ANNEX 3

REPORT OF THE NAMMCO WORKING GROUP ON MARINE MAMMALS AND FISHERIES IN THE NORTH ATLANTIC: ESTIMATING CONSUMPTION AND MODELLING INTERACTIONS

Reykjavik, Iceland, 15-17 April 2009

1. OPENING REMARKS

Chair Walløe welcomed the participants (Section 5.8) to the meeting.

By way of background in 1996 a Working Group (WG) looked at the feeding ecology of minke whales, harp and hooded seals and found that there were many uncertainties involved in estimating consumption by these species (NAMMCO 1998). It also considered the use of multi-species models to assess species interactions in the Barents Sea and Central North Atlantic. The Scientific Committee, based on the results from the WG, concluded that minke whales, harp seals and hooded seals in the North Atlantic might have substantial direct and / or indirect effects on commercial fish stocks.

In 1997, the Council requested the Scientific Committee to pay special attention to studies related to competition and the economic aspects of marine mammal-fisheries interactions. The Scientific Committee, in response, convened a WG on the Economic Aspects of Marine Mammal - Fisheries Interactions (NAMMCO 1999). This WG considered bio-economic models of varying complexity and associated ecosystem models, and concluded that "many of the analyses were in a preliminary stage and should only be taken as first indications”. They further concluded that, despite the preliminary nature of the results, the emerging cost-benefit figures warranted serious consideration, as the overall costs to the fishing, whaling and sealing industries incurred by not whaling and/or not sealing could be quite considerable, and that the effects due to predation could be an important part of the overall picture.

At its 8th meeting in Oslo, September 1998, the NAMMCO Council tasked the Scientific Committee with providing advice on the following:

1. to identify the most important sources of uncertainty and gaps in knowledge with respect to the economic evaluation of harvesting marine mammals in different areas;
2. to advise on research required to fill such gaps, both in terms of refinement of ecological and economic models, and collection of basic biological and economic data required as inputs for the models,
3. to discuss specific areas where the present state of knowledge may allow quantification of the economic aspects of marine mammal-fisheries interaction;
    a) what could be the economic consequences of a total stop in harp seal exploitation, versus different levels of continued sustainable harvest?
    b) what could be the economic consequences of different levels of sustainable harvest vs. no exploitation of minke whales?

The WG on the Economic Aspects of Marine Mammal - Fisheries Interactions met in February 2000 to consider parts 1) and 2) of the request. One of the conclusions of the WG was that significant uncertainties remained in the calculation of consumption by marine mammals, and this uncertainty was the most important factor hindering the development of models linking consumption with fishery economics (NAMMCO 2001). Considering this conclusion, the Scientific Committee decided to convene a WG to further investigate the methodological and analytical problems in estimating consumption by marine mammals.

At its meeting in Tromsø, 26-28 September 2001 the WG continued work on the above mentioned Terms of Reference (TOR) and considered the methodological approaches to the calculation of consumption by marine mammals, making a detailed assessment of their relative merits. The two approaches of analyses of stomach contents in combination with estimates of stomach evacuation rates, and analyses of stomach or intestinal content or faeces scaled to satisfy the estimated energy expenditure of the animals were considered. The level of assumptions required and general lack of data about evacuation rate for most marine mammals render these methods unsuitable for the calculation of consumption by North Atlantic marine mammals. For the latter method diet composition and energy expenditure may be investigated independently to each other. The WG concluded that the proportions of various prey items in the diet can be safely derived from undigested items in fresh stomach samples if such samples are available. Interpretation becomes increasingly more difficult as digestion proceeds. However, errors associated with identifying the prey eaten by seals from intestinal contents or faeces can be assessed using captive feeding experiments. There is a range of methods available for measuring metabolic rate of seals in the field, but all have serious limitations. However, a main conclusion was that for all the relevant species of marine mammals in the North Atlantic the uncertainties in energy expenditure are small compared to the uncertainties in the estimates of abundance and compared to the uncertainties and lack of knowledge of the diet composition. As a first approximation it can be assumed that the marine mammals eat 3% of their body weight per day.

The Scientific Committee hosted a workshop in Reykjavik, Iceland in September 2002 under the title “Modelling Marine Mammal – Fisheries Interactions in the North Atlantic”. This workshop recommended a general modelling approach involving the use of “minimum realistic” models, and developed specific recommendations for their application to candidate areas of the North Atlantic. However the WG emphasized that better data on diet and consumption were needed before marine mammals could be adequately represented in models.

In Oslo, 22-24 October 2004 the WG reviewed the progress made in the previous two years, in two specific areas: 1) quantifying the diet and consumption of marine mammals, and 2) the application of multi-species models that include marine mammals to candidate areas of the North Atlantic. The WG concluded that the development of multi-species modelling was not proceeding as fast as it should, given the emphasis politicians and management authorities have placed on multi-species (ecosystem) approaches to the management of marine resources. Once again the WG emphasised that progress in this area will not be made unless substantial additional resources are dedicated to it.

At its recent 17th meeting, in Sisimiut, Greenland 2-4 September 2008 the NAMMCO Council, acknowledging the standing requests to the Scientific Committee:

- *to monitor progress made in multi-species modelling and in the collection of input data and to decide when enough progress has been made to warrant further efforts in this area;*
- *to review the results of the Icelandic programme on the feeding ecology of minke whales and multi-species modelling as soon as these become available;*

requested the Scientific Committee:

> *"In addressing the standing requests on ecosystem modelling and marine mammal and fisheries interaction, to extend the focus to include all areas under NAMMCO jurisdiction. In the light of the distributional shifts (of species) seen under T-NASS 2007, the Scientific Committee should investigate dynamic changes in spatial distribution due to ecosystem changes and functional responses."*

The Working Group was therefore given the task:

a. to monitor progress made in multi-species modelling and in the collection of input data;
b. to extend the focus (Barents Sea and Iceland) to include all areas under NAMMCO jurisdiction;
c. to investigate dynamic changes in spatial distribution due to ecosystem changes and functional responses, in the light of the distributional shifts seen under T-NASS 2007;
d. to review the results of the Icelandic programme on the feeding ecology of minke whales.

And in addition

e. to evaluate how a projected decrease in the total population of Northwest Atlantic harp seals might affect the proportion of animals summering in Greenland.

The Chair reminded the members that the WG should provide an indication of the kind of research needed to proceed towards ecosystem based management within NAMMCO. In this respect work conducted in other oceans is welcomed as it is useful for the definition of methods and applications which can be transferred to the North Atlantic and areas around Greenland.

2. ADOPTION OF AGENDA

The agenda was adopted. (Appendix 1)

3. APPOINTMENT OF RAPPORTEUR

Acquarone, Scientific Secretary of NAMMCO, was appointed as rapporteur for the meeting, with the help of other members as needed.

4. REVIEW OF AVAILABLE DOCUMENTS

Documents available to the meeting are listed in Appendix 2.

5. RECENT DEVELOPMENTS IN THE QUANTITATIVE DESCRIPTION OF MARINE MAMMAL DIETS

a) Minke whales

Western North Pacific

Murase presented document SC/16/MMFI/07 in which the stomach contents of common minke, sei and Bryde's whales sampled in the western North Pacific from May to September were analysed. Sampling was conducted in the second phase of the Japanese Whale Research Programme in the Western North Pacific (JARPN II) from 2002 to 2007. The purpose of this study was to estimate the amount of fish resources consumed by the three whale species. Prey species of whales were identified by examining their stomach contents. The amount of prey consumed in the research area was estimated by extrapolation using information on prey consumption per individuals and abundance of whales. Daily prey consumption was estimated based on Sigurjónsson and Víkingsson (1997). Minke whales fed mainly on higher trophic level prey whereas sei and Bryde's whales mainly fed on lower trophic level prey. The results of this study suggested that these three baleen whales species should be considered as euryphagous. Length compositions of prey in the stomachs suggested that minke whales tended to feed on large size prey in comparison with sei and Bryde's whales. Daily prey consumption rates were estimated by maturity stage for three baleen whales and ranged between 2 % to 6 % of their body weight. The total prey consumption by these three baleen whale species in the survey area during the feeding season was estimated as 1.6 million tonnes per year.

Comments:

- The WG notes that the diet of minke whales in the North Pacific and in the North Atlantic were similar but that sei whales in the North Pacific feed on small fish as well as crustaceans which constitute their complete diet in the North Atlantic.

Murase went on to present document SC/16/MMFI/11 where prey preferences of common minke, Bryde's and sei whales at the meso scale were estimated using data from the cooperative surveys of cetacean sampling and prey of cetaceans. The surveys were conducted as a part of the offshore component of JARPN II from 2002 to 2007. This constitutes the first evaluation of prey preferences of minke, Bryde's and sei whales in the offshore region of the western North Pacific. A prey preference index, Manly's α, was used in the analysis. Though prey of the three baleen whale species overlapped, Manly's α suggested the species' preferences were different from each other. Minke and Bryde's whales showed a preference for pelagic fishes while sei whales showed a preference toward copepods. Accumulation of prey preference data for long periods will provide the basis for appropriate choice of functional response form which is required by ecosystem models for fisheries management. Continuation of long term synoptic research such as JARPN II is important to develop reliable ecosystem models.

Comments:

- The WG notes that the spatio-temporal differences in feeding location might explain the differences in prey preference among the whale species as location might constrain prey choice.

- Furthermore the group underlines the importance of stomach content sampling for determination of whale diets and especially the trophic level of whale prey species. Alternatively information on prey trophic level could be obtained via stable isotope analysis of biopsies. For the Barents Sea there is a wealth of information that would facilitate a similar experiment on prey preferences and food partitioning.

Iceland

Víkingsson presented document SC/16/MMFI/04 which gives an account of an ongoing study into the feeding ecology of common minke whales in Icelandic waters. Sampling of a total of 200 minke whales took place during 2003-2007. Progress has been reported annually to the NAMMCO Scientific Committee and some preliminary results were presented in 2004 (NAMMCO SC/12/IN/4). Overall, sandeel was the most common prey, while other important prey species included herring, haddock, capelin, cod and krill. Compared to limited data collected opportunistically during 1977-1997, the present study showed higher proportions of sandeel and large benthic fish species and lower incidence of krill and capelin.

Although the sample size was small, indications of considerable geographical variation were found in the minke whale diet as well as appreciable changes over the study period. The latter appear to be related to changes in other components of the marine ecosystem in the Icelandic continental shelf area. Thus a decreasing contribution of sandeel to the diet during the study period coincided with a recruitment failure of sandeel in 2005 and to a lesser degree in 2004. Increased proportions of herring and haddock are also in good agreement with information on increasing trends in these species in recent years.

In relation to the large recent changes observed in hydrographical parameters and various components of the ecosystem in the Icelandic continental shelf area it is noteworthy that the abundance of minke whales in this area in 2007 was less than half that in 2001.

Comments:

- The WG notes that Atlantic cod represented an important part of the diet of Icelandic minke whales; on several occasions the stomachs contained this species only. The apparent geographical differences in the diet may have been affected by the small sample size and / or inter-annual variations.

- The WG suggests comparing samples collected annually from the same areas collected in different years to determine whether the past changes observed represent inter-annual variations or are a consequence of geographic variations in sampling locations.

Barents Sea

Haug reported on the status of Norwegian progress on the description of minke whale diets. After the research whaling under scientific permit in 1992-1994, Norwegian scientists continued to collect stomach samples of minke whales caught in the commercial hunt until 2004. The first part of this time series on minke whale diet (1992-1999, including only the Barents Sea area) was published by Haug *et al.* (2002)[20] , whereas document SC/16/MMFI/O07 summarises the continued sampling in 2000-2004. Substantial changes have occurred in the Barents Sea ecosystem over the past 30 years, the most conspicuous being related to the rises and falls of stocks of the two dominant pelagic shoaling fish species: capelin and herring. Effects of these ecological changes are clearly seen in the diet of minke whales. Following a collapse in the capelin stock in 1992/1993, minke whales foraging in the northern Barents Sea apparently switched from a capelin-dominated diet to a diet comprised almost completely comprised of krill. The second half of the 1990s saw a clear improvement in the capelin stock, and the species was again observed in the whale diet in the northern areas in 2000. In the southern area of the Barents Sea, capelin has increasingly been observed as prey of minke whales since 1995. In this area, gadoids and, more importantly, krill and herring, are also the food items of interest for the whales. The southern region of the Barents Sea includes important nursery areas for the Norwegian spring spawning herring. Good recruitment to this stock gives strong cohorts (e.g. 1991, 1992 and 1998) and large numbers of adolescent herring (0-3 years old) which serve as the main minke whale prey in the area. Recruitment failure with subsequent weak cohorts (e.g. 1993-1997) seems, however, to reduce the availability of adolescent herring to such an extent that minke whales switch to other prey items such as krill, capelin and, to some extent, gadoid fish. After 1999, sampling was extended to include areas outside the Barents Sea in addition. The material collected during late May-June 2000-2004 revealed a relatively mixed diet at the population level, whereas on an individual level, each whale had fed upon mainly one species. There were significant differences in diet composition between areas and some significant differences between years. The importance of krill in the Barents Sea increased with latitude and dominated the Spitsbergen diet. Capelin dominated the diet around Bear Island and contributed considerably to the diet along the coast of northern Norway. In the latter area, herring and haddock were also a large part of the diet. The diet in the Norwegian Sea consisted of mainly mature herring, while the diet in the North Sea was dominated by sandeels and mackerel. The whales were found to feed on a wide range of prey sizes apparently determined by the availability of different size classes.

[20] Haug, T., Lindstrøm, U. and Nilssen, K.T. 2002. Variations in minke whale *Balaenoptera acutorostrata* diets in response to environmental changes in the Barents Sea. *Sarsia* 87: 409-422.

No minke whale diet studies have been performed in Norwegian waters since 2004. It is, however, considered important to resume the sampling and data collection for long term monitoring of minke whale feeding habits in these areas, and new collections will most probably be undertaken during commercial whaling in 2009. A pilot study to assess the usefulness of fatty acid compositions in blubber profiles to estimate the diets of some captured animals will also be conducted. If the results are positive, future monitoring of minke whale diets might be conducted using the fatty acid method. For modelling purposes, it is also recommended that some process orientated studies be performed, where collection of diet data are combined with simultaneous mapping of prey abundance. As seen from document SC/16/MMFI/O08, current knowledge of the Barents Sea ecosystem is already comprehensive at many trophic levels – this area may therefore be particularly well suited for such studies.

Comments:

- The WG noted the Norwegian plans to resume the sampling of data to monitor minke whale feeding habits in Norwegian waters with appreciation. Regular sampling of such data is of great importance for understanding the ecological role of minke whales.
- The WG noted that fatty acid analysis may be able to help discriminate among size classes of the prey if they exhibit changes in diet during development (e.g. Atlantic cod).

b) Harp seals

Barents Sea

Haug reported on progress in the quantitative description of harp seal diets (document SC/16/MMFI/O12). In 2001 and 2002, Norwegian and Russian scientists undertook an aerial survey to assess whether there was an overlap in distribution, and thus potential predation, between harp seals and capelin in the Barents Sea. This experiment is now being followed by boat-based surveys aimed to study pelagic feeding by harp seals in the Barents Sea during summer and autumn. In May/June 2004, June/July 2005, and May/June 2006, Norwegian surveys were conducted, aimed at studying the feeding habits of harp seals occurring in the open waters of the Barents Sea (document SC/16/MMFI/O12). Very few seals were observed along the coast of Finnmark, and no seals were seen in the open, ice-free areas. In the north-western parts of the Barents Sea, however, very large numbers of seals were observed along the ice edge and 20-30 nautical miles south of this. In 2004, 2005 and 2006, 33, 55 and 57 harp seals respectively were shot and sampled (stomachs, intestines, and blubber cores) in these areas. Additionally, samples of faeces were taken from haul out sites on the ice. Preliminary results from the analyses of gastrointestinal tract contents and scats indicate that the summer consumption was to a large extent dominated by krill, with polar cod also contributing importantly. All sampling was performed during a period of low capelin abundance – this may have influenced the results. The 2006 survey also included synoptic assessment of prey abundance (using acoustics and trawling) in the areas where the seals were captured – these data are now being analyzed to assess potential prey preferences of the seals. Furthermore, potential prey items from the trawl hauls are now being analyzed for fatty acid composition – this will be compared with results from similar analyses of blubber cores from the captured seals in order to see if this is a useful way to describe harp seal diets.

Haug added that management agencies in Norway and Russia have expressed concerns over the current size of the Northeast Atlantic harp seal populations and their predation on fish stocks, in particular in the Barents Sea. To be able to assess the ecological role of harp seals by estimation of the relative contribution of various prey items to their total food consumption, a Joint Norwegian-Russian Research Programme on Harp Seal Ecology has been initiated. The focus of this programme will be to:

1. assess the spatial distribution of harp seals throughout the year (experiments with satellite-based tags)
2. assess and quantify overlap between harp seals and potential prey organisms (ecosystem surveys)
3. identify relative composition of harp seal diets in areas and periods of particular intensive feeding (seal diet studies in selected areas)
4. secure the availability of data necessary for abundance estimation
5. estimate the total consumption by harp seals in the Barents Sea (modelling)
6. implement harp seal predation in assessment models for other relevant resources (modelling).

The Programme was adopted by the Joint Norwegian-Russian Fisheries Commission and supported by the NAMMCO Scientific Committee in 2006 and 2008. However, although both ecosystem surveys and abundance estimation of harp seals are in progress, the core activities of the Programme have not yet been started fully, the reason being that Russian authorities refused to permit deployment of satellite tags on harp seals in the White Sea in May, all of 2007, 2008 and 2009. To ensure that tagging will take place in 2010, Norway and Russia have agreed to organize a research cruise in late-May/early-June that year, to deploy satellite tags on harp seals on ice in the Hopen area southeast of Spitsbergen. The cruise will be part of the joint Harp Seal Programme, involving both Norwegian and Russian scientists. However, tagging seals in the White Sea is still the most preferable approach, as it ensures that only seals from the White Sea stock are tagged, and because tagging of different sex and age groups can be balanced easily. Therefore, the Russian scientists will apply for permission to tag seals in the White Sea also in 2010. The Norwegian scientists will provide all necessary technical information about the tags and the operation, whereas the Russian scientists will secure that all logistics in the White Sea area are ready in early May 2010.

Comments:

- There is an urgent need for more data on the feeding habits of harp seals in the Northeast Atlantic. The WG commended the planned Norwegian-Russian efforts to conduct a comprehensive Harp Seal Ecology Research programme in the Barents Sea and recommended that this very important programme be facilitated by the Russian authorities.
- The use of fatty acid compositions in blubber profiles may present a useful way to estimate the diets of seals and whales. The WG acknowledges, however, that there

are many questions that need to be answered by methodological studies before the method's usefulness can be assessed.

- For modelling purposes, the WG recommends that some process orientated studies be performed for the most important mammal predators, where collection of diet data is combined with simultaneous mapping of prey abundance.

Atlantic Canada

Stenson presented information on recent estimates of diet and consumption by Northwest Atlantic harp seals. Dramatic declines in the abundance of a number of groundfish species along the Atlantic coast of Canada were observed during the late 1980s and early 1990s. The largest of these was the stock of Atlantic cod found off the east coast of Newfoundland in NAFO Divisions 2J3KL ('Northern Cod'). Although commercial fishing was halted in 1992, this stock has failed to recover. A number of reasons for this failure have been postulated but a serious concern continues to be the impact of predation by harp seals. The first step in determining the potential impact of predation is to estimate the amount of Atlantic cod consumed by harp seals. Consumption of Atlantic cod by harp seals off the east coast of Newfoundland in NAFO Divisions 2J3KL was estimated in 2001 using data available up to the late 1990s. Since that time, considerable efforts have been made to update data on abundance, movements and diets in this area. Recent consumption by harp seals was estimated by integrating information on the numbers at age, age specific energy requirements, seasonal distribution and diet of harp seals in the Newfoundland area. Abundance was estimated using a population model integrating pup production between the late 1970s and 2004, annual estimates of reproductive rates from 1954-1998 and data on age specific removals from 1952-2008. Energy requirements of the population were estimated using a simple allometric model based on body mass obtained from monthly, sex-specific growth curves. The proportion of energy obtained in 2J3KL was estimated using data obtained from satellite telemetry and traditional tagging studies. The diet of harp seals in nearshore and offshore waters during winter (October – March) and spring (April – September) was determined by reconstructing the wet weight of stomachs collected in 1982 and 1986-2007. The impact of different diet determination methods was explored by estimating consumption based upon the proportion of cod in the diet obtained using a multinomial regression approach and fatty acid signatures. Uncertainty in the consumption estimates was approximated by incorporating the uncertainty in the numbers at ages, diets, energy requirements and seasonal distribution.

From these studies the total population of Northwest Atlantic harp seals was estimated to be 5.6 million (95% C.I. 3.9-7.2 m) in 2008. Of their total energy requirement, approximately 20% and 19% were obtained in the Newfoundland areas during the winter and spring periods respectively. Although specific diets varied with season, location, year and method of estimation, forage fish such as capelin, Arctic cod, sandlance (sandeel) and herring were the primary prey consumed. Incorporating data obtained from the reconstruction of stomach contents collected up to 2007 resulted in important changes in the average diet compared to previous estimates. Reduced proportions of American plaice and other pleuronectids were observed, along with lower proportions of Arctic cod in the near-shore diets and capelin in offshore diets. In contrast, higher proportions of shrimp were observed, particularly in the offshore, while the proportion of Atlantic cod was slightly higher. These changes were also observed when annual diets were estimated using a multinomial regression method. However, this method also resulted in estimates of appreciable proportions of Atlantic cod in the offshore diets. In contrast, diet estimates based on fatty acid signatures showed extremely low levels of Atlantic cod in the diet and none in offshore diets. Diets of seals collected in different areas and seasons obtained from fatty acids were more similar than those estimated from reconstructed hard parts, likely as a result of the longer integration period represented by this method. This method also resulted in higher estimates of sandlance (sandeel), redfish and amphipods, and lower estimates of Arctic cod, capelin and Atlantic herring in the harp seal diet.

Stenson continued that using these three methods of estimating diets resulted in very different estimates of cod consumption, although all were highly imprecise. Based upon the average diet obtained from reconstructed hard parts in the stomachs, consumption of Atlantic cod increased from approximately 40,000 tonnes in 1960 to over 80,000 tonnes by the mid 1990s. Since then it has remained relatively constant. Dividing the diet into northern and southern areas resulted in slightly higher estimates. Using the diet estimated from the multinomial regression method resulted in estimates of cod consumption approximately three times higher, primarily due to the higher proportion of cod in all components of the diet. Unlike the average diet, cod consumption is estimated to be increasing in recent years. In contrast to diets based on harp part analysis, only 1,000 tonnes of Atlantic cod are estimated to have been consumed by harp seals based upon the diets obtained from the fatty acid signatures. The length of cod consumed was estimated from the otoliths; samples collected in the 1980s and 1990s indicated that the vast majority of cod consumed were between 5 and 15 cm in length. Samples collected since 2000, however, indicate that larger cod have been consumed in recent years.

He went on to add that although these data indicate that considerable quantities of cod may be consumed by harp seals, this alone does not indicate their impact on the population dynamics of the 2J3KL cod stock. Other hypotheses have been proposed including reduced recruitment and / or survival due to reduced prey availability and / or food quality (i.e. lack of capelin), as well as fisheries catches and environmental effects. To explore the potential importance of these various hypotheses, a bioenergetic-allometric biomass dynamic model was constructed which incorporates seal predation, capelin availability, and fisheries catches as external drivers of the Northern cod dynamics. The model was fitted by maximum likelihood to the cod biomass fall survey index for the period 1985-2007, and different model configurations were compared using the Akaike Information Criterion corrected for sample size (AICc). In order to fully represent the high variability across estimates of cod consumed by harp seals, two different shapes for the trend in consumption were used. One assumes consumption by seals was that obtained from the average seal diet over time, and hence, the trend in consumption follows the seal population trajectory, while the other one assumed the consumption estimated from a multinomial regression approach to diet analysis (i.e. larger amounts with an increasing consumption over the entire study period). In addition, both consumption series were also allowed to scale up or down by fitting a scale parameter that multiplied them. All these alternative representations of seal consumption, plus the inclusion or removal of capelin and fisheries effects were used to define the scenarios explored. Overall, the best model to fit the data was one including capelin and fisheries catches, but without seal consumption. The differences in AICc between this model fit and the ones from other scenarios (all differences >10) indicated that all alternative models could be dismissed from further consideration. Based upon the results of this simple model, consumption of cod by harp seals does not appear to be an important driver of Northern cod during the study period. Instead, fisheries and availability of food appear to be the important drivers of the dynamics of this stock. Furthermore, these results indicate that a depressed capelin stock could be a serious impediment for cod rebuilding. The current model is being refined to determine if these preliminary results are supported.

Comments:

- It may be possible to determine diets using fatty acid signatures but the assumptions and biases inherent in this method need to be examined in more detail.
- Every method of diet determination has inherent biases; these must be identified and considered when interpreting the results.
- Using multiple methods of estimating diet is likely necessary to understand the true diet.
- The uncertainty associated with all inputs into the models used must be accounted for in a realistic manner.
- The level of precision required depends upon the questions being asked; determining precise estimates of consumption may not be necessary.
- The multinomial regression method for filling data gaps for diet studies appears to be more reliable for large sample size.

c) Other cetaceans and pinnipeds

Harp and hooded seals - Norway

Haug reported on a Norwegian project on harp and hooded seals in the North Atlantic. To enable an assessment of the ecological role of harp and hooded seals throughout their distributional range of the Nordic Seas (Iceland, Norwegian, Greenland Seas), a project was initiated in 1999 by members of the NAMMCO Scientific Committee. The project paid special attention to the period July-February period (i.e. between moulting and breeding), which is known to be the most intensive feeding period for both harp and hooded seals. Seals were collected for scientific purposes on expeditions conducted in the pack ice belt east of Greenland in September/October 1999, 2002 and 2003 (autumn), July/August 2000 (summer), and February/March 2001 and 2002 (winter).

During sampling in summer (July/August) in 2000 and winter (February/March) in 2001, harp and hooded seals were observed to co-occur in the sampling areas. This facilitated description and comparison of their diets (document SC/16/MMFI/O11). For hooded seals, the squid *Gonatus fabricii* and capelin were the dominant food items in winter 2001, but the summer 2000 diet comprised a mixture of this squid and polar cod. Pelagic amphipods (*Parathemisto libellula)* were most important for the harp seals during summer 2000, whereas in winter 2001 the contribution from krill and capelin were comparable to that of *Parathemisto*. Multivariate analyses revealed significant differences in the intestinal contents of hooded and harp seals in areas where the two species showed spatial overlap. Different foraging depths of the two seal species may have contributed to the observed differences in diets.

Haug added that studies of diving behaviour of harp and hooded seals in the Greenland Sea have revealed that both species usually perform more shallow dives during summer than during winter, and that hooded seals dive to deeper waters than harp seals in both these periods. Except for the youngest stages, which may occur in the upper water layers during summer, the major hooded seal prey *G. fabricii* has a typical mesopelagic distribution with occurrence mainly at depths greater than 400 m. This is in contrast to the distribution of the major food of harp seals: the observed krill and amphipod species are usually confined to the more upper water layers (<200m depth).

Results from analyses of stomach and intestinal contents of hooded seals captured during the entire study period revealed that the diet of the species was comprised of relatively few prey *taxa* (document SC/16/MMFI/O10). The squid *G. fabricii* and polar cod were particularly important, whereas capelin and sandeels contributed more occasionally. *G. fabricii* was the most important food item in autumn and winter, whereas the observed summer diet was more characterized by polar cod, though with important contribution also from *G. fabricii* and sandeels. The latter was observed on the hooded seal menu only during the summer period, while polar cod, which contributed importantly also during the autumn survey, was almost absent from the winter samples. During the latter survey, capelin also contributed to the hooded seal diet. Samples obtained in more coastal waters indicated a varied, fish based (polar cod, redfish, Greenland halibut) diet.

Haug informed the WG that during the 1999-2003 surveys to the Greenland Sea, blubber and muscle tissues were also secured from the captured harp and hooded seals. The sampled tissues were used for analyses of fatty acid profiles and stable isotopes (document SC/16/MMFI/O09). The application of fatty acids analysis combined with stable isotopes in food web studies in marine ecosystems is an efficient tool, as it reflects dietary intake and assimilation over longer time periods than stomach content analysis. The use of Fatty Acid Trophic Markers (FATM) to trace the energy transfer from phytoplankton to top predators is based on the observation that primary and some secondary producers synthesize characteristic fatty acids and that this fatty acid signal is conservatively transferred through food chains. Stable isotopes reveal information about food carbon sources and trophic position of the species. The stable isotopes ratios of carbon and nitrogen ($\delta^{13}C$ and $\delta^{15}N$) in consumer proteins and fatty acid signature in consumer lipids both reflect those of their prey. Even if the two seal species showed considerable overlap in diet and occur at relatively similar trophic levels, the fatty acid profile indicated that the base of the food chain of harp and hooded seals was different. The fatty acids of harp seals originated from diatom based food chain, typically for high Arctic ice-covered ecosystems. The fatty acids of hooded seals originated from dinoflagellate and the prymnesiophyte *Phaeocystis pouchetii* based food chain, which associates this species with more open Atlantic waters ecosystems.

Hooded seals – Canada

Stenson presented recent work on the diet of Northwest Atlantic hooded seals[21]. Reconstructing the stomach contents of hooded seals collect in the waters off the coast of Newfoundland and southern Labrador, Canada indicated that diets vary spatially and temporally. The main prey species in nearshore waters were squid (*Gonatus* sp.) and Greenland halibut, while the main prey species identified in a small sample of seals collected in offshore areas (n=40) were flatfish (Pleuronectidae), Atlantic cod and squid. Greenland halibut and redfish were also important prey.

The diet of hooded seals was also estimated using fatty acid signatures. Generally, the diets of adult males and females were similar, but differed from those of juveniles. During the pre-breeding period, adult hooded seals fed primarily upon redfish, amphipods, capelin and Atlantic argentine. Juveniles fed mainly upon capelin although argentine, sandlance (sandeel), amphipods and herring were also eaten. During the post breeding period, redfish were the most important prey for adult hooded seals. Lower proportions of capelin, argentine and long fin hake were also consumed. In contrast to data obtained from hard part analyses, fatty acids suggest that amphipods and argentine are important prey for hooded seals. The latter species has never been seen in the stomach contents although this may be due to its off-shelf distribution.

Impact of seals on Atlantic cod in Canada

Stenson presented document SC/16/MMFI/13. In the past two decades, virtually all of the stocks of Atlantic cod (*Gadus morhua*) in Atlantic Canada have collapsed. These stocks have shown little or no signs of recovery in spite of lengthy moratoria or reduced fishing. Many of these stocks continue to exhibit high levels of unexplained natural mortality. During this same period, populations of harp (*Pagophilus groenlandicus*), hooded (*Cystophora cristata*) and grey (*Halichoerus grypus*) seals in the area have increased significantly which has resulted in considerable speculation about the impact of seals on cod population dynamics. Workshops to review the evidence on impacts of seals on Atlantic cod stocks in eastern Canadian waters were held in Halifax November 12-16, 2007 and November 24-28, 2008. The first workshop reviewed what is known about seal-cod interactions and identified 1) gaps in our understanding, 2) analyses that could be completed for review at the second workshop, and 3) longer term research needs. The workshop report is available as CSAS Proceedings 2008/021. The second workshop reviewed additional analyses relevant to cod-seal interactions and examined evidence for and against various hypotheses for the cause of elevated natural mortality of cod. The report of this workshop is not yet completed, but preliminary conclusions are presented here.

---

[21] Tucker, S., Bowen, W.D., Iverson, S.J., Blanchard, W. and Stenson, G.B. 2009. Sources of variation in diets of harp (*Pagophilus groenlandicus*) and hooded (*Cystophora cristata*) seals estimated from quantitative fatty acid signature analysis (QFASA). *MEPS* (in press).

A small, but seasonally variable proportion (9-20%) of the grey seal population uses the 4X area. Grey seals presumably contribute directly to the mortality of 4X cod, but the level of this contribution is unknown due to a lack of diet data for 4X. Assuming the diet indicated by fatty acids for 4VsW, the effect would be negligible.

A large proportion of the Northwest Atlantic grey seal population used the 4VsW area throughout the year where they are known to consume cod. However, estimates derived from fatty acids indicate only a small fraction (~2%) of the diet is cod while historical estimates based on otoliths indicate that cod account for a higher (~12%) proportion. Based on diets estimated by fatty acids, grey seal predation is considered to be a minor factor in the lack of recovery of cod; however, given the uncertainties in the diet, a more important contribution to the lack of recovery cannot be ruled out.

There are temporal and spatial corrections between the abundance of grey seals and changes in natural mortality (*M*) of cod in the southern Gulf of St. Lawrence (4T). Estimates of consumption indicate that significant amounts of 4T cod are being consumed (10,000-12,000 tonnes) but the stomach content data indicate that the diet is dominated by fish smaller than 35 cm long which is inconsistent with *M* being high for larger adult cod. Although the causes of elevated *M* in this stock remain unknown, the hypothesis which cannot be eliminated is that predation by grey seals is an important cause of this elevated *M*.

Harp seals are estimated to consume 28,000 tonnes of 3Pn4RS cod, predominantly (56%) pre-recruits under 3 years of age. Grey seals were estimated to consume 14,000 tonnes of 3Pn4RS cod in 1996, with a preference for larger cod than harp seals (25-35 cm versus 10-15 cm). Modelling indicates harp seals could have significant impact on recruitment, under good conditions. Under poor oceanographic conditions other factors limiting recruitment are more important than harp seal predation.

Estimates of Atlantic cod consumption by harp seals in the 2J3KL area are imprecise and dependent on the diet assumed. There are indications of an increase in the amount of cod consumed by harp seals since the late 1980s, due primarily to increased occurrence of Atlantic cod in offshore diet samples. Modelling results are inconclusive. A mass-balance model developed in 2001 indicated that harp seals may have an impact on the recovery of 2J3KL cod, whereas a recent simple biomass model suggests that seal predation is not a significant factor in the lack of recovery to date. The recent model suggests that low productivity, as indicated by capelin abundance, is the major factor in failure of cod to recover.

The impact of seals on 3Ps cod has not been examined. Although harp seals are known to consume cod in this area, they are transient and resident for only short periods. The use of this area by other seal species (e.g. grey seals) appears to be relatively minor. Similarly, impacts of seals on 3NO cod are thought to be insignificant because relatively few seals use this area.

The impact of cetaceans on cod has not been examined. Significant numbers occur in many of these areas and although the diet of most cetaceans species in the region are unknown, data from harbour porpoise and cetaceans in other areas indicate that Atlantic cod are consumed. Therefore, the recovery of cod may be impacted by cetaceans with through direct predation or competition for food.

Fin whales - Iceland

Lockyer presented published data for fin whales based on research in Iceland in the period 1978 – 1985 (Lockyer, 1987a[22], 1987b[23], 2007[24]). She emphasised that the prey taken by baleen whales ranged from copepods to pelagic fish, and noted that despite the large size of fin whales, their feeding had been focused on the pelagic euphausiid *Meganyctiphanes norvegica* around Iceland for a consistently long period of time. There can be up to a threefold difference in energy density between some planktonic crustaceans and fish, so that fin whales are not feeding on optimum energy density prey. Referring to findings of Víkingsson (1992[25], 1997[26]) the daily consumption of euphausiids by fin whales of average size 18.6 m is 677 – 1,356 kg, based on passage time and full stomach of 500-600 kg. Pregnant females consume the most of all classes. Lockyer focused on the female 2-year cycle of reproduction and annual migration where concentrated feeding occurs every summer (June – September) in Icelandic waters for about 3-4 months. The difference in weight between the lean post-lactation female and pregnant female is about 18.5 t after 12 weeks of feeding, representing an energy density approaching 100 x 10^6 Kcal. This amount represents the cost of the two-year reproductive cycle (11 months' pregnancy and 6 months' lacatation) and would be met by a consumption of about 120 tonnes of euphausiids (Lockyer, 1987a[3]). This also emphasizes the importance of including estimation of consumption by age and maturity class in a population.

Lockyer pointed out the potential effects of temporal and spatial changes in feeding conditions and demonstrated the extreme variation in body mass (in terms of fat condition) between 1978 and 1985, with lows and highs directly correlated with euphausiid abundance in the area, and also reflected in ovulation / pregnancy rate in females. Lockyer pointed out the importance of acknowledging such variations in any ecosystem model. Finally, data were presented showing that poorer prey availability (thus affecting the female's feeding intensity and fat deposition) can have effects on the

[22] Lockyer, C. 1987a. The relationship between body fat, food resource and reproductive energy costs in North Atlantic fin whales (*Balaenoptera physalus*). *Symposium of the Zoological Society of London* 57, 343–361.

[23] Lockyer, C. 1987b. Evaluation of the role of fat reserves in relation to the ecology of North Atlantic fin and sei whales. In *Approaches to marine mammal energetics* (ed. A.C. Huntley et al.), pp. 183–203. Society for Marine Mammalogy Special Publication, no. 1.

[24] Lockyer, C. 2007. All creatures great and smaller: a study in cetacean life history energetic. *J. Mar. Biol. Ass. U.K.* (2007) 87, 1035–1045.

[25] Víkingsson, G.A. 1992. Feeding of fin whales off Iceland—diurnal variation and feeding rates. *Report of the International Whaling Commission* 42, 768.

[26] Víkingsson, G.A. 1997. Feeding of fin whales (*Balaenoptera physalus*) off Iceland—diurnal and seasonal variation and possible rates. *Journal of North East Atlantic Fisheries Science* 22, 77–89.

body weight of near-term foetuses (Lockyer, 1990[27]). In turn this could affect recruitment and survival of young in the whale population.

East Greenland Walrus

Acquarone presented a published work on walrus diet by Born *et al.* (2003)[28]. Food consumption of Atlantic walruses (*Odobenus rosmarus rosmarus* L.) was quantified by combining underwater observations of feeding with satellite-telemetry data on movement and diving activity. The study was conducted between 31 July and 7 August 2001 in Young Sound (74°N–20°W) in Northeast Greenland. On ten occasions, divers were able to accompany foraging walruses to the sea floor and collect the shells of newly predated bivalves (*Mya truncata*, *Hiatella arctica*, *Serripes groenlandicus*) for determination of number of prey and biomass ingested per dive. Simultaneously, the activity of a 1,200 kg adult male walrus was studied by use of satellite-telemetry during an entire foraging cycle that included 74 hr at sea followed by a 23 hr rest on land. An average of 53.2 bivalves were consumed per dive, corresponding to 149.0 g shell-free dry matter, or 2,576 kJ per dive. During the foraging trip, the walrus spent 57% of the time diving to depths of between 6 and 32 m, and it made a total of 412 dives that lasted between 5 and 7 min (i.e. typical foraging dives). If the entire feeding cycle is considered (97 hr), the estimated daily gross energy intake was 214 kJ per kg body mass, corresponding to the ingestion of 57 kg wet weight bivalve biomass per day, or 4.7% of total walrus body mass. Due to ice cover, walrus access to the plentiful inshore bivalve banks in the area is restricted to the short summer period, where walruses rely on these banks for replenishing energy stores.

General comments to all presentations under item 5c:

The WG welcomes the new information presented, and in particular the Icelandic data on minke whale diet, as well as the recent research in the North Pacific and Northwest Atlantic. However, the WG notes that in general, the degree of progress from the last meeting is not extensive and considerable amount of work still remains to be completed. Some new approaches to estimating diet appear promising but still required verification.

Regarding the request "*to review the results of the Icelandic programme on the feeding ecology of minke whales*" the WG commends the progress made in the analysis. However, the analysis is not yet completed and an overall review of the results must await the finalisation of the programme. The WG **recommends** that Iceland proceed swiftly with these analyses.

6. RECENT DEVELOPMENTS (IF ANY) IN THE ESTIMATION OF ENERGY CONSUMPTION

[27] Lockyer, C. 1990. The importance of biological parameters in population assessments with special reference to fin whales from the N.E.Atlantic. In, *Whaling Communities in the North Atlantic*, *North Atlantic Studies* 2(1 and 2):22-31.

[28] Born, E.W., Rysgaard, S., Ehlmé, G., Sejr, M., Acquarone, M. and Levermann, N. 2003. Underwater observations of foraging free-living Atlantic walruses (*Odobenus rosmarus rosmarus*) and estimates of their food consumption. *Polar Biol.* 26:348-357.

Isotope studies in walrus

Acquarone presented a published paper on the metabolic rates of walrus (Acquarone *et al.* 2006[29]). Although costly and difficult to apply, the double-labelled water (DLW) method is one of the few possible methods generating estimates of energy demands for unrestrained, free-living animals. The results of its application on two free-living adult, male, Atlantic Walruses (*Odobenus rosmarus rosmarus*), weighing 1,370 kg and 1,250 kg respectively (estimated from length and girth measures) were presented. These data extend the size range of the 7 pinniped species for which the DLW method has been applied by a factor of 10. The animals were measured at a site in northeast Greenland (76° N) during the summer. Field metabolic rate (*FMR*) was dependent on the pool model for estimating metabolic rate and was approximately 13% higher when using the single-pool compared with the two-pool model. The estimates using the two-pool model were 328.1 MJ•day^{-1} and 365.4 MJ•day^{-1} for each of the two walruses. These figures were combined with estimated *FMR* using the same method in 7 other pinniped species to derive a new, refined predictive equation for pinniped *FMR* of

1. $$Ln\,FMR\left[MJ * day^{-1}\right] = 0.173 + 0.816 * Ln\,Total\;Body\;Mass\left[kg\right]$$

This equation suggests that pinniped food requirements might sometimes be twice as high as often assumed in some fisheries models, which are based on multiples of the theoretical basal metabolism.

Isotope studies in harbour porpoise

Acquarone reported on an unpublished study in which he and colleagues had measured the *FMR* of an adult male harbour porpoise (40.5 kg) in human care by the labelled bicarbonate technique. The results estimated *FMR* to 22,285 kJ•day^{-1}. During the same period the porpoise was fed fish of approximately 26,000 kJ•day^{-1} in raw energy, corresponding to 8.5% of the animal's body weight. After taking into consideration losses by digestive and assimilation efficiency the results from the bicarbonate measure are remarkably similar and suggest that daily food ingestion rates for this species might be remarkably higher than the 4% of body weight customarily assumed for cetaceans (Sergeant, 1969)[30], but similar to the 7-9.5% body weight reported by Lockyer *et al.* (2003)[31] for porpoises.

Comments:

- The high metabolic rates observed in walruses and porpoises are results that should be taken in to account in considering metabolic rates for other species, particularly for harp seals (considering their population size).

---

[29] Acquarone, M., Born, E.W. and Speakman, J.R. 2006. Field Metabolic Rates of Walrus (*Odobenus rosmarus*) Measured by the Doubly Labeled Water Method. *Aquatic Mammals* 32(3):363-369.

[30] Sergeant, D.E. 1969. Feeding rates of *Cetacea*. *Fiskeridir. Skr. (Havunders.)* 15:246-258.

[31] Lockyer, C., Desportes, G., Hansen, K., Labberté, S. and Siebert, S. 2003. Monitoring growth and energy utilisation of the harbour porpoise (*Phocoena phocoena*) in human care. *NAMMCO Sci.Publ*. 5:107-120.

7. RECENT DEVELOPMENTS IN MULTI-SPECIES MODELLING

a) The SCENARIO model (*post-mortem*)

Schweder presented the SCENARIO BARENTS SEA project[32]. In this project, management of the marine ecosystem is regarded as a game played by the Government Agency against Nature. The quality of the management strategy is evaluated using models for the strategy taken by Nature. These models should be sufficiently realistic, but also practical to implement and investigate on a computer. Whaling and sealing in the Barents Sea are of little economic interest in themselves, but might impact some other fisheries positively. The model to evaluate strategies for whaling and sealing includes cod, herring, capelin, harp seals and minke whales, and emphasises interactions between these populations caused by predation. For proposed management strategies, the stochastic system is repeatedly simulated over 100 years, and the strategies are evaluated by the resulting cod, capelin and herring Total Allowable Catches (TACs) that are calculated from fixed rules. This line of study was first pursued in the 1990s with an emphasis on management strategies for cod, herring and minke whales. The model is structured with respect to area (7 regions) and length for fish (5 cm groups for cod), and has a time step of one month. The model is fitted piecewise to available data, and using published results. It was later improved particularly with respect to the spatial structure and migration, the estimation method, and the predation model. The estimation is conducted simultaneously for all the available raw data by maximizing the joint likelihood. Inspired from discrete choice models in economics, a logistic model was established for how the consumption need for each predator is distributed over the potential prey units. The fraction taken by a predator of each respective prey population depends also on the abundance in the region of all other prey populations. The model was also extended to include harp seals. There are some 5 million harp seals in the Barents Sea consuming cod, herring, capelin and other prey. Despite their importance as predators, data are scarce and possibly less than representative with respect to diet choice for harp seals. As it turned out, the model parameters were difficult to estimate. Having struggled to estimate recruitment- and mortality parameters by fitting the model to historical data, the fitted models were not satisfactorily balanced. When simulating the model, stock trajectories in some of the runs were implausible, and varied too much between runs compared to historical data. The project must be regarded as unsuccessful, as when harp seals were included, no comparative simulation experiments useful for management could be performed. The project might have been useful as a learning exercise, but more research is needed to establish a sufficiently credible model as would be needed for ecosystem management.

Comments:

---

[32] Schweder, T. 2006. The Scenario Barents Sea study: a case of minimal realistic modelling to compare management strategies for marine ecosystems. In: *Top Predators in Marine Ecosystems. Their Role in Monitoring and Management.*. Cambridge, UK.: Cambridge University Press. ISBN 978-0-521-84773-5. s. 310-323

1. Inclusion of the harp seal in the model made it difficult to estimate the parameters. This is most likely due to the weak data on harp seal feeding ecology, and the fact that the harp seal is a major top predator in the system.
2. The, probably sub-optimally, estimated model gave simulation results that were implausible in part. The model was simply not sufficiently stable. A possible reason for this is that important feedback mechanisms are lacking.
3. The WG considers that the model had many attractive features, both in its structure, and not the least in the functional response part, and in that a rather comprehensive handling of uncertainty was attempted. The *post-mortem* is unfortunate – it should rather have been a revival.
4. The WG underlines the importance of all modelling exercises even when the resulting model does not successfully reflect the actual situation. In the case of the Scenario Barents Sea project, elements of the model might be of value for other approaches.

b) Globally applicable Area-Disaggregated General Ecosystem Toolbox (GADGET) based models

Stefansson gave a presentation on the GADGET (Globally applicable Area-Disaggregated General Ecosystem Toolbox) based models as summarised below. GADGET is a fully parametric forward simulation model which can be used for parameter estimation. A simulation results in population trends by species, size class, age group, area and time step. These trends can subsequently be compared to data using appropriate likelihood functions, eventually minimizing a negative log-likelihood function to obtain parameter estimates.

Consumption within GADGET is modelled using suitability functions and mortality can be due either due to predation, other natural causes or fishing. Growth is implemented via movement up through length classes and can be based on consumption or growth functions, with several growth update mechanisms already available. Migration is implemented through movement matrices. In principle these can vary by time step, but in typical case studies they are assumed to be fixed in time. The species life cycle can be closed within GADGET, so the spawning component (or mature females) can generate a new year-class. The model is completely symmetric across species and areas so that e.g. a predator's behaviour is defined only through associated data sets and parameterisation.

Parameters are estimated using maximum likelihood. A number of likelihood functions have been implemented but recent work indicates that many common data sets defy the most common statistical assumptions. It has also been seen that model "stiffness" implies that too much weight given to a data source (i.e. incorrect likelihood function) can lead to widely varying population trends, which is in stark contrast to well-known results in linear statistical models where incorrect variance assumptions tend to be of minor significance.

Since GADGET is a parametric model, it can in principle run without data. For data-poor species, highly detailed models which require large numbers of parameters cannot be reasonably implemented and the modeller is forced to use simpler models with fewer parameters. For some marine species highly detailed data are available and these can then be used to fine-tune more detailed models.

Given the data requirements, it is obvious that if data are entered into GADGET data files by hand or using manual extractions from raw data bases, revisions of spatial aggregations or length groupings would require considerable revisions of the data files. For this reason a data warehouse has been defined in such a way that it consists of mildly aggregated data in standardized tables. Extraction routines for assessment purposes have been written along with extraction routines for GADGET.

Case studies include several species within Icelandic waters, the Barents Sea, the Celtic Sea, North Sea herring, the Tyrrhenian Sea and the Bay of Biscay. For each of these areas single or multispecies models have been implemented using GADGET with data extracted from standardized tables for each area.

Current implementations include several species within Icelandic waters (single species, single area and up through 3-species in 10 areas) and Barents Sea cod. In spite of known problems, the program is currently used for assessments in several cases where no alternatives exist to account for known important processes within the system.

Recent work includes obtaining apparently reliable bootstrap estimates of uncertainty, implementations of tagged sub-populations, development of new likelihood functions and closing the life cycle. Given the correlated nature of the measurements, the most promising approach to variance estimation appears to be bootstrapping of aggregates from the GADGET database.

Planned work includes setting up the GADGET data base for minke whales in Icelandic waters, based on the Marine Research Institute (MRI) data bases and developing initial simple models of the population dynamics based on earlier work with GADGET models for seals. Subsequently the minke whale model should be linked to updated models for cod, but it is not clear whether reasonable models for sand eels can be developed although this may be quite important.

Several sets of parameters can in principle be modelled as random effects rather than the traditional fixed effects. This has considerable potential and will be investigated.

c) Ecopath with Ecosim (EwE) models

Morissette presented document SC/16/MMFI/15. Food webs have always been considered as a central issue of ecology, and their value and usefulness are frequently discussed. Consequently, the comparability of different food webs is a key to possible applications. In that sense, comparative analyses based on a common modelling approach are of great interest. It was thus decided to use different *Ecopath with Ecosim* (*EwE*) models for these analyses. *EwE* is a software package which has become widely used for the analysis of exploited aquatic ecosystems. Currently, the software counts more than 2,800 registered users from approximately 120 countries. A good coverage based on the same modelling methodology is thus available throughout the world's oceans, and it is therefore possible to use models based on this approach to quantify and analyse the trophic interactions between marine mammals and fisheries.

In *EwE*, several systems' indices are computed to describe the food web, its complexity, and the way trophic groups interact with one another. The software also allows making dynamic simulations based on *Ecosim*, a dynamic modelling application for exploring past and future impacts of fishing and environmental disturbances. *Ecosim* converts the trophic flows of *Ecopath* into dynamic, time-dependent predictions (full details of the *EwE* modelling approach and equations are available from http://www.ecopath.org).

Morissette presented different approaches on how to quantitatively assess the impact of marine mammals in marine ecosystems. She had used the Mixed Trophic Impacts (MTI) routine from *EwE*'s network analysis to quantify direct and indirect interactions between all trophic groups in different food webs (examples are provided in Morissette et al. 2006[33], and other ecosystems were also presented). This routine assesses the direct and indirect interactions between species in the ecosystem and gives an ecosystem overview of the trophic interactions. In that sense, it represents an interesting tool for studying marine mammals-fisheries interactions. It synthesizes the effects that a small change in the biomass of a group will have on the biomass of other groups in a system (in other words, it shows if the presence of a predator is beneficial or detrimental to all the other species of the system). The approach is derived from Leontief economic input-output analysis, and quantifies all the direct and indirect trophic impacts of all groups in the system based on the assumption that the direct impact between group *i* and group *j* can be estimated from the difference between the proportion that group *i* contributes to the diet of group *j*, and the proportion that group *i* takes from the production of group *j* (see *EwE* user's guide on http://www.ecopath.org). The MTI for living groups is calculated by constructing a matrix, where the i,j^{th} element representing the interaction between the impacting group *i* and the impacted group *j* is:

2. $MTI_{ij} = DC_{ij} - FC_{j,i}$

where DC_{ij} is the diet composition term expressing how much *j* contributes to the diet of *i*, and $FC_{j,i}$ is a host composition term giving the proportion of the predation on *j* that is due to *i* as a predator. When calculating the host compositions, the fishing fleets are included as "predators". Beneficial predation is calculated as the percentage of the overall trophic impact by marine mammals, that is positive for any prey group of this predator. Although counter-intuitive, beneficial predation is frequent, due to the important indirect effects occurring in ecosystems.

[33] Morissette, L., Hammill, M.O. and C. Savenkoff. 2006. The trophic role of marine mammals in the Northern Gulf of St. Lawrence. *Marine Mammal Science* 22(1): 74-103.

The last part of Morissette's presentation referred to work in progress, regarding these indirect effects in marine ecosystems. Trophic interactions between marine mammals and fisheries have been the subject for considerable research during the last decade. However, the extent to which the issue is addressed in an ecosystem, multi-species context is still limited. Consequently, there is still a lack of unequivocal evidence for competition between marine mammals and fisheries on a global scale. This may be due to (1) the absence of appropriately scaled information on marine mammals' diet and ecology; (2) the lack of consideration of all trophic groups in the ecosystems where these interactions might happen; or (3) the indirect effects being more important than initially thought in food webs. Recent efforts to understand how interaction strengths affect both structure and dynamics in food webs have shown that the indirect effects have a fundamental importance in governing ecosystem dynamics. Thus, the use of an ecosystem approach integrating the whole range of trophic diversity (from plankton to marine mammals) is essential for assessing the true interactions between marine mammals and fisheries. SC/16/MMFI/15 (work in progress) will investigate the importance of indirect effects from 30 marine ecosystem models, and will assess the overall impact of marine mammals in these systems. Beneficial predation from marine mammals on their prey will be quantified and particular attention will be given to the magnitude of indirect effects in food webs. The structure and pathways allowing this to happen will be discussed, along with the importance of addressing the interactions between marine mammals and fisheries with a multi-species modelling approach.

Comments:

- *EwE* is a good tool for developing an overview of how the whole ecosystem works, and to address ecological questions. However, the *Ecopath* analysis has to deal properly with uncertainty before it could be considered for other uses. Consequently, there is a need for more uncertainty analyses for these models but these are rarely conducted.
- The proposed work on the indirect trophic effects is interesting and challenging. However, since there is no way to control the quality of input data in all the 30 models, reliability of the results of the meta-analysis becomes questionable. *Ecoranger* could be a way to impose the same sensitivity control to all models and show uncertainty on the results (indirect effects).
- There needs to be an investigation of how far down the indirect effects go, through the food webs. Estimating trophic effects by considering only a few species of marine mammals and fish (the top of the food web) might not capture the behaviour of trophic interactions in the ecosystem fully. Benthos and plankton, although further down the food web, might be important ecosystem components that must be examined in such trophic analyses.
- In order to use *EwE* for management advice, the models will have to address uncertainty better than in many cases so far.

<u>Developments based on Ecopath-with Ecosim</u>

Murase presented document SC/16/MMFI/09 by Mori *et al.* To evaluate the possible impact of whales (minke, Bryde's, sei and sperm whales) on Japan's fisheries resources, an initial ecosystem model of the western North Pacific is built using the

Ecopath-with *Ecosim* software. The impact of no harvesting and harvesting 4% of the whales for the coming 50 years on catch of the fisheries are investigated. When running the harvesting scenario, uncertainties in the functional response forms and trophic flow are considered. The results suggest that in average terms: 1) when minke, sei and Bryde's whales are all harvested by 4% of their biomass, an increase in catch is expected for most of the fish resources, indicating the effectiveness of harvesting several whale species simultaneously; and 2) when sperm whales are the only species that is harvested at 4% of its biomass annually, depending on the functional response form assumed for the species, the catch of neon-flying squid may increase. The main advantage in building such a model is that it allows quantitative evaluation of the possible effects of whaling on fisheries resources.

Comments:
The WG commended this interesting work, but noted that the *Ecopath* structure of this model is recognized to require some rebalancing. Moreover, it is important to add extensive uncertainty analysis to the estimates provided. The paper presented some exploration of uncertainty into the type of functional response assumed, but uncertainty in parameter inputs also needs to be incorporated.

d) Other types of modelling approach

Butterworth presented a summary of a multispecies model of the Antarctic ecosystem which he had co-authored with Mori (Mori and Butterworth 2006[34]). He first briefly summarised the history of human harvests of seals, whales, fish and krill in the Antarctic, and emphasised the central role played by krill. The background to the hypothesis of a krill surplus in the mid-20th century was described, and the information on population and trend levels that has become available since the postulation was first advanced was listed. The objective of the study had been to determine whether predator-prey interactions alone can broadly explain observed population trends without the need for recourse to environmental change hypotheses. The model developed included krill, four baleen whale (blue, fin, humpback and minke) and two seal (Antarctic fur and crabeater) species. The model commenced in 1780 (the onset of fur seal harvests) and distinguished the Atlantic / Indian and Pacific Ocean sectors of the Southern Ocean in view of the much larger past harvests in the former. Amongst the key inferences of the study are that: (i) species interaction effects alone can explain observed predator abundance trends, though not without some difficulty; (ii) it is necessary to consider other species, in addition to baleen whales and krill, to explain observed trends – crabeater seals seemingly play an important role and constitute a particular priority for improved abundance and trend information; (iii) the Atlantic / Indian Ocean sector shows major changes in species abundances, in contrast to the Pacific Ocean sector, which is much more stable; (iv) baleen whales have to be able to achieve relatively high growth rates in order to explain observed trends; and (v) Laws' estimate in 1977 of some 150 million tonnes for the krill surplus may be appreciably too high as a result of his calculations omitting consideration of density-dependent

[34] Mori, M. and Butterworth, D.S. 2006. A first step towards modelling the krill-predator dynamics of the Antarctic ecosystem. *CCAMLR Science* 13: 217–277.

effects in feeding rates. Further work on the approach awaits improved estimates of the time series of abundance of the major species in the ecosystem – an exercise currently being jointly conducted by the IWC and CCAMLR scientific committees.

Comments:
It was noted that this is a broad scale multispecies model, however there were a number of problems, in particular:
- Insufficient data on abundance and trends of key species such as crabeater seals.
- The somewhat arbitrary nature of the values accorded to the density-dependent mortality parameters introduced for each predator species.
- Might the incorporation of further species, particular ones with faster dynamics than whales and seals, qualitatively change predictions?
- Specification of a northern boundary, which has implications for the proportion of consumption by fin whales considered to occur in the region being modelled.

SeaStar, Bifrost and GADGET (Barents Sea)
Lindström presented different models applied to the Barents Sea with reference to documents SC/16/MMFI/O012, -O013, -O014, and -O015. The Barents Sea, with its relatively simple food web (low diversity) and long and detailed time series of data, provides an ideal setting to develop, calibrate and compare multi- and extended single species models. The current modelling approaches in the Barents Sea, including multispecies interactions, range from extended single species assessment models to detailed age-length structured multispecies models. The models presented were SeaStar (Tjelmeland and Lindstrøm 2005[35]), Bifrost and GADGET (Lindstrøm *et al.* 2008[36]).

SeaStar is an extended single species assessment model, developed for the assessment of Norwegian Spring spawning herring, which has incorporated the predation by minke whales. The estimated consumption is included in the objective function and the parameters determining the modelled consumption are estimated together with other free parameters of the model in a single operation. From an ecosystem perspective it is important to be able to separate the total natural mortality into different mortality components. The modelling results suggest that minke whales can inflict major mortality on adult and juvenile herring and that minke whales display a type III functional response.

Fish stocks are generally managed on a strictly single species basis. One exception is the assessment model of capelin in the Barents Sea (Bifrost), in which predation on pre-spawning and juvenile capelin by cod and juvenile herring, respectively, is accounted for. Bifrost, in which species are structured by age, length and maturity, can potentially serve as a simulator where the herring-cod-capelin harvesting control rules

[35] Tjelmeland, S. and Lindstrøm, U. 2005. An ecosystem element added to the assessment of Norwegian spring-spawning herring: implementing predation by minke whales. *ICES J. Mar. Sci.* 62: 285-294.
[36] Lindstrøm, U., Smout, S., Howell, D. and Bogstad, B. 2008. Modelling multispecies interactions in the Barents Sea with special emphasis on minke whales, cod, herring and capelin. *Deep Sea Research* II: Topical Studies in Oceanography. *In Press.*

can be studied. Presently, the predation on cod and capelin by harp seals has been included in the model. Preliminary results indicate that harp seals have considerable impact on the capelin stock. By running two harp seal abundance scenarios, one with the stock being constant at the present level and another with the stock being constant at 50% of the present level, indicate that the maximum long-term catch of capelin is sensitive to number of harp seals in the Barents Sea; a reduced harp seal population generated a 100% greater maximum long-term catch of capelin.

More recently, an age-length structured multispecies model (GADGET) has been parameterised for the Barents Sea ecosystem. The species modelled are cod, capelin, herring and minke whales with minke whales and cod as predators, and capelin, herring and cod as prey. The model has been fitted to historical data and then been used to examine possible effects of a number of plausible biological and fisheries scenarios in hind casting and in the future. Indirect effects are shown to be important in the Barents Sea; cod fishing pressure, cod cannibalism and whale predation on cod having an indirect impact on capelin, emphasising the importance of multi-species modelling in understanding and managing ecosystems.

Comments:

- The model reproduces well the historical patterns of fish stocks.
- It was noted that details of modelled fishing, stock dynamics and predation can be provided.
- The model can be projected into the future.
- There is the potential to include uncertainty in model projections.

Statistical regression approach

Hjermann presented a review of some population models developed for the Barents Sea (Hjermann *et al.* 2004a[37],b[38], Hjermann *et al.* 2007[39]). These models concentrate on the two large fish stocks: Northeast Arctic cod and Barents Sea capelin, and the interactions between these fish stocks and Norwegian Spring-spawning herring, as well as effects of climate. They used a statistical regression approach based on age-specific abundance (and possibly mean length). The results give some insight into the dynamics and the importance of variation in different processes.

In the authors' view the model reflects good explanatory power for historical data. The main disadvantage of this approach is that it is basically a correlation approach, and

[37] Hjermann, D. Ø., Ottersen, G. and Stenseth, N.C. 2004a. Competition among fishermen and fish causes the collapse of Barents Sea capelin. *Proceedings of the National Academy of Sciences (USA)* 101:11679–11684.
[38] Hjermann, D. Ø., Stenseth, N. C., and Ottersen, G. 2004b. The population dynamics of North-east Arctic cod through two decades: an analysis based on survey data. *Canadian Journal of Fishery and Aquatic Science* 61:1747–1755.
[39] Hjermann, D.Ø., Bogstad, B., Eikeset, A. M., Ottersen, G., Gjosaeter, H. and Stenseth, N.C. 2007. Food web dynamics affect Northeast Arctic cod recruitment. *Proceedings of the Royal Society B* 274:661–669.

correlations tend to break down at some point in time. Also, it is based on survey data – in contrast to VPA, it cannot be used if only catch-at-age data are available. Also, nothing stops it from breaking fundamental biological principles (mass-balance, physiology, etc.).

Comments:

- The WG considered that this approach is useful for understanding the past, but in its current implementation (separately estimated regression models), it is not a good tool for simulating the results of applications of different management scenarios in the future.
- The parameters were fitted for each sub-model (abundance or length at a specific age) separately. This method is not the optimal statistical methodology. Also, there are estimation errors on both sides of each equations; this is not taken into account.
- The model should be developed into a state-space model with simultaneous fitting of parameters; this would also allow realistic bounds to be placed on parameter values. Such a model could be used to simulate the results of applying different management scenarios in the future.

8. RECOMMENDATIONS FOR FUTURE RESEARCH

a) Diet

The WG recognized the potential of Fatty Acid (FA) analysis for the determination of both qualitative and quantitative aspects of the diet of marine mammals. The advantage of this method compared to the analysis of stomach contents relate to the longer integration time. However, the methodology has to be further developed and validated as there are indications that the assimilation rates of prey fatty acids in the blubber may vary among species and among fatty acids. Furthermore, another aspect which needs to be investigated is the destination of the dietary fatty acids in the blubber profile and the differential utilization of the blubber profile by the animal.

The **WG therefore recommends** further investigations on:

- FA assimilation times, modes and location in the blubber
- Differential utilisation of different FA.

Based on the developments mentioned under item 6, the **WG recommends** that further investigations on energy consumption should be initiated in particular for harp seals.

The **WG further recommends** the regular gathering of data on predator and prey distribution and density, as well as diet data. Account should be taken of the fact that energy content of prey items varies in time.

The **WG also recognizes** that there is lack of information on the location of foraging grounds during part of the year for some species (e.g. minke whales) and **recommends** that further information be gathered as soon as possible.

b) Modelling

The multispecies modelling required for addressing management questions such as the impact on allowable catch levels for some commercial fish species of changes in the abundance of certain marine mammal populations is complex.

In some circumstances different models, whose merits cannot be distinguished given existing data, can provide very different answers to such a question. Thus **the only basis** on which scientific advice on such management questions could potentially be provided with confidence is if the outputs from a number of quite different models were in broad qualitative agreement in their predictions of the impact of possible management actions. Thus, for example, to advise reliably that an increased take of a marine mammal would lead to greater potential yield from a commercial fish species would require that:

a) the confidence / probability ranges about estimates of such an increased yield were entirely positive for a model and associated sensitivity tests;
b) furthermore, this held true not only for one but for a majority of different plausible models.

Carrying through such a multi-model exercise to conclusion will be possible only for a coordinated and funded multi-year project. The **WG recommends** that the NAMMCO Scientific Committee endorses and motivates for funding support for such a coordinated modelling effort.

This effort would need to include at least 3 different modelling approaches. Possible candidates, together with group leaders were identified as:

- Minimal realistic model implemented using GADGET (Stefansson)
- *Ecopath with Ecosim* (Morissette)
- Time series regression (Hjermann)

It was suggested that a simple biomass-based model such as one recently applied in eastern Canada should also be considered, and that model structures should allow for the possibility of multiple stable equilibria in the absence of exploitation.

If the models give qualitatively different predictions this could provide the basis to determine the factors giving rise to such different predictions, and hence indicate the risk of being wrong in choosing a certain management scenario, and also designate direction to future research to resolve uncertainties about those particular factors. The first phase of the work would involve fitting the different models to the available data and comparing their projection results. Ideally, in a second stage, the models could each be subjected to common simulation testing for an indication of which might be providing the more reliable results.

The exercise should be carried out for a single area, or two areas if resources are sufficient. Candidates put forward were the Barents Sea and the region around Iceland.

The pros and cons of each of these two areas will need to be listed for the consideration of the Scientific Committee.

c) Other recommendations

There were no other recommendations.

9. NORTHWEST ATLANTIC HARP SEALS – REQUEST FOR ADVICE RE. GREENLAND SUMMERING HARP SEALS

Rosing-Asvid presented document SC/16/MMFI/12 which described the catch history of harp seals in Greenland and showed that catches are strongly correlated with the size of the Northwest Atlantic harp seal population. The correlation was exponential for catches south of the ice edge (67°N), where both the number of seals and the duration of their stay increased when the population increased. More seals are seen late in the season and in recent years, whelping has been observed along the coast.

A reduction in the harp seal population from N_{max} (5.9 million) by 30% (4.1 million) would reduce the population to levels last seen in the early 1990s, when catches in Southwest Greenland were about 50% below the current level. Reduction by 50% (2.95 million) would bring the population back to the 1983 level, when the catches in Southwest Greenland were about 5% of current levels.

Rosing-Asvid added that high catch numbers and the observation of seals whelping off West Greenland is a pattern that also existed prior to the commercial sealing. Other species have also reverted to a previously existing distribution pattern during the recent decades. The number of polar bears caught along the Greenlandic west coast increased from close to zero during the 1970s and early 1980s to more than 100 polar bears in some of the years before a quota system was introduced after 2005. Bowhead whales increased in the same period from being extremely rare in the 1980s to a point estimate of more than 1,200 in 2006 in the Disko Bay area and humpback whales and fin whales have also increased strongly. The paper discussed how a change of the harp distribution might influence the ecosystems and thereby potentially have influenced the distribution patterns of other species.

Comments:

- In response to the request *"to evaluate how a projected decrease in the total population of Northwest Atlantic harp seals might affect the population of animals summering in Greenland"* the WG agreed that there were clear positive correlations between catches of harp seals off Northwest and Southwest Greenland and abundance estimates of these seals off Canada. Hence if numbers off Canada decreased, it is likely that the catches off Greenland would also decrease.

- Estimating the magnitude of a decrease in the Greenland catch for a given drop in abundance off Canada is, however, less straightforward. If one wishes to attempt estimating this relationship, this should be done through multi-linear regression analysis which takes account, at least, of any information available on annual hunting effort and periods for which the seals stay off Greenland, as well as the Canadian abundance estimates. This would also allow the calculation of confidence limits associated with any estimate of a decrease in catch.

10. WORKPLAN

Diets
Regular meetings, perhaps on a biennial basis, should be held to review progress on dietary studies.

Modelling
Should the coordinated modelling exercise be endorsed by the Scientific Committee and NAMMCO, the key steps in the project development would be:

1) A meeting to compile detailed proposals and budgets; leaders of the different modelling terms would be essential participants. To be held before the end of 2009.
2) A data oriented meeting – common data would need to be carefully pre-agreed to ensure that the results from the different models were comparable.
3) A meeting of the modelling groups to critically compare and suggest improvements to their first attempts to fit their models to the data.
4) A meeting at which final model results are tabled for consolidation, and draft consequent management-related recommendations are developed.

Two years would probably be a realistic time-span for the whole process. It might be possible to combine meetings 1) and 2) above into one.

11. OTHER BUSINESS

There was no other business

12. ADOPTION OF REPORT

The draft report was approved in a preliminary form at the closing of the meeting and was circulated for approval by correspondence. The final draft was approved by correspondence.

Appendix 1

AGENDA

1. OPENING REMARKS
2. ADOPTION OF AGENDA
3. APPOINTMENT OF RAPPORTEUR(S)
4. REVIEW OF AVAILABLE DOCUMENTS
5. RECENT DEVELOPMENTS IN THE QUANTITATIVE DESCRIPTION OF MARINE MAMMAL DIETS
   a) Minke whales
   b) Harp seals
   c) Other cetaceans and pinnipeds
6. RECENT DEVELOPMENTS (IF ANY) IN THE ESTIMATION OF ENERGY CONSUMPTION
7. RECENT DEVELOPMENTS IN MULTISPECIES MODELLING
   a) The SCENARIO model (*post-mortem*)
   b) GADGET-based models
   c) ECOPATH-ECOSIM models
   d) Other types of modelling approach
8. RECOMMENDATIONS FOR FUTURE RESEARCH
   a) Diet
   b) Modelling
   c) Other recommendations
9. NORTHWEST ATLANTIC HARP SEALS – REQUEST FOR ADVICE RE. GREENLAND SUMMERING HARP SEALS
10. WORKPLAN
11. OTHER BUSINESS
12. ADOPTION OF REPORT.

Appendix 2

LIST OF DOCUMENTS

Document	Title	Presenting author
SC/16/MMFI/01	List of Documents	Secretariat
SC/16/MMFI/02	Draft Agenda	Chair
SC/16/MMFI/03	List of participants	Chair, Secretariat
SC/16/MMFI/04	Diet of of common minke whales (*Balaenoptera acutorostrata*) in Icelandic waters during 2003-2007. Preliminary results.	Gísli Víkingsson
SC/16/MMFI/05	Regression-based models of the Barents Sea ecosystem	Dag Hjermann
SC/16/MMFI/06	Prey consumption and feeding habits of common minke, sei and Bryde's whales in the western North Pacific (presentation)	Hiroto Murase
SC/16/MMFI/07	Prey consumption and feeding habits of common minke, sei and Bryde's whales in the western North Pacific (paper)	Hiroto Murase
SC/16/MMFI/08	Development of and ecosystem model of the Western North Pacific (presentation)	Hiroto Murase
SC/16/MMFI/09	Development of and ecosystem model of the Western North Pacific (paper)	Hiroto Murase
SC/16/MMFI/10	Prey preferences of minke, Bryde's and sei whales in the offshore component of JARPN II from 2002 to 2007 (presentation)	Hiroto Murase
SC/16/MMFI/11	Prey preferences of common minke (*Balaenoptera acutorostrata*), Bryde's (*B. edeni*) and sei (*B. borealis*) whales in offshore component of JARPN II from 2002 to 2007 (paper)	Hiroto Murase
SC/16/MMFI/12	How do changes in the West Atlantic harp seal population affect the number of harp seals summering in Greenland?	Aqqalu Rosing-Asvid
SC/16/MMFI/13	The Current State of Knowledge of Seal-Fisheries Interactions in Atlantic Canada	Garry Stenson

SC/16/MMFI/14	Marine mammals - fisheries interactions: the role of ecosystem modelling to capture ecological complexity	Lyne Morisette
SC/16/MMFI/O01	Report of the WG on the Economic Aspects of Marine Mammal – Fisheries Interactions, 16-17 February 2000, Copenhagen	
SC/16/MMFI/O02	Report of the Workshop on Marine Mammals: from Feeding Behaviour or Stomach Contents to Annual Consumption – What are the Main Uncertainties? Tromsø, 26 - 28 September, 2001	
SC/16/MMFI/O03	Report of the workshop on Modelling Marine Mammal – Fisheries Interactions in the North Atlantic, Reykjavik, 13 - 15 September, 2002	
SC/16/MMFI/O04	Report of the WG on Marine Mammals and Fisheries in the North Atlantic: Estimating Consumption and Modelling Interactions, Oslo, 22-24 October, 2004	
SC/16/MMFI/O05	Report of the *Ad Hoc* WG on Enhancing Ecosystem-based Management, Copenhagen, 3-4 December 2003	
SC/16/MMFI/O06	Report of the *Ad Hoc* WG on Enhancing Ecosystem-based Management, Aberdeen, 20-21 September 2005	
SC/16/MMFI/O07	Relative abundance and size composition of prey in the common minke whale diet in selected areas of the northeastern Atlantic during 2000-04	Tore Haug
SC/16/MMFI/O08	Food webs and carbon flux in the Barents Sea	Tore Haug
SC/16/MMFI/O09	Transfer of lipids from plankton to blubber of harp and hooded seals off East Greenland	Tore Haug
SC/16/MMFI/O010	Diets of hooded seals (*Cystophora cristata*) in coastal waters and drift ice waters along the east coast of Greenland	Tore Haug

SC/16/MMFI/O011	Feeding habits of harp and hooded seals in drift ice waters along the east of Greenland in summer and winter	Tore Haug
SC/16/MMFI/O012	Prey consumption by Barents Sea harp seals in the period 1990-2005	Ulf Lindström
SC/16/MMFI/O013	An ecosystem element added to the assessment of Norwegian Spring-spawning herring: implementing predation by minke whales	Ulf Lindström
SC/16/MMFI/O014	Multispecies functional response of the minke whale *Balaenoptera acutorostrata* based on small-scale foraging studies	Ulf Lindström
SC/16/MMFI/O015	Modelling multi-species interactions in the Barents Sea ecosystem with special emphasis on minke whales and their interactions with cod, herring and capelin	Ulf Lindström
SC/16/MMFI/O016	Role of predation by harp seals *Pagophilus groenlandicus* in the collapse and non-recovery of northern Gulf of St. Lawrence cod *Gadus morhua*	Garry Stenson
SC/16/MMFI/O017	Current Research on the Impact of Pinnipeds on Commercial Fish Stocks in the Northwest Atlantic	Garry Stenson
SC/16/MMFI/O018	Proceedings of the National Workshop on the Impacts of Seals on Fish Populations in Eastern Canada (Part 1), Halifax, Nova Scotia, 12-16 November 2007	Garry Stenson
SC/16/MMFI/O019	The trophic role of marine mammals in the northern Gulf of St Lawrence	Lyne Morisette

5.8
REPORT OF THE NAMMCO WORKING GROUP ON MARINE MAMMALS AND FISHERIES IN THE NORTH ATLANTIC: ESTIMATING CONSUMPTION AND MODELLING INTERACTIONS

Mario Acquarone
North Atlantic Marine Mammal Commission - NAMMCO
P.O. Box 6453 Sykehusveien 21-23
N-9294 Tromsø
Norway.
Tel: +47 77687373
Fax: +47 77687374
mario@nammco.no

Doug Butterworth
Dept of Mathematics & Applied Mathematics
University of Cape Town
Rondebosch, 7701
South Africa.
Tel: +27 21 650 2343
Fax: +27 21 650 2334
Doug.Butterworth@uct.ac.za

Geneviève Desportes
Faroese Museum of Natural History
c/o GDnatur
Stejlestræde 9, Bregnør
DK-5300 Kerteminde
Denmark.
Tel: +45 65321767
genevieve@gdnatur.dk

Bjarki Elvarsson
Marine Research Institute
PO Box 1390
121 Reykjavík
Iceland.
bthe@hafro.is

Thorvaldur Gunnlaugsson
Marine Research Institute
PO Box 1390
121 Reykjavík
Iceland.
Tel.: +354 5331363
Fax: +354 5623 790
thg@hafro.is

Tore Haug
Institute of Marine Research
PO Box 6404
N-9294 Tromsø
Norway.
Tel: +47 77609727
Fax: +47 77609701
toreha@imr.no

Dag Hjermann
University of Oslo
P.O.Box 1066
Blindern
N-0316 Oslo
Norway.
Tel: +47 22854795
Mobile +47 97655636
d.o.hjermann@bio.uio.no and dag.hjermann@gmail.com

Ulf Lindstrøm
Institute of Marine Research
PO Box 6404
N-9294 Tromsø
Norway.
Tel: +47 77609728
Mobile +47 91515669
ulf.lindstroem@imr.no

Christina Lockyer
North Atlantic Marine Mammal Commission - NAMMCO
P.O. Box 6453 Sykehusveien 21-23
N-9294 Tromsø
Norway.
Tel: +47 77687372
Fax: +47 77687374
christina.lockyer@nammco.no

Addresses

Lyne Morissette
University of Guelph & Institut des Sciences de la Mer de Rimouski (UQAR-ISMER)
310 Alléedes Ursulines
C.P.3300
Rimouski QC
G5L 3A1
Canada.
Tel: +1 418 723 1986 #1981
Fax: +1 418 724 1842
lyne.morissette@globetrotter.net

Hiroto Murase
Institute of Cetacean Research
4-5 Toyomi-cho, Chuo-ku,
Tokyo 104-0055
Japan.
Tel: +81 3 35366576
Fax: +81 3 35366522
murase@cetacean.jp

Droplaug Olafsdottír
Marine Research Institute
PO Box 1390
121 Reykjavík
Iceland.
Tel: +354 5520 240
Fax: +354 5623 790
droplaug@hafro.is

Aqqalu Rosing-Asvid
Greenalnd Institute of Natural Resources
P.O.Box 570
DK-3900 Nuuk
Greenland.
Tel: +299 36 12 00
Fax: +299 36 12 12
aqqalu@natur.gl

Tore Schweder
University of Oslo
P.O.Box 1095
Blindern
N-0317 Oslo
Norway.
Tel: +47 95142380
Fax: +47 22855035
tore.schweder@econ.uio.no

Gunnar Stefansson
Marine Research Institute
PO Box 1390
121 Reykjavík
Iceland.
Tel: +354 5255915
gstefans@gmail.com

Garry Stenson
Northwest Atlantic Fisheries Centre
Dept Fisheries & Oceans
P.O. Box 5667
St. John's
Newfoundland A1C 5X1
Canada.
Tel: +1 709 7725578
Fax: +1 709 7724188
garry.stenson@DFO-MPO.GC.CA

Gísli Víkingsson
Marine Research Institute
PO Box 1390
121 Reykjavík
Iceland.
Tel: +354 5752000
Fax: +354 5752001
Gisli@hafro.is

Lars Walløe (Chair)
University of Oslo
P.O. Box 1103 Blindern
Sognsvannsveien 9
N-0317 Oslo
Norway.
Tel: +47 22 85 12 18
Fax: +47 22 85 12 49
lars.walloe@basalmed.uio.no