Appendix 1

Composition of baleen whale species in the JARPA research area

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ABSTRACT

The Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) was designed as a large-scaled and long-term monitoring program using line transect surveys. These have been carried out in a consistent way during the Austral summer every other year in Areas IV and V since the 1987/88 season . The established sighting procedures have matched those of the IWC/ SOWER (Southern Ocean Whale and Ecosystem Research) cruises to the extent possible. The current research area was set in the Antarctic Areas IIIE (35 ^{o}E-70^{o}E), IV(70^{o}E-130^{o}E), V (130^{o}E-170^{o}W) and VIW (170^{o}W -145^{o}W) in the waters south of 60 ^{o}S. Major cetacean species sighted in the research areas were Antarctic minke *(Balaenoptera bonaerensis*), humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*) and blue (*Balaenoptera musculus intermedia*) whales. Current abundances were estimated using the most recent stock boundaries of these species. A "shift in baleen whale dominance" from Antarctic minke to humpback whales, was observed in Area IV since 1997/98 season. In 1989/90 season, biomass of Antarctic minke was higher (382,000 tons) than humpback whales (128,000 tons), and after 15 years, the biomass of humpback (841,000 tons) increased twice than that of Antarctic minke (335,000 tons). Habitat expansion of humpback and fin whales were also observed in Area IV from the first half (1989/90-1996/97) to the later half of surveys (1997/98 -2002/04). At this morment, abundance of Antarctic minke whales is stable in Area IV, however, increases of abundance and habitat expansion of humpback and fin whales, may cause competition with Antarctic minke whales. Yearly change in some biological fetures also suggest this "Event". Further monitoring survey will be required for the baleen whale management in the Antarctic Ocean.

1. DISTRIBUTION AND ABUNDANCE OF MAJOR BALEEN WHALES IN THE JARPA RESEARCH AREA

The Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) was designed as a large-scaled and long-term monitoring program using line transect surveys. It has been carried out in a consistent way during the Austral summer seasons every other year in IWC Areas IV and V since the 1987/88 season. The sighting procedures have been established to match the IWC/IDCR (International Decade for Cetacean Research) and SOWER (Southern Ocean Whale and Ecosystem Research) cruises to the extent possible. The trackline was designed in order to cover the strata uniformly and all the schools sighted were recorded (Figure 1). Sighting surveys were conducted only conditions when wind speed was 20 knot or less for the northern strata and 25 knot or less in the southern strata. The current research area was set in the Antarctic Areas IIIE (35 ^{o}E-70^{o}E), IV(70^{o}E-130^{o}E), V (130^{o}E-170^{o}W) and VIW (170^{o}W -145^{o}W) in the waters south of 60 ^{o}S. Major cetacean species sighted in the research Areas were Antarctic minke (*Balaenoptera bonaerensis*), humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*) and blue (*Balaenoptera musculus intermedia*) whales (Nishiwaki *et al*,, 2003, Ishikawa *et al*,, 2004).

Abundance of Antarctic minke whale was estimated by Hakamada *et al,* (2005). Abundance of other baleen whales were estimated by Matsuoka *et al,* (2005). Table 1 summarize current abundance estimates of Antarctic minke (Eastern Indian Ocean Stock (I-stock) & Western South Pacific Stock (P-stock)), humpback, (Western Australian Stock (D-stock) & Eastern Australian Stock (E-stock), fin (Indian Ocean Stock (IO–stock) & Western South Pacific Stock (WP-stock)) and blue whales based on the most recent stock boundaries of these species (Pastene *et al*,, 2005a and 2005b) using JARPA sighting survey data.

1.1. Antarctic minke whale

Antarctic minke whales were widely distributed in the northern and southern strata. They also tended to distribute in the southern strata rather than northern strata. High density areas were observed in the southern strata, specially the Ross Sea and Prydz Bay (Figure 2). Abundance of this species between 1989/90 and 2003/04 were estimated by Hakamada *et al,* (2005).

I-stock: 35°E-165°E

For the Indian Ocean stock (I-stock), because abundance estimates in Area IIIE are available only from the JARPA survey in the 1995/96 season, abundance of this stock were estimated from the 1995/96 to the 2003/04 seasons. Table 2 and Figure 3 show abundance estimates of this stock in the research area (south of 60°S, 35°E-165°E). Abundance of this stock was stable between the 1995/96 and 2003/04 seasons.

P-stock: 165°E-145°W

For the Western South Pacific Stock (P-stock), because abundance estimates in Area VIW are available only from the JARPA survey in the 1996/97 season, abundance of this stock were estimated from the 1996/97 to the 2002/03 seasons. Table 2 and Figure 3 show abundance estimates of this stock in the research area (south of 60°S, 165°E-145°W).

1.2. Humpback whales

D-stock: 70°E-130°E

Humpback whales were concentrated between 90°and 120°E in northern and southern strata, and were widely dispersed in the other parts of Area IV (Figure 4). Comparison of the distribution pattern between the first half of JARPA (1989/90-1996/97) and the later half (1997/98-2003/04) shows an increase in the number of sightings in Area IV between 90°and 120°E (Figure 5), and that the concentration area of this species was expanded to the southern and eastern strata year by year. Average latitude of the concentration area was 60°30’S in the first half, and 62°30’S in the later half of the JARPA (Figure 6).

The catch of humpback whales in the Antarctic was banned in 1963. Bannister (1994) reported that a total population size of some 3,000 whales off Shark Bay, Western Australia, based on the results from comparison of the 1991 sighting rate with those from a 1963 commercial aerial spotter. In the late 1990’s, analyses from coastal aerial surveys, 8,000-14,000 whales was estimated (rate of increase was 10.2±4.6%) off Western Australia (Bannister and Hedley, 2001). Abundance estimate using IWC/SOWER data for the part of Area IV (80 ° -130 ° E) in 1998/99 was estimated as 17,300 (CV=0.17) whales (Matsuoka *et al,*., 2003). At the start of JARPA, abundance of this stock was only 5,200 (1989/90 season), but current abundance estimates of this stock was estimated as 31,800 (CV=0.11) in 2003/04 season (Table3 and Figure 7). Recent abundance (average of 2001/02 and 2003/04) was 32,380 (CV=0.08). Increasing rate of this stock in the feeding ground (south of 60 ° S) was estimated as 16.2±6.4%,because recent habitat extension of this stock may cause this high estimate (Matsuoka *et al,*., 2005). As a results of stock assessment, near complete recoveries to pristine levels are suggested in some 10 years for this stock (Johnston and Butterworth, 2005).

E-stock: 130°E-170°W

For the E-stock in Area V, they tended to distributed in the eastern part of Area V except the Ross sea. They were distributed clearly along the Pacific Antarctic ridge where the southern boundary of the Antarctic Circumpolar Current was observed. Table3 shows abundance estimates for this stock. Yearly fluctuations of abundance estimation were observed for this stock.

There are several reports on abundance estimates of humpback whales in the late 1990’s off Eastern Australia and Antarctic Area V. Estimate of East Australian humpback whales using land-based survey was 3,185 (s.e.=208) whales in the 1996 (Brown *et al,*., 1997). The estimate in the Antarctic Area V in 1991/92 season using IWC/IDCR data was 2,104 whales (CV=0.52) (Brown and Butterworth, 1999). Recent JARPA estimates (average of 2000/01 and 2002/03) are 3,728 (CV=0.15) whales which are consistent as a rate of increasing has been assumed to be some 10 %. As a results of stock assessment, near complete recoveries to pristine levels are suggested in some 15-20 years for the currently more depleted E-stock (Johnston and Butterworth, 2005).

1.3. Fin whales

Estimate of abundance of this species in the whole Antarctic waters based on IWC/IDCR and Japanese Scouting Vessels (JSV) was 18,000 (CV=0.47) in the south of 30°S (Butterworth *et al*,., 1994). Recent estimates of this species in the whole area south of 60°S based on the IWC/IDCR and SOWER data were 2,100 (1978/79-1983/84, CV=0.36), 2,100 (1985/86-1990/91, CV=0.45) and 5,500 (1991/92-1997/98: not completed, CV=0.53) in the first, second and third circumpolar series, respectively (Branch and Butterworth, 2001). In half of Antarctic area (south of 60°S, 35°E -145°W), 15,000 (CV=0.20) whales was estimated using JARPA 1989/90- 2003/04 data, and the first estimates in this area shows significant increase (Matsuoka *et al*,, 2005). Figure 8 shows the distribution pattern of this species by the JSV data.

IO-stock: 35°E-130°E

Indian Ocean Stock (IO-stock) of this species were widely distributed in the Areas IIIE and IV, and they tended to be distributed in Area IIIE rather than Area IV. They were widely dispersed and also rarely found within the Prydz Bay (Figure 9). Comparison of the distribution pattern during the first half of JARPA (1989/90-1995/96) and the later half (1996/97-2003/04), shows that fin whales appeared more frequently in the western part of Area IV in recent years (Figure 10).

No abundance estimation of this stock from sightings data was reported. Recent abundance (average of 2001/02 and 2003/04) was estimated as 8,621 (CV=0.19) for south of 60°S (Table 4 and Figure 11). Because they are mainly distributed in the area north of 60°S (Kasamatsu, 1993), large yearly fluctuation in the area south of 60°S in Areas IIIE and IV might be attributable to such distribution. For abundance estimation of the whole IO-stock, it is possible to extrapolate current abundance to the north of 60°S using Japanese scouting vessel (JSV) data. The abundance in January and February with consideration of seasonal distribution changes of this species were estimated to be 31,000 whales (CV=0.26) for this stock (south of 40°S, 35°E-130°E), from the results of the JARPA-2003/04 data.

WP-stock : 130°E-145°W

For the WP-stock of this species in the area south of 60°S, recent abundance (average of 2000/01 and 2002/03) was estimated 4,691 (CV=0.17) (Table 4 and Figure 11).

For the whole Western Pacific Stock abundance estimation, it is possible to extrapolate current abundance to the north of 60°S using Japanese scouting vessel (JSV) data (Miyashita *et al*,, 1995), because this species also distributed in areas more north of 60°S. The abundance in January and February with consideration of seasonal distribution changes of this species were estimated to be 16,000 whales (CV=0.29) for this stock (south of 40°S, 130°E-145°W), from the results of the JARPA-2002/03 data.

1.4. Blue whales (35°E-145°W)

There is no stock information of blue whales in the JARPA research area. Initially, there were as many as 200,000 blue whales in the whole Antarctic as calculated by a logistic model, but their number was greatly reduced by over-hunting, and their take was banned in 1964. After forty years, however, they still small number less than 2,000 (Branch *et al*,, 2004).

In the JARPA research area, blue whales were rarely encountered by the surveys though they were widely distributed in the research area. They were usually found in Area IIIE and Area VE (Figure 13). In Area IV, the number of sightings of this species increased in the later half JARPA (Figure 14). Abundance of this species (south of 60°S, 35°E-145°W) was 900 (CI: 500-1,600) in 1999/2000 + 2000/01 seasons and 500 whales (CI: 300-1,000) in 2001/02 + 2002/03 seasons (Table 5). They still number less than 1,000 (biomass: less than 8,000 tons) in the JARPA research area. Also, the number of survey years is still too short to detect any precise yearly trend. Further surveys are necessary for improving the precision of estimates of the annual rate of increase in the feeding ground.

A "SHIFT IN BALEEN WHALE DOMINANCE" FROM ANTARCTIC MINKE TO HUMPBACK WHALES IN AREA IV

Biomass of Antarctic minke, humpback, fin and blue whales in Area IV are shown in Figure 15. A "Shift in baleen whale dominance" from Antarctic minke to humpback whales was observed in this Area since 1997/98 season. In 1989/90 season, biomass of Antarctic minke was higher (382,000 tons) than humpback whales (128,000 ton), and after 15 years in 2003/04 season, biomass of humpback (841,000 tons) was twice than Antarctic minke (335,000 tons). Increase of fin whale was observed in Areas IIIE and IV. In 1989/90 season, biomass of fin was 5,000 tons, and after 15 years in 2003/04 season, biomass of fin was 67,000 tons as over 10 times (20 % of Antarctic minke biomass). Abundance of Antarctic minke whales is stable in Areas IV and V, however, the decrease in blubber thickness in Area IV was observed (Konishi and Tamura, 2005), and the decreasing pattern in stomach content weights of matured minke whales was also observed in Area IV since 1987/88 season using JARPA biological data (Tamura and Konishi, 2005). It is also reasonable to support a view that increase and habitat expansion of humpback and fin whales in Area IV, may cause competition with Antarctic minke. Further monitoring survey was required in order to understanding Antarctic ecosystem and for the baleen whale management in the Antarctic Ocean.

3. MONITORING WHALE POPULATION

In the Antarctic Ocean, catch of southern right, humpback, blue, fin and sei whales was prohibited in 1932, 1963, 1964, 1976 and 1978, respectively. Seventy years passed already since southern right whale has been protected, and more than 40 years have passed since humpback whale and blue whale have been protected. In coastal waters of south America, South Africa and east and west coast of Australia, significant recovery of southern right whale and humpback whales are reported recently in these breeding areas. On the other hand, the information on the present status of pelagic species, such as blue, fin and sei whales were limited. The IWC/IDCR-SOWER cruises, however not sufficient enough for the monitoring of ecosystem, as survey covers the same area once in every over 6 years. In this situation, JARPA have been monitoring for baleen whale species population by the large-scaled and long-term line transect survey for over 15 years in Areas IV and V. The number of survey years is still too short to detect precise yearly trend for whales population. Further monitoring survey was required for the baleen whale management in the Antarctic Ocean.

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Table 1. Recent abundance estimates (P) of Antarctic minke whale, humpback, fin and blue whales for each stock using JARPA 2002/03 and 2003/04 data (south of 60°S). For humpback and fin whales, average of latest two seaosns abundance were used. The g (0) is assumed to be 1. Avarage weights used for the biomass, were 7, 26.5, 48 and, 83 tons for Antarctic minke, humpback, fin and blue whales, respectively.

Species	longitude	P	CV	Biomass(ton)	Ref.
Antarctic minke (I-stock)	35E-165E	129,000	(0.25)	903,000	1
Antarctic minke (P-stock)	165E-145W	95,000	(0.17)	665,000	1
Humpback (D-stock)	70E-130E	32,400	(0.08)	858,600	2
Humpback (E-stock)	130E-170W	3,700	(0.15)	98,050	2
Fin (IO-stock)	35E-130E	8,600	(0.19)	412,800	2
Fin (WP-stock)	130E-145W	4,700	(0.17)	225,600	2
Blue	35E-145W	500	(0.29)	41,500	2

Ref. 1: Hakamada et al., 2005.
2: Matsuoka et al., 2005.

Table 2. Abundance estimates (P) of Antarctic minke whale (I-stock and P-stock) between 1995/96 and 2003/04 seasons (south of 60°S). The g (0) is assumed to be 1 (Hakamada *et al*,, 2005). Avarage weight of this species was 7 tons for the biomass.

I-stock

Season	P	CV	Biomass
1995/96	82,975	0.165	580,825
1997/98	124,301	0.187	870,107
1999/2000	128,110	0.227	896,770
2001/02	228,349	0.142	1,598,444
2003/04	128,695	0.248	900,864

P-stock

Season	P	CV	Biomass
1996/97	156,323	0.267	1,094,261
1998/99	82,489	0.219	577,423
2000/01	179,417	0.197	1,255,919
2002/03	95,116	0.168	665,812
2004/05	-	-	-

Table 3. Abundance estimates (P) of humpback whale for the D-stock and E-stock (both south of 60°S), between 1989/90 and 2003/04 (Matsuoka *et al*,, 2005). Avarage weight of this species was 26.5 tons for the biomass.

D-stock

Season	P	CV	Biomass
1989/90	5,230	0.301	138,605
1991/92	5,350	0.190	141,775
1993/94	2,740	0.154	72,615
1995/96	8,850	0.142	234,529
1997/98	10,874	0.166	288,168
1999/2000	16,211	0.146	429,588
2001/02	33,010	0.112	874,758
2003/04	31,750	0.114	841,382

E-stock

Season	P	CV	Biomass
1990/91	1,354	0.196	35,891
1992/93	3,837	0.633	101,675
1994/95	3,567	0.306	94,538
1996/97	1,543	0.281	40,897
1998/99	8,301	0.308	219,973
2000/01	4,720	0.217	125,068
2002/03	2,735	0.159	72,481
2004/05	-	-	-

Table 4. Abundance estimates (P) of fin whale (south of 60°S) for the Indian Ocean stock (IO-stock)and Western South Pacific stock (WP-stock), between 1989/90 and 2003/04 (Matsuoka *et al,*, 2005). Avarage weight of this species was 48 tons for the biomass.

IO-stock

Season	P	CV	Biomass
1995/96	4,305	0.197	206,629
1997/98	715	0.307	34,326
1999/2000	4,478	0.221	214,929
2001/02	10,668	0.255	512,052
2003/04	6,573	0.256	315,512

WP-stock

Season	P	CV	Biomass
1996/97	1,714	0.252	82,258
1998/99	4,850	0.354	232,779
2000/01	5,876	0.211	282,051
2002/03	3,505	0.287	168,250
2004/05	-	-	-

Table 5. Abundance estimates (P) of blue whale (south of 60°S) between 1989/90 and 2003/04. Average weight of this species was 83 tons for the biomass.

Blue	Area IIIE		Area IV		Area V		Area VIW		Total		
Seasons	P	CV	P	CV	P	CV	P	CV	P	CV	Biomass(ton)
1989/90 + 1990/91	-	-	65	0.48	205	1.01	-	-	270	0.78	22,410
1991/92+ 1992/93	-	-	17	1.08	231	0.67	-	-	248	0.63	20,584
1993/94+ 1994/95	-	-	64	0.62	275	0.64	-	-	339	0.53	28,137
1995/96+ 1996/97	293	0.43	6	0.94	7	0.75	58	0.45	364	0.35	30,212
1997/98+ 1998/99	248	0.49	153	0.61	221	2.07	0	-	622	0.78	51,626
1999/00+ 2000/01	352	0.59	218	0.40	294	0.49	0	-	864	0.31	71,712
2001/02+ 2002/03	80	0.62	295	0.44	142	0.53	28	0.94	545	0.29	45,235
2003/04+ 2004/05	540	0.34	92	0.72	-	-	-	-	-	-	-

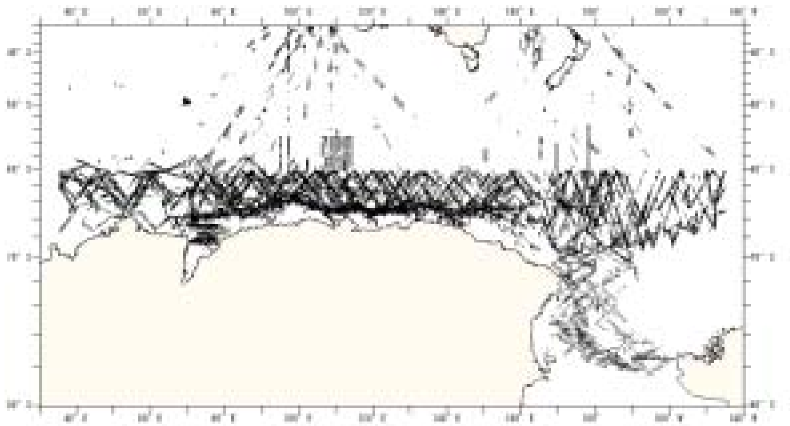

Fig. 1. Distribution of the searching efforts in JARPA1987/88-2003/04 seasons. Including middle latitude transit sighting survey.

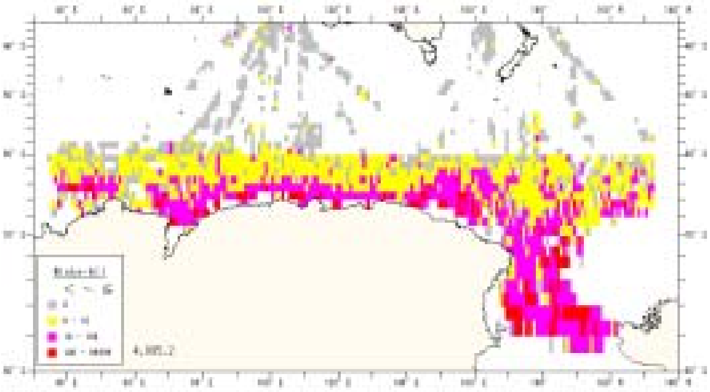

Fig. 2. Map of the Density Index (number of primary sightings of whales / 100 n.miles) of Antarctic minke whales during JARPA -1987/88-2003/04 seasons by 1°×1°square.

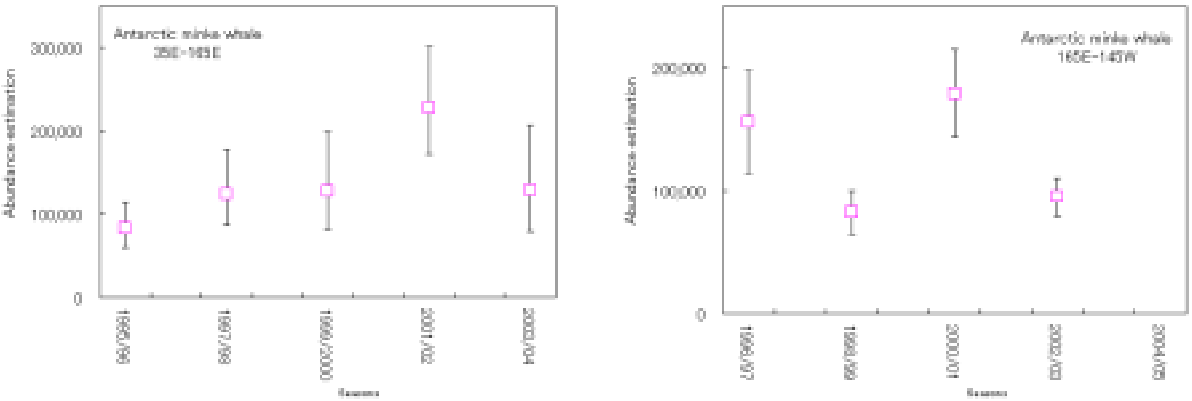

Fig. 3. Abundance estimates (south of 60°S) of Antarctic minke whales (Left side: I-stock: 35°E-165°E, Right side: P-stock 165°E-145°W) in the research area.

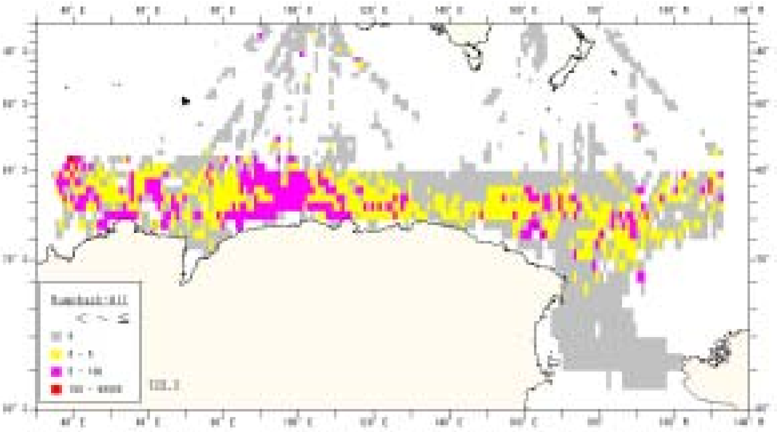

Fig. 4. Map of the Density Index (number of primary sightings of whales / 100 n.miles) of humpback whales during JARPA -1987/88-2003/04 seasons by 1°×1°square.

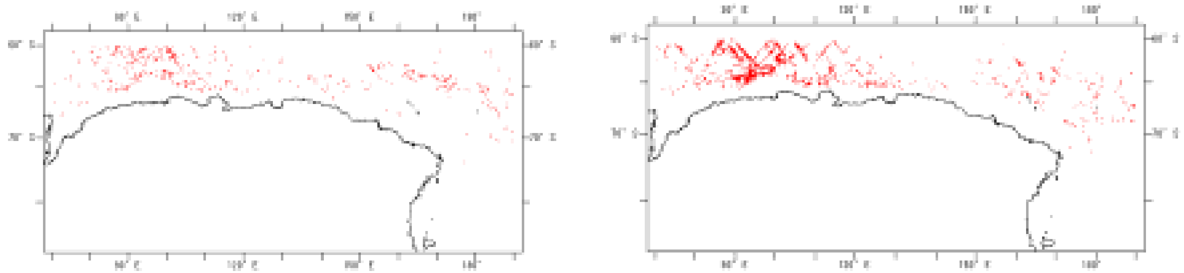

Fig. 5. Comparison of the distribution plot (Primary sightings) pattern between the first half of surveys (Left: 1989/90 - 1996/97) and late of surveys (Right: 1997/98-2003/04) by three vessels. Number of sightings were increased in the Area IV between 90^{o}and 120^{o}E.

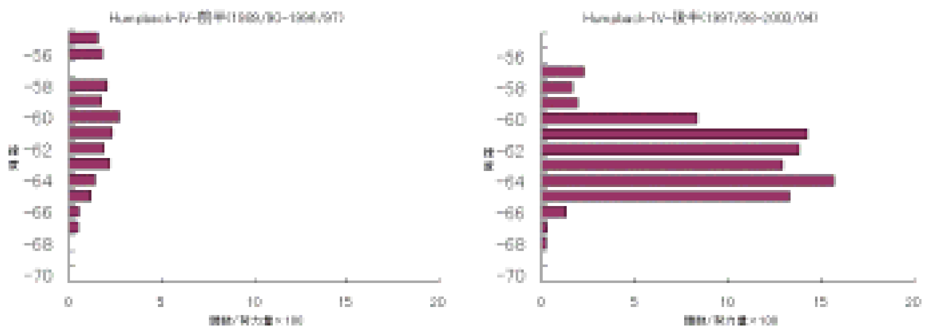

Fig. 6. Comparison of the latitudinal density Index (number of primary sightings of whales / 100 n.miles) between the first half of JARPA (Left: 1989/90-1996/97) and the later half of JARPA (Right: 1997/98-2003/04). Average of the latitude was 6030'S in the half of surveys, and was 6230'S in the second half of the surveys.

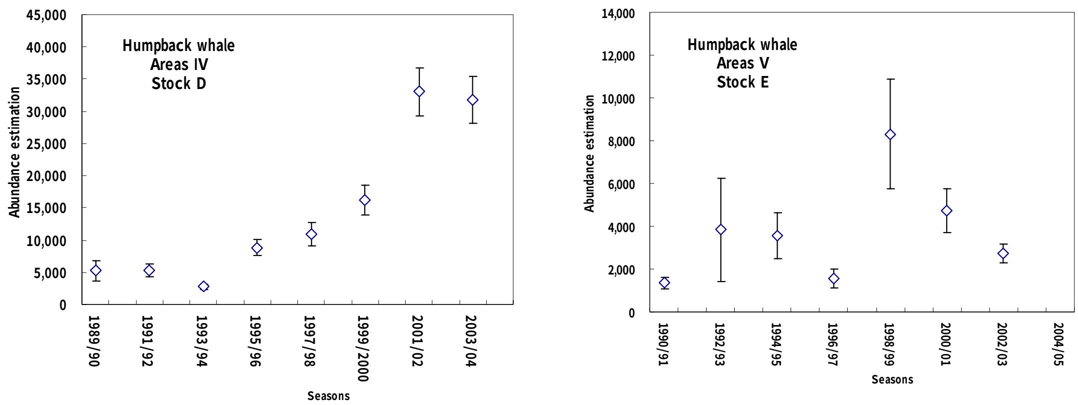

Fig. 7. Abundance estimates of humpback whales (south of 60^{o}S) between 1989/90 and 2003/2004 seasons (over 15 years) in relation to Table 3. Vertical lines show standard errors. Left side; D-stock, Right side; E-stock.

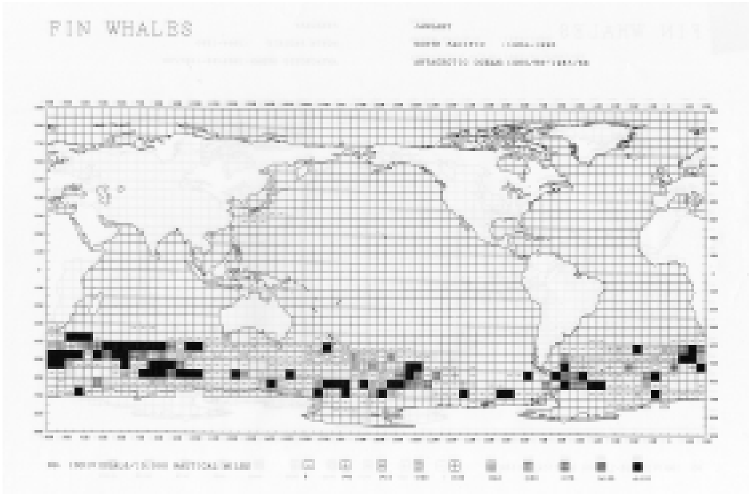

Fig. 8. The Japanese Scouting Vessel (JSV) data (sighting rate of 5°×5°square) for fin whales sighted in January during 1965/66 to1987/88 (Miyashita *et al*,, 1995).

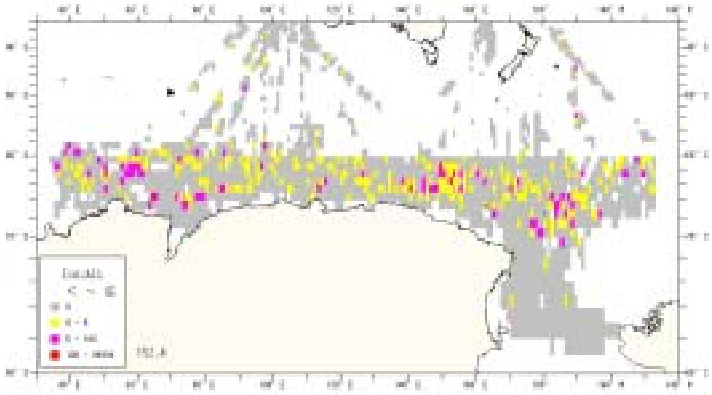

Fig. 9. Map of the Density Index (number of primary sightings of whales / 100 n.miles) of fin whales during JARPA - 1987/88-2003/04 seasons by 1°×1°square.

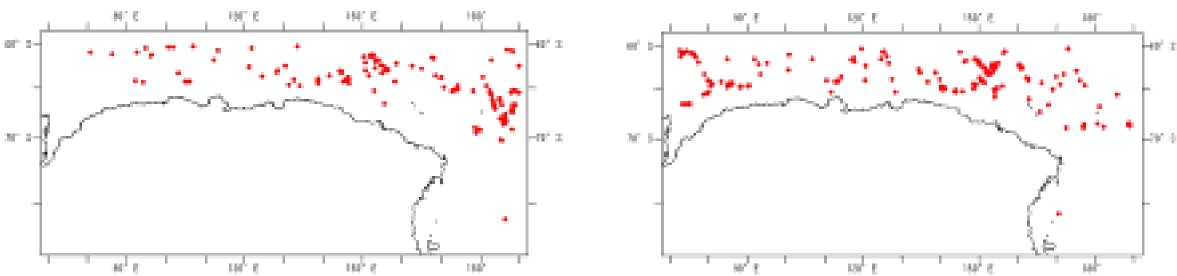

Fig. 10. Comparison of the distribution plot (Primary sightings) pattern between the first half of surveys (Left: 1989/90 -1996/97) and late of surveys (Right: 1997/98-2003/04) by three vessels. Number of sightings were increased in the Area IV between 70^{o}and 100^{o}E.

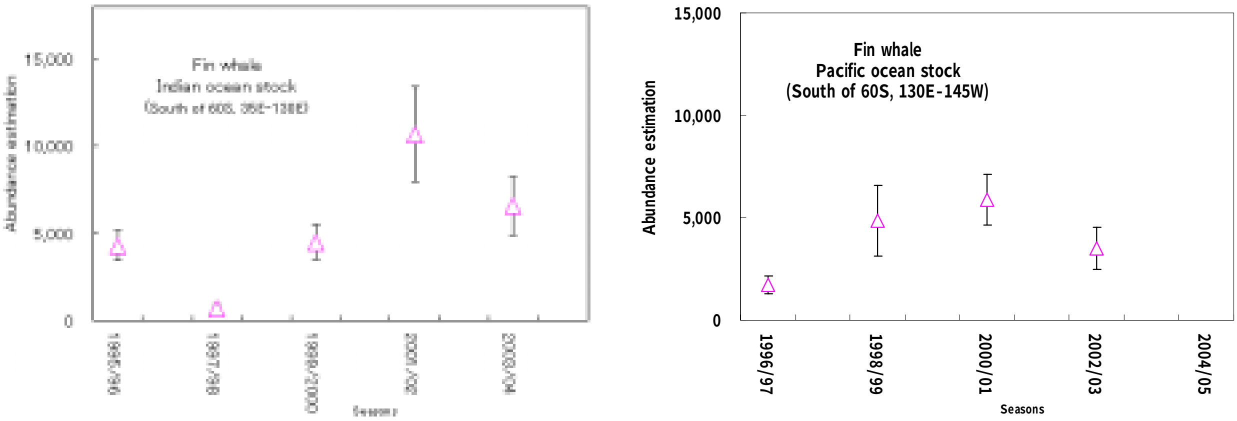

Fig. 11. Abundance estimates of fin whales (Indian Ocean stock: south of 60oS, 35^{o}E-130^{o}E) between 1989/90 and 2003/2004 seasons (over 15 years) in relation to Table 4. Vertical lines show standard errors.

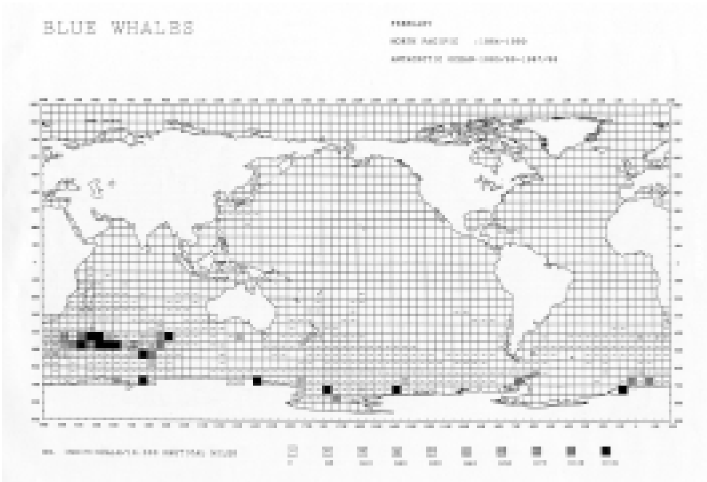

Fig. 12. The Japanese Scouting Vessel (JSV) data (sighting rate of 5°×5°square) for blue whales sighted in February during 1965/66 to1987/88 (Miyashita *et al*,, 1995).

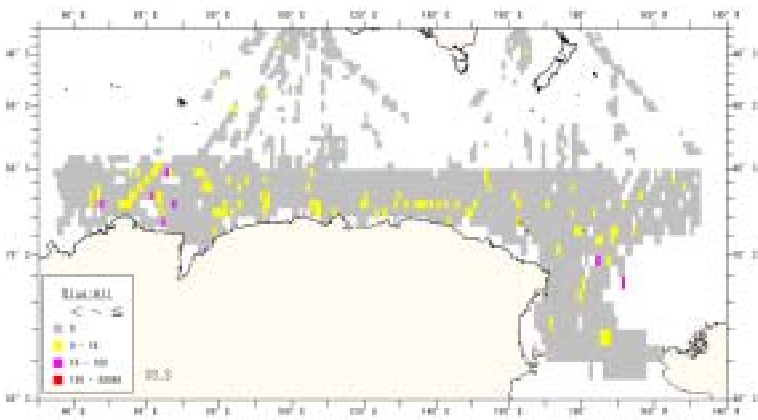

Fig. 13. Map of the Density Index (number of primary sightings of whales / 100 n.miles) of fin whales during JARPA - 1987/88-2003/04 seasons by 1°×1°square.

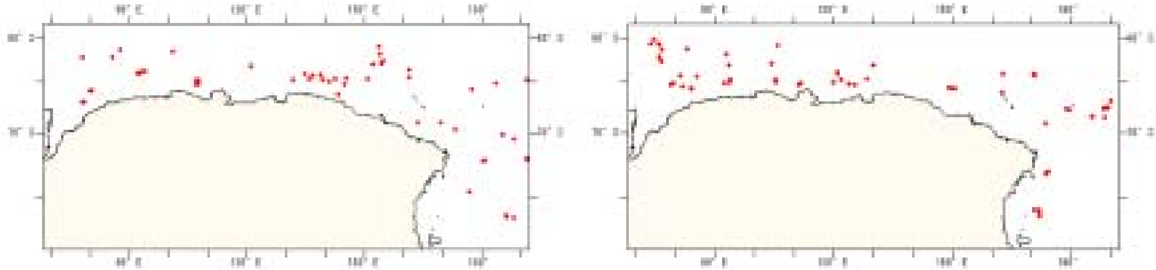

Fig. 14. Comparison of the distribution plot (Primary sightings) pattern for blue whales between the first half of surveys (Left: 1989/90 -1996/97) and late of surveys (Right: 1997/98-2003/04) by three vessels. Number of sightings were increased in the Area IV.

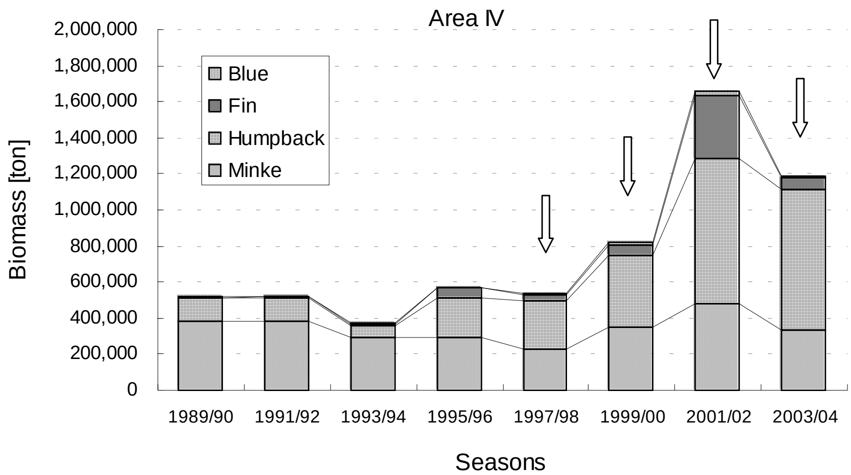

Fig. 15. Biomass of Antarctic minke, humpback, fin and blue whales in Area IV (south of 60^{o}S) surveyed during January to February, between 1989/90 and 2003/2004 seasons (over 15 years). Abundance of Antarctic minke were estimated by Hakamada *et al*,, (2005). A “shift in baleen whale dominance” from Antarctic minke to humpback whales was observed since 1997/98 season (arrows).

Appendix 2

What has happened to the Antarctic minke whale stocks? - A interprepation of results from JARPA -

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ABSTRACT

Historical changes in the Antarctic minke whale stocks were examined based on various results from JARPA including age at sexual maturity, growth curve, blubber thickness, prey consumption, and ADPT-VPA analysis of the stocks as well as results from 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 (see IWC, 19xx).

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 will end in 2004/05. Research in various fields has been conducted together with surveys and analyses related to the program objectives. Phenomena suggesting qualitative and quantitative changes on 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 predicts possible future changes.

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.*, 2005), blubber thickness (Ohsumi *et al.*, 1997; Konishi and Tamura, 2005), and estimated prey consumption (Tamura and Konishi, 2005) using samples from commercial whaling and JARPA, ADPT-VPA analysis of the stocks (Butterworth *et al.*,1999), and study of mercury accumulation in the whale body (Honda, 1985; Honda *et al.*, 1987; Fujise *et al.*, 1997; Yasunaga and Fujise, 2005) and other reports.

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

Data for 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 from Bando *et al.* (2005) which were 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, 2005). 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 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). 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).

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 (2005) examined the stomach contents of Antarctic minke whales using data from the JARPA 1987/88 to 2003/04 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.*, (2005) 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.*, 2005). 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 lat. 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 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, the following possible changes are considered to have occurred in the Antarctic minke whale stocks.

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.*, 2005).

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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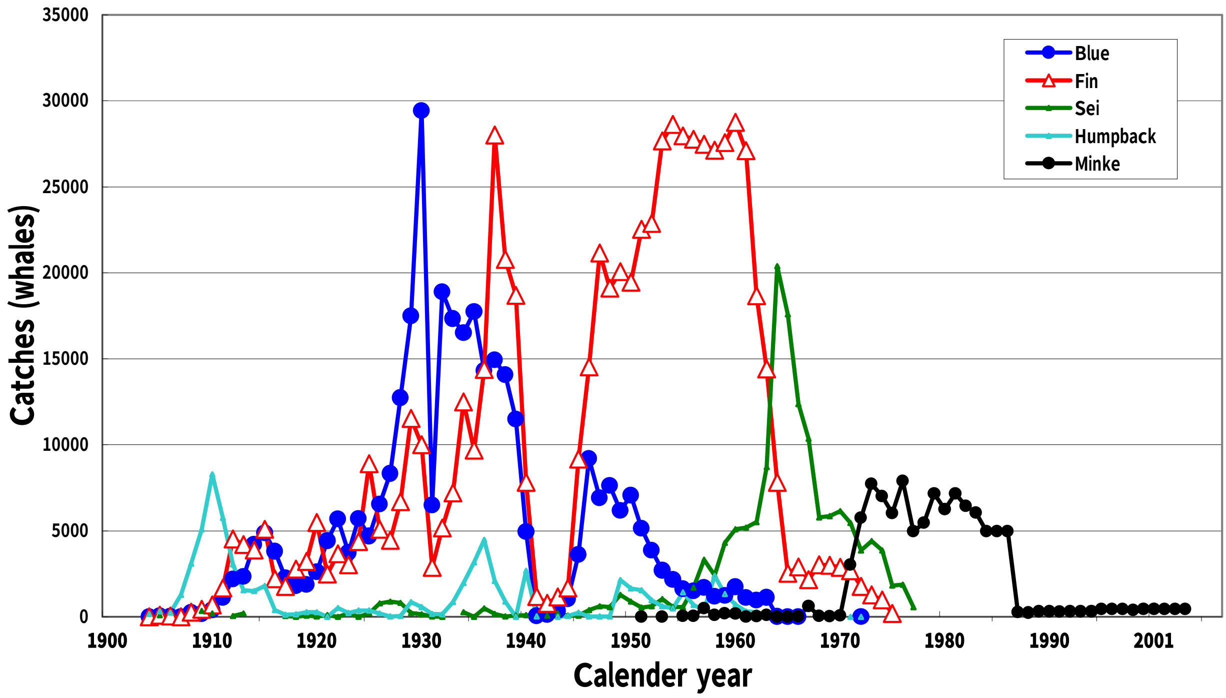

Fig. 1. Catch history of large sized baleen whales in the Antarctic since 1904.

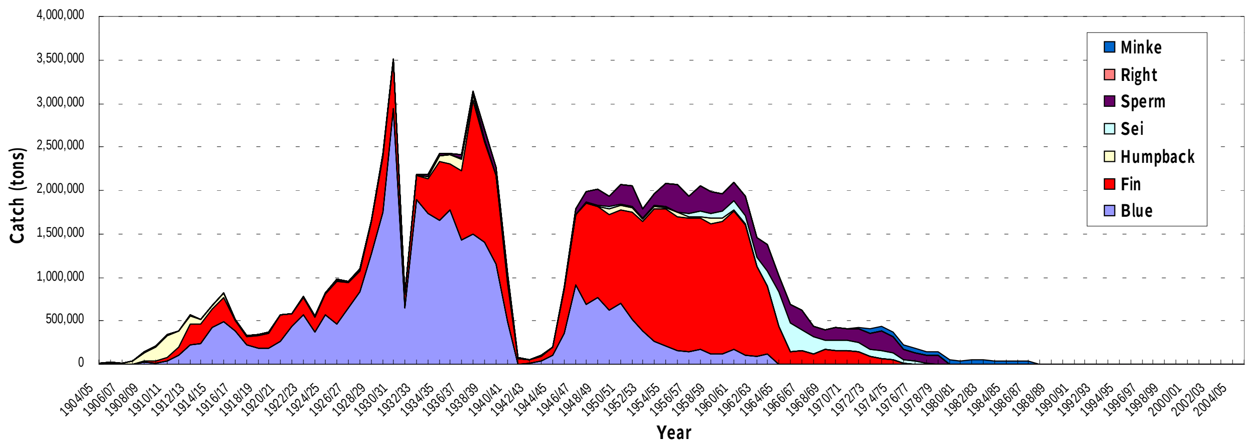

Fig. 2. Total biomass of harvested large sized baleen whales in the Antarctic since 1904.

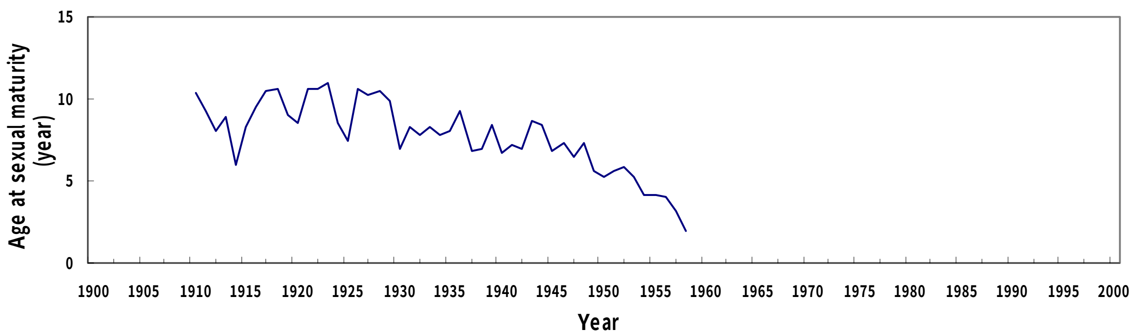

Fig. 3. Trend of age at sexual maturity of southern fin whales by cohort (Lockyer, 1982)

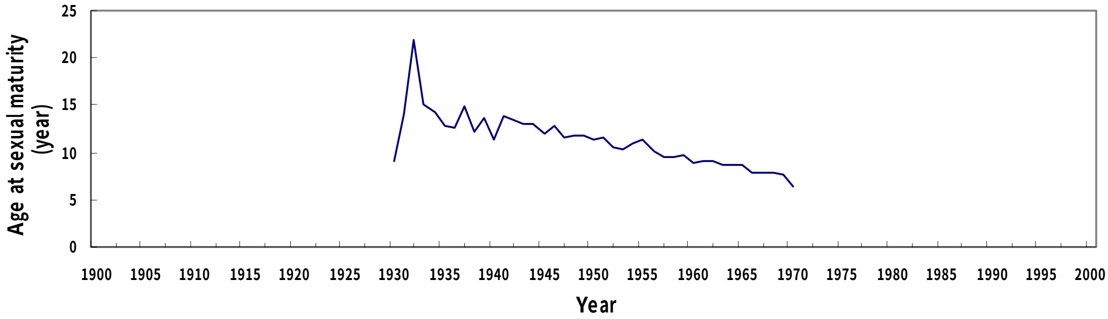

Fig. 4. Trend of age at sexual maturity of Antarctic minke whales by cohort (Kato, 1987)

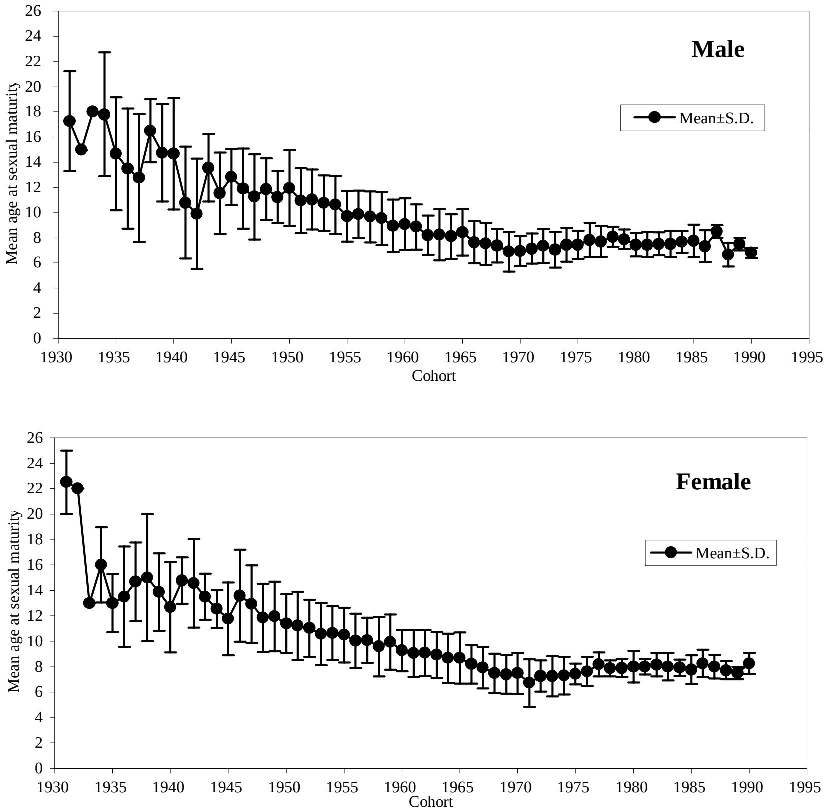

Fig. 5. Trend of age at sexual maturity of Antarctic minke whales by cohort (Zenitani and Kato, 2005)

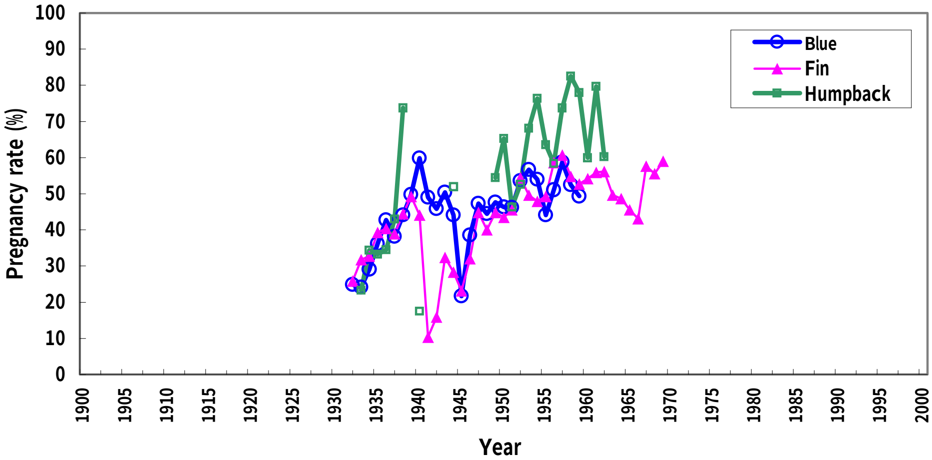

Fig. 6. Yearly changes of apparent pregnancy rate of blue, fin and humpback whales in the Antarctic (data from Lockyer (1982) and BIWS).

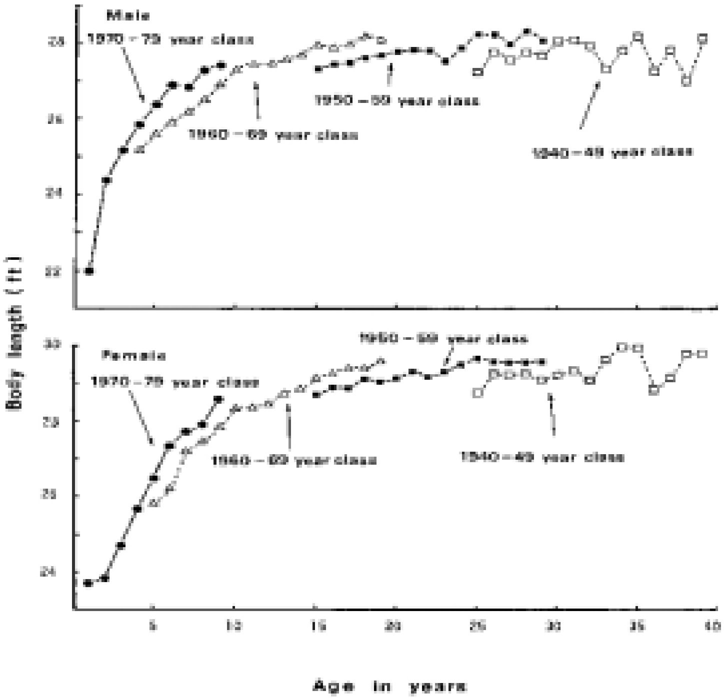

Fig. 7. Yearly changes of growth curve of Antarctic minke whales using samples from commercial whaling (Kato, 1987).

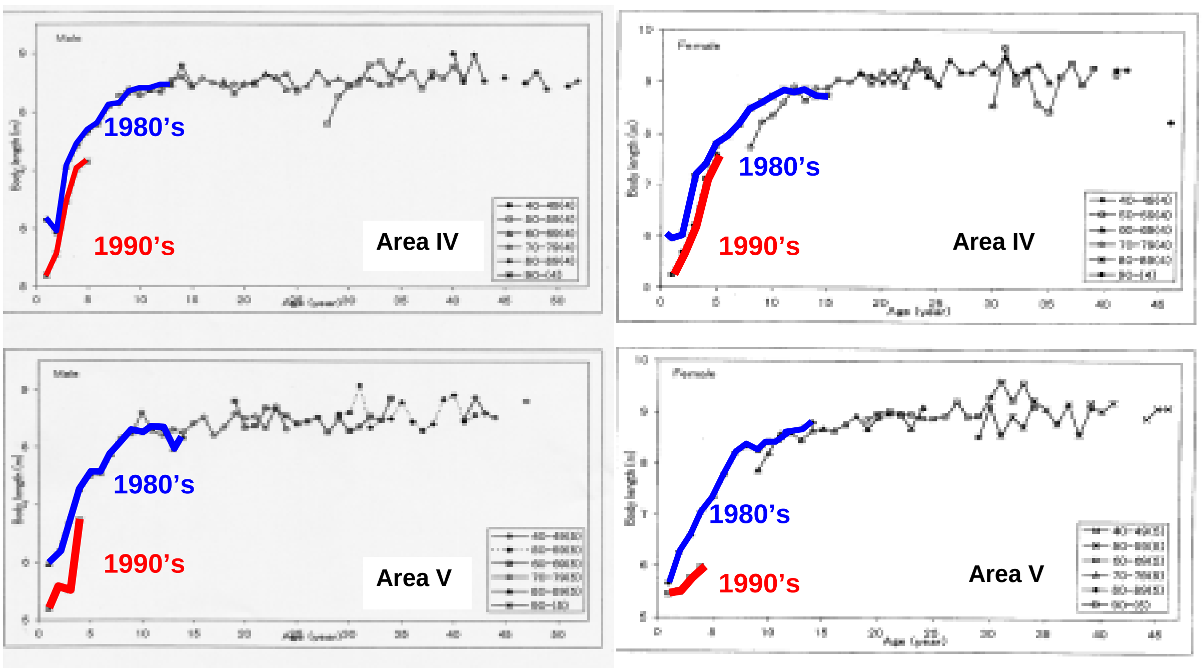

Fig. 8. Comparison of growth curve of body length in each cohort for Antarctic minke whales. Left column indicate male, and right female. Upper and lower figures indicate Area IV and Area V, respectively. Age data in this figure were used from Ms. Zenitani (unpublished data).

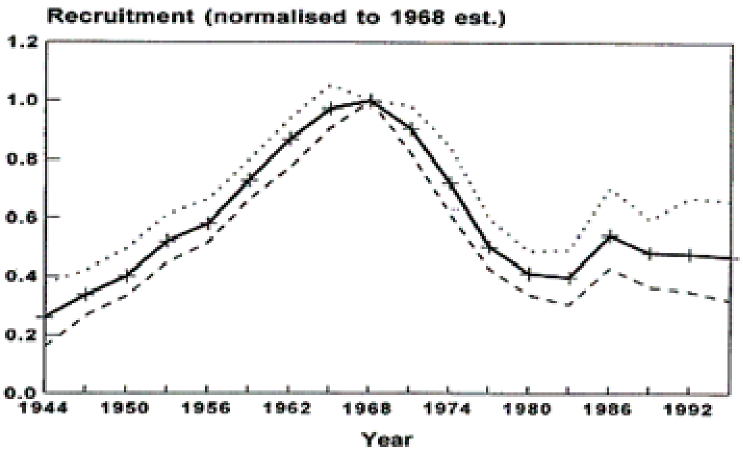

Fig. 9. Boot strap estimates of median (solid line), and 5%- and 95%-iles (dotted lines), for recruitment $N_{y,2}$ (relative to its estimated 1968 level for the corresponding bootstrap replicate) for Area IV for the base-case estimator when M is fixed at its corresponding best estimate of o.o57yr^{-1}. (Butterworth *et al.*, 1999)

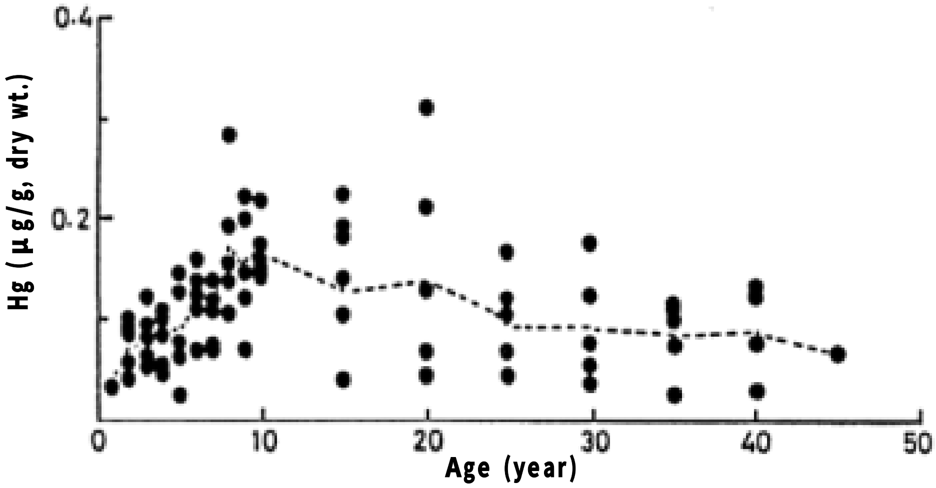

Fig. 10. Age trend of hepatic mercury concentrations (μg/g) in Antarctic minke whales using samples from commercial whaling in 1980/81 season . (Honda *et al.*, 1987)

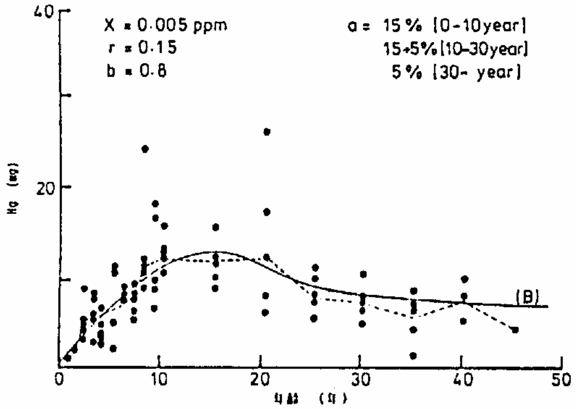

Fig. 11. Age trend of mercury load (mg) in the body of Antarctic minke whales, and accumulation curve obtained from the simulation of accumulation model (Honda, 1984).

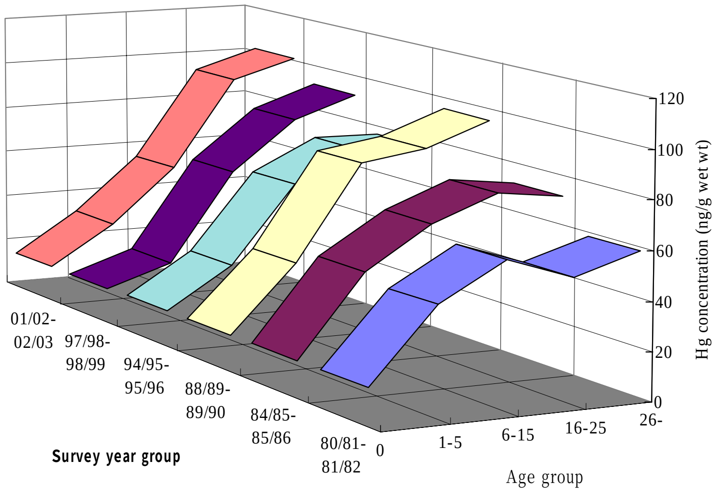

Fig. 12. Comparison of age trends of hepatic Hg concentrations (ng/g) of Antarctic minke whales during five survey year groups (1980/81+1981/82, 1984/85+1985/86, 1988/89+1989/90, 1994/95+1995/96, 1997/98+1998/99, 2001/02+2002/03).

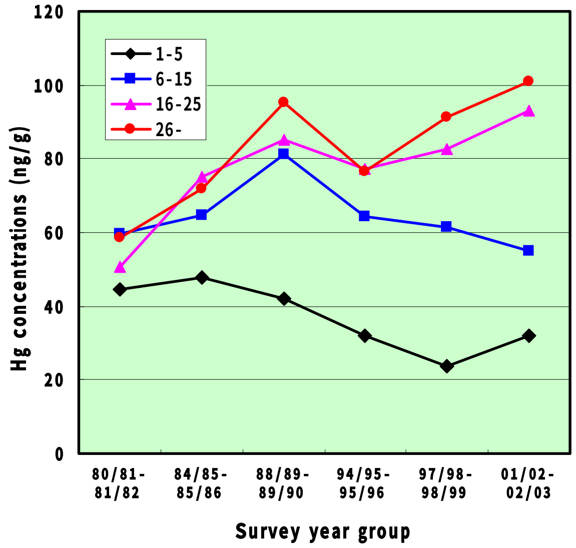

Fig. 13. Yearly changes of hepatic Hg concentrations (ng/g) in minke whales from four age groups (1-5, 6-15, 16-25, 26 or more).

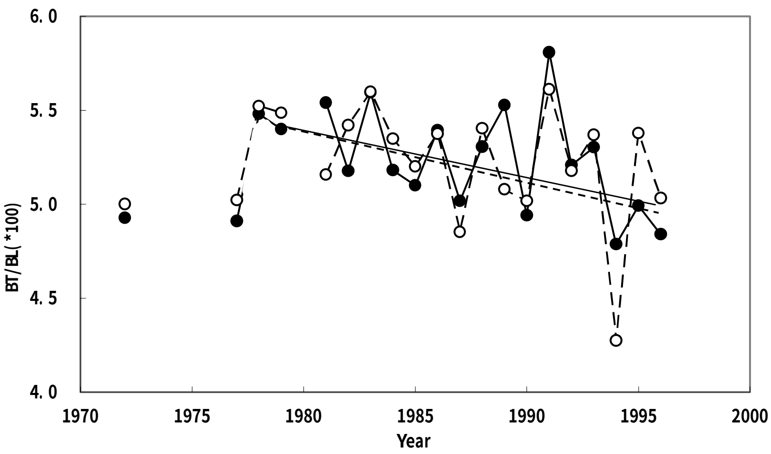

Fig. 14. Yearly changes in average fattyness index of blubber thickness in February (closed circle indicates males, open circle females. (Ohsumi *et al.*, 1997)

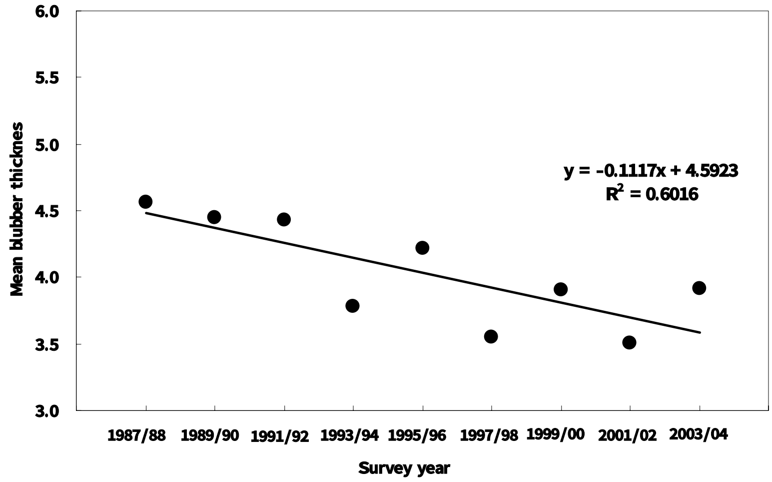

Fig. 15. Yearly changes in average blubber thickness of pregnant females in February (Konishi and Tamura, 2005).

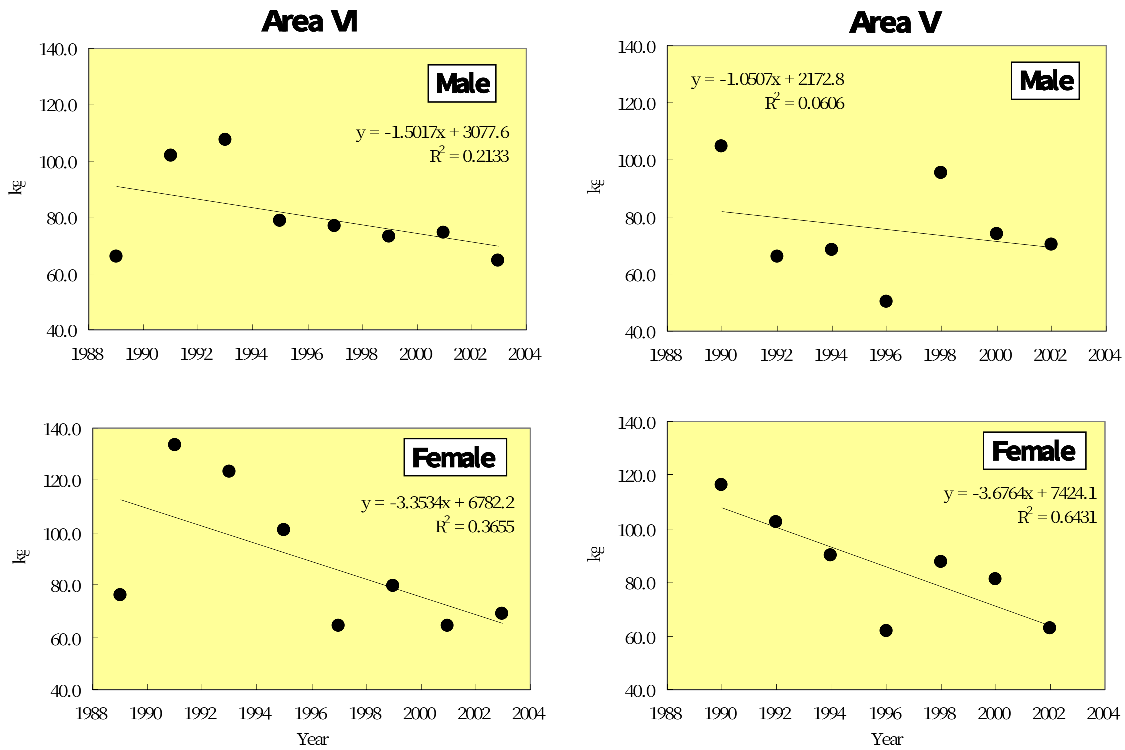

Fig. 16. Yearly changes of stomach contents (kg) of mature Antarctic minke whales in Area IV and V (Tamura and Konishi, 2005). Data used was from individuals collected from an area south of 63 degree S in January and February. The content weight was combined the first and second stomachs.

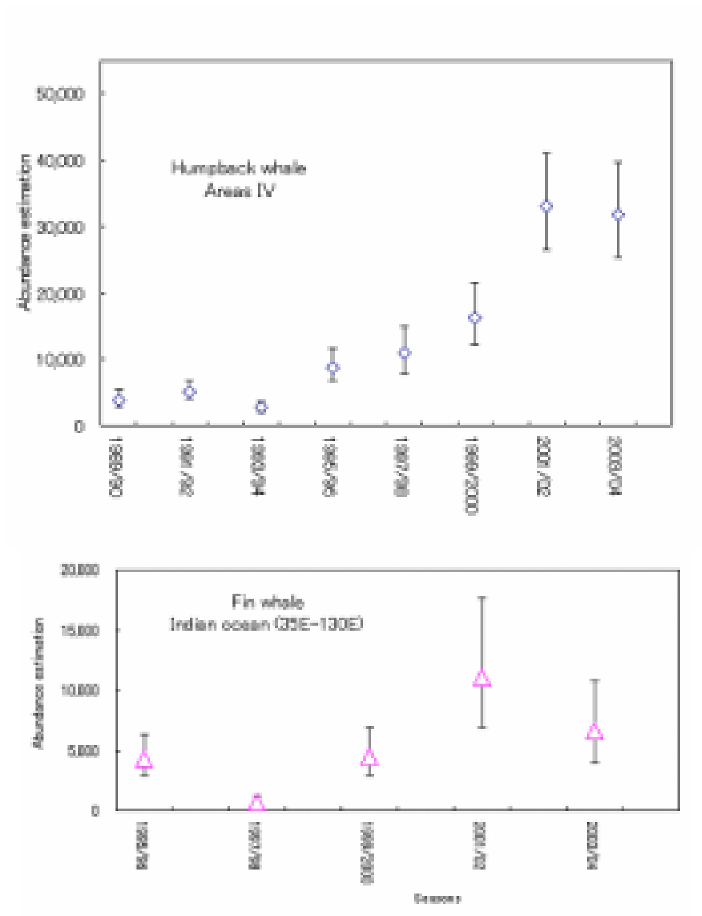

Fig. 17. Yearly changes of abundance estimates for humpback and fin whales in Antarctic Area IV (70E-130E). Upper figure shows humpback whales, lower figure fin whale (Matsuoka *et al.*, 2005)

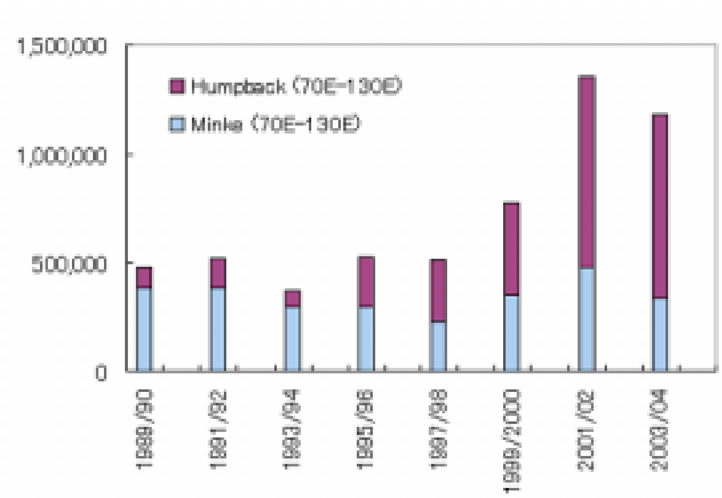

Fig. 18. Biomass of Humpback and Antarctic minke whales in Antarctic Area IV (70E-130E) using data from 1989/90 to 2003/04 JARPA (Matsuoka *et al.*, 2005).

Appendix 3

Temporal and spatial changes in stock structure of baleen whale species in the Antarctic feeding grounds

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Information on stock structure of the main whale species comprising the Antarctic ecosystem is important for a better interpretation of the estimation of abundance and trends, estimation of biological parameters and for the implementation of management procedures.

The levels of available information on stock structure are different among the several baleen whale species inhabiting the Antarctic. Furthermore in absence of geographical barriers, temporal and spatial changes in stock structure could occur, particularly in the Antarctic feeding ground, which is subjected to changes in oceanographic and other environmental conditions. Here we provide a background on stock structure for each of the main species and identify additional research needs on stock structure.

1- TRUE BLUE WHALE

Little information is currently available on the stock structure of this species in the Antarctic. Past Mark-recapture analysis conducted showed that a large proportion of whales tended to return year after year to the same part of the Antarctic (Brown, 1954). Mark-recapture analysis based on a larger number of data (Brown, 1962) and analysis of catch distribution suggested that the six IWC whaling areas were probably valid for this species (Brown, 1962; Mackintosh, 1965).

No analysis based on genetics has been conducted to investigate stock structure of true blue whale in the Antarctic. During the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA), biopsy samples have been collected but low sample size prevented us from studying their stock structure.

Effort will be made during JARPA II to collect more biopsy samples from traditional IWC areas III, IV and V and to evaluate whether the Area division is still valid for this species. Genetic analyses will be based on the standard mtDNA control region sequencing and microsatellites. As an initial step, it is desirable the collection of 20-50 samples from each of the management areas (IWC, 1991).

In addition tagging methods will be developed for data loggers (TDR) and satellite tagging transmitters.

2- FIN WHALE

Little information is currently available on the stock structure of this species in the Antarctic. As in the case of the blue whale, earlier mark-recapture analysis showed that most whales returned to the same part of the Antarctic year after year (Brown, 1954). Historical non-genetic studies showed that the six whaling areas were probably better valid for blue and humpback whales than for fin whales (Mackintosh, 1965). There was certain segregation in the feeding ground between certain longitudes in four sectors which lie: South of the Atlantic Ocean, South of the Indian Ocean, South of Western South Pacific Ocean and South of Eastern South Pacific Ocean (Mackintosh, 1965). South of the Indian Ocean corresponds approximately to JARPA Areas IIIE and IV and South of Western South Pacific to JARPA Areas V and VIW.

Only a single study based on mtDNA and biopsy samples collected by JARPA has been conducted to examine genetic difference between the whales from IIIE+IV and VW (Pastene *et al*., 2005b). However, sample size was too small (8 and 15, respectively) to make a firm conclusion on stock structure of this species in the Antarctic.

Acquiring additional genetic data should be important for testing the hypothesis of segregation in the feeding ground by oceanic areas. The number of fin whales to be sampled in JARPA II for the objective of monitoring of biological parameters will be 50 in each year. These samples will be used to examine stock structure of the species in conjunction with biopsy samples that also will be obtained during JARPAII. In this way comparison between Indian Ocean and Western South Pacific populations can be achieved. Genetic (e.g. mtDNA, microsatellites) and non-genetic techniques (e.g. mean body length of physically matured whales, morphometric, ecological markers) will be used for this purpose. For genetic analysis the IWC has recommended sample size of 20-50 from each population (IWC, 1991). However this should be interpreted as a general recommendation as the sample size depends on the effect size of each species.

In addition tagging methods will be developed for data loggers (TDR) and satellite tagging transmitters.

Both blue and fin whales have experimented substantial changes in abundance in the Antarctic and it can be expected that stock structure changed from that postulated in the past. Identification of such changes is important for the adequate interpretation of abundance estimation and biological parameters.

3- MINKE WHALE

One of the research objectives of the JARPA was the elucidation of stock structure of the Antarctic minke whale to improve stock management of this species. Based on the available JARPA samples, several analytical approaches, involving both genetics and non-genetics methods, were used to investigate stock structure of this species (Pastene *et al*., 2005a).

The JARPA review meeting called by the Government of Japan agreed that the most reasonable explanation for the results of the analyses on stock structure was the two stocks present in the research area: an eastern Indian (I) and a western South Pacific (P). These stocks appeared to mix across a soft boundary, which would probably be best placed near 165°E. The meeting also suggested that further analyses could usefully estimate the proportion of the I and P animals in an overlap area such as Area VW (130°-165°E), using a method similar to that used in the case of North Pacific minke whale (IWC, 2003).

JARPA II will attempt to investigate the pattern of mixing between the I and P-Stocks in the suggested overlap sector, in particular it will test whether or not there is significant yearly differences in this pattern. The required sample size for such analyses was investigated based on the samples obtained by JARPA.

3-1 Method

Mixing proportion of the I-Stock in the mixed assemblage was estimated using a simple Bayesian method (IWC, 2003) and mtDNA haplotype frequency data. In this method, the baseline stocks (I and P in this case) are assumed to be pure (and known) and there is a prior on the mixing proportion of I and P-Stocks in the overlap sector (VW in this case). The analysis assumes no uncertainty about the proportion of different haplotypes in the I and P-Stocks.

3-2 Annual changes in I-stock proportion (MP) in VW

For this analysis the following baseline stocks were used:

I-Stock Baseline: Area IV, all JARPA surveys (n=2,655)

P-Stock Baseline: Area VE+VIW, all JARPA surveys (n=1,637)

	MP	SD
90/91 (n=180) 173	0.6246	0.1253
92/93 (n=193) 192	0.4907	0.1513
94/95 (n=130) 129	0.6046	0.1708
96/97 (n=121) 119	0.2446	0.1576
98/99 (n=171) 170	0.6512	0.1363
00/01 (n=133) 131	0.4847	0.1713
02/03 (n=89) 89	0.4267	0.2193
All years (n=1,017) 1003	0.5320	0.0652

From this table, MP in 1996/97 appears to be smaller than in other years.

3-3 Estimating the required sample size to find significant differences in mixing proportion between 1996/97 and AYC (All Years Combined)
In the next analysis the samples from all but 1996/97 years were combined, which is named as 'AYC', and the AYC was considered as the sample representative of the mixing rate of I and P-Stocks in VW. The sample from 1996/97 is considered as a 'variable' sample. The required sample size was calculated to detect the difference observed between the AYC and the variable sample.

For this analysis the following baseline stocks were then used:

I-Stock baseline: Area IV (n=2,655)

P-Stock baseline: Area VE+VIW–(96/97) (n= 1,335)

The Bayesian method used can inform precision implications of the sample size in the overlap sector (VW).

The number of samples by haplotype was therefore scaled upwards in sector VW of the 1996/97 season. The Bayesian program was run repeatedly with increasing sample size from initial n=121 until the Credibility Intervals (CI) of MP in 1996/97 season did not overlap with the CI of MP in AYC.

	1996/97						AYC		
	n	MP	Credibility Intervals	n1 (scaled upward)	MP	Credibility Intervals	n	MP	Credibility Intervals
VW (130-165°E)	121	0.2479	0.0130-0.5990	300	0.1975	0.0150-0.4430	896	0.5975	0.4630-0.7290

Results obtained showed that for non-overlapping 95% credibility intervals between the estimates of the mixing proportions over 130-165°E, a sample size in that region of about 300 will be required. This sample size will provide the power to detect an annual change as big as the one that appears to have occurred in 1996/97 season.

3-4 Remarks
Samples in VW should be taken equally over the sector VW (about 100 samples in each 10° sector). This will allow similar analysis conducted at smaller longitudinal sectors. The analysis at smaller longitudinal sector was not possible using JARPA data because the annual average number of samples by 10° sector in VW was only 48.

Monitoring of changes in stock structure is important for management purpose. For example catch quotas based on stock will have to be adjusted for a shifting in stock boundaries (or equivalently changes of the relative proportions of stocks in mixing areas). Otherwise there is the risk of a negative impact on the stock.

The ecological factor(s) is important to be investigated for the possible causes deriving such shifting.

It should be noted that the distributions of minke and humpback whale overlap in Area IV. One of the possibilities for the changes in stock structure of minke whale stock could be a response to the stable rate of increase in abundance of Stock D humpback whales in Area IV.

4- Humpback whale
As a result of the comprehensive assessment of this species by the IWC/SC, breeding areas, feeding areas and migratory corridors of the southern humpback whale were defined (see Fig. 1 in IWC, 2001). Using biopsy samples taken by JARPA, we tested the validity of stock structure in these feeding areas in the Antarctic: Stock C (35-55°E, n=34), Stock D (80-110°E, n=79), Stock E (130°E-170°W, n=64) and Stock F (170-145°W, n=36). All the pairwise comparisons of mtDNA haplotype frequencies (by randomized chi-square test) resulted in significant statistical differences. Therefore genetic analysis of JARPA samples showed a segregation of humpback whales Stocks C, D, E and F in the feeding ground (Pastene *et al.*, 2005b).

It is also known that Stock D of southern humpback whale has shown a stable rate of increase in abundance (Bannister and Hedley, 2001). This is likely reflected in changes in proportion of Stock D in the mixing sector 110-130°E suggested by past mark-recapture analysis (Chittleborough, 1959; Dawbin, 1966).

Sector/Survey	Proportion of Stock D (SD)
110-130°E (n=10, 93/94, 95/96)	0.6015 (0.1865)
110-130°E (n=11, 97/98, 99/00)	0.6640 (0.2166)
110-130°E (n=13, 01/02, 03/04)	0.7591 (0.1172)
110-130°E (n=34, total)	0.7422 (0.0999)

Although the standard deviations of the estimates are large due to small sample size, proportion of this stock in the mixed area seems to have increased with time. These results are consistent with the results of sighting surveys that indicate that this stock is increasing its abundance.

The number of humpback whales to be sampled in JARPA II in Area IV for the objectives of monitoring of biological parameters is 50 in each year. This sample, in conjunction with new biopsy samples obtained in the research area, will be used to examine yearly variation in the pattern of stock structure. Of particular importance is the examination of the contribution of stock D in the sector 110-130°E and east in order to investigate possible expansion of the D stock. Genetic (e.g. mtDNA, STR) and non-genetic techniques (e.g. mean body length of physically matured whales, morphometric, ecological markers) will be used for this purpose.

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Appendix 4

Monitoring of environmental pollutants in cetaceans and the marine ecosystem in the Antarctic Ocean and the western North Pacific Ocean

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INTRODUCTION

It is known that the distribution of anthropogenic pollutants, such as organochlorines and heavy metals, in the open ocean air and water is global in extent. The spatial and temporal distribution of these pollutants must be revealed in order to predict changes in the future. Environmental monitoring of the pollutants generally uses environmental samples, such as air and seawater, however, the pollutant levels are extremely low in the open ocean. Whales are high in the food chain in the ocean, thus they may be particularly suitable as monitors of pollutant levels and their adverse effects.

The Antarctic is an important area for environmental monitoring of the pollutants, since it is at the end of their global transport as are the middle and low latitude areas, such as western North Pacific, which is where the primary anthropogenic pollutant sources are located. Thus, the pollutants levels of the baleen whales in the Antarctic are lower than those in middle and low latitudes of the northern hemisphere (Fig. 1). Comparison of polluted and control areas is useful for monitoring of global distribution and behaviour of the pollutants.

Pollutants, especially organochlorines, mainly affect the immune system of vertebrates. Control animals are necessary for laboratory study of toxicology. Therefore, Antarctic baleen whales are well suited as control animals for toxicology studies of free-ranging whales.

From these points of view, pollutant dynamics in whales will be examined by monitoring pollution in baleen whales in the JARPA II combined with JARPN II in the western North Pacific. Furthermore, the fate of the pollutants from a more global perspective will be examined by analyses of pollutant levels in air, seawater and prey species. The relationship between the pollutant levels and some adverse effects in whales will also be examined in this research.

OBJECTIVES

The following three objectives for the comprehensive monitoring of environmental pollutants in whales, their food items and environmental samples is conducted as a part of the ecosystem monitoring which is one of the main objectives of the JARPA II plan.

1. Elucidation of future accumulation and biological processes of pollutants in whales from the Antarctic and the western North Pacific
2. Elucidation of transport and fate of pollutants in the Antarctic and the western North Pacific ecosystem
3. Elucidation of adverse effects of the pollutants for whales in the Antarctic and the western North Pacific Ocean.

METHODOLOGY

To clarify the distribution and behaviour of pollutants globally, it is necessary to conduct comprehensive monitoring of pollutants in cetaceans and the marine ecosystem in control areas, such as Antarctic Ocean (JARPA II), as well as polluted areas such as western North Pacific Ocean (JARPN II).

1) Organochlorine compounds

In the JARPN II research, man-made compounds, such as PCBs, DDTs and HCHs, have been analysed in three baleen whales (minke, Bryde's and sei whales), one tooth whale (sperm whales), their prey species (fishes, krill etc) and environmental samples (air and seawater) in the western North Pacific. Accordingly, in the JARPA II research, these compounds will be analysed in three baleen whales (Antarctic minke, humpback and fin whales), their prey species (Antarctic krill etc) and environmental samples (air and seawater) in the Antarctic Ocean. Both research results will be combined for analysis of the fate and distribution of pollutants in the ecosystem. The blubber and liver of whales are used for analysis of organochlorines because of higher levels and sensitivity however, this protocol may be modified as needed.

2) Heavy metals

In the JARPN II research, harmful heavy metals, such as Hg, Cd and Pb have been analysed in three baleen whales (minke, Bryde's and sei whales), one tooth whale (sperm whales), their prey species (fishes, krill etc) and environmental samples (air and seawater) in the western North Pacific. Accordingly, in the JARPA II research, these compounds will be analysed in three baleen whales (Antarctic minke, humpback and fin whales), their prey species (Antarctic krill etc) and environmental samples (air and seawater) in the Antarctic Ocean. Both research results will be combined for analysis of the fate and distribution of the pollutants in the ecosystem. The liver and muscle of whales are used for analysis of heavy metals because of higher levels and sensitivity however, as for organochlorines, this protocol may be modifed as needed.

3) Relationship between chemical pollutants and cetacean health

Ecotoxicological and pathological approaches are used to detect dose-effect relationships of pollutants for whales.

3-1) Ecotoxicological study

It is known that some organochlorines have adverse effects on the immune system of whales, however, there have been few reports on these effects in free-ranging whales. Therefore, dose-effect relationships of pollutants for whales are examined by toxicological approaches, follow as: 1) examination of the relationship between biomarkers, such as cytochrome P-450, thyroid hormones, vitamin A and metallothionein, and the pollutant levels in whales; 2) understanding of the contaminant sensitivity of whales; 3) examination of the relationship between pollutant levels and expression of chemical related genes in the whales.

3-2) Pathology examinations

It is known that some organochlorines have adverse effects on the immune system of whales. Therefore, necropsies are carried out to examine immnological effects, such as exodermis and lymph nodes inflammation. In the western North Pacific, a considerable number of minke whales are observed with anomalous testis tissues. Similarly, this phenomenon is observed in Antarctic baleen whales. This phenomenon suggests that the relationship between the pollutant levels and prevalence rate of pathological events in whales requires examination.

SAMPLE SIZE

In the JARPA II survey, the sample size for pathological monitoring in baleen whales was calculated by the prevalence rate. Table 1 shows the relationship between precisions and prevalence rates for pathological monitoring at the 95% confidence level.

There have been few reports on the statistical pathology in free-ranging whales such as the Antarctic minke whale. Exodermis and lymph nodes inflammation in the feasibility observations of the JARPA surveys were equal to or smaller than 10%. The prevalence rate of these effects in free-ranging whales on a global basis may be expected to be similar to these levels.

For Antarctic minke whales (their prevalence rate=10%), a minimum of 864 animals is required in each cell with 40% precision. This precision value is generally used to estimate of prevalence rate in epidemiology (Nakamura, 2002). Eight handred fifty animals expected in this research would be sufficient for estimation of prevalence rates in order to elucidate of relationship between pollutants and their effects, while are not complete enough to conduct all the pathological research.

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Table 1. Necessary sample size of estimation of the prevalence rate in pathological study at the 95% confidence level.

Precision	Prevalence rate (%)					
	5	10	15	20	25	30
40%	1825	864	544	384	288	224
30%	3244	1537	968	683	512	398
20%	7299	3457	2177	1537	1152	896
10%	29196	13830	8708	6147	4610	3585

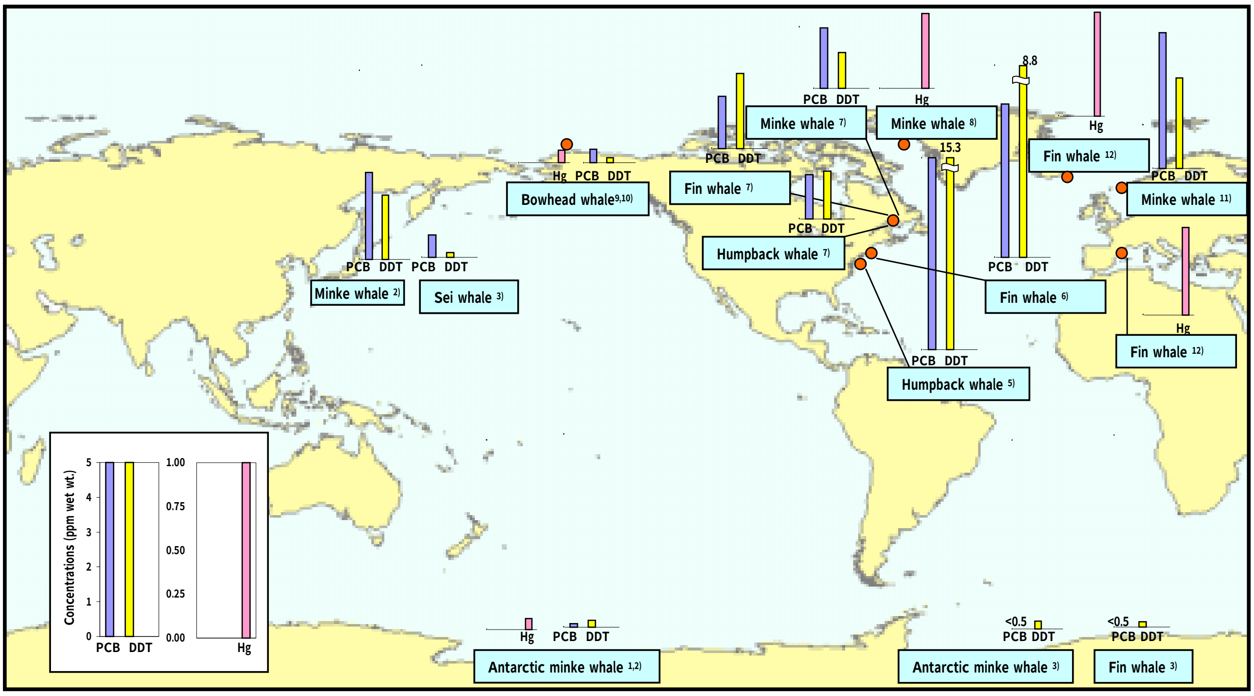

Fig. 1. PCB, DDT Levels in the Blubber and Hg Levels in the Liver of Baleen Whales.
1) Honda *et al.* (1987); 2) Aono *et al.* (1997); 3) Henry and Best (1983); 4) Tomita and Nishimura (1973) ; 5) Taruski *et al.* (1975) ; 6) Hobbs *et al.* (2001); 7) Gauthier *et al.* (1997); 8) Hansen *et al.* (1990); 9) O'Hara *et al.* (1999); 10) Krone *et al.* (1999); 11) Kleivane and Skaare (1998); 12) Sanpera *et al.* (1993)

Appendix 5

Hypotheses on the the abundance changes of krill predators in the Antarctic ecosystem

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I propose the following hypotheses on the abundance changes of krill predators, such as baleen whales, crabeater seal and penguins in the Antarctic ecosystem. These hypotheses will be examined and selected based on data obtained by JARPA and future JARPA II programs on the course of developing the ecosystem model.

1. HYPOTHESIS OF CONSTANT OVERALL CARRYING CAPACITY

The total carrying capacity for the four baleen whale species (blue, fin, humpback, and Antarctic minke whales) that mainly prey on Antarctic krill is constant depending on krill biomass in the feeding grounds. It is equivalent to the total biomass of four species before the days of commercial whaling in the Antarctic Ocean. However, carrying capacity may change depending on fluctuations in krill biomass and composition (relative abundances) of the whale species. Based on abundance estimates in their pristine level and in past and recent years and their daily krill consumption estimates, some estimates of total krill consumption by large whales will be obtained. The plausibility of this hypothesis will be checked through the comparison of these estimates.

2. HYPOTHESIS OF KRILL SURPLUS

The decline in large whale stocks due to commercial hunting resulted in a large surplus of krill which had been consumed by large whales. Other predators of krill, such as Antarctic minke whales, pinnipeds, and sea birds, fed on the surplus and increased in abundance. This hypothesis is an established theory, and will be the basic concept of the ecosystem model.

3. HYPOTHESIS OF CHANGING CARRYING CAPACITY BY SPECIES

Carrying capacity may be fixed for the total biomass of all baleen whales, but may change for individual species. The carrying capacity for Antarctic minke whales has increased greatly with the decline in blue, fin, and humpback whales. The abundance of the minke before 1940 and that in recent years (760,000 animals, IWC, 1990) probably indicates two levels of carrying capacity for Antarctic minke whales. This hypothesis will be used in the model as an assumption.

4. HYPOTHESIS OF STOCK INCREASE DUE TO A DECLINING OF AGE AT SEXUAL MATURITY

The trophic condition of juveniles improves with the surplus in krill, inducing faster growth, which results in a younger age at sexual maturity. The proportion of adults in the stocks increases as a result, which in turn increases recruitment so that abundance increases at a faster rate. At the same time, growth of fetus and calves would be enhanced since mature cows are well fed and able to provide ample milk, and which would most likely lead to a lower infant mortality rate. Such a mechanism will probably be an important process to express quantitatively in the competition model among whale species. The sexual maturity age of Antarctic minke and fin whales is observed to have decreased, and the JARPA Phase I data on the former could be useful. It would probably be possible to determine the recent sexual maturity age of fin and humpback whales from the samples taken. The number of parents and the resulting number of recruits can be estimated with the VPA analysis, and it will be confirmed whether or not the decline of age at sexual maturity can explain quantitatively the increase of recruitment. Then equations for expressing the process of population growth will be considered.

5. HYPOTHESIS OF A PREDOMINANT SPECIES IN THE ECOSYSTEM

The humpback whale, which is predominant (highest biomass) in the ecosystem, can increase even if the minke whale is near the upper limit of its carrying capacity and there is no surplus in krill. On the contrary, the minke, which is in an inferior position, cannot increase by pushing aside other whale species. If we examine the balance among whale species before any whaling had begun, the blue, fin, and humpback whales were in a more predominant position in this sense than the Antarctic minke. At that time Antarctic minke whales occupied only narrow niches when other large whales were dominant. The plausibility and necessity of this hypothesis (assumption) will be checked on the course of model construction.

6. HYPOTHESIS OF DECLINING PREGNANCY RATES AND/OR JUVENILE SURVIVAL RATES DUE TO INADEQUATE TROPHIC CONDITIONS

It has been observed that the blubber thickness of Antarctic minke whales is decreasing. This fact indicates that they are becoming unable to store sufficient nutrition during their feeding period. Consequently, the proportion of animals capable of becoming pregnant is decreasing, resulting in lower pregnancy rates. At the same time, the age at maturity increases. In other words, it is the reverse process of hypothesis No.4, which results in a decrease in abundance. It is possible to estimate sexual maturity age of year classes going back several years or a decade or so from the time samples were taken since it is estimated by observing the transition phase of the growth layer in their earplugs. However, the blubber thickness and pregnancy rates are measured only just after the time samples are taken. They are however important indices that enable real-time tracking of qualitative changes in the stocks. Based on data of blubber thickness, krill consumption and pregnancy rate, the relationships among them will be analysed. The decreasing process of mink whale abundance will be considered through these analyses.

7. HYPOTHESIS OF COMPETITION AMONG WHALE SPECIES

As the abundance of humpback and fin whales (and blue whales) recover, Antarctic minke whales will begin to decrease in abundance. The major mechanisms behind the decline will be increasing sexual maturity age leading to decreasing recruitment and lower pregnancy rates due to inadequate trophic conditions or unfavourable feeding conditions. These mechanisms will be formularized based on past JARPA data as well as those to be collected through monitoring in JARPA II and incorporated into the model.

8. HYPOTHESIS OF SLOW RECOVERY

Blue whales have been so severely depleted by over-hunting that mating opportunities are limited; and although there is indication of abundance increase they are far from full recovery. Long-term monitoring will be necessary to determine whether their rate of recovery will remain slow or increase.

9. HYPOTHESIS OF ENVIRONMENTAL CHANGES AFFECTING CETACEANS

Climatic changes such as global warming will bring about changes in the production and biomass of krill. The change in feeding conditions of baleen whales will affect growth and recruitment rates. The effects may differ depending on the whale species. These effects will be formularized using information from CCAMLR and other organizations and data obtained from monitoring krill density in the research area.

Appendix 6

Sample sizes of Antarctic minke, humpback and fin whales required for statistical examination of yearly trend in biological parameters

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Biological parameters such as pregnancy rate and age at sexual maturity in baleen whales are thought to change in response to changes in abundance, food availability and competition with other species (Gambell, 1973; Kato, 1987; Masaki, 1979; Lockyer, 1979; 1984). Monitoring of biological parameters to detect change in quality of habitat for baleen whales is one of the objectives of JARPA II.

Sample sizes required for statistical examination of yearly trend in the proportion of pregnant in matured female (PPF) of Antarctic minke whales, apparent pregnancy rate of humpback and fin whales and age at sexual maturity for minke and fin whales were calculated.

Ideally “true pregnancy rate”, which is the probability that one mature female would become pregnant in one year, should be used. However since estimation of “true pregnancy rate” is difficult, the “apparent pregnancy rate”, which is the ratio of pregnant females in the mature female samples caught in a certain area, is conventionally used as an approximation of the “true pregnancy rate”.

It is known that the apparent pregnancy rate could be biased by segregation or date of sampling. However in the case of fin whale, apparent pregnancy rate estimated from commercial whaling data was considered to change in response to changes in abundance or density. Therefore apparent pregnancy rate in fin whale reflects “true pregnancy rate” to some degree (Kato, 1991). Therefore apparent pregnancy rate was used in this study for fin whale as an approximation of the “true pregnancy rate”.

There was no information about the degree of bias of apparent pregnancy rate in humpback whale. However, the apparent pregnancy rate estimated from commercial whaling data showed the same yearly trend as in the fin whale and was considered to vary in response to changes in abundance or density. Thus, apparent pregnancy rate was also used for humpback whale as an approximation of the ‘true pregnancy rate’.

In the case of the Antarctic minke whale, a substantial degree of bias appears to occur in the estimation of apparent pregnancy rate. Timing of migration from assumed equatorial breeding areas to Antarctic feeding areas differs 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).

Observed apparent pregnancy rate in the Antarctic commercial whaling data was about 0.9 which was thought to be biased upward from the “true pregnancy rate” of 0.78 (Best, 1982), which was estimated from commercial whaling data in breeding areas (Kato, 1991).

It is concluded that the apparent pregnancy rate in Antarctic minke whales might not reflect “true pregnancy rate”. Therefore in the case of this species the term ‘proportion of pregnant in matured females’ is used instead of ‘apparent pregnancy rate’. This ratio is an important parameter to monitor migration strategy, distribution pattern and feeding environment of Antarctic minke whale, so, this parameter was included in calculation.

1. BIOLOGICAL PARAMETERS USED IN THIS STUDY.

1) Apparent pregnancy rate (APR) (humpback and fin whales): ratio of pregnant whales in total mature female samples.

2) Proportion of pregnant in matured female (PPF) (Antarctic minke whale): Same statistic as “apparent pregnancy rate”.

3) Age at sexual maturity (ASM): Mean TP (Transition Phase) value in each year class.

2. METHOD

Sample sizes required for examining statistically significant trends in the regression lines (applied to the value of biological parameters in each year), were calculated. Details of these calculations are shown in the appendix. Initial value and rate of change in APR and PPF were deduced from JARPA samples and knowledge from past commercial whaling data. Frequency of year-classes samples of females was deduced from 1999/2000-2003/04 (for 6 years research period) and 1993/94-2003/04 (for 12 years research period) JARPA samples collected in south of 62S in Area IV. Variance of error was deduced from linear regression analysis conducted to female of 1971-1990 year classes collected by JARPA survey in 1987/88-2003/04 in Area IV.

3. SAMPLE SIZE REQUIRED FOR STATISTICAL EXAMINATION OF YEARLY TREND IN THE PPF AND APR

3.1 Yearly trend of PPF in the Antarctic minke whale.

The PPF calculated from past commercial whaling data in the period of 1971/72-1986/87 and JARPA sample in the period of 1987/88-1999/2000 in Areas IV and V stabled around 90% and slight increasing and decreasing trend was observed in Area V in commercial whaling data and JARPA samples, respectively, although the trends were not significant (Fig. 1) (Zenitani *et al*. 2001).

3.2 Yearly trend of APR in humpback and fin whale,

The number of mature and pregnant females (classified by reference to body length and presence of fetus) of humpback and fin whale was extracted from the International Whaling Statistics (IWS). APR was calculated from these data (Fig. 2).

APR in humpback whale increased from about 30% in the early 1930’s to 70% in the 1960’s with large yearly variation. Rate of increase was calculated as 3.95%/year in the period 1933/34-1937/38 and 1.30%/year in the period 1949/50-1962/63.

APR in fin whale showed the same trend as in humpback whale. In this case APR increased from 30% to 50% in the 1930’s and increased again from the end of WW2 to about 60% in the late 1950’s. From that date to the 1970’s it remained stable. Rate of increase was calculated as 2.46%/year in the period of 1930/31-1939/40 and 1.78%/year in the period of 1946/47-1957/58. Gambell (1973) conducted similar analysis for Antarctic fin whales and reported an increasing trend of APR during pre-war years and post-war years.

From the observed past yearly trend of PPF in Antarctic minke whales and APR for humpback and fin whales, the initial values and rates of change needed to calculate sample size were set as follows:

Initial rate (PPF)： 80%、90%

Initial rate (APR)： 30%, 40%, 50%, 60%, 70%

Rate of change： 1.0%/year、1.5%/year、2.0%/year、2.5％/year、3.0%/year

3.3 Sample size of mature females required for statistical examination of yearly trends.

The calculated sample size of mature females required for statistical examination of yearly trends are shown in Table 1.

3.4 Correction coefficient

To calculate required total sample size, sample size of mature female should be divided according to expected ratio of mature female in total samples. Sexual and maturity composition of Antarctic minke whales collected in south of 62S in Areas IV and V in the 1989/90-2003/04 JARPA survey and of humpback and fin whales taken in past commercial whaling in Antarctic is shown in Figs. 3-1, 3-2 and 3-3, respectively. Correction coefficient was calculated as 3.00 for Antarctic minke whale, 2.91 for humpback whale and 2.72 for fin whale.

3.5 Calculation of total sample size

3.5.1 Total sample size required for statistical examination of yearly trend of PPF in Antarctic minke whale

Calculated total sample size is shown in Table 2. As explained above, PPF of Antarctic minke whale is about 90% at this stage and it is important to detect the start of decreasing. Sample size required for statistical examination of yearly trend at the rate of 1.0-1.5%/year in 6-years research period was calculated as follows.

Rate of change = -1.0%/year → Sample size = 1617

Rate of change = -1.5%/year → Sample size = 663

3.5.2 Total sample size required for statistical examination of yearly trend of APR in humpback and fin whales

3.5.2.1 CALCULATED SAMPLE SIZE OF HUMPBACK WHALE

Sample size required for statistical examination of yearly trend in 12-years research period was calculated as follows, considering APR as 30-70% and yearly rate of change as 1.5-3.0%/year (Table 3).

APR = 30% → Sample size = 41-160

APR = 50% → Sample size = 56-181

APR= 70% → Sample size = 41-160

3.5.2.2 CALCULATED SAMPLE SIZE OF FIN WHALE

Sample size required for statistical examination of yearly trend in 12-year research period was calculated as follows, considering APR as 30-60% and yearly rate of change as 2.0-2.5%/year (Table 4).

APR = 30% → Sample size = 55-107

APR = 50% → Sample size = 69-99

APR = 60% → Sample size = 63-99

4. SAMPLE SIZE REQUIRED FOR STATISTICAL EXAMINATION OF YEARLY TREND OF ASM

4.1 Yearly trend of ASM in Antarctic minke and fin whales

Yearly trend of ASM (estimated from TP) was studied in Antarctic minke whale using past commercial whaling data and JARPA samples. ASM in females decreased from the 1945 year class to the 1970 year class and the rate of change was calculated as 0.2/year (Fig. 4) (Kato, 1987). Stable or slightly increasing trend was found from the 1970's using JARPA samples (Zenitani and Kato, 2005).

A decreasing trend in ASM in females was also found in fin whales from commercial whaling data. Age at sexual maturity decreased from 10-14 years old in the 1930's year classes to 6-10 years old in the 1960's year classes (Lockyer, 1979) and rate of change was calculated as about 0.1/year (Fig.5).

Yearly trend of ASM was not available for humpback whales because when the ear plug was demonstrated to be useful for age determination in this species in the mid 1950's, the level of catches of humpback whale had already decreased substantially.

From the observed yearly trend of ASM, the rate of change needed to calculate sample size was set as follows.

Rate of change: 0.05/year, 0.10/year, 0.15/year, 0.20/year

4.2 Calculation of sample size of target year class required for statistical examination of yearly trend of ASM.

ASM was calculated till the 1990 year class based on JARPA samples. Frequency of recent 6 year classes was deduced from frequency of 1985-1990 year classes in samples collected in south of 62S in Area IV in the 1999/2000-2003/04 JARPA survey. Frequency of recent 12 year classes was also deduced by the same manner, from frequency of 1979-1990 year classes in samples collected in south of 62S in Area IV in the 1993/94-2003/04 JARPA survey. Variance of error from regression line was deduced from regression analysis conducted to 1971-1990 year classes of females collected in Area IV by 1987/88-2003/04 JARPA surveys.

Calculated sample sizes for 6-years research period and 12-years research period is shown in Table 5.

4.3 Correction coefficient

To calculate the required total sample size, sample size of target year classes should be divided according to expected ratio of target year classes in the total samples.

Collection coefficient for 6-years research period was deduced from ratio of 1985-1990 year classes of females in the samples collected in south of 62S in Area IV during 1999/2000-2003/04 JARPA surveys (Fig.6-1; 25.7). Collection coefficient for 12-years research period was also deduced by the same manner, from ratio of 1979-1990 year classes of females in the samples collected in south of 62S in Area IV during 1993/94-2003/04 JARPA surveys (Fig. 6-2; 16.2).

As for fin whale, no data was available about year class composition in the total samples. Correction coefficient calculated for Antarctic minke whale was used for fin whale as an approximation.

4.4 Total sample size required for statistical examination of yearly trend of ASM

The calculated total sample size is shown in Table 6.

4.4.1 Calculated sample size of Antarctic minke whale

As explained above, rate of change in ASM observed in Antarctic minke whale from commercial data and JARPA sample was about 0.20/year and stable around zero or slightly increasing in recent year class. It is not plausible that the change starts in the rate of 0.2/year, rather it seems to start more slowly. Then the required total sample size for statistical examination of yearly trend of ASM in 6-years research period, assuming initial rate of change as 0.10/year, was calculated as 1288 in each research year.

4.4.2 Calculated sample size of fin whale

As explained above, rate of change in ASM observed in fin whale from commercial whaling data was about 0.1/year. The required total sample size for statistical examination of yearly trend of ASM in 12-years research period was calculated as 131 samples in each research year for that rate of change.

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Table 1. Sample size of mature females required for statistical examination of yearly trend.

Research period	Initial Rate(%)	Rate of change									
		+1%	-1%	+1.5%	-1.5%	+2%	-2%	+2.5%	-2.5%	+3%	-3%
6 years	30%	1060	944	462	438	256	259	162	175	111	131
	40%	1175	1118	519	507	291	292	186	192	130	138
	50%	1195	1195	534	534	303	303	197	197	139	139
	60%	1118	1175	507	519	292	291	192	186	138	130
	70%	944	1060	438	462	259	256	175	162	131	111
	80%	674	848	328	363	206	197	154	123	134	83
	90%	304	539	203	221	-	116	-	70	-	46
12 years	30%	126	99	55	50	31	35	20	39	14	-
	40%	136	122	61	58	35	36	23	26	17	23
	50%	135	135	62	62	36	36	25	25	19	19
	60%	122	136	58	61	36	35	26	23	23	17
	70%	99	126	50	55	35	31	39	20	-	14
	80%	63	104	43	44	-	24	-	15	-	10
	90%	-	71	-	29	-	15	-	9	-	6

Table 2. Total sample size of Antarctic minke whales required for statistical examination of yearly trend.

Research period	Initial Rate(%)	Rate of change									
		+1%	-1%	+1.5%	-1.5%	+2%	-2%	+2.5%	-2.5%	+3%	-3%
6 years	80%	2022	2544	984	1089	618	591	462	369	402	249
	90%	912	**1617**	609	**663**	-	**348**	-	**210**	-	**138**
12 years	80%	189	312	129	132	-	72	-	45	-	30
	90%	-	213	-	87	-	45	-	27	-	18

Table 3. Total sample size of humpback whales required for statistical examination of yearly trend .

Research period	Initial Rate(%)	Rate of change									
		+1%	-1%	+1.5%	-1.5%	+2%	-2%	+2.5%	-2.5%	+3%	-3%
6 years	30%	3083	2746	1344	1274	745	754	472	509	323	381
	40%	3417	3252	1510	1475	847	850	541	559	379	402
	50%	3475	3475	1553	1553	882	882	573	573	405	405
	60%	3252	3417	1475	1510	850	847	559	541	402	379
	70%	2746	3083	1274	1344	754	745	509	472	381	323
12 years	30%	367	288	**160**	**146**	91	102	59	114	**41**	**-**
	40%	396	355	**178**	**169**	102	105	67	76	**50**	**67**
	50%	393	393	**181**	**181**	105	105	73	73	**56**	**56**
	60%	355	396	**169**	**178**	105	102	76	67	**67**	**50**
	70%	288	367	**146**	**160**	102	91	114	59	**-**	**41**

Table 4. Total sample size of fin whales required for statistical examination of yearly trend.

Research period	Initial Rate(%)	Rate of change									
		+1%	-1%	+1.5%	-1.5%	+2%	-2%	+2.5%	-2.5%	+3%	-3%
6 years	30%	2887	2571	1259	1193	698	706	442	477	303	357
	40%	3200	3045	1414	1381	793	796	507	523	355	376
	50%	3255	3255	1455	1455	826	826	537	537	379	379
	60%	3045	3200	1381	1414	796	793	523	507	376	355
12 years	30%	344	270	150	137	**85**	**96**	**55**	**107**	39	-
	40%	371	333	167	158	**96**	**99**	**63**	**71**	47	63
	50%	368	368	169	169	**99**	**99**	**69**	**69**	52	52
	60%	333	371	158	167	**99**	**96**	**71**	**63**	63	47

Table 5. Sample size of female whales of recent 6(12) year classes required for statistical examination of yearly trend of ASM.

Research period	Rate of change			
	0.05/year	0.10/year	0.15/year	0.20/year
6 years	199	**50**	23	**13**
12 years	30	**8**	4	**2**

Table 6. Total sample size required for statistical examination of yearly trend of ASM.

Research period	Rate of change			
	0.05/year	0.10/year	0.15/year	0.20/year
6 years	5125	**1288**	594	**336**
12 years	488	**131**	66	**35**

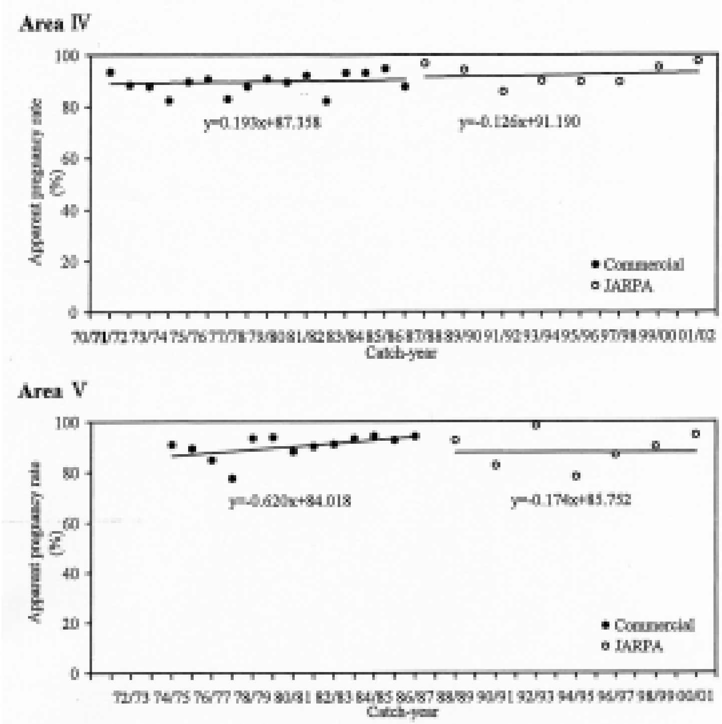


Fig. 1. PPF of Antarctic minke whales, caught during 1971/72-1986/87 by commercial whaling and 1987/88-2001/02 by JARPA surveys conducted in Areas IV and V (From Zenitani *et al*. (2001)) .

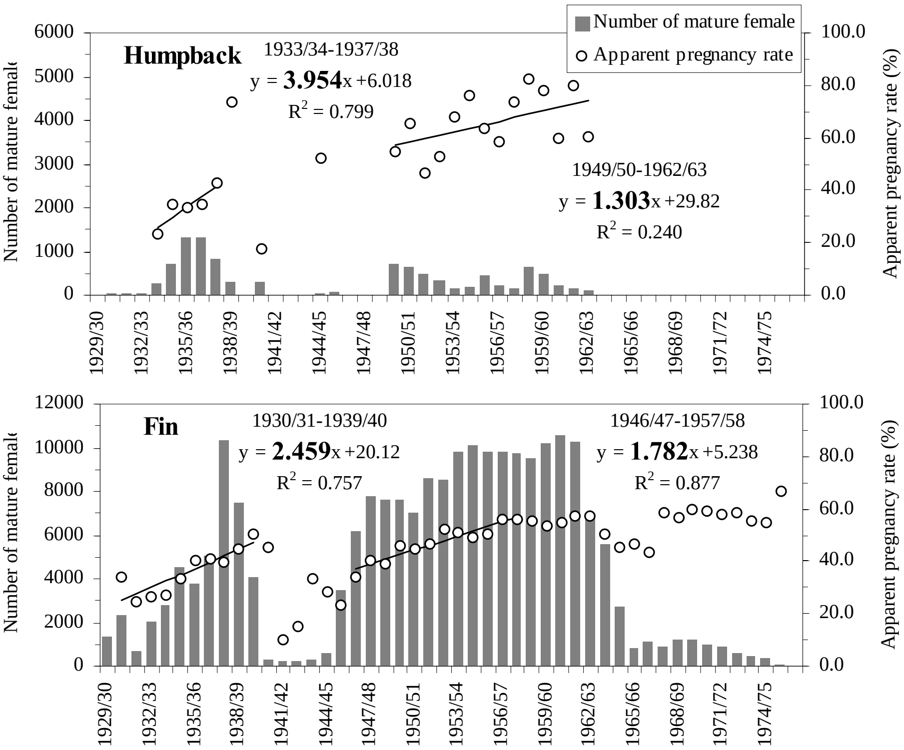


Fig. 2. APR of humpback and fin whales caught in Antarctic Ocean (Data extracted from International Whaling Statistics).

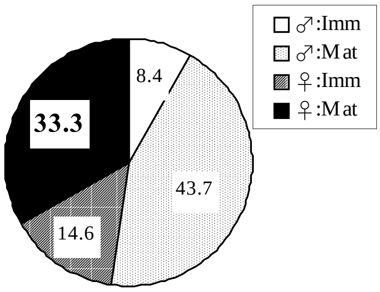


Fig. 3-1. Sexual and maturity composition of Antarctic minke whales taken by JARPA surveys in 1989/90-2003/04 in south of 62° S

in Antarctic Areas IV and V.

Correction coefficient

=100/33.3 =3.00

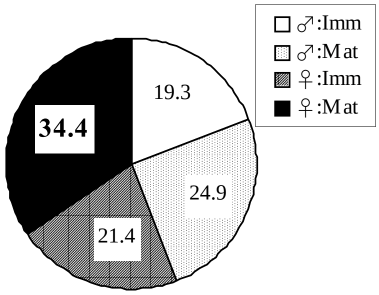


Fig. 3-2. Sexual and maturity composition of humpback whales taken by commercial whaling in 1930/31-1965/66 in Antarctic.

(Data extracted from International Whaling Statistics)

Correction coefficient

=100/34.4=2.91

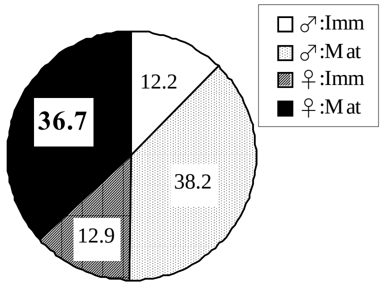
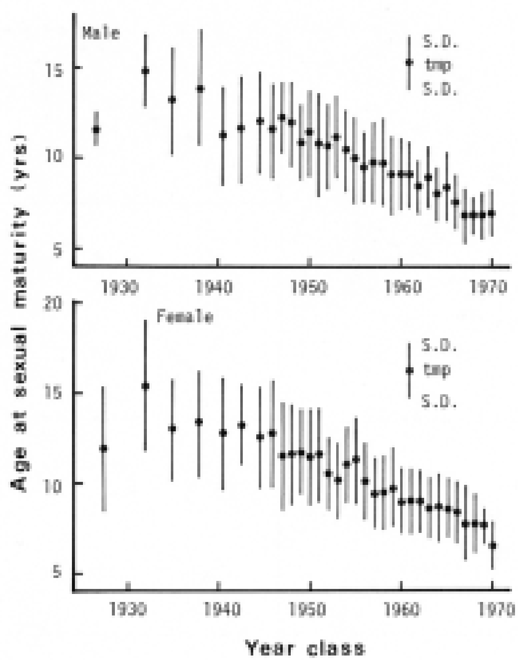


Fig. 3-3. Sexual and maturity composition of fin whales taken by commercial whaling in 1929/30-1975/76 in Antarctic.

(Data extracted from International Whaling Statistics)

Correction coefficient

= 100/36.7=2.72



Regression line fitted to 1945-1970 year classes

(Weight by sample size)

Male: Age at sexual maturity = 22.15-**0.219**t

Female: Age at sexual maturity = 21.64-**0.206**t

(From Kato (1987))

Fig. 4. Yearly trend of ASM in Antarctic minke whale (From Kato (1987)).

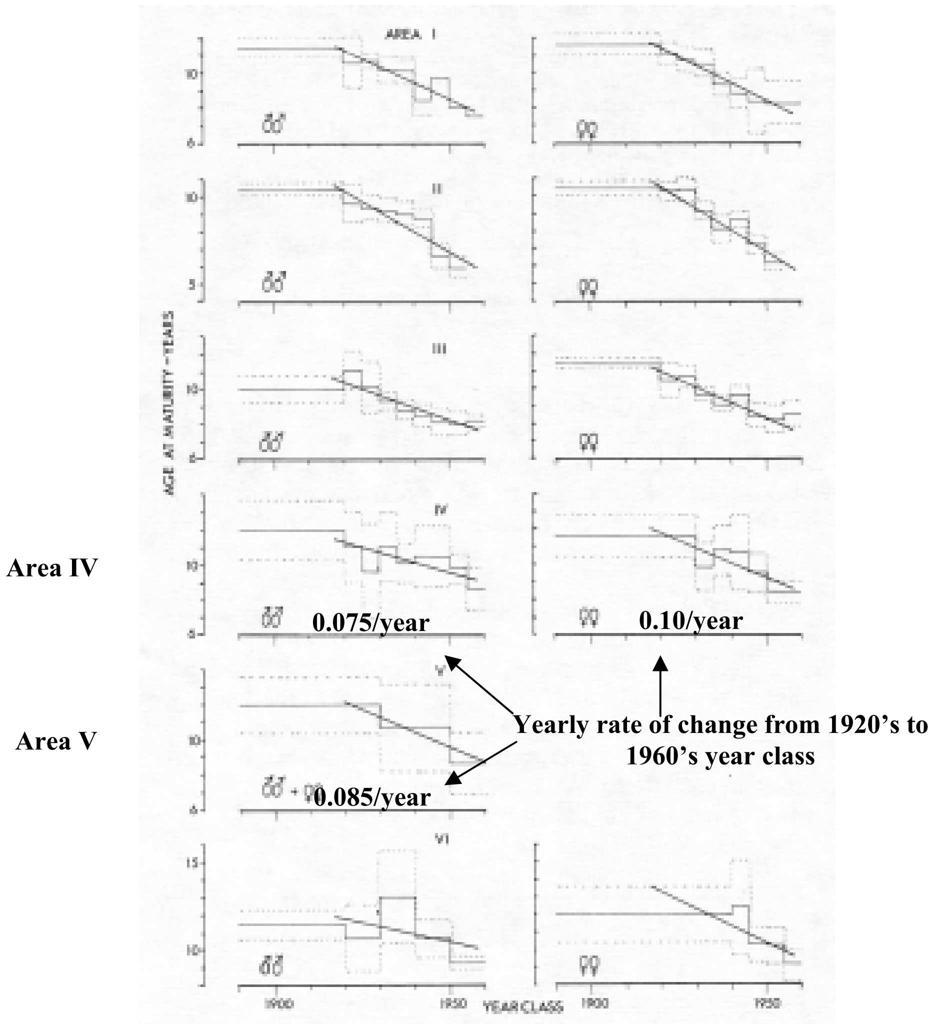


Fig. 5. Yearly trend of ASM in female fin whales (From Lockyer (1979)).

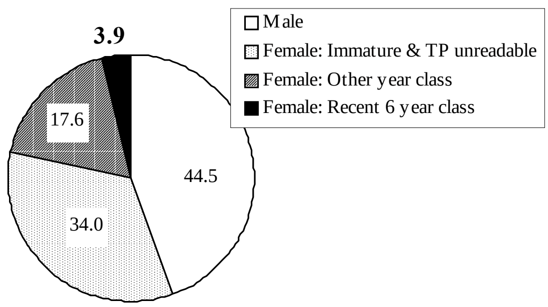


Fig. 6-1. Ratio of recent 6 year classes in the total whales sampled in south of 62° S in Area IV during 1999/2000-2003/04 JARPA surveys.

Correction coefficient

=100/3.9=25.7

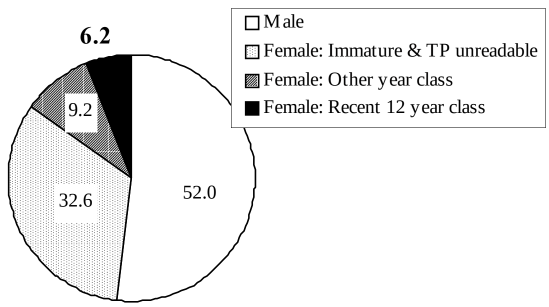


Fig. 6-2. Ratio of recent 12 year classes in the total whales sampled in south of 62° S in Area IV during 1993/94-2003/04 JARPA surveys.

Correction coefficient

=100/6.2=16.2

Appendix:

Estimation of sample size

This appendix explains the method of estimation of required sample size to test whether a significant increase or decrease of biological parameters is observed at the 5% level (i.e. to test if the slope of the regression is significantly different from 0 at the 5% level). For some biological parameters, not all samples are used for the analysis. Therefore estimated minimum simple size should be divided by the ratio of the sample size used for the analysis to overall samples.

In order to estimate increasing/decreasing rate per year of variable *y* per year during *a* years (In case of age at sexual maturity (Transition Phase (TP)), *a* year-classes) using samples collected bienniary, we consider a regression model following;

$$y_i = \beta_0 + \beta_1 x_i \quad (i=1,\cdots,m) \qquad (1)$$

where, *m* is the number of data to fit to the regression model. Then, upper and lower bound of the confidence interval are expressed by

$$\hat{\beta}_1 \pm t(0.025, m-2)\sqrt{\hat{V}(\hat{\beta}_1)} \qquad (2)$$

where, $\hat{\beta}_1$ is estimator of β_1 (i.e. level of the change per year we intend to detect), $\hat{V}(\hat{\beta}_1)$ is estimated variance of $\hat{\beta}_1$ and $t(0.025, m-2)$ is upper 2.5%-ile of t-distribution of *m* –2 degrees of freedom. For simplicity, in this calculation, it is assumed $t(0.025, m-2)$ 1.96 because t-distribution is asymptotically normal distribution. $\hat{V}(\hat{\beta}_1)$ can be expressed by the formula

$$\hat{V}(\hat{\beta}_1) = \frac{\hat{\sigma}^2}{\sum_{i=1}^{m}(x_i - \overline{X})^2} \qquad (3)$$

where, $\hat{\sigma}^2$ is residual mean square and $\overline{X}$ is estimated mean of *x* among the samples. From here, the formulation is different for the case of TP and that of APR and PPF. Therefore we separate the description into each case.

< PPF/ APR >

In this case, m=a/2, $x_i = 2i - 1$ and variance-covariance matrix for estimated value of APR/PPF (p_{x_i}) is as follows.

$$\mathbf{V} = \frac{1}{n}\mathbf{\Omega} = \frac{1}{n}\begin{bmatrix} p_1(1-p_1) & 0 & \cdots & 0 \\ 0 & p_3(1-p_3) & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & p_{2m-1}(1-p_{2m-1}) \end{bmatrix} \qquad (4)$$

In the case that generalized least-squares estimate $\hat{\beta}_1$>0, if $\hat{\beta}_1 - 1.96\sqrt{V(\hat{\beta}_1)} > 0$, would be significantly different from 0. Therefore, required sample size *n* can be estimated by solving inequality with respect to *n* following, which is derived from formulas (4).

$$n > \left(\frac{1.96}{\hat{\beta}_1}\right)^2 c_{22} \qquad (5)$$

In this case, c_{22} means element of matrix $\left[\mathbf{X}^{\mathbf{t}}\mathbf{\Omega}^{-1}\mathbf{X}\right]^{-1}$.

$$\mathbf{X} = \begin{bmatrix} 1 & x_1 \\ \cdots & \cdots \\ 1 & x_m \end{bmatrix}$$

In the case that $\hat{\beta}_1$<0, the inequality (5) would be derived, similarly.

Substituting the values to the formula (5), required sample size can be estimated.

＜Age at sexual maturity estimated by transition phase (TP)＞

As for TP, because compositions of year-classes are different by year, samples should be appropriately weighted to estimate value of the denominator of formula (3) $\sum_{i=1}^{m}(x_i - \overline{X})^2$. For a=6, we calculated a weighted $\sum_{i=1}^{m}(x_i - \overline{X})^2$ for 1985-1990 year-classes from samples collected in south of 62S in Area IV during 1999/2000-2003/04 JARPA surveys. For a=12, we calculated a weighted $\sum_{i=1}^{m}(x_i - \overline{X})^2$ for 1979-1990 year-classes from samples collected in south of 62S in Area IV during 1993/94-2003/04 JARPA surveys. The following paragraph shows how samples are weighted by sample size.

Setting n_{jk} as the number of samples of year-class k caught in year j and n_j as the total sample size of a year-classes caught in year j, the denominator of formula (3) is

$$\sum_{i=1}^{m}(x_i - \overline{X})^2 = \sum_{j=1}^{b}\sum_{k=1}^{a} n_{j,k}(x_k - \overline{X})^2$$
$$= \sum_{j=1}^{b} n_j \sum_{k=1}^{a}\left(\frac{n_{j,k}}{n_j}\right)(x_k - \overline{X})^2$$

where b is the number of years when survey is conducted. For simplicity, assuming that the number of samples of year-class a (n_j) and composition of the numbers of samples by year-class (n_{jk}/n_j) is constant every year, this formula became

$$\sum_{i=1}^{m}(x_i - \overline{X})^2 = bn\sum_{k=1}^{a}\left(\frac{n_k}{n}\right)(x_k - \overline{X})^2 \qquad (6).$$

Substituting the right hand side of formula (6) to denominator of formula (3),

$$V(\hat{\beta}_1) = \frac{\hat{\sigma}^2}{bn\sum_{k=1}^{a}\left(\frac{n_k}{n}\right)(x_k - \overline{X})^2} \qquad (3)''$$

Similar to the derivation of the formula (5), from this formula,

$$n > \left(\frac{1.96}{\hat{\beta}_1}\right)^2 \frac{\hat{\sigma}^2}{b\sum_{k=1}^{a}\left(\frac{n_k}{n}\right)(x_k - \overline{X})^2} \qquad (7)$$

is derived ($b\sum_{k=1}^{a}\left(\frac{n_k}{n}\right)(x_k - \overline{X})^2$ =7.7 for a=6 and 51.1 for a=12).

Residual mean square ($\hat{\sigma}^2$) was deduced from regression analysis conducted to 1971-1990 year classes class (the period of which distinct yearly change in TP had not occurred) of females collected in Area IV by 1987/88-2003/04 JARPA surveys. By substituting this figure to σ^2 in formula (7), the required sample size can be calculated.

Similarly, required sample size can be estimated in the case of other parameters.

Appendix 7

Sample size of Antarctic minke whale for the purpose of monitoring yearly trend of blubber thickness

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We calculated the required sample size of the Antarctic minke whale to examine the yearly trend of blubber thickness in the Antarctic. This calculation is explained in detail by Bando et al. (in Appendix 6) which tests whether there is significant trend of blubber thickness at the 5 % level for 6 years periods. For this calculation, we used mature males and pregnant females (not lactating) sampled at southward of 62°S by JARPA. Because the blubber thickness is highly affected by the feeding period, samples taken at the end of the feeding season (February) were used.

The change of blubber thicknesses per year were estimated as approximately 0.05 cm for both mature males and pregnant females, using JARPA data in Area IV (Figs. 1 and 2). The calculated sample sizes for each mature male and pregnant female in February were 123 and 145, respectively. The correction coefficients (inverse numbers of each sexual stage proportion in total samples collected at southward of 62°S in Area IV from 1999/2000 to 2003/04) used to estimate entire sample sizes from the sample sizes of each sexual maturity group in February were 7.90 and 5.64, respectively (Bando and Zenitani, unpublished). Using these correction coefficients, total sample sizes for mature male and pregnant female in entire survey season were calculated as 972 and 818, respectively.

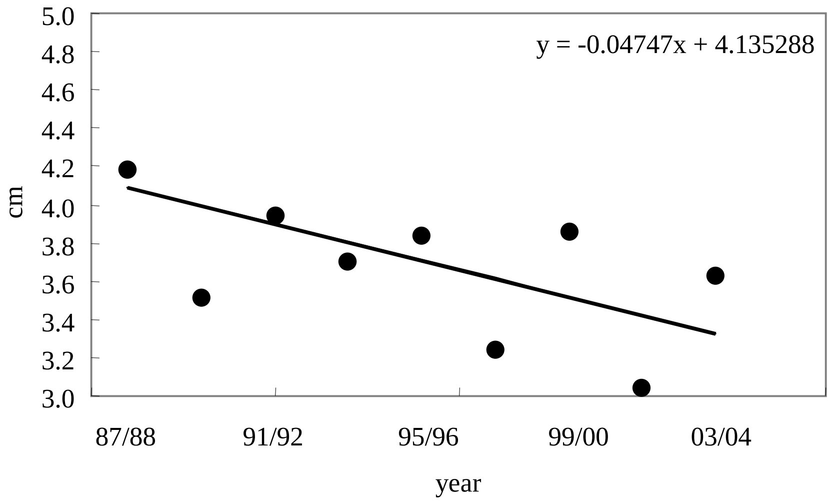

Fig. 1. Trend of blubber thickness of mature male in Area IV (southward of 62S) in February.

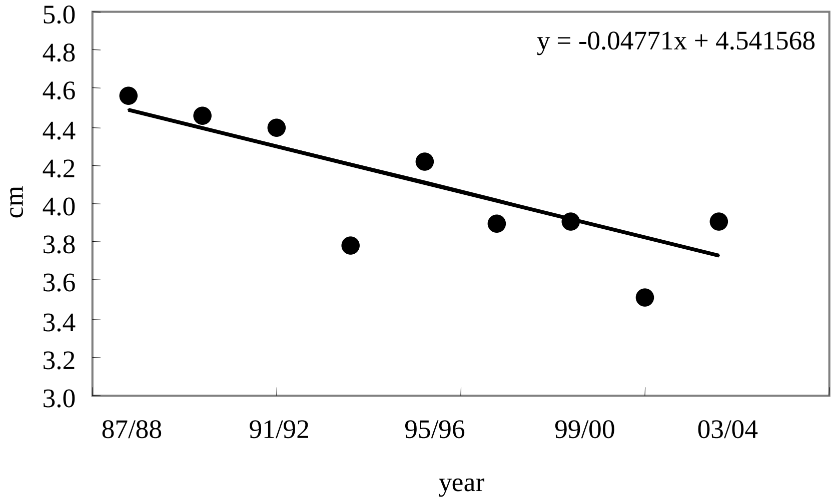

Fig. 2. Trend of blubber thickness of pregnant female in Area IV (southward of 62S) in February.

Appendix 8

Sample size required for genetic mark-recapture method to monitor population trend

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INTRODUCTION

Mark-recapture method has been used in whale studies to estimate population abundance and to examine migration pattern. Such studies in recent years have utilized biopsy sampling and molecular genetic markers. Use of the biopsy samples, however, is not very practical because the amount of effort involved to obtain large number of sample size is excessive. In order to compensate the deficiency, paternity testing in catches on the basis of DNA profiles of mother-fetus pairs and those of matured males genotyped from a set of microsatellite markers is more effective. Suspected fathers for the fetus are looked for, and such matchings combined with the traditional mark-recapture analysis such as the Petersen method can be used to estimate population abundance and to monitor population trend (e.g., Skaug and Øien, 2004). Attempts with this approach may be also used to describe stock structure and migration pattern.

Here we calculated sample size required to conduct the above approach in JARPAII for the Antarctic minke whales from the Area IV+V west .

METHODS

Biological information: The number of matured males and fetus in future JARPAII samples were projected from the data obtained during the JARPA averaged over the eight seasons (Table 1). The number of fetus was equaled the number of pregnant females.

Mark-recapture method: In this analysis, the total number of mature males genotyped in a sample formed the first capture sample, the total number of fetus genotyped formed the second capture, and the total number of father-fetus matchings formed the recapture. It is then important to note that this method estimate male abundance in the population. Petersen mark-recapture method modified by Chapman (1951) was used to infer male abundance (Nm):

$$Nm = \{(M+1)(C+1) / (R+1)\}-1,$$

with variance,

$$V(Nm) = (M+1)(C+1)(M-R)(C-R) / (R+1)(R+1)(R+2),$$

where, for the Antarctic minke whales analysis, M is the number of the captured mature males, C is the total number of genotyped fetus, and R is the number of fetus in C that matched to the fathers in M.

These three parameters were then replaced with the reproductive information given in Table 2 that also incorporate sample size, S, such as M=0.462S and C=0.243S. R depends on matching percent, so that R=0.243S (matching percent).

The minke whale abundance in this area was estimated to be on average approximately 100,000 (102,292: 63,971 to 170,047) from the number of sightings between 1990/91 to 2002/03 seasons (Hakamada et al., 2005; T. Hakamada, personal communication). Applying the biological information we used (% mature males in the total sample), this population abundance indicates that the male abundance in this area is slightly below 50,000.

RESULTS AND DISCUSSION

Table 2 shows the samples size from 400 to 1000 with four different matching percent (1.0, 1.5, 2.0, and 2.5%) giving different levels of abundance estimates and coefficient of variation (CV). As expected, single year samplings provide lower abundance and higher CV than when the samples were pooled for three seasons obtained from six years research. Hereafter, we consider only the latter.

Biological information we used (i.e., M and C in the equation) and the male abundance we have (50,000) were thought to be the most reliable among the all parameters we used because these values were obtained from the large amount of data of the JARPA. The calculations showed that in order to have the male abundance of about 50,000 the combinations of % matching-sample size should be 1%-1200, 1.5%-1800, 2%-2400, and 2.5%-3000. In other word, with male abundance estimate of about 50,000, we expect to see the % matching from 1% to 2.5% with sample size from 400 to 1000. These % matchings are comparable to the reported values in the similar studies (e.g., Skaug and Øien, 2004). In Norway, similar approach was conducted to the Atlantic minke whales in their DNA register. From four matchings with reasonable statistical power from the DNA profiles of 288 mother-fetus pairs compared to the total of 3301 registered minke whales yielded five true fathers expected in the Norwegian DNA database.

The key issue that would influence our approach, however, is the number of microsatellite loci in the paternity analysis part of the method. Currently, up to 10 loci has been used for individual identification in the Antarctic minke whales in our institution, which is similar to Skaug and Øien (2004). The effort will then apply to increase the number of the loci for the analysis in order to have better resolution and higher statistical power. In addition, DNA profiles of the fathers estimated from the mother-fetus pairs is partial, so that likelihood function of the paternity will be required to evaluate the statistical confidence of the paternity (Marshall et al., 1998). It is also important to note that, even with increased number of maker loci, we might not have any matchings in our samples if the population abundance is much higher than previously estimated.

CONCLUSION

Considering that we will conduct long-term monitoring of trends in population abundance, values of Nm estimated in future based on the method we are proposing need to be higher confidence, i.e., Nm with low CV. This indicates the sample size of 800-1000 per year will be suitable.

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Table 1. Biological information of Antarctic minke whales from Area IV+VW obtained from JARPA surveys.

	Biological information					
	Males			Females		
JARPA season	MT	MMM	MMT	FT	PFF	PFT
89/90-90/91	48.9	89.7	43.9	51.1	64	32.7
91/92-92/93	56.3	83.9	47.2	43.7	62.4	27.3
93/94-94/95	68.4	83.2	56.9	31.6	44.2	14
95/96-96/97	56.7	81.5	46.2	43.3	61.1	26.5
97/98-98/99	58.8	77.4	45.5	41.2	36.5	15
99/00-00/01	56.4	80.3	45.3	43.6	57.1	24.9
01/02-02/03	46.7	80.6	37.6	53.3	62	33.1
Average	56	82.4	46.2	44	55.3	24.3

Abbreviations: MT = Proportion of males in total sample, MMM = Proportion of matured males in total males, MMT = Proportion of matured males in total sample, FT = Proportion of females in total sample, PFF = Proportion of pregnant females in total females, PFT = Proportion of pregnant females in total females.

Table 2. Sample sizes (S) and coefficient of variance (CV) for abundance estimates calculated from Petersen mark-recapture method modified by Chapman (1951) with different matching %. SD = standard deviation, and see text for other abbreviations (M, C, R, Nm).

Single year sampling							Three seasons pooled						
S	M	C	R	Nm	SD	CV	S	M	C	R	Nm	SD	CV
1.0% matching													
400	184.8	97.2	1.0	9251	5285	0.571	1200	554.4	291.6	2.9	41498	18526	0.446
600	277.2	145.8	1.5	16614	8821	0.531	1800	831.6	437.4	4.4	67921	26651	0.392
800	369.6	194.4	1.9	24597	12243	0.498	2400	1108.8	583.2	5.8	94897	33607	0.354
1000	462.0	243.0	2.4	32935	15481	0.470	3000	1386.0	729.0	7.3	122135	39724	0.325
1.5% matching													
400	184.8	97.2	1.5	7422	3915	0.528	1200	554.4	291.6	4.4	30239	11810	0.391
600	277.2	145.8	2.2	12814	6159	0.481	1800	831.6	437.4	6.6	48275	16282	0.337
800	369.6	194.4	2.9	18491	8213	0.444	2400	1108.8	583.2	8.7	66510	20029	0.301
1000	462.0	243.0	3.6	24320	10088	0.415	3000	1386.0	729.0	10.9	84834	23294	0.275
2.0% matching													
400	184.8	97.2	1.9	6197	3049	0.492	1200	554.4	291.6	5.8	23786	8348	0.351
600	277.2	145.8	2.9	10428	4608	0.442	1800	831.6	437.4	8.7	37444	11228	0.300
800	369.6	194.4	3.9	14814	5989	0.404	2400	1108.8	583.2	11.7	51195	13621	0.266
1000	462.0	243.0	4.9	19278	7226	0.375	3000	1386.0	729.0	14.6	64987	15700	0.242
2.5% matching													
400	184.8	97.2	2.4	5318	2460	0.463	1200	554.4	291.6	7.3	19602	6292	0.321
600	277.2	145.8	3.6	8791	3611	0.411	1800	831.6	437.4	10.9	30582	8327	0.272
800	369.6	194.4	4.9	12357	4610	0.373	2400	1108.8	583.2	14.6	41613	10012	0.241
1000	462.0	243.0	6.1	15967	5495	0.344	3000	1386.0	729.0	18.2	52665	11475	0.218

Appendix 9

Effect on the stock of the catches during JARPA II

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The possible effects of an annual take of 850 minke whales (425 males and 425 females) during JARPA II on Eastern Indian Ocean stock (I-stock) and Western South Pacific stock (P-stock), respectively, are examined by using Hitter Methodology. Further, the possible effects of an annual take of 50 humpback whales (25 males and 25 females) from Areas IV and V alternatively on Western Australian Stock (D-stock) and Eastern Australian Stock (E-stock), respectively, are also examined by using population dynamics model in Johnston and Butterworth (2005).

MATERIALS AND METHODS

Minke whale

Based on the knowledge on stock structure, it is assumed a scenario that there is one stock in west of 165oE (I-stock) and another in east of 165°E (P-stock), respectively and that I-stock and P-stock are mixing between 130 °E and 175 °E. Table 2 shows previous catches by sex from I-stock and P-stock, respectively. Survey will be conducted in 35 °E-175 °E in the first year and in 130 °E-145 °W in the second year. Survey will be conducted in each area every two years alternately. Therefore, animals will be taken in 130 °E-175 °E every year, where the two stocks are assumed to be mixing. As for sex ratio of minke whales to be harvested in the future, we have assumed that it will be 1:1. A standard scenario as for future catches is as follows. Assuming that the number of animals taken and mixing rate in 130 °E-175 °E is almost same in the first year and the second year, the number of animals taken from P-stock in the first year and the number of animals from I-stock in the second year would be almost same. For example, assuming approximately 284 (=850/3) animals are taken in 130 °E-175 °E every year and that mixing rate of I-stock is 50% in this sector, from I-stock, 708 animals would be taken in the first year and 142 in the second year and, from P-stock, 142 animals would be taken in the first year and 708 animals in the second year. Therefore, it is assumed that 850 animals are taken from I-stock and P-stock every two years, alternately, as a standard catch scenario. As sensitivity test with respect to future catches, the case that animals in 130 °E-175 °E are from I-stock is also examined. Because a ratio of averaged abundance in western part of Area V (130 oE -165oE) estimated from 1996/97–2002/03 JARPA to that in 130 °E –145 °W is about 1/3. It can be assumed that 850 animals (425 males and 425 females) are taken from I-stock in the first year and 284 animals (142 males and 142 females) are taken in the second year. Future catches assumed in standard scenario and in sensitivity test are shown in Table 3.

As for abundance estimate, two scenarios are assumed. One is assumption that 192,653 (CV=0.192) in I-stock and 212,258 (CV=0.152) in P-stock based on estimates from CPII in Branch and Butterworth (2001). The other is 228,349 (CV=0.092) in I-stock and 95,116 (CV=0.168) based on the latest abundance estimate from JARPA in 2001/02 and 2002/03 (Hakamada et al., 2005). It is also assumed that g(0)=0.611 (Okamura et al., in press). The case where the abundances are assumed to be the 90% lower limit for the estimate has been also investigated as in past examinations for impacts on the stock using the Hitter methodology.

Humpback whale

The population dynamics model described in Johnston and Butterworth (2005) is used to examine the effect of the catches during JARPA II on the D-stock and E-stock. In the first year, 50 animals are planned to be taken from Area IV and 50 animals from Area V in the second year. The survey will be conducted in this way in each area every two years alternately. The previous catches from Areas IV and V in the south of 40°S are shown in Table 4. The previous catches from D-stock and E-stock in the breeding ground (North of 40°S) are shown in Table 5. Future catches assumed in this study are shown in Table 6.

Population dynamics model used in this study is following. Population dynamics model in breeding ground is

$$N_{y+1}^{B,D} = N_y^{B,D} + r^D N_y^{B,D} \left\{ 1 - \left(\frac{N_y^{B,D}}{K^D} \right)^{2.39} \right\} - C_y^D \qquad (1)$$

$$N_{y+1}^{B,E} = N_y^{B,E} + r^E N_y^{B,E} \left\{ 1 - \left(\frac{N_y^{B,E}}{K^E} \right)^{2.39} \right\} - C_y^E \qquad (2)$$

where $N_y^{B,D}$ and $N_y^{B,E}$ are the number of whales D-stock and E-stock in the breeding area at the start of year y, respectively, r^D and r^E are the intrinsic growth rate (the maximum per capita the population can achieve, when its size is very low) for D-stock and E-stock, respectively, K^D and K^E are the carrying capacity of D-stock and E-stock, respectively and C_y^D and C_y^E are the number of catches from D-stock and E-stock at the start of year y. Taking possibility of mixing of D-stock and E-stock animals in feeding area into account, population dynamics model in feeding area is

$$N_y^{F,IV} = \alpha N_y^{B,D} + (1-\beta) N_y^{B,E} \qquad (3)$$

$$N_y^{F,V} = (1-\alpha) N_y^{B,D} + \beta N_y^{B,E} \qquad (4)$$

where $N_y^{F,IV}$ and $N_y^{F,V}$ are abundances in Areas IV and V at the start of year y, α is the population of D-stock which feeds in Area IV and β is the population of E-stock which feeds in Area V. Catches in Areas IV and V are allocated in the proportion of abundance for D-stock and E-stock in these Areas.

Information on abundance used to estimate intrinsic growth rate and initial population size of the stocks in Johnston and Butterworth (2005) are relative abundance estimates in breeding area (IWC, 1996; Brown et al., 1997), CPUE data in breeding area (Chittleborough, 1965), Abundance estimates in feeding area from JARPA (Matsuoka et al., 2005), Abundance estimate in breeding area (Bannister and Hedley, 2001;Brown et al., 1997) and Abundance estimates in feeding area from IWC/IDCR-SOWER (Branch and Butterworth, 2002). The abundance estimates from JARPA are treated as a relative index of abundance in this study same as Johnston and Butterworth (2005). These figures are shown in Table 7 – 11.

By fitting the models described above to abundance data, Johnston and Butterworth (2005) obtained estimates r^D =0.122, r^E =0.126, K^D =16,879, K^E =33,857, α =0.944 and β =0.671. These estimates are used in this study.

RESULTS AND DISCUSSIONS

Minke whale

For each option, depletions in 1987/88 (when commercial whaling ceased), in 2005/06 (present), in 2011/12 (after 6 times of surveys) are shown. For reference, depletion after 30 years is also shown.

As shown in Table 12, both for best estimate and for 90% lower limit, even if MSYR(1+)=1%, abundance would show increasing trend when 850 whales are taken every year from 2005/06. For P-stock, abundance keeps nearly carrying capacity.

Table 13 shows results of sensitivity test. This table shows similar results in Table 13 and suggests no ill effect of the catches on the I-stock and P-stock.

Therefore, it can be concluded that there would be no negative effect on the minke whale stocks of these future catches.

Humpback whale

Figs. 1 and 2 show that population trajectories relative to initial population size for D-stock and E-stock, respectively. For comparison, the population trajectories in the case of 0 future catch are also shown. As both Figs. show, there is little difference among the trajectory for 50 annual caches and that for 0 future catches. Therefore, it can be concluded that there is no negative effect on the humpback whale stocks.

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Table 1. Abundance estimates used in this study.

survey	I-stock	P-stock
IWC-IDCR	192,653 (CV=0.162) in 1987/88	212,258 (CV=0.152) in 1988/89
JARPA	228,349 (CV=0.142) in 2002/03	95,116 (CV=0.168) in 2002/03

Table 2. Previous catches (1955/56-2004/05) by sex from I-stock and P-stock. We assume all samples are taken from I-stock and P-stock, respectively, because 2004/05 JARPA haven't completed yet.

	I-stock		P-stock	
year	Male	Female	Male	Female
1955	1	1	0	0
1956	0	0	0	0
1957	208	273	0	0
1958	18	24	0	0
1959	76	99	0	0
1960	33	39	31	43
1961	1	0	1	0
1962	9	10	0	0
1963	81	20	3	3
1964	2	3	0	0
1965	1	0	4	3
1966	7	2	1	4
1967	390	211	0	1
1968	108	39	2	2
1969	85	53	7	4
1970	120	82	0	0
1971	1222	1965	0	0
1972	2911	2780	0	0
1973	2161	3855	10	3
1974	1769	2622	0	0
1975	1620	2156	18	13
1976	2272	3669	0	0
1977	1117	2477	357	249
1978	1454	2660	73	52
1979	2228	2636	2	4
1980	1740	2969	336	591
1981	1383	2705	644	183
1982	1619	3357	287	489
1983	1466	2297	148	399
1984	944	2060	294	90
1985	805	1752	302	98
1986	692	1895	129	285
1987	154	119	0	0
1988	0	0	86	155
1989	185	144	0	0
1990	99	90	65	73
1991	165	123	0	0
1992	110	96	57	67
1993	200	130	0	0
1994	85	55	115	75
1995	273	167	0	0
1996	59	68	146	167
1997	279	159	0	0
1998	116	68	131	74
1999	233	206	0	0
2000	86	55	172	127
2001	201	239	0	0
2002	51	49	184	156
2003	200	240	0	0
2004	220	220	220	220

Table 3. Assumed future catches from I-stock and P-stock under standard scenario and sensitivity test, respectively.

standard scenario

	I-stock		P-stock	
year	Male	Female	Male	Female
2005	425	425	0	0
2006	0	0	425	425
2007	425	425	0	0
2008	0	0	425	425
2009	425	425	0	0
2010	0	0	425	425
2011	425	425	0	0
2012	0	0	425	425
2013	425	425	0	0
2014	0	0	425	425
2015	425	425	0	0
2016	0	0	425	425
2017	425	425	0	0
2018	0	0	425	425
2019	425	425	0	0
2020	0	0	425	425
2021	425	425	0	0
2022	0	0	425	425
2023	425	425	0	0
2024	0	0	425	425
2025	425	425	0	0
2026	0	0	425	425
2027	425	425	0	0
2028	0	0	425	425
2029	425	425	0	0
2030	0	0	425	425
2031	425	425	0	0
2032	0	0	425	425
2033	425	425	0	0
2034	0	0	425	425

sensitivity test

	I-stock		P-stock	
year	Male	Female	Male	Female
2005	425	425	0	0
2006	142	142	283	283
2007	425	425	0	0
2008	142	142	283	283
2009	425	425	0	0
2010	142	142	283	283
2011	425	425	0	0
2012	142	142	283	283
2013	425	425	0	0
2014	142	142	283	283
2015	425	425	0	0
2016	142	142	283	283
2017	425	425	0	0
2018	142	142	283	283
2019	425	425	0	0
2020	142	142	283	283
2021	425	425	0	0
2022	142	142	283	283
2023	425	425	0	0
2024	142	142	283	283
2025	425	425	0	0
2026	142	142	283	283
2027	425	425	0	0
2028	142	142	283	283
2029	425	425	0	0
2030	142	142	283	283
2031	425	425	0	0
2032	142	142	283	283
2033	425	425	0	0
2034	142	142	283	283

Table 4. The catches of humpback whales from Areas IV and V in the south of 40^oS

Year	Area IV	Area V	Year	Area IV	Area V
1904	0	0	1955	844	157
1905	0	0	1956	27	182
1906	0	0	1957	545	1,159
1907	0	0	1958	1,661	3,182
1908	217	0	1959	66	13,159
1909	118	0	1960	779	9,847
1910	83	0	1961	468	1,936
1911	0	0	1962	2,352	291
1912	0	0	1963	289	322
1913	0	0	1964	92	71
1914	0	0	1965	76	266
1915	0	0	1966	172	112
1916	0	0	1967	98	27
1917	0	0	1968	0	0
1918	0	0	1969	0	0
1919	0	0	1970	0	0
1920	0	0	1971	0	0
1921	0	0	1972	0	0
1922	0	0	1973	0	0
1923	0	0	1974	0	0
1924	0	0	1975	0	0
1925	0	0	1976	0	0
1926	0	0	1977	0	0
1927	0	0	1978	0	0
1928	11	0	1979	0	0
1929	0	0	1980	0	0
1930	0	0	1981	0	0
1931	159	0	1982	0	0
1932	82	0	1983	0	0
1933	593	0	1984	0	0
1934	1,340	0	1985	0	0
1935	938	4	1986	0	0
1936	1,435	0	1987	0	0
1937	832	0	1988	0	0
1938	835	24	1989	0	0
1939	0	0	1990	0	0
1940	0	0	1991	0	0
1941	0	0	1992	0	0
1942	0	0	1993	0	0
1943	0	0	1994	0	0
1944	0	0	1995	0	0
1945	0	0	1996	0	0
1946	0	0	1997	0	0
1947	1	0	1998	0	0
1948	11	74	1999	0	0
1949	725	1,308	2000	0	0
1950	1,208	998	2001	0	0
1951	958	487	2002	0	0
1952	224	723	2003	0	0
1953	310	1,121	2004	0	0
1954	379	2,615			

Table 5. The previous catches of humpback whales in the breeding ground (in the north of 40^{o}S)

Year	D-stock	E-stock
1904	0	0
1905	0	0
1906	0	0
1907	0	0
1908	0	0
1909	0	0
1910	0	0
1911	0	0
1912	296	296
1913	670.5	670.5
1914	1968	0
1915	1430	0
1916	0	0
1917	0	0
1918	0	0
1919	0	0
1920	0	0
1921	0	0
1922	155	0
1923	166	0
1924	0	0
1925	669	0
1926	735	0
1927	996	0
1928	1033	0
1929	0	0
1930	0	78
1931	0	110
1932	0	18
1933	0	44
1934	0	52
1935	0	57
1936	3072	69
1937	3242	55
1938	917	75
1939	0	80
1940	0	107
1941	0	86
1942	0	71
1943	0	90
1944	0	88
1945	0	107
1946	0	110
1947	2	101
1948	4	92
1949	193	141
1950	388	79
1951	1224	111
1952	1187	721
1953	1300	809
1954	1320	898
1955	1126	832
1956	1119	1013
1957	1120	1025
1958	967	1023
1959	737	1278
1960	573	1341
1961	587	981
1962	548	209
1963	87	0
1964	1	0
1965	5	0
1966	28	0
1967	12	0
1968	0	0
1969	0	0
1970	0	0
1971	0	0
1972	0	0
1973	0	0
1974	0	0
1975	0	0
1976	0	0
1977	0	0
1978	0	0
1979	0	0
1980	0	0
1981	0	0
1982	0	0
1983	0	0
1984	0	0
1985	0	0
1986	0	0
1987	0	0
1988	0	0
1989	0	0
1990	0	0
1991	0	0
1992	0	0
1993	0	0
1994	0	0
1995	0	0
1996	0	0
1997	0	0
1998	0	0
1999	0	0
2000	0	0
2001	0	0
2002	0	0
2003	0	0
2004	0	0

Table 6. Assumed future catches of humpback whales from Areas IV and V

Year	Area IV	Area V
2005	0	0
2006	0	0
2007	50	0
2008	0	50
2009	50	0
2010	0	50
2011	50	0
2012	0	50
2013	50	0
2014	0	50
2015	50	0
2016	0	50
2017	50	0
2018	0	50
2019	50	0
2020	0	50
2021	50	0
2022	0	50
2023	50	0
2024	0	50
2025	50	0
2026	0	50
2027	50	0
2028	0	50
2029	50	0
2030	0	50
2031	50	0
2032	0	50
2033	50	0
2034	0	50

Table 7. Relative abundance estimates in D-stock (IWC, 1996) and E-stock (Brown *et al*, 1997)

year	D-stock
1982	10.2
1986	16.7
1988	12.7
1991	23.6
1994	36.0
year	E-stock
1981	381
1982	493
1986	1008
1987	879
1991	1533
1993	1807
1996	2872

Table 8. CPUE data off the west and east coast of Australia (Chittleborough, 1965).

year	west（D-stock）	east（E-stock）
1950	0.475	
1951	0.424	
1952	0.347	
1953	0.353	0.972
1954	0.351	0.755
1955	0.244	0.779
1956	0.178	0.704
1957	0.146	0.714
1958	0.123	0.750
1959	0.090	0.740
1960	0.062	0.522
1961	0.055	0.230
1962	0.051	0.069

Table 9. JARPA estimates of abundance of humpback whales in feeding Areas IV and V (Matsuoka *et al*., 2005).

year	Area IV
1989/90	3873
1991/92	5203
1993/94	2740
1995/96	8850
1997/98	10874
1999/2000	16211
2001/02	33010
2003/04	31750
year	Area V
1990/91	767
1992/93	3837
1994/95	3567
1996/97	1543
1998/99	8301
2000/01	4720
2002/03	2735

Table 10. Estimates of breeding ground abundance of humpback whales used in the model

stock	abundance	year	source
D-stock	8000	1999	Bannister and Hedley (2001)
E-stock	3200	1996	Brown *et al*. (1997)

Table 11. Estimates of abundance of humpback whales south of 60^{o}S from the IWC/IDCR-SOWER sighting surveys.

year	circumpolar surveys	Area IV	Area V
1978/79	I	1039	-
1980/81	I	-	966
1985/86	II	-	568
1988/89	II	3375	-
1991/92	III	-	2066

Table 4. Effects on the Antarctic minke whales of 850 animals (425 males and 425 females) from I-stock and P-stock every two years alternately using Hitter Methodology.

I-stock

a. Assuming that abundance estimate from IDCR in CPII.

i) Hit 1987/88 total (1+) population of 315,245 (best estimate)

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	386,992	373,212	362,490	354,130	347,580
Depletion - 1987	81.5%	84.5%	87.0%	89.0%	90.7%
Depletion - 2005	85.2%	91.6%	95.2%	97.1%	98.1%
Depletion - 2011	86.4%	93.2%	96.4%	97.9%	98.6%
Depletion - 2035	90.3%	96.6%	98.3%	98.9%	99.2%
RY - 2005	831	1,125	1,112	988	850
MSY (+1)	2,322	4,479	6,525	8,499	10,427

ii) Hit 1987/88 total (1+) population of 228,741(90% lower limit)

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	301,953	288,992	278,628	270,336	263,684
Depletion - 1987	66.7%	67.0%	67.4%	67.8%	68.3%
Depletion - 2005	75.8%	82.4%	87.1%	90.3%	92.4%
Depletion - 2011	77.5%	85.3%	90.2%	93.0%	94.6%
Depletion - 2035	83.3%	92.5%	95.5%	96.6%	97.1%
RY - 2005	777	1,125	1,161	1,055	915
MSY (+1)	1,812	3,468	5,015	6,488	7,911

(Table 4 continued)

b. Assuming that latest abundance estimate from JARPA.

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	432,578	407,798	393,825	386,084	381,742
Depletion - 1987	76.8%	76.8%	77.2%	77.7%	78.4%
Depletion - 2005	84.0%	88.6%	91.8%	93.9%	95.2%
Depletion - 2011	85.3%	90.6%	93.8%	95.6%	96.6%
Depletion - 2035	89.6%	95.2%	97.0%	97.7%	98.0%
RY - 2005	848	1,123	1,099	971	834
MSY (+1)	2,595	4,894	7,089	9,266	11,452

i) Hit 2002/03 total (1+) population of 373,655 (best estimate)

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	339,807	315,157	300,402	291,880	286,997
Depletion - 1987	70.4%	69.8%	69.9%	70.3%	71.0%
Depletion - 2005	78.9%	84.3%	88.4%	91.3%	93.2%
Depletion - 2011	80.5%	87.0%	91.2%	93.7%	95.2%
Depletion - 2035	85.8%	93.3%	95.9%	96.9%	97.3%
RY - 2005	805	1,127	1,146	1,033	892
MSY (+1)	2,039	3,782	5,407	7,005	8,610

ii) Hit 1990 total (1+) population of 278,082 (90% lower limit)

(Table 4 continued)

P-stock

a. Assuming that abundance estimate from IDCR in CPII.

a) Hit 1988/89 total (1+) population of 347,324 (best estimate).

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	351,999	351,079	350,363	349,802	349,361
Depletion - 1987	98.1%	98.1%	98.1%	98.1%	98.2%
Depletion - 2005	98.2%	98.6%	98.9%	99.1%	99.2%
Depletion - 2011	97.4%	97.9%	98.2%	98.3%	98.4%
Depletion - 2035	95.7%	96.7%	97.2%	97.5%	97.7%
RY - 2005	160	184	188	185	180
MSY (+1)	2,112	4,213	6,307	8,395	10,481

b) Hit 1988/89 total (1+) population of 255,322 (90% lower limit)

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	260,005	259,089	258,373	257,812	257,370
Depletion - 1987	97.4%	97.4%	97.5%	97.5%	97.5%
Depletion - 2005	97.6%	98.2%	98.5%	98.7%	98.9%
Depletion - 2011	96.5%	97.1%	97.5%	97.7%	97.8%
Depletion - 2035	94.2%	95.5%	96.2%	96.6%	96.9%
RY - 2005	160	184	188	185	180
MSY (+1)	1,560	3,109	4,651	6,187	7,721

(Table 4 continued)

b. Assuming that latest abundance estimate from JARPA.

a) Hit 2002/03 total (1+) population of 155,641 (best estimate).

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	160,047	158,361	157,422	156,875	156,539
Depletion - 1987	95.8%	95.8%	95.8%	95.9%	95.9%
Depletion - 2005	96.1%	97.0%	97.5%	97.9%	98.1%
Depletion - 2011	94.3%	95.3%	95.9%	96.2%	96.4%
Depletion - 2035	90.4%	92.6%	93.8%	94.4%	94.9%
RY - 2005	159	184	188	185	181
MSY (+1)	960	1,900	2,834	3,765	4,696

b) Hit 2002/03 total (1+) population of 112,042 (90% lower limit)

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	116,492	114,801	113,849	113,293	112,952
Depletion - 1987	94.2%	94.2%	94.2%	94.3%	94.3%
Depletion - 2005	94.6%	95.8%	96.6%	97.1%	97.4%
Depletion - 2011	92.1%	93.5%	94.3%	94.7%	95.0%
Depletion - 2035	86.6%	89.7%	91.3%	92.2%	92.9%
RY - 2005	158	184	189	186	181
MSY (+1)	699	1,378	2,049	2,719	3,389

Table 5. Results of sensitivity test with respect to future catches. It is assumed that 284 animals (142 males and 142 females) are taken from I-stock and 566 (283 males and 283 females) from P-stock, instead of 850 animals from P-stock, during surveys in 130^{o}E –145^{o}W.

I-stock

a. Assuming that abundance estimate from IDCR in CPII.

i) Hit 1987/88 total (1+) population of 315,245 (best estimate)

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	386,992	373,212	362,490	354,130	347,580
Depletion - 1987	74.1%	74.6%	75.1%	75.7%	76.2%
Depletion - 2005	81.9%	87.3%	90.9%	93.2%	94.7%
Depletion - 2011	82.9%	89.1%	92.7%	94.7%	95.8%
Depletion - 2035	86.8%	93.6%	95.8%	96.7%	97.0%
RY - 2005	831	1,125	1,112	988	850
MSY (+1)	2,322	4,479	6,525	8,499	10,427

ii) Hit 1987/88 total (1+) population of 228,741(90% lower limit)

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	301,953	288,992	278,628	270,336	263,684
Depletion - 1987	66.7%	67.0%	67.4%	67.8%	68.3%
Depletion - 2005	75.8%	82.4%	87.1%	90.3%	92.4%
Depletion - 2011	77.0%	84.9%	89.7%	92.5%	94.1%
Depletion - 2035	81.7%	91.1%	94.4%	95.5%	96.0%
RY - 2005	777	1,125	1,161	1,055	915
MSY (+1)	1,812	3,468	5,015	6,488	7,911

(Table 5 continued)

b. Assuming that latest abundance estimate from JARPA.

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	432,578	407,798	393,825	386,084	381,742
Depletion - 1987	76.8%	76.8%	77.2%	77.7%	78.4%
Depletion - 2005	84.0%	88.6%	91.8%	93.9%	95.2%
Depletion - 2011	85.0%	90.3%	93.4%	95.2%	96.2%
Depletion - 2035	88.5%	94.3%	96.2%	96.9%	97.3%
RY - 2005	848	1,123	1,099	971	834
MSY (+1)	2,595	4,894	7,089	9,266	11,452

i) Hit 2002/03 total (1+) population of 373,655 (best estimate)

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	339,807	315,157	300,402	291,880	286,997
Depletion - 1987	70.4%	69.8%	69.9%	70.3%	71.0%
Depletion - 2005	78.9%	84.3%	88.4%	91.3%	93.2%
Depletion - 2011	80.1%	86.5%	90.7%	93.2%	94.7%
Depletion - 2035	84.4%	92.1%	94.8%	95.9%	96.4%
RY - 2005	805	1,127	1,146	1,033	892
MSY (+1)	2,039	3,782	5,407	7,005	8,610

ii) Hit 2002/03 total (1+) population of 278,082 (90% lower limit)

(Table 5 continued)

P-stock

a. Assuming that abundance estimate from IDCR in CPII.

a) Hit 1988/89 total (1+) population of 347,324 (best estimate).

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	160,047	158,361	157,422	156,875	156,539
Depletion - 1987	95.8%	95.8%	95.8%	95.9%	95.9%
Depletion - 2005	96.1%	97.0%	97.5%	97.9%	98.1%
Depletion - 2011	95.1%	96.2%	96.8%	97.1%	97.3%
Depletion - 2035	93.1%	95.0%	95.8%	96.3%	96.6%
RY - 2005	159	184	188	185	181
MSY (+1)	960	1,900	2,834	3,765	4,696

b) Hit 1988/89 total (1+) population of 255,322 (90% lower limit)

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	116,492	114,801	113,849	113,293	112,952
Depletion - 1987	94.2%	94.2%	94.2%	94.3%	94.3%
Depletion - 2005	94.6%	95.8%	96.6%	97.1%	97.4%
Depletion - 2011	93.3%	94.7%	95.5%	96.0%	96.2%
Depletion - 2035	90.4%	93.0%	94.2%	94.8%	95.3%
RY - 2005	158	184	189	186	181
MSY (+1)	699	1,378	2,049	2,719	3,389

(Table 5 continued)

b. Assuming that latest abundance estimate from JARPA.

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	160,047	158,361	157,422	156,875	156,539
Depletion - 1987	95.8%	95.8%	95.8%	95.9%	95.9%
Depletion - 2005	96.1%	97.0%	97.5%	97.9%	98.1%
Depletion - 2011	94.7%	95.8%	96.3%	96.7%	96.9%
Depletion - 2035	91.8%	93.9%	94.9%	95.4%	95.8%
RY - 2005	159	184	188	185	181
MSY (+1)	960	1,900	2,834	3,765	4,696

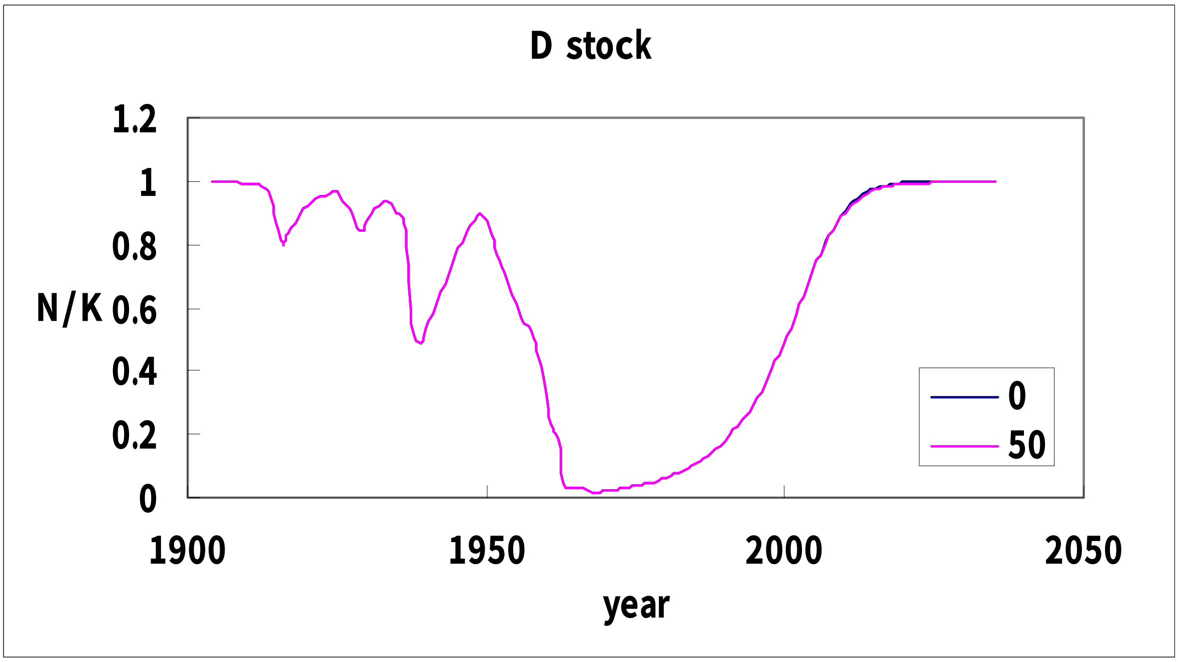
a) Hit 2002/03 total (1+) population of 155,641 (best estimate).

Statistic	MSYR (1+) (%)				
	1	2	3	4	5
K (1+)	116,492	114,801	113,849	113,293	112,952
Depletion - 1987	94.2%	94.2%	94.2%	94.3%	94.3%
Depletion - 2005	95.1%	96.2%	97.0%	97.5%	97.8%
Depletion - 2011	92.7%	94.1%	94.9%	95.4%	95.7%
Depletion - 2035	88.7%	91.4%	92.8%	93.6%	94.1%
RY - 2005	158	184	189	186	181
MSY (+1)	699	1,378	2,049	2,719	3,389

b) Hit 2002/03 total (1+) population of 112,042 (90% lower limit)

Fig. 1. D stock population trajectories relative to initial population size *K* in the case of 0 future catch and in the case annual 50 catches from Areas IV and V alternatively.

Fig. 2. E stock population trajectories relative to initial population size *K* in the case of 0 future catch and in the case of



annual 50 catches from Areas IV and V alternatively.