Digestibility of krill (*Euphausia superba* and *Thysanoessa* sp.) in minke whales (*Balaenoptera acutorostrata*) and crabeater seals (*Lobodon carcinophagus*)*

BY P.-E. MÅRTENSSON, E. S. NORDØY AND A. S. BLIX

Department of Arctic Biology and Institute of Medical Biology, University of Tromsø, N-9037 Tromsø, Norway

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Apparent digestible efficiency (% DE) was studied by use of dietary Mn as an inert marker, in minke whales (*Balaenoptera acutorostrata*) and crabeater seals (*Lobodon carcinophagus*) which had been eating krill. Median % DE in minke whales (*n* 5) eating krill of the genus *Thysanoessa* sp. (energy density (ED) 23·8 kJ/g) was 93 (range 87–93). Median % DE in crabeater seals (*n* 6) eating krill of the species *Euphausia superba* (ED 20·8 kJ/g) was 84 (range 79–85), which is significantly lower than the % DE of krill in minke whales ($P = 0{\cdot}008$). Since the chemical composition in *E. superba* and in *Thysanoessa* sp. is similar, it is suggested that the complex multi-stomached system of minke whales, which contains both chitinase (*EC* 3 . 2 . 1 . 14)-producing as well as several other types of bacteria, is superior to the single-stomached system of crabeater seals with regard to krill digestion. It is worth noting, however, that the % DE of krill in the crabeater seal is still very high.

Apparent digestibility efficiency: Mn inert marker technique: Minke whale: Crabeater seal: Krill

Both minke whales (*Balaenoptera acutorostrata*) and crabeater seals (*Lobodon carcinophagus*) prey on various kinds of krill. In the north Atlantic the minke whale eats mainly *Thysanoessa* sp. and a variety of fish (Jonsgård, 1982; Nordøy & Blix, 1992; Haug *et al.* 1993), while in the southern ocean it preys almost exclusively on *Euphausia superba* (Ohsumi *et al.* 1979). This is also the case for the Antarctic crabeater seal which preys primarily on the same species of krill (Øritsland, 1977).

The minke whales have a multi-stomached system with a large forestomach containing chitinase (*EC* 3 . 2 . 1 . 14)-producing as well as numerous other bacteria for microbial fermentation of the prey (Mathiesen *et al.* 1990; Olsen *et al.* 1994). The crabeater seal, on the other hand, relies on a single-stomached system without microbial fermentation. In the present study we have compared the abilities of minke whales and crabeater seals to digest krill using the Mn technique of Fadely *et al.* (1990).

MATERIALS AND METHODS

Six crabeater seals (*Lobodon carcinophagus*), with an age (Laws, 1958) and sex distribution given in Table 1, were killed off Queen Maud land in Antarctica (70° 25′ S, 08° 10′ W) during the Nordic Antarctic Research Expedition in February 1993. The stomach and the colon of the animals were collected and frozen immediately after death and kept at −20° until analysis at the Department of Arctic Biology, University of Tromsø, Norway. All the crabeater seals had recently eaten krill (*E. superba*), and faeces analysis confirmed that this had been the case for at least 5 h, which is the transit time of the digesta in some other pinnipeds (Helm, 1984; Markussen, 1993).

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Table 1. *Sex and length of minke whales* (Balaenoptera acutorostrata) *and sex and age of crabeater seals* (Lobodon carcinophagus)

Minke whale			Crabeater seal		
Whale no.	Sex	Length (m)	Seal no.	Sex	Age (years)
			2	M	7·5
S15	F	7·97	3	M	19·5
B1	M	7·67	4	M	3·5
B14	M	7·40	5	M	2·5
B17	F	7·90	6	F	8·5
B18	M	8·67	7	F	4·5

Five minke whales (*Balaenoptera acutorostrata*) were killed in the north-east Atlantic during the Norwegian scientific whaling programme in July and August 1992. Forestomach and colon contents were collected and frozen immediately after death and kept at −20° until analysis. Again, forestomach and faecal analysis revealed that the animals had for some time been eating krill (*Thysanoessa* sp.). The transit time of the digesta of the minke whale is presently unknown.

Samples of fresh *E. superba* were obtained by trawling in Antarctica (February 1992) and kept frozen at −20° until analysis. The energy density (ED) of these samples was not significantly different ($P = 0{\cdot}39$) from the value which was obtained on analysis of fresh stomach contents of three of the crabeater seals (Table 2). Samples of fresh *Thysanoessa* sp. were obtained by trawling in the Bear Island area of the Barents Sea in early August 1992, and again the samples were kept at −20° until analysis (Table 2).

Stomach contents (*E. superba*) and faeces from crabeater seals, as well as trawl samples of *Thysanoessa* sp. and faeces from minke whales, were dried at 60° in an incubator to constant weight and homogenized. ED values of these samples were subsequently determined using a bomb calorimeter MK 200 (Franz Morat KG, Eisenbach, Germany). Mn concentrations in food and faeces were measured by use of a Perkin Elmer 603 atomic absorption spectrophotometer (Norwalk, CT., USA), with 279·5 nm wavelength, 0·2 nm slit width and an air–acetylene flame. Three subsamples in duplicate from each diet and one faeces sample in duplicate from each animal were analysed for energy content and Mn concentration (Table 2).

Subtraction of faecal energy from gross energy intake (GEI) gives the digestible energy (DE). DE can be expressed also as apparent digestible efficiency (% DE), which is the proportion of GEI which has been absorbed through the intestinal wall and entered the bloodstream (Kleiber, 1975; Lavigne *et al.* 1982). To estimate % DE a method based on dietary Mn^{2+} as an inert marker was used (Fadely *et al.* 1990); % DE was calculated as follows: $\%\ DE = (1-(C_i \times E_f/C_f \times E_i)) \times 100$, where C is the concentration of Mn and E is the ED of the food (i) and faeces (f) expressed on a dry matter basis (modified from Kleiber, 1975).

Differences in % DE between the diets were tested using a two-tailed Mann–Whitney U-test. $P < 0{\cdot}05$ was regarded as significant.

RESULTS

The ED and Mn concentrations of both minke whale and crabeater seal prey and faeces are given in Table 2. Median % DE for minke whales on a krill (*Thysanoessa* sp.) diet was

Table 2. *Average energy density (ED; kJ/g dry weight) and manganese concentration (μg/g) of the faeces and the krill diet of minke whales and* (Balaenoptera acutorostrata) *crabeater seals* (Lobodon carcinophagus) *eating* Thysanoessa *sp. and* Euphausia superba *respectively**

(Values are means for two determinations for faeces and for three determinations performed in duplicate for diet)

Minke whale			Crabeater seals		
Whale no.	Faecal ED (kJ/g)	Faecal Mn (μg/g)	Seal no.	Faecal ED (kJ/g)	Faecal Mn (μg/g)
			2	11·61	19·7
S15	11·32	28·8	3	12·22	19·0
B1	17·31	33·2	4	12·06	20·4
B14	20·40	26·8	5	11·18	18·6
B17	11·43	29·0	6	14·02	20·2
B18	12·02	29·4	7	13·21	16·1
Diet	23·81	4·1	Diet	20·89	5·3

* For details of animals and procedures, see Table 1 and pp. 713–714.

93 (range 87–93, *n* 5), while median % DE for crabeater seals on a krill (*E. superba*) diet was 84 (range 79–85, *n* 6). These values are significantly different ($P = 0{\cdot}008$).

DISCUSSION

The present study has shown that the ability to digest krill is higher in minke whales than in crabeater seals. Krill has an exoskeleton which is mainly made of chitin, which probably to some extent prevents the action of digestive enzymes on other parts of the prey. Degradation of the chitin skeleton will eliminate this barrier and also release the chemical energy bound in the chitin itself. In *E. superba*, for example, the chitin skeleton contributes about 10% to the total energy content of the animal (Clarke, 1980). Both the ED (present study) and the gross chemical composition (Saether *et al.* 1987) of *E. superba* and *Thysanoessa* sp. are quite similar. Mathiesen *et al.* (1990) have shown that the forestomach of krill-eating minke whales is rich in chitinase-producing bacteria. Such bacteria are probably responsible for the more efficient digestion of krill by minke whales compared with crabeater seals. Olsen *et al.* (1994), moreover, suggested that the multi-chambered stomach of minke whales increases passage time and consequently increases the time available for both microbial and enzymic digestion of such complex structures as the exoskeleton of krill.

In a previous study (Nordøy *et al.* 1993) based on an *in vitro* three-stage digestion technique simulating the different compartments of the digestive system in minke whales, a mean % DE of 92 of herring (*Clupea harengus*) was obtained. When we used the present Mn method on minke whales which had eaten 0-group herring and capelin (*Mallotus villosus*) we got a median % DE of 90 (range 88–92) and 95 (range 94–96) respectively (P.-E. Mårtensson, unpublished results). In another study, Mårtensson *et al.* (1994), using the present Mn method, obtained a 94% DE of capelin in the harp seal (*Phoca groenlandicus*), which feeds both on fish and crustaceans. This suggests that the complex multi-stomached system of baleen whales holds no advantage over the single-stomached system of seals when it comes to digestion of fish. However, as mentioned previously, the minke whale is significantly better than the crabeater seal in digesting krill, in spite of the

fact that the crabeaters feed almost exclusively on krill. Moreover, the % DE of 84 for krill in crabeater seals is almost identical to the % DE of 83 for krill in harp seals (Mårtensson *et al.* 1994), which enjoy a very varied diet (e.g. Lydersen *et al.* 1991). This suggests that crabeaters are no better than other phocid seals in digesting crustaceans, but it should be noted that even if they are inferior to minke whales, they are still very good at it.

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