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Decline in energy storage in the Antarctic minke whale *Balaenoptera bonaerensis* in the Southern Ocean

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ABSTRACT

The annual trend in energy storage in the Antarctic minke whale was examined using catch data from all 18 JARPA survey years. The results of stepwise multiple linear regression analyses show that blubber thickness in minke whales has been decreasing for nearly two decades. The decrease in blubber thickness is estimated at -0.0190 cm/year, or close to 10 % for the whole JARPA period. Furthermore, “date”, “extent of diatom adhesion”, “sex”, “body length”, “fetus length” and “longitude” were all identified as partially independent predictors of blubber thickness. The direct interpretation of the decline in energy storage in the minke whales with time in terms of food availability is difficult, since no long term krill abundance series is available. However, competition among krill feeders must be considered as the most likely explanation of the decline, given the recent recovery of the stocks of large baleen whales.

INTRODUCTION

The Southern Ocean supports a simple food web with high productivity, and is an important feeding ground for many consumers. The Antarctic krill *Euphausia superba* is the most abundant and main prey for large baleen whales, seals and seabirds. The Antarctic minke whale *B. bonaerensis*, which is a small baleen whale, also depends largely on *E. superba* (Ohsumi 1979, Armstrong and Siegfried 1991, Ichii and Kato 1991, Ichii 1997).

Krill availability in the Antarctic Ocean is generally considered to be the most important limiting factor for population sizes of many krill feeders. Krill biomass is very high and many animals depend on this species, so that a sudden decrease in certain krill consumers could cause drastic changes in the population sizes of other consumers in Antarctic ecosystem. It has been hypothesised that after more than 50 years of commercial whaling and overexploitation of the large baleen whales, the relative abundance of the whale species was totally changed from the situation in the pre-whaling period (Laws 1977, Brown and Lockyer 1984). In parallel with the decline in abundance of the large baleen whales, the minke whale population presumably started to grow. According to the “whale reduction” or “krill surplus” hypothesis (Laws 1977), this growth is considered to be a result of abundant food supplies available to the minke whale after the decline of the large baleen whale populations.

The main objective of the present study was to examine trends in body condition of the Antarctic minke whale during the JARPA period. A second objective was to examine other factors that could have affected body condition and to review the energetic status of minke whales in the Southern Ocean.

MATERIALS AND METHODS

Sampling and measurements

Blubber thickness and all other variables used in the present investigation were measured in nearly all Antarctic minke whales taken by the Japanese Whaling Research Program under Special Permit in the Antarctic (JARPA) from 1987/88 to 2004/05. To avoid any bias resulting from growth or lactation, we used only mature males and pregnant females, but not lactating females or immature animals, for the present analyses (Table 2).

The research area covers the International Whaling Commission (IWC) Management Area III (East), Area IV, Area V and Area VI (West), south of 60°S in alternate years in austral summer seasons (Fig. 1). After capturing by three sighting/sampling vessels, the animals were placed aboard a research base vessel where they were examined. After outer observations were completed, body length (from snout tip to tail fluke notch in a straight line along the deck) and other morphological measurements were taken. Blubber thickness was measured to the nearest mm, by dissecting perpendicularly from skin to muscle without including connective tissue or black surface skin. The blubber thickness at mid-lateral region was used because this is a good indicator of body condition (Konishi 2006) (Fig. 2). Sex and maturity were recorded for each whale on the basis of routine observations of reproductive organs during dissection and tissue observations in the laboratory. The relevant stocks of Antarctic minke whale were defined as follows: Eastern Indian Ocean Stock (I-stock) Areas IIIE, IV and VW, Western South Pacific Stock (P-stock) Areas VE and VIW (see paper in this meeting). A diatom film is sometimes observed on the surface of the whales and may cover the entire body. The extent of diatom adhesion on the skin is a rough indicator of how long a whale has spent in cold waters (Table 1).

Statistical analysis

Whales accumulate fat during the summer feeding period and migrate to low latitude areas for reproduction. Like other baleen whales, the minke whale migrates to the Antarctic where it spends the austral summer feeding (Kato and Miyashita 1991, Kasamatsu *et al*. 1995). Thus, the time spent in the feeding area and geographical and biological variables which could be related to blubber thickness should be considered in body condition analysis. To take these factors into account and possibly exclude some of them, we conducted stepwise multiple linear regression analyses. Blubber thickness (in cm) was the independent variable. In the first run, we allowed the following independent variables: “date” (December 1st=day 1), “diatom adhesion” (0 to 4, Table 1), “sex” (1: male, 2: female), “stock” (1: I-stock, 2: P-stock), “body length” (in m) and “fetus length” (in cm). “Year” was also included as an independent variable to investigate a possible annual trend (87/88=1 88/89=2 89/91=3...). In a second run, “longitude” (in degrees east) was substituted for “stock”. At each step of the regression analysis, the next variable was included in the equation if the corresponding p-value was below 5 %.

RESULTS

Factors affecting body condition and its yearly trend

Blubber thickness ranged from 1.1 to 7.2 cm in mature males, and from 1.5 to 7.7 cm in pregnant females in both areas over the whole research period (Table 2).

In preliminary analyses, the yearly trend in blubber thickness near the end of the feeding season (only whales caught in February) for each sex and stocks (I and P) was examined. The results from the I-stock are displayed in Figure 3. Results from the P-stock were similar. In this analysis the variability the other variables (“date”, “diatom adhesion”, “body length”, “fetus length”) result in the large SDs displayed in the figure.

The stepwise multiple linear regression analyses included all possible dependent variables as predictors of blubber thickness at the 5 % level in both runs (Table 3 and 4). Thus, no variable was excluded. “Date” was the best predictor of blubber thickness followed by “diatom”, “sex”, “fetus length”, “year”, “stock” and “body length” in that order. The second run gave similar results. “Date” was the best predictor of the blubber thickness followed by “diatom”, “sex” and “fetus length”, “year”, “longitude” and “body length”. The coefficients of “year” were -0.0191cm/year (±0.0022 SE) and -0.0189 cm/year (±0.0022 SE), respectively in the two runs, showing that blubber thickness decreased significantly over the years (Table 3 and 4). The results also indicated that blubber thickness increased with time spent feeding and from west to east. The blubber layer was found to be 0.366 cm thinner in males than in females.

DISCUSSION

Annual trend in body condition

The results from the statistical analyses clearly show that blubber thickness in Antarctic minke whales has decreased during the last 18 years. This is the first time a long-term decline in energy storage in minke whales has been demonstrated, although Ohsumi *et al.* (1997) found some non-significant indications of a decline starting in the early 1980s. Blubber thickness varies considerably between years. Recent studies, such as Ichii *et al.* (1998), have shown that this variation in body condition is correlated with the extent of ice coverage in the JARPA survey area. The large inter annual variation in blubber thickness may be the main reason why the decline has not been recognised earlier.

Elucidation of the role of cetaceans in the Antarctic ecosystem

At the mid-term JARPA review meeting in 1997, there was discussion about which of the two hypotheses "whale reduction/krill surplus" or "environmental change" was more likely to explain a putative decline in body condition in the Antarctic minke whale over the previous decade. However, neither of the hypotheses could be excluded because there was little available information either on trends in minke whale conditions or on krill abundance (see Ichii 1997). Environmental change could be an important factor since it is known to affect krill abundance. The abundance of krill around the Antarctic Peninsula is known to have declined since the 1970, because the extent of the sea ice has decreased as a result of high temperatures (Loeb *et al*. 1997, Atkinson *et al*. 2004). However, no such environmental trend has been observed in the JARPA survey area (Watanabe *et al*. 2005).

The results of this study and of Ohsumi et al (1997) indicate that food availability for the minke whale has been declining since about 1980, and that the decline in blubber thickness over this period has been about 10 %. It has been estimated that the recruitment of minke whales reached a peak around 1970 (Mitsuyo - this meeting), and multi-species modelling work by Mori and Butterworth (2006) indicates that a decline in krill biomass started somewhat earlier. If the physical environment has been stable, it is conceivable that the total biomass of consumers was already near carrying capacity about thirty years ago. Sighting surveys carried out by the Southern Ocean Whale and Ecosystem Research (SOWER) programme and JARPA have demonstrated the recent recovery of humpback (*Megaptera novaeangliae*) and fin whales (*B. physalus*) (Matsuoka *et al*. 2005). Branch *et al*. (2004) also reported that the Antarctic blue whale (*B. musculus*) population has increased, although it is still small. These large whales also feed on the Antarctic krill and share same food niche as the minke whale (Nemoto 1962, Kawamura 1980), so their ongoing recovery could cause a further decline in food availability for the minke whale.

Our results also show that blubber thickness increases from west to east, suggesting that there has been a geographical difference in food availability for minke whales.

Understanding how krill demography is affected by changes in physical environmental factors and by predator consumption, and how, in turn, this influences predator performance and survival, is an essential basis for predicting future change in the Antarctic marine ecosystem (Reid and Croxall 2001). However, investigating and understanding the dynamics of the widely distributed krill population is difficult, so that monitoring energy storage by a krill consumer, such as the minke whale, can be very useful. Understanding the status of the Antarctic minke whale is one of the keys to predicting changes in the populations of large krill consumers, and also of crucial importance in detecting food web interactions and changes in the krill population itself.

Conclusions and further studies

The results of our study lead to the conclusion that the "krill surplus" period ended more than twenty years ago. The JARPA data have not as yet provided evidence of environmental change (Watanabe *et al*. 2005). However, there is substantial overlap between the habitats of different whale species, suggesting possible interference between minke and blue whales in Antarctic waters (Kasamatsu *et al.* 2000). If other krill consumers also increase in abundance, the body condition and abundance of the Antarctic minke whale may continue to decline, because the ongoing recovery of large baleen whales could further reduce food availability for the minke whales.

Therefore, we need to focus on interactions between krill consumers and study intra- and inter-specific population dynamics in whale species. The study of body condition is a necessary part of ecosystem monitoring in the Southern Ocean. Simultaneous monitoring of the physical and prey environment is also important (Ichii 1997). The comprehensive work will provide important information on what is likely to happen in Southern Ocean ecosystem in the near future, which will be valuable for sustainable management of whales.

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Table 1: Extent of diatom film

Scale	Level
0	none
1	Limited
2	Moderate
3	Most of body
4	Entire body

Table 2 Data used in the analyses:

		n	mean	SD	min	max
Mature males	Body length (m)	2890	8.4	0.4	6.3	9.6
	Blubber thickness (cm)	2872	3.6	0.9	1.1	7.2
Pregnant females	Body length (m)	1814	8.9	0.4	7.6	10.2
	Blubber thickness (cm)	1806	4.0	1.0	1.5	7.7

Table 3 Results of one of the multiple stepwise regression analyses

	Coefficient		P value	95% confidence interval of B	
	B	SE		Lower bound	Upper bound
Constant	0.9693	0.2263	0.000	0.5257	1.4130
Date (Dec. 1st=1)	0.0139	0.0004	0.000	0.0131	0.0147
Diatom	0.1818	0.0099	0.000	0.1624	0.2012
Sex (male=1, female=2)	0.3659	0.0275	0.000	0.3119	0.4198
Fetus length (cm)	0.0057	0.0004	0.000	0.0048	0.0065
Year (87/88=1)	-0.0190	0.0022	0.000	-0.0234	-0.0147
Stock (P=1,I=2)	0.1652	0.0241	0.000	0.1180	0.2124
Body length (m)	0.0823	0.0276	0.003	0.0281	0.1365

Table 4 Results of another regression analysis. In this analysis, the variable “Longitude” (in degrees east) was substituted for “Stock”

	Coefficient		P value	95% confidence interval of B	
	B	SE		Lower bound	Upper bound
Constant	0.9119	0.2240	0.000	0.4728	1.3510
Date (Dec. 1st=1)	0.0135	0.0004	0.000	0.0127	0.0143
Diatom	0.1809	0.0099	0.000	0.1615	0.2002
Sex (male=1, female=2)	0.3666	0.0273	0.000	0.3132	0.4201
Fetus length (cm)	0.0056	0.0004	0.000	0.0048	0.0065
Year (87/88=1)	-0.0189	0.0022	0.000	-0.0232	-0.0146
Longitude (deg E)	0.0022	0.0003	0.000	0.0017	0.0027
Body length (m)	0.0839	0.0274	0.002	0.0302	0.1376

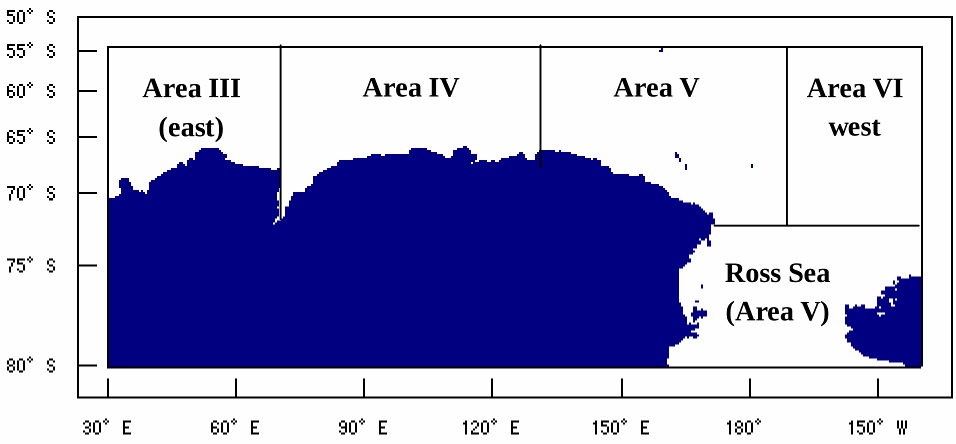

Figure 1 Map of JARPA survey area (Areas III-East, IV, V and VI-West).

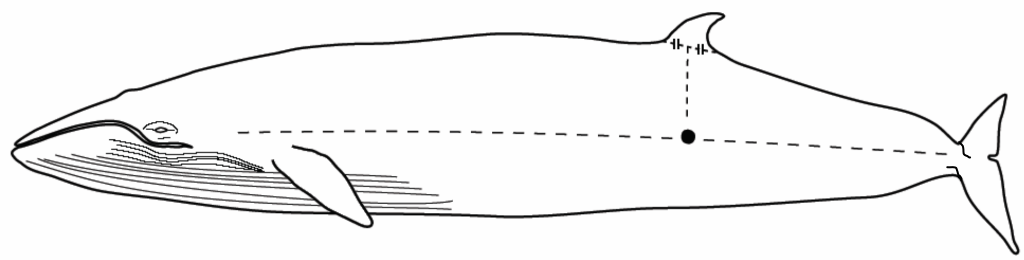

Figure 2 Position of blubber thickness measurement

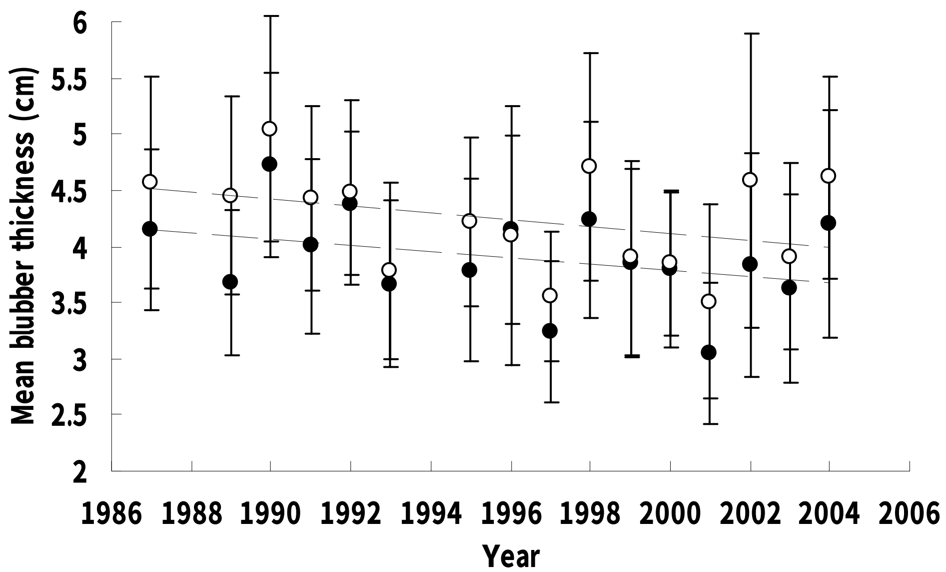

Figure 3 Trend in blubber thickness in the Antarctic minke whale over the JARPA survey period. P-stock in February. (Error bars represent SD) closed circle: mature male, open circle: pregnant female.