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DEVELOPMENT OF STANDARDIZED SAMPLING METHODS FOR USE IN REGULAR DIET STUDIES OF NORTHEAST ATLANTIC MINKE WHALES *BALAENOPTERA ACUTOROSTRATA*

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ABSTRACT

Implementation of predator-prey interactions in multispecies models requires regularly updated information about stomach contents of individual top predators. Minke whales *Balaenoptera acutorostrata* are now included in the multispecies modelling of the Barents Sea resources. This has actualized development of an effective and feasible method designed to provide regular and representative information about stomach contents from the species. It is assumed that this may be obtained most conveniently by collection of data from commercial catches. However, it was acknowledged that the comprehensive and time- and resource-consuming methods used in recent Norwegian scientific catch operations where the diet studies were based on total forestomach contents (varying from 1 to 150 l) from each whale, had to be simplified considerably. Experiments designed to achieve this were started on a pilot scale during scientific whaling in 1994, and continued more comprehensively during commercial whaling in 1995. The results indicate that such simplification is possible. Under certain assumptions, randomized collection of relatively small (2-3 l) subsamples taken directly from the opened forestomach appears to be sufficient for an adequate and representative description of minke whale diets. The 1995 minke whale diets, as observed on 6 vessels participating in the commercial catches, was characterized by an almost total dominance of krill *Thysanoessa* sp. in the northern Barents Sea (including areas west of Spitsbergen). The southern Barents Sea area was characterized by a more mixed minke whale diet which contained krill and herring *Clupea harengus* in comparable amounts, but also considerable amounts of capelin *Mallotus villosus*, cod *Gadus morhua* and haddock *Melanogrammus aeglefinus*.

INTRODUCTION

In the management of fish stocks, a strategy for a gradual implementation of a multispecies approach is currently being investigated. The modelling effort for resources in the Barents Sea has yielded an area-structured multispecies model, MULTSPEC, where particular emphasis is placed on the stocks of key fish species; capelin *Mallotus villosus*, herring *Clupea harengus* and cod *Gadus morhua*. (Ulltang 1995). Although these fish stocks constitute the core of the model, Ulltang (loc.cit.) emphasizes that the inclusion of marine mammals is essential in multispecies models for the Barents Sea. The current main purpose for including the two most numerous marine mammal species in the area, harp seals *Phoca groenlandica* and minke whales *Balaenoptera acutorostrata*, in the model is to try to determine what data is necessary to predict the effects of these two species' predation on the stocks of capelin, herring and cod. To a more limited extent, it is also attempted to investigate, through simulation studies, likely long-term effects of different exploitation strategies on the fish and mammals stocks on the ecosystem.

The main use of MULTSPEC in a management context has so far been to quantify the cod-capelin interactions, more specifically to estimate the predation mortalities of mature capelin generated by cod (Ulltang 1995). Additionally, Bogstad *et al.* (1996) have described MULTSPEC as a simulation model where herring is included and where the sensitivity of the model to assumptions of food preferences and stock sizes of minke whales and harp seals are explored.

The development of multispecies models has given the analysis of the feeding ecology of important top predators particular actuality. The northeast Atlantic stock of minke whales is boreo-arctic, with migrations to feeding areas in the far north in spring and early summer, and southwards to breeding areas in the autumn (Jonsgård 1966). In order to evaluate the ecological significance of this stock, a scientific whaling program, addressing particularly questions concerning feeding ecology by using stomach analyses and concurrent estimates of prey availability, was conducted by Norway in 1992-1994 (Haug *et al.* 1995a,b, 1996a, Skaug *et al.* 1996). When choosing food preference parameters for minke whales in the MULTSPEC model, results from the 1992-1994 diet studies were used for setting the likely ranges of the parameter values (Bogstad *et al.* 1996).

The estimation part of the MULTSPEC program requires updated information from annual field samplings targeted especially towards stomach content data (at present only from the predator cod). Used as a simulation model, however, the need of annually updated stomach content data is not equally critical. On a longer term, however, it is desirable also to include interactions other than the cod-capelin interaction in the estimation part of the MULTSPEC program. This will require regularly updated information about stomach contents of other included top predators such as minke whales. It will be particularly important to have data describing the whale diets under different ecological situations, and to identify what happens when changes occur.

Scientific whaling operations are extensive and expensive and unlikely to be carried out routinely. Thus, in order to provide regular data on minke whale feeding ecology, a simpler solution has to be sought. The most convenient way to obtain such data is probably by collection of adequate material from minke whales taken in commercial catches. The methods used during the scientific whaling operations were based on the examination of the total forestomach contents (ranging in volume from less than 1 l to more than 150 l) in each whale, and were, therefore, extremely time- and resource-consuming (see Haug *et al.* 1995a, 1996a, b, Lindstrøm *et al.* 1996). Routine sampling from commercial catches will, therefore, require substantial simplifications. The development of an effective and feasible method which gives representative stomach content data during commercial minke whaling operations was the main purpose of the investigations reported here. Some pilot samples were taken during scientific whaling operations in 1994, whereas the major sampling took place during the 1995 commercial whaling season.

MATERIAL AND METHODS

Sampling of whales

In 1993, the International Whaling Commission (IWC) decided that the so-called "small areas" boundaries should be retained for the management of Northeast Atlantic minke whales. According to this division, minke whales from the North Sea (EN), coastal areas of Lofoten and Vesterålen (EC), coast of Finnmark and the Barents Sea (EB), and Bear Island and Spitsbergen waters (ES) are considered to belong to different breeding stocks (see Fig 1), although there was evidence of exchange among some of the areas, in particular EB-ES-EN (Anon. 1993). During commercial catch operations, quotas are set per small area, and each operating vessel is allocated a particular boat quota in one or two of the designated small areas in each season. In 1995, stomach samples were collected from whales caught by three vessels operating in area EB, two vessels opearting in area ES and one vessel with separate quotas in both these areas. Adequate samples were obtained from 37 minke whales (18 in area EB, 19 in area ES, see Fig. 1). In the methodological analyses, stomach samples from 16 minke whales taken in the 1994 scientific whaling operations (3 from EC, 6 from EB and 7 from ES) were also included (see Haug *et al.* 1996a).

Whales taken during the 1994 scientific whaling operations (6 July - 6 September) were sampled randomly on chartered whaling vessels using procedures which included searching along predetermined transects (Haug *et al.* 1996a). The whales taken in the 1995 commercial whaling operations were sampled opportunistically in areas with expected high densities of whales (Christensen & Øien 1990) during the period 13 May - 11 June.

Analyses and reconstruction of minke whale stomach contents

The complete digestive tract was taken out of the whale as soon as possible (1-3 hours *post mortem*). Minke whale stomachs consist of a series of four chambers (Olsen *et al.* 1994), but Lindstrøm *et al.* (1996) have shown that sampling and analyses of contents from the first chamber (the forestomach) is sufficient to describe the minke whale diet. Thus, only forestomach contents were used in these analyses. The onboard and laboratory treatment of the full forestomach contents are as described in detail by Haug *et al.* (1995a, 1996a).

In addition to the ordinary forestomach samples taken to estimate the total content (TS), smaller sub-samples (SS) of 2-3 l (after liquid had been filtered off) were collected from 43 forestomachs in 1994 and 1995. In cases where the forestomachs contained undigested, large fish (such as gadoids), these were removed, counted and measured onboard, after which the remaining and more digested contents, if present, were subsampled. In all other cases the subsamples were taken randomly from the total forestomach contents. All subsamples were frozen onboard for later laboratory treatment. The contents remaining in the forestomach after subsampling was transferred to the tub and sieve system and treated as described by Haug *et al.* (1995a, 1996a). Laboratory treatment of subsamples and remaining contents from the forestomachs were identical, and their sum became the estimated total forestomach sample.

Intact specimens of fish were identified according to gross morphological characteristics (Pethon 1985), while sagittal otoliths and crustaceans were identified to lowest possible taxon (Enkell 1980, Breiby 1985, Härkönen 1986). The total number of each fish species was calculated by adding the number of fresh specimens, intact skulls and half the total number of otoliths. For large gadoids, such as cod, haddock and saithe, free otoliths were separated into right and left otoliths and divided into geometric classes (with 0.2 mm intervals) whereas otoliths present in skulls, were paired and measured. From otolith length-fish length/mass correlations and random sub-samples of 200 undigested otoliths (or as many as possible) from each fish species, the initial prey masses at the time of ingestion were estimated.

When estimating the biomass of crustaceans found in the stomachs at the time of ingestion, mean individual weights of digested crustaceans were recorded. These masses were based on weights of a known number of individuals (usually 250-300) in a subsample. Using known mean masses of fresh crustaceans (see Haug *et al.*, 1995a), the original biomass of the crustaceans eaten by the minke whales was crudely estimated.

Several feeding indices are commonly used in stomach analyses of top predators (Hyslop 1980, Pierce & Boyle 1991). In the 1992-1994 diet studies of the minke whale, the prey was quantified using frequency of occurrence, and mass and numerical fractions of individual prey categories (Haug *et al.* 1995a, 1996a). No feeding index, however, gives a complete or fully realistic picture of dietary composition. The estimated masses of individual minke whale forestomach contents vary considerably (0-250 kg, see Haug *et al.*, 1996b) in response to the various states of satiation the whales were caught at. By using the traditional numerical and mass fractions of individual prey categories to describe the minke whale diet, forestomachs containing large amounts of food are given exaggerated importance compared to those containing little food. This problem may be avoided, however, by using an alternative mass index, calculated by summarising the percentage of each prey species from each individual whale and dividing this by the total summarised percentages of all prey specimens from all whales. This index give each forestomach the same importance irrespective of the very variable content mass.

In this paper, the 1995 diet data are presented as frequency of occurrence of each prey item and as percentage weight of each prey species (method A) using the alternative mass index:

$$WI_i = \frac{\sum_{t=1}^{n} w_{ti}}{\sum_{i=1}^{7}\sum_{t=1}^{n} w_{ti}}$$

where w_{ti} is the relative contribution of mass (%) by prey species **i** to the contents in forestomach **t** and **n** is the number of forestomachs included in the investigation. To simplify the presentations and calculations, prey items were grouped into the following taxa (see Figs 2 and 3): ZOOPLANKTON [krill (*Thysanoessa* sp.), copepods (*Calanus* sp.) and amphipods (*Parathemisto* sp.)], HERRING, CAPELIN, COD, HADDOCK *Melanogrammus aeglefinus*, PELAGIC FISH [sandeel (*Ammodytes* sp.) and saithe *Pollachius virens*] and VARIOUS FISH. Thus, **i** = 7.

When comparing the food composition in the total forestomach sample (TS) with the sub-sample (SS), the mass index method (method A) was compared with the more traditional bulk biomass index method (method B):

$$B_i = (b_i/b_t) \times 100$$

where b_i is the total mass of prey category **i** (i = 7), and b_t is the total mass of all prey categories

RESULTS

The 1995 diet

A minimum of 12 different prey species were identified in the stomachs of the minke whales sampled during commercial whaling operations in 1995 (Table 1). Herring and krill occurred in most stomachs in the southern coastal EB area where 11 prey species were observed. Only 4 prey species were observed in the more northern ES area where the occurrence of krill was particularly conspicuous. Using a Fisher's exact test, it was evident that minke whales in the northern ES area had eaten krill significantly more frequently than whales in the south (EB) ($P<0.05$).

In terms of calculated fresh mass (Fig. 2), zooplankton (krill) and herring (30% and 24%, respectively) constituted more than half of the prey biomass in area EB, where also capelin (19%), haddock (14%) and cod (13%) were observed in considerable amounts. The prey biomass in area ES was characterized by an almost total dominance (nearly 100%) of krill.

Subsamples vs. total samples of contents from forestomachs

Comparison of subsamples (SS) with total samples (TS) were made on the basis of pooled data from forestomachs sampled during scientific (1994) and commercial (1995) whaling operations. The material reveals a dominance in reconstructed prey biomass of zooplankton and herring, with smaller contributions of capelin, cod, haddock and pelagic fish (Fig. 3). Apparently, the use of the recommended method A (the percentage mass index method) instead of method B (the more traditional bulk biomass index method) increased the relative importance of zooplankton and correspondingly decrased the importance of most fish species. More interestingly, however, it appears that the use of method A gives more similar results when comparison is made between the SS and TS samples. For instance, the contribution of zooplankton and herring to the total biomass was similar (54% and 25%, respectively) when method A was applied to both the SS and TS data. Applying method B, however, the corresponding numbers differed between SS and TS and were, respectively, 32% and 44% for zooplankton and 42% and 28 % for herring. Pairwise comparisons of the relative importance of all 7 prey taxa, as calculated using method A, between SS and TS using a Wilcoxon signed test, revealed no significant differences (all $p>0.05$).

DISCUSSION

The observed 1995 minke whale diet was characterized by a dominance of zooplankton, mainly krill, in the northern (ES) area and of fish in the southern (EB) area.

The prominent role of krill in the northern area resembles observations made during scientific whaling in 1993 and 1994 (Haug *et al.* 1995b, 1996a), and is consistent with the current status of the Barents Sea ecosystem which, since 1992, has been characterized by relatively large amounts of zooplankton and a very low abundance of capelin (Anon. 1996). Although krill has been shown to play an important role on the minke whale diet in area ES in previous years (Jonsgård 1951, 1982, Nordøy & Blix 1992), it is known that capelin, if abundant in sufficient amounts, may also be an important dietary constituent there (Jonsgård 1951, Haug *et al.* 1995a).

The mixed fish diet documented in the EB area resembles observations made during the spring and summer in all years (1992-1994) of scientific whaling when also herring and gadoids characterized the minke whale diets in the more southern parts of the Barents Sea and coastal areas of North Norway (Haug *et al.* 1995a,b, 1996a). The timing of the 1995 sampling from commercial catches coincided with parts of both the spring and summer sampling periods of the 1992-1994 investigations. Summer predation of minke whales upon herring has also been observed in coastal areas of North Norway in previous years (Jonsgård 1951, 1982, Lydersen *et al.* 1991, Nordøy & Blix 1992).

While krill was scarce in the observed 1992-1994 diets of minke whales in the southern coastal areas of the Barents Sea and North Norway, it contributed significantly to the EB area diet in 1995. Analyses of the data collected during the scientific whaling operations clearly showed that minke whale meals consisting of zooplankton tended to be smaller than those consisting of herring, cod and haddock (Haug *et al.* 1996b). Furthermore, it is evident that the use of traditional numerical and mass fraction of individual prey categories tends to give whale forestomachs that contain large amounts of food an exaggerated importance compared with those containing little food. Use of the traditional diet indices when presenting the results from the 1992-1994 scientific whaling operations (Haug *et al.* 1995a, 1996a) may, therefore, have contributed to an underrepresentation of zooplankton as compared to fish species. Use of the percentage mass index (method A), gives each stomach the same importance irrespective of stomach content mass and eliminates the problem with prey specific variations. Certainly, krill is known to have been important food for minke whales in area EB also in previous years (Christensen 1972, 1974, Nordøy & Blix 1992).

A comparison of the forestomach total (TS) and sub (SS) samples using both method A and the more traditional bulk biomass index (method B) shows how the importance of fish increases and zooplankton decreases when the latter method is used. Also, the use of method B appears to result in considerable differences in prey importance between the subsample and total sample, whereas method A gives similar results for the two sets of forestomach samples. In summary, the present study seems to indicate that the collection of relatively small forestomach subsamples appears to be sufficient for an adequate and representative description of the diet of minke whales. Forestomachs containing undigested large fish (such as gadoids) will, however, need a somewhat different treatment, either through increasing the size of the subsample or through the analyses of the undigested portion (counted and measured) on the ship. A prerequisite for the use of subsamples is the application of the percentage weight index (method A) when the importance of the different prey items is quantified.

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Table 1. Frequency of occurrence of empty forestomachs and species identified in forestomachs of minke whales caught in two regions in the Northeast Atlantic in May-June 1995. The two most important prey species are shaded. N = number of stomachs examined.

	PERCENTAGE OCCURRENCE	
PREY ITEM	EB (N=19)	ES (N=18)
Empty stomachs	0	0
Crustaceans		
Calanoida		
Calanus spp.		5.6
Euphausiacea		
Thysanoessa spp.	63.2	100
Meganyctiphanes norvegica	21.1	55.6
Pisces		
Clupeidae		
Clupea harengus	68.4	
Osmeridae		
Mallotus villosus	26.3	5.6
Gadidae		
Gadus morhua	15.8	
Melanogrammus aeglefinus	31.6	
Pollachius virens	5.3	
Molva molva	5.3	
Unid. gadoid remains	15.8	
Scorpenidae		
Sebastes sp.	5.3	
Myctophidae		
Benthosema glaciale	10.5	
Ammodytidae		
Ammodytes sp.	5.3	
Unidentified remains	31.6	

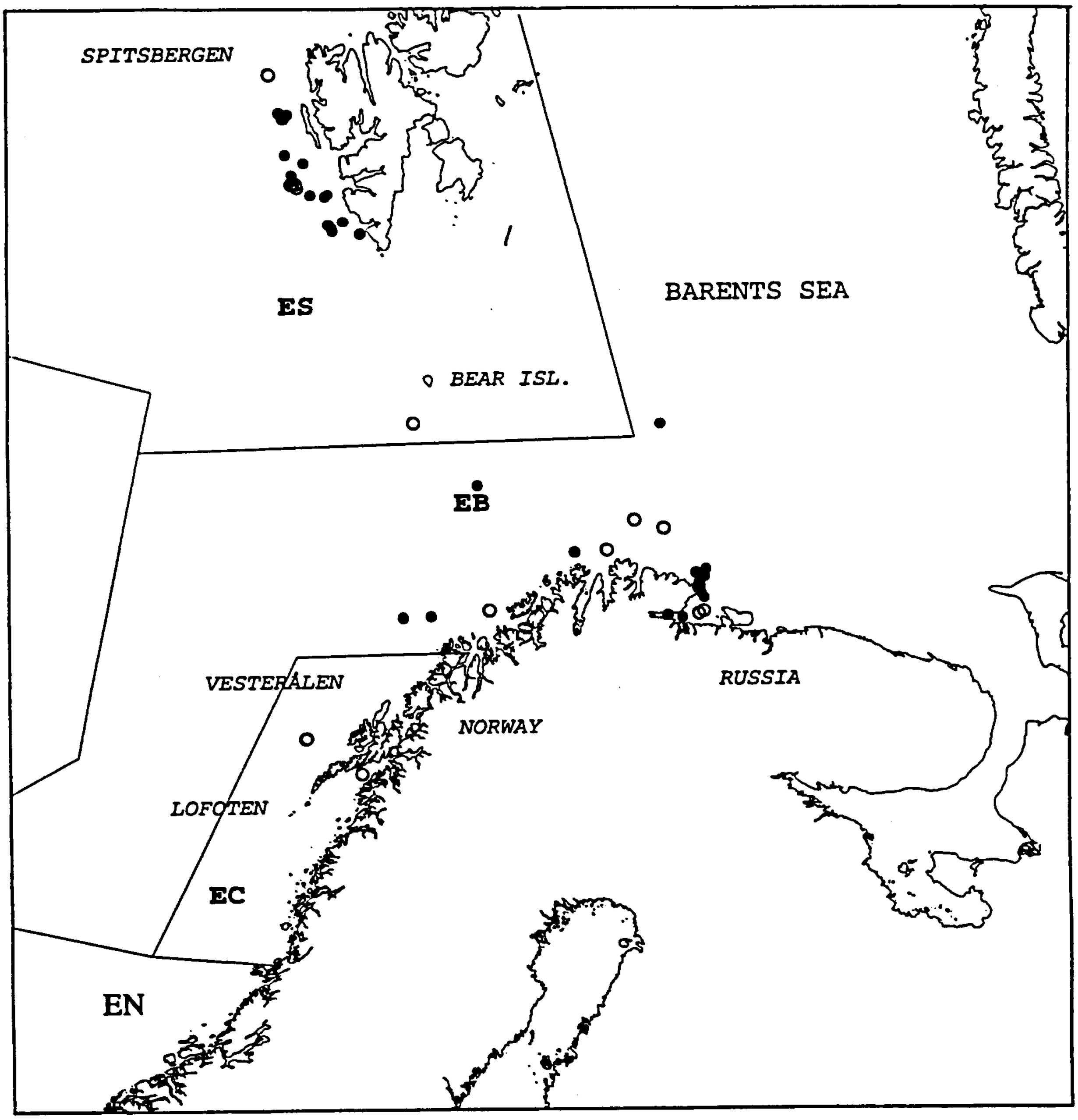

Fig. 1.
Ecological studies of northeast Atlantic minke whales based on forestomach analyses: Catch positions for minke whales taken in 1994 (scientific whaling, n = 16; open circles) and 1995 (commercial whaling, n = 37; filled circles) in catch areas EC, EB and ES (see text for explanation).

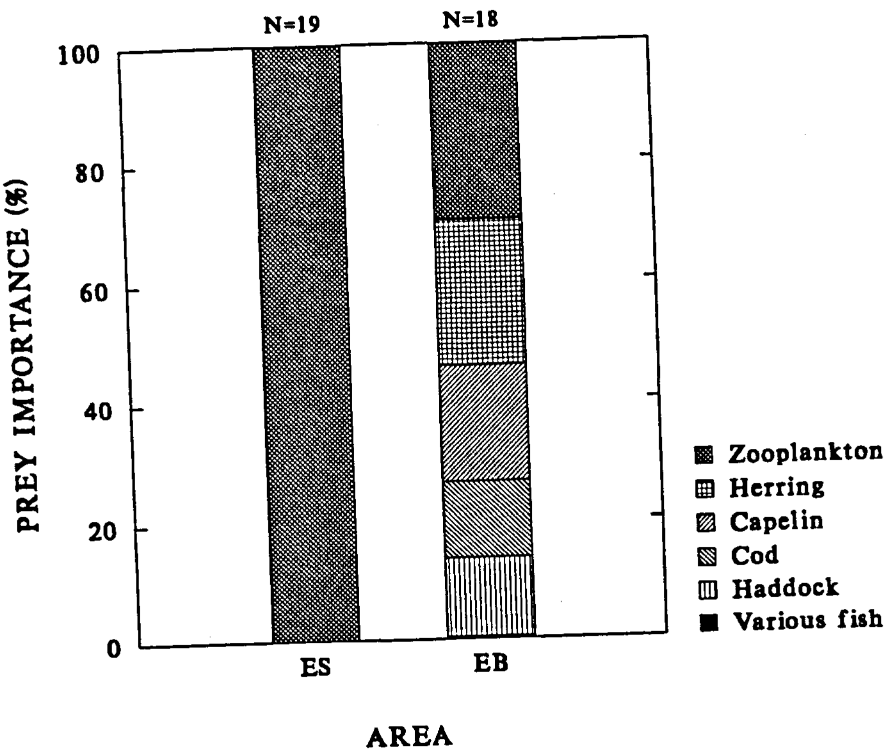

Fig. 2.
Ecological studies of northeast Atlantic minke whales based on forestomach analyses: Relative dietary importance of prey items, measured by method A (see text) applied to total forestomachs samples, in whales taken in commercial catch operations in areas EB and ES in 1995.

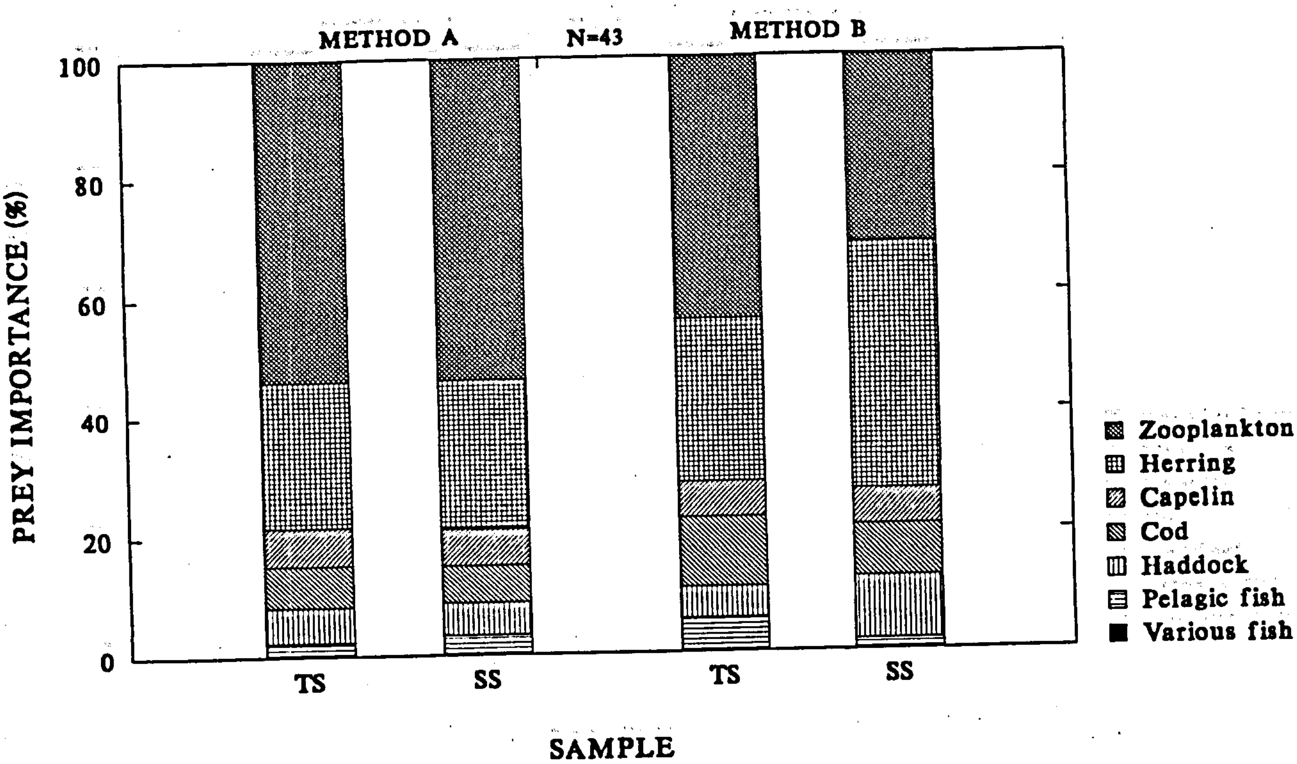

Fig. 3.
Ecological studies of northeast Atlantic minke whales based on forestomach analyses: Comparison of dietary importance of prey items, measured by methods A and B (see text) applied to total and sub samples of forestomach contents, in whales taken in scientific whaling operations in 1994 and in commercial whaling operations in 1995.