Biological parameters of the Antarctic minke whale based on materials collected by the JARPA survey in 1987/88 to 2003/04

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ABSTRACT

Using materials collected by the JARPA surveys in Areas IIIE, IV, V and VIW in 1987/88 to 2003/04, the present study examined some biological parameters of the Antarctic minke whales by incorporating a 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), foetal sex ratio and occurrence of multiple births. Resultant estimate of the parameters were: male sex ratio, 54.8% (I stock), 47.0% (P stock); sexual maturity rate, 80.8% (I, Male), 85.6% (P, Male), 63.5% (I, Female), 79.8% (P, Female); body length at first ovulation, 8.40m (I), 8.34m (P); body length at 50% sexual maturity, 7.26m (I, M), 7.13m (P, M), 8.18m (I, F), 7.97m(P, F); age at first ovulation, 7.9 years (I), 8.6 years (P); age at 50% sexual maturity, 5.3 years (I, M), 5.3 years (P, M), 7.6 years (I, F), 8.2 years(P, F); body length at physical maturity, 8.35m (I, M), 8.18m (P, M), 9.02m (I, F), 8.69m(P, F); age at physical maturity, 16.6 years (I, M), 16.7 years (P, M), 20.6 years (I, F), 19.8 years(P, F); PPF, 92.5% (I), 87.4% (P); foetal sex ratio (male%), 51.8% (I), 46.7% (P); occurrence of multiple births, 0.006 (I), 0.016 (P). Significant differences were detected between two stocks in sex ratio, sexual maturity rate for both sex, body length at 50% sexual maturity for female, age at 50% sexual maturity for female, body length at physical maturity for both sex, PPF and foetal sex ratio. Significant yearly trend was detected among male's for the following parameters by linear regression analysis; decreasing trend in sexual maturity rate in I-stock, increasing trends in body length and age at 50% sexual maturity in I-stock and body length and age at physical maturity in P-stock. Year was also selected as an explanatory variable for age at physical maturity and body length at physical maturity by use of stepwise logistic regression analysis, but for age and body length at sexual maturity was not selected. These results suggest the possibility that expansion of carrying capacity for the Antarctic minke whales has ceased and that the ecosystem begun to return towards the conditions that existed before the expanding had taken place.

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

INTRODUCTION

Biological parameters such as age at sexual maturity and pregnancy rate directly correlate to reproduction of whale stock, and are known to change in response to change in abundance, food availability or competition with other species (Gambell, 1973; Kato, 1986a, 1986b, 1987; Masaki, 1979; Lockyer, 1972, 1979, 1984). Therefore, monitoring of biological parameter is indispensable for sustainable management of baleen whale stocks (Ohsumi *et al*. 1997).

Biological parameters in Antarctic minke whale had been studied mainly from commercial whaling data, yearly trend and difference between area were studied 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 conducted in 1987/88 and 1988/89). Some results were reported to Scientific Committee of IWC and JARPA review meeting held at Tokyo in 1997(IWC, 1998; Tanaka *et al*., 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 Antarctic Ocean was studied by using genetic and non-genetic samples, new stock hypothesis that two discrete stock 'Eastern Indian Ocean Stock (I-stock)' and 'Western South Pacific Stock (P-stock)' migrates to Antarctic Ocean and boundary exists around 165°E, was deduced (Pastene *et al*., 2005). Therefore, biological parameters were estimated for presumed two stocks (I-stock and P-stock) and yearly trend were examined in this study. In addition, biological parameters were estimated by conventional area division for reference and results were shown in appendix.

MATERIALS AND METHODS

Biological samples and data used

All samples collected during 1987/88-2003/04 JARPA survey (Area IIIE: 549 animals, Area IV: 2864 animals, Area V: 2535 animals and Area VIW:390 animals) were used to estimate body length and age at sexual maturity (first ovulation), foetal sex ratio and occurrence of multiple births. Samples from main feeding season (mainly January and February in Areas IV and V; Area IV: 2317 animals, Area V: 2066 animals) collected during 1989/90-2003/04 JARPA surveys were used to estimate male ratio in sample, sexual maturity rate in sample, body length and age at sexual maturity (50% sexual maturity), body length and age at physical maturity and proportion of pregnant in matured female (PPF), because these parameters were thought to be biased by date of sampling (Kato, 1987; Kato and Miyashita, 1991).

Sexual maturity determination

Sexual maturity for male 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 to be sexually mature (Kato, 1986; Kato *et al*., 1990, 1991). Sexual maturity for females was determined by the presence of corpus luteum or albicans in both ovaries.

Physical maturity determination

The fusion of the vertebral epiphysis to the centrum was known to start at anterior cervical, then at posterior caudal vertebra, 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 epiphyses fused to centrum even a part was determined 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).

Body length and age at sexual maturity

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

Body length and age at first ovulation

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

Body length and age at 50% sexual maturity

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.

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.

Proportion of pregnant in matured female (PPF)

Proportion of pregnant in matured female is defined as the proportion of pregnant female within sampled total sexually matured females.

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 *et al*. (2005). As JARPA was conducted every two years in Areas IIIE+IV and V+VIW, sample of VW in particular season was added to samples of Area IIIE+IV in 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. In addition, biological parameters were estimated by conventional area division (Areas IIIE, IV, V and VIW) by using same samples.

Statistical method

Linear regression analysis was applied to catch year and biological parameters to detect yearly trend of biological parameters. 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 body length and age at first ovulation. Estimated annual value was used for body length and age at 50% sexual maturity, body length and age at 50% physical maturity and proportion of pregnant in matured female. Difference of biological parameters between two stock was examined by t-test for body length and age at first ovulation, likelihood ratio test for body length and age at 50% sexual maturity and body length and age at 50% physical maturity and χ^2-test for PPF and foetal sex ratio, respectively. SPSS ver 13.0 (SPSS Co Ltd.) was used for calculation.

Stepwise logistic regression analysis

To further investigate the possible change of the age and body length at sexual maturity and the age and body length at physical maturity with year during the JARPA period considering correlation between variables, four different stepwise logistic regression runs have been carried out. In two of these runs the binary variables 'sexual maturity' (0: immature, 1: mature) was the dependent variable, in the two other runs the binary variable 'physical maturity' (0: immature, 1: mature) was the dependent variable. In two of the runs, the 'age' of the whale is one of the independent variable. In the two other, the 'body length' of the whale is one of the independent variables. The other independent variables in all runs were 'sex' (1: male, 2: female), stock (1: I-stock, 2: P-stock) and 'year' (1989/90: year = 1989).

RESULTS

Sex ratio (male%) in sample

I-stock

Male ratio in sample (male%) was calculated as 54.8% (range: 41.8-68.4%) in I-stock (Fig. 1, Table 1). Male ratio fluctuated between 40 to 60% with large yearly variation and no significant yearly trend was detected (t-test, p=0.25).

P-stock

Male ratio in sample (male%) was calculated as 47.0% (range:32.5-76.6%) in P-stock(Fig. 1, Table 1). Male ratio in 1998/99 was extremely high (this would be caused by no samples obtained from the Ross sea, where mature female predominant (Nishiwaki, *et al*., 1999)) and fluctuated around 40% for other years. Consequently, increasing trend was observed but slope of the regression was not significantly different from zero (t-test, p=0.21).

I-stock vs P-stock

Estimated male ratio in sample was higher in I-stock than in P-stock and difference was significant(χ^2-test, p<0.01)(Table 11).

Sexual maturity rate in sample

I-stock

Sexual maturity ratio in I-stock was calculated as 80.8% (range:70.3-89.7%) for male and 63.5% (range:42.7-74.0%) for female, respectively (Fig. 2, Table 1). For male, sexual maturity rate was high in 1989/90+1990/91 and low in 2003/04 while other years were almost stable around 80%. Consequently, decreasing trend was observed and slope of the regression was significantly different from zero (t-test, p<0.01). As for female, extremely low value was estimated in 1997/98+1998/99 (this would be caused by existence of wide ice-free waters inside of the ice edge, where mature female predominant but research ship could not enter, in 1997/98 survey (Ishikawa, *et al*., 1998)) and large yearly variation was observed for other years. Consequently, no significant yearly trend was detected for female (t-test, p=0.96).

P-stock

Sexual maturity ratio in P-stock was calculated as 85.6% (range:80.0-95.9%) for male and 79.8% (range:52.9-92.2%) for female, respectively (Fig. 2, Table 1). For male, sexual maturity rate stabled around 80% and no significant yearly trend was detected (t-test, p=0.23). As for female, sexual maturity rate stabled around 80% except 1998/99 (this would also be caused by no samples obtained from the Ross sea (Nishiwaki, *et al*., 1999)) and decreasing yearly trend was observed, although slope of regression was not significantly different from zero (t-test, p=0.37).

I-stock vs P-stock

Estimated sexual maturity rate was lower in I-stock than in P-stock and difference was significant for both sex(χ^2-test, p=0.01 for male, p<0.01 for female)(Table 11).

Body length at sexual maturity

I-stock

Mean body length of females at first ovulation was calculated as 8.40m (range:8.30-8.78m) in I-stock (Table 2, Fig. 3). Mean body length stabled around 8.40m, although high value was estimated in 1995/96-1996/97. No significant yearly trend was detected (t-test, p=0.60).

P-stock

Mean body length of females at first ovulation was calculated as 8.34m (range:8.09-8.68m) in P-stock (Table 2, Fig. 3). Sample size of P-stock was small and no sample was obtained in 1990/91 and 1994/95. No significant yearly trend was detected (t-test, p=0.94).

I-stock vs P-stock
Estimated body length at first ovulation was slightly higher in I-stock than p-stock, but no significant difference was detected (t-test, p=0.43)(Table 11).

Body length at 50% sexual maturity
I-stock
Body length at 50% sexual maturity in I-stock was estimated as 7.26m (range:7.00-7.46m) for male and 8.18m (range: 8.01-8.26m) for female, respectively (Table 3, Fig. 4,5). Significant increasing trend was detected for male (t-test, p<0.01), but no significant yearly trend was detected for female (t-test, p=0.92).

P-stock
Body length at 50% sexual maturity in P-stock was estimated as 7.13m (range:6.97-7.60m) for male and 7.97m (range:7.85-8.14m) for female, respectively (Table 3, Fig. 4,5). High values were observed in 1990/91 and 1996/97 for male, but no significant yearly trend was detected (t-test, p=0.69). As for female, decreasing trend was observed but slope of the regression was not significantly different from zero (t-test, p=0.09).

I-stock vs P-stock
Body length at 50% sexual maturity in I-stock was higher than that in P-stock for both sex but significant difference was detected only for female (likelihood ratio test, p<0.01 for female, Table 11).

Age at sexual maturity
Mean age at first ovulation
I-stock
Mean age of females at first ovulation was calculated as 7.9 years (range:6.5-10.5 years) in I-stock (Table 4, Fig.6). Low value was observed in 1989/90-1990/91 and high value in 1995/96-1996-97. Consequently, increasing trend was observed but slope of the regression was not significantly different from zero (t-test, p=0.35).

P-stock
Mean age of females at first ovulation was calculated as 8.6 years (range:7.8-10.0 years) in P-stock (Table 4, Fig.6). Sample size of P-stock was small and no sample was obtained in 1990/91 and 1994/95. No significant yearly trend was detected (t-test, p=0.74).

I-stock vs P-stock
Estimated age at first ovulation was slightly lower in I-stock than p-stock, but no significant difference was detected (t-test, p=0.10)(Table 11).

Age at 50% sexual maturity
I-stock
Age at 50% sexual maturity in I-stock was estimated as 5.3 years (range:4.3-6.0 years) for male and 7.6 years (range:7.0-8.4 years) for female, respectively (Table 5, Figs. 7,8). Increasing yearly trend was observed for male and slope of the regression was significantly different from zero (t-test, p=0.03). As for female, high value were observed in 1995/96-1996/97 and 1997/98-1998/99 but almost stable for other seasons. Consequently, no significant yearly trend was detected (t-test, p=0.91).

P-stock
Age at 50% sexual maturity in P-stock was estimated as 5.3 years (range:3.5-6.5 years) for male and 8.2 years (range:7.0-9.9 years) for female, respectively (Table 5, Figs. 7,8). Extremely low value was observed for male in 1992/93 and large yearly variation was observed for other seasons. Consequently, increasing trend was observed but slope of the regression was not significantly different from zero (t-test, p=0.49). As for female, extremely high value was observed in 1996/97 and low value was observed in 2000/01 and 2002/03. Consequently, decreasing trend was observed but slope of the regression was not significantly different from zero (t-test, p=0.23).

I-stock vs P-stock
Estimated age at sexual maturity in each stock was same for male but significantly higher in P-stock than I-stock for female (likelihood ratio test, p<0.01)(Table 11).

Body length at physical maturity
I-stock
Body length at 50% physical maturity in I-stock was estimated as 8.35m (range:8.17-8.46m) for male and 9.02m (range:8.73-9.24m) for female, respectively (Table 6, Figs. 9,10). Estimated value in 1989/90-1990/91 and 1995/96-1996/97 showed lower value than other seasons and increasing trend was observed for both sex, although slope

of the regression was not significantly different from zero (t-test, p=0.16 for male, p=0.14 for female).

P-stock
Body length at 50% physical maturity in P-stock was estimated as 8.18m (range:7.89-8.34m) for male and 8.69m (range:8.52-9.05m) for female, respectively (Table 6, Figs. 9,10). Increasing trend with large yearly variation was observed for both sex but slope of the regression was significantly different from zero only for male (t-test, p=0.01 for male, p=0.16 for female).

I-stock vs P-stock
Estimated body length at 50% physical maturity in I-stock was larger than that in P-stock and significant difference was detected for both sex (likelihood test, p<0.01, Table 11).

Age at physical maturity
I-stock
Age at 50% physical maturity in P-stock was estimated as 16.6 years (range:13.3-19.5 years) for male and 20.6 years (range:16.0-23.6 years) for female, respectively (Table 7, Figs. 11,12). Estimated value in 1989/90-1990/91 and 1995/96-1996/97 showed lower value than other seasons and increasing trend with large yearly variation was observed for both sex, although slope of the regression was not significantly different from zero (t-test, p=0.15 for male, p=0.09 for female).

P-stock
Age at 50% physical maturity in P-stock was estimated as 16.7 years (range:13.8-19.0 years) for male and 19.8 years (range:17.4-25.1 years) for female, respectively (Table 7, Figs. 11,12). Increasing trend was observed for both sex but yearly variation was high for female. Consequently, slope of the regression was significantly different from zero only for male (t-test, p=0.02 for male, p=0.22 for female).

I-stock vs P-stock
Estimated age at physical maturity in each stock was almost same for male but higher in I-stock than P-stock for female, although difference was not significant (likelihood ratio test, p>0.05)(Table 11).

Proportion of pregnant in matured female (PPF)
I-stock
PPF was calculated as 92.5% (range: 90.0-94.8%) in I-stock (Fig. 13, Table 8). The value stabled around 90% and no significant yearly trend was detected (t-test, p=0.60).

P-stock
PPF was calculated as 87.4% (range:73.6-96.4%) in P-stock (Fig. 13, Table 8). Yearly increasing trend was observed due to low value in 1990/91 and 1994/95, but the slope of the regression was not significantly different from zero (t-test, p=0.18).

I-stock vs P-stock
Estimated PPF in I-stock was significantly higher than that in P-stock (χ^2-test, p<0.01)(Table 11).

Foetal sex ratio
I-stock
Foetal sex ratio (male%) was calculated as 51.8% (range: 44.0-56.9%) in I-stock (Fig. 14, Table 9). Foetal sex ratio fluctuated from 40% to 60% but all of the observed foetal sex ratio are not significantly different from equality (χ^2-test, p>0.05).

P-stock
Foetal sex ratio (male%) was calculated as 46.7% (range:37.9-66.7%) in P-stock (Fig. 14, Table 9). Foetal sex ratio fluctuated largely than I-stock, but all of the observed foetal sex ratio are not significantly different from equality (χ^2-test, p>0.05).

I-stock vs P-stock
Estimated foetal sex ratio(male%) in I-stock was higher than that in P-stock and the difference was significant (χ^2-test, p=0.049)(Table 11).

Occurrence of multiple births
I-stock
Occurrence of multiple births was calculated as 0.006 (range: 0.000-0.015) in I-stock (Fig. 15, Table 10).

P-stock
Occurrence of multiple births was calculated as 0.016 (range:0.000-0.032) in P-stock (Fig. 15, Table 10).

I-stock vs P-stock
No significant difference was detected between two stock (χ^2-test,p=0.06)(Table 11).

Further investigation of yearly trend
Both for the age at sexual maturity and body length at sexual maturity, sex and stock were selected as explanatory variable at the 5% level by stepwise logistic regression analysis, but year was not (Table 12). However, both for the age at physical maturity and the body length at physical maturity, year was selected as explanatory variable in addition to sex and stock for body length at physical maturity and sex for age at physical maturity (Table 12).

DISCUSSION

Summary of estimated biological parameters, observed yearly trend and results of comparison between I-stock and P-stock were shown in Table 11.

Biological parameters would differ between biological stocks, therefore estimation should be conducted by biological stock for management purpose. ‘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 sample revealed stock structure of Antarctic minke whales in Antarctic feeding ground (Pastene *et al*., 2005). Therefore, biological parameters were firstly estimated by biological stock in this study. Significant differences were detected in some biological parameters such as sex ratio, sexual maturity rate for both sex, age and body length at 50% sexual maturity for female, body length at 50% physical maturity for both sex, PPF and foetal sex ratio. This shows that whales of I-stock attain sexual and physical maturity larger than P-stock.

Antarctic minke whales are known to segregate in the Antarctic, mature female mainly distributes in the ice-edge zone, immature whale mainly distributes in offshore zone and mature male widely distributes from ice-edge to offshore zone (Fujise *et al*., 1990; 1991; 1992; 1994; 1999; Kasamatsu and Ohsumi, 1981; Kato *et al*., 1990; 1991). Samples of Antarctic minke whales from commercial whaling were biased to female and mature individual, 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 random sampling method (Fujise *et al*., 1997, Ishikawa *et al*., 2005). Therefore, estimated biological parameters were thought to be less biased than estimation from commercial catch. Kato (1987) compared age at sexual maturity of female Antarctic minke whales estimated by age at 50% maturity and age at first ovulation, 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 whaling and showed that age at 50% sexual maturity were constantly 0.5-2.0 years lower than age at first ovulation due to biases. As the difference between 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 for female were thought to be less biased than estimation from commercial samples.

As for male, estimated age at 50% sexual maturity (5.3years) was higher than that from commercial whaling catches (2.5years) collected in Areas IV in 1971/72-1979/80 Japanese commercial whaling (Kato, 1982). Therefore, biological parameters of less biased than estimation from commercial catches would be derived. However, estimated age at 50% sexual maturity was lower than female. Opposite yearly trends were observed between sexual maturity rate and age or body length at 50% sexual maturity for male in I-stock (Figs.2,5,8), which might suggest the possibility that sampling bias caused by segregation might not be dissolved completely. Furthermore, as biological parameters were estimated by research year in this study, sample size for each year was not so large especially in P-stock. Therefore, precision of estimated values might be low in some cases.

Distinct yearly trends were detected especially for male by linear regression analysis. Age and body length at 50% sexual maturity and age and body length at 50% physical maturity significantly increased with year in I-stock and P-stock, respectively. In addition, increasing yearly trends were also detected for age at physical maturity and body length at physical maturity by use of stepwise logistic regression analysis, although for age and body length at sexual maturity were not. They might be showing the possibility that some change has been ongoing about Antarctic minke whale. Carrying capacity for Antarctic minke whales was thought to be increased by decrease of other large Balaenopterids, which competes with Antarctic minke whales about food. Decreasing trend of age at sexual maturity estimated from mean value of transition phase (TP) from 1940’s year class to 1970’s year class was reported (Kato, 1987). But recent analysis shows that decreasing trend of age at sexual maturity has ceased in 1980’s year class and it might be increasing in recent year class (Zenitani *et al*., 2005). Furthermore, decreasing trend was detected in blubber thickness in Antarctic minke whales sampled in Areas IV and V during JARPA survey (Konishi *et al*., 2005), which suggests the possibility that nutritional condition of Antarctic minke whale would be decreasing. Increasing trend of age at sexual and physical maturity 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 the expanding had taken place. However, observed yearly trend was not same for each stock and sex, which suggests that degree of change in nutritional condition of Antarctic minke whale might differ geographically and sexually. Furthermore, increasing trend observed in body length at physical maturity shows the possibility that nutritional condition of Antarctic minke whale might be increasing (Kato, 1987), which contradict to the scenario deduced from yearly trend of age at sexual and physical maturity. Further investigation incorporating segregation study should be necessary for elucidation of the cause of yearly trend.

Although the cause was not so clear, yearly trend observed in these biological parameters might suggest the possibility that some change has been ongoing about nutritional condition, which would be affected by food availability or interrelationship with other whale species, for Antarctic minke whales. Thus, further monitoring of biological parameters should be necessary for sustainable management of this stock.

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Table 1. Reproductive status, maturity rate and sex ratio in Antarctic minke whales sampled by the JARPA surveys, 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(%)
I-stock	1989/90-1990/91	16	139	2	157	89.7	48.9	48	4	5	105	0	1	1	116	164	70.7
	1991/92-1992/93	26	135	0	161	83.9	56.3	37	3	3	78	1	2	1	88	125	70.4
	1993/94-1994/95	47	232	0	279	83.2	68.4	59	2	3	57	0	7	1	70	129	54.3
	1995/96-1996/97	48	211	0	259	81.5	56.7	64	4	7	121	0	1	1	134	198	67.7
	1997/98-1998/99	68	233	0	301	77.4	58.8	121	4	4	77	1	4	0	90	211	42.7
	1999/00-2000/01	52	212	1	265	80.3	56.4	78	4	4	117	0	2	0	127	205	62.0
	2001/02-2002/03	39	162	0	201	80.6	46.7	74	5	3	142	0	5	0	155	229	67.7
	2003/04	41	97	0	138	70.3	41.8	50	1	9	124	2	6	0	142	192	74.0
	Combined	337	1421	3	1761	80.8	54.8	531	27	38	821	4	28	4	922	1453	63.5
P-stock	1990/91	4	33	0	37	89.2	32.5	6	3	13	55	0	0	0	71	77	92.2
	1992/93	2	47	0	49	95.9	40.2	16	0	1	54	1	0	1	57	73	78.1
	1994/95	14	56	0	70	80.0	42.4	23	0	19	53	0	0	0	72	95	75.8
	1996/97	10	67	0	77	87.0	37.9	18	2	14	90	0	0	2	108	126	85.7
	1998/99	16	95	0	111	85.6	76.6	16	0	2	16	0	0	0	18	34	52.9
	2000/01	15	76	0	91	83.5	47.9	14	3	1	79	0	1	1	85	99	85.9
	2002/03	18	96	0	114	84.2	49.6	32	0	3	81	0	0	0	84	116	72.4
	Combined	79	470	0	549	85.6	47.0	125	8	53	428	1	1	4	495	620	79.8

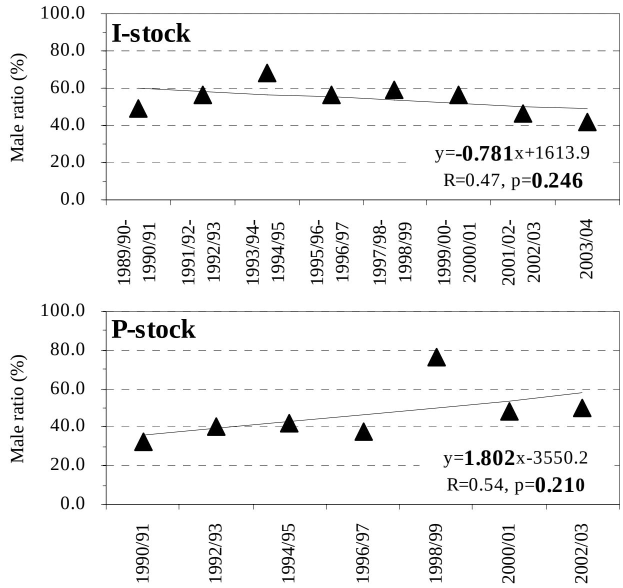

Fig. 1. Male ratio (%) of Antarctic minke whales sampled by JARPA survey.

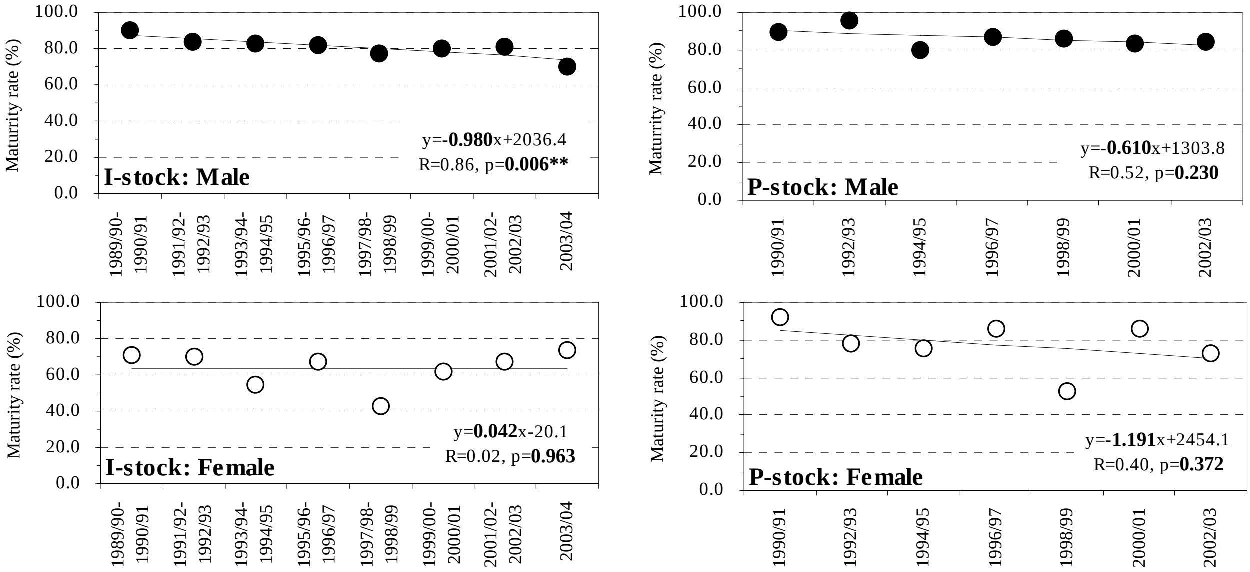

Fig. 2. Sexual maturity rate of Antarctic minke whales sampled by JARPA survey.

Table 2. Mean body length of Antarctic minke whales having CL of the first ovulation.

Area	Year	n	mean	S.D.	min	max
I-stock	1987/88	7	8.28	0.33	8.00	9.01
	1989/90-1990/91	12	8.34	0.24	7.93	8.79
	1991/92-1992/93	6	8.33	0.42	7.78	8.80
	1993/94-1994/95	9	8.61	0.20	8.32	9.00
	1995/96-1996/97	2	8.78	0.15	8.63	8.92
	1997/98-1998/99	8	8.48	0.37	7.96	9.30
	1999/00-2000/01	3	8.30	0.09	8.22	8.42
	2001/02-2002/03	13	8.35	0.27	7.94	8.89
	2003/04	1	8.41	0.00	8.41	8.41
	Combined	61	8.40	0.31	7.78	9.30
P-stock	1988/89	1	8.27	0.00	8.27	8.27
	1990/91	0				
	1992/93	3	8.34	0.05	8.27	8.39
	1994/95	0				
	1996/97	2	8.48	0.17	8.30	8.65
	1998/99	1	8.68	0.00	8.68	8.68
	2000/01	5	8.47	0.22	8.11	8.73
	2002/03	5	8.09	0.39	7.57	8.53
	Combined	17	8.34	0.31	7.57	8.73

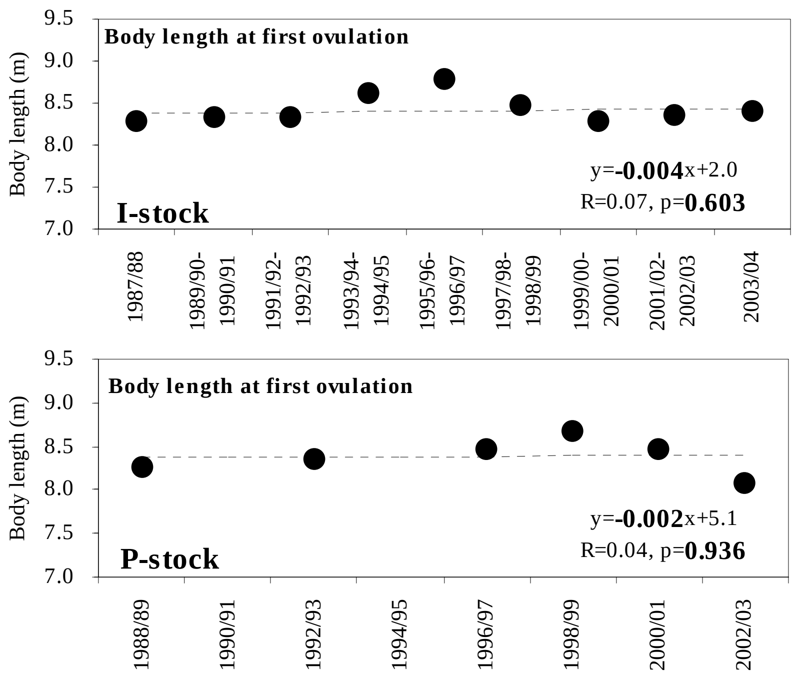

Fig. 3. Mean body length of female Antarctic minke whales having CL of the first ovulation.

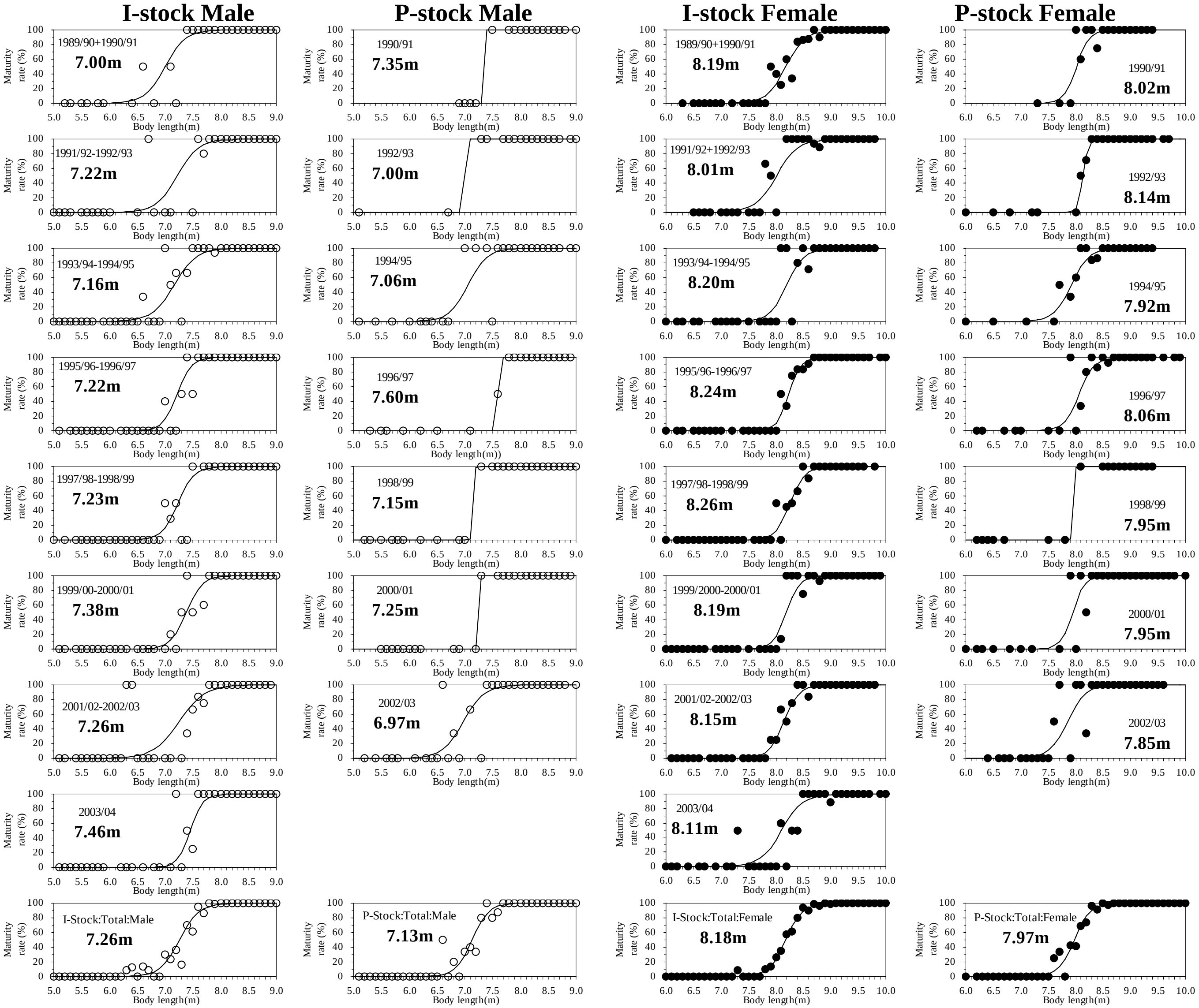

Fig. 4. Body length of Antarctic minke whales at 50% sexual maturity.

Table 3. Body length of Antarctic minke whales at 50% sexual maturity.

Area	Year	Male	Female
I-stock	1989/90-1990/91	7.00	8.19
	1991/92-1992/93	7.22	8.01
	1993/94-1994/95	7.16	8.20
	1995/96-1996/97	7.22	8.24
	1997/98-1998/99	7.23	8.26
	1999/00-2000/01	7.38	8.19
	2001/02-2002/03	7.26	8.15
	2003/04	7.46	8.11
	Combined	7.26	8.18
P-stock	1990/91	7.35	8.02
	1992/93	7.00	8.14
	1994/95	7.06	7.92
	1996/97	7.60	8.06
	1998/99	7.15	7.95
	2000/01	7.25	7.95
	2002/03	6.97	7.85
	Combined	7.13	7.97

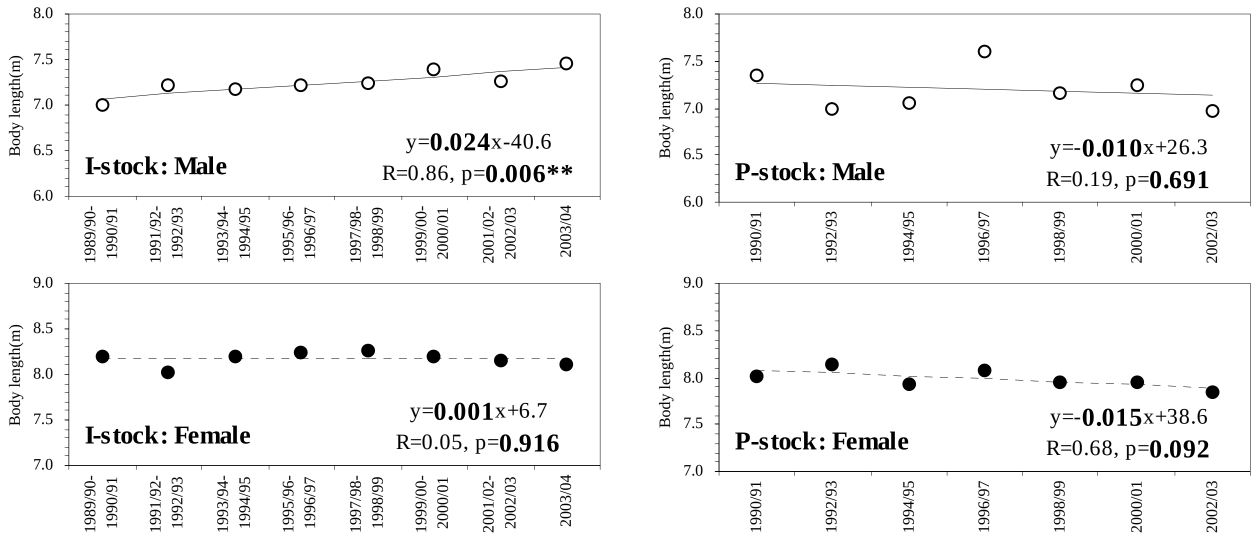

Fig. 5. Body length of Antarctic minke whales at 50% sexual maturity.

Table 4. Mean age of Antarctic minke whales having CL of the first ovulation.

Area	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	1	8.0	0.0	8	8
	Combined	54	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	4	7.8	0.4	7	8
	Combined	16	8.6	1.1	7	10

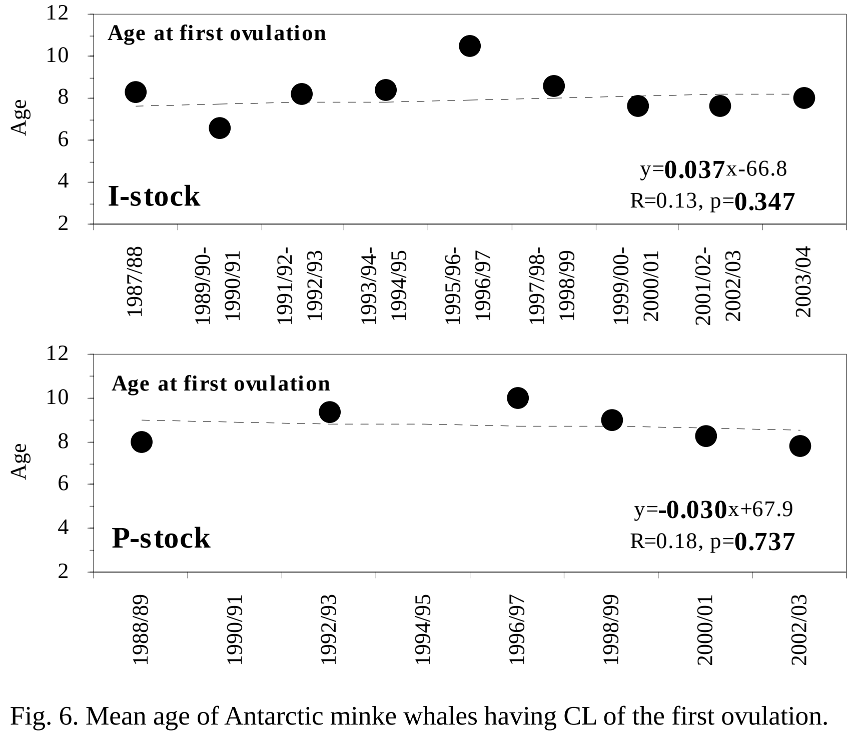

Fig. 6. Mean age of Antarctic minke whales having CL of the first ovulation.

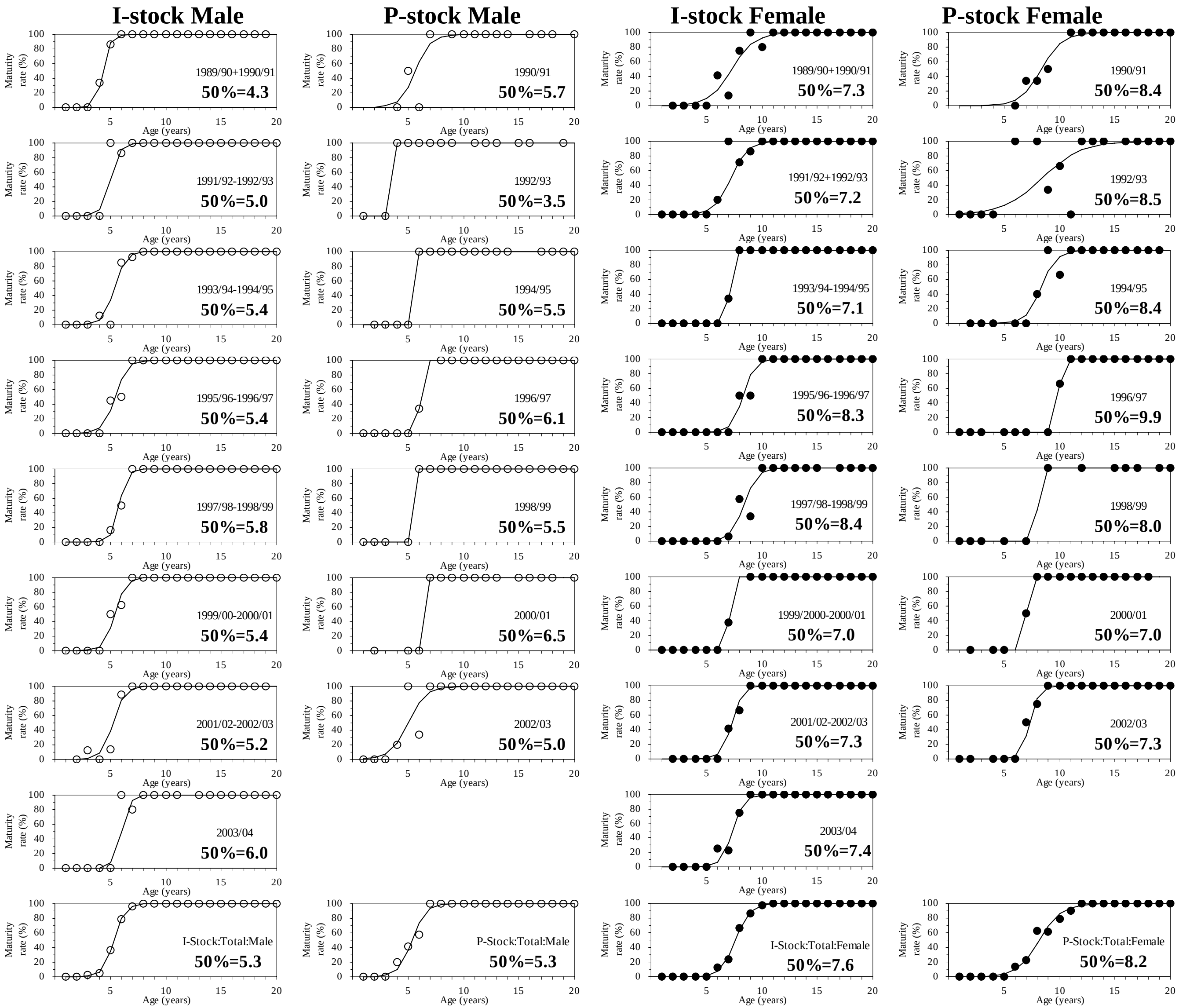

Fig. 7. Age of Antarctic minke whales at 50% sexual maturity.

Table 5. Age of Antarctic minke whales at 50% sexual maturity.

Area	Year	Male	Female
I-stock	1989/90-1990/91	4.3	7.3
	1991/92-1992/93	5.0	7.2
	1993/94-1994/95	5.4	7.1
	1995/96-1996/97	5.4	8.3
	1997/98-1998/99	5.8	8.4
	1999/00-2000/01	5.4	7.0
	2001/02-2002/03	5.2	7.3
	2003/04	6.0	7.4
	Combined	5.3	7.6
P-stock	1990/91	5.7	8.4
	1992/93	3.5	8.5
	1994/95	5.5	8.4
	1996/97	6.1	9.9
	1998/99	5.5	8.0
	2000/01	6.5	7.0
	2002/03	5.0	7.3
	Combined	5.3	8.2

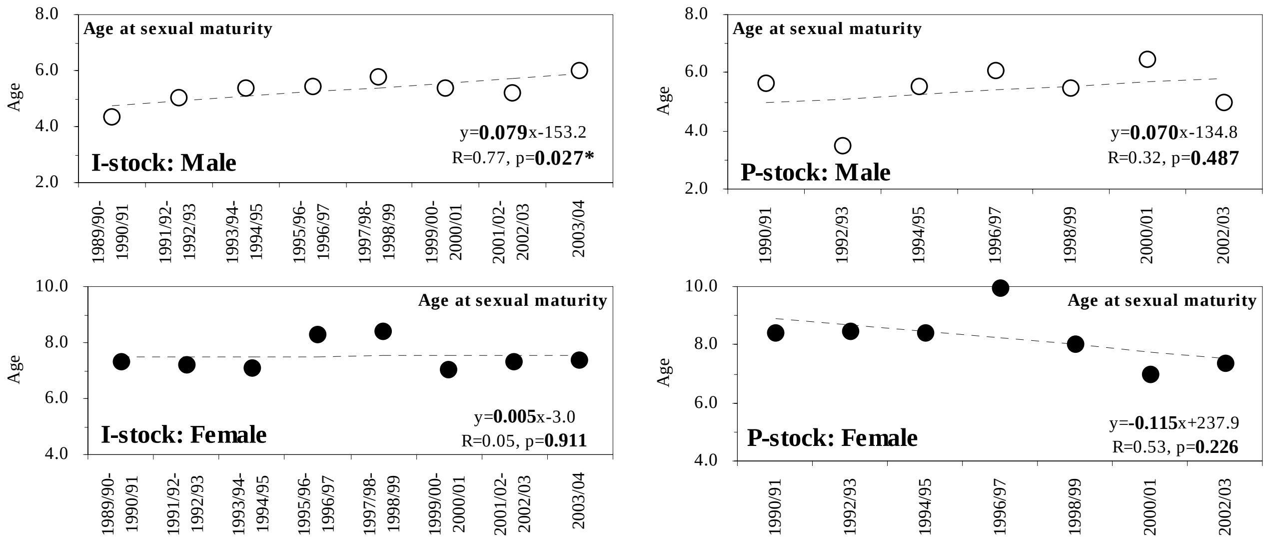

Fig. 8. Age of Antarctic minke whales at 50% sexual maturity.

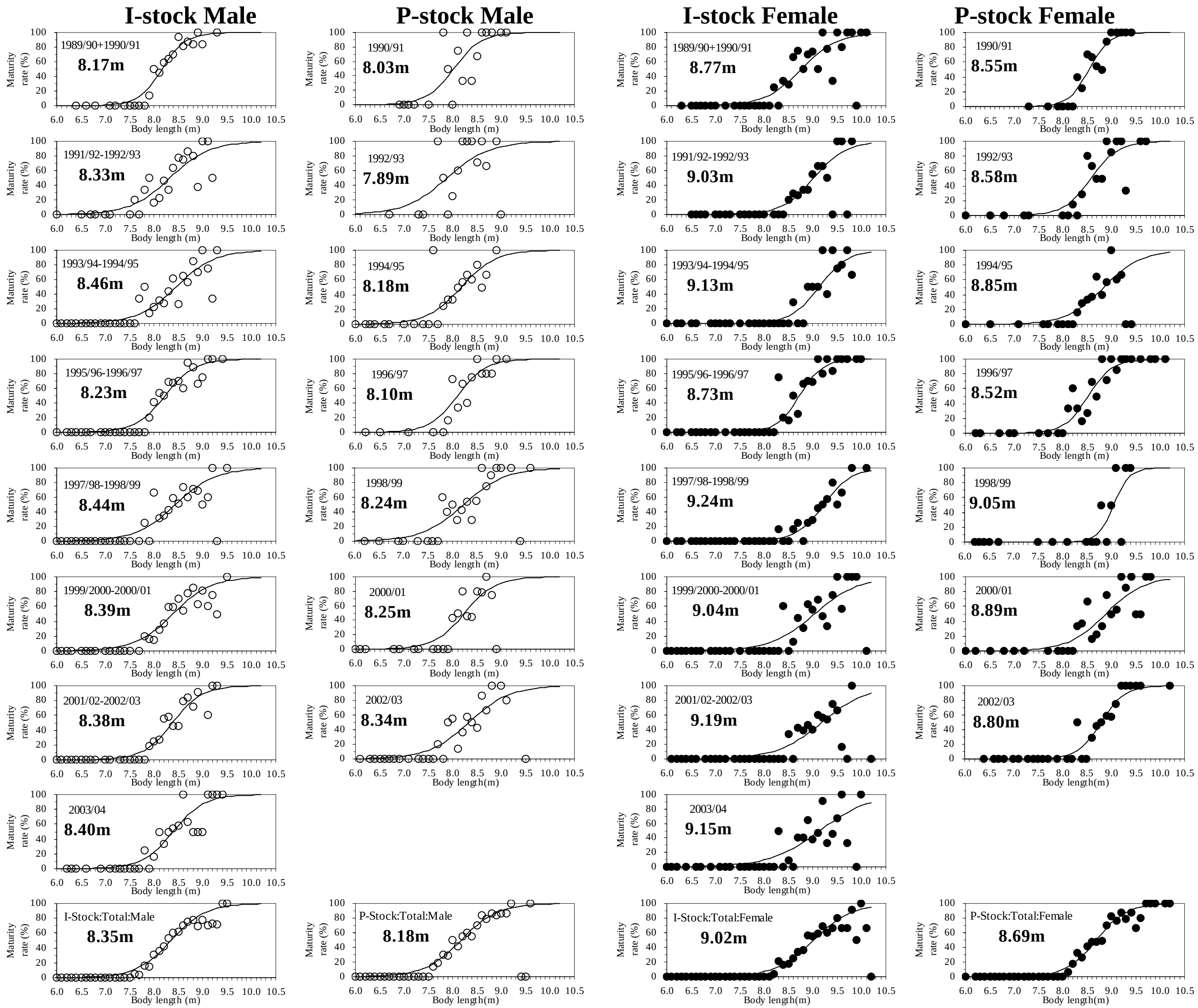

Fig. 9. Body length of Antarctic minke whales at 50% physical maturity.

Table 6. Body length of Antarctic minke whales at 50% physical maturity.

Area	Year	Male	Female
I-stock	1989/90-1990/91	8.17	8.77
	1991/92-1992/93	8.33	9.03
	1993/94-1994/95	8.46	9.13
	1995/96-1996/97	8.23	8.73
	1997/98-1998/99	8.44	9.24
	1999/00-2000/01	8.39	9.04
	2001/02-2002/03	8.38	9.19
	2003/04	8.40	9.15
	Combined	8.35	9.02
P-stock	1990/91	8.03	8.55
	1992/93	7.89	8.58
	1994/95	8.18	8.85
	1996/97	8.10	8.52
	1998/99	8.24	9.05
	2000/01	8.25	8.89
	2002/03	8.34	8.80
	Combined	8.18	8.69

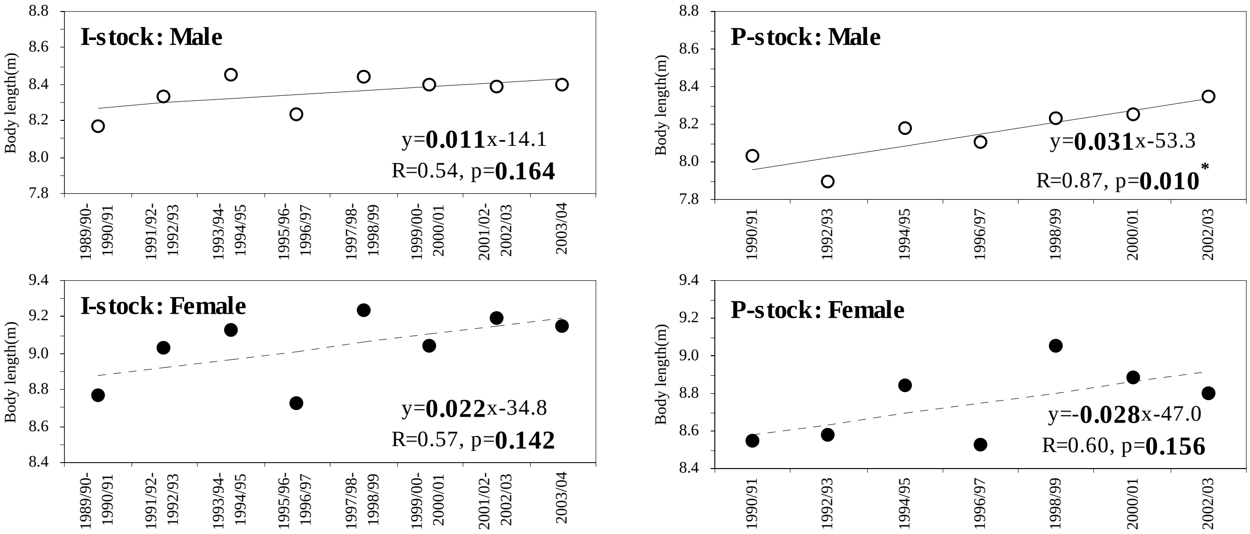

Fig. 10. Body length of Antarctic minke whales at 50% physical maturity.

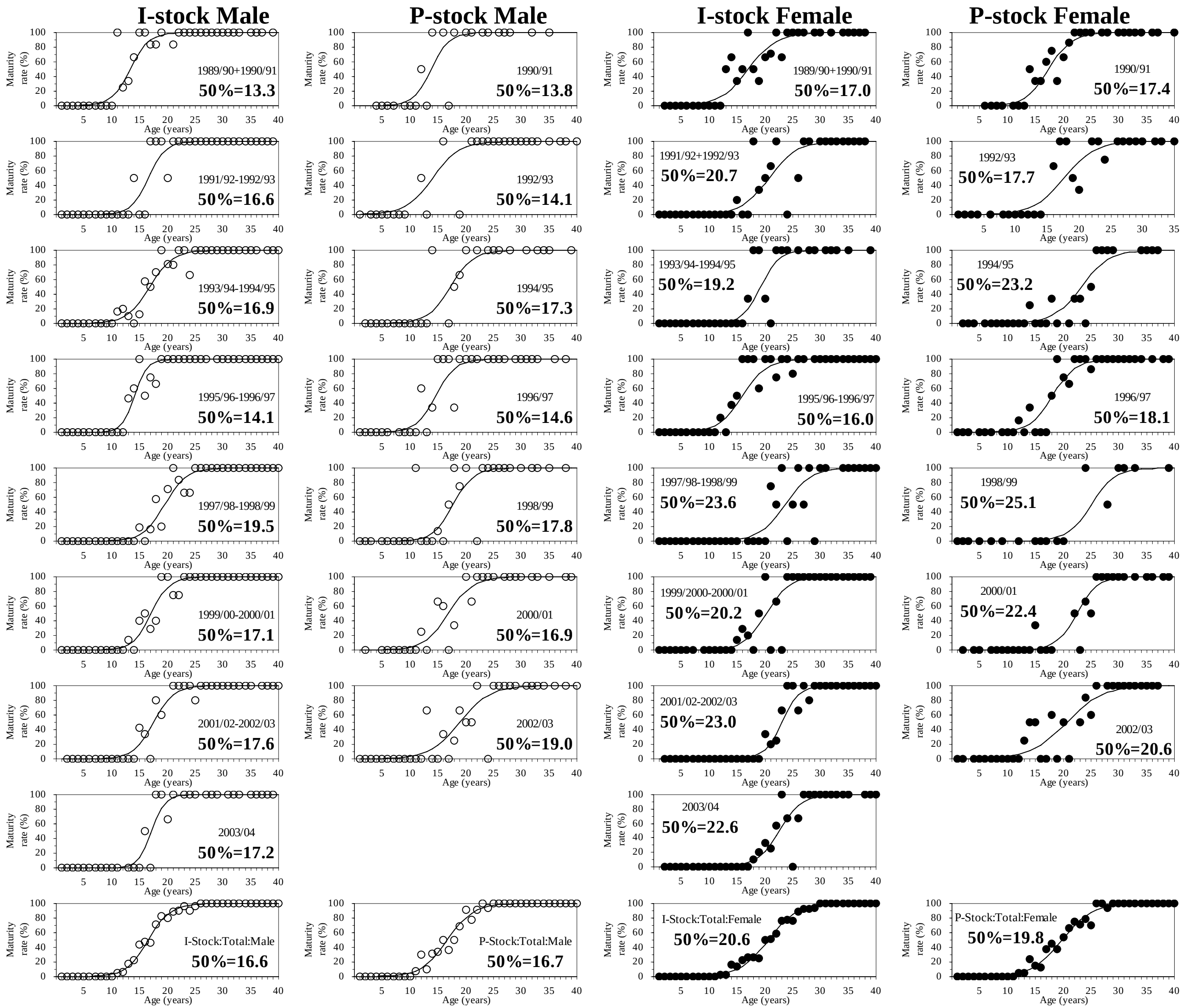

Fig. 11. Age of Antarctic minke whales at 50% physical maturity.

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

Area	Year	Male	Female
I-stock	1989/90-1990/91	13.3	17.0
	1991/92-1992/93	16.6	20.7
	1993/94-1994/95	16.9	19.2
	1995/96-1996/97	14.1	16.0
	1997/98-1998/99	19.5	23.6
	1999/00-2000/01	17.1	20.2
	2001/02-2002/03	17.6	23.0
	2003/04	17.2	22.6
	Combined	16.6	20.6
P-stock	1990/91	13.8	17.4
	1992/93	14.1	17.7
	1994/95	17.3	23.2
	1996/97	14.6	18.1
	1998/99	17.8	25.1
	2000/01	16.9	22.4
	2002/03	19.0	20.6
	Combined	16.7	19.8

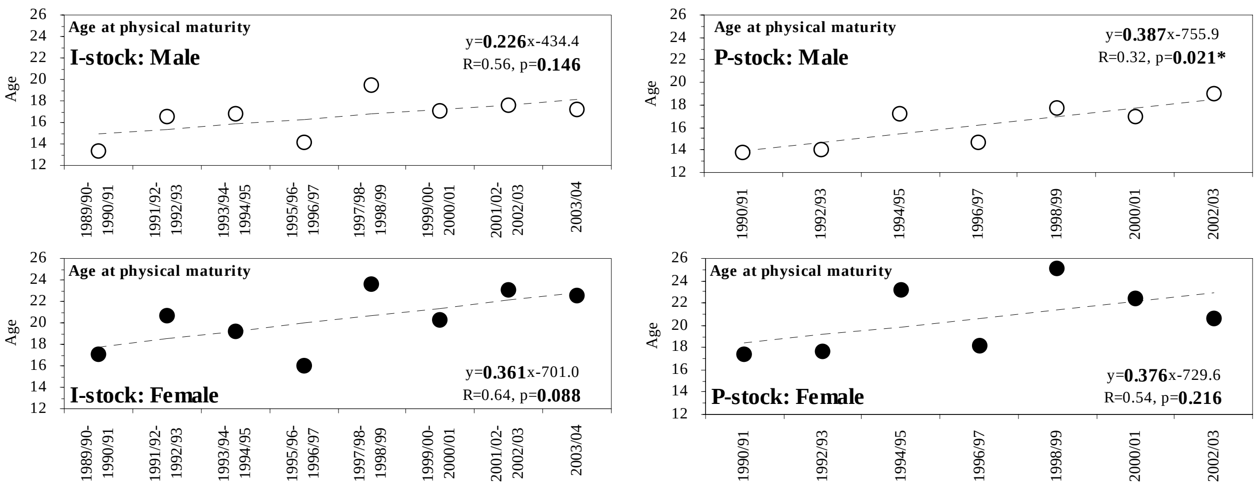

Fig. 12. Age of Antarctic minke whales at 50% physical maturity.

Table 8. Proportion of pregnant in matured female(PPF) in Antarctic minke whales sampled by JARPA surveys.

Area		Mature Female			PPF (%)
		non Preg.	Preg	Total	
I-stock	1989/90-1990/91	9	106	115	92.2
	1991/92-1992/93	7	80	87	92.0
	1993/94-1994/95	5	64	69	92.8
	1995/96-1996/97	11	122	133	91.7
	1997/98-1998/99	9	81	90	90.0
	1999/00-2000/01	8	119	127	93.7
	2001/02-2002/03	8	147	155	94.8
	2003/04	12	130	142	91.5
	Combined	69	849	918	92.5
P-stock	1990/91	16	55	71	77.5
	1992/93	2	54	56	96.4
	1994/95	19	53	72	73.6
	1996/97	16	90	106	84.9
	1998/99	2	16	18	88.9
	2000/01	4	80	84	95.2
	2002/03	3	81	84	96.4
	Combined	62	429	491	87.4

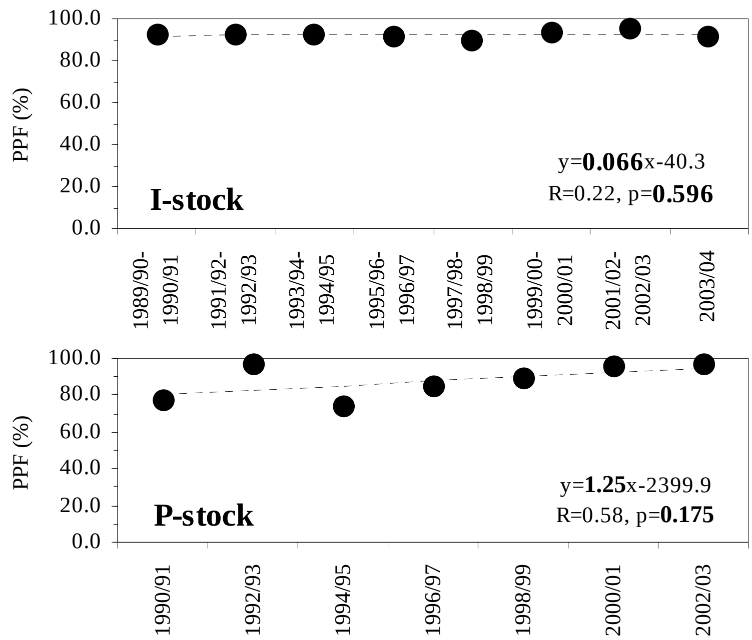

Fig. 13. Proportion of pregnant in matured female(PPF) in Antarctic minke whales sampled by JARPA surveys.

Table 9. Foetal sex ratio in Antarctic minke whales sampled by JARPA surveys.

Area		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	78	59	17	154	56.9	0.105
	Combined	548	510	51	1109	51.8	0.243
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
	Combined	269	307	6	582	46.7	0.113

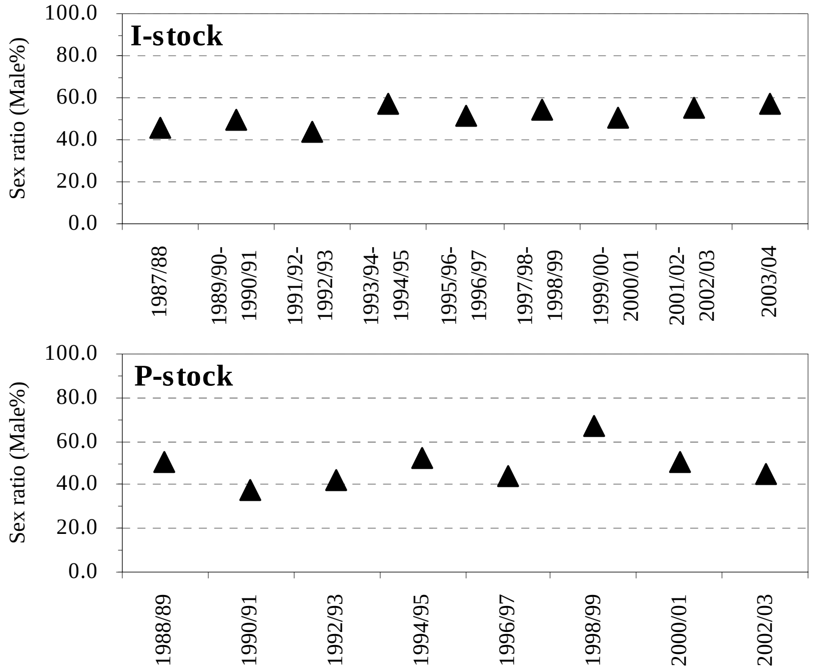

Fig. 14. Foetal sex ratio in Antarctic minke whales sampled by JARPA surveys.

Table 10. Occurrence of multiple births of Antarctic minke whales sampled by JARPA surveys.

Area		Number of fetus		Occurrence of multiple births
		1	2	
I-stock	1987/88	57	0	0.000
	1989/90-1990/91	130	1	0.008
	1991/92-1992/93	134	2	0.015
	1993/94-1994/95	75	1	0.013
	1995/96-1996/97	149	0	0.000
	1997/98-1998/99	97	1	0.010
	1999/00-2000/01	126	1	0.008
	2001/02-2002/03	174	1	0.006
	2003/04	154	0	0.000
	Combined	1096	7	0.006
P-stock	1988/89	92	3	0.032
	1990/91	56	1	0.018
	1992/93	53	1	0.019
	1994/95	53	1	0.019
	1996/97	111	1	0.009
	1998/99	15	0	0.000
	2000/01	94	0	0.000
	2002/03	90	2	0.022
	Combined	564	9	0.016

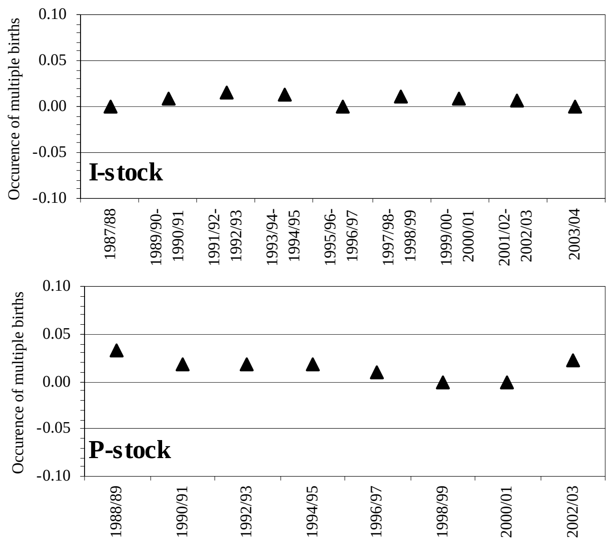

Fig. 15. Occurrence of multiple births of Antarctic minke whales sampled by JARPA surveys.

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

		Male					**Female**				
		I-stock (Area IIIE+IV+VW)			**P-stock (Area VE+VIW)**		**I-stock (Area IIIE+IV+VW)**			**P-stock (Area VE+VIW)**	
		Estimate	Trend	I vs P	Estimate	Trend	Estimate	Trend	I vs P	Estimate	Trend
Sex ratio (male%)		**54.8%** (41.8-68.4%) Large yearly variation	→	>**	**47.0%** (32.5-76.6%) 1998/99high(76.6%)	↑					
Sexual maturity rate (%)		**80.8%** (70.3-89.7%) 1989/90+1990/91high(89.7%) 2003/04low(70.3%)	↓ *	<**	**85.6%** (80.0-95.9%)	→	**63.5%** (42.7-74.0%) 1997/98+1998/99low(42.7%) Large yearly variation	→	<**	**79.8%** (52.9-92.2%) 1998/99low(52.9%) Large yearly variation	→
Body length at sexual maturity (m)	Mean of first ovulation						**8.40m** (8.30-8.78m) Large yearly variation	→	>	**8.34m** (8.09-8.68m) Large yearly variation	→
	50%mature	**7.26m** (7.00-7.46m)	↑ **	>	**7.13m** (6.97-7.60m) 1990/91large(7.35m) 1996/97large(7.60m)	→	**8.18m** (8.01-8.26m)	→	>**	**7.97m** (7.85-8.14m)	↓
Age at sexual maturity	Mean of first ovulation						**7.9** (6.5-10.5) Large yearly variation	→	<	**8.6** (7.8-10.0) Large yearly variation	→
	50%mature	**5.3**(4.3-6.0) 1989/90-1990/91low(4.3) 2003/04high(6.0)	↑ *	=	**5.3**(3.5-6.5) 1992/93low (3.5)	↑	**7.6**(7.0-8.4) 1995/96+1996/97high (8.3) 1997/98+1998/99high (8.4)	→	<*	**8.2**(7.0-9.9) 1996/97high (9.9) 2000/01low (7.0) 2002/03low (7.3)	↓
Body length at physical maturity (m)	50%mature	**8.35m** (8.17-8.46m) Large yearly variation	↑	>**	**8.18m** (7.89-8.34m) Large yearly variation	↑ *	**9.02m**(8.73-9.24m) Large yearly variation	↑	>**	**8.69m**(8.52-9.05m) Large yearly variation	↑
Age at physical maturity	50%mature	**16.6**(13.3-19.5) 1989/90+1990/91low (13.3) 1995/96+1996/97low (14.1)	↑	=	**16.7** (13.8-19.0)	↑ *	**20.6** (16.0-23.6) Large yearly variation	↑	>	**19.8**(17.4-25.1) Large yearly variation	↑
Ratio of pregnant whale in mature female (%)							**92.5%** (90.0-94.8%)	→	>**	**87.4%**(73.6-96.4%) 1990/91low(77.5%) 1994/95low(73.6%)	↑
Foetal sex ratio (Male%)							**51.8%** (44.0-56.9%)		>*	**46.7%** (37.9-66.7%)	
Occurrence of multiple births							**0.006** (0.000-0.015)		<	**0.016** (0.000-0.032)	

*: $p<0.05$, **: $p<0.01$

Table 12. Result of stepwise logistic regression analysis. Coefficients selected by 5% level are shown.

Parameter	Independent Variable					Constant
	Age	Body Length	Sex	Stock	Research Year	
Age at Sexual maturity	**1.546****		**-3.853****	**-0.590***	n.s.	**-3.609****
Body length at sexual maturity		**6.239****	**-5.525****	**1.241****	n.s.	**-41.142****
Age at physical maturity	**0.457****		**-1.588****	n.s.	**-0.159****	**311.957****
Body length at physical maturity		**2.794****	**-1.707****	**0.693****	**-0.055****	**87.989****

*: $p<0.05$, **: $p<0.01$