What has happened to the Antarctic Minke Whale Stocks? - An interprepation of results from JARPA -

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ABSTRACT

Historical changes in the Antarctic minke whale stocks were examined based on various results obtained from JARPA including age at sexual maturity, growth curve, blubber thickness, prey consumption, and ADAPT-VPA analysis of the stocks as well as research on mercury accumulation etc. It has been assumed that feeding conditions of the minke whale improved with the removal of large baleen whales such as the blue whale by commercial whaling, which promoted rapid growth and younger age at sexual maturity; however, around 1970, conditions gradually shifted unfavourably, resulting in slower rates of change in the foregoing parameters. These changes were then arrested by the 1980s to the 1990s. Reflecting these unfavourable changes, it was observed that blubber thickness and stomach content weight were reduced, which indicated less prey consumption. There was also a decrease in the accumulation of mercury resulting from less prey consumption. Also, the distribution area of humpback and fin whales in the feeding season expanded southward in the Antarctic from around 1990, suggesting further deterioration of feeding conditions for the Antarctic minke whales.

KEYWORDS: ANTARCTIC MINKE WHALE; BLUE WHALE; FIN WHALE; HUMPBACK WHALE, COMPETITION; LONG-TERM CHANGE; HEAVY METALS; AGE AT SEXUAL MATURITY; PREGNANCY RATE

INTRODUCTION

Abundance and biological parameters of Antarctic minke whales have greatly changed over the years, and since the late 1970s the IWC/SC has spent considerable time discussing possible reasons and trying to understand this phenomenon (e.g. IWC, 1985).

Due to uncertainties related to the estimation of biological parameters, there was no agreement at that time concerning the data necessary for stock management, including natural mortality rate. This resulted in difficulties in calculating the catch quota and was the primary reason for the moratorium on commercial whaling. The Government of Japan, therefore, launched a whale research program under the Article VIII of the International Convention for the Regulation of Whaling (ICRR), in the Antarctic in 1987/88, with the estimation of biological parameters necessary for the management of Antarctic minke whales as the first objective. The elucidation of the role of cetaceans in the Antarctic ecosystem was the secondary objective. The program was called JARPA, and in 1994 and 1995, the elucidation of the effects of environmental changes on cetaceans and, the Antarctic minke whale stock structure were added to the research objectives.

The JARPA program spanning over eighteen years completed in 2004/05. Research in various fields were conducted together with surveys and analyses related to the program objectives. Phenomena suggesting qualitative and quantitative changes in the Antarctic minke whale stocks have been observed, some of which have been reported at the IWC/SC (e.g. IWC, 1988).

This paper rearranges the results reflecting changes in the Antarctic minke whale stocks, examines what has happened in these stocks, and propose a hypothesis of changes in the Antarctic ecosystem in the 20th Century.

MATERIALS AND METHOD

Examination of the changes in the Antarctic minke whale stocks since whaling began, is based on analyses of sexual maturity age and growth curve (Kato, 1987; Zenitani *et al.*, 2006), blubber thickness (Ohsumi *et al.*, 1997; Konishi and Tamura, 2005), and estimated prey consumption (Tamura and Konishi, 2006) using samples from commercial whaling and JARPA, ADAPT-VPA analysis of the stocks (Butterworth *et al.*, 1999; Mori *et al.*, 2006), and study of mercury accumulation in the whale body (Honda, 1985; Honda *et al.*, 1987; Fujise *et al.*, 1997; Yasunaga *et al.*, 2006) and other reports.

Age at sexual maturity estimated by the transition phase of the growth layer in cetacean earplugs has been used here.

Data on age at sexual maturity for fin and Antarctic minke whales used in this study are from Lockyer (1972) and Kato (1987), respectively. Apparent pregnancy rates for blue and fin whales are from Gambell (1972). Apparent pregnancy rate for humpback whales are calculated from the International Whaling Statistics.

RESULTS AND DISCUSSIONS

Catch History and Biomass of Large Cetaceans in the Antarctic Ocean

Commercial whaling began in the Antarctic in 1904. Initially, whaling mainly targeted the blue whales that had high commercial value and humpback whales that are slow swimmers. Later, the object of commercial whaling gradually shifted to the fin, sei and Antarctic minke whales with reduction of the former target whale stocks (Fig. 1).

Blue whales

In the 1911/12 season, more than 1,000 blue whales were taken. In 1928/29, the yearly catch exceeded 10,000, and in the 1930/31 season, 29,410 whales were taken as the largest catch on record. Annual catches continued in the tens of thousands until the 1939/40 season. It temporarily decreased during World War II, but recorded 9,192 in the 1946/47 hunting season, then declined rapidly (Fig. 1). The take of blue whales was banned in 1964. Total catch amounted to 331,644 whales. In terms of biomass, this means that a maximum of 2,941,000 tons in a year, and an average of 526,408 tons per year were removed from the stocks, calculated with an average body weight of 100 tons (Fig. 2).

*Fin whale*s

Fin whales were also hunted from the initial period. More than 10,000 were taken in the 1929/30 season, and in 1937/38, more than 20,000, exceeding the catch of blue whales, when the fin became the major target of commercial whaling. As with blue whales, catches temporarily decreased during World War II, but recovered when whaling was resumed after the end of the War, and in the 1951/52 season it again exceeded 20,000. Annual catches continued in the tens of thousands until the 1963/64 season (Fig. 1). The largest catch on record was made in the 1960/61 season, when 28,761 whales were taken. Total catches came to 691,890 until the take of fin whales was banned in 1976. In terms of biomass, this means that a maximum of 1,581,855 tons in a year, and an average of 528,527 tons per year were removed from the stocks, calculated with an average body weight of 55 tons (Fig. 2).

Sei whales

There is a record of the take of sei whales in 1905/06, but full-scale hunting began in the 1957/58 season. Since then annual catches increased to a peak of 20,380 in the 1964/65 season and decreased rapidly after that (Fig. 1). Total catch till 1977/78 was 149,594 or, an average of 2,301 whales taken annually. In terms of biomass, this means that a total of 2,917,083 tons, a maximum of 397,410 tons in a year, and an average of 44,878 tons per year were removed from the stocks, calculated with an average body weight of 19.5 tons (Fig. 2).

Antarctic minke whales

The take of Antarctic minke whales has been recorded in 1951/52, but it was in the 1971/72 season that full-scale whaling for them began. About 6,000 whales were taken annually from the 1972/73 to the 1986/87 season, when commercial whaling was suspended. Since then, 330 or less have been taken under the special permit of the Japanese Government up till 1994/95, and 440 or less till 2003/04 (Fig. 1). The largest catch on record was made in the 1976/77 season, when 7,900 were taken. Total catch came to 97,810 whales until the 1986/87 season, when commercial whaling was suspended or, an average of 2,877 whales taken annually (for reference, total catch is 104,165 and yearly average 2,042 whales if those taken under special permit are included). In terms of biomass, this means that a total of 723,794 tons, a maximum of 58,460 tons in a year, and an average of 21,288 tons per year were removed from the stocks, calculated with an average body weight of 7.4 tons (for reference, total biomass is 770,821 tons, and annual average 15,114 if those taken under special permit are included) (Fig. 2).

Humpback whales

Humpback whales were taken as the major target species from the 1904/05 season, when commercial whaling began in the Antarctic Ocean, since they were easy to hunt. Their status as the major target continued until the 1913/14 season. In the 1910/11 season, more than 8,000 whales were taken, but after the 1913/14 season, the target shifted to blue and fin whales, and catch gradually decreased until the 1916/17 season, after which it declined to 1,000 or less. From the 1934/35 to 1940/41, and from the 1949/50 to 1959/60 seasons, 1,000 to 2,000 whales were taken, but the take of humpback whales was banned in 1963 (Fig. 1). The largest catch on record was made in the 1936/37 season, when 4,477 whales were taken. Total catch came to 68,294 or, an annual average of 1,102. In terms of biomass, this means that a total of 2,117,114 tons and an average of 33,605 tons per year were removed from the stock, calculated with an average body weight of 31 tons (Fig. 2).

Until around 1970 while fin whales were being hunted, about 2 million tons of whales had been removed from the stocks. Krill consumed by the whales would have amounted to 60,000 tons per day, assuming that consumption is 3% of body weight of whales. This all became a surplus since whales were removed by the hunts. If we assume that the blue, fin, humpback and other large whales stayed in the Antarctic Ocean for one hundred days, as much as 3 million tons of krill would have been left over as surplus every year.

Age at sexual maturity

Age at sexual maturity of the fin and Antarctic minke whales is discussed here since biological data for these species are comparatively abundant.

Fin whales

Fig. 3 shows the changes in the age at sexual maturity of fin whales in the Antarctic (Lockyer, 1972). Their catch continued from 1904, when whaling began in the Antarctic, to 1976. Age at sexual maturity declined markedly from year classes in 1920 to 1930 and this trend is observed until the 1957 year class for which there are data.

Antarctic minke whales

Fig. 4 shows the changes in age at sexual maturity deduced from the transition phase in earplugs of female Antarctic minke whales (Kato, 1987). Full-scale whaling for the Antarctic minke whales began in the 1971/72 season, but the age at sexual maturity already began to decline before the season which full-scale whaling was started. It seems the decline began from around the 1932 year class. Significant decline was observed from the 1950 to 1977 year classes (Kato, 1987).

After the moratorium on commercial whaling was implemented in 1987, samples were collected by the JARPA, which are shown in Fig. 5 (Zenitani and Kato, 2006). The decline tendency in the age at sexual maturity gradually slowed down around the 1960s, and almost stopped around 1965 to 1980. In case of females, increasing trends was observed after the 1990 year class.

Pregnancy Rate

Fig. 6 shows the changes in the pregnancy rates of the blue, fin, and humpback whales over the years. The rates of the three whale species show the tendency to increase from the 1930s, although there are yearly fluctuations. Pregnancy rates of blue whales increased from about 1930 to 1960, fin whales from around 1930 to 1970, and humpback whales from about 1930 to 1960, although the yearly fluctuation is great.

It is considered that Antarctic minke whales are capable of reproducing every year, and the apparent pregnancy rate estimated from those migrating to the Antarctic is high and constantly in the ninetieth percentile since 1970s. However, they are segregated by sex and reproductive status, and the 78% (Best, 1982) estimated in their breeding ground is considered to be appropriate. No detailed reports are available on the changes over the years.

Growth Curve

The growth curve of Antarctic minke whales using samples from commercial whaling is shown in Fig. 6 (Kato, 1987). Kato (1987) reported that growth rate increased from year classes in 1940 to 1949 and for those in 1970 to 1979, and that they matured at a younger age and became larger in size.

We compared the growth curve after the above period, using JARPA samples, and found that the growth rate has slowed down for year classes in the 1990s, compared with those in the 1980s. The growth curve shows that the 1990s year group tend to be below those for 1980s (Fig. 8).

VPA Analysis of Antarctic Minke Whale Stocks

Catch-at-age analysis using ADAPT-VPA and others have shown that recruitment of Antarctic minke whales increased from 1944 to 1968 (Sakuramoto and Tanaka, 1985; 1986; Butterworth *et al.*, 1999; Mori, Butterworth and Kitakado, 2006). It then decreased until about 1980, after which the declining trend has halted. The causes for these changes have long been the subject of discussion at the IWC (see IWC, 1989; 1990; 1991; 1992a; 1992b; 1995; Sakuramoto and Tanaka, 1986; Butterworth *et al.*, 1999; Butterworth and Punt, 1999).

Accumulation of Pollutants

Honda *et al.* (1987) analyzed heavy metals in the livers of Antarctic minke whales commercially taken in the 1980/81 season. He found that Hg concentration did not increase with age; rather it decreased after age ten. It is well known that Hg concentration in the liver increases with age in marine mammals including cetaceans. However, he reported that such age-related accumulation was not detected in the minke whale samples. Changes in Hg concentration in the prey was not a plausible explanation, since Hg in the environment has not greatly changed, and he considered that it was a result of an increase in prey consumption, hence the increase of Hg intake. As a factor, he pointed out that feeding conditions had improved for the Antarctic minke, with the decrease in the abundance of larger whales (Honda *et al.*, 1987).

Further, in order to understand the apparent decreasing pattern of Hg concentration, Honda (1985) estimated the total mercury loads (burdens) accumulated in the whale, and examined conditions that would best fit the mercury accumulation age curve using an accumulation model. In this simulation, he assumed that Hg concentration in the environment (prey) has not greatly changed and used 4.6 years for the biological half-life of mercury as determined in the striped dolphin. The assumed feeding conditions that fit the curve was that in 1980/81, whales up to ten years old consumed prey amounting to 15% of body weight, while consumption decreased from 15% to 5% for those from ten to thirty; and for those over thirty, it was 5% (Fig. 11). The trend was observed by analyzing samples taken during the 1980/81 to 1981/82 whaling seasons, from which can be deduced that feeding conditions became favourable around 1950, which is thirty years prior to these sampling dates.

Fujise *et al.* (1997) continued to monitor Hg accumulation in Antarctic minke whales using JARPA samples. They clarified the process that reflects an increase in mercury intake for all ages. Examination of the accumulation changes up to recent years, shows a rise in mercury intake due to increased consumption of prey. This was found in all age groups. It was confirmed that Hg concentration also increased in Antarctic minke whales with age as with other cetaceans (Fig. 12).

Furthermore, Hg concentration tends to be lower in the younger age group (one to five year olds), when the details of these accumulation curves for the most recent (2003/04) JARPA samples are examined (Fig. 13).

Similar trend of the Hg accumulations in Antarctic minke whales is observed in recent studies using JARPA samples in 2004/05 season (Yasunaga *et al.*, 2006).

Blubber Thickness

Ohsumi *et al.* (1997) examined blubber thickness using data from commercial whaling which began in 1971/72 and the JARPA data from 1987/88 to 1995/96. They reported that a reduction in blubber thickness was observed after 1978 (Fig. 14).

Konishi and Tamura (2005) analyzed blubber thickness using the JARPA data from 1987/88 to 2003/04, and reported that the decrease in thickness found by Ohsumi *et al.* (1997) was still in evidence (Fig. 15).

Changes in Stomach Content Weight of Antarctic Minke Whales

Tamura and Konishi (2006) examined the stomach contents of Antarctic minke whales using data from the JARPA 1987/88 to 2004/05 seasons. They reported that the decreasing pattern in stomach content weights of mature minke whales was observed since the 1987/88 season in which JARPA was started (Fig. 16).

Competition with Larger Baleen Whales (Humpback and Fin Whales)

In recent years, it has become known that larger baleen whale stocks, including humpback whales, are recovering. Matsuoka *et al.*, (2006) estimated abundance of humpback and fin whales in the Antarctic Areas III (East), IV, V and VI (West), using the whale sighting data from JARPA. They reported that the number of humpback and fin whales migrating to Antarctic Areas IV and V have been increasing (Fig. 17) and that the biomass of these species has become larger than that of Antarctic minke whale in recent years (Fig. 18; Matsuoka *et al.*, 2006). In Area IV, especially, the humpback whale has been seen to be encroaching on the distribution range of Antarctic minke whales. Many minke whales were sighted in the research area south of 60°S in recent years, but it was observed in the 2003/04 surveys that they tended to be pushed back into the pack ice (Ishikawa *et al.*, 2004).

Humpback and fin whales used to be only sighted offshore until the 1990s, but in recent years, their distribution range has become overlapped with that of the Antarctic minke whale. The overlapping of two or more whale species in the feeding grounds of the Antarctic suggests competition among these whale species occurs over krill, which is the key species, especially in a simple marine ecosystem structure as the Antarctic Ocean. The reduced range of Antarctic minke whales in their feeding ground suggests that those niches have become sub-optimal.

What Has Happened to the Antarctic Minke Whale Stocks?
The above considerations can be summarized as follows:

Changes found from 1940 to 1970:

* Increase in recruitment (VPA)

* Acceleration in growth rate (growth curve)

* Decrease in the age at sexual maturity (earplug transition phase)

* Increase in mercury intake

Changes found from 1970 to 1980:

* Decrease in recruitment (VPA)

* Halt in the decreasing trend in the age at sexual maturity (earplug transition phase)

* Mercury intake stabilizes at fixed level

Changes found from 1980 onwards:

* Decreasing growth rate (growth curve)

* Decrease in blubber thickness (from 1980 to present)

* Decrease in stomach contents weight (from latter half of 1980 to present)

* Decrease in mercury intake

Examining the above phenomenon comprehensively, a following history of the ecosystem change in the 20th century is hypothesized in the Antarctic Ocean.

Feeding conditions became favourable for the Antarctic minke whales around 1940, at the latest, with the depletion in large baleen whales such as blue and other whales due to overhunting, and the nutritional status of each minke whale individual improved. Thus, growth rate increased for the minke, and they grew to mature body length earlier, reaching sexual maturity younger. The increased breeding capability resulted in increased abundance. Declining age at sexual maturity and increasing pregnancy rates were also observed in fin, humpback and other large baleen whales, suggesting improved feeding conditions for them as well. Overall improvement in feeding conditions is indicated, arising from lower population density due to the decrease in the number of large baleen whales which consumed huge amounts of krill in the Antarctic Ocean (Kato, 1987).

The amount of available prey (krill) per minke whale as a consumer became restricted about 1970. Around that time, growth rate and the declining the age at sexual maturity slowed down. By 1980 a halt in the latter trend was observed. It seems that the growth rate of whales in year classes of the 1990s was lower than that of those in year classes of the 1980s. The change in feeding conditions was reflected in blubber thickness. Blubber thickness of Antarctic minke whale has shown a constant decline since 1978/88. Also, the number of humpback and fin whales which are higher in their niches than the number of Antarctic minke whales, migrating to the Antarctic increased from 1990. This suggests the recovery of these stocks, while indicating a further deterioration in feeding conditions for Antarctic minke whales.

Other factors that may have contributed to the changes in feeding conditions include environmental changes such as global warming. Melting of fast ice in the seas around the Antarctic Peninsula has been reported, and a decrease in the number of penguins which incubate on ice has been observed (Croxall *et al.*, 2002). However, Areas IV and V of the Antarctic Ocean, which are the concern of this paper, are on the opposite side of the Antarctic Peninsula and no major melting of fast ice has been reported to date. Analysis of satellite data and oceanographic observations carried out in the JARPA programs have not shown any constant change in the marine environment, although annual fluctuations due to El Nino and La Nina have been observed (Watanabe *et al.*, 2006).

It is highly possible that nutritional conditions for the Antarctic minke whales have changed due to competition with other whale species such as the humpback whale, and possibly the change in carrying capacity, in the Antarctic marine ecosystem.

For the appropriate management and sustainable use of Antarctic minke whale stocks, we would need to collect not only data on abundance and biological parameters of major whale species, but also data on their habitat environment and their responses to environmental changes.

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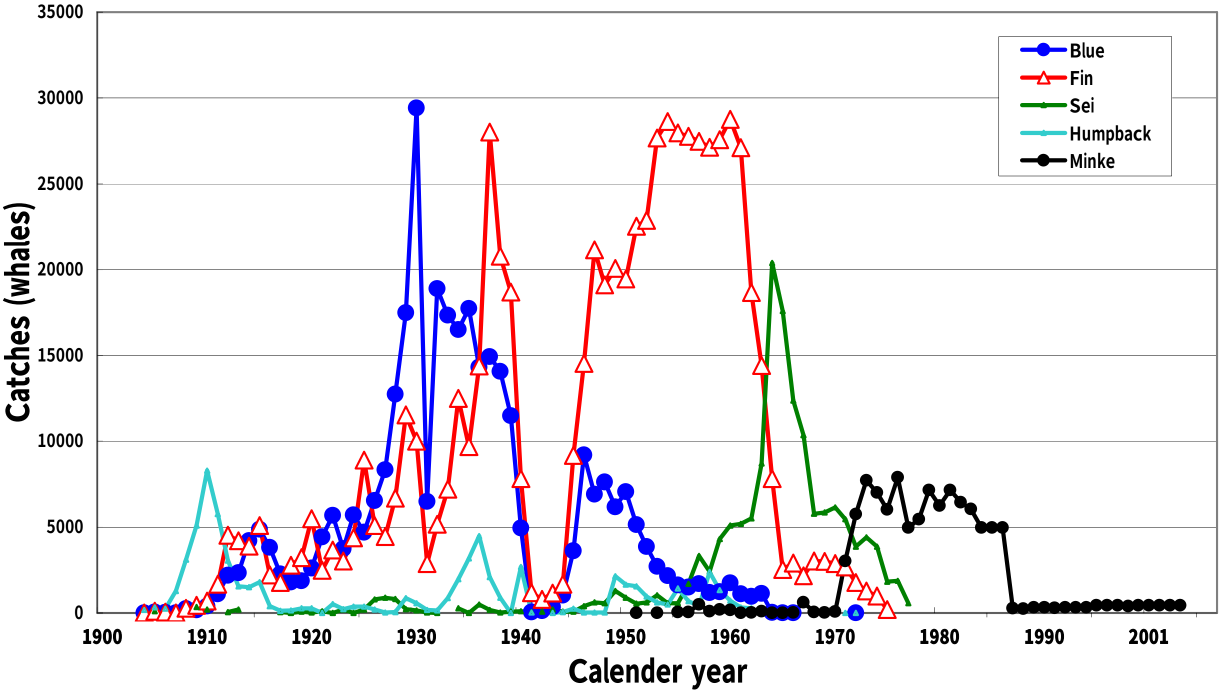

Fig. 1. Catch history of large sized baleen whales in the Antarctic since 1904.

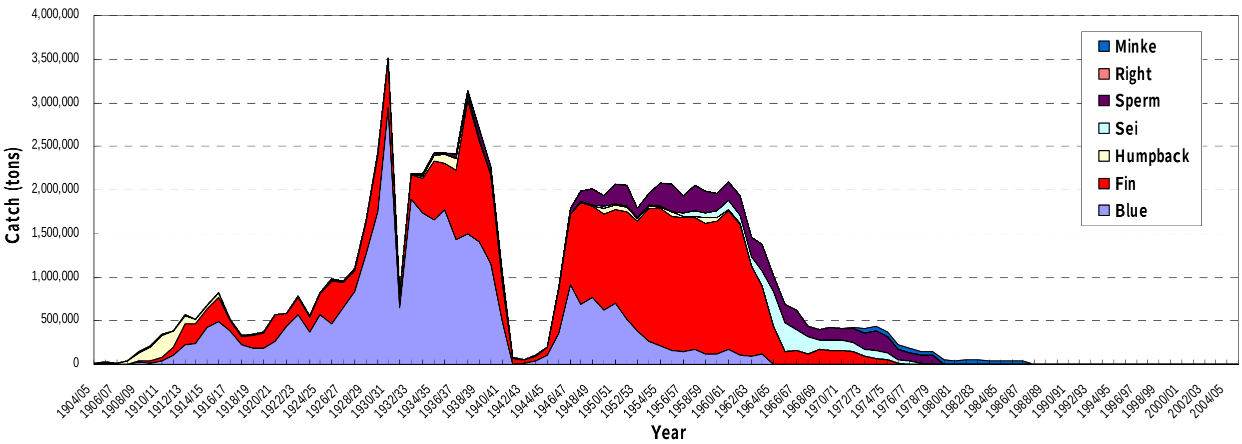

Fig. 2. Total biomass of harvested large sized baleen whales in the Antarctic since 1904.

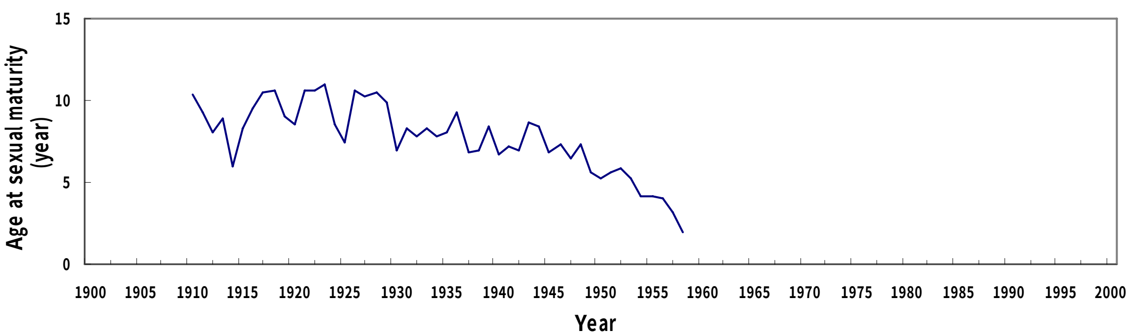

Fig. 3. Trend of age at sexual maturity of Southern fin whales by cohort (Lockyer, 1982)

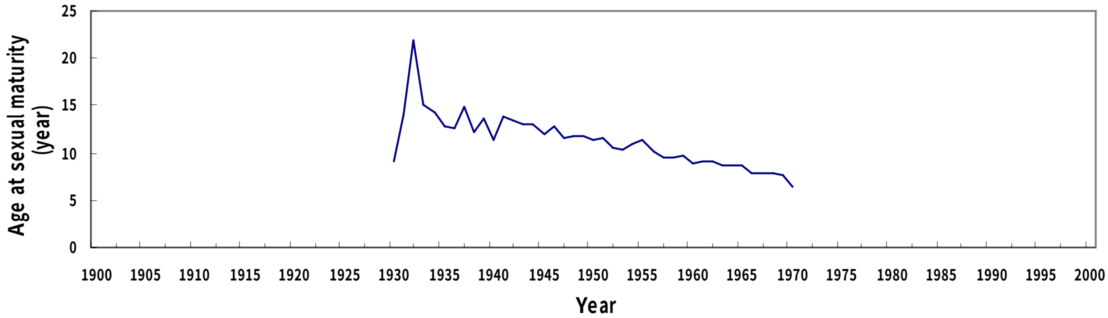

Fig. 4. Trend of age at sexual maturity of Antarctic minke whales by cohort (Kato, 1987)

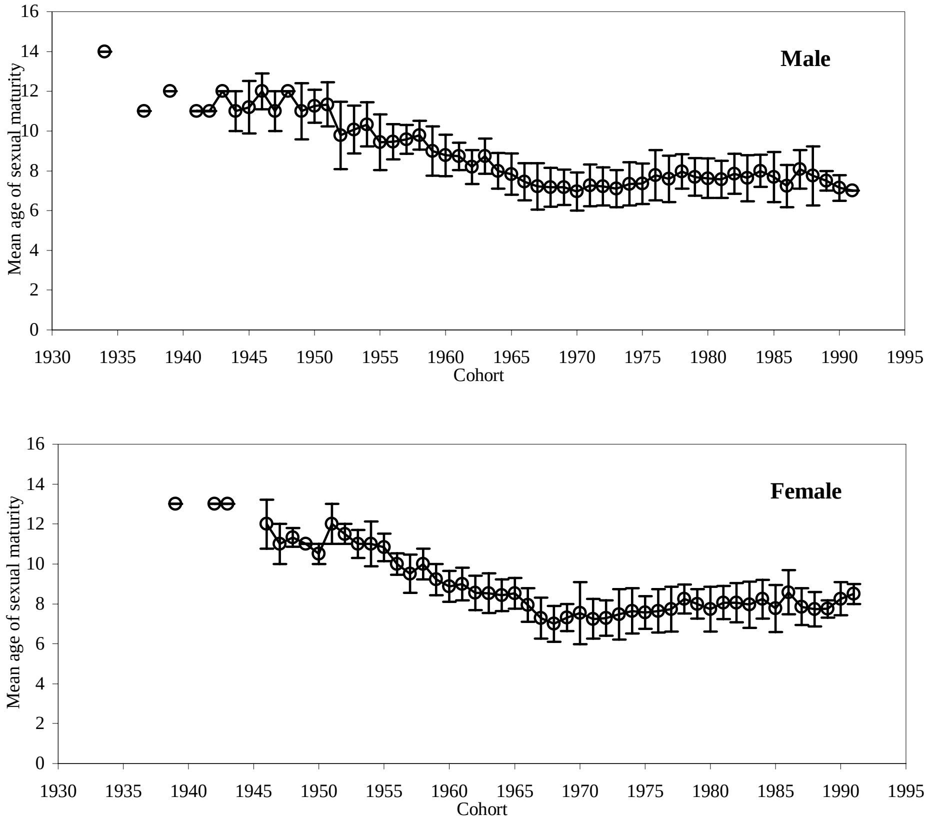

Fig. 5. Trend of age at sexual maturity of Antarctic minke whales (I-stock) by cohort (Zenitani and Kato, 2006)

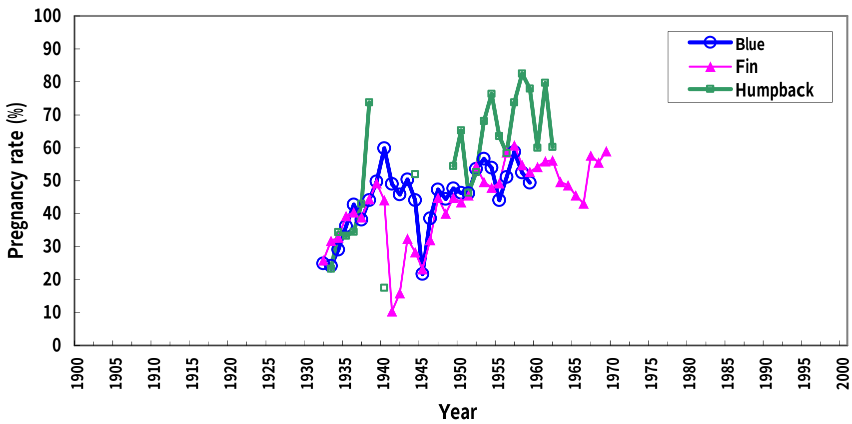

Fig. 6. Yearly changes of apparent pregnancy rate of blue, fin and humpback whales in the Antarctic (data from Lockyer (1982) and BIWS).

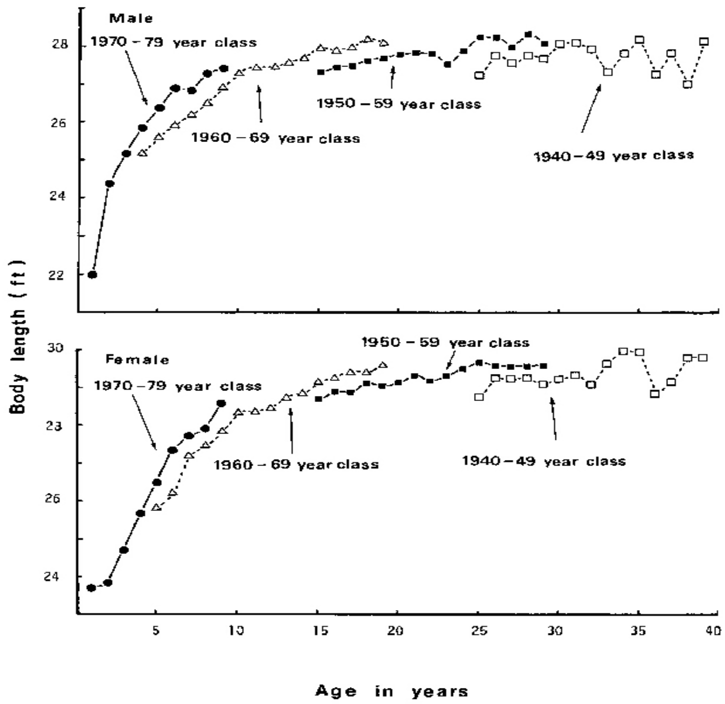

Fig. 7. Yearly changes in growth curve of Antarctic minke whales using samples from commercial whaling (Kato, 1987).

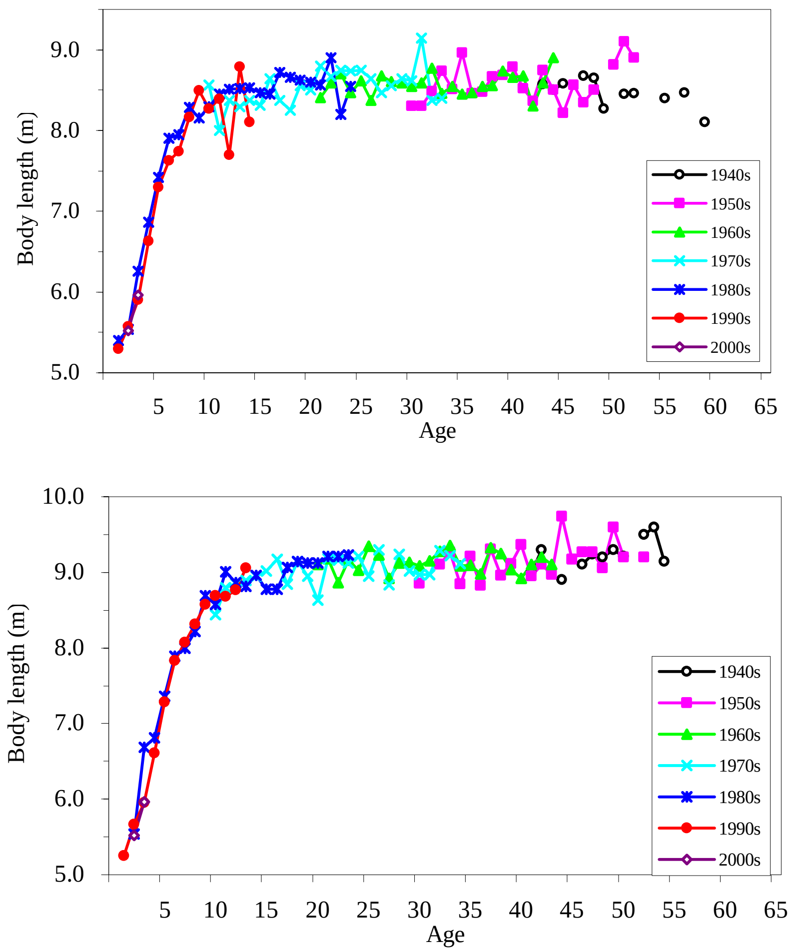

Fig. 8. Comparison of growth curve of body length in each cohort for Antarctic minke whales (I-stock). Upper indicates male, and lower female, respectively (Bando *et al.*, 2006).

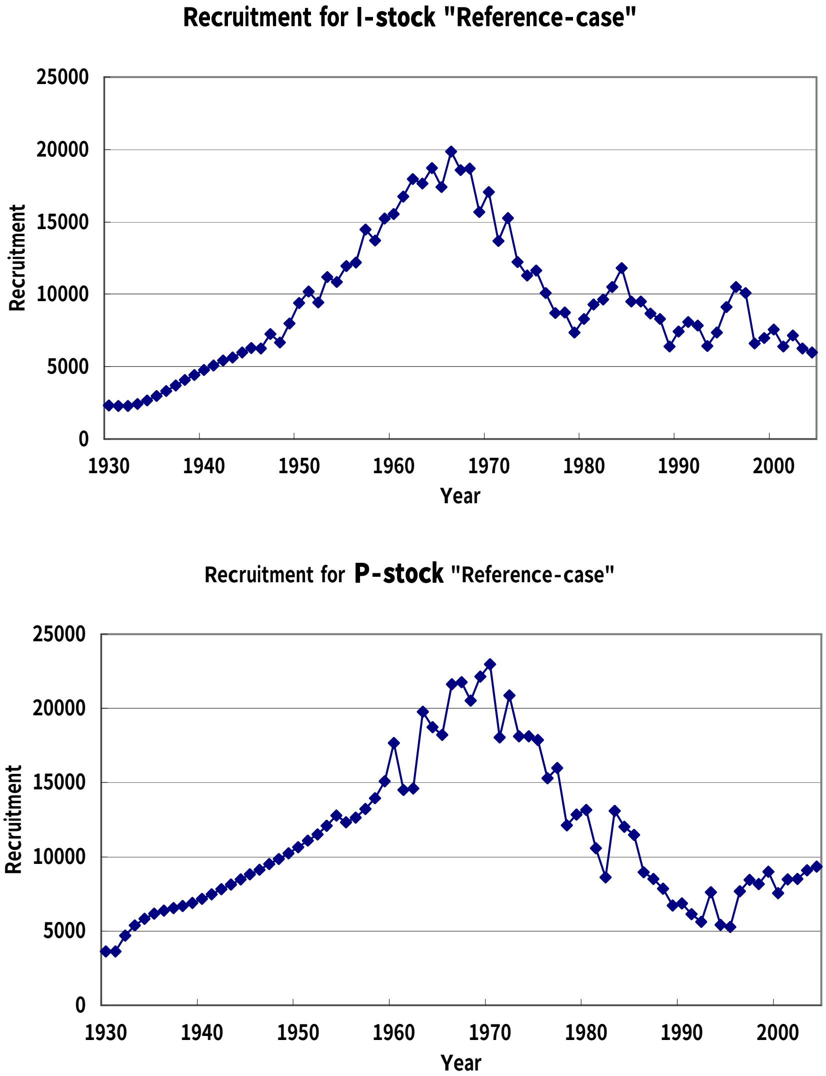

Fig. 9. Yearly changes in recruitment for I –stock and P-stock of Antarctic minke whale derived from VPA-analysis. (Mori *et al.*, 2006)

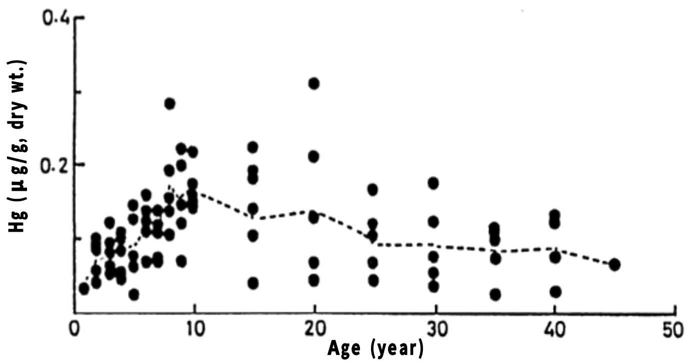

Fig. 10. Relation between age and hepatic mercury concentrations (μg/g) in Antarctic minke whales using samples from commercial whaling in 1980/81 season (Honda *et al.*, 1987)

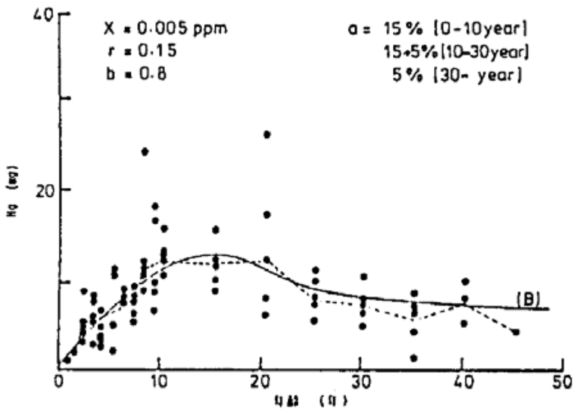

Fig. 11. Relation between age and mercury load (mg) in the body of Antarctic minke whales, and accumulation curve obtained from the simulation of accumulation model (Honda, 1984).

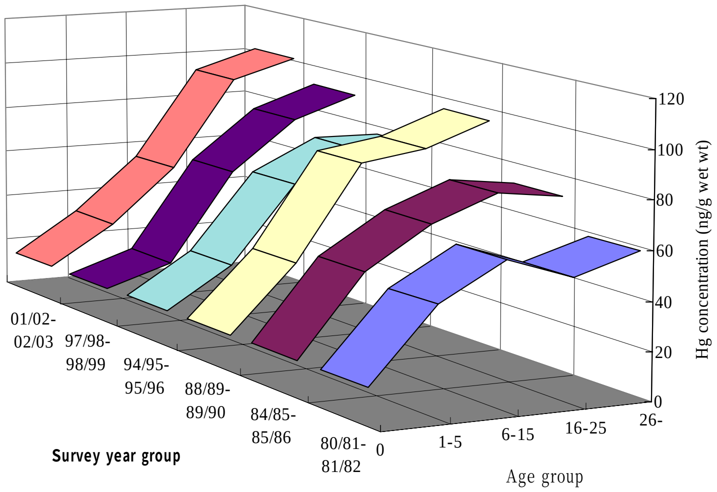

Fig. 12. Comparison of age trends of hepatic Hg concentrations (ng/g) of Antarctic minke whales during five survey year groups (1980/81+1981/82, 1984/85+1985/86, 1988/89+1989/90, 1994/95+1995/96, 1997/98+1998/99, 2001/02+2002/03).

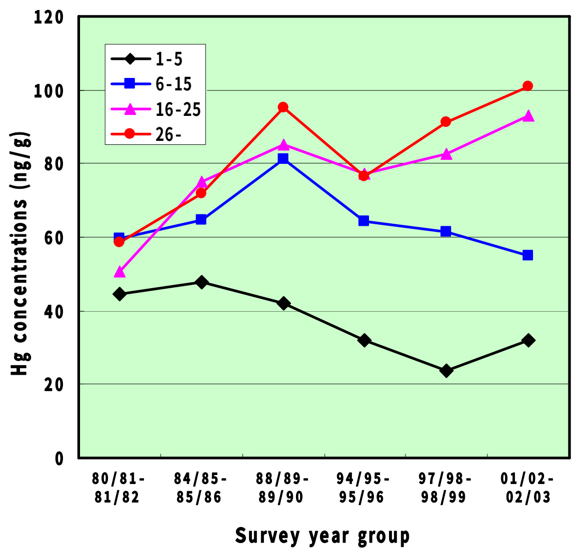

Fig. 13. Yearly changes in hepatic Hg concentrations (ng/g) of minke whales from four age groups (1-5, 6-15, 16-25, 26 or more).

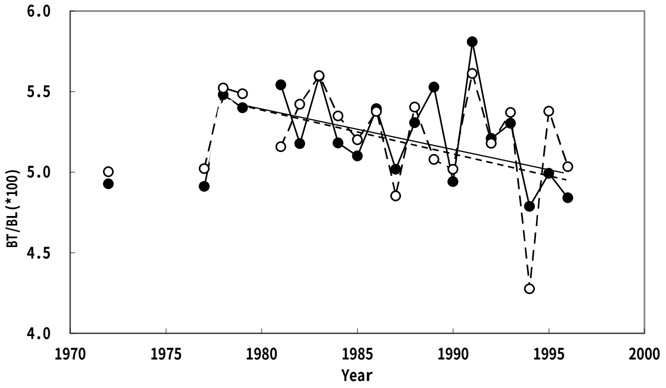

Fig. 14. Yearly changes in average fattyness index of blubber thickness in February (closed circle indicates males, open circle females. (Ohsumi *et al.*, 1997)

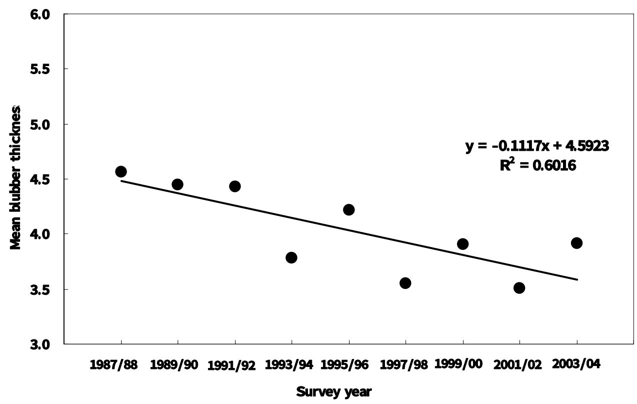

Fig. 15. Yearly changes in average blubber thickness of pregnant females in February (Konishi and Tamura, 2005).

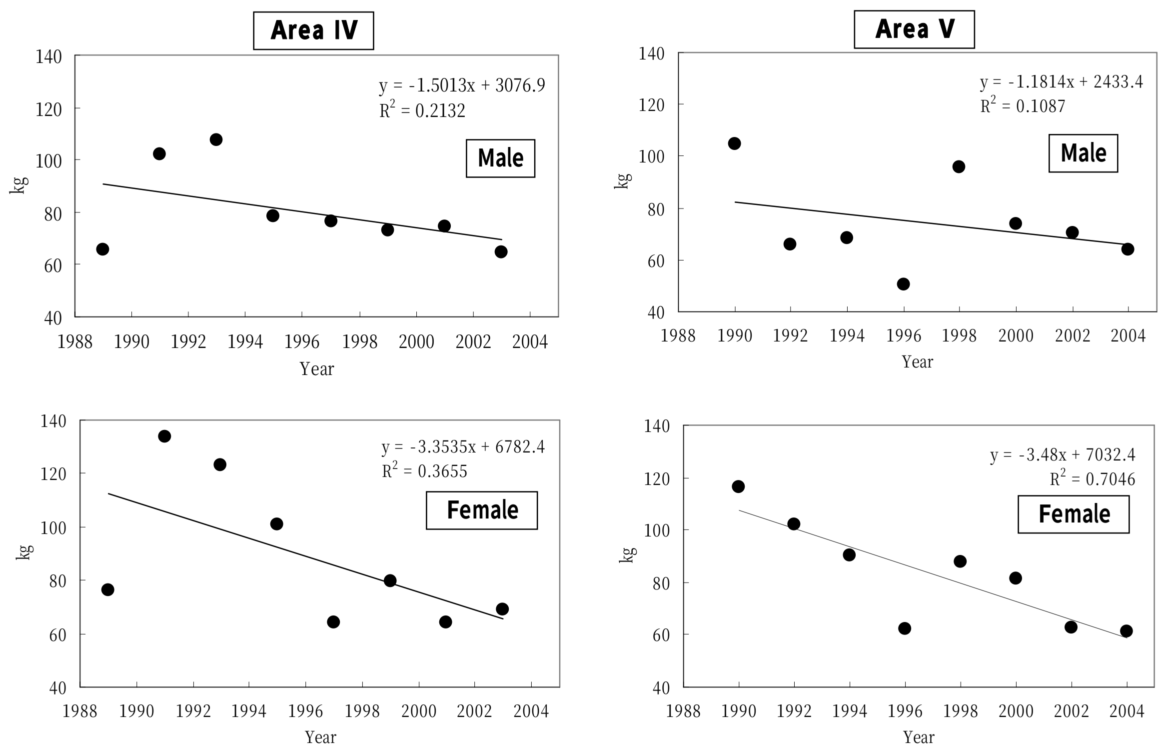

Fig. 16. Yearly changes in stomach contents (kg) of mature Antarctic minke whales in Area IV and V (Tamura and Konishi, 2006). Data used was from individuals collected from the area south of 63 degree S in January and February. The content weight was the first and second stomachs combined.

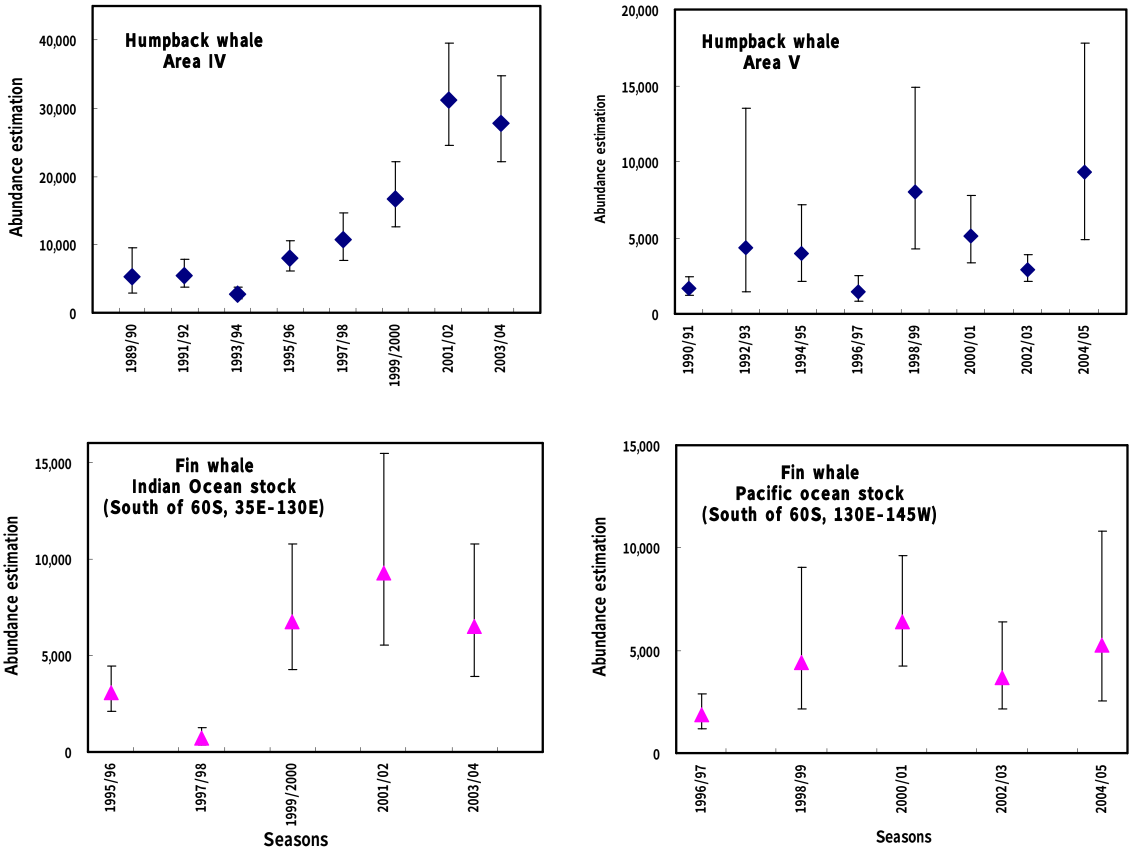

Fig. 17. Yearly changes in abundance estimates for humpback whales in Areas IV and V and fin whales in Areas IIIE+IV (35E-130E) and Areas V+VIW (130E-145W). Upper figure shows humpback whales, lower figure shows fin whale (Matsuoka *et al.*, 2006)

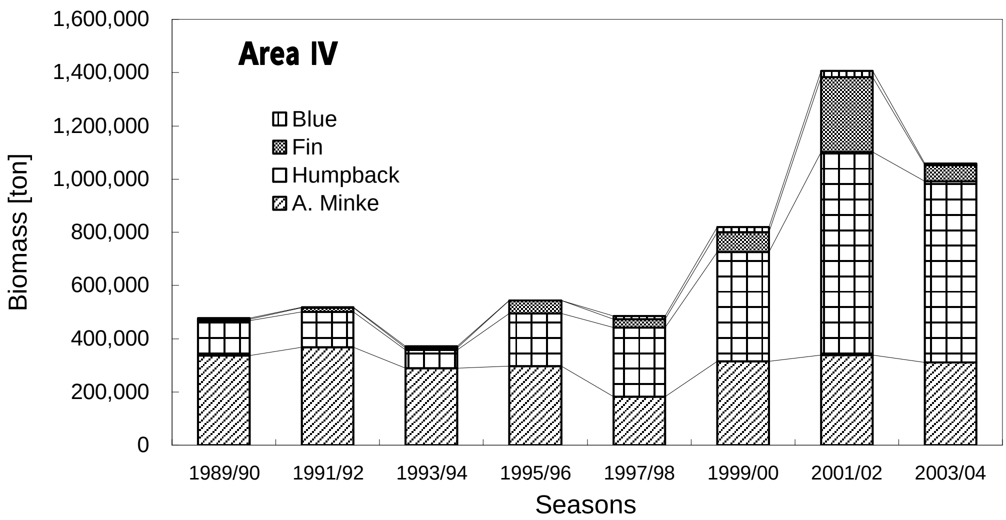

Fig. 18. Biomass of blue, fin, humpback and Antarctic minke whales in Antarctic Area IV (70E-130E) using data from 1989/90 to 2003/04 JARPA (Matsuoka *et al.*, 2006).