.* 6: 283-92.

Murase, H., Nishiwaki, S., Matsuoka, K., Hakamada, T. and Kitakado, T. 2011. Changes in baleen whale distribution patterns between CPII and CPIII. Paper SC/63/IA11 presented to the IWC Scientific Committee, May 2011 (unpublished). 15pp.

Murase, H. and Shimada, H. 2004. Alternative estimation of Antarctic minke whale abundance taking account of possible animals in the unsurveyed large polynya: A case study in Area II in 1997/98. Paper SC/56/IA14, presented to the IWC Scientific Committee, June 2004 (unpublished). 13pp.

Murase, H. and Shimada, H. 2004. Possible impact due to variability of sea ice condition on Antarctic minke whale abundance estimation in the Antarctic from 1978 to 2002. Paper SC/56/IA10, presented to the IWC Scientific Committee, June 2004 (unpublished). 15pp.

Murase, H., Shimada, H. and Kitakado, T. 2005. Alternative estimation of Antarctic minke whale abundance taking account of possible animals in the unsurveyed large polynya using GAM-based spatial analysis: A case study in Area II in 1997/98 IWC/SOWER. Paper SC/57/IA6, presented to the IWC Scientific Committee, May 2005 (unpublished). 13pp

Naito, Y. 1982. Sightings records of minke whales in the pack ice and adjacent waters off the coast of Enderby Land. *Rep. Int. Whal. Commn* 32: 929-933.

Nakamura, G., Kadowaki, I., Nagatsuka, S., Fujise, Y., Kishiro, T. and Kato, H. 2014. Variation in a color pattern of white patch on the flippers of North Pacific common minke whales: Potential application for their interoceanic difference. *La mer* 52: 31-47.

Nishiwaki, S., Ishikawa, H. and Fujise, Y. 2006. Review of general methodology and survey procedure under the JARPA. Paper SC/D06/0J2 presented to the JARPA Review Workshop, Tokyo, 4–8 December 2006 (unpublished). 24pp.

Nishiwaki, S., Ishikawa, H., Goto, M., Matsuoka, K. and Tamura, T. 2014. Review of general methodology and survey procedures under the JARPAII. Paper SC/F14/J02 presented to the JARPA II Special Permit Review Workshop, February 2014 (unpublished). 34pp.

Nishiwaki, S., Matsuoka, K., Kawasaki, M., Kishino, H. and Kasamatsu, , F. 1997. Review of the sighting surveys in the JARPA. Paper SC/M97/1 presented to the international working group to review data and results from special permit research on minke whales in the Antarctic, Tokyo, May 1997. (unpublished). 42pp.

Næss, A., Haug, T., Nilssen, M. 1998. Seasonal variation in body condition and muscular lipid contents in Northeast Atlantic minke whale *Balaenoptera acutorostrata*. *Sarsia* 83:211–8.

Okamura, H., Kitakado, T., Hiramatsu, K. and Mori, M. 2002. A new variant of hazard probability model for abundance estimation of minke whales in the Antarctic. Paper SC/54/IA10 presented to the IWC Scientific Committee, April-May 2002 (unpublished). 28pp.

Okamura, H. and Kitakado, T. 2012. Abundance estimates of Antarctic minke whales using the OK method. Paper SC/64/IA2 presented to the IWC Scientific Committee, June 2012, Panama City (unpublished). 24pp.

Omura, H. 1975. Osteological study of the minke whale from the Antarctic. *Sci Rep Whal Res Inst Tokyo* 21:1-78.

Palka, D. and Smith, D. 2003. Description of data simulating the IDCR/SOWER minke whale suveys. SC/55/IA9 presented to the IWC Scientific Committee, May 2003. (unpublished). 3pp.

Pastene, L. 2006. What do we know about the stock structure of the Antarctic minke whale? A summary of studies and hypotheses. Paper SC/D06/J12 presented to the JARPA Review Workshop, Tokyo, 4–8 December 2006 (unpublished). 24pp.

Pastene, L.A., Acevedo, J., Goto, M., Zerbini, A.N., Acuna, P. and Aguayo-Lobo, A. 2010. Population structure and possible migratory links of common minke whales, *Balaenoptera acutorostrata*, in the Southern Hemisphere. *Conserv Genet* 11:1553-1558.

Pastene, L.A., Fujise, Y. and Numachi, K. 1994. Differentiation of mitochondrial DNA between ordinary and dwarf forms of southern minke whale. *Rep. int. Whal. Commn* 44:277-281.

Pastene, L.A. and Goto, M. 2016. Genetic characterization and population genetic structure of the Antarctic minke whale *Balaenoptera bonaerensis* in the Indo-Pacific region of the Southern Ocean. *Fish. Sci.* 82:873-886.

Pastene, L.A., Goto, M., Itoh, S. and Numachi, K. 1996. Spatial and temporal patterns of mitochondrial DNA variation in minke whale from Antarctic Areas IV and V. *Rep. int. Whal. Commn* 46:305-314.

Pastene, L.A., Goto, M. and Kanda, N. 2006. Genetic analysis on stock structure in the Antarctic minke whales from the JARPA research area based on mitochondrial DNA and microsatellites. Paper SC/D06/J9 presented to the Intersessional Workshop to Review Data and Results from Special Permit Research on Minke Whales in the Antarctic, Tokyo December 2006. (unpublished) 22pp.

Pastene, L.A., Goto, M., Kanda, N., Zerbini, A.N., Kerem, D., Watanabe, K., Bessho, Y., Hasegawa, M., Nielsen, R., Larsen, F. and Palsboll, P.J. 2007. Radiation and speciation of pelagic organisms during periods of global warming: the case of the common minke whale, *Balaenoptera acutorostrata*. *Mol. Ecol.* 16:1481-1495.

Pastene, L.A., Kobayashi, T., Fujise, Y. and Numachi, K. 1993. Mitochondrial DNA differentiation in Antarctic minke whales. *Rep int. Whal. Commn* 43:349-55.

Perrin, W.F. and Brownell Jr., R.L. 2009. Minke whales *Balaenoptera acutorostrata* and *B. bonaerensis. In* 'Encyclopedia of Marine Mammals' (W.F. Perrin, B. Wursig and J.G.M Thewissen, eds) pp 733-735. Academic Press.

Pitman, R.L. and Ensor, P. 2003. Three forms of killer whales (*Orcinus orca*) in Antarctic waters. *J. Cetacean Res. Manage.* 5: 131-9.

Punt, A.E. 2014. A summary history of the application of Statistical Catch-At-Age Analysis to Antarctic minke whales J. *Cetacean. Res. Manage.* 14:81–92.

Punt, A.E. In review. Review of contemporary cetacean stock assessment methods. *J. Cetacean Res. Manage.* 00:00-00.

Punt, A.E., Hakamada, T., Bando, T. and Kitkado, T. 2014. Assessment of Antarctic Minke Whales using Statistical Catch-at-age Analysis (SCAA). *J. Cet. Res. Manage.* 14:93-116.

Punt, A.E. and Polacheck, T. 2005. Application of statistical catch-at-age analysis for Southern Hemisphere minke whales in Antarctic Areas IV and V. Paper SC/57/IA9 presented to the IWC Scientific Committee, June 2005 (unpublished) 71pp.

Punt, A.E. and Polacheck, T. 2006. Further statistical catch-at-age analyses for Southern Hemisphere minke whales. Paper SC/58/IA2 presented to the IWC Scientific Committee, June 2006 (unpublished) 40pp.

Rademeyer, R.A. and Butterworth, D.S. 2002. Miscellaneous aspects of minke whale abundance estimation for the IDCR-SOWER surveys. Paper SC/54/IA29 presented to the IWC Scientific Committee, April-May 2002 (unpublished).

Reilly, S., S. Hedley, J. Borberg, R. Hewitt, D. Thiele, J. Watkins, and M. Naganobu. 2004. Biomass and energy transfer to baleen whales in the South Atlantic sector of the Southern Ocean. *Deep Sea Res. II.* 51:1397-409.

Ribic, C. A., Ainley, D. G. and Fraser, W. R. 1991. Habitat selection by marine mammals in the marginal ice zone. *Antarct. Sci.* 3:181-186.

Rice, D.W. 1998. Marine mammals of the world: systematics and distribution. Special Publication Number 4, the Society for Marine Mammalogy. Allen Press. USA.

Sakuramoto, K. and Tanka, S. 1985. A new multi-cohort methods for estimating Southern Hemisphere minke whale populations. *Rep. int. Whal. Commn* 35:261–71.

Sakuramoto, K. and Tanka, S. 1986. Further development of an assessment technique for Southern Hemisphere minke whale populations using a multi-cohort method. *Rep. int. Whal. Commn* 36:207–12.

Scheidat, M., Friedlaender, A., Kock, K.-H., Lehnert, L., Boebel, O., Roberts, J. and Williams, R. 2011. Cetacean surveys in the Southern Ocean using icebreaker-supported helicopters. *Polar Biol.* 34:1513-22.

Schweder, T., Kitakado, T., Kanda, N., Pastene, L. and Walloe, L. 2011. Dynamic population segregation by genetics and morphometrics in Antarctic minke whales. Paper SC/63/IA7 presented to the IWC Scientific Committee. May 2011 (unpublished). 20pp.

Schmitt, N.T., Double, M.C., Jarman, S.N., Gales, N., Marthick, J.R., Polanowski, A.M., Baker, C.S., Steel, D., Jenner, K.C.S., Jenner, M.N.M., Gales, R., Paton, D. and Peakall, R. 2012. Low levels of genetic differentiation characterize Australian humpback whale (*Megaptera novaeangliae*) populations. *Mar .Mamm. Sci.*30:221–241.

Sekiguchi, K., Fukutome, K., Morse, L., Shinyashiki, Y. and Oedekoven, C. 2010. 2009-2010 International Whaling Commission-Southern Ocean Whale and Ecosystem Research (IWC-SOWER) Cruise. Paper SC/62/IA1 presented to the IWC Scientific Committee, May 2010 (unpublished). 51 pp.

Shimada, H. and Burt, M. 2007. Relationship between minke whale abundance and pack ice extent examined by 10° longitudinal slices. Paper SC/59/IA26, presented to the 59th IWC Scientific Committee, May 2007 (unpublished). 5pp.

Shimada, H. and Kato, A. 2005. Preliminary report on a sighting survey of Antarctic minke whale within ice field conducted by the Ice Breaker, Shirase in 2004/2005. Paper SC/57/IA7, presented to the IWC Scientific Committee, May 2005 (unpublished). 14pp.

Shimada, H. and Kato, A. 2006. Tentative population assessment of the Antarctic minke whale within ice field using sighting data on the ice breaker, Shirase in 2004/2005. Paper SC/58/IA11, presented to the 58th IWC Scientific Committee, May 2006 (unpublished). 10pp.

Shimada, H. and Kato, A. 2007. Population assessment of the Antarctic minke whale within and out of ice field using a sighting data on the Ice Breaker and the IWC SOWER vessels in 2004/2005. Paper SC/59/IA16, presented to theI WC Scientific Committee, May 2007 (unpublished). 8pp.

Shimada, H. and Murase, H. 2002. Some analysis on sea ice condition in relation to changes in the Antarctic minke whale distribution pattern in the Antarctic Area IV. Paper SC/54/IA18 presented to the IWC Scientific Committee, April 2002 (unpublished). 8pp

Shimada, H. and Murase, H. 2003. Further examination of sea ice condition in relation to changes in the Antarctic minke whale distribution pattern in the Antarctic Area IV. Paper SC/55/IA7 presented to the IWC Scientific Committee, May 2003. (unpublished). 3pp.

Shimada, H., Segawa, K. and Murase, H. 2001. Tentative trial for estimation of Antarctic minke whale abundance within pack ice region incorporating IDCR/SOWER data with meteorological satellites data. Paper SC/53/IA14 presented to the IWC Scientific Committee, July 2001 (unpublished). 6pp.

Shimada, H., Segawa, K. and Murase, H. 2002. A preliminary trial: estimation of the Antarcitc minke whale abundance within the sea ice area incorporating IDCR/SOWER data with meteorological satellites data. Paper SC/54/IA19 presented to the IWC Scientific Committee, April 2002 (unpublished). 6pp.

Strindberg, S., and L. Burt. 2004. IWC Database-Estimation Software System (DESS) User Manual. University of St Andrews, St Andrews. 450 pp.

Tamura, T. and Konishi, K. 2009. Feeding habits and prey consumption of Antarctic minke whale (*Balaenoptera bonaerensis*) in the Southern Ocean. *J. Northw. Atl. Fish. Sci.* 42:13-25.

Tamura, T., Konishi, K., Isoda, T., Okamoto, R., Bando, T. and Hakamada, T. 2009. Some examinations of uncertainties in the prey consumption estimates of common minke, sei and Bryde’s whales in the western North Pacific. Paper SC/61/JR2 presented to the IWC Scientific Committee, June 2009 (unpublished). 24pp.

Taylor, R. J. F. 1957. An unusual record of three species of whale being restricted to pools in Antarctic sea-ice. *Proc. Zool. Soc. Lond.* 129:325-331.

Thiele, D., Chester, E. T. and Asmus, K. 2005. Antarctic sea ice: measuring habitat complexity, and seasonal and regional variability in habitat use for minke whales. Paper SC/57/E1, presented to the IWC Scientific Committee, May 2005 (unpublished). 21pp.

Thiele, D., Chester, E. and Friedlaender, A. 2002. Antarctic sea-ice habitat for minke whales (*Balaenoptera acutorostrata* sp.). Results of a line transect survey in East Antarctica. Paper SC/54/IA6 presented to the IWC Scientific Committee, April 2002 (unpublished). 14pp

Thiele, D. and Gill, P. C. 1999. Cetacean observations during a winter voyage into Antarctic sea ice south of Australia. *Antarct. Sci.* 11:48-53.

Thomson, R. B., Butterworth D. S. and Kato, H. 1999. Has the age transition of southern hemisphere minke whales declined over recent decades? *Mar. Mamm. Sci*. 15: 661-82.

van Utrecht, W.L. and van der Spoel, S. 1962. Observations on a minke whale (Mammalia, Cetacea) from the Antarctic. *Z Saugetierkd* 27: 217-221.

Vikingsson, G. A. 1995. Body condition of fin whales during summer off Iceland. In: Blix AS, Walløe L, Ulltang Ø (eds) Whales, seals, fish and man. Elsevier, Amsterdam, pp 361–9.

Wada, S., Kobayashi, T. and Numachi, K. 1991. Genetic variability and differentiation of mitochondrial DNA in minke whales. *Rep int Whal Commn* (Special Issue 13): 203-215.

Watanabe, I., Yamamoto, Y., Honda, K., Fujise, Y., Kato, H., Tanabe, S. and Tatsukawa, R. 1998. Comparison of mercury accumulation in Antarctic minke whale collected in 1980-82 and 1984-86. *Nippon Suisan Gakkaishi*. 64:105-109 (in Japanese with English abstract).

Williamson, G.R. 1959. Three unusual rorqual whales from the Antarctic. *Proc Zool Soc Lond* 133:135-144.

Yasunaga, G., Bando, T., Fujise, Y. 2014. Preliminary estimation of the age of Antarctic minke whales based on aspartic acid racemization. Paper SC/F14/J12 presented to the Expert Workshop to Review the Japanese JARPAII Special Permit Research programme, Tokyo, February 2014 (unpublished). 10pp.

Yasunaga, G., Bando, T. and Fujise, Y. 2014a. Pattern of mercury accumulation in the Antarctic minke whale and its prey based on JARPAII data. Paper SC/F14/J23 presented to the JARPA II Special Permit Review Workshop, February 2014 (unpublished). 7pp.

Yasunaga, G., Bando, T. and Fujise, Y. 2014b. Pattern of organochlorine accumulation in the Antarctic minke whale based on JARPAII data. Paper SC/F14/J24 presented to the JARPA II Special Permit Review Workshop, February 2014 (unpublished). 7pp.

Yasunaga, G., Fujise, Y., Zenitani, R., Honda, K. and Kato, H. 2006a. Yearly trend of trace element accumulation in liver of Antarctic minke whale, *Balaenoptera bonaerensis*. Paper SC/D06/J28 presented to the IWC Sponsored Meeting to Review Data and Results from the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) (JARPA Review Meeting), December 2006 (unpublished). 23pp.

Yasunaga, G., Fujise, Y., Zenitani, R., Tanabe, S. and Kato, H. 2006b. Spatial and temporal variations in organochlorine contaminants in the Antarctic minke whale, *Balaenoptera bonaerensis*. Paper SC/D06/J29 presented to the IWC Sponsored Meeting to Review Data and Results from the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) (JARPA Review Meeting), December 2006 (unpublished). 13pp.

Yasunaga, G., Fujise, Y., Zenitani, R., Tanabe, S. and Kato, H. 2015. Spatial and temporal variation of PCBs and organochlorine pesticides in the Antarctic minke whales, *Balaenoptera bonaerensis*, in the period 1987-2005. *Chemosphere* 126:11-17.

Zenitani, R. and Kato, H. 2006. Temporal trend of age at sexual maturity of Antarctic minke whales based on transition phase in earplugs obtained under JARPA surveys from 1987/88-2004/05. Paper SC/D06/J15 presented to the JARPA Review Workshop, Tokyo, December 2006 (unpublished). 9pp.

CONTRIBUTORS

Takeharu Bando
The Institute of Cetacean Research
(Biological Information)

Takashi Hakamada
The Institute of Cetacean Research
(Abundance)

Tatsuya Isoda
The Institute of Cetacean Research
(Pollutants and Marine Debris)

Hidehiro Kato
Tokyo University of Marine Science and Technology
(Systematics, Catch, Surveys, Biological Information)

Toshihide Kitakado
Tokyo University of Marine Science and Technology
(Abundance, Population Dynamics, Species Interactions)

Kenji Konishi
The Institute of Cetacean Research
(Food Habit and Energetics)

Koji Matsuoka
The Institute of Cetacean Research
(Surveys, Abundance)

Hiroto Murase
National Research Institute of Far Seas Fisheries, Japan Fisheries Research and Education Agency (FRA)
(Catch, Surveys, Abundance, Spatial Distribution, Species Interactions)

Hiroshi Okamura
National Research Institute of Fisheries Science, Japan Fisheries Research and Education Agency (FRA)
(Abundance)

Debra Palka
NOAA Fisheries, Northeast Fisheries Science Center

(Introduction, Discussion and Conclusions)

Luis Pastene
The Institute of Cetacean Research
(Systematics, Surveys, Stock Structure)

Andre Punt
School of Aquatic and Fishery Sciences, University of Washington
(Population Dynamics)

Tsutomu Tamura
The Institute of Cetacean Research
(Food habit and energetics)

Genta Yasunaga
The Institute of Cetacean Research
(Pollutants and Marine Debris)

Table 1. Longitudinal ranges of six areas in the in the Antarctic for management of large whale established by the IWC (Donovan, 1991).

Area	Longitudinal range
I	120°W-60°W
II	60°W-0°
III	0°-70°E
IV	70°E-130°E
V	130°E-170°W
VI	170°W-120°W

Table 2. Longitudinal ranges of eastern and western strata of Areas III, IV, V and VI.

Area and stratum	Abbreviation	Longitudinal range
III East	III-E	35°E-70°E
IV West	IV-W	70°E-100°E
IV East	IV-E	100°E-130°E
V West	V-W	130°E-165°E
V East	V-E	165°E-170°W
VI West	VI-W	170°W-145°W

Table 3. Agreed abundance estimates for CPII and CPIII in each IWC Management Area (IWC, 2013b). CNB: Common Northern Boundary. AV: Additional Variance. See text for explanation.

CP		IWC Management Area I	II	III	IV	V	VI	Total
II	Survey once	85,688	130,083	93,215	55,237	300,214	55,617	720,054
	CNB	84,978	120,025	86,804	51,241	285,559	49,885	678,493
	CV internal	0.16	0.14	0.2	0.17	0.13	0.22	0.08
	CV with AV	0.34	0.4	0.44	0.39	0.31	0.39	0.18
III	Survey once	38,930	57,206	94,219	59,677	183,915	80,835	514,783
	CNB	34,369	58,382	68,975	55,899	180,183	72,059	469,866
	CV internal	0.2	0.19	0.15	0.34	0.11	0.14	0.09
	CV with AV	0.39	0.38	0.35	0.49	0.36	0.37	0.18
CPIII:CPII		0.4	0.49	0.79	1.09	0.63	1.44	0.69

Table 4. Agreed abundance estimates of Antarctic minke whales in Areas IIIE, V, V and VIW by using IDCR/SOWER CPII and CPIII data (IWC, 2013b). These estimates were used as input data to the population dynamics model.

CP	Year	Area	Area size (n.mile^2)	Abundance	CV
II	1986	V-E	553,315	154,658	0.19
II	1986	V-W	369,337	105,951	0.16
II	1988	III-E	216,439	11,782	0.44
II	1989	IV	473,477	46,763	0.17
II	1991	VI-W	311,778	20,438	0.27
III	1995	III-E	269,356	34,659	0.24
III	1996	VI-W	446,457	48,206	0.18
III	1997	IV	476,894	55,873	0.34
III	2002	V-W	349,951	43,640	0.14
III	2004	V-E	478,019	136,457	0.13

Table 5. Abundance estimates of Antarctic minke whales applying approach in Hakamada *et al.* (2013) to JARPA and JARPAII data during 1989/90 – 2008/09 with (a) and without (b) taking into account model error. These estimates were used as input data to the population dynamics model.

(a)

Area	Average	Minimum		Maximum	
	Estimate	Estimate	CV	Estimate	CV
III-E	18,759	4,478	0.911	48,540	0.711
IV	32,714	15,088	0.645	63,794	0.509
V	101,106	67,661	0.308	151,072	0.326
VI-E	15,486	8,434	0.601	27,790	0.507

(b)

Area	Average	Minimum		Maximum	
	Estimate	Estimate	CV	Estimate	CV
III-E	18,569	5,566	0.367	44,801	0.582
IV	32,474	14,739	0.570	62,979	0.334
V	114,550	69,771	0.228	170,621	0.129
VI-E	15,603	7,530	0.226	26,364	0.218

Table 6. Summary of biological parameters of Antarctic minke whales estimated by stock (Bando *et al*. (2006)).

Parameters		I-stock (AreaS III-E, IV and V-W)		P-stock (Areas V-E and VI-W)	
		Male	Female	Male	Female
Body length at sexual maturity (m)	*Lmov*	-	8.4	-	8.3
	Lm50%	7.29	8.16	7.17	7.97
Age at sexual maturity	*tmov*	-	7.9	-	8.4
	tm50%	5.3	7.6	5.4	8.0
Body length at physical maturity (m)	50% mature	8.32	9.12	8.22	8.73
Age at physical maturity	50% mature	16.0	21.2	17.0	20.6
Growth curve		$y=8.61(1-e^{-(0.27x+0.54)})$	$y=9.16(1-e^{-(0.23x+0.49)})$	$y=8.45(1-e^{-(0.29x+0.51)})$	$y=8.93(1-e^{-(0.21x+0.59)})$
Proportion of pregnant in matured female (%)		-	92.9	-	85.4
Foetal sex ratio (male %)		-	51.8	-	46.8
Litter size		-	1.007	-	1.013

Table 7. Reliability of conclusions from the SCAA (Punt, 2014) as recorded in IWC (2014).

Model output	Conclusion
Historical trends in abundance	Relative trends generally consistent – modelled through changes in carrying capacity over about four decades, with abundance peaking in around 1970. The early and peak abundances are not quantitatively reliable. Recent abundance fitted to CPII and CPIII estimates.
Extent of change from CPII to CPIII	Trends in abundance over the most recent 20 years are relatively flat. Differences can be explained as variability in distribution.
MSYR	Not robust.
M (natural mortality)	Weakly different by stock. CVs unrealistically low. Further investigation recommended.
Growth curves	Not reliable – a proxy for some unmodeled source of variation.
Stock identity	An input; variable spatial distribution used to account for variability in abundance estimates. Further exploration needed.
Errors in age determination	Important to take into account.
JARPA/JARPA II abundance estimates	Biased low
JARPA/JARPA II selectivity	Younger animals under-represented.

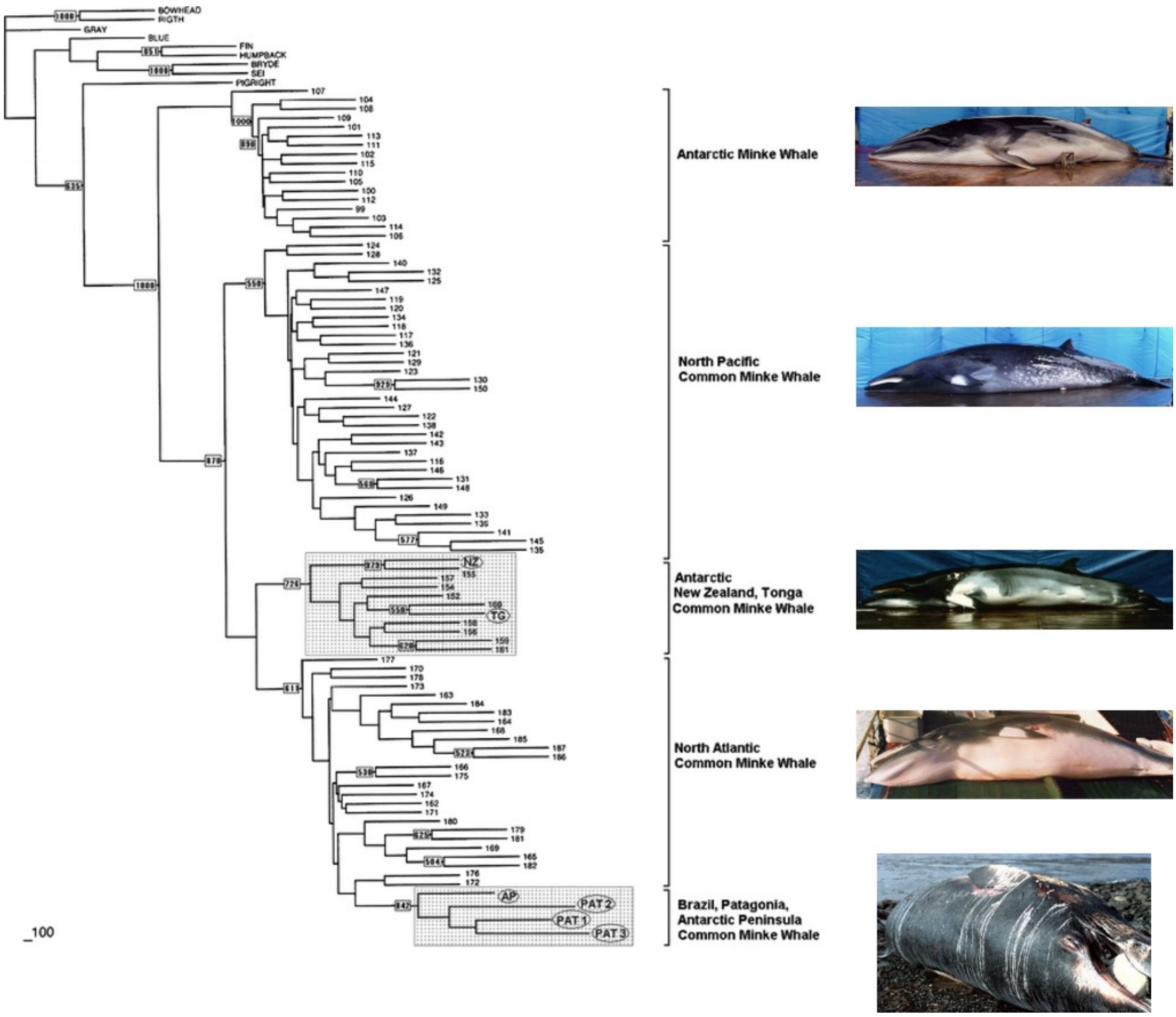

Fig. 1. Phylogeneny of mtDNA haplotypes of minke whale worldwide (modified version of Pastene *et al*., 2010)

Fig. 2. Lateral view showing flipper and dorsal fin (top); view of the head (bottom) of *B. bonaerensis*

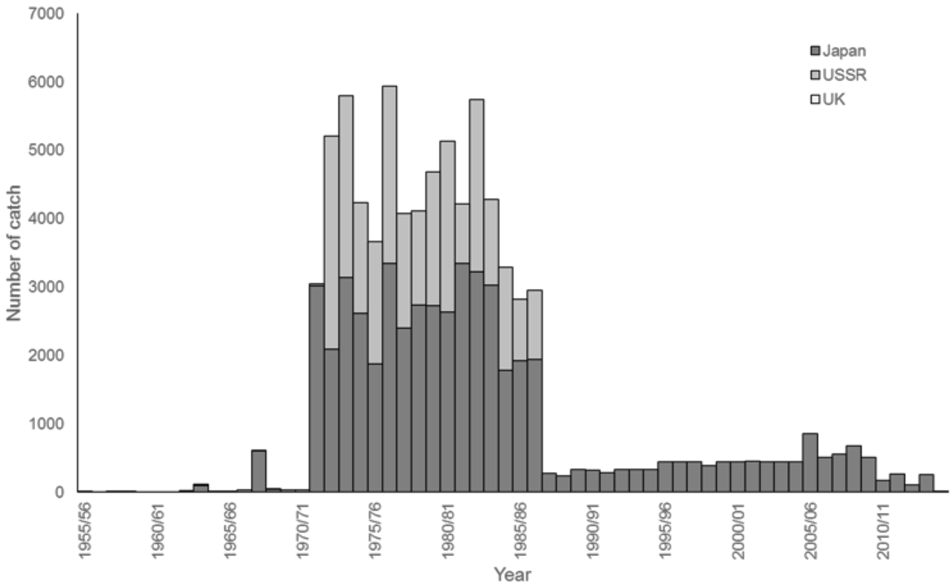

Fig 3. Number of Antarctic minke whales taken by commercial and scientific expeditions in the Indo-Pacific sector of the Antarctic (35°E-145°W) from 1956 to 2014. Lost individuals are included in the number. UK caught 3 individuals from 1956/57 to 1959/60 but they are virtually invisible in this figure. Catch data were extracted from Allison (2016).

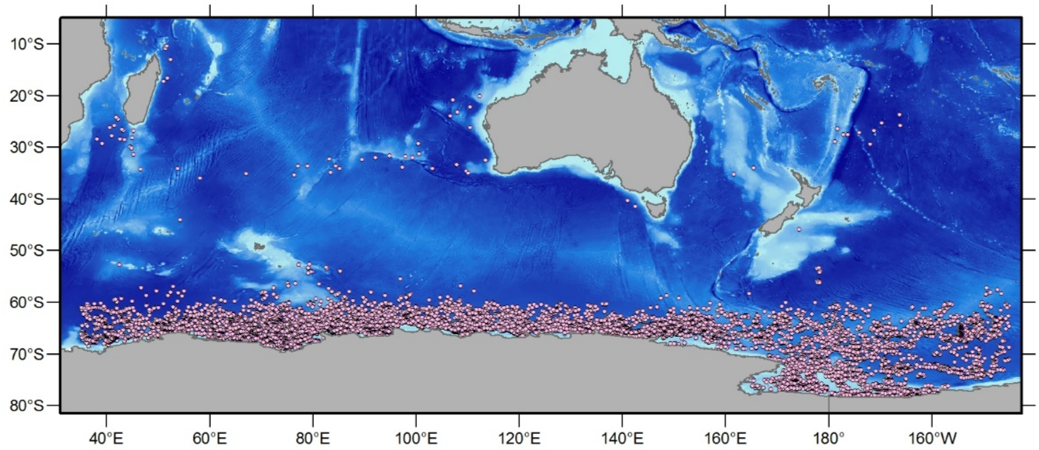

Fig. 4. Catch positions of Antarctic minke whales (pink circles) by commercial and scientific expeditions in the Indo-Pacific sector of the Antarctic (35°E-145°W) from 1956 to 2014. Catch data were extracted from Allison (2016). Bathymetry (Amante and Eakins, 2009) is also shown for illustrative purpose.

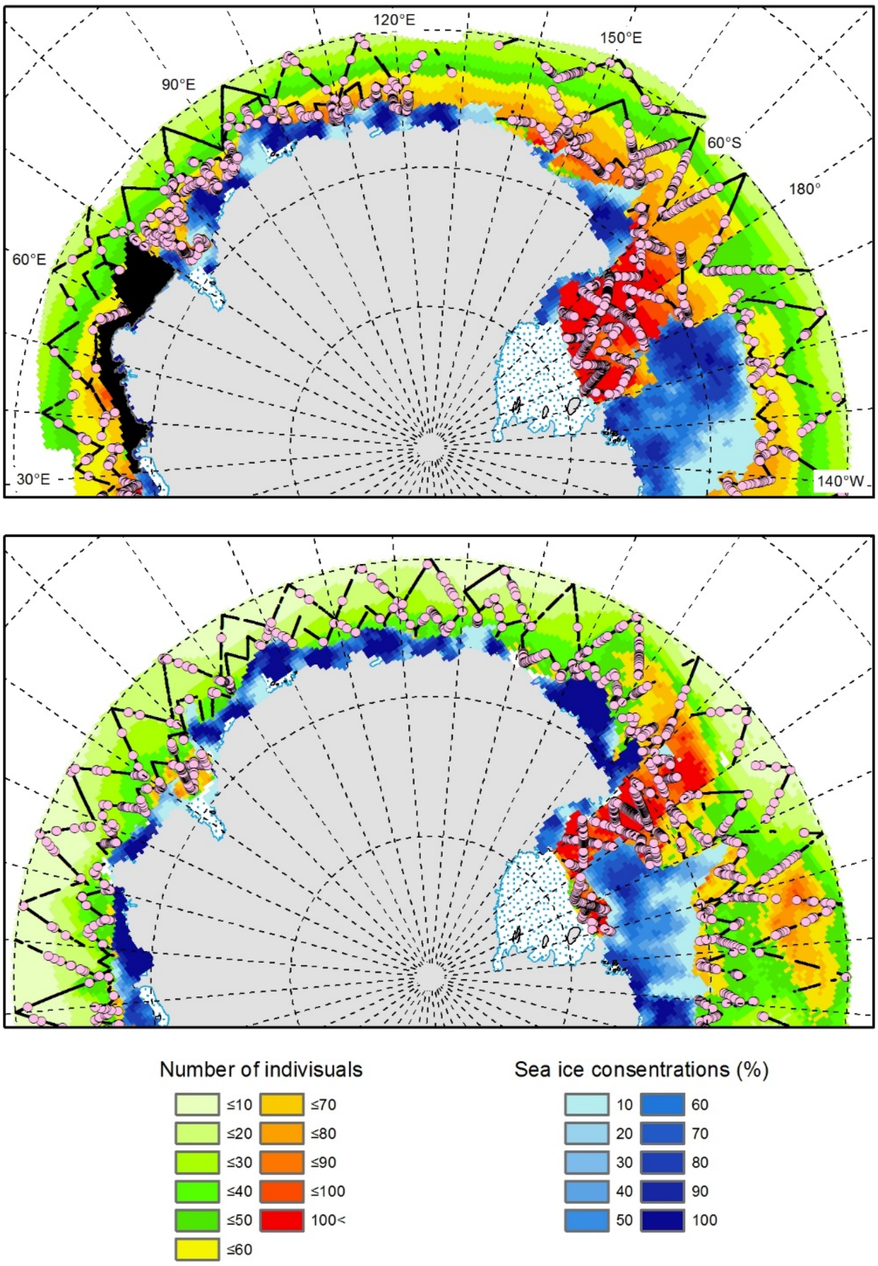

Fig. 5. Estimated spatial distribution (expressed in number of individuals) of Antarctic minke whales in the Indo-Pacific sector of CPII (top) and CPIII (bottom; redrawn from Murase *et al*., submitted). Sighting effort (black lines) and sighting positions of Antarctic minke whales (pink circles) are overlaid on the estimated spatial distribution map. Sea ice concentrations at the time of the surveys (from Murase *et al*., 2011) are also shown. Note that because satellite sea ice data is not available between 30°E and 70°E in CPII, the area is masked in black.

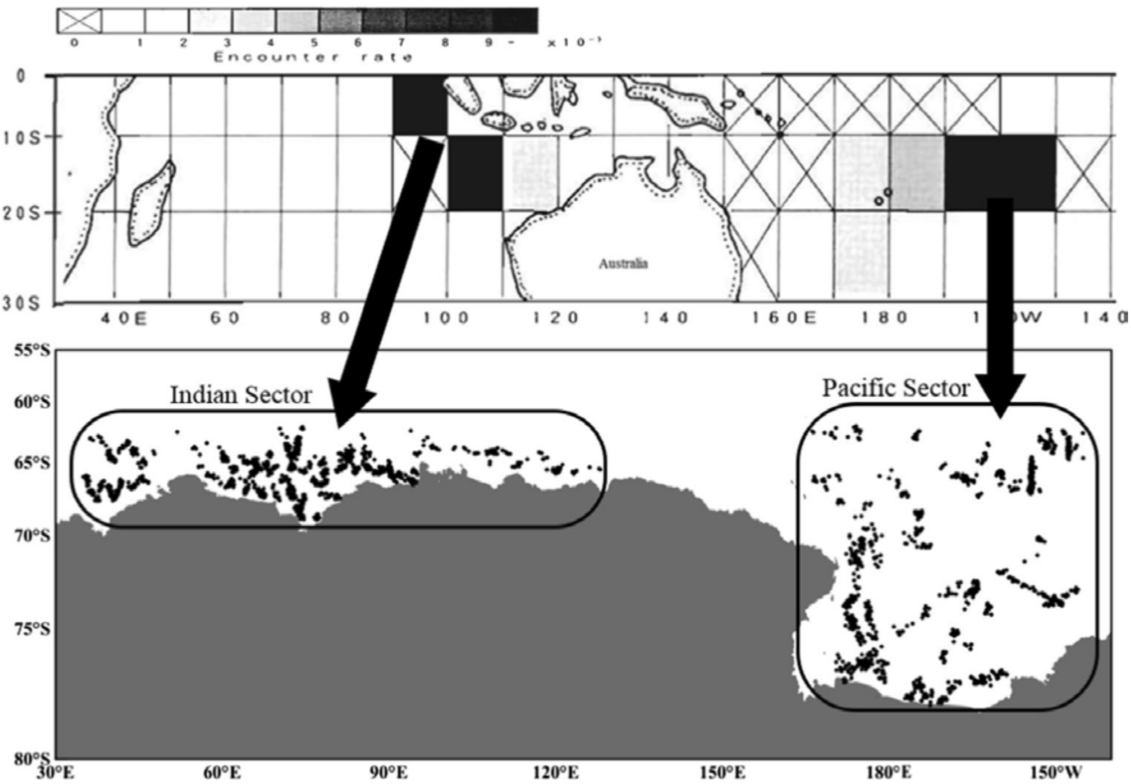

Fig. 6. Possible correspondence between areas of high sighting densities in the eastern Indian Ocean and western South Pacific (Kasamatsu *et al.*, 1995) and feeding areas in the Antarctic (from Pastene and Goto, 2016) (see text for details).

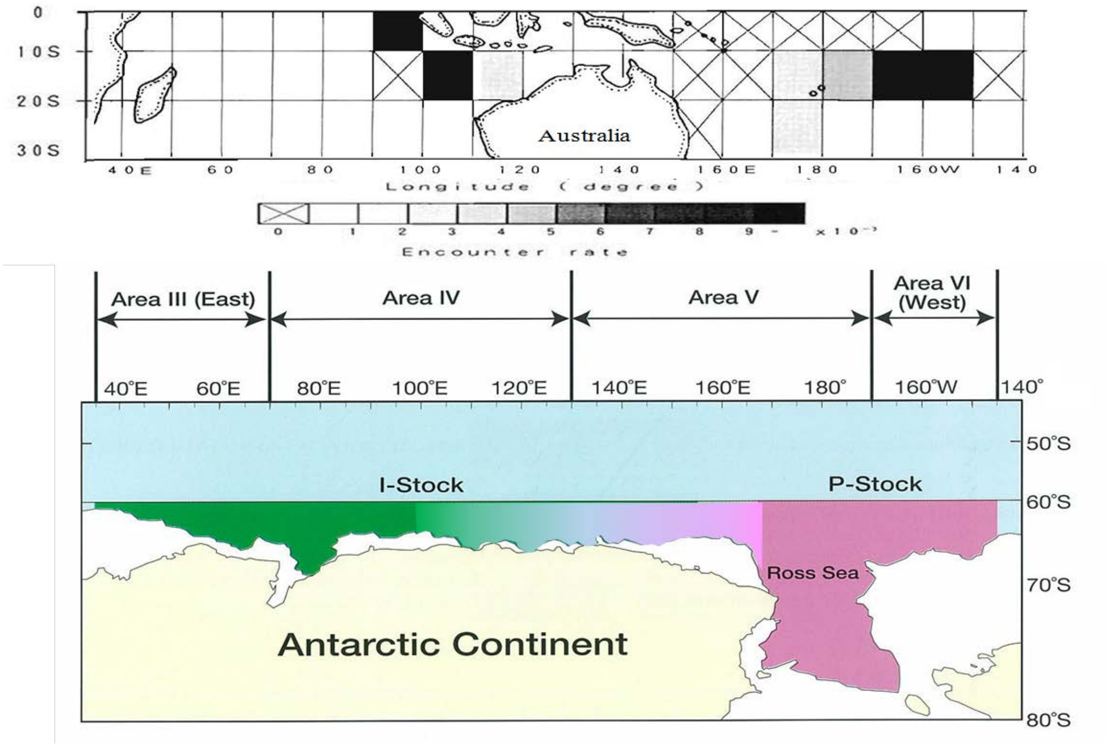

Fig. 7. Current hypothesis on stock structure of the Antarctic minke whale. At least two stocks occur in the research area of JARPA/JARPAII, which mix through a transition area, which appear to change by year and sex.

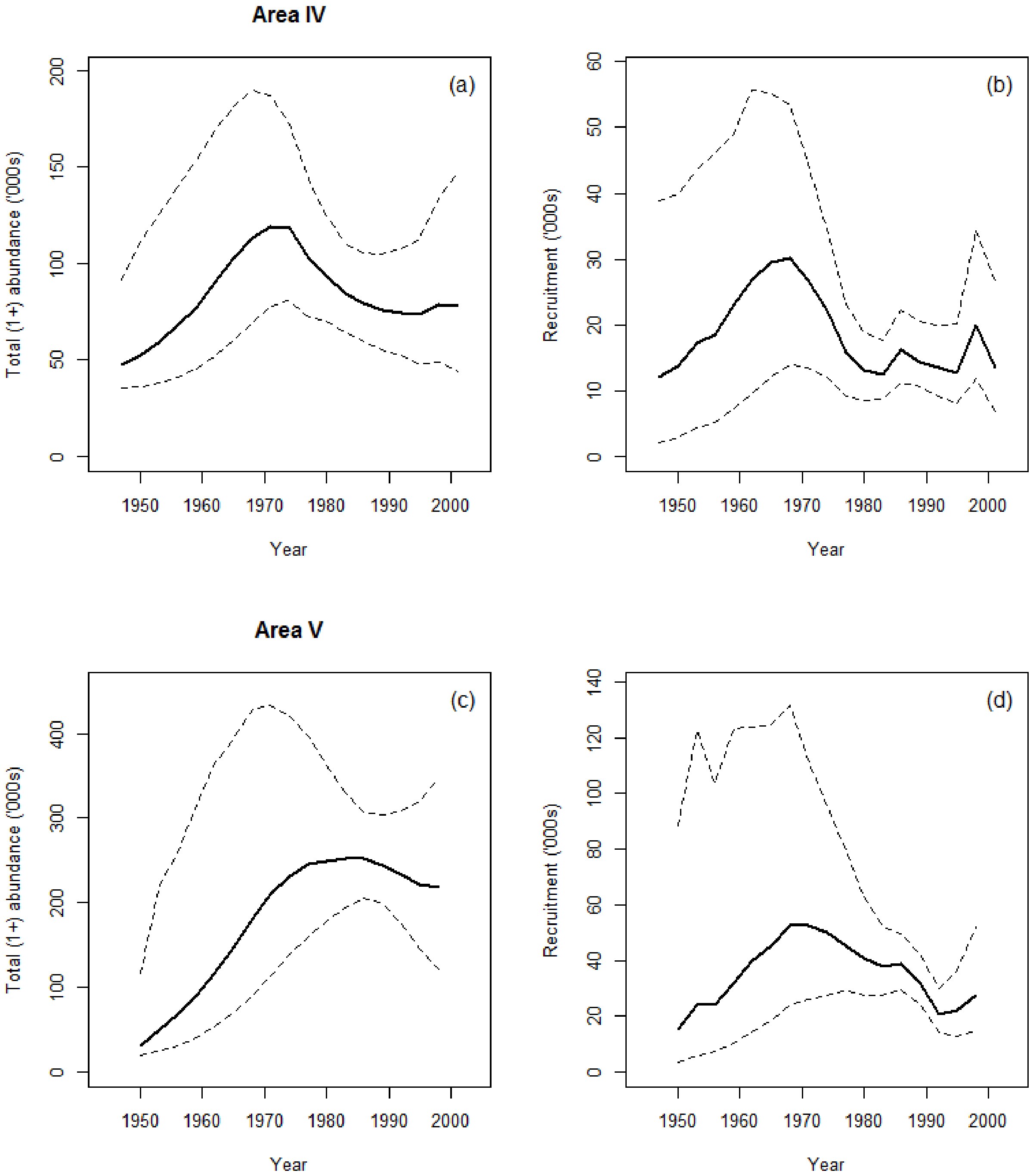

Fig. 8. Bootstrap estimates of total (1+) population size and recruitment for minke whales in Antarctic Areas IV and V based on the VPA, shown as medians together with estimates of 95% CI's.(recomputed from Butterworth . 2002)

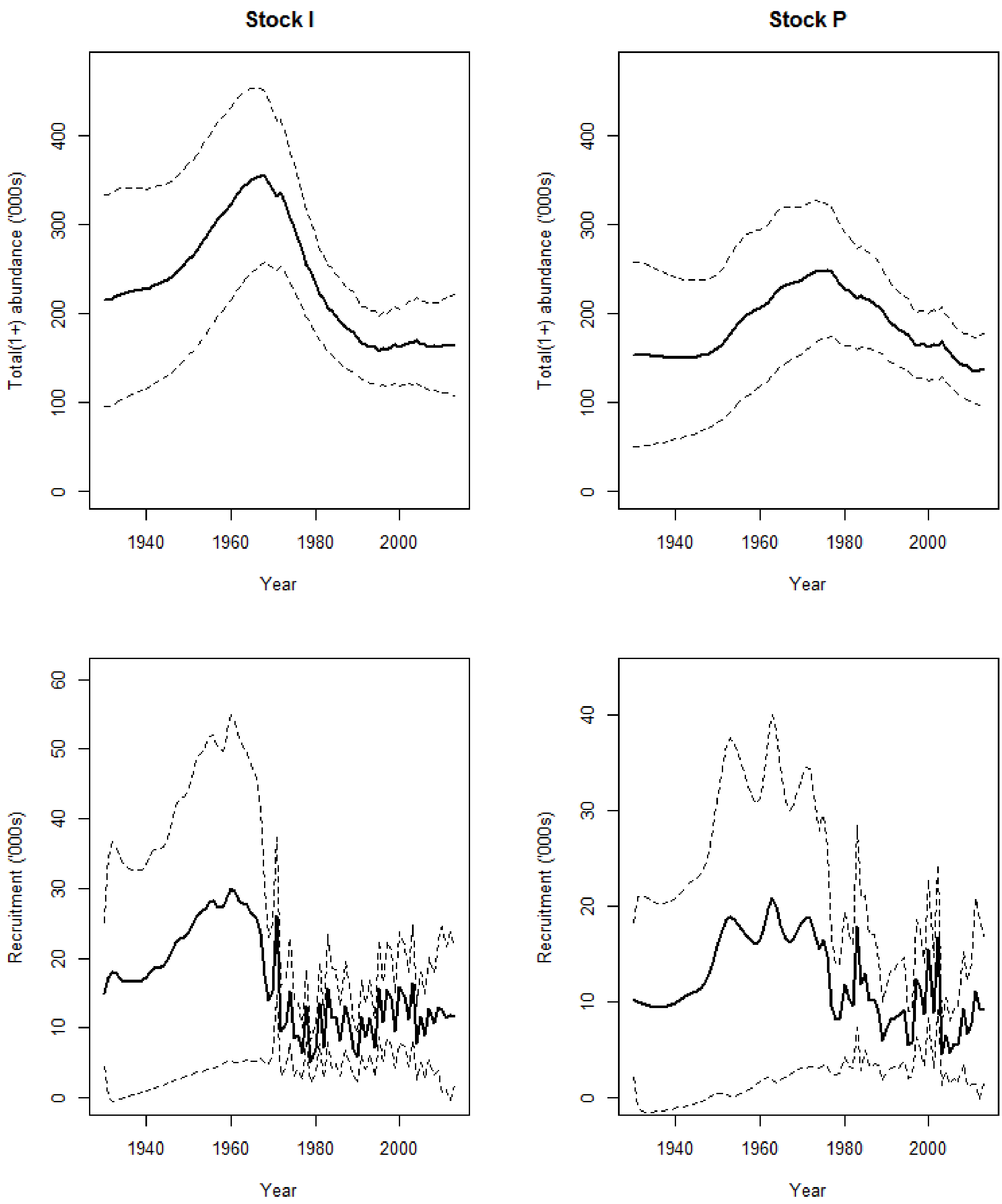

Fig. 9. Estimates of total (1+) population size and recruitment for Stock I and P minke whales based on the SCAA. The dashed lines indicate 95% asymptotic confidence intervals

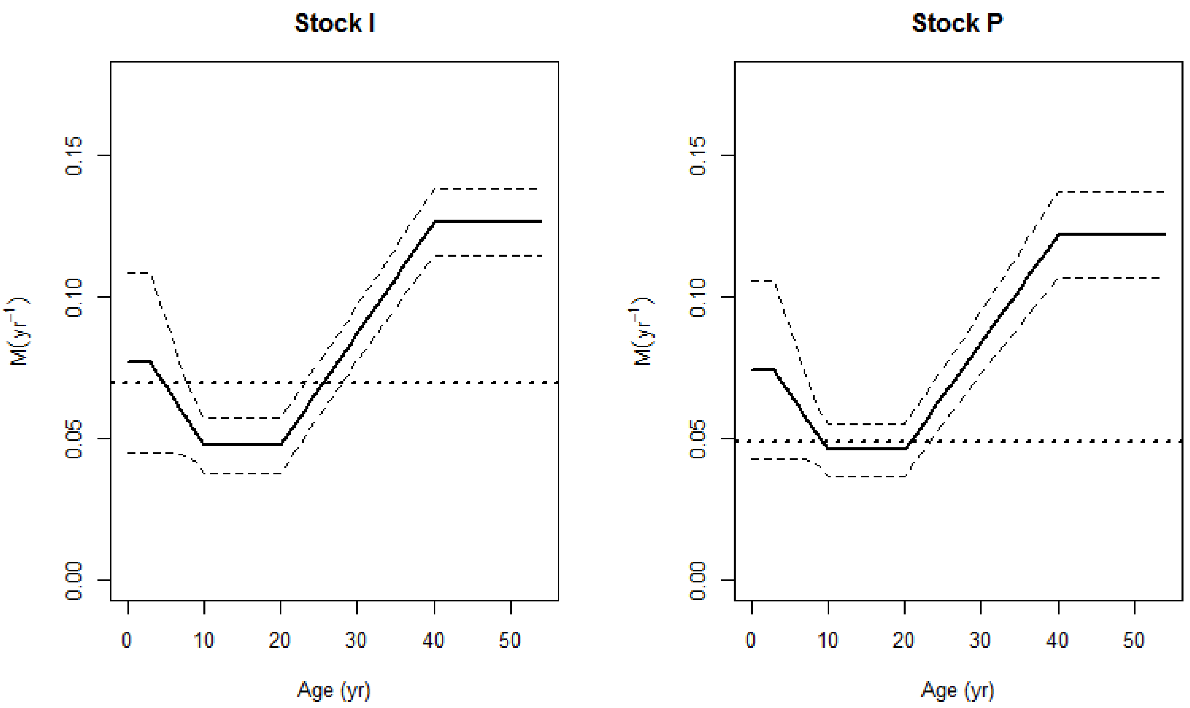

Fig. 10. Estimates of natural mortality for Stock I and P minke whales based on the SCAA. The dashed lines indicate 95% asymptotic confidence intervals. The horizontal dotted lines are the estimates of natural mortality from the VPA for Antarctic Areas IV and V.