Additional analysis of stomach contents weight of the Antarctic minke whale *Balaenoptera bonaerensis* in the Southern Ocean

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ABSTRACT

The annual trend in stomach contents weight per capita in the Antarctic minke whale was examined using data from all 18 JARPA surveys. The results of stepwise multiple linear regression analyses showed that stomach contents weight in the minke whales has decreased for almost two decades. The decrease in stomach contents is estimated at -0.694 kg/year in an animal, which was about 16 % for the whole JARPA period. Furthermore, "body length", "time", "latitude" and "date" were all identified as partially independent predictors of stomach contents weight. "Longitude of sampling position", "sex", and "chasing time" were excluded. The direct interpretation of food availability on the decline in stomach contents in the minke whales with time (year) is difficult, since no long term krill abundance series is available. However, competition among krill feeders and/or the decrease of krill resources must be a candidate for the explanation of the decline.

KEYWORDS: ANTARCTIC, ANTARCTIC MINKE WHALE; FEEDING; TRENDS

INTRODUCTION

In the ecosystem in the Southern Ocean, although the Antarctic krill (*Euphausia superba*) is preyed upon by many predators such as baleen whales, seals, sea birds, fish and squid, the prey consumption by whales can not be disregarded in trying to understand the ecosystem because of their large biomass (Miller and Hampton, 1989). The Antarctic minke whale (*Balaenoptera bonaerensis*) is the most abundant baleen whale species in the Southern Ocean (south of 60°S) estimated to be as high as at 760,396 animals with 95 % confidence interval (510,000 – 1,140,000) in the austral summer of the 1980s (IWC 1991). New abundance estimation is being discussed by the SC/IWC. Minke whales breed in austral winter at lower latitudes and migrate to the Antarctic Ocean for feeding in austral summer (Kasamatsu *et al*. 1995). In Southern Ocean, Antarctic minke whales feed mostly on Antarctic krill in offshore areas (*e.g*. Kawamura 1980, Bushuev 1986, Ichii and Kato 1991), and on ice krill (*E. crystallorophias*) in coastal (shallow) areas of the continental shelf such as the Ross Sea and Prydz Bay (Bushuev 1986, Tamura 1998).

Previous estimates of the daily prey consumption of the whales were made on the basis of energy-requirement calculations (Hinga 1979, Lockyer 1981a, 1981b, Armstrong and Siegfried 1991, Reilly *et al.* 2004) since there was little quantitative data of stomach contents until now. Data such as stomach contents, sexual maturity, body length, and abundance estimates of Antarctic minke whale together with krill biomass estimates from the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) provided us to the means to understand the feeding ecology of Antarctic minke whales.

In this paper, we examined trends in stomach contents weight of the Antarctic minke whale during the JARPA period (1987/88 – 2004/2005). A second objective was to examine other factors that could have affected stomach contents of the minke whales in the Southern Ocean. Analyses showing a decline in the weight of stomach contents in the minke whales were presented to the 2006 JARPA Review Meeting held in Tokyo. The meeting recommended additional analyses to consider factors such as: i) determination of the duration of the feeding period; ii) examination at smaller spatial scales; iii) use multivariate analysis to examine trend, incorporating covariates such as age, size and reproductive status of whales as well as the date and time of day. The additional analysis presented here is in response to item iii). The following covariates were incorporated into the analyses: "undigested stomach contents weight per capita" (kg), "Body length" (in m), "Sighting time of captured whales",

"Latitude of sampling position", "Longitude of sampling position", "Date of sampling", "Sex", "Chasing time" and "Year".

MATERIALS AND METHODS

Sampling and measurements

Stomach contents weight 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 (Table 1).

The research area covers the International Whaling Commission (IWC) Management Areas III (East), IV, V and 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 tip of snout to tail fluke notch in a straight line along the axis) and other morphological measurements were taken. All Balaenopterid species have four chambered stomach system (Hosokawa and Kamiya 1971, Olsen *et al.* 1994). As soon as the whale was on board, the four chambered stomach was removed and divided into four compartments: the forestomach, the fundus chamber, the pyloric chamber and the duodenal ampulla. Each compartments mass were weighed to the nearest 0.1 kg. The freshness of forestomach contents was classified into one of four categories after examination by the naked eye (F = fresh, fff = lightly digested, ff = moderately digested, f = heavily digested, See Appendix. 1). As the prey consumption per capita, we applied the total of forestomach content and fundus chamber content weight of undigested status category data (F and fff) to avoid any bias resulting from digestion of stomach contents. Because, the contents in both the forestomach and fundus chamber can move easily, the freshness of forestomach contents and fundus chamber contents was almost the same status.

Statistical analysis

Whales accumulate fat during the summer feeding period and then 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 (Kasamatsu *et al.* 1995). Thus, the time spent in the feeding area and geographical and biological variables which could be related to stomach contents weight should be considered. To take these factors into account and possibly exclude some of them, we conducted stepwise multiple linear regression analyses. Stomach contents weight per capita (in kg) was the dependent variable. In the run, we allowed the following independent variables: "Body length" (in m), "Sighting time of captured whales", "Latitude of sampling position", "Longitude of sampling position", "Date" (December 1st=day 1), "Sex" and "Chasing time". "Year" was also included as an independent variable to investigate a possible annual trend (87/88=1 88/89=2 89/91=3...). At each step of the regression analysis, the next variable was included in the equation if the corresponding *p*-value was below 5 %.

RESULTS AND DISCUSSION

Factors affecting stomach contents weight and its yearly trend

The stepwise multiple linear regression analyses included all possible dependent variables as predictors of stomach contents weight at the 5 % level (Table 2). "Body length" was the best predictor of stomach contents weight followed by "Sighting time", "Latitude of sampling position", "Date" and "Year" in that order. "Longitude of sampling position", "Sex", and "Chasing time" were excluded. The coefficients of "year" were -0.693 kg/year (±0.199 SE), indicating that stomach contents weight decreased over the years (Table 2).

Annual trend in stomach contents weight

The results from the statistical analyses clearly show that stomach contents weight per capita in Antarctic minke whales has decreased during the last 18 years. This phenomenon indicates that the krill abundance has decreased year by year in the JARPA research area.

We calculated the stomach contents weight (M) during the austral summer of Antarctic minke whale according to following equations:

$$M = \alpha + \beta_1 BL + \beta_2 Time + \beta_3 Latitude + \beta_4 Date + \beta_5 Year$$

M: The both contents in forestomach and fundus chamber weight (kg), α : Constant (68.217), BL: Body length (m), Time: Sighting time of captured whales, Latitude: Latitude of sampling position, Date: Sampling date (December 1st=day 1), Year: Research season (*e.g.* 1987/1988 season=1).

We assumed the following scenarios for detection of the yearly trend.

Scenario1: Body length is 6 m. Time is 10 o'clock. Latitude is south of 65 degree.
Date is 90 days (February 1st). Year are 1, 2, 3 ⋯18.
Scenario2: Body length is 7 m. Time is 10 o'clock. Latitude is south of 65 degree.
Date is 90 days (February 1st). Year are 1, 2, 3 ⋯18.
Scenario3: Body length is 8 m. Time is 10 o'clock. Latitude is south of 65 degree.
Date is 90 days (February 1st). Year are 1, 2, 3 ⋯18.
Scenario4: Body length is 9 m. Time is 10 o'clock. Latitude is south of 65 degree.
Date is 90 days (February 1st). Year are 1, 2, 3 ⋯18.

These results are shown in Appendix 2. It suggests the decline of food availability per capita of Antarctic minke whale in the JARPA survey area from the 1987/88 to the 2004/05 season. Possible explanations for this include: 1) inter-specific competition, 2) intra-specific competition among baleen whales and other organisms, 3) decreasing of krill resources due to environment change. Long-term data collection of baleen whales and krill should be continued to monitor changes in the Antarctic marine ecosystem. Construction of ecosystem models is needed to consider the existence of inter-specific competition and/or intra-specific competition among baleen whales and other organisms and to improve management of whale resources in the JARPA research area.

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Table 1 Data used in the analyses

Year	Male	Female	Total
1987/88	37	23	60
1988/89	14	30	44
1989/90	56	30	86
1990/91	25	27	52
1991/92	31	16	47
1992/93	45	42	87
1993/94	66	36	102
1994/95	67	62	129
1995/96	92	30	122
1996/97	79	85	164
1997/98	139	58	197
1998/99	111	40	151
1999/2000	108	106	214
2000/01	120	73	193
2001/02	119	127	246
2002/03	112	105	217
2003/04	100	103	203
2004/05	91	114	205
Total	1,412	1,107	2,519

Table 2 Results of the multiple stepwise regression analyses

	Coefficient		P value	95% confidence interval of B		F value	R square
	B	SE		Lower bound	Upper bound		
Constant	68.217	16.122	0.000	36.604	99.830		
Body length (m)	19.251	0.936	0.000	17.415	21.087	394.424	0.135
Time	-2.909	0.260	0.000	-3.419	-2.399	278.347	0.181
Latitude	-1.980	0.245	0.000	-2.460	-1.500	205.008	0.196
Date	0.201	0.035	0.000	0.133	0.270	166.166	0.209
Year (87/88=1)	-0.693	0.199	0.001	-1.083	-0.303	135.943	0.213

Results of step-wise multiple regression at 5% level for JARPA all year (87/88-04/05) results
Area 3-6
Dependent variable= SC (kg) Explanatory variables=Body length, Time (sighting), Latitude, Date, Year
Date:Dec.1st=1,sex:male(1) female(2), Year(87/88=1)

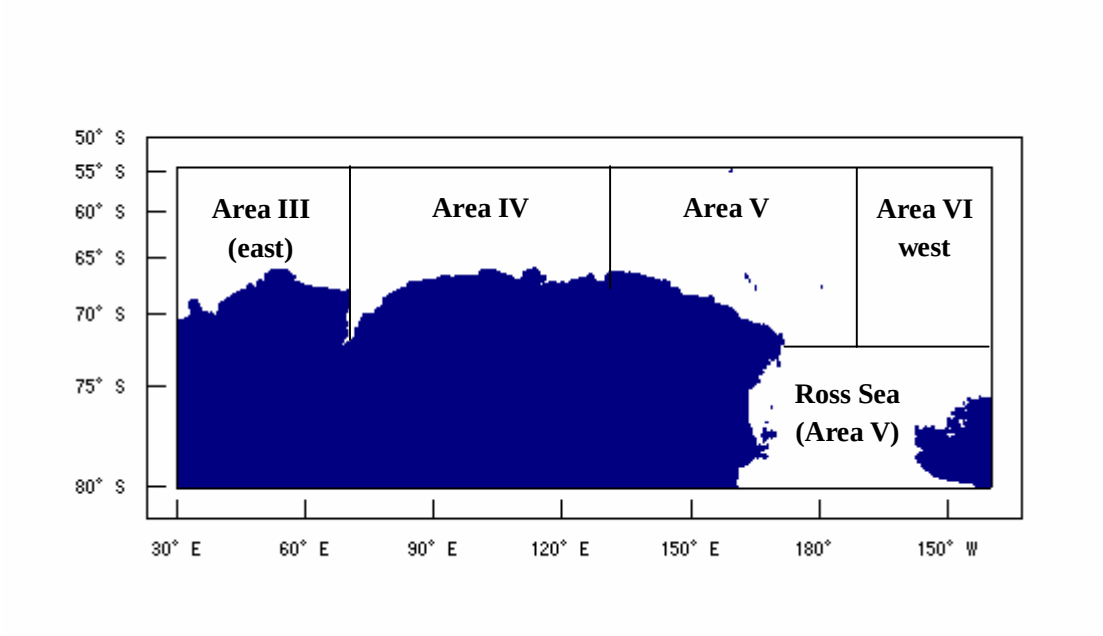

Figure 1. Map of JARPA survey area (Areas III-East, IV, V and VI-West).

Appendix. 1. Classification of digestion status of stomach contents.

Code	Class	Description
F	Freash	Prey not affected by digestion
fff	Lightly digested	Prey slightly affected by digestion
ff	Moderately digested	Prey moderattory to highly fragmented
f	Heavily digested	Unidentifiable remains or indigestible parts only

Appendix. 2. The yearly trend of stomach contents of Antarctic minke whales in JARPA research area from the 1987/88 season to the 2004/2005 season.