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Biological parameters of the Antarctic minke whale based on materials collected by the JARPA survey in 1987/88 to 2004/05

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ABSTRACT

Using materials collected by the JARPA survey in Areas IIIE, IV, V and VIW from 1987/88 to 2004/05, the present study examined some biological parameters in the Antarctic minke whale by incorporating new sample grouping at 165°E based on the new stock scenario ('Eastern Indian Ocean Stock (I-stock)' and 'Western South Pacific Stock (P-stock)'), which are sex ratio, sexual maturity rate, body length and age at sexual maturity, body length and age at physical maturity, proportion of pregnant in matured female (PPF), growth curve, foetal sex ratio and litter size. The correction factor for sampling rate in each strata and school size were applied to correct sampling bias. Resultant estimate of the parameters, which are a much more representative value for population than previous estimates, were: male ratio, 57.3% (I stock), 44.0% (P stock); sexual maturity rate, 86.5% (I, Male), 89.5% (P, Male), 72.3% (I, Female), 84.9% (P, Female); body length at first ovulation (*Lmov*), 8.40m (I), 8.30m (P); body length at 50% sexual maturity (*Lm50%*), 7.29m (I, M), 7.17m (P, M), 8.16m (I, F), 7.97m (P, F); age at first ovulation (*tmov*), 7.9 years (I), 8.4 years (P); age at 50% sexual maturity (*tm50%*), 5.3 years (I, M), 5.4 years (P, M), 7.6 years (I, F), 8.0 years (P, F); body length at physical maturity, 8.32m (I, M), 8.22m (P, M), 9.12m (I, F), 8.73m (P, F); age at physical maturity, 16.0 years (I, M), 17.0 years (P, M), 21.2 years (I, F), 20.6 years (P, F); growth curve, $y=8.61(1-e^{-(0.27x+0.54)})$ (I, M), $y=8.45(1-e^{-(0.29x+0.51)})$ (P, M), $y=9.16(1-e^{-(0.23x+0.49)})$ (I, F), $y=8.93(1-e^{-(0.21x+0.59)})$ (P, F); PPF, 92.9% (I), 85.4% (P); foetal sex ratio (male%), 51.8% (I), 46.8% (P); litter size, 1.007 (I), 1.013 (P). More improved estimates compared to those from commercial samples were derived from JARPA samples which adopted the line-transect method in a wide research area and continued for 18 years. Increasing trend of growth rates, which was suggested in 1940s to 1970s year classes from commercial samples, has ceased in recent year classes. This suggests the possibility that expanding of carrying capacity for the minke whale has ceased and begun to return toward the previous environmental circumstance before the expanding had taken place. Monitoring of biological parameters is useful for understanding of stocks in present status and to predict future trend, which are essential for sustainable management of whale stocks. Furthermore, biological parameters were useful to RMP *Implementation* and to improve the performance of RMP.

KEY WORDS: ANTARCTIC MINKE WHALE, BIOLOGICAL PARAMETER, YEARLY TREND

INTRODUCTION

Biological parameters such as age at sexual maturity and growth curve directly correlate to reproduction of whale stocks. Information on sex ratio and age at sexual maturity is necessary to assess proportion of whales which contribute to reproduction, and pregnancy rate, fetus sex ratio and litter size are necessary to estimate composition of young whales which recruit into the stock. Some of these parameters are known to change in response to changes in abundance, food availability or competition with other species

(Gambell, 1973; Kato, 1986a, 1986b, 1987; Kato and Sakuramoto, 1991; Masaki, 1979; Lockyer, 1972, 1979, 1984). Therefore, monitoring of biological parameters is indispensable for sustainable management of baleen whale stocks (Ohsumi *et al*. 1997) and could lead to improvement of the IST in the RMP.

Biological parameters in Antarctic minke whale had been studied mainly from commercial whaling data by several authors (Best, 1982; Kato, 1982, 1983, 1987; Masaki, 1979; Ohsumi *et al*., 1970; Ohsumi and Masaki 1975). 'Estimation of the biological parameters to improve the stock management of the Southern Hemisphere minke whale' is one of the major objectives of JARPA and data and samples were collected continuously from the start of the full scale JARPA survey in 1989/90 (in addition, two years feasibility study were conducted in 1987/88 and 1988/89). Some results were reported to the Scientific Committee of IWC and JARPA review meeting held at Tokyo in 1997 (IWC, 1998; Tanaka and Fujise, 1997; Ohsumi *et al.*, 1997; Zenitani *et al*., 1997, 2001). In the JARPA review meeting, 'recalculation of biological parameters by biological stock' was identified as future work (IWC, 1998). Since then, stock structure of Antarctic minke whale in the Antarctic Ocean was studied by using genetic and non-genetic methods, new stock hypothesis that two discrete stocks 'Eastern Indian Ocean Stock (I-stock)' and 'Western South Pacific Stock (P-stock)' migrate to Antarctic Ocean, and stock boundary existing around 165° E, was deduced (Pastene, 2006).

JARPA adopted the line-transect method and track lines were designed in each stratum independently. One or two whales were sampled from each school. Therefore, sampling rate differs between strata or school size. In addition, whales of smaller school size were more difficult to detect than those of large school size. This leads to over representativeness of samples from large school size. Correction of such bias is necessary for estimation of biological parameters.

In this study, biological parameters were estimated for presumed two stocks (I-stock and P-stock) incorporating correction factor for sampling rate in each strata and school size. Furthermore, yearly trend of biological parameters was examined.

MATERIALS AND METHODS

Biological parameters

The following parameters were estimated in this study. Sex ratio (male ratio), sexual maturity rate, body length and age at sexual maturity (*Lmov, Lm50%, tmov, tm50%*; Kato (1987)), body length and age at physical maturity, growth curve, proportion of pregnant in matured female (PPF), foetal sex ratio and litter size.

Biological samples and data used

All samples collected during 1987/88 to 2004/05 JARPA surveys (Area IIIE: 549 animals, Area IV: 2864 animals, Area V: 2865 animals and Area VIW: 500 animals) were used to estimate body length and age at first ovulation (*Lmov, tmov*), foetal sex ratio and litter size. Because following parameters were thought to be biased by date of sampling (Kato, 1987; Kato and Miyashita, 1991), samples from main feeding season (mainly January and February in Areas IV and V; Area IV: 2317 animals, Area V: 2396 animals) collected during 1989/90-2004/05 JARPA surveys were used to estimate male ratio, sexual maturity rate, body length and age at sexual maturity (*Lm50%, tm50%*), body length and age at physical maturity, growth curve and proportion of pregnant in matured female (PPF).

Sexual maturity determination

Sexual maturity of males was determined by examination of histological sample of testis. Males with seminiferous tubules over 100 μm diameter, spermatid or open lumen in the tubules were determined as sexually mature (Kato, 1986a; Kato *et al*., 1990, 1991). Sexual maturity for females was determined by the presence of corpora luteum or albicans in both ovaries.

Physical maturity determination

Physical maturity status was identified by examination of vertebrae. The fusion of the vertebral epiphysis to the centrum was known to start at anterior cervical, then at posterior caudal vertebrae, and is completed on the middle or posterior dorsal vertebrae (Kato, 1988). Physical maturity was determined by examination of the 6th dorsal vertebrae 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 centrum were defined as physically mature.

Age determination

Individual age was determined using growth layers in earplug counted by Kato or Zenitani using a stereoscopic microscope. In addition, baleen plates were used for age determination of some juvenile whales based on method developed by Kato and Zenitani (1990).

Correction of sampling rate in each strata and school size

Correction factor derived from number of samples and abundance estimate in each strata and school size was applied for estimation of the following parameters; sex ratio, sexual maturity rate, *Lm50%*, *tm50%*, body length and age at physical maturity, growth curve and PPF. Abundance in each stratum and school size was calculated by the program "DISTANCE (Backland *et al*., 1993)" from sighting data obtained by SSVs (Sighting and Sampling Vessels) (Table 1; see Hakamada *et al.*, (2006) for detail). Sampling rate was defined as number of samples per estimated abundance in each stratum and school size. Correction factor was defined as reciprocal of sampling rate (Table 1). Each sample was weighed by correction factor.

It is known that composition of Antarctic minke whales differs between school sizes because of segregation (Fujise *et al*., 1999). Preliminary examination showed significant difference of composition such as sexual maturity rate between school size 1 and more than 1. However no distinct difference was detected within samples from school size of more than 1. Therefore, school size was categorized as 1 and more than 1.

Body length and age at sexual maturity

Body length and age at sexual maturity was estimated by two methods.

Body length and age at first ovulation (*Lmov* , *tmov* (Kato, 1987))

Mean body length and age were calculated for the whales with one corpus luteum and no corpus albicans in both ovaries.

Body length and age at 50% sexual maturity (*Lm50%, tm50%* (Kato, 1987))

Body length and age at 50% sexual maturity was calculated by applying logistic regression curve to sexual maturity rate in each body length and age weighed by correction factor.

Body length and age at physical maturity

Body length and age at 50% physical maturity was calculated by applying logistic regression curve to maturity rate in each body length and age weighed by correction factor.

Individual plot of body length/age at 50% sexual/physical maturity in each season is shown in Appendix (Figs. 1-4).

Growth curve

Growth curve was estimated by applying equation of von Bertalanffy ($y=BL_{max}(1-e^{-(ax+b)})$) to body length and age weighed by correction factor. Yearly trend was examined by the method of Kato (1987). Ten year classes were pooled (e.g. 1950s means from 1950 to 1959 year classes) and growth curves were plotted independently.

Proportion of pregnant in matured female (PPF)

Proportion of pregnant in matured female is defined as the proportion of pregnant females within sampled sexually matured females weighed by correction factor.

Grouping of data

Whales collected in Areas IIIE, IV and VW were treated as 'Eastern Indian Ocean Stock' (I-stock) and whales collected in Areas VE and VIW were treated as 'Western South Pacific Stock' (P-stock), following Pastene (2006). As JARPA survey was conducted every two years in Areas IIIE+IV and V+VIW, samples of VW in a particular season were added to samples of Area IIIE+IV in the previous season (i.e. sample of Area VW in 1990/91 was added to sample of Areas IIIE+IV in 1989/90) to typify the year of sampling.

Statistical method

Linear regression analysis was conducted to research year and biological parameters to examine yearly trend. The null hypothesis was set as H_0: the slope = 0 and examined whether the slope of the regression line of biological parameters on catch-year is significantly different from zero at 5% level. Total sample was used to conduct linear regression analysis for *Lmov* and *tmov*. Estimated annual value was used for *Lm50%*, *tm50%*, body length and age at 50% physical maturity and PPF. Difference from parity was tested by χ^2-test for foetal sex ratio.

RESULTS

Sex ratio (male ratio)

Reproductive status estimated in each stock is shown in Table 2. Male ratio was estimated as 57.3% for I-stock and 44.0% for P-stock, respectively (Table 2, Fig. 1). Large yearly variation was observed and 1998/99 in P-stock showed extremely high male ratio than ordinary years, which would be caused by no samples obtained from the Ross sea in this season, where mature female predominant (Nishiwaki, *et al*., 1999). No significant yearly trend was detected for both stocks.

Sexual maturity rate

I-stock

Sexual maturity ratio in I-stock was estimated as 86.5% for male and 72.3% for female, respectively (Table 2, Fig. 2). For male, sexual maturity rate was almost stable at around 80-90%. On the other hand, large yearly variation was observed for female and 1997/98-1998/99 showed extremely low value (44.5%) compared to other seasons. In 1997/98, JARPA research vessels could not enter ice-free area build in south of ice-edge (Ishikawa, *et al*., 1998, Ishikawa, 2003), where high density of mature females was expected. This would have caused low sexual maturity rate in this season. No significant yearly trend was detected for both sexes.

P-stock

Sexual maturity ratio in P-stock was estimated as 89.5% for male and 84.9% for female, respectively (Table 2, Fig. 2). For male, sexual maturity rate was stable around 80-90%, although regression slope was significantly lower than zero. As for female, sexual maturity rate was higher than I-stock and fluctuated between years. No significant yearly trend was detected.

Body length at sexual maturity

Lmov

I-stock

Lmov of I-stock estimated in each year is shown in Table 3 and Fig. 3. *Lmov* was stable around 8.4m, although sample size in each year was small. No significant yearly trend was detected and *Lmov* was estimated as 8.40m from total samples.

P-stock

Lmov of P-stock estimated in each year is shown in Table 3 and Fig. 3. Sample size in each year was small and no sample was obtained in 1990/91 and 1994/95. No significant yearly trend was detected and *Lmov* was estimated as 8.30m from total samples.

Lm50%

I-stock

Lm50% of I-stock estimated in each year is shown in Table 4 and Fig. 4. *Lm50%* in male was stable around 7.3m and no significant yearly trend was detected. Consequently, *Lm50%* was estimated as 7.29m from total samples. As for female, *Lm50%* stabled around 8.0m to 8.2m and no significant yearly trend was detected. *Lm50%* was estimated as 8.16m from total samples.

P-stock

Lm50% of P-stock estimated in each year is shown in Table 4 and Fig. 4. *Lm50%* in male was estimated only in 1994/95 and 2002/03 because of small sample size. Linear regression analysis could not be applied in this case. Consequently, *Lm50%* was estimated from total samples as 7.17m. As for female, *Lm50%* was estimated in all seasons except 1998/99. Estimated value stabled around 8.0m and no significant yearly variation was detected. *Lm50%* was estimated as 7.97m from total samples.

Age at sexual maturity

tmov

I-stock

Tmov of I-stock estimated in each year is shown in Table 5 and Fig. 5. As for *tmov*, sample size in each year was small. Large yearly fluctuation was observed but no significant yearly trend was detected. Consequently, *Tmov* was estimated from total samples as 7.9years.

P-stock
Tmov of P-stock estimated in each year is shown in Table 5 and Fig. 5. Sample size was small in each year, no sample was obtained in 1990/91 and 1994/95 and one sample was obtained in 1988/89 and 1996/97, although significant yearly decreasing trend was detected. Consequently, *tmov* was estimated from total samples as 8.4 years.

tm50%
I-stock
Tm50% estimated for I-stock in each year and sex is shown in Table 6 and Fig. 6. *Tm50%* of male fluctuated around 5 years but no significant yearly trend was detected. As for female, estimation was not conducted in 1993/94+1994/95 and 1999/2000+2000/01 because of small sample size. Estimated female *tm50%* was larger than that for male and fluctuated around 7 to 8 years. No significant yearly trend was detected. Consequently, *tm50%* was estimated from total samples as 5.3 years for male and 7.6 years for female, respectively.

P-stock
Tm50% estimated for P-stock in each year and sex is shown in Table 6 and Fig. 6. Sample size of P-stock was not enough and estimation was conducted only for 2 seasons (1990/91 and 2002/03) for male and 5 seasons for female, respectively. Examination of yearly trend was only applied for female and slope of regression was not significantly different from zero. Consequently, *tm50%* was estimated from total samples as 5.4 years for male and 8.0 years for female, respectively.

Body length at physical maturity
I-stock
Body length at 50% physical maturity in I-stock estimated in each year and sex is shown in Table 7 and Fig. 7. Estimated value of male was stable around 8.2m to 8.4m and no significant yearly trend was detected. On the other hand, estimated value of female showed a large yearly fluctuation from 8.83m in 1995/96+1996/97 to 9.39m in 1997/98+1998/99. Regression slope was not significantly different from zero. Consequently, body length at 50% sexual maturity was estimated from total sample as 8.32m for male and 9.12m for female, respectively.

P-stock
Body length at 50% physical maturity in I-stock estimated in each year and sex is shown in Table 7 and Fig. 7. Large yearly fluctuation was observed in male, which showed extremely low value in 1990/91 (7.73m) and high value in 1998/99 (8.50m) and 2002/03 (8.45m). No significant yearly trend was detected. As for female, estimated value was stable around 8.7m to 8.9m except for a low value in 1996/97 (8.53m). No significant yearly trend was detected. Consequently, body length at 50% sexual maturity was estimated from total samples as 8.22m for male and 8.73m for female, respectively.

Age at physical maturity
I-stock
Age at 50% physical maturity of I-stock estimated in each year and sex is shown in Table 8 and Fig. 8. Estimated value of male was stable around 15 to 16 years except for a high value (18.5 years) in 1997/98+1998/99. No significant yearly trend was detected. As for female, estimated value was larger than male and fluctuated between years. A slightly increasing trend was observed but regression slope was not significantly different from zero. Consequently, age at 50% physical maturity was estimated from total samples as 16.0 years for male and 21.2 years for female, respectively.

P-stock
Age at 50% physical maturity of P-stock estimated in each year and sex is shown in Table 8 and Fig. 8.
Estimation was not conducted in 1992/93 for male and 1998/99 for female because of small sample size. Estimated value fluctuated between years and a slightly increasing trend was observed for both sexes, although regression slope was not significantly different from zero. Consequently, age at physical maturity was estimated as 17.0 for male and 20.6 for female, respectively.

Growth curve

Relationship between mean body length and age in each stock and sex is shown in Fig. 9. Mean body length increased rapidly until around 7 years and afterwards, growth speed decreased and ceased at around 15-20 years. Growth curves were fitted from age 1 to over 50 in each stock and sex. The following von Bertalanffy equations were derived as growth curve.

I-stock, Male: $y = 8.61(1-e^{-(0.27x+0.54)})$
I-stock, Female: $y = 9.16(1-e^{-(0.23x+0.49)})$
P-stock, Male: $y = 8.45(1-e^{-(0.29x+0.51)})$
P-stock, Female: $y = 8.93(1-e^{-(0.21x+0.59)})$

Fitting of growth curves was good for both sex and stock, although fitting to old ages was not as good as younger ages because of large dispersion in mean body length of old ages.

Relationship between mean body length and age estimated by year classes pooled by decade is shown in Fig. 10. Growth curves of each year class overlap one another and no distinct difference was observed between year classes.

Proportion of pregnant in matured female (PPF)

I-stock

Proportion of pregnant in matured female (PPF) of I-stock estimated in each year is shown in Table 9 and Fig. 11. PPF was stable at high level of around 90% during research period, except 1997/98+19998/99, which showed the lower PPF of 76.3%. No significant yearly trend was detected and PPF was calculated as 92.9% from total samples.

P-stock

PPF of P-stock estimated in each year is shown in Table 9 and Fig. 11. PPF was stable around 90% except 1990/91 and 1994/95, which showed lower value (72.2% in 1990/91 and 70.6% in 1994/95, respectively) than ordinary years. No significant yearly trend was detected and PPF was estimated as 85.4% from total samples.

Foetal sex ratio

I-stock

Foetal sex ratio (male%) of I-stock calculated in each year is shown in Table 10 and Fig. 12. Foetal sex ratio fluctuated between years from 44.0% to 56.8%, although calculated values in each season were not significantly different from parity. In total, 568 males and 528 females, excluding 53 sex-unknown fetuses, were identified and fetal male ratio was calculated as 51.8%, which was not significantly different from parity.

P-stock

Foetal sex ratio (male%) of P-stock calculated in each year is shown in Table 10 and Fig. 12. 338 males and 378 females, excluding 15 sex-unknown fetus were identified and fetus male ratio was calculated as 46.8%. Yearly fluctuation was larger than I-stock and calculated value from total samples was slightly skewed to female, although no significant difference from parity was detected in each year and total samples.

Litter size

I-stock

Litter size of I-stock calculated in each year is shown in Table 11 and Fig. 13. Almost all of Antarctic minke whales had only one fetus and the presence of twins was occurred only in 8 cases of 1,142 pregnant females examined. Multiplets of more than two fetuses were not observed. Litter size was calculated as 1.006.

P-stock

Litter size of P-stock calculated in each year is shown in Table 11 and Fig. 13. Twins occurred in 9 cases of 717 pregnant females examined. Litter size was calculated as 1.013. No distinct difference was observed in the occurrence of multiplets between years or stock.

DISCUSSION

Biological parameters would differ between biological stocks. Therefore estimation should be conducted by biological stock for management purposes. 'Elucidation of the stock structure of the Southern Hemisphere minke whales to improve stock management' is one of the main objectives of JARPA and multiple analyses including genetic and non-genetic methods revealed two stock hypothesis of Antarctic minke whales in the Antarctic feeding grounds (Pastene, 2006). Therefore, biological parameters were estimated by biological stock for the first time (Table 12).

Antarctic minke whales are known to segregate in the Antarctic, mature females mainly distribute in the ice-edge zone, immature whales mainly distribute in the offshore zone and mature males distribute widely from ice-edge to offshore (Fujise *et al*., 1990, 1991, 1992, 1994, 1999; Kasamatsu and Ohsumi, 1981; Kato *et al*., 1990, 1991). Samples of Antarctic minke whales from commercial catch were biased to female and mature individuals, because whaling operation was mainly conducted in the ice-edge zone and selectivity of whalers to larger whales. Therefore, biological parameters, such as age at 50% sexual maturity estimated from commercial catch were known to be underestimated (Kato, 1982, 1987). On the other hand, JARPA survey was designed to cover wider latitude than commercial whaling and to collect samples randomly and systematically incorporating line-transect method in each established stratum (Fujise *et al*., 1997; Nishiwaki *et al*., 2006). This continuous and consistent method leads to less-biased samples compared to commercial catch. For example, younger individuals were rare in commercial sample, but JARPA sample covered wide range of ages including early juvenile, which lead to improved estimation of biological parameters such as growth curve and age at sexual maturity.

Kato (1987) compared age at sexual maturity of female Antarctic minke whales estimated by age at 50% maturity (*tm50%*) and age at first ovulation (*tmov*), the later was thought to be free from biases, based on samples collected in Areas III and IV in 1971/72-1982/83 Japanese commercial catch and showed that *tm50%* were constantly 0.5-2.0 years lower than *tmov* due to biases. Difference between the two estimated values based on JARPA samples was only 0.3 in I-stock and 0.4 in P-stock, respectively. Therefore, these estimated values were less biased than estimation from commercial catch.

As for male, estimated *tm50%* (5.3 years for I-stock, 5.4 years for P-stock, respectively) was lower than mean value of transition phase in earplug (*tmp*), which shows 7-8 years in the early 1970s cohort onwards (Zenitani and Kato, 2006). One possible cause of observed difference is segregation of male whales. Although sampling rate was corrected, sexual maturity rate of males was still high in both stocks. This suggests that some juvenile males would not migrate into the research area of JARPA. Bias from segregation might have remained to some extent in this study. However, estimated *tm50%* was higher than that from commercial catches (2.5 years) collected in Area IV in 1971/72-1979/80 Japanese commercial whaling (Kato, 1982). Therefore, more improved biological parameters than estimation from commercial catches would be derived.

PPF (92.9% in I-stock and 85.4% in P-stock, respectively) showed high value as well as that from commercial catches (88.8% in commercial catches from 1971/72 to 1979/80, Kato (1982)), although JARPA collected samples from wide research area and correction factor for sampling rate was applied. Timing of migration of Antarctic minke whales from assumed equatorial breeding areas to Antarctic feeding areas are known to differ according to reproductive status, whales that conceive earlier in the breeding season tend to migrate to Antarctic feeding areas earlier (Kato and Miyashita, 1991; Kato, 1995). Therefore, PPF in Antarctic commercial samples are thought to be an overestimate from true pregnancy rate, which was estimated to be 0.78 (Best, 1982) from commercial whaling samples in breeding areas (Kato, 1991). However, annual ovulation rate, which means upper limit of the true pregnancy rate, was calculated as 0.98 for I-stock and 1.01 for P-stock, respectively (Fig. 14). Observed high annual ovulation rate and low rate of resting whales in matured females (3.5% in I-stock and 12.0% in P-stock, respectively) implies that Antarctic minke whale may maintain true pregnancy rate of around 0.90.

Increasing trend of growth speed was observed in 1940s to 1970s year class from commercial samples (Kato, 1987). This increasing trend was not observed in 1990s and 2000s year classes from JARPA samples. This might be showing the possibility that some change has been ongoing about Antarctic minke whale. Carrying capacity for Antarctic minke whales was thought to have expanded by decrease of other large Balaenopterids which compete with Antarctic minke whales for food. Decreasing trend of age at sexual maturity estimated from mean value of transition phase (*tmp*) from 1940s year class to 1970s year class was reported (Kato, 1987). But JARPA samples showed that decreasing trend of age at sexual maturity has ceased in early 1970s year class and it might be stable or increasing afterwards (Zenitani and Kato, 2006). Furthermore, decreasing trend was detected in blubber thickness in Antarctic minke whales sampled during JARPA survey (Konishi *et al*., 2006), which suggests the possibility that nutritional condition of Antarctic minke whale would be decreasing. Suspension of increasing trend of growth speed detected in this study might be also showing recent decreasing trend of nutritional condition, and carrying capacity for the Antarctic minke whale has begun to return toward to previous environmental circumstance before its expanding had taken place.

Biological parameters are an effective tool not only for understanding of present status but also prediction of future trend of stock condition. Thus, further monitoring of biological parameters should be necessary for sustainable management of whale stocks. Furthermore, some biological parameters estimated in this study such as age at sexual maturity and foetal sex ratio were required for RMP *Implementation* (IWC, 2006) and precise parameters would improve the performance of RMP.

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Table 1. Abundance estimate (upper), number of samples (middle) and correction factor (lower) of Antarctic minke whales in each year, stratum and school size.

Abundance estimate: 'A'

Area IV	IVWN		IVWS		IVEN		IVES		PB	
Year	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2
1989/90	3,966	4,675	752	1,291	2,570	7,888	1,364	5,446	676	2,220
1991/92	4,460	7,135	892	1,511	2,193	753	635	1,095	1,512	9,635
1993/94	2,987	2,345	998	2,623	3,134	4,564	543	3,128	1,250	4,266
1995/96	934	2,949	3,149	4,119	6,925	2,817	1,481	3,001	1,158	814
1997/98	2,444	4,233	463	510	2,916	2,091	1,091	421	359	2,266
1999/00	2,680	12,365	1,987	12,179	5,420	17,263	1,472	50,255	1,072	10,218
2001/02	3,637	2,626	998	1,055	6,277	6,029	1,836	3,870	4,953	14,484
2003/04	2,892	1,490	1,919	7,514	1,766	886	1,023	227	6,302	22,572

Area V	VWN		VWS		VEN		VES	
Year	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2
1990/91	11,703	14,191	2,878	5,385	11,845	7,170	14,874	21,197
1992/93	8,156	7,007	1,232	6,371	7,388	4,834	5,794	18,361
1994/95	1,912	6,651	711	2,361	7,508	8,135	10,206	44,574
1996/97	4,797	6,071	861	2,939	6,372	10,054	4,294	57,900
1998/99	10,747	32,774	1,431	11,574	9,134	55,164	1,135	3,432
2000/01	2,989	4,471	3,305	3,233	15,568	25,027	6,691	42,442
2002/03	4,948	16,704	7,632	25,109	4,999	7,407	9,730	42,671
2004/05	266	1,320	2,626	23,851	8,621	7,701	7,095	18,406

Number of samples: 'n'

Area IV	IVWN		IVWS		IVEN		IVES		PB	
Year	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2
1989/90	18	7	10	39	8	24	7	65	6	17
1991/92	30	34	16	50	11	3	8	13	10	25
1993/94	26	14	38	54	30	23	15	44	3	21
1995/96	21	29	50	80	22	12	18	22	43	33
1997/98	44	30	43	32	43	15	41	32	13	35
1999/00	42	8	9	26	69	24	22	115	7	8
2001/02	51	18	38	23	35	28	66	46	11	14
2003/04	32	12	72	69	30	13	45	32	9	16

Area V	VWN		VWS		VEN		VES	
Year	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2
1990/91	26	18	13	63	4	30	26	54
1992/93	6	7	16	57	19	10	32	61
1994/95	28	27	29	56	37	20	42	66
1996/97	21	23	28	55	44	51	39	69
1998/99	11	16	48	109	11	29	43	62
2000/01	26	6	47	61	42	41	58	49
2002/03	13	18	14	55	70	55	33	72
2004/05	1	3	35	42	46	17	112	74

Correction factor 'A/n'

Area IV	IVWN		IVWS		IVEN		IVES		PB	
Year	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2
1989/90	220.3	667.9	75.2	33.1	321.2	328.7	194.8	83.8	112.6	130.6
1991/92	148.7	209.9	55.8	30.2	199.3	250.9	79.4	84.2	151.2	385.4
1993/94	114.9	167.5	26.3	48.6	104.5	198.4	36.2	71.1	416.8	203.1
1995/96	44.5	101.7	63.0	51.5	314.8	234.7	82.3	136.4	26.9	24.7
1997/98	55.6	141.1	10.8	16.0	67.8	139.4	26.6	13.2	27.6	64.7
1999/00	63.8	1,545.6	220.7	468.4	78.5	719.3	66.9	437.0	153.1	1,277.3
2001/02	71.3	145.9	26.3	45.9	179.3	215.3	27.8	84.1	450.3	1,034.6
2003/04	90.4	124.2	26.6	108.9	58.9	68.1	22.7	7.1	700.3	1,410.7

Area V	VWN		VWS		VEN		VES	
Year	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2	SS=1	SS>=2
1990/91	450.1	788.4	221.4	85.5	2,961.1	239.0	572.1	392.5
1992/93	1,359.4	1,001.1	77.0	111.8	388.8	483.4	181.1	301.0
1994/95	68.3	246.3	24.5	42.2	202.9	406.8	243.0	675.4
1996/97	228.4	263.9	30.7	53.4	144.8	197.1	110.1	839.1
1998/99	977.0	2,048.4	29.8	106.2	830.4	1,902.2	26.4	55.3
2000/01	115.0	745.2	70.3	53.0	370.7	610.4	115.4	866.2
2002/03	380.7	928.0	545.1	456.5	71.4	134.7	294.8	592.7
2004/05	265.8	440.0	75.0	567.9	187.4	453.0	63.3	248.7

Table 2. Reproductive status, sexual maturity rate and sex ratio in Antarctic minke whales estimated from JARPA samples, by season and stock.

Stock	Year	Male					Sex ratio (Male(%))	Female										
									Mature									
		Imm.	Mat.	Unk.	Total	Maturity rate(%)		Imm.	Ovu.	Rest.	Preg.	Lact.	Preg. &Lact.	Unk.	Total	Total	Maturity rate(%)	Total
I-stock	1989/90-1990/91	0.080	0.520	0.000	0.600	86.7	60.0	0.140	0.006	0.016	0.234	0.000	0.002	0.001	0.260	0.400	65.0	1.000
	1991/92-1992/93	0.070	0.562	0.000	0.633	88.9	63.3	0.085	0.011	0.002	0.262	0.001	0.007	0.001	0.283	0.367	77.0	1.000
	1993/94-1994/95	0.102	0.570	0.000	0.672	84.8	67.2	0.125	0.003	0.004	0.175	0.000	0.017	0.005	0.204	0.328	62.0	1.000
	1995/96-1996/97	0.151	0.500	0.000	0.651	76.8	65.1	0.145	0.011	0.015	0.176	0.000	0.001	0.001	0.204	0.349	58.5	1.000
	1997/98-1998/99	0.119	0.551	0.000	0.671	82.2	67.1	0.183	0.005	0.030	0.107	0.000	0.005	0.000	0.147	0.329	44.5	1.000
	1999/00-2000/01	0.058	0.479	0.001	0.538	89.1	53.8	0.116	0.011	0.005	0.326	0.000	0.004	0.000	0.346	0.462	74.9	1.000
	2001/02-2002/03	0.048	0.437	0.000	0.485	90.1	48.5	0.105	0.019	0.007	0.374	0.000	0.010	0.000	0.410	0.515	79.6	1.000
	2003/04-2004/05	0.057	0.437	0.000	0.494	88.5	49.4	0.063	0.009	0.009	0.422	0.001	0.003	0.000	0.443	0.506	87.6	1.000
	Combined	0.077	0.495	0.000	0.573	86.5	57.3	0.118	0.010	0.011	0.282	0.000	0.006	0.001	0.309	0.427	72.3	1.000
P-stock	1990/91	0.017	0.323	0.000	0.340	94.9	34.0	0.043	0.021	0.150	0.445	0.000	0.000	0.000	0.616	0.660	93.4	1.000
	1992/93	0.016	0.426	0.000	0.442	96.5	44.2	0.135	0.000	0.008	0.397	0.013	0.000	0.005	0.424	0.558	75.9	1.000
	1994/95	0.051	0.332	0.000	0.383	86.7	38.3	0.114	0.000	0.148	0.355	0.000	0.000	0.000	0.503	0.617	81.5	1.000
	1996/97	0.020	0.267	0.000	0.287	93.1	28.7	0.061	0.012	0.078	0.551	0.000	0.000	0.012	0.653	0.713	91.5	1.000
	1998/99	0.081	0.760	0.000	0.841	90.4	84.1	0.058	0.000	0.001	0.100	0.000	0.000	0.000	0.101	0.159	63.5	1.000
	2000/01	0.064	0.426	0.000	0.491	86.9	49.1	0.068	0.015	0.010	0.407	0.000	0.004	0.005	0.441	0.509	86.6	1.000
	2002/03	0.031	0.278	0.000	0.309	89.9	30.9	0.100	0.000	0.023	0.568	0.000	0.000	0.000	0.591	0.691	85.6	1.000
	2004/05	0.077	0.310	0.000	0.387	80.1	38.7	0.143	0.012	0.030	0.414	0.000	0.008	0.006	0.470	0.613	76.6	1.000
	Combined	0.046	0.394	0.000	0.440	89.5	44.0	0.084	0.008	0.057	0.405	0.001	0.001	0.004	0.476	0.560	84.9	1.000

Table 3. Mean body length of Antarctic minke whales having CL of the first ovulation.

Stock	Year	n	mean	S.D.	min	max
I-stock	1987/88	7	8.27	0.32	8.0	9.0
	1989/90-1990/91	12	8.34	0.24	7.9	8.8
	1991/92-1992/93	6	8.33	0.41	7.8	8.8
	1993/94-1994/95	9	8.59	0.21	8.3	9.0
	1995/96-1996/97	2	8.75	0.15	8.6	8.9
	1997/98-1998/99	8	8.49	0.36	8.0	9.3
	1999/00-2000/01	3	8.30	0.08	8.2	8.4
	2001/02-2002/03	13	8.35	0.28	7.9	8.9
	2003/04-2004/05	2	8.45	0.05	8.4	8.5
	Combined	62	8.40	0.31	7.8	9.3
P-stock	1988/89	1	8.30	0.00	8.3	8.3
	1990/91	0	-	-	-	-
	1992/93	3	8.37	0.05	8.3	8.4
	1994/95	0	-	-	-	-
	1996/97	2	8.50	0.20	8.3	8.7
	1998/99	1	8.70	0.00	8.7	8.7
	2000/01	5	8.48	0.22	8.1	8.7
	2002/03	5	8.08	0.38	7.6	8.5
	2004/05	4	8.08	0.16	7.8	8.2
	Combined	21	8.30	0.31	7.6	8.7

Table 4. Body length of Antarctic minke whales at 50% sexual maturity.

Stock	Year	Male	Female
I-stock	1989/90-1990/91	7.27	8.28
	1991/92-1992/93	7.33	7.98
	1993/94-1994/95	7.14	8.17
	1995/96-1996/97	7.25	8.25
	1997/98-1998/99	7.23	8.20
	1999/00-2000/01	7.31	8.17
	2001/02-2002/03	7.30	8.11
	2003/04-2004/05	7.51	8.02
	Combined	7.29	8.16
P-stock	1990/91	N.A.	8.04
	1992/93	N.A.	8.15
	1994/95	7.02	7.92
	1996/97	N.A.	7.89
	1998/99	N.A.	N.A.
	2000/01	N.A.	8.08
	2002/03	7.03	7.80
	2004/05	N.A.	8.07
	Combined	7.17	7.97

N.A.: not analysed

Table 5. Mean age of Antarctic minke whales having CL of the first ovulation.

Stock	Year	n	mean	S.D.	min	max
I-stock	1987/88	7	8.3	1.8	6	11
	1989/90-1990/91	11	6.5	1.1	5	9
	1991/92-1992/93	5	8.2	1.2	7	10
	1993/94-1994/95	7	8.4	1.4	7	11
	1995/96-1996/97	2	10.5	0.5	10	11
	1997/98-1998/99	7	8.6	1.5	7	12
	1999/00-2000/01	3	7.7	0.9	7	9
	2001/02-2002/03	11	7.6	0.6	7	9
	2003/04-2004/05	2	8.0	0.0	8	8
	Combined	55	7.9	1.5	5	12
P-stock	1988/89	1	8.0	0.0	8	8
	1990/91	0	-	-	-	-
	1992/93	3	9.3	0.9	8	10
	1994/95	0	-	-	-	-
	1996/97	2	10.0	0.0	10	10
	1998/99	1	9.0	0.0	9	9
	2000/01	5	8.2	1.0	7	10
	2002/03	3	8.0	0.0	8	8
	2004/05	4	7.8	0.4	7	8
	Combined	20	8.4	1.0	7	10

Table 6. Age of Antarctic minke whales at 50% sexual maturity.

Stock	Year	Male	Female
I-stock	1989/90-1990/91	5.0	8.0
	1991/92-1992/93	4.5	7.1
	1993/94-1994/95	5.5	N.A.
	1995/96-1996/97	5.5	8.6
	1997/98-1998/99	5.8	8.3
	1999/00-2000/01	5.0	N.A.
	2001/02-2002/03	5.3	7.6
	2003/04-2004/05	6.4	7.2
	Combined	5.3	7.6
P-stock	1990/91	5.7	8.5
	1992/93	N.A.	8.9
	1994/95	N.A.	8.3
	1996/97	N.A.	N.A.
	1998/99	N.A.	N.A.
	2000/01	N.A.	N.A.
	2002/03	4.8	7.3
	2004/05	N.A.	7.4
	Combined	5.4	8.0

N.A.: not analysed

Table 7. Body length of Antarctic minke whales at 50% physical maturity.

Stock	Year	Male	Female
I-stock	1989/90-1990/91	8.30	8.86
	1991/92-1992/93	8.32	9.09
	1993/94-1994/95	8.35	9.19
	1995/96-1996/97	8.22	8.83
	1997/98-1998/99	8.38	9.39
	1999/00-2000/01	8.28	9.14
	2001/02-2002/03	8.37	9.26
	2003/04-2004/05	8.34	9.04
	Combined	8.32	9.12
P-stock	1990/91	7.73	8.71
	1992/93	8.05	8.74
	1994/95	8.15	8.78
	1996/97	8.22	8.53
	1998/99	8.50	8.95
	2000/01	8.25	8.87
	2002/03	8.45	8.83
	2004/05	8.13	8.72
	Combined	8.22	8.73

Table 8. Age of Antarctic minke whales at 50% physical maturity.

Stock	Year	Male	Female
I-stock	1989/90-1990/91	15.3	18.7
	1991/92-1992/93	16.0	20.4
	1993/94-1994/95	16.5	18.8
	1995/96-1996/97	15.5	19.5
	1997/98-1998/99	18.5	22.5
	1999/00-2000/01	15.3	21.8
	2001/02-2002/03	15.7	22.5
	2003/04-2004/05	16.9	20.2
	Combined	16.0	21.2
P-stock	1990/91	14.3	19.2
	1992/93	N.A.	19.9
	1994/95	16.8	22.4
	1996/97	16.4	19.4
	1998/99	17.8	N.A.
	2000/01	16.5	22.8
	2002/03	19.1	21.7
	2004/05	16.0	20.7
	Combined	17.0	20.6

N.A.: not analysed

Table 9. Proportion of pregnant in matured female (PPF) in Antarctic minke whales estimated from JARPA samples.

Stock	Year	Mature Female			PPF (%)
		non Preg.	Preg	Total	
I-stock	1989/90-1990/91	0.091	0.909	1.000	90.9
	1991/92-1992/93	0.050	0.950	1.000	95.0
	1993/94-1994/95	0.056	0.944	1.000	94.4
	1995/96-1996/97	0.135	0.865	1.000	86.5
	1997/98-1998/99	0.237	0.763	1.000	76.3
	1999/00-2000/01	0.049	0.951	1.000	95.1
	2001/02-2002/03	0.063	0.937	1.000	93.7
	2003/04-2004/05	0.041	0.959	1.000	95.9
	Combined	0.071	0.929	1.000	92.9
P-stock	1990/91	0.278	0.722	1.000	72.2
	1992/93	0.063	0.937	1.000	93.7
	1994/95	0.294	0.706	1.000	70.6
	1996/97	0.156	0.844	1.000	84.4
	1998/99	0.012	0.988	1.000	98.8
	2000/01	0.068	0.932	1.000	93.2
	2002/03	0.039	0.961	1.000	96.1
	2004/05	0.102	0.898	1.000	89.8
	Combined	0.146	0.854	1.000	85.4

Table 10. Foetal sex ratio in Antarctic minke whales sampled by JARPA surveys.

Stock	Year	Male	Female	Unknown	Total	Male%	p-value (χ^2 test)
I-stock	1987/88	25	30	2	57	45.5	0.500
	1989/90-1990/91	64	64	4	132	50.0	1.000
	1991/92-1992/93	59	75	4	138	44.0	0.167
	1993/94-1994/95	42	32	3	77	56.8	0.245
	1995/96-1996/97	75	71	3	149	51.4	0.741
	1997/98-1998/99	52	43	4	99	54.7	0.356
	1999/00-2000/01	63	62	3	128	50.4	0.929
	2001/02-2002/03	90	74	11	175	54.9	0.212
	2003/04-2004/05	97	77	19	193	55.7	0.129
	Combined	567	528	53	1148	51.8	0.239
P-stock	1988/89	49	49	0	98	50.0	1.000
	1990/91	22	36	0	58	37.9	0.066
	1992/93	23	31	1	55	42.6	0.276
	1994/95	28	26	1	55	51.9	0.785
	1996/97	49	63	1	113	43.8	0.186
	1998/99	10	5	0	15	66.7	0.197
	2000/01	47	47	0	94	50.0	1.000
	2002/03	41	50	3	94	45.1	0.345
	2004/05	64	71	9	144	47.4	0.547
	Combined	333	378	15	726	46.8	0.091

Table 11. Litter size of Antarctic minke whales sampled by JARPA surveys.

Stock	Year	Number of fetus		Litter size
		1	2	
I-stock	1987/88	57	0	1.000
	1989/90-1990/91	130	1	1.008
	1991/92-1992/93	134	2	1.015
	1993/94-1994/95	75	1	1.013
	1995/96-1996/97	149	0	1.000
	1997/98-1998/99	97	1	1.010
	1999/00-2000/01	126	1	1.008
	2001/02-2002/03	174	1	1.006
	2003/04-2004/05	192	1	1.005
	Combined	1134	8	1.007
P-stock	1988/89	92	3	1.032
	1990/91	56	1	1.018
	1992/93	53	1	1.019
	1994/95	53	1	1.019
	1996/97	111	1	1.009
	1998/99	15	0	1.000
	2000/01	94	0	1.000
	2002/03	90	2	1.022
	2004/05	144	0	1.000
	Combined	708	9	1.013

Table 12. Summary of biological parameters estimated by each stock.

		I-stock (Area IIIE+IV+VW)		P-stock (Area VE+VIW)	
		Male	**Female**	**Male**	**Female**
Body length at sexual maturity (m)	*Lmov*		**8.40m**		**8.30m**
	Lm50%	**7.29m**	**8.16m**	**7.17m**	**7.97m**
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	**8.32m**	**9.12m**	**8.22m**	**8.73m**
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**

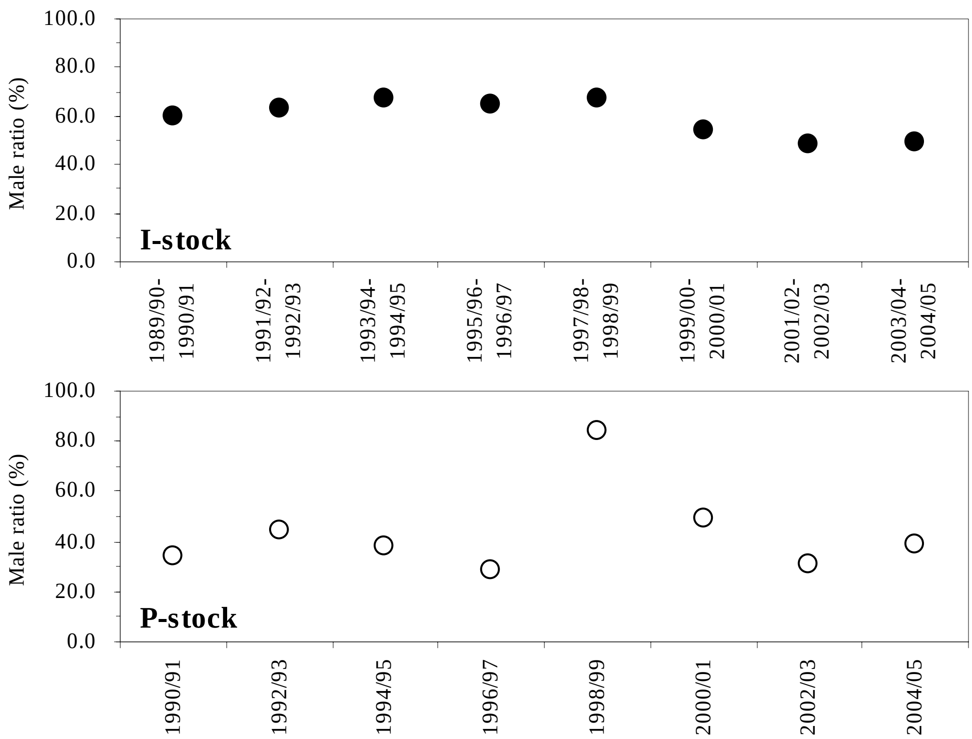

Fig. 1. Male ratio (%) of Antarctic minke whales estimated from JARPA samples.

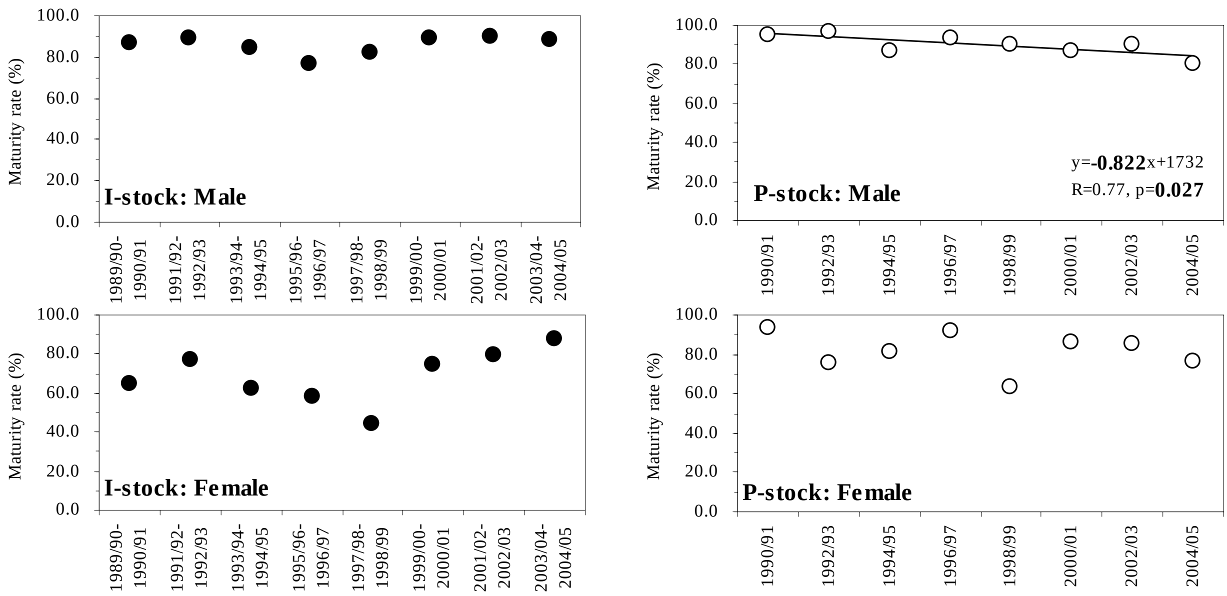

Fig. 2. Sexual maturity rate of Antarctic minke whales estimated from JARPA samples.

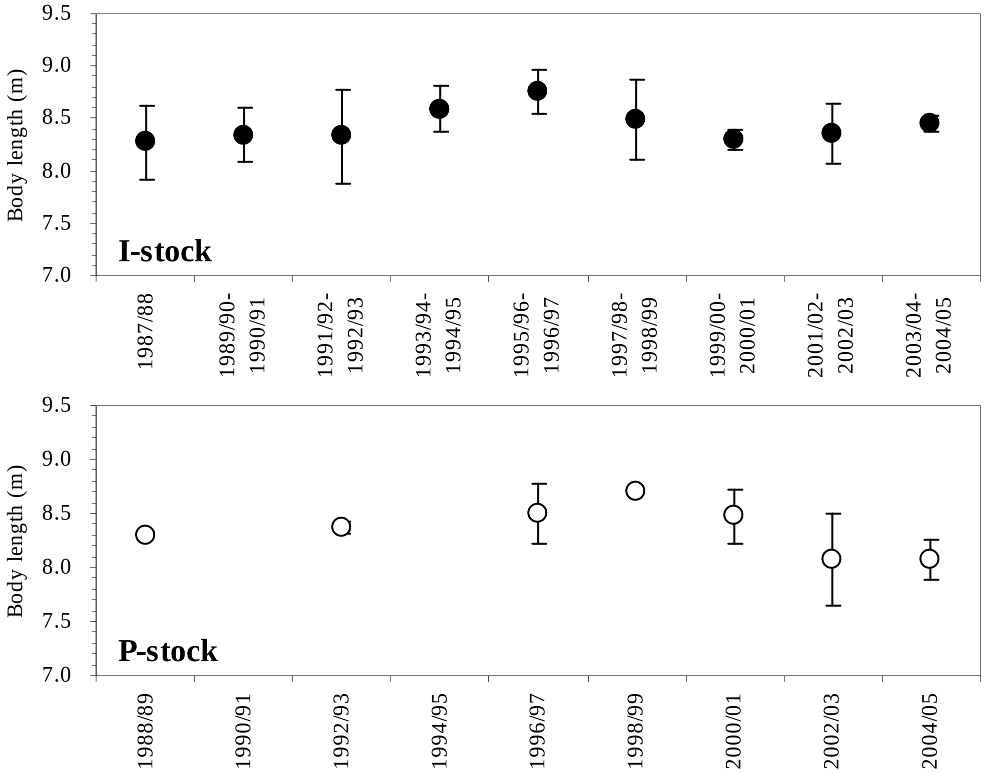

Fig. 3. Mean body length of Antarctic minke whales having CL of first ovulation.

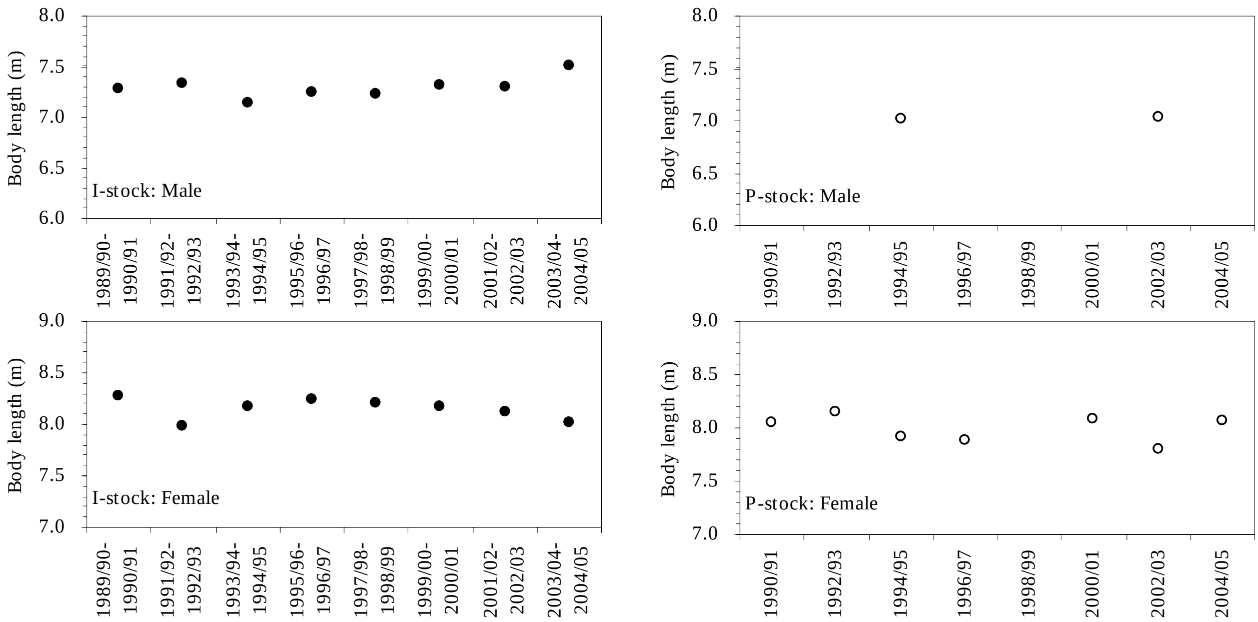

Fig. 4. Body length of Antarctic minke whales at 50% sexual maturity estimated from JARPA samples.

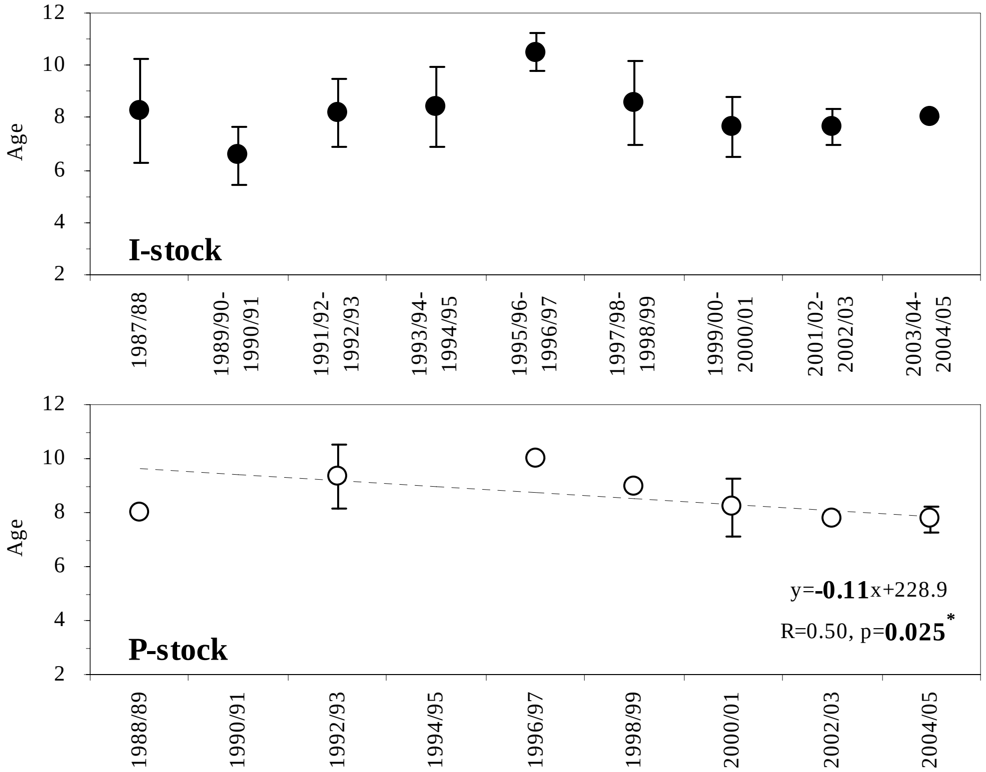

Fig. 5. Mean age of Antarctic minke whales having CL of first ovulation.

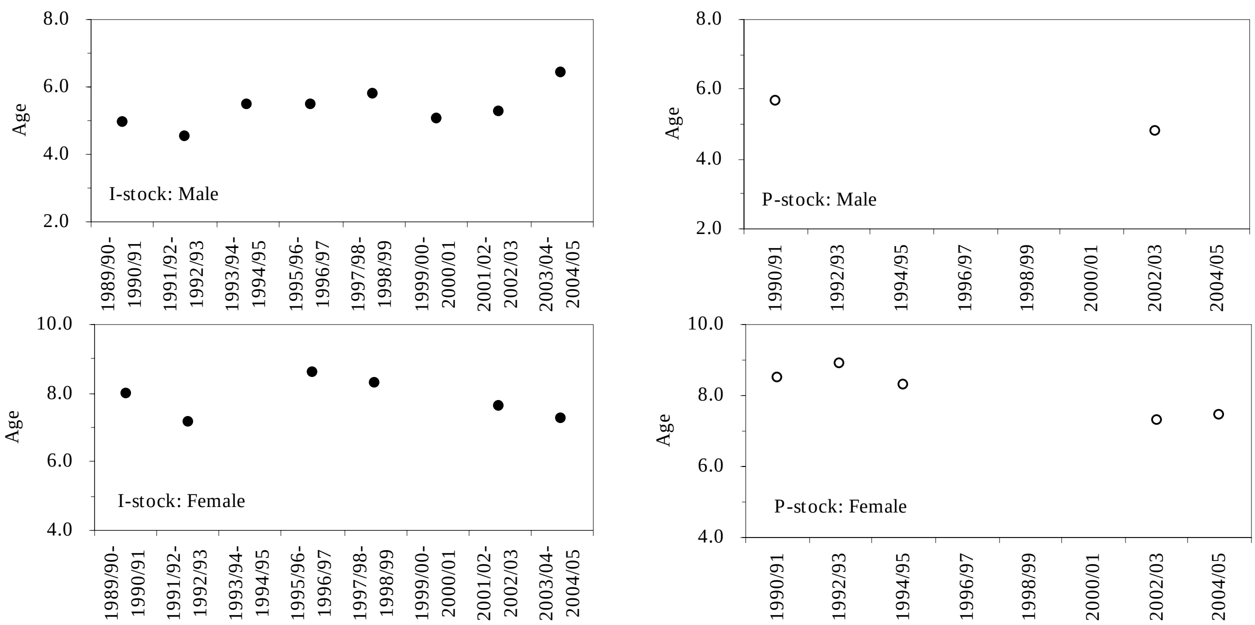

Fig. 6. Age of Antarctic minke whales at 50% sexual maturity.

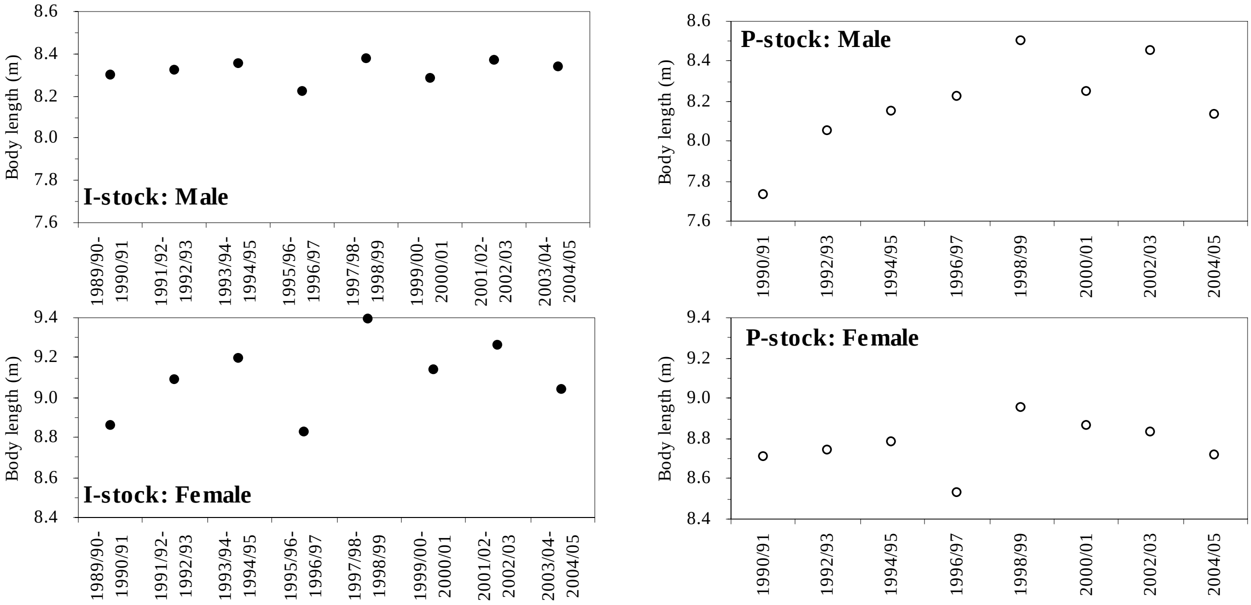

Fig. 7. Body length of Antarctic minke whales at 50% physical maturity.

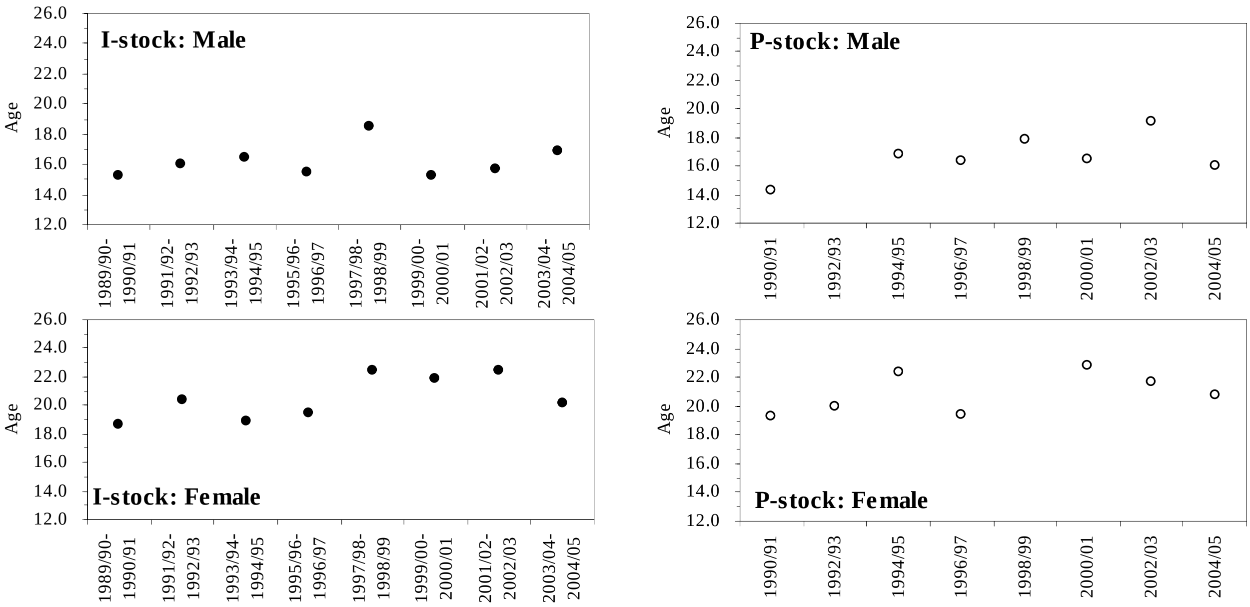

Fig. 8. Age of Antarctic minke whales at 50% physical maturity.

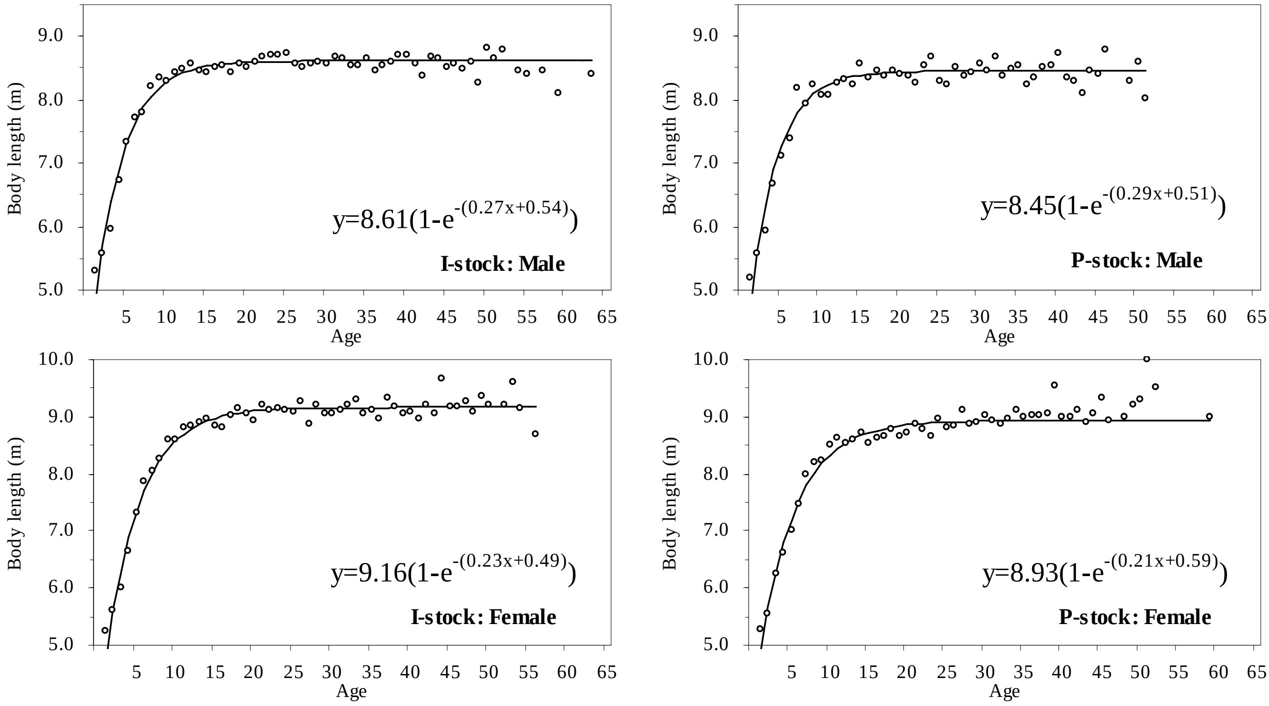

Fig. 9. Growth curve of Antarctic minke whales estimated from JARPA samples.

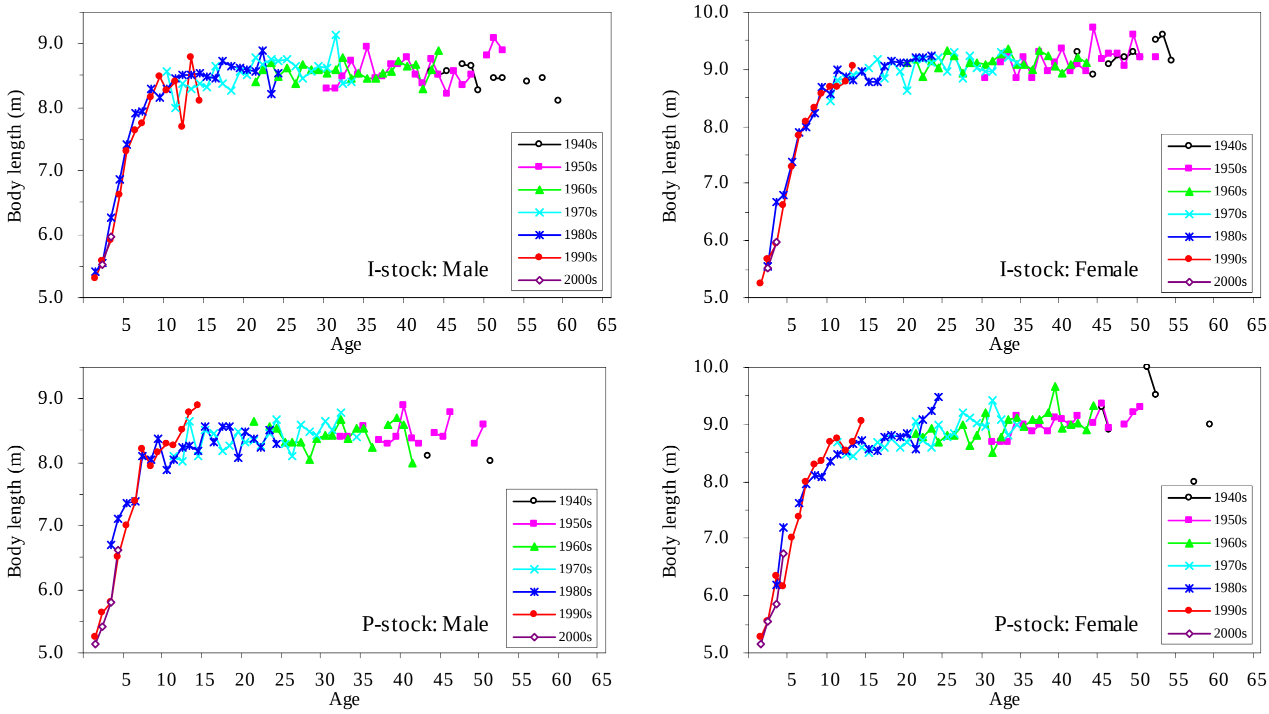

Fig. 10. Mean body length plotted on age at capture of Antarctic minke whales in each 10 year-class group.

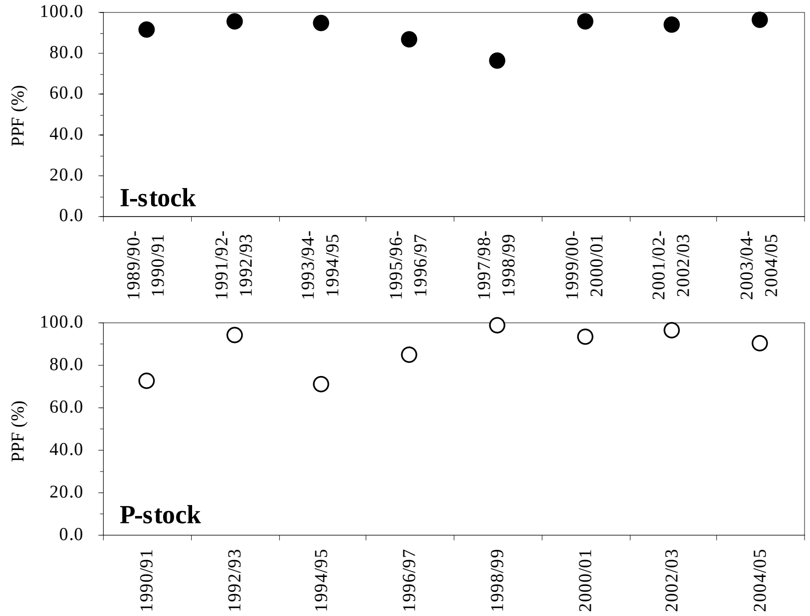

Fig. 11. Proportion of pregnant in matured female (PPF) in Antarctic minke whales estimated from JARPA samples.

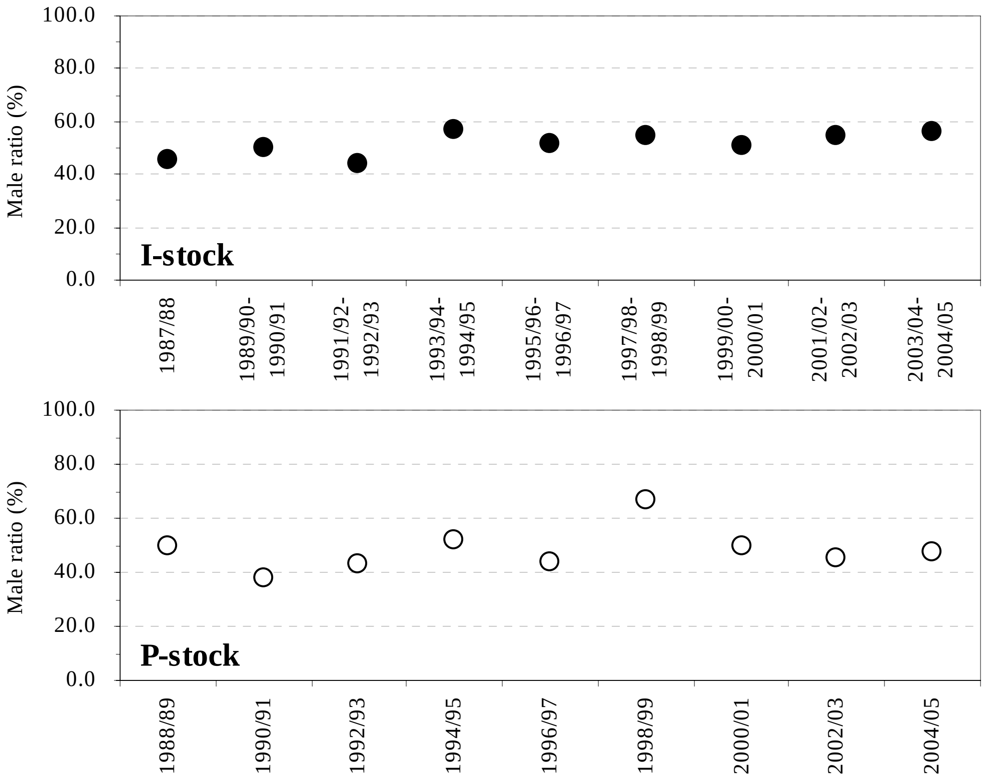

Fig. 12. Foetal sex ratio in Antarctic minke whales sampled by JARPA surveys.

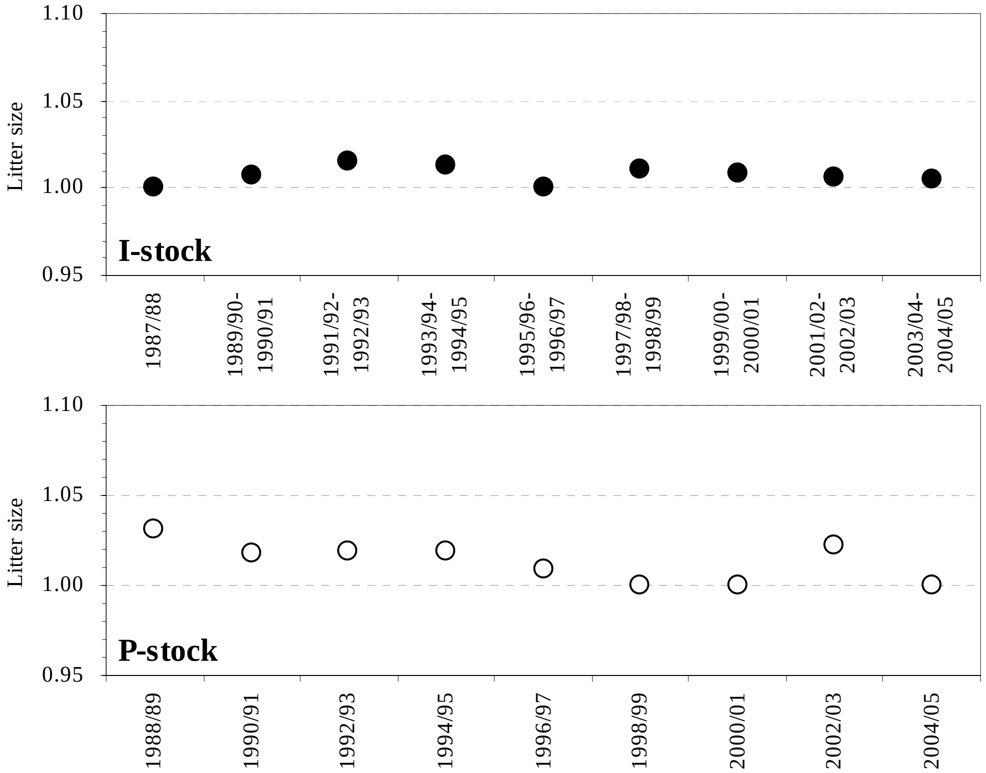

Fig. 13. Litter size of Antarctic minke whales sampled by JARPA surveys.

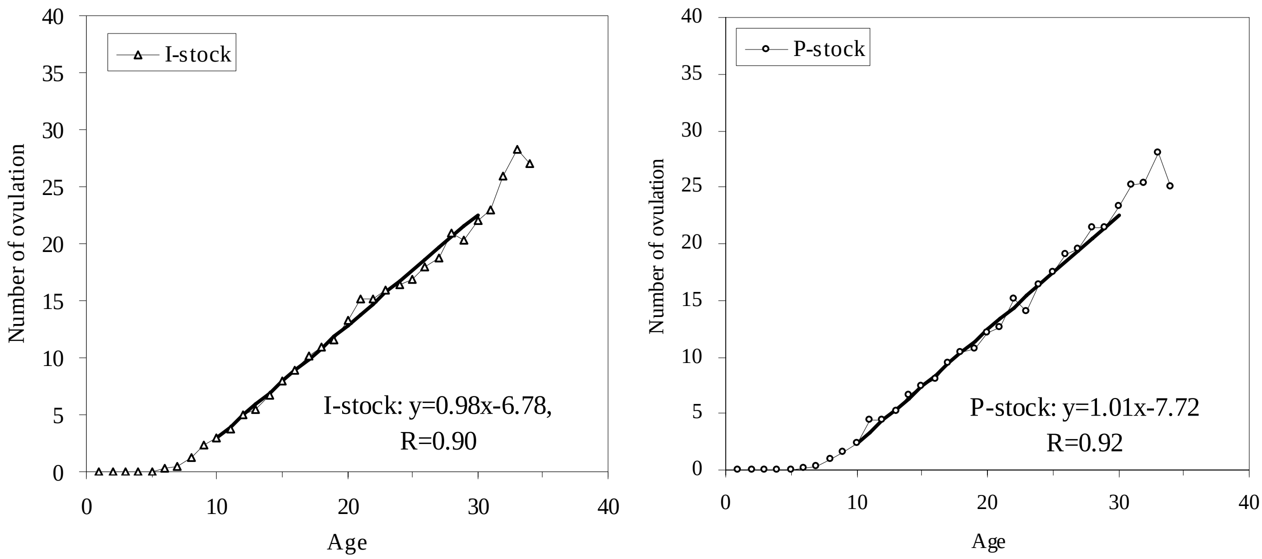

Fig. 14. Relationship between mean number of ovulations and age of Antarctic minke whales in each stock. Whales of after 1970 year class were used to avoid effect of yearly change in age at sexual maturity (Kato *et al.*, 1984, 1985; Zenitani and Kato, 2006). Regression lines were fitted from age 10 to 30.

Appendix: Body length/age at 50% sexual/physical maturity estimated in each stock, sex and year

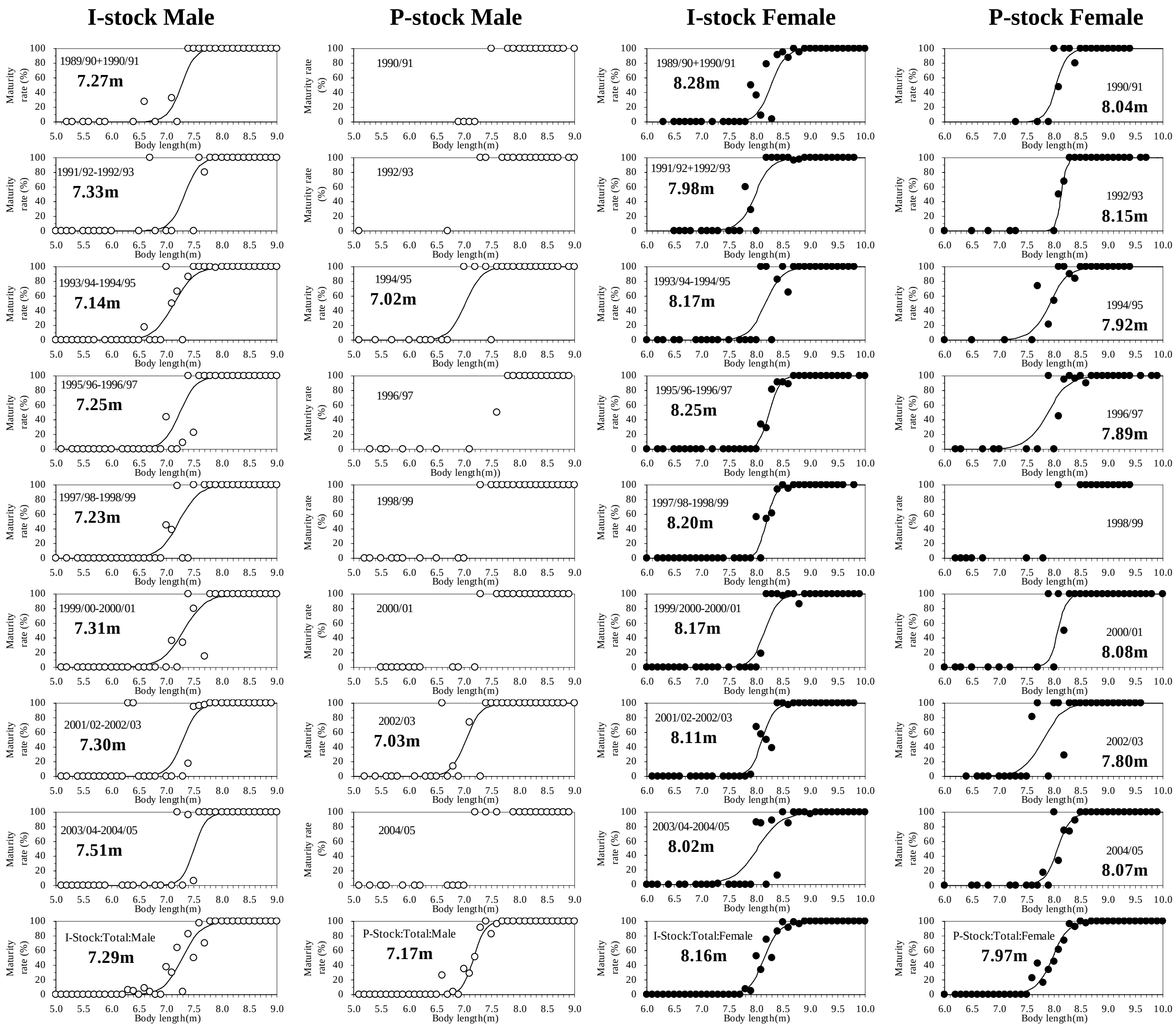

Fig. 1. Body length of Antarctic minke whales at 50% sexual maturity estimated in each year.

Appendix: Body length/age at 50% sexual/physical maturity estimated in each stock, sex and year

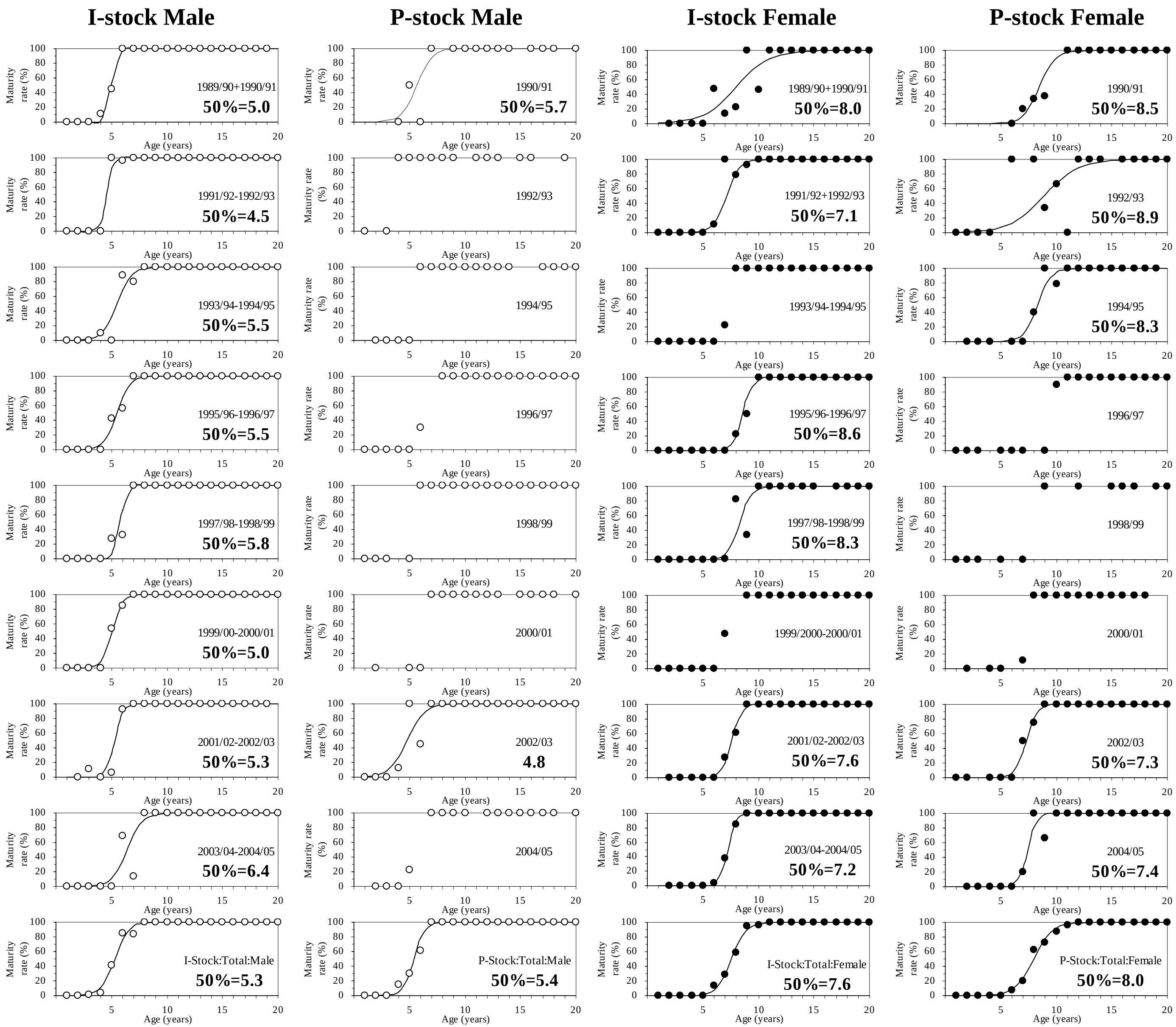

Fig. 2. Age of Antarctic minke whales at 50% sexual maturity estimated in each year.

Appendix: Body length/age at 50% sexual/physical maturity estimated in each stock, sex and year

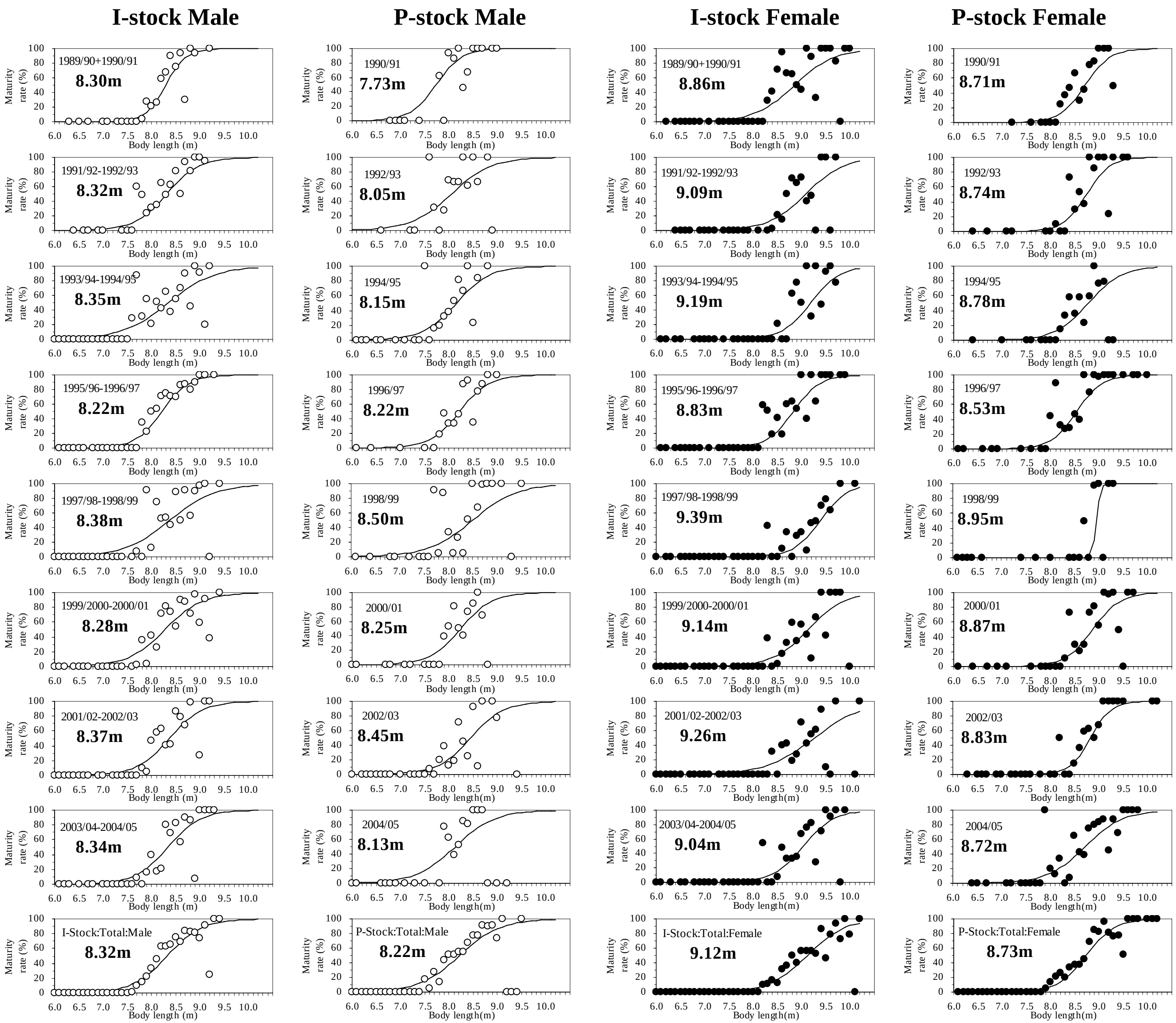

Fig. 3. Body length of Antarctic minke whales at 50% physical maturity estimated in each year.

Appendix: Body length/age at 50% sexual/physical maturity estimated in each stock, sex and year

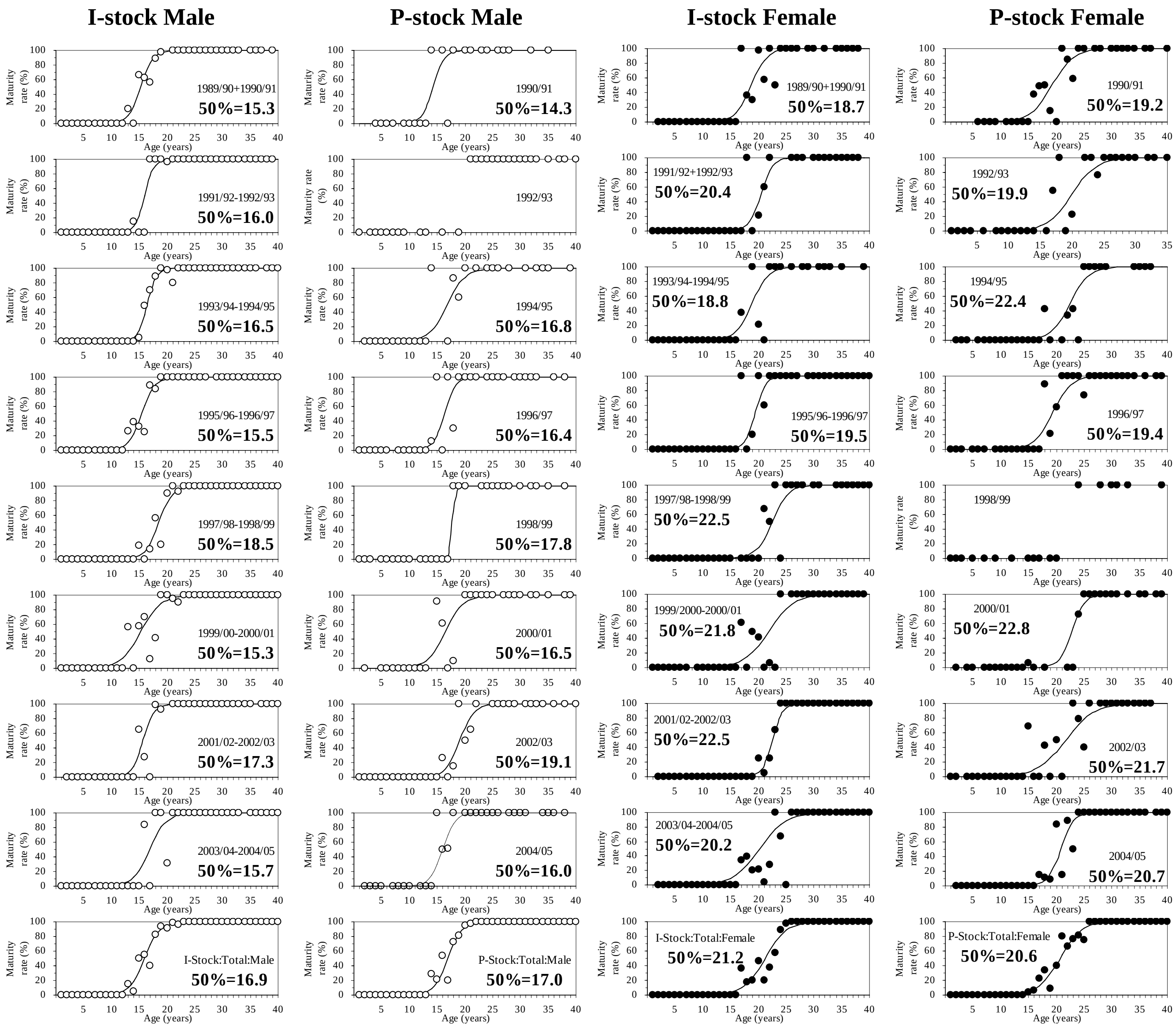

Fig. 4. Age of Antarctic minke whales at 50% physical maturity estimated in each year.