This paper not to be cited without prior reference to the authors

International Council for the Exploration of the Sea

C.M. 1992 / N:8 Ref. G+H
Marine Mammals Committee
Reference - Demersal Fish Committee + Pelagic Fish Committee

A RESEARCH PROPOSAL TO EVALUATE THE ECOLOGICAL IMPORTANCE OF MINKE WHALES *BALAENOPTERA ACUTOROSTRATA* IN THE NORTHEAST ATLANTIC[1]

TORE HAUG, HARALD GJØSÆTER, ERLING S. NORDØY & TORE SCHWEDER

Correspondence address:
The Secretariat of the Norwegian Marine Mammal Research Programme
c/o Norwegian Institute of Fisheries and Aquaculture
P.O.Box 2511, N-9002 Tromsø, Norway

ABSTRACT

In order to evaluate the feeding ecology and importance of minke whales Balaenoptera acutorostrata in Norwegian waters, a scientific whaling programme addressing particularly the following points is proposed:

i An analysis of the stomach contents of a random sample of whales to quantify the various types of prey consumed by minke whales in the northeastern Atlantic area.

ii A correlation of the type and quantity of prey in the stomachs of the random sample of whales with the estimated availability of the various types of prey in the area and period, to enable the estimation of food preferences of minke whales.

The search operation preceeding the catch is to be scientifically controlled to ensure random sampling and maximum coordination with trawling and other sampling methods used to determine the abundance of potential prey species. The scientific catch of minke whales will also make possible estimates of various other biological parameters such as age and growth, sexual maturity, pregnancy rates, sex proportion, stock identity, pollution etc.

1The proposed scientific programme implies sampling of minke whales with concurrent estimates of potential prey resources in 5 defined areas in Norwegian and adjacent waters (west of

[1]Prepared for and accepted by the Steering Committee of the Norwegian Marine Mammal Programme

Spitsbergen, Bear Island area, southeastern Barents Sea, coastal banks off Finnmark, and Vesterålen/Lofoten) during three periods of the year (spring, summer and autumn). The sampling design is based on statistical analyses aimed to keep the catch to the lowest possible level. A minimum catch of 382 animals, taken over a period of three years, e.g., 1992 (110), 1993 (136) and 1994 (136), will be necessary to fullfill the scientific objectives of the programme.

Tore Haug: Norwegian Institute of Fisheries and Aquaculture, P.O.Box 2511, N-9002 Tromsø, Norway

Harald Gjøsæter: Institute of Marine Research, P.O.Box 1870 Nordnes, N-5024 Bergen, Norway

Erling S. Nordøy: Department of Arctic Biology and Institute of Medical Biology, University of Tromsø, Breivika N-9037 Tromsø, Norway

Tore Schweder: University of Oslo, P.O.Box 1070 Blindern, 0316 Oslo 3, Norway

CONTENTS

1. INTRODUCTION

The minke whale Balaenoptera acutorostrata is a boreo-arctic species, which in the North Atlantic, migrates regularly northwards in the spring and early summer and southwards in the autumn (Jonsgård 1966). The extent of the wintering areas of the species (in general at low latitudes although some individuals may stay in high latitudes throughout the year), is uncertain. Their spring, summer and autumn appearance at higher latitudes has, however, been known for a long time, and minke whales have been hunted in Norwegian waters for several hundred years. A "modern" type of whaling (i.e., an industry carried out with motor vessels equipped with harpoon guns, so called "small-type whaling") was adopted in the early 1920s and prevailed up to 1987 when Norwegian commercial harvesting of minke whales was provisionally stopped, following a recommendation from the International Whaling Commission (IWC) (see Jonsgård 1951, 1955, Øien et al. 1987, Christensen & Øien 1990, Christensen et al. 1990).

A coordinated national research programme on marine mammals was initiated by Norwegian authorities in 1988 (Anon. 1988). Included in this programme are ecological studies designed to provide information for future multispecies management of the Barents Sea resources, and studies to provide a basis for a rational management of minke whales in future small-type whaling in Norwegian waters, and also to assess the ecological significance of the species in the area.

2. BACKGROUND

2.1. Ecology

The best available data of the abundance of minke whales in the northeast Atlantic are from a sightings survey performed in July

1989 (NASS-89, see Øien 1991). Based on these data, IWC agreed upon the number 68.447 as the best abundance estimate for this area (Anon. 1992). When reviewing this estimate, the Scientific Committee of the IWC expressed its belief that any effect of the possible bias factors was likely to be negative in this abundance estimate (Anon. 1992). From catch and effort data, Schweder et al. (1991a) found that the minke whale abundance in the northeast Atlantic has varied cyclically with a periodicity of about 20 years between 1952 to 1983 (Fig. 1). The Scientific Committee of IWC concluded its review of the relative abundance series by stating that the results show that there has been a statistically significant decline in the Barents Sea minke whale CPUE during the period 1952-1983, without giving an estimate of this decline (Anon. 1992).

The many changes in the marine ecosystem in Norwegian waters in the period between the late 1960s and today, especially the stock collapses of the two major pelagic shoaling species Atlanto Scandian herring Clupea harengus and Barents Sea capelin Mallotus villosus (Anon. 1991a, see also Figs 2 and 3), actualize analyses of the feeding ecology of the most numerous top predators in the area. Recent attempts to analyse multispecies interactions and ecosystem functions on the Norwegian coast and in the Barents Sea have highlighted obvious gaps and deficiencies in both data and knowledge, and this applies in particular to marine mammals (Bax et al. 1991). Increased effort in undertaking investigations aimed to supply data for such studies were greatly encouraged in the conclusion of a Nordic seminar on "Predation and predatory processes in marine mammals and sea-birds" held in Tromsø in May 1991 (Anon. 1991b). Currently, studies of the feeding ecology of important predators are being carried out on cod Gadus morhua (Mehl 1989, Aijad 1990, Mehl & Sunnanå 1991), sea birds (Erikstad 1990, Erikstad et al. 1990) and harp seals Phoca groenlandica (Haug et al. 1991, Nilssen et al. 1991). Supplementary studies of the role of the numerous minke whale as a top predator are also clearly needed.

The minke whale is known to feed on various species of zooplankton and fish such as herring, capelin and cod (Sergeant 1963, Larsen & Kapel 1981, Jonsgård 1951, 1982). The collapse of two of these important prey species (herring and capelin, Anon. 1991a) is likely to have had a substantial impact on the feeding habit of the whale and possibly its migratory behaviour. Results of stomach analyses made from previous commercial catches (e.g., Jonsgård 1951, 1982, Christensen 1972, 1974, Øritsland & Christensen 1982) are, therefore, difficult to put in present-day perspective because they relate to periods and areas with changing prey availability or with prey abundance much different from today.

Current studies of the ecological significance of minke whales in Norwegian waters have shown that the availability of relevant field data, in particular from more recent years, is very restricted. This applies especially to the feeding habits of the whales in the different areas of distribution throughout the year, data which is of crucial importance for calculations in multi-species models. For example, without such information, it is imposssible to address questions related to the impact of the minke whale on the collapse of the Atlanto Scandian herring and the Barents Sea capelin. Furthermore, the minke whale might also have had an impact on the development of the Barents Sea cod throughout the 1980s. The 1983 0-group class of this stock was very strong, but the growth of the stock in subsequent years turned out to be much slower than predicted (Anon. 1990b). The numerous minke whales might have contributed to this either by feeding directly on the cod or through competing with the cod in consuming capelin which was then in short supply.

Conversely, one may ask: What adverse effect has the collapse of the herring and capelin stocks had on the minke whale stock? To understand the aspects of the environment which are important and possibly vital for the minke whale, the feeding ecology of the whale needs to be studied. There have been dramatic changes in the marine environment in the past, and similar changes cannot be ruled out in the future. Some of these are influenced by human activity, and are subject to management.

2.2. Management context

The management context is two-sided: the whaling itself is regulated through the IWC, while the fisheries are managed by the Norwegian/Soviet Commission based upon advice from the International Council for the Exploration of the Sea (ICES).

The present proposal will be presented to IWC. In Section 3.2 it is argued that, in the broader sense of whale management, information on the feeding ecology of minke whales is a critical research need. This includes management questions also related to that part of the environment which is important to the whale.

On the other side, ICES and regulatory bodies for fisheries, have an interest in how whaling and also the environment for whales is managed as it pertains to fisheries management. In particular, they have an interest in the role of the whale as a top predator and its direct implications for fisheries management (see Section 3.1.). The Multispecies Research Program and the Fishery Stock Assessment Program are the relevant activities of ICES. Management of the fish stocks in the Barents Sea has been based on the stock assessment advice obtained from ICES, particularly that developed in the Atlanto-Scandian Herring and Capelin Working Group (Anon. 1991c, d) and the Arctic Fisheries Working Group (Anon. 1991e), as vetted through the Advisory Committee on Fisheries Management (ACFM). Multispecies considerations are now taken into account by ICES in its management advice as, e.g., reflected in the report of the Atlanto-Scandian Herring and Capelin Working Group for its October 1990 meeting (Anon. 1991c), where calculations of the amount of capelin likely to be consumed by cod were used in an argument to reduce the catch of capelin. The concerns of ACFM for the multispecies aspects of the Barents Sea assessments were further amplified in the draft terms of reference for the Multispecies Assessment Working Group, the

Arctic Fisheries Working Group and the Atlanto-Scandian Herring and Capelin Working Group which were developed during the 1991 ICES Statutory Meeting in La Rochelle, France, in late September. The terms of reference for the latter included an item to "evaluate the available data from the multispecies studies and consider how they can be utilised in the assessments of capelin, herring and cod stocks". The terms of reference for the Multispecies Assessment Working Group included an item "for the diversity of ecosystems being studied by ICES member countries, evaluate the statistical properties of food and feeding data, with particular reference to variability in total food consumption and emphasising the potential implications for such estimates of sampling design". And finally the terms of reference for the Arctic Fisheries Working Group implied that this body should assess the status and provide catch limits for stocks of cod, haddock *Melanogrammus aeglefinus*, saithe *Pollachius virens*, redfish *Sebastes marinus*, and Greenland halibut *Reinhardtius hippoglossoides*, "taking account of biological interactions between cod and capelin as far as possible".

These recent developments confirm the increased intentions of ICES to account for multispecies interactions in the Barents Sea (and other areas). Although the state of art for multispecies assessment is not very advanced, the Multispecies Working Group of ICES is actively working to develop the field. The modelling effort in the Barents Sea multispecies model (MULTSPEC, see Bogsttad & Tjelmeland 1990) has mainly focussed on the predation on capelin by cod (see Anon. 1991b). Recently, however, the model has been expanded to include other top predators such as minke whales and harp seals (see section 4.3).

The present research proposal will be reviewed by IWC, and submitted for information to the Norwegian/Soviet Commission, the North Atlantic Committee for Cooperation on Research on Marine Mammals, and to the Marine Mammals Committee at the 1992 ICES Statutory Meeting.

3. RESEARCH NEEDS

3.1. Information needed for whale management

The Scientific Committee of IWC has in recent years developed procedures for whale stock management. The focus has been on developing procedures using a minimal amount of data on which to base catch quotas which in the long run show good robustness properties with respect to the conservation objective. The secondary objective for the management procedure is to give high continued yield. In its present core version, there is no room for data on feeding ecology of whales in the C-procedure, which was adopted by the Scientific Committee in 1991.

In the narrow context of the core C-procedure, there is no critical need for research on the feeding ecology of minke whales as identified by the Scientific Committee. It found, in fact, that "all five potential revised management procedures had performed satisfactorily on each of the base case and robustness trials for single stocks". The robustness with respect to trend in carrying capacity and episodic events were found to be surprisingly good. In the broader perspective, we will argue that feeding ecology is an area of important research as a basis for whale management for three main reasons:

3.1.1. Future improvements in the revised management procedure

The Scientific Committee of IWC "agreed that amendments and improvements could be made to management procedures from time to time after careful consideration. Such amendments could include incorporation of additional information available for a particular stock/region". The scope for improving the pure feed-back procedure is probably limited. It is by extending the model in an ecological direction that headway is possible. Basic information on the feeding ecology of the minke whale is of vital importance to investigate the scope for improvement in this direction. Such information is also vital for designing relevant trials for testing whether a proposed more ecological management procedure for the North Eastern Atlantic minke whale is indeed more efficient and at least as robust as the C-procedure.

3.1.2. Monitoring the stock of minke whales

The Scientific Committee furthermore said that in cases ancillary information suggests major changes to catch limits set by the revised management procedure, such changes should be made only after very careful consideration by the Committee. It is most unlikely that the Scientific Committee will abstain from closely monitoring the various whale stocks, and particularly those which are harvested. This monitoring will have to be based on the general biological/ecological understanding of the stock. The lack of information on the feeding ecology of the minke whale hampers the monitoring of this stock. To distinguish between vitally important changes in the environment of the minke whale and not so important changes, it is clearly important to investigate its feeding ecology.

3.1.3. Management of the environment of the minke whale

At present, whale management is thought of as a passively adaptive procedure for quota setting, given environmental conditions set externally. The management of the environment of whales has not been considered the responsibility of IWC. Environmental processes which directly lead to whale mortality, such as gill net fishing, has, however, attracted considerable attention from the Scientific Committee and the Commission. Through information gathered by the proposed scientific catch, we will obtain a better understanding of which environmental processes reduce feeding opportunities for minke whales (and other whale species with which the minke whales compete for food, e.g., fin *Balaenoptera physalus* and humpback *Megaptera novaeangliae* whales, see Christensen et al. in subm.) and which may, in future, cause an increase in mortality and a decrease in fecundity. It is timely for the Scientific Committee to encourage research which can result in fisheries and other environmental processes important for whales being managed better to the benefit of the whale. The proposed research on feeding ecology of minke whales is therefore of importance for the management of the (environment of) minke whales.

3.2. Information needed for fish management

The Barents Sea capelin stock is managed by setting quotas for the next year based on the information obtained during a large scale survey each September. The basic philosophy is to secure a minimum spawning stock. The quotas are allocated to the winter season (January-April) and autumn season (August-December) separately. During the winter season mainly mature capelin is caught. The mature capelin spawns in the beginning of April and is supposed to die after spawning. During the autumn season both immature capelin and capelin that will mature the following spring are caught.

The winter quotas for 1990 and 1991 were based on multispecies considerations, in that the consumption by cod was estimated using predictions of the cod stock made by the ICES Arctic Fisheries Working Group (see Anon. 1991c). The consumption estimate was based on historical calculations of consumption per cod stock biomass unit.

The autumn capelin quotas are based on a 1 1/2 year prediction and the natural mortality parameter is based on previous estimates using September-to-September runs with a mathematical model for capelin. The model is at present under revision (model CAPSEX), and a new model for the natural mortality is being developed.

The first step is to estimate the natural mortality connected to spawning and draw the remaining natural mortality at random from the observed residuals. Initial work indicates that the uncertainty in a management situation may be large. A substantial part of the natural mortality might be caused by predation from minke whales and harp seals. In order to reduce the variance on the natural mortality improvements in the natural mortality model are needed, for instance through the following steps:

1). Make an estimate of consumption of capelin per minke whale biomass unit.

2). Make an estimate of consumption of capelin per harp seal biomass unit.

3). Implement minke whales and harp seals as predators by connecting yearly abundance estimates stocks.

4). Recalculate the (reduced) residual mortalities.

This procedure parallells the present evaluation of the predation by cod in the ICES Atlanto-Scandian Herring and Capelin Working Group. It should, therefore, be easy to implement the results into practical management.

The inputs are:

1). Estimate the energy requirements of minke whales and harp seals.

2). Estimate the total consumption of the harp seals and of the minke whales in the period when they are in the Barents Sea.

3). Estimate the capelin part of the total consumption.

4). Yearly estimates of harp seal and minke whale abundance.

The weakness of the above procedure is that the consumption is independent on capelin abundance. A revision of the procedure is, therefore, to implement the consumption of capelin by harp seals and minke whales in a model where all three sea stocks are dynamic.

The interaction between harp seals - minke whales and capelin should then take into consideration the strong yearly north-south migration of capelin. Many different models for treating dynamic overlaps between species are conceiveable, ranging from the more to the less aggregated and differing in structural assumptions. A reasearch program is set up in Norway to encourage research and development of such multi-species models for fish management. The IMR MULTSPEC model has a dominant place in this picture, but other competing models are likely to be developed. The information needed to implement minke whales in MULTSPEC is described below.

3.3. Information needed for inclusion in MULTSPEC

In MULTSPEC (see Bogstad & Tjelmeland 1990), the species are divided on spatial as well as on biological characteristics. Predation is described using a two-parameter function, being proportional to the predator stock for high prey abundance and to both the prey and predator stocks for low prey abundance. The parameters in the predation function are estimated by comparing modelled consumption to measured consumption. The modelled consumption is based on temperature, predator size and feeding level (modelled food abundance in relation to the food abundance at which the predator feeds at maximum). In the present version of MULTSPEC the effect of starvation on feeding activity is not implemented, although this might easily be done. The measured consumption is based on temperature, measured stomach content and experimentally determined stomach evacuation rates.

In order to implement predation by mammals on fish in MULTSPEC, the following information is needed:

1). Geographically distributed abundance estimates, to assess the overlap between predators and prey.

2). Stomach content data and evacuation rates to determine consumption on the modelled prey species (i.e., capelin, herring, polar cod).

3). Rate of maximum feeding related to body size, and possibly temperature and starvation level.

4). Estimates of the amount of food present but not presently included into the model, e.g. the most important items for both harp seals and minke whales are possibly crustaceans (such as krill and amphipods).

5). Temperature data.

In order to implement growth of mammals in the MULTSPEC model reliable weight at age data for each year are needed in addition to the information needs listed above. However, once the consumption parameters have been estimated, it will be possible to use a wider time scale for estimating growth than the proposed 3-years catch programme.

Studies of the feeding ecology of harp seals, aimed to yield data relevant to MULTSPEC, are currently being carried out in the Barents Sea area (Haug et al. 1990, 1991, Nilssen et al. 1991).

4. PRESENT KNOWLEDGE

4.1. Minke whale abundance, migration, segregation

From analyses of catch statistics, Jonsgård (1951) concluded that minke whales migrate into Norwegian and Arctic waters in the spring (March/April). Adult and adolescent animals evidently proceed northwards along the coast to the Barents Sea and to the waters round Bear Island and Spitsbergen (Fig. 4), where they are frequent in the summer. They return in the autumn (October) via Norwegian waters to unknown breeding grounds in temperate areas. During their northward migration the whales appear to be segregated by size and sex. The adult females and immatures are usually found nearer the coast than the adult males which tend to remain in more open waters. Calves are found almost exclusively off the west coast of Norway and probably do not migrate further north during their first year. Apparently, the southward autumn migration proceeds in more open waters for all animals. Jonsgård's (1951) description of minke whale migrations in Norwegian waters, in particular the Barents Sea, has been confirmed by later tagging experiments carried out by the Institute of Marine Research (Ivar Christensen, Institute of

Marine Research, Bergen, Norway, pers. comm.).

Minke whales are not uniformly distributed but are found in greater aggregations in particular parts of the Norwegian waters throughout the season (see Figs. 5 and 6). The spatial distribution of catches (covering mainly the period May-July) shows that the two most important whaling grounds for minke whales in 1938-1985 have been the Vesterålen-Lofoten area (in particular Vestfjord) and the areas north of the Kola coast in the southeastern Barents Sea (Øien et al. 1987). According to Øien et al. (loc.cit.), the recorded catch positions further north changed significantly through the years: The easternmost parts of the Barents Sea along the coast of Novaya Zemlja and northeast of Hopen were very important whaling grounds during the 1950s and early 1960s. Later, however, catches increased further west off the coast of Finnmark, around the Bear Island and to the west of Spitsbergen. Thus, in the 1980s, whaling in the Barents Sea area was mainly concentrated within a narrow strip from the mouth of the White Sea, along the Kola and Finnmark coasts and across to the Bear Island and the west coast of Spitsbergen. Some whales were also taken in the North Sea every year both in the 1980s and in previous years. This summer distribution of minke whales was confirmed during the sightings surveys in 1987-1989 (Øien 1989, 1990, 1991).

IWC gives 68.447 as the best available abundance estimate of minke whales in the northeast Atlantic during the summer season (Anon. 1992).

4.2. Feeding ecology

Unlike the southern Antarctic minke whales, which prey almost exclusively on krill species (Ichii & Kato 1991), minke whales in the North Atlantic are generally known to be rather euryphagous, preying on pelagic crustaceans and several fish species such as capelin, herring, cod and haddock (Sergeant 1963, Larsen & Kapel 1981, Jonsgård 1951, 1982). A few data on the diet composition of the Northeast Atlantic stock of minke whales exist from the period 1943-1968 (Jonsgård 1951, 1982), whereafter only very limited information is available (Christensen 1972, 1974, Øritsland & Christensen 1982, Nordøy & Blix 1991, Lydersen et al. 1991).

A certain heterogeneity in diet, both with respect to geographic area and time of the year, has been suggested from available data. Thus, an investigation designed to evaluate the feeding ecology of minke whales should cover several of the most important feeding areas in Norwegian waters at different times of the year.

4.3. Potential prey resource abundance

We already have some knowledge of the abundance of potential prey resources in the actual areas. The zooplankton in the areas of interest are subjected to dynamic processes, and year-to-year variations caused by variations in physical parameters, must be expected (Anon. 1991f). Clearly, this necessitates close cooperation between scientists working on zooplankton dynamics in the actual years of scientific whaling and the scientists involved in the whale studies.

Going from north to south, the following brief summary of known potential minke whale food resources is given in six different areas.

4.3.1. West of Spitsbergen

The composition of food resources in this area is not known in detail. The area is characterized by Atlantic water, and the zooplankton community reflects this in being dominated by Atlantic forms such as the copepod *Calanus finmarchicus* (Skjoldal & Rey 1989). The euphausiids *Thysanoessa inermis* and *T. raschii* are also important. The pelagic fish species found here are capelin and polar cod Boreogadus saida, both being most numerous during late summer and autumn. The minke whale stomachs analysed in this area contained mostly krill Thysanoessa spp (Jonsgård 1951, 1981, Nordøy & Blix 1991).

4.3.2. Bear Island (+ east of Hopen)

This area is situated in the polar front area, where relatively warm Atlantic water mixes with cold Arctic water flowing south along the east coast of Spitsbergen. This is a highly productive area, with a mixture of Atlantic and Arctic plankton. Capelin dominates the pelagic fish fauna in all seasons, and this is an important feeding area for the capelin during late summer and autumn (Gjøsæther & Loeng 1984). Cod and haddock may occur pelagically in some years during summer and autumn. Minke whales taken in this area during summer appear to have eaten mainly crustaceans (in particular krill T. inermis, and to a certain extent also the copepod C. finmarchicus), although some capelin were also found in stomach samples (Jonsgård 1951, 1982, Nordøy & Blix 1991).

4.3.3. Kola (+ coast of Novaya Zemlja)

These areas are dominated by the eastern branches of the Norwegian Coastal Current and the Nordkapp Current, but this relatively warm water is mixed with Arctic water as it flows north along the Novaya Zemlja coast. The plankton production is highly variable, but the plankton communities are often dominated by relatively large forms such as euphausiids and (in the eastern cold areas) amphipods. The capelin will in some years move through these areas during its spawning migration to the Kola and Finnmark coasts in early spring. Capelin and polar cod are more or less absent from the more southerly areas during summer and autumn, but both species are found along the Novaya Zemlja coast during this time of the year. The young stages (two to four years old) of herring will, when present in the Barents Sea, stay in the western part of this region during most of the year (Røttingen 1986, 1987). These areas are also inhabited by larvae and fry of all the major fish species in the Barents Sea during autumn. Summer observations indicate that krill is the main minke whale prey in this area, but fish species such as capelin, polar cod and haddock have also been recorded in their menu (Christensen 1972, 1974).

4.3.4. Coastal banks off Finnmark

These areas are dominated by coastal water and Atlantic water. The spring bloom is relatively early, and the region is rich in zooplankton during summer. In early spring the capelin move through this area during its spawning migration. The only pelagic species inhabiting the coastal banks off Finnmark in late spring, summer and autumn is the herring, if present in the Barents sea. The fry of many fish species also drift through these areas during late summer. Cod, haddock and redfish are found here during most of the year (Bergstad et al. 1987). Very little material from minke whale stomachs is available from the area, but there is some evidence that they prey upon krill (*Meganyctiphanes norvegica* and *T. inermis*) during summer, possibly also on 0-group herring, cod and haddock (Nordøy & Blix 1991). A substantial mortality of 0-group fish has been observed off Finnmark during summer (Bjørke et al. 1991), and heavy predation from top predators such as minke whales has been suggested as a possible explanation for this (Victor Øiestad, Norwegian College of Fisheries Science, Tromsø, Norway, pers. comm.).

4.3.5. Vesterålen and Lofoten

This area is dominated by the Norwegian Coastal Current. The dominating fish species in spring are cod and haddock, which both spawn there in March-April. In summer and autumn, herring may be found, together with larvae and fry of herring, cod, and haddock. According to Jonsgård (1951, 1982), minke whales fed on cod, to a smaller extent also on haddock, in spring, whereas herring was the main prey in these areas in summer and autumn in the 1940ies. Summer/autumn predation upon herring (to a smaller amount also some cod) have also been confirmed in the 1980ies (Nordøy & Blix 1991, Lydersen et al. 1991).

4.3.6. North and Norwegian Seas

The North Sea is a highly productive area, both with respect to zooplankton and pelagic fish. The plankton community is dominated by copepods, and is, in summer, mixed with eggs and larvae of many fish species. Herring, sandeel *Ammodytes* sp, and mackerel *Scomber scombrus* are the main pelagic species inhabiting this area during spring, summer and autumn.

Potential prey in the more open waters of the Norwegian Sea are unknown. Minke whale stomach data are unavailable both from the North Sea and the Norwegian Sea.

4.4. Energetics

During the scientific whaling in 1988-1990, the energy requirements and the energy utilization of different foods of minke whales were studied using several methods (Øritsland et al. 1989, Folkow & Blix 1990a, b, Markussen & Ryg 1990, Mathiesen et al. 1990, Mathiesen & Nordøy 1990, Nordøy et al. 1990). Studies of energy requirements involved indirect measurements of basal metabolic rates (BMR) and energy required for swimming. In addition, some unknown amount of energy is used for the deposition of a thick layer of blubber when minke whales stay in northern waters. Preliminary measurements of the condition of minke whales have been made, but due to the restricted summer period during which the scientific whaling was carried out and the low number of animals taken, the condition data available so far are very limited. A more extensive scientific catch will yield a larger material of condition measurements taken over a longer period of the year. This data may then be used in calculations of total amounts of energy stored in minke whales during their feeding season in Norwegian waters. Combined with previous estimates of energy required for swimming and BMR these data may then be used to calculate total energy intake.

4.5. Experience gained from previous scientific catch

A low scale scientific whaling in 1988-1990 (totalling 51 whales) was mainly designed to address methodological questions and to study the physiology, digestion and energetics, but also to collect preliminary diet data (Øritsland et al. 1989, Folkow & Blix 1990a, b, Markussen & Ryg 1990, Mathiesen et al. 1990, Mathiesen & Nordøy 1990, Nordøy & Blix 1991, Nordøy et al. 1990, Lydersen et al. 1991). Catches were made along the coast of northern Norway from Lofoten to western Finnmark in 1988 and 1990, and primarily west and north of Spitsbergen in 1989. Of the 34 minke whales caught off northern Norway, 91% had eaten fish only, while krill was found in 94% of the stomachs of minke whales caught in Spitsbergen waters (Nordøy & Blix 1991).

To relate the diet composition of minke whales with prey abundance, the data from 1988 and 1989 was compared with data gained from general resource surveys conducted by research vessels. Although these surveys were somewhat separated from the catch of minke whales in space and time, their proximity gave some indication that minke whales search out areas with high prey densities and are likely to feed on the most abundant species of prey.

In 1990, a closer cooperation between resource survey vessels and the scientific whaling vessel was undertaken to relate the diet of 5 minke whales to prey abundance. A restricted resource survey was performed a few days before the catch of 3 minke whales in the Vesterålen area, while a more comprehensive resource survey was conducted a few days later in the same area where 2 minke whales were caught off Sørøya, Finnmark. In the latter case a vessel was directed into the area where the whales were caught. These limited studies indicated that minke whales ate the most abundant species of prey in the respective areas. It is impossible to conclude that minke whales prefer any particular food as the minke whale may seek areas where the most preferred food item is most abundant.

5. PURPOSE OF THE RESEARCH PROPOSAL

5.1. General purpose

The main issue of a scientific catch of minke whales in Norwegian waters will be to obtain data on feeding (including both stomach samples and concurrent estimates of prey availability) and changes in energetic status of the species in certain key areas.

To evaluate the ecological importance of minke whales in Norwegian waters detailed information about the food selection of the whales in areas where they are common is also necessary. When this is known, estimates of the relative contribution of the various marine resources to the minke whale diet will be feasible, and a better basis for calculations involving minke whales in multi-species models (e.g., MULTSPEC) will be available.

In addition to the sampling of stomach and body condition data from the captured whales, the ecological study of minke whales in Norwegian waters will be supplemented by concurrent estimates of the available prey organisms in all areas and at all times when whales are caught. This will permit an evaluation of the relationship between choice and availability of prey organisms and contribute to a better understanding of the feeding mechanisms of minke whales. It will also give some idea as to why minke whales seem to prefer some areas more than others (Øien et al. 1987, Øien 1989, 1990, 1991). When the food selectivity has been estimated in direct studies of whale stomach contents, data on prey availability in combination with non-lethal studies of whales (sightings, radio-taggings etc.) may be of use when estimates of the quantity of the various prey items consumed by minke whales are needed at a later date. Apart from one minor study during the scientific whaling in 1990 (see Appendix 2), none of the previous minke whale feeding studies have included concurrent estimates of prey availability.

5.2. Specific purposes

5.2.1. Stomach analyses

The first objective of the program is to obtain a certain number of minke whale stomachs and inspect their contents closely, qualitatively as well as quantitatively. All prey items must be identified (either by gross morphological characteristics or by the aid of remaining hard parts such as fish otoliths and squid beaks). The numerical contribution of each prey species to the whale diet must be established, and backcalculations giving the original fresh weight of the various prey items must be performed. To estimate the dietary contribution of different prey items to the whale diet, particular indices (percentage occurrence as well as relative frequencies of occurrence based on both numerical and biomass contribution) will be applied (see Haug et al. 1991, Anon. 1991b). The material will be treated so that potential variations with sex, age and areas are easily detected.

5.2.2. Relative and total consumption

When the stomach analyses have yielded the relative contribution of the various food items to an average diet of the whales occurring in an area and a period, the next step will be to establish an estimate for the total amount of food taken by these whales. This implies the calculation of the "relative consumption" of the animals, i.e., the consumption that is obtained solely from calculations based on the observed stomach data. This relative consumption must then be converted to absolute total consumption. For this purpose, previous estimates of energy expenditure (Folkow & Blix 1990) and energy utilization of food (Nordøy et al. 1990) will be used in order to calculate total food consumption of individual whales. Moreover, for estimation of food consumption of the total population of minke whales, whale abundance estimates are necessary. For the summer season, the latter may be drawn from the 1989 sightings surveys (Øien 1991).

5.2.3. Correlate prey abundance with stomach content locally

Measurements of prey abundance and distribution in the locality and at the approximate time of catch, will enable the correlation of prey abundance with stomach content locally. This makes it possible to estimate selection probabilities for the various prey items given their immediate availability.

5.2.4. Correlate prey abundance with prey consumption at a larger geographical scale

It is not known whether the minke whale forage passively or actively seek prey (see Nordøy & Blix 1991). Local correlation between stomach content and prey availability cannot, therefore, be used to predict total consumption of the various prey items since it disregards the purposeful medium scale movement of the whales when feeding. By estimating the aggregated consumption rate by prey type for whales in an area of intermediate size as a function of the integrated prey availability and distribution in the area, it will be possible to predict consumption rates on basis of prey abundance. The area of intermediate size to be studied are taken to be the sampling areas of Fig. 4.

5.3. By-lines of the proposed sampling

5.3.1. Data relevant to future non-lethal studies

Non-lethal study methods have been used to determine predation patterns of whales, e.g. by combined studies of potential prey availavility and whale abundance (see, e.g., Murison & Gaskin 1989, Mayo & Marx 1990, Payne et al. 1986, 1990). A supposition for the applicability of such methods is that information of food preferences based on stomach analyses are already available. The seemingly euryphagous nature of minke whales implies that such information will be of particular importance with respect to this species. Since the minke whale is in all probability the most ichthyophagous of all baleen whale species (Gaskin 1982), it is also evident that assessment of the relative contribution of different prey species to the diet based on faeces analyses would be very unreliable (cfr. Jobling & Breiby 1986, Jobling 1987). As an important byline, however, the proposed scientific whaling will provide the food preference data necessary for possible future non lethal studies of the species.

5.3.2. Data on demography and productivity

As another important byline, the suggested ecological studies of minke whales will provide demographic data (sampled over a relatively restricted period of years), plus reproductive organs for studies of productivity parameters such as time of parturition, pregnancy rates and age/size at sexual maturity.

Demographic data are essential in the management of all longliving renewable resources. Different methods to correctly age minke whales have been suggested during the last 4-5 decades, but the most promising one seems to be analyses of bone layers, in particular laminated structures in the tympanic bullae (Christensen 1981, 1990). This method is still under development and verification. Sampling of tympanic bullae from minke whales taken in a future scientific whaling program will, therefore, provide material necessary to solve the remaining methodological problems (Ivar Christensen, Institute of marine Research, Bergen, Norway, pers. comm.).

Life history parameters such as growth, reproduction, recruitment and mortality are important both when the net productivity of the population and the energy costs of its maintenance are to be estimated (see Lockyer 1990). Precise age determination will enable evaluation of the population dynamics of minke whales, including analyses of parameters such as growth, age at maturity, length of reproductive life span, and longevity. Provided Christensens (1981) observations of growth layers in the tympanic bullae really do represent annual depositions, it appears that sexual maturity was attained at ages of about 6 (males) and 7 (females) years in the 1970s, whereas the life span of the animals were at least 33 years (during which none of the observed females had attained menopause). In minke whales, the length at sexual maturity appears to be constant, and in the Northeast Atlantic was 22 and 23-24 feet in males and females, respectively, both in the 1940s (Jonsgård 1951) and in the 1970s (Christensen 1972, 1974, 1981). Growth rates, however, seem to be affected by climatic changes and are also subjected to density dependent factors such as changes in food availability, stock size, and number of competing predators (Masaki 1979, Lockyer 1981, 1990). Apparantly, the sexual maturity ages observed in the Northeast Atlantic stocks of minke whales in the 1970s equal those observed for the species in the same period in the Antarctic where a reduction from 14 to 6 years seems to have prevailed since 1940 (Masaki 1979).

Unfortunately, no reliable age data are available from the Northeast Atlantic stock of minke whales prior to the 1970s. Nevertheless, scientific sampling in the 1990s will provide a material which may both give interesting comparisons with the 1970s material and add necessary information concerning the present status of growth and productivity in this population which has been subjected to a very low level of exploitation in the 1980s. Scientific whaling will also permit an evaluation of whether the ovulation and fertility rates of the mature females still suggest a one-year reproductive cycle as previously observed in the 1940s (Jonsgård 1951) and the 1970s (Christensen 1972, 1974, 1981).

5.3.3. Stock identification

Stock identification is one an important objective of the current coordinated research program on minke whales (Anon. 1988). At present, biochemical genetic methods using DNA-techniques (Bakke & El-Gewely 1990) and protein electrophoresis (Anna K. Danielsdottir and Sidsel Grønvik, The Norwegian Marine Mammal Research Programme, Tromsø, Norway, pers. comm.) are being applied. The Norwegian stock identification studies are coordinated with similar studies in Icelandic and Greenland waters. The analyses so far have been based on a very restricted material, and the results have been inconclusive (Folkow 1991).

A larger and more extensive material is, therefore, pressing, and will be collected during the proposed scientific whaling programme.

5.3.4. Pollutants

In the coordinated national research programme on marine mammals (Anon. 1988), the studies of pollution and pollutants in whales and seals are also included. Scientific whaling will enable the collection of material (including tissues such as liver, kidney, brain, muscles and lipids) for such studies. Relevant pollution studies in the areas in question include the effect of petroleum, heavy metals and radioactivity on minke whales.

6. SURVEY DESIGN

6.1. Periods of sampling

Minke whales are most common in Norwegian waters from March/April to October (Jonsgård 1951), and the scientific whaling will have to be restricted to this period. Observations made by Christensen (1972) indicate that a considerable number of whales reach the northernmost parts of their distributional areas (to the west of Spitsbergen) already by the beginning of May. Observations made to the east of Spitsbergen (at 79°20'N, 34°00'E) in 1991 confirm that considerable numbers of minke whales may stay in the northernmost parts of their distributional areas to feed until at least the middle of September (Kjell T. Nilssen, Institute of Marine Research/Norwegian College of Fisheries Science, University of Tromsø, Norway, pers. comm.). Taking this into consideration, and in order to get the longest possible span of the period of sampling, scientific whaling is proposed to take place within in the following three two-month periods:

1. 15 March - 15 May
2. 1 June - 31 July
3. 15 August - 15 October

The actual whaling operations are planned to last from 25 to 32 days per area in each of the periods.

6.2. Areas of sampling

The proposed operational areas are chosen on the basis of data obtained mainly in the period May-July. The plan for sampling which is described below is provisional. If important departures from the assumptions on which the design is based are detected during the sampling period, a revised sampling design may have to be worked out.

From the review of the spatial distribution of catches and the observations made during sightings surveys (Øien et al. 1987, Øien 1989, 1990, 1991), it appears that the total area of interest may be divided into 7 subareas (Fig. 4):

1. West of Spitsbergen
2. Bear Island and the northern Barents Sea
3. Kola and southeastern Barents Sea
4. Southwestern Barents Sea
5. Coastal areas northwest of Norway
6. Norwegian Sea
7. North Sea

Within these 7 subareas, there are smaller areas with higher densities of whales and within which the major effort will be made to sample whales. These sampling areas are, consecutively numbered from north to south:

- 1.1. West of Spitsbergen
- 2.1. Bear Island (+ east of Hopen)
- 3.1. Kola (+ coast of Novaya Zemlja)
- 4.1. Coastal banks off Finnmark
- 5.1. Vesterålen and Lofoten

The main sampling areas are indicated on Fig. 4. A more detailed description of these areas and the transects to be followed within them must await decisions concerning the design of the resource surveys for the actual years. The latter surveys are subjected to year-to-year changes depending on practical questions as well as variations in biological processes and management/assessment needs.

Sampling will be confined to the 5 main sampling areas for three reasons: 1). If stratified random sampling was to be conducted in the whole of the Northeast Atlantic, more effort would be needed to catch the same number of whales since whale density is considerably lower outside the sampling areas. Funding is limited, and we propose to use the available resources to obtain a reasonable coverage in the sampling areas. 2). A second reason to limit the sampling areas is to enable reasonable estimates of prey abundance to be available both locally in conjunction with the actual whaling (section 5.2.3), but also at an intermediate geographical scale (section 5.2.4). Where possible, the resource cruises will provide integrated abundance estimates for each prey item for each of the sampling areas. 3). The third reason for limiting the sampling areas is to make possible a reasonable re-design of the sampling scheme for the second and third year based on data on relative whale abundance and prey abundance in the spring and autumn period obtained the first year. With no limits to the sampling areas, estimation of the relative quantities would be difficult.

The North Sea off Scotland would also have been a natural sampling area, but it is not included in the current proposal for political reasons.

6.3. Transect sampling for whale catch

The design of the transects to be followed by the whale catcher vessels within the areas shown in Fig. 4 will take into consideration both the transects used in the shipboard surveys NASS-89 (Fig. 7) and the final design of the resource surveys within each of the actual years. The vessel shall move along the transect at a speed of 7-10 knots (depending on vessel capacity).

When a whale has been sighted, the whale is chased until lost or caught. As soon as a whale is caught, processing and biological sampling is to be completed before the vessel resumes search for a new whale. New search is resumed at the point of the transect where the chase of the last whale was started.

No whale shall be caught or chased unless the vessel is in search mode on the transect. When sighting conditions are unacceptable, the catcher boat may move to preassigned points to resume search from there when the weather improves. The decision to move to another point rests with the coordinating scientist for the whole project. A move to a preassigned point may also be decided to make possible proximity in time and space of prey abundance estimation and whale sampling.

6.4. Resource surveys

In order to collect data necessary for the monitoring and management of marine fish resources, most of the proposed areas for scientific whaling are surveyed routinely several times a year (see Table 1) by the research vessels belonging to the Institute of Marine Research, Bergen, Norway (Anon. 1991g). These surveys are not designed to estimate the density of whales but rather the abundance of various species of fish and zooplankton. The surveys provide data needed for estimating the local correlation between stomach content and prey abundance (5.2.3.) and also to estimate the relation between aggregated consumption rates by prey type and integrated prey abundance over areas of intermediate size (5.2.4.).

While the periods and areas of annual resource surveys are more or less identical from year to year, the vessels involved may vary consderaibly. The following description is based on the 1991 survey season (Table 1). R/V 'G O Sars' usually surveys capelin (including ecological studies of available plankton) in parts of the Barents Sea (covering the proposed main sampling areas 2.1 and 4.1) in the last half of March. Furthermore, the same vessel carries out a cruise aimed to study herring and coastal ecology in the North Sea in April, and another survey aimed to study 0-group saithe and general coastal ecology on the coast of Møre and northern Norway (including proposed main sampling area 5.1) in the first half of May. A second vessel, R/V 'Johan Hjort', has two cruises which will include proposed main sampling area 5.1 from the middle of April to the middle of May: One is designed to study the great silver smelt Argentina silus, another to study the dynamics of the annual production of cod larvae. The third vessel belonging to the Institute of Marine Research, R/V 'Michael Sars' has one cruise aimed to study cod in Lofoten-Vesterålen (proposed main sampling area 5.1) in the last half of March and another to the Barents Sea (probably covering proposed main sampling area 4.1) in the first half of May. From this (see Table 1) it appears that the North Sea and three of the proposed main sampling areas are well covered by resource surveys during the first proposed period of scientific whaling (15 March - 15 May), while areas 1.1 (west of Spitsbergen) and 3.1 (Kola and the coast of Novaya Zemlja) are not.

During the second proposed period of scientific whaling (1 June - 31 July), 'G O Sars' has one cruise (to study herring, capelin and zooplankton) to the Barents Sea and the coast of northern Norway, and a second to study the abundance of postlarvae of commercial fish species in the coastal areas of northern Norway. This implies a coverage of proposed main sampling areas 2.1, 3.1, 4.1 and 5.1 by this vessel. In the same period, 'Johan Hjort' has two cruises to study fish (in particular sandeel Ammodytes tobianus, herring and mackerel) in the North Sea, while 'Michael Sars' surveys capelin and zooplankton in the Barents Sea and fish fry on the coast of Norway from Finnmark to Møre and thus covers main sampling areas 4.1 and 5.1. Thus, during the second period of proposed scientific whaling 4 of the main areas (and the North Sea) are well covered by resource surveys leaving only main area 1.1 (west of Spitsbergen) unsurveyed.

During the first half of the last proposed period of scientific whaling (15 August - 15 October) all three Institute of Marine Research vessels are engaged in international 0-group fish surveys (see Anon. 1991h) in the Barents Sea and to the west of Spitsbergen, thus covering the proposed main sampling areas 1.1, 2.1, 3.1 and 4.1. The three vessels will also operate in these areas in the second half of the third period of proposed scientific whaling, now surveying pelagic fish resources and zooplankton. Thus, it appears that the main area not covered by resource surveys in the last proposed period of scientific whaling is area 5.1 (Vesterålen and Lofoten).

Figs 8-11 give examples of survey routes and station grids as used by Norwegian research vessels during resource surveys in 1991.

6.5. Coordination between whaling and resource surveys

Small adjustments may be made in all the actual resource surveys (e.g. stopping for more detailed sampling in areas containing many minke whales or where scientific whaling already takes place) to make them fit the minke whale investigations in the best possible way. Thus, by coordinating the whaling and resource surveys, information both on the general abundance of potential prey organisms over a large area and, in particular, prey abundances where minke whales congregate and where also whaling is carried out, will be available.

Some of the actual whaling areas are not covered by resource surveys. In these areas the applied whaling vessels must also be fitted with the necessary trawling equipment needed to conduct detailed surveys of the whole water column from the surface to the bottom. Trawling may be carried out in the area when the weather is not good enough for whaling operations, and will therefore not necessarily prolong the operational period for the vessel.

6.6. Sample size and distribution by area and period

During the first year, sampling will only occur in the summer period. The total sample size and its distribution over the 5 sampling areas is calculated for that season. For latter years, sample size by area and period is calculated.

The feeding ecology of the minke whale is the main objective of the future scientific whaling. Activities must thus be organised such that several secondary questions can be addressed and handled. This implies a multi purpose sampling with the main aims given by sections 5.2.1-5.2.4. Several criteria, therefore, determine sampling design, and a choice must be made. Since virtually nothing is known about the feeding strategy of the minke whale (its condition, feeding choice and rate given prey abundance), both locally and on a larger geographical scale, it is exceedingly difficult to develop a sampling design to optimize performance for purpose 5.2.3 and 5.2.4. A balanced design seems, however, reasonable over areas and periods.

Our choice is to optimize performance with respect to future calculations of the relative consumption (see section 5.2.2) over the entire area of the various prey items. More specificially, a design is sought which minimizes the sum of variances for the estimated relative consumption of herring, capelin and crustaceans over the sampling areas. This is done under certain simplifying assumptions. It is also based upon the estimated mean and standard deviation of forestomach quantity by prey type given in Table 2 (estimated from the scientific catch taken in 1988-1990, Nordøy & Blix 1991) and on guestimated probabilities of a randomly sampled whale having prey of given types in its forestomach as given in Table 3. The guestimated relative number of meals taken by whales over area and period as given in Table 4 is also needed. The sensitivity of the performance of the design for the summer period in the first year, with respect to these assumptions, is briefly studied below (sections 8.1-8.4).

The statistical analysis carried out for determining the optimal design is detailed in the Appendix.

For year 2 and 3, a design is also needed. Since the first year study will provide a better basis for working out the design for the subsequent years, the one presented here is tentative. The same rational as that used for the summer period of the first year is used for determining the tentative design for the subsequent years. In this case, the sum over the 3 prey types of variance of the estimated total consumption aggregated over area and period is minimized.

The minimization of the sum of variances is carried out conditional on the total sample size for the year. This total is then found as the smallest number which makes the relative precision as measured by the coefficient of variation of total consumption less than 0.2 for each prey type.

The resulting sampling design, shown in Table 5, implies a minimum take of 110 minke whales during the first year. The tentative numbers of whales needed to be taken during the two subsequent years are 136 in each.

6.7. Possible redesign after first year.

With data from the first year, the design for the summer season of the second year will be reconsidered. It is also possible that the design will need improvement for the spring and autumn season that year. Correlation between consumption and prey abundance as seen during summer 1992, possibly also together with measured prey and whale abundance in spring 1992, may be used for redesigning. If the correlation between consumption and prey abundance in autumn and spring the second year turns out to be different from that in the summer, the sampling design will be altered accordingly for the third year.

The total sample size is expected to be approximately 136 the second and third year. The redesigning will mainly consist of allocating the total over areas and seasons so as to obtain efficiency in the estimates of relative consumption aggregated over area and season. With a total of about 136 whales, the coefficient of variation of relative consumption is around 0.2 as long as the allocation is not too inefficient for the true state of affairs, whatever this is.

If a clear pattern emerge for the feeding strategy of the minke whales, i.e., strong and persistent correlations are observed, the method of estimating relative consumption should take this pattern into account, and the precision will improve.

7. METHODS

7.1. Random whale sampling

To obtain the maximum information from the total sample to be taken, a stringent sampling procedure is necessary. The method of transect search for the whales within the area of expected minke whale occurrence is already mentioned. Furthermore, whales must be sampled as randomly as possible. That is, the first sighted whale must be caught - if possible. No preference for any particular size, sex, behaviour or other attributes must be made. Whales actively approaching the vessel should not be taken. See also section 6.3.

The proposed scientific catch procedure is somewhat different to that used during commercial catches. Thus the number of whales caught per day at sea is likely to be lower under the restrictions imposed for scientific reasons, than during commercial whaling. Three to six boats should however be sufficient to complete the scientific catch during the three years. When the area quota is filled and there is still time left, the boats should move to a neighbouring area to help fill the quota in that area.

7.2. Collection of the biological material

The sex and total length of the whales are to be determined. For the condition studies, girth circumferences, blubber thickness and blubber weight are registered. Samples of blubber and meat for analyses of chemical composition and energy content are also to be taken.

A main objective and a necessary supposition for the whole programme is that stomachs are obtained for analyses. Experience from the scientific whaling in 1988-1990 suggest that sampling from the forestomach will give sufficient data to evaluate the diet of the animals (see Mathiesen & Nordøy 1990, Nordøy et al. 1990, Nordøy & Blix 1991). In addition, samples should be taken from predetermined areas of the digestive tract between the forestomach and the anal opening in order to determine if the food items observed in the forestomachs can be recognized representatively all the way through the digestive system of the whale. Such data is important to investigators who attempt to study whale feeding by collecting faeces from living animals.

Minke whale stomachs are large (50-100 l), and in cases where contents are fresh and easy to identify, some of the analyses may be carried out on board. Freezing of subsamples will be necessary, and when digestion is more advanced it may be necessary to freeze the whole stomach for later laboratory examination of food remains (e.g. for otoliths). In the analyses, both the numerical and biomass contribution of each prey species will be evaluated. A more detailed description of the methods used in such analyses is given in the publication of results from similar feeding studies of harp seals (Haug et al. 1991, Nilssen et al. 1991), and is also reviewed in the report from the Nordic seminar on "Predation and predatory processes in marine mammals and sea-birds" held in Tromsø, Norway, in May 1991 (Anon. 1991b).

For age determinations, both <u>tympanic bullae</u> are to be sampled from each animal. These will be sliced and prepared for age reading (using the laminated structures) according to the metods given by Christensen (1981, 1990). Reproductive organs (including the testes and the ovaries and utera with potential foetuses) will be sampled and fixed in formalin for later laboratory analyses of vital reproduction parameters (see Jonsgård 1951).

Sampling and freezing (either in a conventional freezer at -20°C or in liquid nitrogen) of a number of tissue types such as baleen, brain, kidney, blubber, liver, heart, muscle etc. will be done in order to secure material for analyses of parameters such as stock identity and pollutant levels.

7.3. Prey abundance measured locally

The more detailed estimation of potential minke whale prey abundance will be examined by using various types of trawl gear in areas with apparent aggregations of whales and where whales are actually taken. The bottom will be surveyed using small meshed (35 mm mesh size in the cod end) prawn trawls. Trawling in the water column will be performed using pelagic trawl fitted with trawl eye to monitor trawl depths and with fine (mesh size < 10 mm) 'tobis' net in the cod end to ensure sampling of small crustaceans. Pelagic trawling must be performed both in the surface layers and in the layers just above the bottom. Furthermore, acoustically registered echo-layers in mid-water depths must be sampled. In order to eliminate biases imposed by daily vertical migrations of the prey organsims, trawling in a given area must be repeated several times throughout a 24 h period. Trawl hauls will be standardized according to the procedures usually followed during resource surveys. Volumes, numbers and individual lengths of fish specimens will be measured. Crustaceans (classified to the lowest possible taxon), squid and other items taken in the trawl catches are also measured.

7.4. Prey abundance measured on a larger scale

Information on abundance of pelagic fish species will be gathered from accoustic surveys carried out by the Institute of Marine Research, Bergen. In these surveys, standard methods of acoustic fish abundance estimation are used. The results of these surveys are, for some of the species, used by the ICES Working Groups for assessments purposes. A brief outline of the method used is given below.

The ship covers a more or less predefined survey track, which is adjusted for observed fish distribution in the area of interest. To measure echo density along the sailed tracks, an echo integration system (Foote et al. 1991) is used. The mean echo density inside squares in a predefined grid is calculated based on the assumption that the densities along the survey tracks are representative for the squares.

The echo density is assigned to fish species according to the character of the recordings on the echogrammes, the target strength of the recordings, and the species composition in trawl hauls which are frequently taken along the survey tracks. The echo density for each species is converted to fish abundance using species- and length-dependent conversion factors. The fish abundance data for each species is then attributed to length and age classes according to the length and age composition in selected trawl hauls.

7.5. Relative whale abundance estimation.

Attempts will be made to place teams of trained whale observers on some of the resource survey vessels. The survey vessels travel at about 10 knots and their wheelhouse roofs are at about 16 meters above sea level. This observation platform will, therefore, be similar to that used during the NASS-89 shipboard survey (Øien 1991).

The resource survey vessel will move on along its preassigned course regardless of whether conditions for minke whale observations are acceptable or not. Observations can, however, only be made when conditions for observation are acceptable based on the criteria used in NASS-89 (see Øien 1991). Part of the preassigned transect for the resource vessel will, therefore, be covered by whale observations. These segments will, however, make up a "random" observation set and the sighting rates observed in other areas and to observation rates in NASS-89. These data will, therefore, be useful for estimating the relative spatial distribution of whales in the three periods of the year, and to estimate the number of whales present in the sampling areas in the spring and autumn periods relative to the summer abundance estimated in NASS-89.

Relative abundance estimates are useful for several purposes. They will be needed for correlating whale density to prey abundance. They will also be useful in conjunction with the absolute abundance estimate from NASS-89 for estimating total consumption of the various prey items based on prey abundance and feeding preference estimates.

8. STATISTICAL METHODS AND PRECISION OF RESULTS

8.1. Stomach content analyses

Based on the simplified assumption that there are 3 types of food (herring, capelin and crustaceans) and that no whale have forestomach content of mixed type, the problem is to estimate the probability p_i of a randomly sampled whale having prey of type i and of estimating the distribution of the quantity X_i. The data will allow for a simple relative frequency estimate of p_i and for estimating the mean and variance of X_i by sample moments.

It will be of interest to investigate how the stomach quantity X depends on prey type, area, season, and possibly sex and age. A linear regression analysis with categorical covariates seems reasonable. Hypotheses to be tested will entail lack of dependence between stomach quantity and its covariates.

Another hypothesis to test is whether the probabilities p_i are independent of sex and age for a given area and period. Simple chi-square tests will be of use. Regression techniques will be of help to describe the structure.

The properties of these estimators and tests are well known. Quantitatively, standard errors and test power will depend on the characteristics of the sample. The age and sex composition will for example not be controlled, and will, therefore, be random. For the first year, the sample size should be marginally adequate for estimating the p_i's within areas for the summer season, and to estimate μ and σ for about half of the cells in the area x prey type table for the summer season, provided our guestimates of prey preferences (Table 3) are reasonable. It will obviously be advantageous to be able to assume that the distribution of forestomach quantity is independent of prey and area.

For subsequent years, the individual parameters will be less precisely estimated. Given the individual prey probabilities of Table 3, only four of the area x season x prey probabilities will be estimated with standard deviation more than 0.2, when the sample sizes are those of Table 5. When splitting the samples further by prey type, the sub-samples get very small indeed, and it is unlikely that mean and variance may be estimated individually for many of the area x season x prey cells. It is impossible to say in advance for which cells this will be possible.

Statistical models of the linear and generalised linear model will be fitted to the data. In some analyses prey type will be the response and in others prey quantity. Some such models are outlined in sections 8.3 and 8.4. A sample of size 136, allocated over area and season as in Table 5, should be adequate for fitting such linear models. Being a first investigation into the feeding ecology of minke whales, one should not expect to arrive at more than descriptive models for prey preference and relative quantity consumed, and for this aim, the sample size should be adequate for all the three years. For the purpose of hypothesis testing and model discrimination, the sample size is on the lower side.

8.2. Relative consumption of various prey items

The relative consumption (see section 5.2.2) of the various prey items will be estimated by blowing up sample means as described in Appendix 1.

The sample size and its areal distribution were found as described in section 6.6 and Appendix 1. This exercise was based on the guestimated values given for prey preference probabilities (Table 3), relative number of meals (Table 4) and on the estimated mean and variance for forestomach content (Table 2). The sample size and its distribution will have to be recalculated after the first year's data have been analysed. It is not very relevant to discuss the precision of the estimated relative consumption of prey items in any depth for year 2 and 3.

The coefficient of variation follows the square root law

$$c.v.=c/\sqrt{n}$$

where n is the total sample for the period or the year and c is a coefficient depending on the particular design and the true characteristics of the feeding ecology of the minke whale.

Based on the true forestomach content probabilities given in Table 3 and the relative consumption weights given in Table 4, the proportionality coefficient, c, for the sampling design compositions of Table 5 (relative numbers) is tabled in Table 6. In this case the suggested break down of the design is optimal. In Table 6 are also given the c.v. for the actual design given in Table 5.

To briefly study the sensitivity of the c.v. of estimated relative consumption of, say, capelin the first summer, to variation in the probabilities and weights of Tables 3 and 4 and also the estimated means and standard deviations of Table 2, the following stochastic simulation was performed for the prey item capelin. In 100 replicates, the expected quantity, μ, in forestomachs with capelin was drawn from the normal distribution with mean 21 and standard deviation $16\sqrt{5}$. The standard deviation in quantity, σ, of forestomachs with capelin was drawn as 16C, where $4C^2$ is chi-square with 4 degrees of freedom. These two distributions should reflect the sampling variability in the estimated parameters of Table 2.

For each area, the probability of a forestomach having capelin was drawn as $U^{3.2}$ where U is uniformly distributed. The mean of this distribution is 0.24 while the mean probability of capelin in summer is 0.23 when calculated from Table 3 over 5 areas. To have approximately the same variability in relative number of whale meals as shown for summer in Table 4, this relative number, W, was drawn from a chi-square distribution with 9 degrees of freedom for each area.

The c.v. was then calculated from formulae 12) and 13) of Appendix 1 for each replicate. The distribution of simulated c.v.'s is shown in Table 7. The mean c.v. was 0.3 and the median 0.25, as compared to 0.2 when the situation is as in Tables 2-4 so that the sampling design of Table 5 is "optimal".

8.3. Measuring the correlation between prey abundance and stomach content locally

There are measurements of prey density D_{il} for prey items i = 1,..,3 and of forestomach type T_l and content X_l for the whale sampled in locality l. If d_i was the true prey density, one would like to estimate the feeding probabilities

$$P(T = i) = p_i(d_1,..,d_3)$$

and the quantity distribution given true densities and given the type of prey present in the forestomach.

For the latter, it will be of interest to see if the forestomach quantity, X, is independent of prey densities given the prey item is present. This may be achieved by testing for independence in a regression of X on $D_1, \ldots, D_3$ for given T = i. The power of such a test would depend on the number of whales sampled concurrently with prey abundance estimation and on the actual degree of dependence relative to the inherent variation in X and on the size of the error involved in the prey abundance measurements.

The precision of the local prey abundance measurement will depend on the type and intensity of prey abundance estimation and on the size of the locality. The research vessels which have access to acoustic measurements in addition to trawl sampling are likely to produce more reliable prey abundance estimates than the catcher vessels fitted with trawl. On the other hand, the research vessels will not give estimates for localities centered in time and space precisely where sampled whales were initially sighted. Since very little is known about the local movements of minke whales when feeding, it is difficult to decide the size of the locality to consider. This question has to be addressed during the first summer season (see also section 7.3).

There is no detailed information on the precision of local prey abundance measured by trawling from catcher vessels. For research vessels, the plan is to have the catcher vessel follow the same transect as the research vessel a short time ahead of the latter. The research vessel will then be able to adjust its course to go through the point of sightings and capture of whales and to trawl in the neighbourhood. A general discussion of methodology, analyses and precision of resource surveys of the type planned in conjunction with the scientific whaling is given by Simmons et al. (1991).

An important problem is that of estimating the prey preference probability $p_i(d_1, \ldots, d_3)$. Several models may be investigated for this purpose. One possibility is to assume that herring is the preferred prey whenever it is in sufficient supply. This could be modelled by

$$p_1(d_1,d_2,d_3) = 1 - \exp(-\beta_1 d_1^{\beta_1^t}),$$

where herring is prey item 1 and β_1 and β_1^t are positive regression coefficients. To investigate whether this is a reasonable model or if perhaps there is another preference ranking between the prey items, a complimentary log-log model of the type

$$p_i(d_1, d_2, d_3) = 1 - \exp(-\exp(b_i + \sum_j \beta_j^i \log D_j)$$

may be fitted for each i and one may test whether $\beta_j^i = 0$ for $j > i$. Because D_j may be assumed to be measurements of d_j with multiplicative errors, the estimate of b_i will be biased estimates of $e^{\beta i}$, while β_j^i will be (asymptotically) unbiasedly estimated.

If the prey item with highest priority has been successfully identified, say it is herring, then one may try to find the second priority item. This may be done by fitting complimentary log-log models in $\log(D_2)$ and $\log(D_3)$ to the sub-sample not having herring in its forestomach. This amounts to fitting conditional models. A possible result of this exercise could be that the following simple model is found to fit the frequency data satisfactorily

$$p_1 = 1 - \exp(-\beta_1 D_1)$$
$$p_2 = (1 - p_1)(1 - \exp(-\beta_2 D_2))$$
$$p_3 = (1 - p_1)(1 - p_2)(1 - \exp(-\beta_3 D_3))$$

and $p_4 = 1 - p_1 - p_2 - p_3$ is the probability of the forestomach being empty.

With the very limited data available after the first year of sampling, the identification of the proper conditional model will be difficult. With only weak discrimination between the various simple conditional models and indeed between more complex models, it is not unlikely that a whole suit of structural models will fit the data. If a simple conditional model is selected among all the acceptable models, it must be understood as a provisional choice which may have to be changed as data accumulates over the second and third year. Eventually, a model as simple as possible in structure is sought which fits the data for all three years and for all areas and seasons. It is possible that covariates involving sex and age and possibly season will be needed in such a model.

The error in measurements of local prey abundance will affect the discriminatory power between structurally different conditional models and it will certainly bias the estimates of the coefficients understood as regression coefficients in true prey abundance. However, the error in measurement will not bias the structural result in the sense that the discrimination between two competing models is made more favourable, for the one over the other because of the error. The errors will blur the discrimination, but not twist it.

8.4. Correlating prey abundance with relative consumption at a larger geographical scale

After the first summer season, there will be estimates of whale abundance, W, prey abundance, $PA_1,\ldots,PA_3$, and relative consumption (see section 5.2.2) $TC_1,\ldots,TC_3$ of each prey item over areas of reasonable size. These data will be used to estimate relative consumption functions of the type

$$TC_i = C_i(W,\ PA_1,\ldots,PA_3) + \text{error}.$$

These functions are intended for prediction purposes. It is, therefore, no problem that they are functions of estimated quantities and not directly observed ones. Predictions will be based on these estimates.

Simplifications will be sought for the structure of the consumption function. The first simplifying assumption will be that C_i is homogeneous in whale abundance

$$TC_i = W\ c_i\ (PA_1/W, \ldots, PA_3/W) + \text{error}$$

Simple conditional models like those discussed in the previous sub-section may turn out to fit the data. One may for example find that

$$TC_1 = W\ \xi_1\ (1 - \exp(-\alpha_1\ PA_1/W)) + \text{error}$$
$$TC_2 = W\ \xi_2\ \exp(-\alpha_1\ PA_1/W)(1 - \exp(-\alpha_2\ PA_2/W)) + \text{error}$$
$$TC_3 = W\ \xi_3\ \exp(-(\alpha_1\ PA_1 + \alpha_2\ PA_2)/W)(1 - \exp(-\alpha_3\ PA_3/W)) + \text{error}$$

gives a reasonable fit. Here, α_1 may be interpreted as the exponential regression coefficient for the fraction of whales feeding on herring when the quantity of herring available per whale is PA_1/W, regardless of abundance of other prey items. The parameter ξ_1 is then the mean relative consumption of herring per whale eating herring. The other parameters have a similar interpretation.

The tentative model specified above is a nonlinear regression model with effectively 2 parameters per prey item. In the first summer season, data will be available from 5 sampling areas. With only 5 data points, the discriminatory power between competing structural models will be limited. To increase the discrimination power and also to improve the applicability of the fitted model, each sampling area should be subdivided into 1, 2 or 3 subareas such that the prey abundance is as homogeneous as possible within subareas and so that the relative error in estimated prey abundance is of similar size across subareas. The number of subareas could be around 10.

The aim is to find production functions which give reliable predictions across areas and periods. The production functions should, therefore, fit all data collected over the three years. The aim is also to use these production functions for predicting relative consumption outside the sampling areas. The validity of this extrapolation can not be tested under the research proposal since no whales will be sampled in these areas.

The parameter α_1 was interpreted as the exponential regression coefficient for the fraction of whales feeding on herring when the quantity of herring available per whale is PA_1/W. This indicates that α_1 may be estimated in a complimentary log-log model for the feeding probability,

$$p_1 = 1 - \exp(-\exp(\sum_{j=1}^{3} \alpha_j^1 \log(PA_j/W))).$$

This model may be estimated on basis of the forestomach content of the individually sampled whales, $T_1, \ldots, T_n$, as in section 8.1.3, but now with the regressors being the availability per whale over the sub-area. The simpler model obtained by setting $\alpha_1^1 = 1$ and $\alpha_2^1 = \alpha_3^1 = 0$ corresponds to the simple model above, where the availability of herring alone determined the fraction of whales feeding on herring. One may test this simple model.

The mean relative consumption parameter, ξ_1, may be estimated as the mean forestomach quantity among whales with herring in the forestomach.

This simpler approach to estimate the parameters shows that the α_i-parameters may be estimated in a binary regression based on n data points and that the ξ_i-parameter will be estimated as the mean of $p_i n$ observations. For both estimators, the square root law applies: the standard deviation is proportional to $1/\sqrt{n}$. The size of the inherent standard deviations (the proportionality coefficient of the standard errors to $1/\sqrt{n}$) is difficult to compute without any clue to the size of the feeding probabilities p_i.

When data have been gathered during the first summer, the design for the consecutive years may have to be recalculated.

9. PARTICIPATION BY GUEST SCIENTISTS

Data for other research projects could be collected upon request. In addition, direct participation in the research under this program by scientists from other nations will be encouraged and welcomed to the extent allowed by the accomodation and other logistic consideration, provided that such participation does not cause inconvenience in the implementation of the programme. Requests concerning participation (including an identification of the institutional belonging of the applicants) should be addressed to the secretariate of the Norwegian Marine Mammal Research Programme.

Costs for material sampling and for direct participation (such as travel expenses to and from the port of embarking on and disembarking from the vessel, meals onboard the vessel, and any instruments required by the participant) are to be borne by the scientists (or scientific institutions) requiring samples/ participation.

10. PLANNED AREAS OF EFFORT

10.1. Areas, periods and gross logistics

From available data on minke whale migrations and distribution in Norwegian waters, five main sampling areas (west of Spitsbergen, Bear Island + Hopen, Kola + Novaya Zemlja, Coastal banks off Finnmark, Vesterålen/Lofoten) and three main periods of sampling (15 March - 15 May, 1 June - 31 July, 15 August - 15 October) have already been proposed for a future scientific whaling.

To perform the catch operations it is evident that 3-6 vessels, fitted with the necessary gear and crew for small-type whaling and enough freezing capacity for the biological samples, must be chartered to cover the 5 main areas of interest. Due to the lack of resource survey coverage in one or two areas in all three proposed periods of sampling, two of the vessels should also be fitted with equipment (bottom and pelagic trawls) needed to estimate the prey availability in these particular areas. The whales will be killed using 50 and 60 mm harpoon guns equipped with 22 g penthrite grenades. Experienced gunners will be trained according to a specified program previous to the start of the scientific catch operations. A scientific personnel of three persons on each vessel will be necessary to carry out the sampling.

To carry out whale observations from the survey vessels it is necessary to have two observers on ships where observations are to be made. To some extent the survey ships overlap with each other in area in some of the periods, thus reducing the necessity to put observers on each ship in every period.

10.2. Organisation of the field work

10.2.1. First year

The size of the programme and the many activities which have to be coordinated indicate that the methodology ought to be tested on a somewhat lower scale during the first year of operations. Thus, it is suggested that in the first year scientific whaling is performed in all areas, but only in the summer period (1 June - 31 July). This is the time of the year when most information about minke whale abundance in Norwegian waters is available. The lack of resource surveys in proposed main sampling area west of Spitsbergen, necessitates that one vessel fitted with acoustic and trawling gear for concurrent estimates of prey is chartered for the operations in this area.

It is suggested that five or six whaling vessels are hired in the first year. Each area is covered by one vessel (see Table 5). It is assumed that, if necessary, by the end of the period the vessel covering the area west of Spitsbergen may assist the operations in the Kola area. Each vessel should be chartered for a minimum of 32 days.

Even though the scientific whaling is only carried out during the summer period, data from the regular resource surveys in the two other periods should also be analysed. This will give valuable information on which the increased activities in the second year of the programme can be based.

10.2.2. Second year

The second year is suggested as the most intensive sampling year. Partly based on the experience gained during the first year of summer sampling, it is suggested that the scientific whaling in the second year should be carried out in all areas and in all the three proposed periods. The use of two whalers fitted with trawl gear will be necessary in the period 15 March - 15 May in the areas west of Spitsbergen and off Kola, and in the period 15 August - 15 October in areas off Vesterålen/Lofoten. As in the first year, only one whaling vessel capable of trawling is necessary during the summer period (to the west of Spitsbergen).

It is suggested that three or four vessels are chartered in each of the three periods. These vessels will cover areas 1.1+2.1, 3.1+4.1, and 5.1, respectively (see Table 5). The vessels covering 1.1+2.1 and 5.1 may assist in areas 3.1+4.1 by the end of each period. Each vessel should be chartered for a minimum of 25 days in each period.

10.2.3. Third year

The activity this year will probably be much the same as in the second year, i.e. the use of 3 vessels in three periods of the year. However, the results from year 1 and 2 may necessitate adjustments and alterations, e.g., reduced sampling in some areas and/or increased sampling in others.

11. REFERENCES

Aijad, A.M. 1990. Variabilities in stomach contents of cod, collected by demersal and pelagic trawl in the southern part of the Barents Sea. ICES CM 1990/G:3: 10 pp.

Anon. 1988. A program to study and monitor Northeast Atlantic minke whales, 1988-1992. Note SPS 8804, Institute of Marine Research, P.O.Box 1870 Nordnes, N-5024 Bergen, Norway.

Anon. 1989. Report of the Scientific Committee. Rep. int. Whal. Commn 39: 56-59.

Anon. 1990a. Report of the Scientific Committee. Rep. int. Whal. Commn 40: 69-71.

Anon. 1990b. Ressursoversikt 1990. Fisken Hav. 1990 (Særnummer 1): 1-80.

Anon. 1991a. Ressursoversikt 1991. Fisken Hav. 1991 (Særnummer 1): 1-79.

Anon. 1991b. Predation and predatory processes in marine mammals and sea-birds - report of a Nordic seminar, Tromsø 25-29 April 1991. Nordiske Seminar- og Arbejdsrapporter 1991(512): 39 pp.

Anon. 1991c. Report of the Atlanto-Scandian Herring and Capelin Working Group, Copenhagen, 15-19 October 1990. ICES CM 1991 / Assess: 9: 58 pp.

Anon. 1991d. Report of the Atlanto-Scandian Herring and Capelin Working Group, Copenhagen, 8-12 April 1991. ICES CM 1991 / Assess:17: 62 pp.

Anon. 1991e. Report of the Arctic Fisheries Working Group, Copenhagen, 18-27 September 1990. ICES CM 1991 / Assess:3: 127 pp.

Anon. 1991f. Miljørapport 1991. Fisken Hav. 1991 (Særnummer 2): 1-72.

Anon. 1991g. Toktprogram 1991. Institute of Marine Research, P.O.Box 1870 Nordnes, N-5024 Bergen, Norway.

Anon. 1991h. Preliminary report of the International 0-group Fish Survey in the Barents Sea and adjacent waters in August-September 1991. ICES CM 1991/G:50: 33 pp.

Anon. 1992. Report of the Scientific Committee. Rep. int. Whal. Commn 42: in prep.

Bakke, I. & El-Gewely, M.R. 1990. Stock identity evaluated by DNA fingerprinting of north Atlantic minke whales. Rep.

int. Whal. Commn SC/42/NHMi 2: 14 pp.

Bax, N.J., Mehl, S., Godø, O.R. & Sunnanå, K. 1991. Transparent multispecies analysis: an exploration of fisheries and survey data off the Norwegian coast and Barents Sea. ICES mar. Sci. Symp. 193: 125-132.

Bergstad, O. A., T. Jørgensen and Dragesund O. 1987. Life history and ecology of the gadoid resources of the Barents Sea. Fish. Res. 5: 119-161

Bjørke, H., Bakkeplass, K. & Hansen, K. 1991. Yngelundersøkelser i juni/juli 1990 utenfor kysten av Nord-Norge. Havforskningsinstituttets egg- og larveprogram (HELP), Rapp. 37: 45 pp.

Bogstad, B. & Tjelmeland, S. 1990. MULTSPEC: An outline of the model. IWC Document SC/42/O4.

Christensen, I. 1972. Vågehvalundersøkelser ved Spitsbergen og i Barentshavet i mai og juni 1972. Fiskets Gang 58: 961-965.

Christensen, I. 1974. Undersøkelser av vågehval i Barentshavet og ved Øst- og Vest-Grønland i 1973. Fiskets Gang 60: 278-286.

Christensen, I. 1981. Age determination of minke whales Balaenoptera acutorostrata, from laminated structures in the tympanic bullae. Rep. int. Whal. Commn 31: 245-257

Christensen, I. 1990. Age determination of baleen whales. North Atlantic Studies 2: 32-35

Christensen, I., Haug, T. & Øien, N. In subm. A review of feeding and reproduction in large baleen whales (Mysticeti) and sperm whales (Physeter macrocephalus) in Norwegian and adjacent waters. Fauna norv. Ser. A: in subm.

Christensen, I., Haug, T. & Wiig, Ø. 1990. Morphometric comparison of minke whales Balaenoptera acutorostrata from different areas of the North Atlantic. Mar. Mamm. Sci. 6: 327-338.

Christensen, I. & Øien, N. 1990. Operational patterns of the Norwegian minke whale fishery. Rep. int. Whal. Commn 40: 343-347.

Cochran, W.G. 1963. Sampling techniques. 2nd Ed. John Wiley.

Erikstad, K.E. 1990. Winter diets of four seabird species in the Barents Sea after a crash in the capelin stock. Polar Biol. 10: 619-627.

Erikstad, K.E., Moum, T. & Vader, W. 1990. Correlations between pelagic distribution of common and Brünnich's guillemots and their prey in the Barents Sea. Polar Res. 8: 77-87.

Folkow, L. 1991. Vågehvalens vandringer og bestandsidentitet i Nord-Atlanteren. Ottar 184(1/91): 3-8.

Folkow, L.P. & Blix, A.S. 1990a. Energy expenditure of minke whales (Balaenoptera acutorostrata). I. Calculations of body heat loss. Paper IWC SC/42/NHMi 5: 33 pp.

Folkow, L.P. & Blix, A.S. 1990b. Energy expenditure of minke whales (Balaenoptera acutorostrata). II. Calculations of oxygen consumption. Paper IWC SC/42/NHMi 6: 22 pp.

Foote, K.G., Knudsen, H.P., Korneliussen, R.J., Nordbø, P.E. & Røang, K. 1991. Postprocessing system for echo sounder data. J. Acc. Soc. Am. 90(1): 37-47.

Gaskin, D.E. 1982. The ecology of whales and dolphins. Heinemann, London and Exeter, New Hampshire. 459 pp.

Gjøsæter, H. and Loeng, H. 1984. Distribution and growth of the capelin in the Barents Sea in relation to water temperature in the period 1974-1983. ICES CM 1984/Gen:16 (Mini-symp.): 10pp.

Haug, T., Krøyer, A.B., Nilssen, K.T., Ugland, K.I. 1990. Harp seal (Phoca groenlandica) invasions in North Norwegian coastal waters: a preliminary report on age composition and feeding habits. ICES CM 1990 / N:6: 24 pp.

Haug, T., Krøyer, A.B., Nilssen, K.T., Ugland, K.I. & Aspholm, P.E. 1991. Harp seal (Phoca groenlandica) invasions in Norwegian coastal waters: age composition and feeding habits. ICES J. mar. Sci. 48: 363-371.

Ichii, T. & Kato, H. 1991. Food and daily food consumption of southern minke whales in the Antarctic. Polar Biol. 11: 479-487.

Jobling, M. 1987. Marine mammal faeces samples as indicators of prey importance - a source of error in bioenergetic studies. Sarsia 72: 255-260.

Jobling, M. & Breiby, A. 1986. The use and abuse of fish otoliths in studies of feeding habits of marine piscivores. Sarsia 71: 265-274.

Jonsgård, Å. 1951. Studies on the little piked whale or minke whale (Balaenoptera acuto-rostrata Lacépède). Norsk Hvalfangsttid. 40: 209-232.

Jonsgård, Å. 1955. Development of the modern Norwegian small whale industry. Norsk Hvalfangsttid. 44: 697-718.

Jonsgård, Å. 1966. The distribution of Balaenopteridae in the north Atlantic ocean. Pp. 114-124 in: Norris, K.S. (ed.), Whales, dolphins and porpoises. University of California Press, Berkeley and Los Angeles.

Jonsgård, Å. 1982. The food of minke whale (Balaenoptera acutorostrata) in northern North Atlantic waters. Rep. int. Whal. Commn 32: 259-262

Larsen, F. & Kapel, F.O. 1981. Collection of biological material of minke whales off West Greenland, 1979. Rep. int. Whal. Commn 31: 279-285.

Lockyer, C. 1981. Estimation of the energy costs of growth, maintenance and reproduction of the female minke whale, Balaenoptera acutorostrata, from the Southern Hemisphere. Rep. int. Whal. Commn 31: 337-343.

Lockyer, C.H. 1990. The importance of biological parameters in population assessments with special reference to fin whales from the N.E. Atlantic. North Atlantic Studies 2: 22-31.

Lockyer, C. & Sigurjonsson, J. 1991. The Icelandic fin whale, (Balaenoptera physalus): biological parameters and their trends over time. Paper IWC SC/F91/F8.

Lydersen, C., Weslawski, J.M. & Øritsland, N.A. 1991. Stomach content analysis of minke whales Balaenoptera acutorostrata from the Lofoten and Vesterålen areas, Norway. Holarct. Ecol. 14: 219-222.

Markussen, N.H. & Ryg, M. 1990. Estimations of the food requirements in a minke whale population by use of a simulation model. Paper IWC SC/42/NHMi 8: 10 pp.

Masaki, Y. 1979. Yearly change of the biological parameters for the Antarctic minke whale. Rep. int. Whal. Commn 29: 375-396.

Mathiesen, S.D., Aagnes, T. & Sørmo, W. 1990. Microbial symbiotic digestion in minke whale (Balaenoptera acutorostrata). Paper IWC SC/42/NHMi 9: 26 pp.

Mathiesen, S.D. & Nordøy, E.S. 1990. Gastro-intestinal anatomy of minke whales (Balaenoptera acutorostrata). Paper IWC SC/42/NHMi 10: 29 pp.

Mayo, C.A. & Marx, M.K. 1990. Surface foraging behaviour of the North Atlantic right whale, Eubalaena glacialis, and associated zooplankton characteristics. Can. J. Zool. 68: 2214-2220.

Mehl, S. 1989. The north-east Arctic cod stock's consumption of commercially exploited prey species in 1984-1986. Rapp. P.-v. Réun. Cons. int. Mer 188: 185-205.

Mehl, S. & Sunnanå, K. 1991. Changes in growth of northeast Arctic cod in relation to food consumption in 1984-1988.

ICES mar. Sci. Symp. 193: 109-112.

Murison, L.D. & Gaskin, D.E. 1989. The distribution of right whales and zooplankton in the Bay of Fundy, Canada. Can. J. Zool. 67: 1411-1420.

Nilssen, K.T., Haug, T. & Potelov, V. 1991. Field studies of harp seal Phoca groenlandica distribution and feeding ecology in the Barents Sea in September 1990. ICES CM 1991/N:3: 23 pp.

Nordøy, E.S. & Blix, A.S. 1991. Diet composition of north-eastern Atlantic minke whales. Paper IWC SC/43/NHMi 6: 9 pp.

Nordøy, E.S., Sørmo, W. & Blix, A.S. 1990. *In vitro* digestion in minke whales for the estimation of digestability of different preys. Paper IWC SC/42/NHMi 12: 18 pp.

Øien, N. 1989. Sighting estimates of northeast Atlantic minke whale abundance from the Norwegian shipboard surveys in July 1987. Rep. int. Whal. Commn 39: 417-421.

Øien, N. 1990. Sightings surveys in the northeast Atlantic in July 1988: distribution and abundance of Cetaceans. Rep. int. Whal. Commn 40: 499-511.

Øien, N. 1991. Abundance of the northeastern Atlantic stock of minke whales based on shipboard surveys conducted in July 1989. Rep. int. Whal. Commn 41: in press.

Øien, N., Jørgensen, T. & Øritsland, T. 1987. A stock assessment for northeast Atlantic minke whales. Rep. int. Whal. Commn 37: 225-236.

Øritsland, T. & Christensen, I. 1982. Vågehvalens næringsopptak i Nordsjøen og Barentshavet 1972-1978. Havforsknings-instituttet i Bergen, Note: 4 pp.

Øritsland, N.A., Cuyler, C., Lydersen, C., Markussen, N.H. & Ryg, M. 1989. Comparative energetics of marine mammals - experimental investigations and model analyses, report for the 1988 minke whale catch. Paper IWC SC/41/O 7: 9 pp.

Payne, P.M., Nicolas, J.R., O'Brien, L. & Powers, K.D. 1986. The distribution of the humpback whale, Megaptera novaeangliae, on Georges Bank and in the Gulf of Maine in relation to densities of the sand eel, Ammodytes americanus. Fish. Bull., U.S. 84: 271-277.

Payne, P.M., Wiley, D.N., Young, S.B., Pittman, S., Clapham, P.J. & Jossi, J.W. 1990. Recent fluctuations in the abundance of baleen whales in the southern Gulf of Maine in relation to changes in selected prey. Fish. Bull., U.S. 88: 687-696.

Røttingen, I. 1986. Data on the 1983 yearclass of Norwegian Spring Spawning Herring from the period June 1985 - August 1986. ICES CM 1986/H:19: 13pp.

Røttingen, I. 1987. Data on the 1983 yearclass of Norwegian Spring Spawning Herring from the period August 1986 - August 1987. ICES CM 1987/H:36: 15pp.

Schweder, T., Ulltang, Ø. & Volden, R. 1991a. A review of the Norwegian catch and effort in North East Atlantic minke whaling from 1952 to 1983. Rep. int. Whal. Commn 41: In press.

Schweder, T., Øien, N. & Høst, G. 1991b. Estimates of the detection probability for shipboarsd surveys of northeastern Atlantic minke whales, based on a parallell ship experiment. Rep. int. Whal. Commn 41: in press.

Sergeant, D.E. 1963. Minke whales, Balaenoptera acutorostrata Lacépède, of the western north Atlantic. J. Fish. Res. Bd Can. 20: 1489-1504.

Simmons, E.J., Williamson, N.J., Gerlotto, F. & Aglen, A. 1991. Survey design and analysis procedures: a comprehensive review of good practice. ICES CM 1991/B:54: 132 pp.

Skjoldal, H. R. and Rey, F. 1989. Pelagic production and variability of the Barents Sea ecosystem. pp 241-286 in: Sherman, K.and L.M. Alexander (eds.) Biomass yields and geography of large marine ecosystems. AAAS Selected Symposium 111.

Table 1. Periods and areas of more or less regular annual resource surveys performed by the Institute of Marine Research, Bergen. The areas are: 1 = West of Spitsbergen, 2 = Bear Island and the northern Barents Sea, 3 = Kola and southeastern Barents Sea, 4 = Southwestern Barents Sea, 5 = Coastal areas north west of Norway, 6 = Norwegian Sea, 7 = North Sea.

VESSEL	AREAS SURVEYED IN THE PERIOD		
	15 MAR - 15 MAY	1 JUN - 31 JUL	15 AUG - 15 OCT
G O Sars	2,4,5,7	2,3,4,5	
Johan Hjort	5	7	1,2,3,4
Michael Sars	5	4,5	
Areas covered	2,4,5,7	2,3,4,5,7	1,2,3,4

Table 2. Estimates of mean (μ) and standard deviation (σ) of volume of forestomach content (l) by dominant prey type. Number of whales in sample (n).

	Herring	Capelin	Krill and crustaceans
μ	34	21	19
σ	29	16	11
n	11	5	7

Table 3. Guestimated probability of the forestomach containing herring, capelin or crustacea in a randomly sampled whale (p_{ijk}).

Area	Spring			Summer			Autumn		
	Herr.	Cap.	Crust.	Herr.	Cap.	Crust.	Herr.	Cap.	Crust.
1.1 West of Spitsbergen	0	0	1	0	.05	.95	.1	.3	.6
2.1 Bear Island	0.2	0.2	.6	0	.20	.80	.0	.3	.7
3.1 Kola	.3	.3	.4	.1	. 5	. 4	.3	.4	.3
4.1 Finnmark	.4	.4	.2	.4	. 4	. 2	.5	.3	.2
5.1 Vesterålen/ Lofoten	1	0	0	.95	0	.05	1	0	0

Table 4. Guestimates of the relative number of meals (W_{jk}). Areas are defined as in Table 3.

Area	Spring	Summer	Autumn	Total
1.1	.5	2	.5	3
2.1	1	2	.5	3.5
3.1	1.5	3	1.5	6
4.1	1.5	1	1.5	4
5.1	2	1	1	4
Total	6.5	9	5	20.5

Table 5. Number of minke whales to be sampled by region, season and year, during the proposed research programme. Areas are defined as in Table 3. The periods are: P1 = spring, P2 = summer, P3 = autumn.

AREA	1. year	2. year				3. year				All
	P2	P1	P2	P3	TOTAL	P1	P2	P3	TOTAL	TOTAL
1.1	15	2	8	3	13	2	8	3	13	41
2.1	19	6	8	2	16	6	8	2	16	51
3.1	41	10	17	10	37	10	17	10	37	115
4.1	18	11	7	12	30	11	7	12	30	78
5.1	17	20	10	10	40	20	10	10	40	97
SUM	110	49	50	37	136	49	50	37	136	382

Table 6. Proportionality coefficient $c = c.v.\sqrt{n}$ for the sample design of Table 5, n is sample size, and c.v. for estimated total contribution of prey items. Forestomach content probabilities and relative contribution of prey items are as in Tables 3 and 4.

FOOD ITEM	1. YEAR; SUMMER c	c.v.	2. AND 3. YEAR c	c.v.
Herring	4.4	.20	2.5	.14
Capelin	4.3	.20	5.5	.20
Crustaceans	1.28	.11	2.1	.12

Table 7. Percentage points of the distribution of c.v. for estimated summer contribution of capelin in the diet in the simulation experiment i Section 8.2.

%	5	25	50	75	95
c.v.	.13	.18	.25	.37	.58

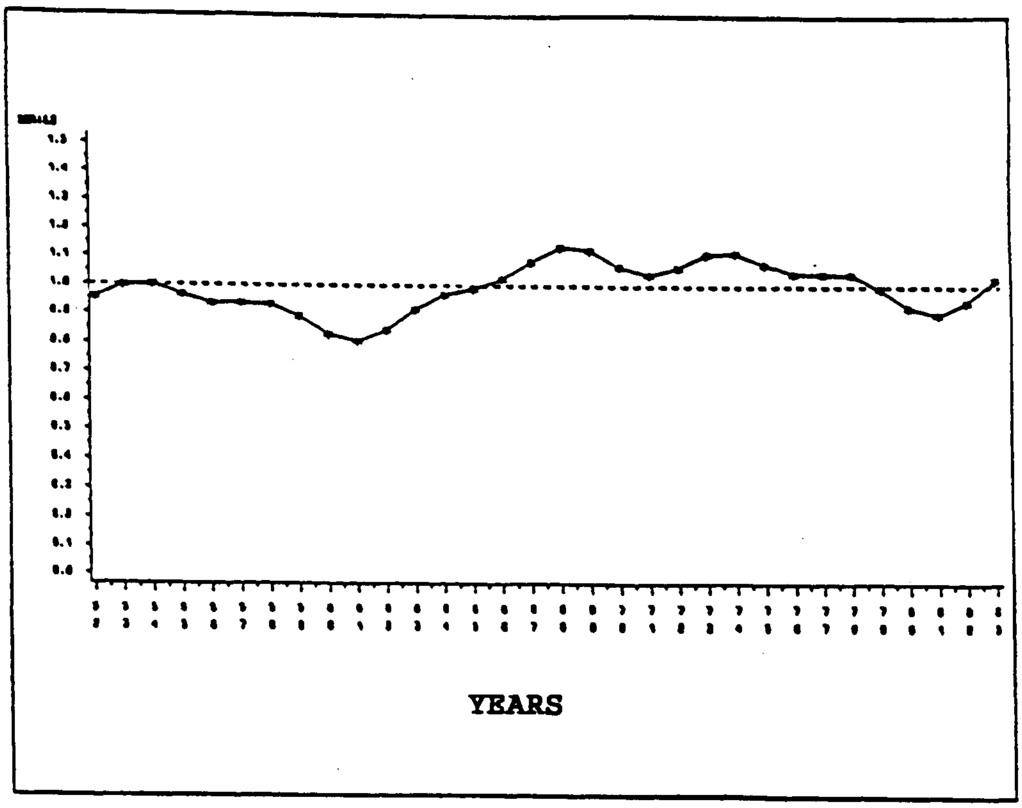

Fig. 1. The relative abundance of minke whales in the northeast Atlantic in 1952-1983 (from Schweder et al. 1991a).

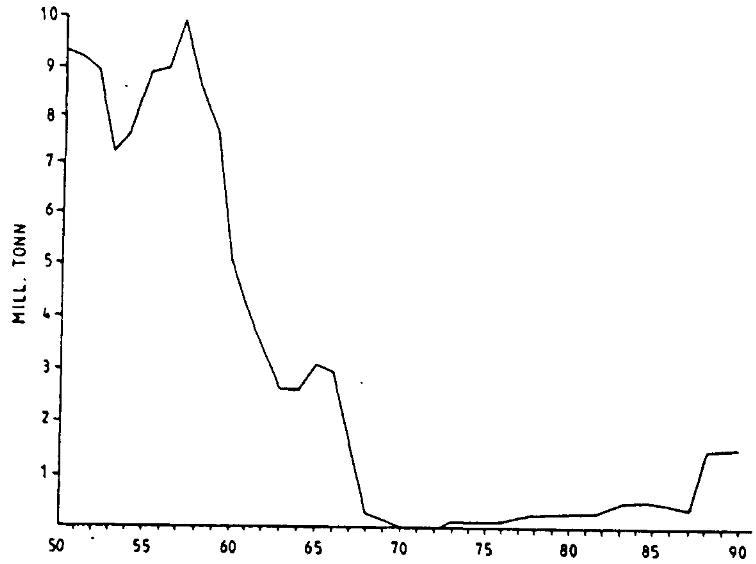

Fig. 2. Development in the stock of Atlanto Scandian herring in 1950-1990 (from Anon. 1991a).

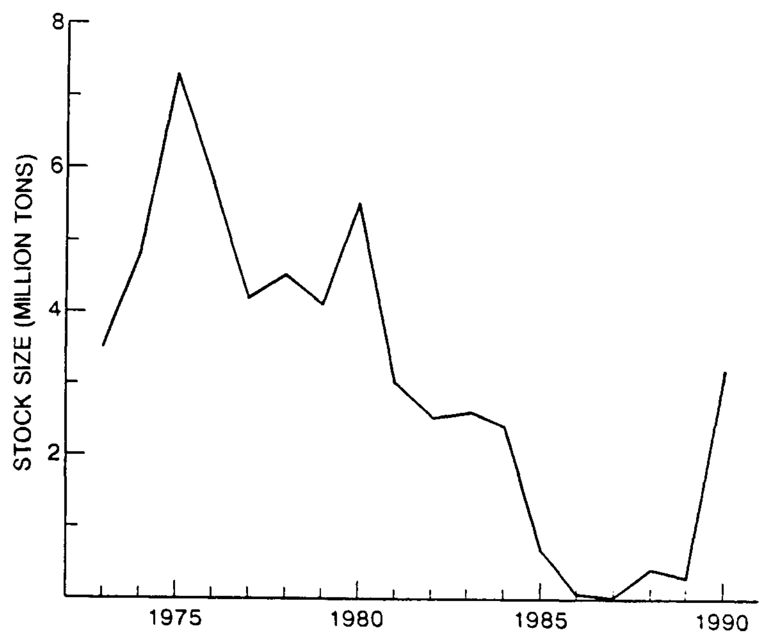

Fig. 3. Development in the Barents Sea capelin stock biomass (fish 2 years old and older) as determined from acoustic surveys in 1973-1990 (based on data given in Anon. 1991a).

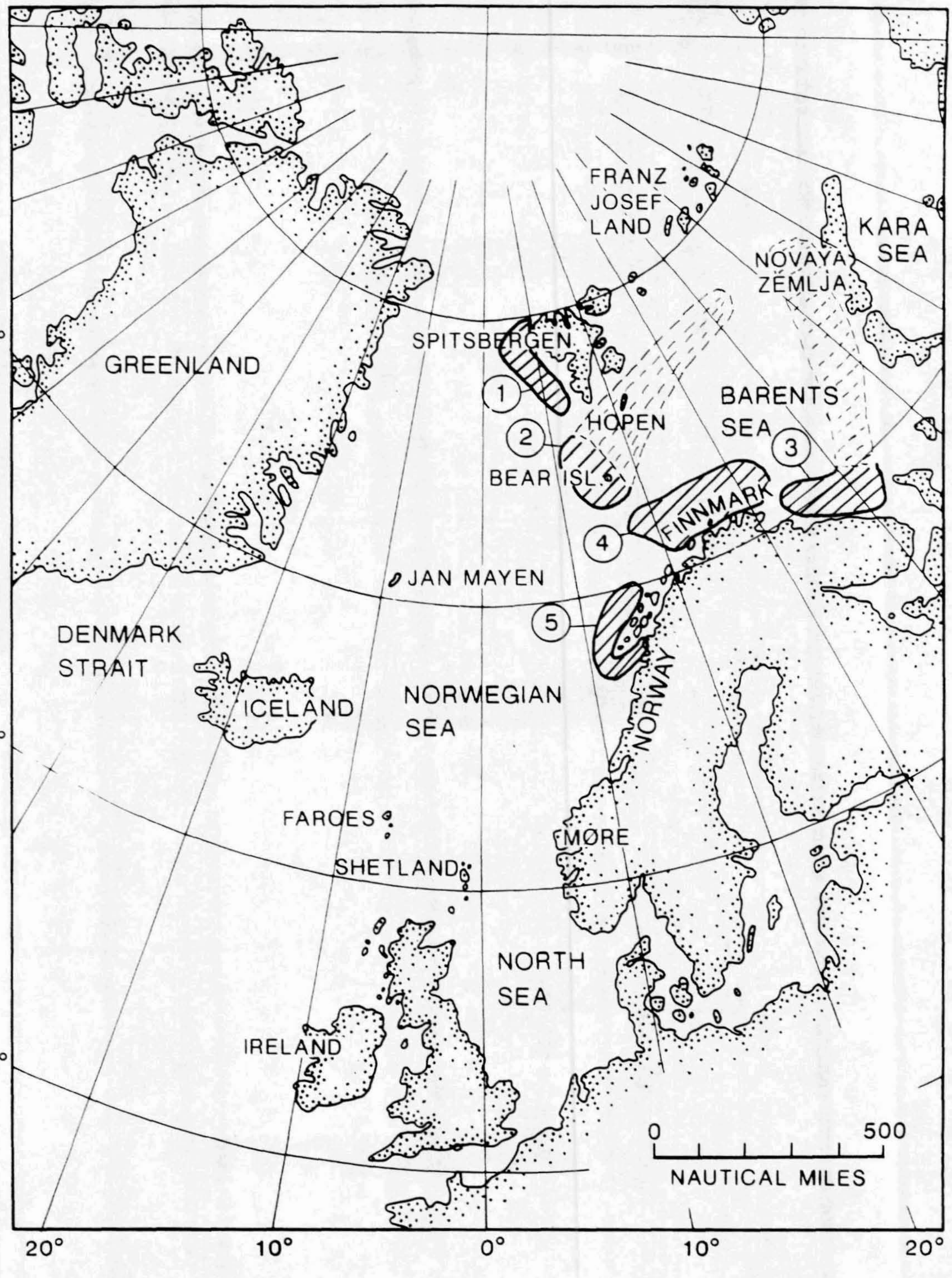

Fig. 4. The Northeast Atlantic with suggested high density areas (hatched) in which minke whales will be sampled during the proposed research operations 1992-1994. The areas referred to on the map are: 1 = West of Spitsbergen, 2 = Bear Island (and Hopen), 3 = Kola (and Novaja Zemlja), 4 = Coastal banks off Finnmark, 5 = Vesterålen and Lofoten.

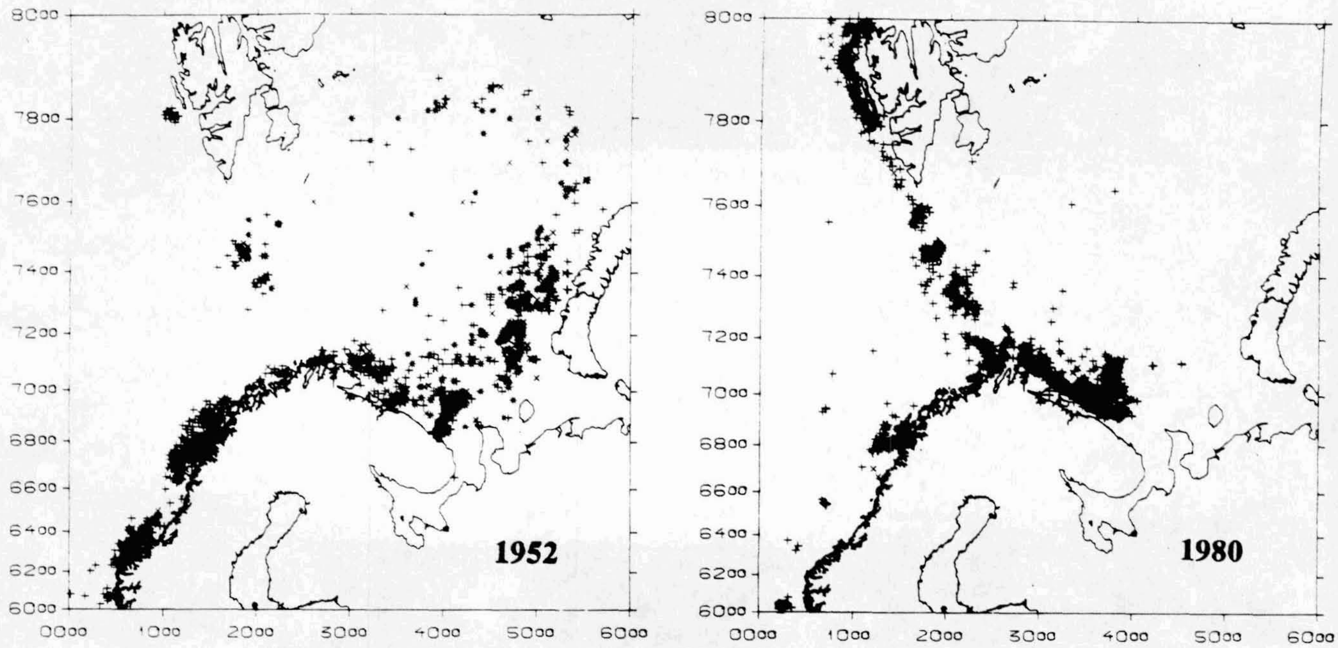

Fig. 5. Positions of minke whales caught by Norwegian small-type whalers in the Northeast Atlantic in 1952 and in 1980. (From Øien et al. 1987)

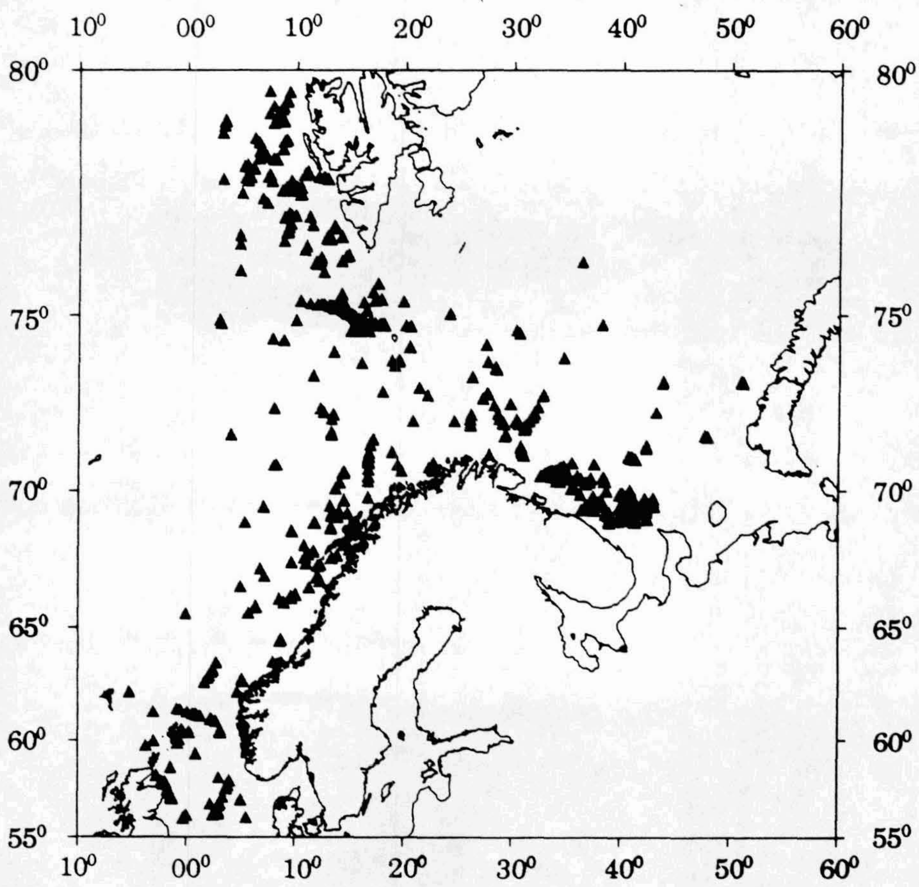

Fig. 6. Observations of minke whales during the 1989 sightings surveys. (From Øien 1991)

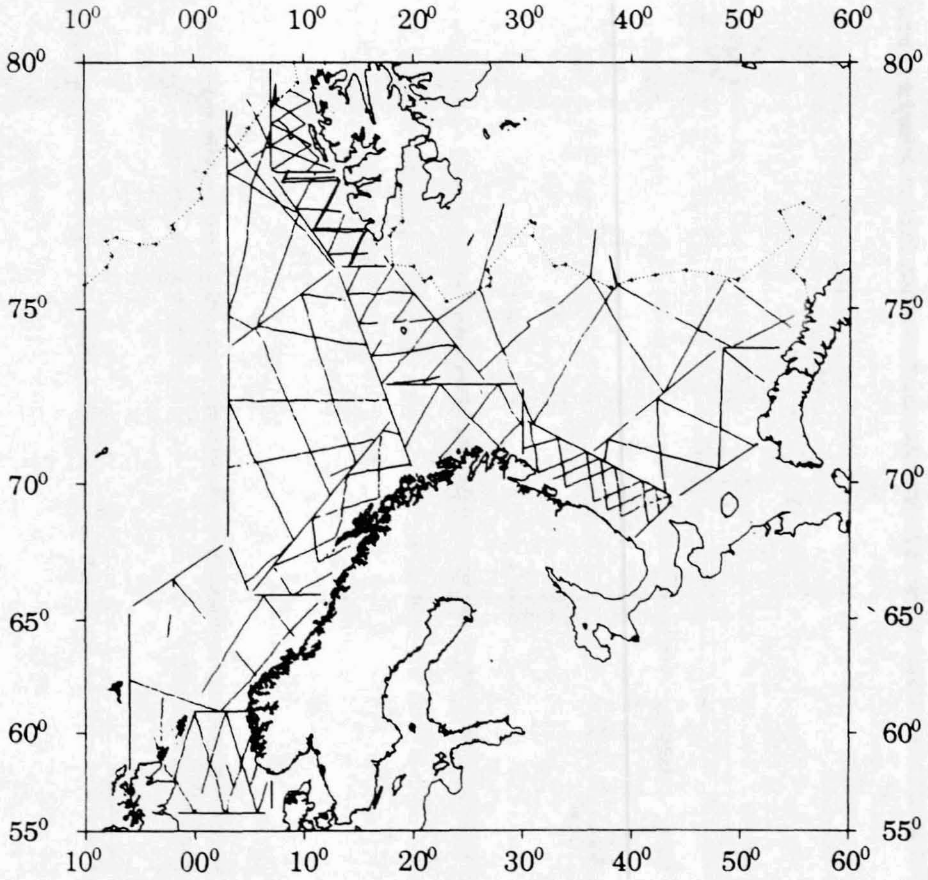

Fig. 7. The area surveyed during the 1989 minke whale sightings surveys NASS-89, including the transects run in primary searching mode. (From Øien 1991)

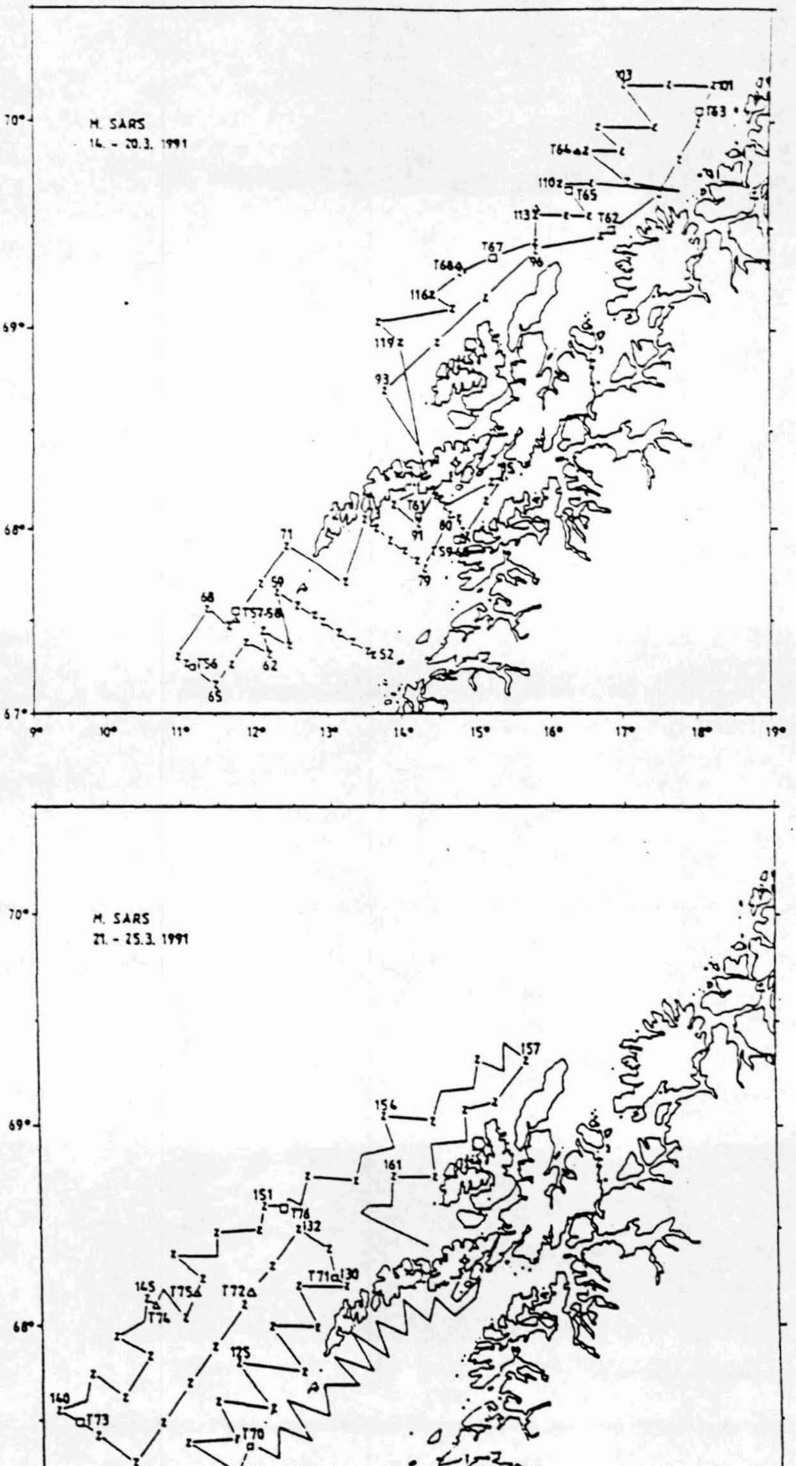

Fig. 8. Survey tracks and the grid of hydrographic and trawling stations of a R/V "Michael Sars" resource cruise in the last half of March 1991. (From internal cruise reports, Institute of Marine Research, Bergen, Norway).

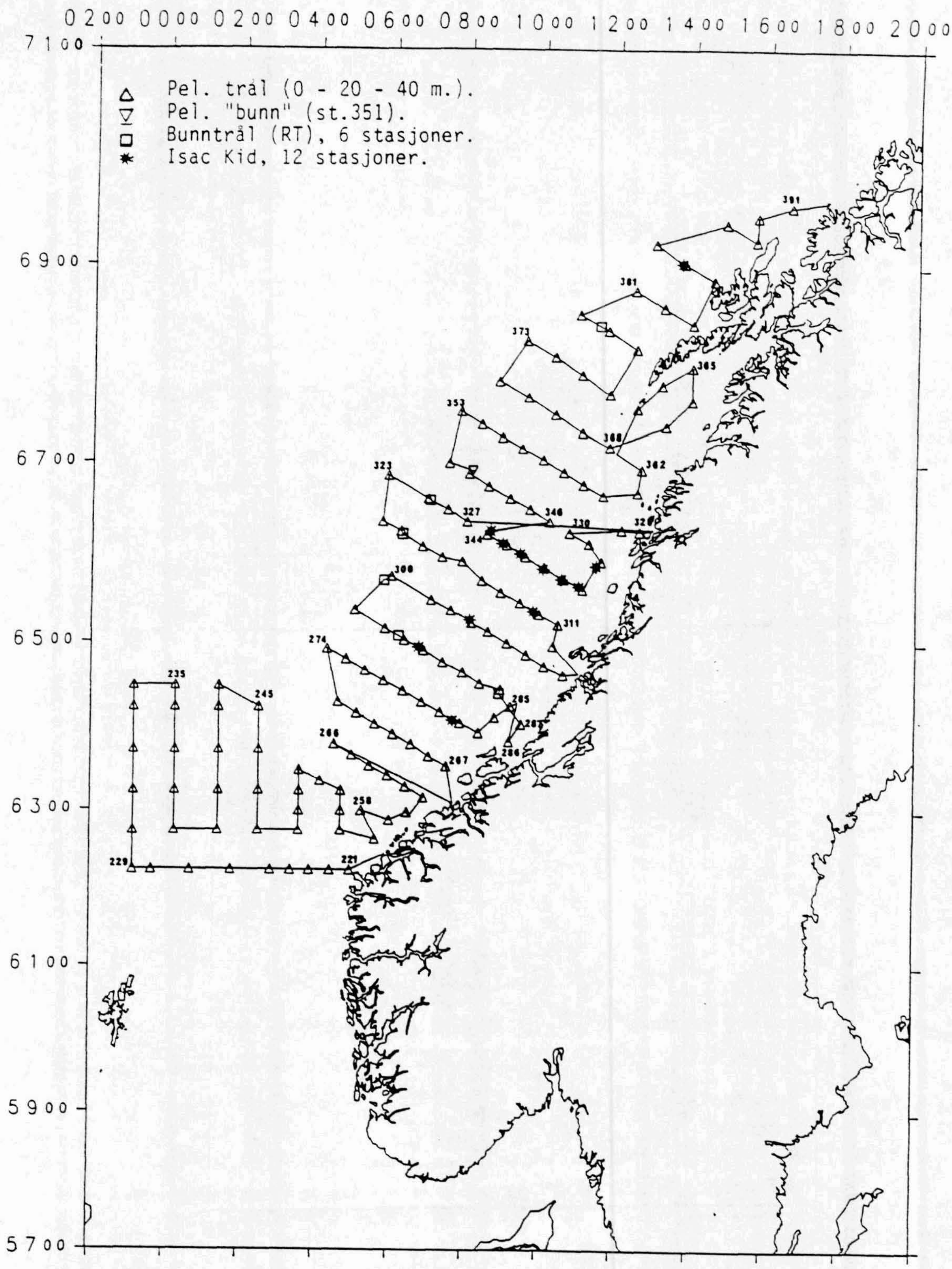

Fig. 9. Survey track and the grid of trawl stations during the May 1991 resource cruise of R/V "G.O. Sars". (From internal cruise reports, Institute of Marine Research, Bergen, Norway).

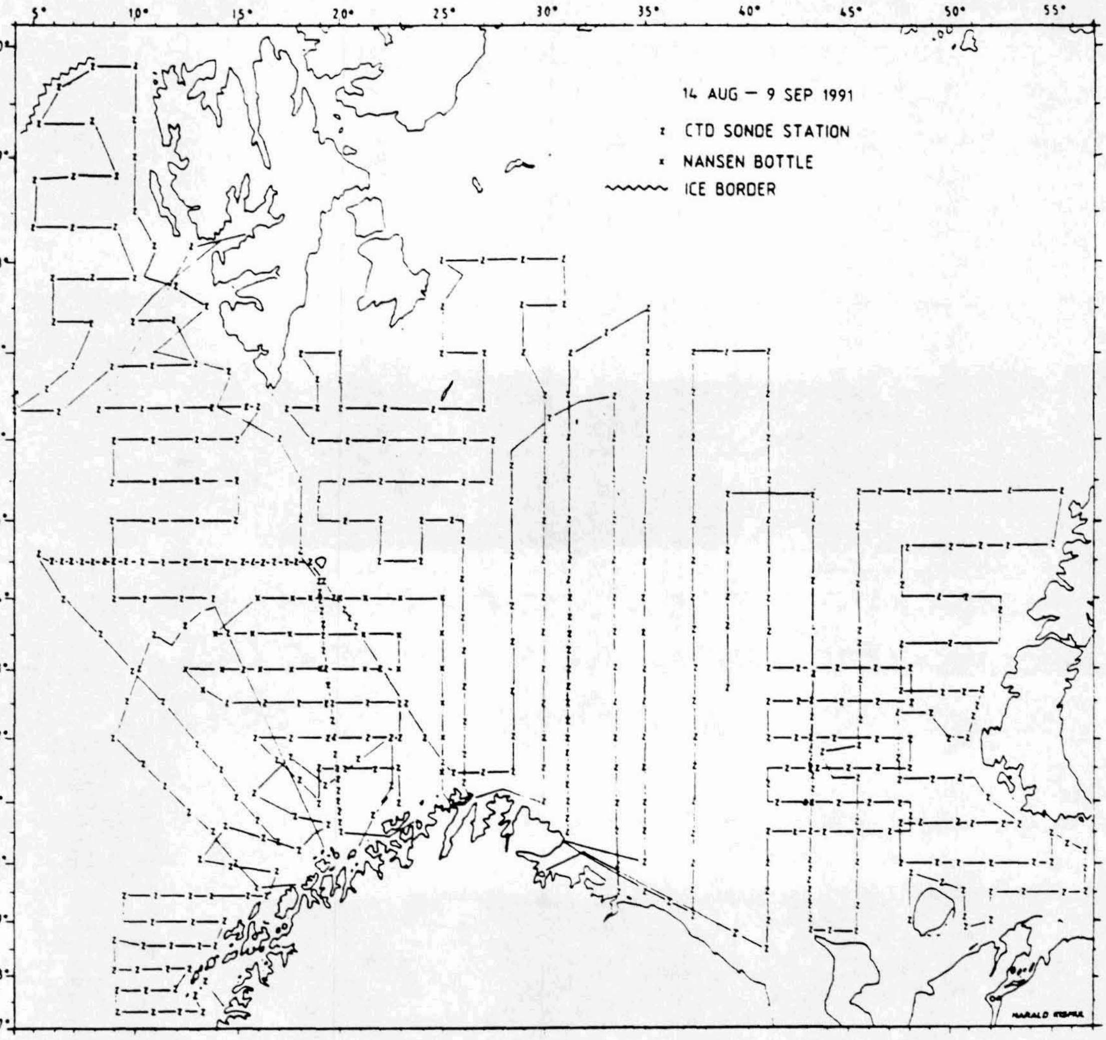

Fig. 10. Survey tracks of the research ships participating in the international 0-group fish survey in August-September 1991 (From Anon. 1991h).

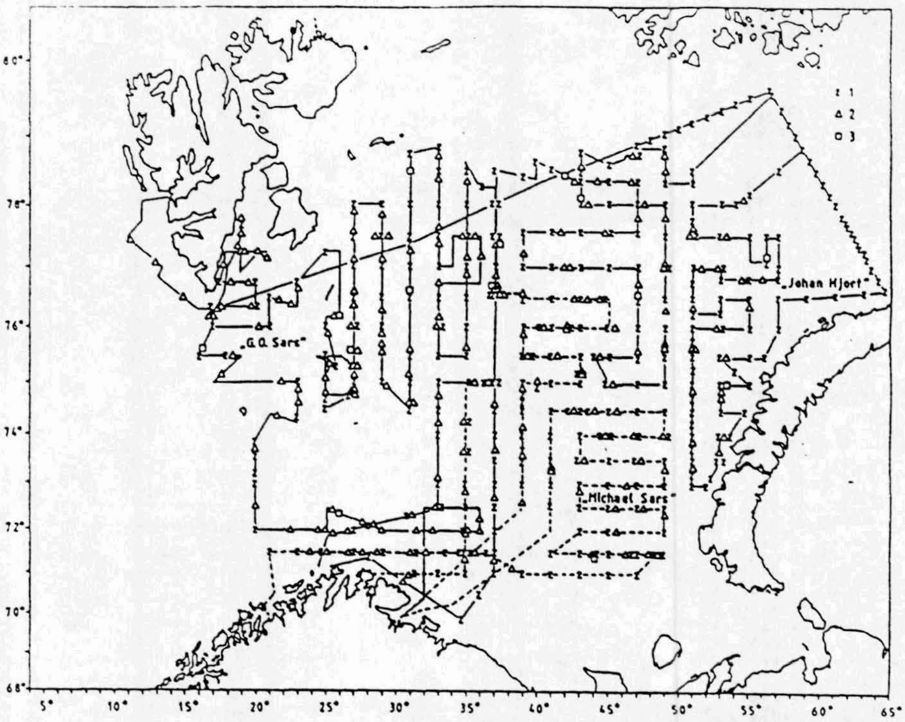

Fig. 11. Survey tracks and hydrography and trawling stations (1 = CTD-sonde, 2 = pelagic trawl, 3 = bottom trawl) of the research ships participating in research cruises aimed to study multispecies relationships in September-October 1991. (From internal cruise reports, Institute of Marine Research, Bergen, Norway).

APPENDIX

STATISTICAL CONSIDERATIONS WITH RESPECT TO SAMPLE SIZE; ESTIMATION METHOD AND DISTRIBUTIONAL PROPERTIES

Let us consider the first year of the scientific catch. For that year the total number of whales to be caught should be determined and allocated to each of the areas of interest. To determine the catch design for the first year, we will make assumptions concerning the true state of affairs and then develop an optimal design under these assumptions.

Consider I types of prey indexed $i = 1,\ldots,I$ and J areas indexed $j = 1,\ldots,J$. We want to determine sample sizes $n_1,\ldots,n_J$.

Focus on a particular area (and drop subscript j). Let for a randomly sampled whale:

X = quantum of food in forestomach

T = type of food

We assume for simplicity that no forestomach has contents of mixed type, so that T has a discrete distribution:

1) $P(T = i) = p_i \quad i = 1,\ldots,I$

Let further the conditional distribution of quantity given type have moments:

2) $E(X|T = i) = \mu_i$

3) $\mathrm{var}(X|T = i) = \sigma_i^2$

If n whales are caught in the area, N_i of these will have prey of type i in their forestomachs. Let the quantities be $X_{i1},\ldots,X_{iNi}$. The key parameters to be estimated are p_i and μ_i

$$4)\qquad \hat{p}_i = \frac{N_i}{n}$$

$$5)\qquad \hat{\mu}_i = \frac{1}{N_i} \sum_{k=1}^{N_i} X_{ik}$$

The estimated mean quantity of type-i food in the forestomach of a random whale is then

$$6)\qquad \hat{p}_i \, \hat{\mu}_i = \frac{1}{n} \sum_{k=1}^{N_i} X_{ik}$$

Let W be the number of meals taken by whales in the area over the period in question. The estimated consumption of prey i is then

$$7)\qquad \hat{C}_i = W \, \hat{p}_i \, \hat{\mu}_i$$

To simplify matters, we disregard uncertainty in W. The mean and variance of $\hat{C}_i$ is then

$$8)\qquad E\,\hat{C}_i = W \, p_i \, \mu_i$$

$$9)\qquad \mathrm{var}\,\hat{C}_i = W^2 \frac{1}{n} p_i \,(\sigma_i^2 + (1-p_i)\,\mu_i^2)$$

The assumption here is that X_{i1}, X_{i2},..... are stochastically independent of the realised sample size, N_i, of whales with prey i in their forestomach.

The formulae 1) - 9) apply to all types of prey, i = 1,...,I and to all areas j = 1,...,J. By also indexing by j, we have the estimated consumption of type i in area j,

$$10) \quad \hat{C}_{ij} = W_j \hat{p}_{ij} \hat{\mu}_{ij}$$

The total consumption of prey i is then estimated by the sum

$$11) \quad \hat{TC}_i = \sum_j \hat{C}_{ij}$$

We have

$$12) \quad E \hat{TC}_i = \sum_{j=1}^{J} W_j p_{ij} \mu_{ij}$$

and by independence between catch areas

$$13) \quad \operatorname{var} \hat{TC}_i = \sum_{j=1}^{J} W_j^2 \frac{1}{n_j} p_{ij} (\sigma_{ij}^2 + (1 - p_{ij}) \mu^2_{ij})$$

The aim is to allocate the total number, n, to areas so as to estimate C_{ij} with optimal precision. Optimality has, however, to be defined in operational and manageable terms. Our choice of criterion is to minimize the total variance

$$14) \quad V = \sum_{i=1}^{I} \sum_{j=1}^{J} \operatorname{var} \hat{C}_{ij} = \sum_{i=1}^{I} \operatorname{var} (\hat{TC}_i)$$

Another sensible criterion is to minimize

$$15) \quad VC^2 = \sum_{i=1}^{I} \sum_{j=1}^{J} \text{c.v.}^2 (\hat{C}_{ij})$$

Other criteria are possible.

The total variance, V, is by 13)

$$16) \quad V = \sum_{j=1}^{J} \frac{1}{n_j} w_j^2$$

where

$$17) \quad w_j = W_j \sqrt{\sum_{i=1}^{I} p_{ij} \left(\sigma_{ij}^2 + (1 - p_{ij})\, \mu^2_{ij}\right)}$$

The mathematical problem is then to minimize 16) under the restriction $n_1 + \ldots + n_J \le n$. This is equivalent to the problem of optimal allocation in stratified sampling (Cochran 1963), and the solution is

$$18) \quad n_j = n\, w_j \Big/ \sum_{k=1}^{J} w_k = n\, \Pi_j$$

If 15) was taken as the criterion, the optimal solution is found in the same way, but it will be dominated by areas where some p_{ij} are close to zero.

Clearly, all estimates $\hat{C}_{ij}$ are improved by increasing the total sample size and allocate this to areas by 18). The marginal utility is however decreasing as n increases. Where to draw the line is a matter of judgement. We propose to determine n so as to control the coefficient of variation for each prey item. The criterion is to chose n as small as possible, but such that

$$19) \quad \text{c.v.}\,(\widehat{TC}_i) \le \alpha \qquad i = 1, \ldots, I$$

Now

$$20) \quad \text{c.v.}^2\,(\widehat{TC}_i) = \frac{1}{n} \left[\sum_{j=1}^{J} \Pi_j^{-1}\, W_j^2\, p_{ij}\, \left(\sigma_{ij}^2 + (1-p_{ij})\mu^2_{ij}\right) \right] \left[\sum_{j=1}^{J} W_j\, p_{ij}\, \mu_{ij} \right]^{-2}$$

$$= \frac{1}{n}\, c_i^2$$

Thus

$$n \geq c_i^2/\alpha^2 \qquad i=1,\ldots,I$$

A value of

$$\alpha = 0.2$$

seems to be a reasonable choice.

We also want to impose a design for the second and third year of the sampling programme. In addition to areas (index j) and prey (index i) there are sampling periods $k = 1,\ldots K$. In the proposal, K=3. With P_{ijk} being the preference probability for prey i in area j and period k, with W_{jk} being the number of meals taken by whales in area j in period k etc., the total consumption of type i in area j and period k is estimated by

$$21)\quad \hat{C}_{ijk} = W_{jk}\,\widehat{p}_{ijk}\,\widehat{\mu}_{ijk}$$

which has variance

$$22)\quad \operatorname{var} \hat{C}_{ijk} = W_{jk}^2 \frac{1}{n_{jk}} p_{ijk} (\sigma_{ijk}^2 + (1 - p_{ijk})\mu_{ijk}^2)$$

Here, uncertainty in W_{jk} is disregarded.

As for the first year, the allocation over area and season is done by minimizing the total variance. The solution is

$$23)\quad n_{jk} = n\, w_{jk} \,/\, \sum_{jk} w_{jk} = n\, \Pi_{jk}$$

$$24)\quad w_{jk} = W_{jk} \sqrt{\sum_i p_{ijk} (\sigma_{ijk}^2 + (1 - p_{ijk})\, \mu_{ijk}^2)}$$

The total sample, n, to be taken in each of these years is found by requiring the coefficient of variation of the total consumption of each type of prey being at most α,

$$\text{c.v.}(\widehat{TC}_i) = \frac{1}{n}\left[\sum_{jk}\frac{1}{\Pi_{jk}} W_{jk}^2\, p_{ijk}\,(\sigma_{ijk}^2 + (1-p_{ijk})\mu_{ijk}^2)\right]\left[\sum_{jk} W_{jk}\, p_{ijk}\, \mu_{ijk}\right]^{-2}$$

$$= \frac{1}{n} c_i^2$$

The criterion is then

$$n \geq c_i^2/\alpha^2 \qquad i=1,\ldots,I.$$

The parameters needed to compute the optimal design are to a large extent unknown. A certain amount of guesswork has therefore been required to set parameter-values which allow the design to be computed. Since virtually no information was available on prey other than herring, capelin and crustaceans, we have limited our analysis to these three types. When analysing data, other types of prey will of course be investigated.

The scientific catch from 1988-1990 (Nordøy & Blix 1991) is of help in estimating some of the parameters required to specify the optimal design. Table 2 gives mean and standard deviation for forestomach quantity by type of prey. Some of the whales had mixed food in their forestomach. For simplicity, they are grouped with their dominant item.

The pattern of prey-preference/presence is more speculative. Table 3 gives the pattern used to derive the design. The estimates of prey preference given in Table 3 are bound to be inaccurate. The design is however not very sensitive to these probabilities.

The abundance of minke whales may be estimated from the 1989 sightings survey (Øien 1990). Table 4 gives estimated relative number of whale meals in the various areas during summer, and is based on a fair amount of guessing. The absolute number of meals do not enter our calculations. This is fortunate since the passage time in the forestomach is unknown as is the feeding frequency. Table 4 is based on a fair amount of guessing.

The sampling design obtained from the numeric values given in Tables 2 - 4 is given in Table 5. From this it appears that 110 minke whales need to be taken during the first year of scientific whaling, while 136 animals must be taken in each of the two following years. If our assumptions are valid and our guestimates correct, this is an optimal allocation in the sense of minimizing the total variance and of assuring that the coefficient of variation (cv) is at most 0,2 for each of the three types of prey.