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An attempt to determine the digestibility of natural food in Antarctic seals using tracer method *). A preliminary study

ABSTRACT: Twelve mineral elements and total ash were examined in regard to the possible use as the estimators of digestibility of natural food in Antarctic seals. Four of them: phosphorus, calcium, copper and zinc have proved to give most reliable results. The estimated total dry mass and organic matter digestibilities of fish food in Weddell seals (*Leptonychotes weddelli* (Lesson)) averaged 82 and 91%, while the corresponding values for krill eaten by crabeaters (*Lobodon carcinophagus* (Hombron and Jaequinot)) and leopard seals (*Hydrourga leptonyx* (Blainville)) reached approximately 87 and 91%, respectively.

Key words: Antarctic seals, digestibility, mineral elements

1. Introduction

The studies on energy and matter cycling in ecosystems require the information about element concentrations in various compartments of the system, and the rates of element flows between the compartments. These last values may be obtained from determinations of the consumption rates of animals, provided that the efficiency of food digestion is known.

To estimate accurately the digestibility of various diets, feeding trials are commonly applied. In some cases, however, the laboratory experiments are difficult to conduct and the results obtained cannot be extrapolated to the field conditions. To avoid such difficulties a ratio technique has been applied by several authors. This method bases the assumptions that (1) if one

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of the food components is undigestible and (2) if it is entirely excreted with faeces, then one can estimate the efficiency of food digestion simply by comparing the concentrations of this element in the food and in faeces. Several artificial markes as well as natural substances have been used as such tracers: cellulose, silica, chromogen, chromium-51, total ash, and particular mineral elements (see Kaufman et al. 1976 for a review).

Using mineral elements one has to accept one more important assumption that (3) during the digestion process the animal would keep a stable mineral balance. Practically, none of these constrains can be hold. Under some circumstances, however, the possible error of the method may be minimized. For example, an adult, non-reproducing animal is very likely to stay in a mineral balance; some elements occur in food in the form of insoluble compounds and in a great excess in respect to the animals requirements, so that the vast majority of the amount eaten is actually excreted with faeces. When applying this method to any particular study one has to check out first which elements may be useful as such indicators.

The aim of this study was to evaluate the ratio technique, using a dozen of mineral elements, for the measurements of digestibility efficiency in Antarctic seals. This preliminary investigation may help in a proper set-up of the further studies. It also allows for a tentative estimation of the digestibility of natural foods in pinnipeds, and brings some information about concentrations of various micro- and macroelements in biological materials from the Antarctic region.

2. Material and methods

The materials were collected on King George Island (South Shetland) in Admiralty Bay, during Austral summer 1978/79. They included the samples of faeces of 6 adult and 1 immature Weddell seals (*Leptonychotes weddelli*), single samples of faeces of crabeater seal (*Lobodon carcinophagus*) and leopard seal (*Hydrurga leptonyx*). Only fresh faeces excreted by the individuals of known sex and age were collected from the snow surface.

Basing on the published information concerning the food composition of Antarctic seals (e.g. Deaborn 1965, Øritsland 1977) and on personal observations (faeces analyses; Woyciechowski, unpubl.), arbitrary assumptions were made concerning the food composition of the species studied. Accordingly, as a representation of the food of crabeaters and leopard seals the samples of krill (*Euphausia superba* Dana) were collected, while as the food of Weddell seals three species of fish were sampled (*Notothenia corriceps neglecta* Nybelin, *Notothenia rossi marmorata* Fischer, *Notothenia gibberifrons* Lönnb.), caught in Admiralty Bay.

Faeces and krill were air-dried and fish conserved in alcohol. After transporting to the laboratory all samples were dried to a constant weight and homogenized (fish sample jointly with conservant). Prior to the determinations of K, Na, P and Ca the materials were mineralized using sulphuric acid with hydrogen peroxide. Phosphorus content was determined with a standard colorimetric technique, using ammonium molybdate. Potassium, calcium and

sodium contents were measured by an emission method on Zeiss AAS-1 spectrophotometer.

Samples for determinations of ash content and microelements (Cd, Pb, Cu, Ni, Zn, Fe, Mg, Mn) were dry-ashed at a temperature of 400° C and the remaining ash, after being weighted, was dissolved with the $HNO_3 + HClO_4$ mixture. The analyses were made on IL-251 atomic absorption spectrophotometer.

The coefficients of digestibility were calculated according to the following formulas (Johnson and Maxell 1966, Johnson and Groepper 1970, Soholt 1973, Kaufman et al. 1976, Maxell unpubl.[1]):

(1) Total dry mass digestibility, calculated from ash content:

$$D_t = \left(1 - \frac{y_o}{y}\right) \times 100$$

(2) Organic matter (i.e. ash-free dry mass) digestibility, calculated from ash content:

$$D_{a-f} = \left[1 - \frac{(1/y) - 1}{(1/y_o) - 1}\right] \times 100$$

(3) Total dry-mass digestibility calculated from the concentration of element i:

$$D_t = \left(1 - \frac{I_i}{E_i}\right) \times 100$$

(4) Organic matter digestibility calculated from the concentration of element i:

$$D_{a-f} = \left[-\frac{I_i/(1-y_o)}{E_i/(1-y)}\right] \times 100$$

where: D_t — total dry mass digestibility, %; D_{a-f} — organic matter (ash-free dry mass digestibility, %; y_o — ash content in ingesta; y — ash content in egesta; I_i — concentration of element i in ingesta; E_i — concentration of element i in egesta.

3. Results

Table I summarizes the results of ash and element content analyses in all samples. The only replicated samples (faeces of adult Weddell seals, n = 6) show the greatest variability in the content of iron, cadmium and manganese (coefficients of variation of 85, 68 and 64%, respectively), while the content of phosphorus, magnesium, potassium, calcium, ash, and nickel were the most constant in all the samples (2.7—11.2% of variability). The faeces of a young Weddell seal contained less phosphorus and calcium,

[1]) Rodent ecology and pronghorn energy relations in the Great Divide Basin of Wyoming. Ph. D. Thesis, University of Wyoming, Laramie, Wyoming 1973.

Table I

Ash content and element concentrations in the dry mass of faeces and potential food items of Antarctic seals

	Item	Element concentration in dry weight												
		% ± S. E.					ppm ± S. E.							
		Ash	P	K	Ca	Na	Cd	Pb	Cu	Ni	Zn	Fe	Mg	Mn
Faeces	Weddell seal, ad. n=6	57.3 ±2.2	10.56 ±0.11	0.291 ±0.01	20.71 ±0.77	0.614 ±0.05	1.09 ±0.30	15.07 ±1.04	43.72 ±5.07	9.98 ±0.46	427.3 ±40.6	2793.9 ±969.2	7211.6 ±202.7	87.37 ±22.92
	Weddell seal, imm. n=1	60.0	7.69	0.378	10.98	0.560	0.54	14.33	259.8	12.54	404.3	2261.6	8860.2	71.68
	Crabeater seal n=1	53.7	7.19	0.674	8.43	1.107	1.11	11.19	342.5	7.41	408.5	3302.4	8851.0	93.40
	Leopard seal n=1	56.1	7.75	0.530	9.82	2.217	0.72	14.56	422.4	12.74	401.3	655.5	8900.8	40.05
Food	Fish (homogenate)	23.5	2.02	1.617	3.66	0.898	unde-tected	3.63	7.63	5.45	74.45	944.8	2067.6	26.16
	Krill (homogenate)	13.8	1.09	0.992	0.91	0.898	0.18	unde-tected	46.63	1.80	64.71	108.5	3250.2	7.95

but distinctly more copper than these of adults. High copper concentrations occurred also in the faeces of crabeater and leopard seals.

The fish homogenate differed considerably from other potential foodstuffs in the high content of total ash, Ca and P. The highest concentrations of copper occurred in krill (Table I).

The estimated coefficients of dry mass digestibility are presented in Tables II and III. Only these elements have been considered which gave the digestibility estimates within a reasonable range of values.

For the coefficients both of the total dry mass and of the organic matter digestibility in adult Weddell seals, the less variable and the most similar were the results obtained with the use of P, Ca, Cu an Zn (estimated D_t = 80.9—82.2°/₀, coeff. of variation 0.6—5.2°/₀, D_{a-f} = 90.1—90.8°/₀, coeff. of variation less than 2°/₀; Table II and III).

The immature Weddell seal had virtually identical coefficient of digestibility as adults when calculated from the concentrations of Pb, Zn, Mg, but lower when estimated from ash, P and Ca, and higher when Cu was used as an indicator.

For the remaining two species: crabeater and leopard seals, the results were similar for each element studied (Table II and III). Within a species, the results were most similar for P, Cu, Zn (D_t = 83.8—86.4°/₀, D_{a-f} = 89.4—90.9°/₀) in the crabeater, and for Ca, Cu, P, Ni and Zn in leopard seal (D_t = 83.9—90.7°/₀, D_{a-f} = 89.4—93.9°/₀). The values obtained with use of Cu as estimator tended to be highest in the two krill-eating species.

4. Discussion

Suitability of various elements as estimators of digestibility in seals.

Among the elements studied, Na and K are known as being almost entirely absorbed and excreted usually with urine. An opposite tendency shown by Al, Fe, Mn and Zn (Kaufman et al. 1976; Luckey and Venugopol 1977). Other elements have intermediate properties and the ratio of the amount absorbed and eventually excreted with urine to the amount excreted with faeces depends, among others factors, on the total concentration of the element in food and on its chemical form.

Kaufman et al. (1976), comparing the direct measurements of digestibility with the results obtained by ratio technique in cotton rats, have revealed that the most suitable elements for such analyses are: Ba, Zn, Ca, P, Mn, and Sr. Except Mn, the results of the present study are quite consistent with their findings. Zn, P and Ca seem to give the most reliable results. Phosphorus and calcium constitute the bone material in fish so that these elements occur in a great excess in seals' food, while the phosphate complex is insoluble. Thus, in fish-eating seals these two elements seem appropriate as estimators of digestibility. The same is true for zinc, which is poorly absorbed and excreted mainly in faeces (Kaufman et al. 1976).

In the krill-eating species, and to some extent also in Weddell seals, copper may be of importance in such studies. The concentration of Cu

Table II

Total dry mass digestibility estimated from ash and elements ratios (%)

Item		Element										Main food assumed
		Ash	P	Ca	Cd	Pb	Cu	Ni	Zn	Mg	Mn	
Weddell seals, adults n=6	$\bar{x}$	69.9	80.9	82.2	—	75.3	81.6	44.5	81.8	71.2	55.0	fish
	±SE	±1.16	±0.20	±0.67	—	±1.88	±1.63	±2.71	±1.73	±0.83	±12.45	
	c.v.	4.1%	0.6%	2.0%	—	6.1%	4.9%	14.9%	5.2%	2.9%	55.5%	
Weddell seal, imm. n=1		60.3	74.4	66.7	—	74.7	97.1	56.5	81.6	76.7	63.5	fish
Crabeater seal n=1		74.9	84.8	89.2	83.8	—	86.4	75.7	84.2	63.3	94.5	krill
Leopard seal n=1		75.6	85.9	90.7	75.0	—	89.0	85.9	83.9	63.5	80.2	krill

Table III

Organic matter digestibility estimated from ash and element ratios

Item		Element										Main food assumed
		Ash	P	Ca	Cd	Pb	Cu	Ni	Zn	Mg	Mn	
Weddell seals, adults n = 6	$\bar{x}$	84.4	90.1	90.8	—	87.3	90.7	71.3	90.7	85.2	75.3	fish
	± SE	±1.4	±0.52	±0.68	—	±1.12	±0.63	±2.65	±0.71	±0.79	±7.85	
	c. v.	4.1%	1.4%	1.9%	—	3.1%	1.7%	9.1%	1.9%	2.3%	25.5%	
Weddell seal, imm. n = 1		72.7	81.9	77.1	—	82.6	98.0	70.1	87.3	84.0	74.9	fish
Crabeater seal n = 1		83.2	90.0	92.8	89.2	—	90.9	83.8	89.4	74.5	94.3	krill
Leopard seal n = 1		84.0	90.8	93.9	83.6	—	92.7	90.7	89.4	76.0	87.0	krill

in krill is relatively high (Table I) due to the role of this element as a component of blood pigments in marine invertebrates. Consequently, high concentrations of Cu have occured in faeces of krill-eating species. Relatively high amount of Cu in faeces of the young Weddell seal (Table I) suggests that this individual was feeding on unknown proportion of fish and krill rather than fish only, as it has been arbitrarily assumed for calculations (Table II and III). A great share of krill in the food of young Weddell seals was reported by Lindsay (1937) and Carrick (1964).

According to formulas 1 through 4, any escape of an element with urine rather than with faeces would cause an underestimation of digestibility coefficients. Thus, one can presume that the highest values obtained by the ratio technique are the most reliable ones (provided that the amounts of a particular element ingested with water or released from the body due to the eunstable mineral balance, are negligible). Assuming this, one can find that the highest values fall again on the same elements: P, Ca, Zn and Cu (Table II abd III).

All the values of digestibility estimated on the basis of ash content are evidently too low, due to the escape of many elements in urine; this effect may also be caused by the different form of mineral compounds in the ash of food and that of faeces.

The remaining elements do not seem to be suitable for markers since they occur in low and/or highly variable concentrations in the materials examined (Table I) and produce distinctly underestimated coefficients of digestibility (Table II and III).

Dry mass digestibility in Antarctic seals.

Due to the scarcity of material and arbitrary assumptions on the diet composition any conclusions concerning digestibility coefficients based on the data presented above should be taken with caution. Nevertheless, the lack of information on this topic has prompted us to present these preliminary results.

Table IV

Total dry mass digestibility coefficients in terrestrial carnivore mammals

Species	Food	Digestibility coefficient (%)	References
Mustela nivalis L.	small mammals	87.0	Moors (1977)
	rabbit	98.0	
	starling	93.0	
Martes pennanti Erxleben	hare	85.6	Davison et al. (1978)
	deer	92.0	
	small mammals	72.3	
Vulpes vulpes (L.)	rabbit	87.0	Vogtsberger and Barret (1973)
Lynx rufus (Schreber)	chicken	76.8	Golley, Pertrides and Jenkins (1965)
	rabbit	86.9	
	deer	89.4	

When taking into account the estimates of digestibility obtained with the use of elements regarded as the most promissing ones, and accepting all the above mentioned assumptions, one can estimate the total dry mass digestibility of fish food in Weddell seals for approximately 82°/₀, and the ash-free digestibility for 91°/₀. The analogous figures for krill-eating species average: 86 and 91°/₀ in crabeaters, and 87 and 92°/₀ in leopard seals.

These results are comparable with data on the digestibility of animal food in terrestrial carnivores (Table IV), especially with those feeding on relatively large prey. However, these terrestrial carnivores which consume the whole prey, have the total digestibility lower than marine mammals.

A more accurate determination of the efficiency of digestion of natural foods in Antarctic seals demand, however, more detailed studies.

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5. Summary

A tracer method was evaluated for estimations of digestibility of natural food in Antarctic seals. Concentrations of 12 mineral elements (K, Na, P, Ca, Cd, Pb, Cu, Ni, Zn, Fe, Mg, Mn) and total ash in faeces and in food samples (fish and krill) were examined for three species: Weddell seal (*Leptonychotes weddelli*), crabeater (*Lobodon carcinophagus*) and leopard seal (*Hydrurga leptonyx*), (Table I). The digestibilities of total dry mass and of organic matter were calculated, based on the increase of concentration of some elements in faeces in relation to the food (Table II and III). The most reliable results were obtained when P, Ca, Cu and Zn were used as indicators. Such estimated coefficients of dry mass digestibility amounted in Weddell seals, crabeater and leopard seal 82, 86 and 87% respectively, while the coefficients of organic matter digestibility reached 91, 91 and 92% in these species. Thus, the digestibility of natural food in seals is similar to that in terrestrial carnivores (Table IV).

6. Резюме

Исследовалась возможность применить метод микроэлементов-показателей для определения удобоваримости естественных кормов у антарктических тюленей. Поэтому установливали концентрацию 12 элементов: (K, Na, P, Ca, Cd, Pb, Cu, Ni, Zn, Fe, Mg, Mn), а также общее количество золы в выделениях и пробах пищи (рыбы и криль) у трех видов: тюленя веделла (*Leptonychotes weddelli*), тюленя крабоеда (*Lobodon carcinophagus*) и морского леопарта (*Hydrurga leptonyx*) (таблица I). На основании роста концентрации некоторых элементов по отношению к пище определялось усвоение общей сухой массы и органической материи (таблицы II и III). Най более повторимыми и перспективными были результаты, полученные при использовании в качестве показателей P, Ca, Cu и Zn. Определенные таким образом коэффициенты удобоваримости сухой массы пищи составляли у тюленя веделла, тюленя крабоеда и морского леопарта соответственно: 82, 86 и 87%, а коэффициенты удобоваримости органической материи у тех же видов составляли 91, 91 и 92%. Итак, удобоваримость естественных кормов у тюленей похожа как у хищников (таблица IV).

7. Streszczenie

Zbadano możliwość użycia metody wskaźnikowej dla określenia strawności naturalnych pokarmów antarktycznych fok. W tym celu zbadano koncentrację 12 pierwiastków (K, Na, P, Ca, Cd, Pb, Cu, Ni, Zn, Fe, Mg, Mn) oraz całkowitego popiołu w kale i w próbkach pokarmu (ryby i kryl) u trzech gatunków: foki Weddella (*Leptonychotes weddelli*), krabojada (*Lobodon carcinophagus*) i lamparta morskiego (*Hydrurga leptonyx*) (tabela I). Na podstawie wzrostu koncentracji niektórych elementów, w stosunku do pokarmu oznaczono przyswajalność całkowitej suchej masy i masy organicznej (tabela II i III). Najbardziej powtarzalne i obiecujące wyniki uzyskano przy zastosowaniu P, Ca, Cu, Zn jako wskaźników. Tak określone wskaźniki strawności suchej masy pokarmu wynosiły u foki Weddella, krabojada i lamparta morskiego odpowiednio: 82, 86 i 87%, zaś współczynniki strawności materii organicznej u tych samych gatunków wynosiły 91, 91 i 92%. Strawność naturalnych pokarmów fok jest więc podobna jak i u drapieżników lądowych (tabela IV).

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