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Yearly trend of blubber thickness in the Antarctic minke whale *Balaenoptera bonaerensis* in Areas IV and V

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ABSTRACT

To examine the recent trend of body condition and factors that affect the body condition in Antarctic minke whale, blubber thickness from 1987/88 to 2003/04 in Areas IV and V were analysed. In the stepwise multiple regression analyses, the blubber thickness at mid-lateral position was used as dependent variable, and date, diatom film adhesion, sex, longitude (Area) and year was used as explanatory variables. To see the trend of body condition in the end of the feeding season, blubber thickness in February were also examined in each Area and sex. The results of multiple regressions confirmed that blubber thickness of the Antarctic minke whale has decreased for JARPA survey period, and showed all explanatory variables were detected as predictor variables. The results in February also showed decline of blubber thickness over JARPA survey without in pregnant female in Area V. These results indicated that food availability for Antarctic minke whale in Antarctic has decreased. This decline possibly caused by both intraspecific and interspecies competitions for krill resources.

INTRODUCTION

The Antarctic Ocean consists of simple food web with high productivity and is an important feeding area for the baleen whale, which is one of the major predator groups, consuming mostly on Antarctic krill (*Euphausia superba*). Whales become fat over summer feeding period and leave for low latitude area for reproduction. Like other baleen whales, the Antarctic minke whale (*Balaenoptera bonaerensis*) migrates to the Antarctic and spend austral summer season to feed.

Generally, it is well known that the overexploitation by commercial whaling in Southern Hemisphere diminished the population of large baleen whales (Laws 1977). Finally, the composition of whale species in abundance was totally changed when the commercial whaling was suspended in 1987, comparing to that in pre-whaling period. The Antarctic minke whale, on the other hand, was not targeted in commercial whaling till 1971, and its population was not affected largely by the whaling. Thus, the minke whale population started to grow after the harvest of large baleen whale was started, and then it continued until recently. This was probably due to the favourable food availability caused by the decline of other large baleen whale populations, so called “krill surplus” hypothesis (Laws 1977).

Recent sighting surveys of SOWER and JARPA demonstrated the recent recovery of humpback (*Megaptera novaeangliae*) and fin whales (*B. physalus*) (Matsuoka *et al*. 2005). Branch *et al*. (2004) also reported that Antarctic blue whale (*B. musculus*) population has increased, although its population size is still small. According to Ohsumi *et al*. (1997), the body condition of minke whale increased until the end of 1970's, then decreased with years, and this yearly trend was caused by environmental change or carrying capacity in the Antarctic. If this is true, the body condition in the Antarctic minke whale presumably continues to decrease, because the recent recovery of large baleen whales could cause further shortage of food availability for minke whales.

Blubber is one of the most important tissues in relation to buoyancy, stream line and energy storage, and its thickness links directly to feeding habits (Mackintosh and Wheeler 1929). Blubber thickness of baleen whales is known to be changed through season, by reproductive activity and growth, and among populations (Mackintosh and Wheeler 1929), and its variation is sometimes expressed as "fatness" or "body condition". Monitoring the body condition of animals is important for assessing energetic health of food availability in a given population (Beck *et al*. 1993). However, the research areas cover broad area, and the research period is almost three month. The density of krill population is not uniform at entire Antarctic Ocean (see Atkinson *et al*. 2004), and migration and pregnancy of whales also affect their body condition. So, duration of stay in feeding area, geographical and biological variation in blubber thickness should be considered for its analysis.

"The elucidation of role of cetaceans in the Antarctic ecosystem" and "The elucidation of effect of environmental change on whale stocks" are objectives of the JARPA project (Government of Japan 1996). In previous review of JARPA, Ichii (1997) concluded that the minke whale is very important top-predator species in terms of amount of krill consumption in Areas IV and V. Ohsumi *et al.* (1997) mentioned that the body condition and its yearly change of Antarctic minke whale will contribute for the JARPA research objectives.

The objective of this study is to examine the recent trends of blubber thickness of the Antarctic minke whale to confirm whether this shows trends similar to those reported previous studies. The second objective is to examine the factors that affect the body condition and discuss the energetic status for the minke whale in the Antarctic Ocean.

MATERIALS AND METHODS

Sampling and measurement

All Antarctic minke whales were taken by the Japanese Whaling Research Program under Special Permit in the Antarctic (JARPA). Animals used in this study were limited to Areas IV and V in alternate years from 1989/90 to 2003/04 (Fig. 1). After capturing by three sighting/sampling vessels, the animals were placed aboard a research base vessel where they were examined. After outer observation was conducted, body length (from snout tip to tail fluke notch in a straight line along the deck) and other morphological parts were measured. Blubber thickness was measured to the nearest mm, perpendicularly from skin to muscle without connective tissue and black surface skin in dissection. The blubber thickness at mid-lateral region (Fig. 2) used in this study have relatively low correlation coefficient with body length ($0 < r < 0.1$) and become thick in relation to feeding days (Ohsumi *et al*. 1997). Sex and maturity were recorded for each whale from the observation of reproductive organs routinely in dissection and tissue observation in laboratory.

Statistical analysis

Juvenile animals are a little fatter than adults (Ohsumi *et al*. 1997), and lactating females are thinner than other female mature classes in baleen whales (Lockyer 1987). So, we used a total of 3796 mature males and pregnant, but not lactating females to avoid biases.

To examine recent trend and what factors influence the variation of blubber thickness, we conducted stepwise multiple regression analyses, and all variables were included in the model at 5% level. Blubber thickness (in cm) was the independent variable. In the first run, we used following independent variables; "date"(December 1st= day 1), "diatom adhesion"(0 to 4, Table 1), "sex"(0:female, 1:male), "area"(4:Area IV, 5:Area V) and "body length"(in m). Additionally, year was also included as an independent variable because it reflects the yearly trend of food availability (87/88=1 89/90=2 91/92=3...). The variables were included in the order: First date, then diatom film, sex, area, year and at last body length. In a second run, "longitude" (in degrees east) was substituted for "area". Diatom is sometimes observed on the surface of the whales like a film and sometimes covers entire bodies. The degree of diatom adhesion on the skin becomes a rough indicator of time period for the whale to stay in the cold waters in general (Ohsumi *et al*. 1997).

We also conducted regression I analyses for mean blubber thickness with year in each Areas IV and V to simply examine the recent trend of blubber thickness. In these analyses, we used data in February (end of feeding season) as same as the last JARPA review (Ohsumi *et al*. 1997).

RESULTS

Blubber thickness ranged from 1.8 to 7.2 cm in mature males, and from 2.0 to 7.7 cm in pregnant females in both areas over all research period (Table 2).

Multiple regressions identified all independent variables as a predictor of blubber thickness in the both runs (Table 4 and 5). The "date" is a best predictor of the blubber thickness followed by "diatom", "sex", "area", "year" and "body length". The second run showed similar result with the first run. The "date" is a best predictor of the blubber thickness followed by "diatom", "sex", "year", "Longitude (E+W)" and "body length". The coefficients of "Year" were -0.024(±0.003SE) in the both runs, indicated the blubber thickness significantly decreased with years (Fig. 3). Blubber thickness change with date and longitude were also shown in Figures 4 and 5. These results indicated that the blubber thickness become thick with feeding dates and toward East. And the blubber in males was thinner than that in females.

Yearly changes of blubber thicknesses in February are shown in Table 3 and Figure 6. The overall blubber thickness decreased through JARPA for males (Area V: $r = -0.77$, $p < 0.05$), although the correlation was not statistically significant in Area IV ($r = -0.62$, $p = 0.08$). The blubber thickness decreased through time for pregnant female in Area IV ($r = -0.78$, $p < 0.05$), but no consistent trend was detected for pregnant females in Area V ($r = 0.05$, $p = 0.91$).

DISCUSSION

Yearly trend of body condition

Our results clearly showed that blubber thickness of Antarctic minke whales has decreased over JARPA in Area IV and V. According to Ohsumi *et al*. (1997), this decline started since late 1970's, indicating these declines has occurred for over twenty years. As already mentioned, blubber thickness is directly linked to food availability, so this continuing deterioration of blubber thickness is equal to the decline of food availability in the Antarctic for each individual. Our results showed blubber in Area IV was thinner than that in Area V, and increased from east to west, suggesting there was a geographical difference of food availability for minke whales.

The elucidation of role of cetaceans in the Antarctic ecosystem

In the last JARPA review meeting in 1997, it was great concern which hypothesis "Whale over-hunting - krill surplus" or "Environmental changes" is better to explain the deterioration of body condition in the Antarctic minke whale over few decades. However both hypotheses were not excluded because of little information (see Ichii 1997). The environmental change is important factor which affect the krill abundance, and the abundance around Antarctic Peninsula decreased since the 1970', because of the sea-ice extension induced by high temperature (Loeb *et al*. 1997, Atkinson *et al*. 2004). However, no such environmental trend was observed in JARPA (Watanabe *et al*. 2005).

Our results indicated the decline of food availability for the minke whale in Area IV has occurred for over two decades, because the decline of body condition started in the end of 1970's (Ohsumi *et al*. 1997). Meanwhile, the peaks of the recruitment in the minke whale were estimated from 1970 to the mid-1980's by Butterworth *et al*. (1999). If the trend of physical environment has been stable, it is conceivable the total biomass of consumers was already near carrying capacity more than twenty years ago. As a reason for the deterioration of food availability for the minke whale, its intraspecific and interspecies competitions for food among krill consumers were both important factors.

Lately the recovery of large baleen whales such as fin and humpback whales (Matsuoka *et al*. 2005) were reported. These large whales feed on the Antarctic krill and share same food niche with the minke whale (Nemoto 1962, Kawamura 1980), so their recovery could cause the further deterioration of food availability for the minke whale.

Conclusion and Future Studies

We conclude, again, the food availability of the Antarctic minke whale has decreased in Area IV and V, so "food surplus period" had already shifted to "competition period". Therefore, we need to focus on interactions among consumers for food to examine population dynamics of whales. To understand the propositional content, the study of body condition is necessary as a part of ecosystem monitoring in the Antarctic Ocean. In addition, the coincidental monitoring of the physical and prey environment is also important (Ichii 1997). The comprehensive work will provide important information of "what is going to happen in Antarctic Ocean ecosystem near future" for sustainable management of whales.

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Table 1 Scale of diatom film adhesion

Scale	Level
0	no adhesion
1	adhesion is slite
2	adhered
3	largely ahdered
4	coverd entire body

Table2 Blubber thickness at mid-lateral region in JARPA from 1987/88 to 2003/04.

	Area	*N*	Mean(cm)	SD	Max	Min
Mature male	IV	1202	3.42	0.82	6.5	1.8
	V	1099	3.90	0.91	7.2	2.0
Pregnant female	IV	677	3.85	0.92	7.0	2.0
	V	818	4.28	0.94	7.7	2.3

Table3 Blubber thickness at mid-lateral region in Februaly from 1987/88 to 2003/04.

	Area	*N*	Mean(cm)	SD	Max	Min
Mature male	IV	321	3.70	0.83	6.5	1.8
	V	439	4.20	0.83	6.4	2.0
Pregnant female	IV	388	4.01	0.91	7.0	2.1
	V	393	4.45	0.82	7.7	2.4

Table4 The final regression coefficients etc were:

	Coefficient		P-value	95% confidence interval of B	
	B	SE		Lower bound	Upper bound
Constant	0.375	0.301	0.213	-0.216	0.965
Date	0.015	0.001	0.000	0.014	0.016
Diatom Film	0.239	0.010	0.000	0.219	0.259
Sex	-0.322	0.029	0.000	-0.379	-0.265
Area	0.263	0.025	0.000	0.213	0.313
Year	-0.024	0.003	0.000	-0.029	-0.019
BL (m)	0.152	0.029	0.000	0.095	0.210

Table5 In a second run “longitude” (in degrees east) was substituted for “area”. Again all independent variables were included at the 5% level.

	Coefficient		P-value	95% confidence interval of B	
	B	SE		Lower bound	Upper bound
Constant	1.075	0.275	0.000	0.537	1.614
Date	0.015	0.001	0.000	0.014	0.016
Diatom Film	0.241	0.010	0.000	0.221	0.261
Sex	-0.317	0.029	0.000	-0.374	-0.259
Year	-0.024	0.003	0.000	-0.029	-0.019
Long (E+W)	0.003	0.000	0.000	0.003	0.004
BL (m)	0.157	0.029	0.000	0.099	0.215

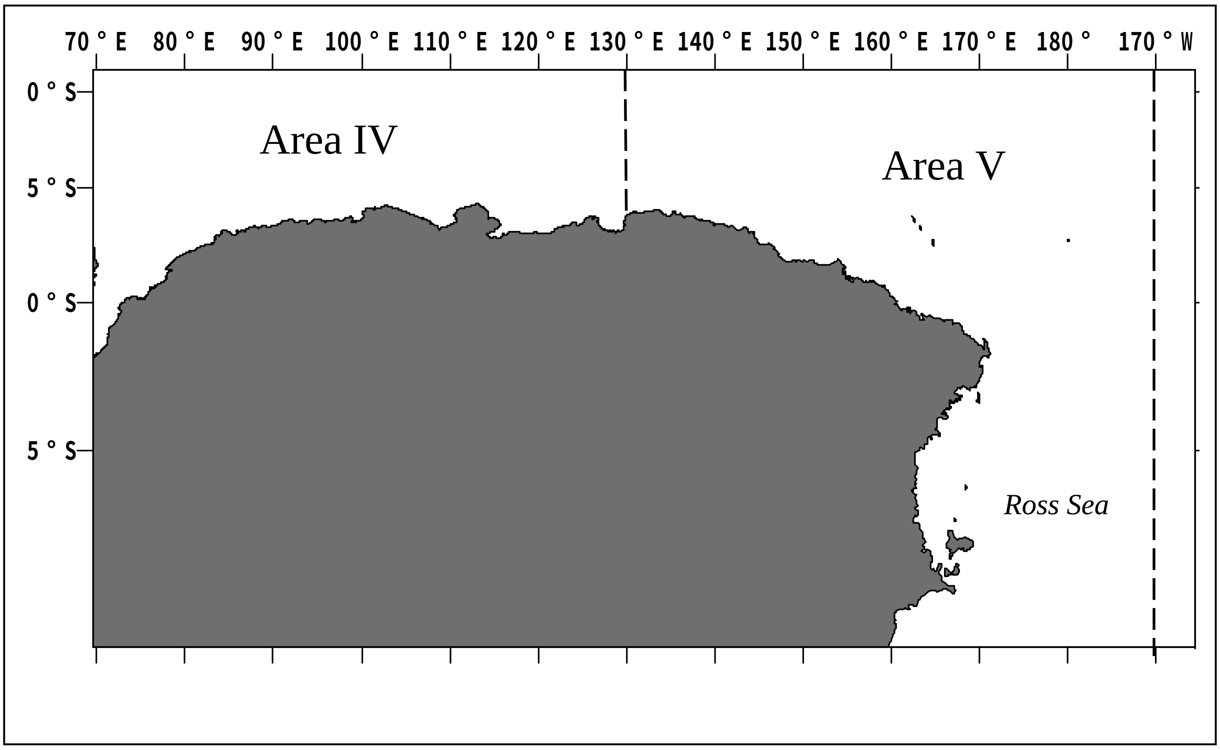


Figure 1 Map showing sampling area.

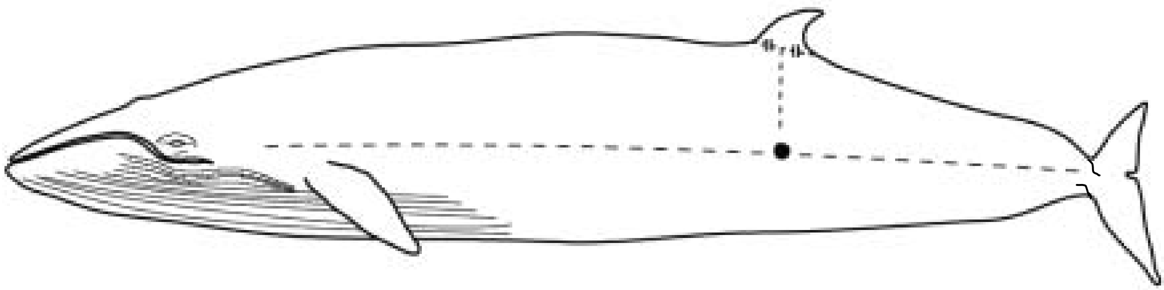


Figure 2 Position of blubber thickness measurement.

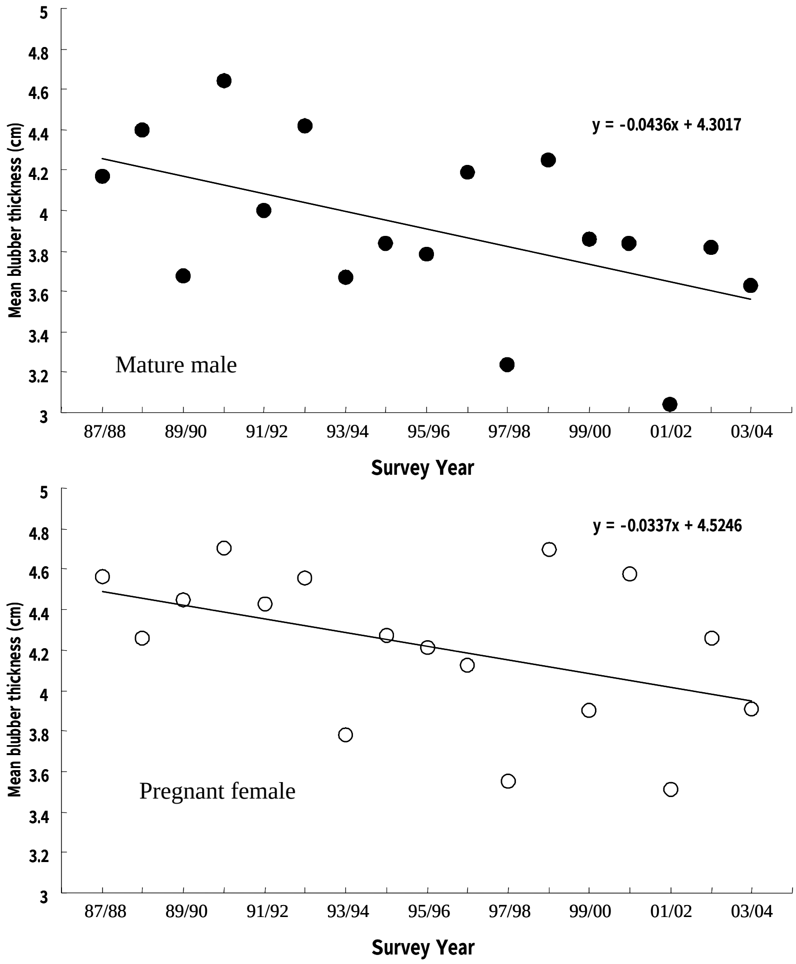


Figure 3 Yearly trend of blubber thickness in Area IV and V.

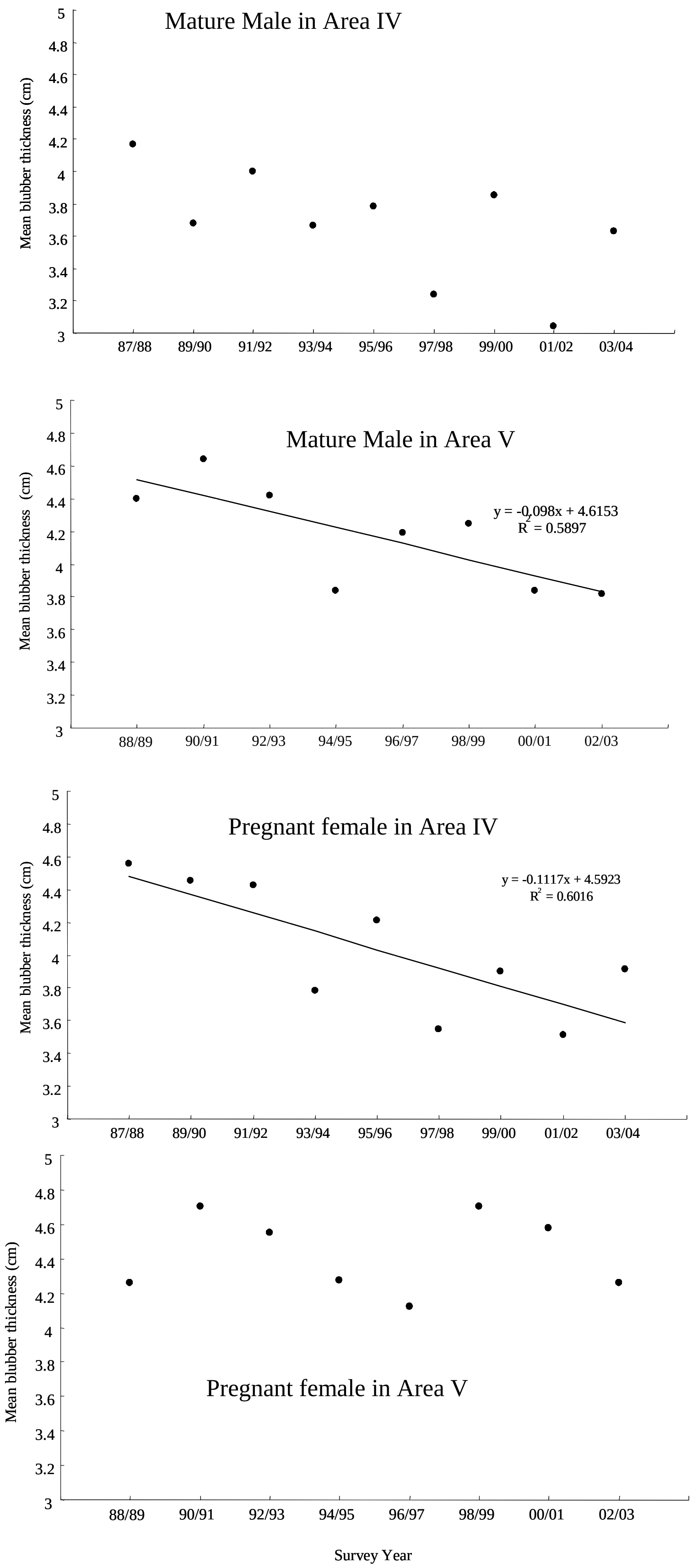
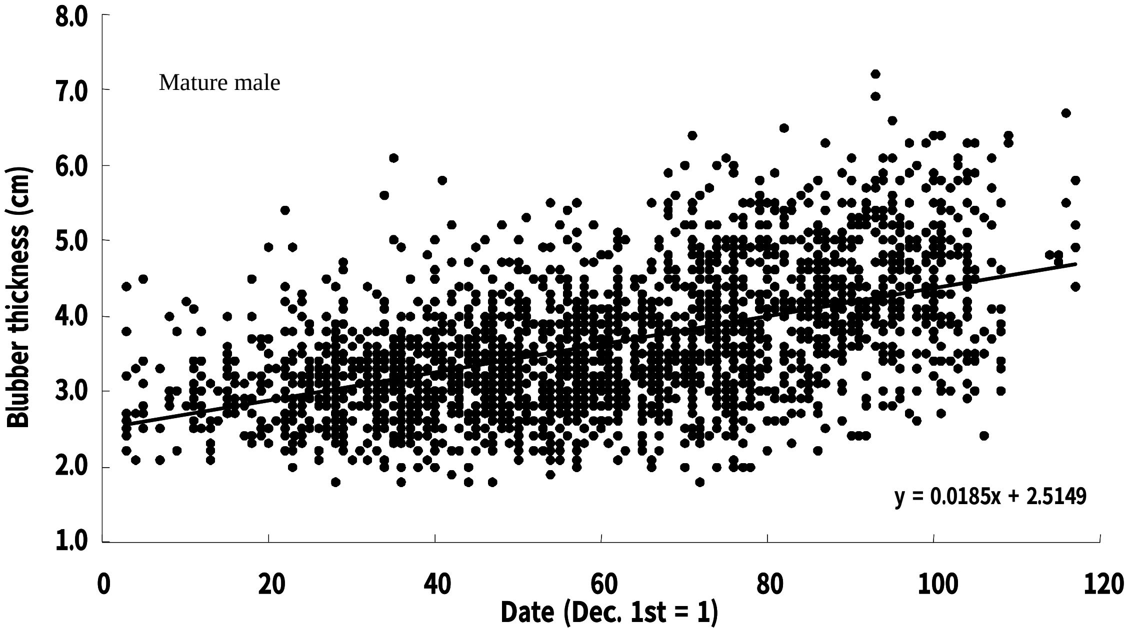


Figure 4 Yearly trend of blubber thickness in February in each maturity and area.



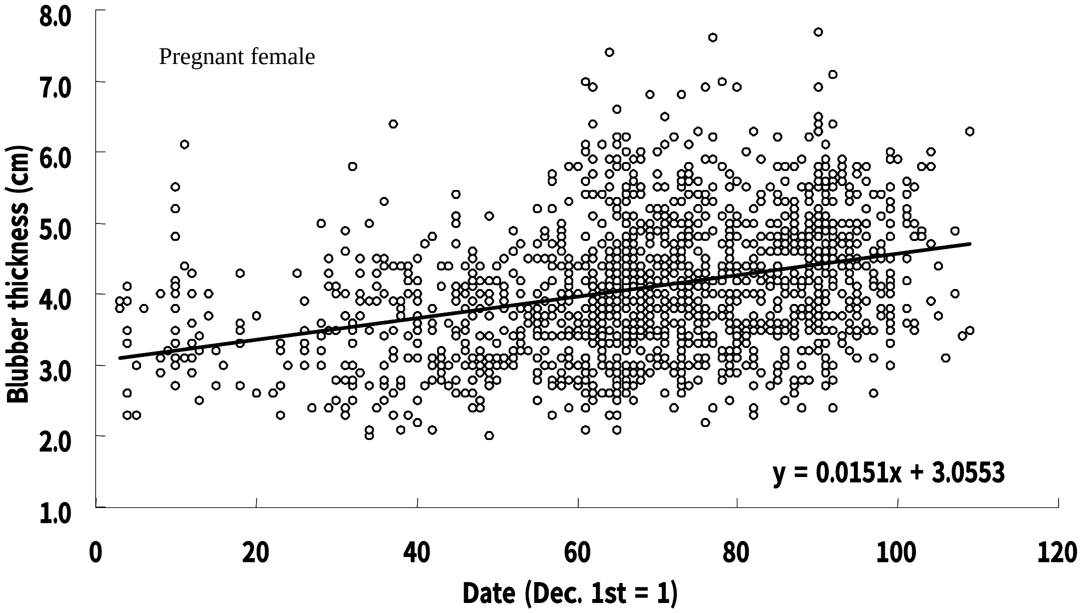


Figure 5 Blubber thickness change with date in the Antarctic.

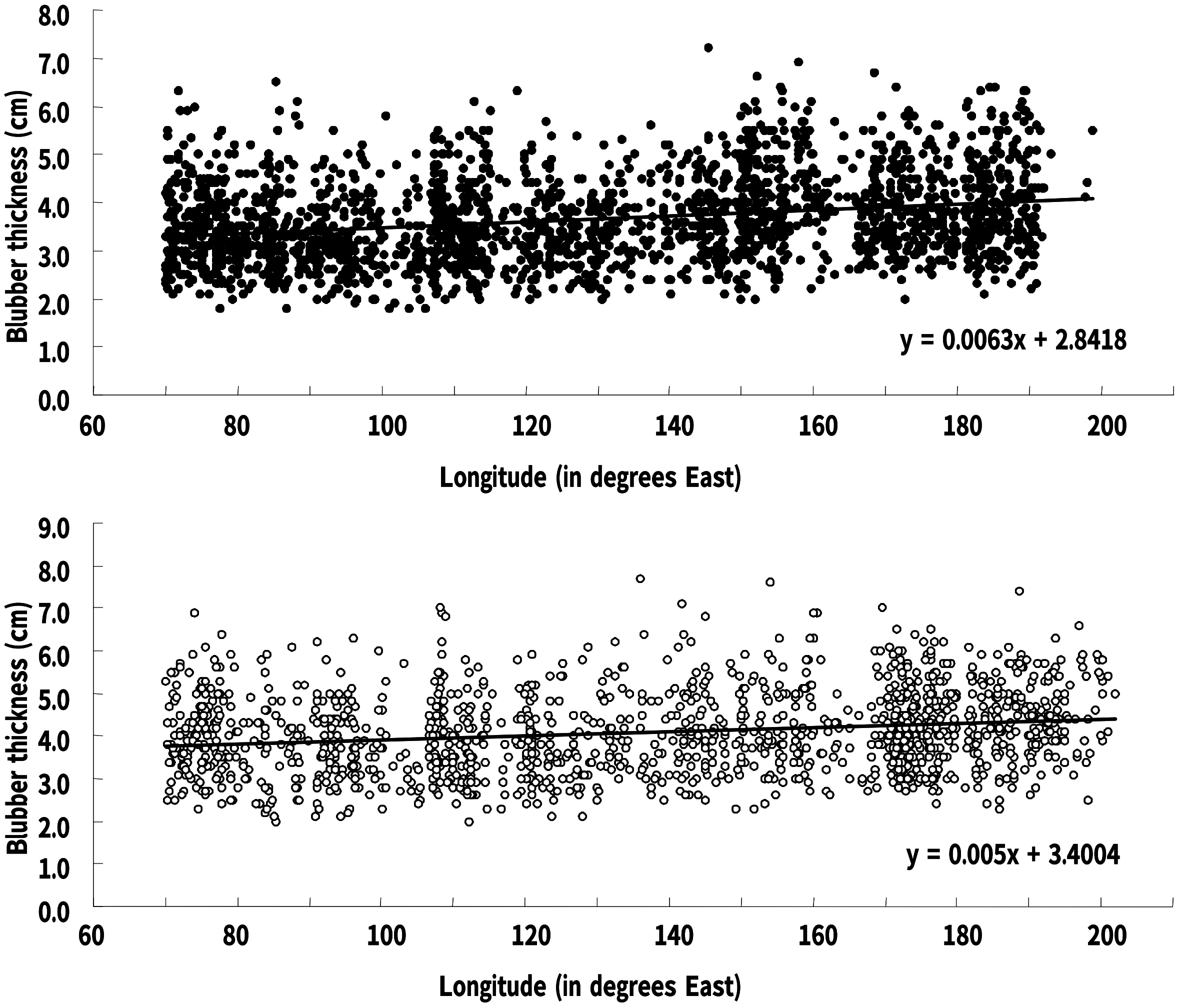


Figure 6 Blubber thickness change with longitude in Areas IV and V.