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PREVIOUS, CURRENT AND FUTURE MONITORING AND MANAGEMENT OF COMMON MINKE WHALES IN NORWAY

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ABSTRACT

An account of the historical, current and possible future management of common minke whales in Norway is presented. The current management is based on an approach very similar to the International Whaling Commission's Revised Management Procedure (RMP) and requires historical and current catch statistics, together with new abundance estimates with associated variance estimates every six years. The abundance estimates are based on visual sampling online-transect sighting surveys with two independent observer platforms. These surveys are no longer economically viable with the current limited commercial harvest. Alternative methods for obtaining abundance estimates are discussed, including a simpler sighting survey design and genetic mark-recapture methods. The RMP requires Implementation Reviews desirably every six years, which take into account all new information available. The associated simulation trials are very technical and complex, and few experts have the insight to run these simulation tests. Simpler alternatives to the current Implementation Reviews are discussed. The objective is to develop more economically viable methods for abundance estimation and a simpler procedure for catch limit calculation without compromising the sustainability of the harvest. Any new procedure for abundance estimation and catch limit calculations will be submitted to the International Whaling Commission Scientific Committee for discussion.

Keywords: Common minke whales, Northeast Atlantic, harvest, monitoring, abundance, ecology, assessment, management

INTRODUCTION

Research and monitoring of key commercially harvested marine mammal species such as common minke whales (*Balaenoptera acutorostrata*) in Norway have been conducted for the past four decades (e.g., Skaug et al., 2004; Haug et al., 2011; Solvang et al., 2021). Most of this work has focussed on obtaining information required for population assessments and modelling, in order to provide management advice to the Norwegian government. While efforts have also been made to collect information aimed at better describing the role of these species as predators in marine ecosystems in the Northeast Atlantic, Norwegian Sea, Barents Sea and Greenland Sea (Haug et al., 1995, 1996, 2002; Lindstrøm & Haug, 2001; Windsland et al., 2007; Bogstad et al., 2015; Meier et al., 2016; Solvang, et al., 2017, 2022), this topic has nevertheless received less focus than the explicit assessment-related activities.

Given the relatively modest size of current commercial harvest of marine mammals in Norway, it could be argued that there is a mismatch between current budgetary priorities and existing knowledge gaps. Specifically, many marine mammal species are important top predators in marine ecosystems and may respond appreciably to ecosystem perturbations caused by e.g., environmental change or changes in commercial fisheries. Conversely, changes in marine mammal harvests may also affect top-down control on marine ecosystems from changing predation pressures, including effects on important commercial fish stocks. Given recent dramatic changes observed in the marine environment and ecosystems, and an increasing emphasis on an ecosystems approach to monitoring and management, it is timely to carry out a re-appraisal of the current "status-quo" in marine mammal monitoring and research activities undertaken in Norwegian and adjacent waters. For harp seals (*Pagophilus groenlandicus*), one of the ecologically most important as well as hunted species in Norwegian and adjacent waters (Bogstad et al., 2015; Skern-Mauritzen et al., 2022), such a re-appraisal has already started (Øigård et al., 2014; Haug & Biuw, 2023).

In the current study, we first review the management history and current management, monitoring and assessment frameworks for common minke whales (*Balaenoptera acutorostrata*), another ecologically important marine mammal species in Norwegian and adjacent waters (Skern-Mauritzen et al., 2022). Common minke whales occur in the entire North Atlantic during the Northern hemisphere summer months, limited in their northern range by the ice (Jonsgård, 1966). Although their winter distribution and thus the location of breeding areas is unknown, they probably fit the general ecological pattern of baleen whales in the Northern hemisphere and migrate to lower latitudes, inhabiting temperate and tropical waters where mating and birth of calves takes place (Stewart & Leatherwood, 1985). As distinct breeding populations have not been identified for the species, stocks have primarily been specified by way of management units chosen on the basis of knowledge about catching grounds during the history of exploitation. Recent genetic analyses have revealed a probable panmictic common minke whale population across the Northeast Atlantic (Quintela et al., 2014); however, little is known about migration routes and habitat use other than that there is a strong geographical segregation

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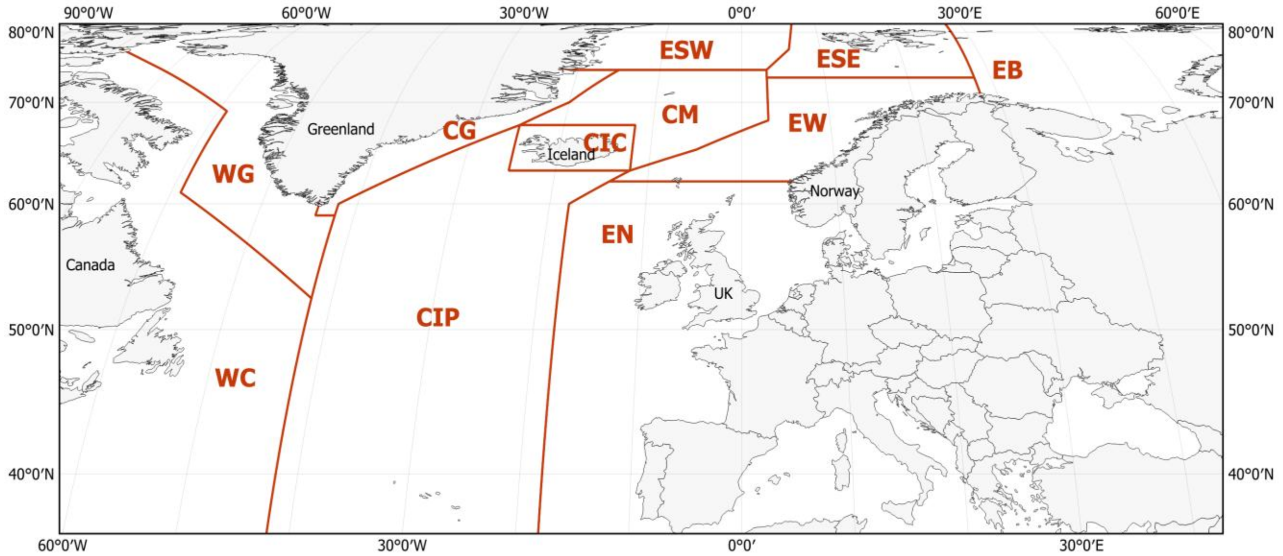

Figure 1. Area divisions used in the implementation of Revised Management Procedure (RMP) based management of North Atlantic minke whales. The Large Area *North Atlantic* is divided into three Medium Areas: Western North Atlantic (W), Central Atlantic (C) and Eastern Atlantic E. The Medium Areas are further divided into 11 Small Areas where the first letter in the label indicates to which Medium Area they belong (from International Whaling Commission, 2011).

related to sex and total length (proxy for age) in the feeding areas.

species has been the focus of comprehensive monitoring and assessment programs in Norway for the past three to four decades. In this paper, we identify current knowledge gaps that limit our ability to provide important management advice, particularly within an ecosystem management framework. Furthermore, we identify areas where new methodology has the potential to streamline and optimise the monitoring and assessment work; and finally, we suggest how the resources released could be put to better use for addressing the knowledge gaps identified.

COMMERCIAL HARVEST

Common minke whales are still harvested in appreciable numbers, and their management is regulated under a variant of the Revised Management Procedure (RMP) developed by the Scientific Committee (SC) of the International Whaling Commission (IWC) (International Whaling Commission, 1994). The RMP implements as a precautionary tool the concept of Large, Medium and Small Areas (Figure 1) for North Atlantic minke whales. While Large Areas usually correspond to larger ocean areas covering the range of biological stocks of a species (for example minke whales in the North Atlantic), Small Areas are:

> Disjoint areas small enough to contain whales from only one biological stock, or be such that if whales from different biological stocks are present in the Small Area, catching operations would not be able to harvest them in proportions substantially different to their proportions in the Small Area. (International Whaling Commission, 2012a, p. 485)

Medium Areas "correspond to known or suspected ranges of distinct biological stocks" (International Whaling Commission, 2012a, p. 485). Catch-limits are given at the Small Area level and can be calculated using a combination of areas.

The common minke whale hunt in Norway started around 1920 (Jonsgård, 1992). The products were meat and fat intended for human consumption. In 1938, a licensing system was introduced with subsequent availability of catch records including numbers taken (Figure 2) and catch positions of each whale caught (Figures 3 and 4). Whaling for minke whales started as a pure coastal operation, but the high participation and catch rate probably depleted the stock locally and during the 1960s an expansion occurred westwards to other new areas around Iceland, the Denmark Strait, and East and West Greenland. Around 1970 explorative expeditions were made to the mid-Atlantic ridge and Newfoundland (see Haug et al., 2011). The catches taken in distant waters were, however, relatively small.

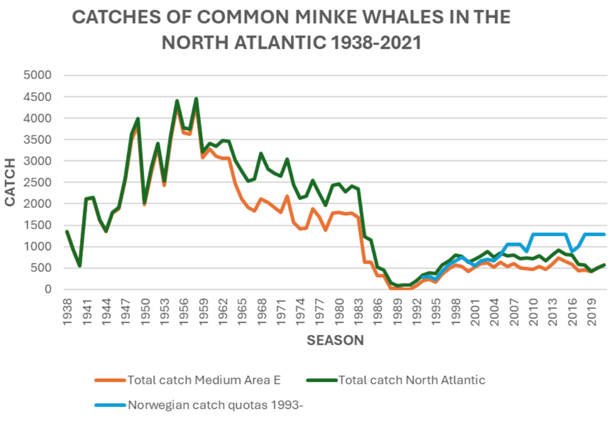

Figure 2. Norwegian catches of minke whales in the North Atlantic. Medium area "E" includes all the small areas ESW, ESE. EB, EW and EN (where only Norway has been hunting minke whales) shown in Figure 1. The Norwegian catch limits after resumption of commercial whaling in 1993 are also shown.

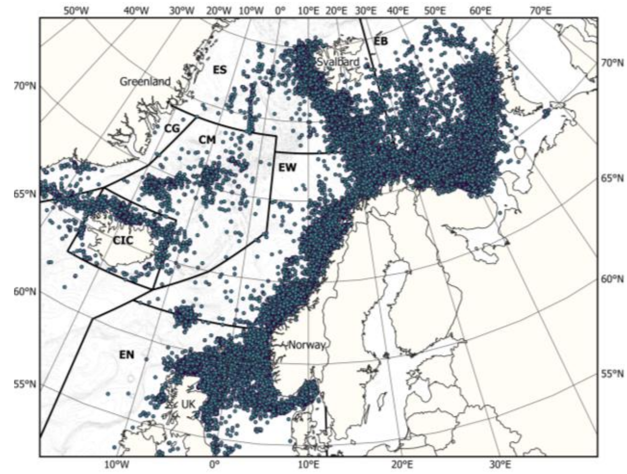

Figure 3. Geographical distribution of Norwegian catches of minke whales from 1938 (the introduction of the licensing system) to 1987, after which the whaling was temporarily stopped. Data from the Norwegian catch statistics, Fiskeridirektoratet (Norwegian Directorate of Fisheries).

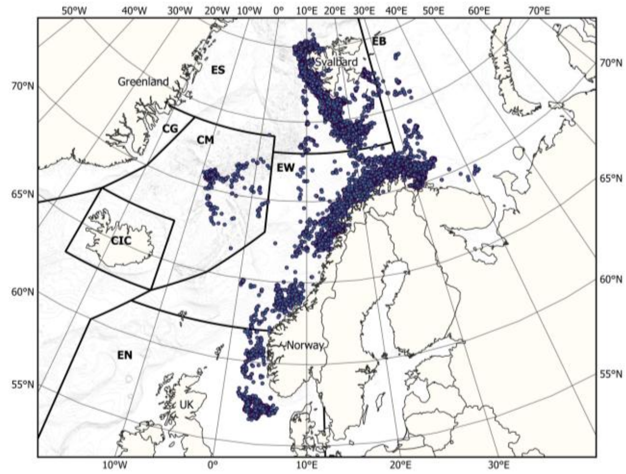

Figure 4. Geographical distribution of Norwegian catches of minke whales from 1992 (after the temporarily halt of the hunt ended) to the present. Data from the Norwegian catch statistics, Fiskeridirektoratet (Norwegian Directorate of Fisheries).

Maximum annual Norwegian catches of nearly 4,500 whales annually were obtained in the mid-1950's. Then there was a decrease to annual levels below 2,500 in the 1970's (Figure 2). Regulation of whaling was by seasonal and areal closures until a total catch limit was introduced from 1976 onwards. The effect of this was to move the catching effort from coastal areas with relatively low catch rates to the Barents Sea proper as well as off Spitsbergen. Both sex and size segregation were observed across catching grounds, with the general pattern that females and the largest whales migrate to the more distant places. Over the period 1938–1985, 73.9% of the minke whales taken off Spitsbergen were females with a mean length of 23.6 feet (Øien, 1988), many of which were pregnant. Within the Barents Sea there was also an excess of females taken, while in the Norwegian and North Seas the sex ratio was closer to 50/50, with even a slight predominance of males.

The International Whaling Commission (IWC) declared a moratorium on all commercial whaling after 1986 (see Skaug et al., 2004). However, Norway, following the rules of the IWC Convention, filed objections to the decision, and was therefore able to continue whaling under national regulation. The commercial minke whaling was, however, temporarily halted after the 1987 season, and a research program on marine mammals was initiated. This research program included development of surveys to estimate the abundance of minke whales, and at the same time, the IWC SC was given the task of developing a Revised Management Procedure for baleen whales which could both ensure the interest of the whaling industry, as well as that the probability of detrimental effects on the whale populations was very low (see Haug et al., 2011). After this RMP was finalized by the IWC SC together with the specifics of its possible application in practice for North Atlantic minke whales, Norway resumed commercial minke whaling in 1992, but now based on a variant of the newly agreed RMP. The RMP requires the catch history and abundance estimates with associated variance estimates as input and calculates annual catch limits for six-year periods. The annual total catches of minke whales in the northeast Atlantic have stabilized at a level between 400 and 600 animals during the most recent decade. While 80–90% of the catch limit for the E Medium Area is utilized, no catches have been taken in the Jan Mayen area (CM) since 2010.

MANAGEMENT HISTORY

When the licensing system was introduced in 1938, there were no other regulations for this hunt. A summer closure was introduced in 1950, and in the following seasons date and area restrictions were imposed of increasing severity (Øien et al., 1987). The first catch limit came in 1976: specifically 2000 minke whales east of Cape Farewell (the southernmost tip of Greenland) and 550 to the west. In 1977, catch limits were allocated to smaller management ("stock") areas. In 1984 and the following years, the catch limits were considerably reduced until a temporary halt in minke whaling, starting in the 1988 season, was declared. The management in these years was based on analyses of catch-per-unit-effort series which were put into context through the IWC's New Management Procedure (NMP) which provided a classification system for status of stocks based on a yield curve.

The NMP, formally adopted by IWC in 1975 (International Whaling Commission, 1977), was in response to a resolution from the UN Conference on the Human Environment, held in Stockholm, proposing to the IWC in 1972 that all a moratorium should be implemented on all whaling. The IWC rejected this proposal with the argument that it was not scientifically based. However, the IWC did react to the external pressure to improve the conservation of whale stocks, and went on to adopt the NMP which set out rules for how stocks should be harvested based on stock size relative to the maximum sustainable yield level (MSYL). This ended the whaling on the most depleted stocks in the Antarctic and other areas. Some whaling continued, including the Norwegian minke whale hunt, but for many of these stocks the situation was data poor with limited information to assess the MSYL and the current size of the stock, which in turn resulted in misclassification of stocks and continued whaling of stocks with uncertain status (see Cooke, 1995). This resulted in anti-whaling nations joining the IWC to implement the resolution from the UN Conference on the Human Environment of 1972. At the IWC annual meeting in

1982 a moratorium on all commercial whaling, starting from the 1986 Northern Hemisphere season, was adopted.

When the Moratorium was introduced in 1986, the IWC Commission asked the Scientific Committee to develop a robust management procedure, later to be known as the Revised Management Procedure. The Commission accepted as appropriate three management objectives for commercial whaling proposed by the Scientific Committee to consider when developing the RMP (International Whaling Commission, 1988):

1. Catch limits should be as stable as possible.
2. Acceptable risk level that a stock not to be depleted below some chosen level (e.g., some fraction of its "carrying capacity"), so that the risk of extinction of the stock is not seriously increased by exploitation.
3. The highest possible continuing yield should be obtained from the stock.

The historical inability of the IWC Commission to protect and manage whale stocks put strong demands on the Scientific Committee to develop a robust and precautionary procedure, taking the above objectives into account. The generic RMP subsequently developed through a comprehensive simulation framework has proved reasonable and useful to estimate sustainable catch limits.

CURRENT MANAGEMENT

As Norway filed an objection to the moratorium on commercial whaling which took effect from 1986 and now in principle has been established as the management approach of the IWC, current management of the Norwegian minke whaling is by national regulation. However, once Norway resumed commercial minke whaling in 1992, it decided that the management should be on a sustainable basis and based on the IWC SC implementation of the RMP for North Atlantic minke whales. The Scientific Committee of IWC conducted a complete *Implementation* (i.e., designing the rules for applying the Catch Limit Algorithm to a specific region, including how this region should be divided into Medium and Small Areas) to the variant of the RMP to apply for North Atlantic minke whales in 1993 (International Whaling Commission, 1994). Several *Implementation Reviews* (i.e., evaluating whether new information requires changes to these rules) to update knowledge have been conducted after that, the most recent one covering the years 2014–2017 (International Whaling Commission, 2018). Thus, although the management of the Norwegian minke whaling now de facto has been by national regulation, it is based on analyses conducted by the Scientific Committee of IWC.

The common minke whale is classified as LC (Least Concern) on the IUCN Red List (Cooke, 2018). Within the CITES framework it is listed on Appendix I (i.e., for species that are threatened with extinction) which means that export is restricted. Norway has, however, registered an objection to the CITES classification and is therefore not bound by it; it treats the minke whale as an Appendix II species (not necessarily threatened with extinction but may become so unless trade is closely controlled).

Data needs and monitoring

Fishery dependent data needed for the RMP include annual catch statistics which for the Norwegian minke whaling are collected through the compulsory licensing and logbook system and reported to the Directorate of Fisheries. The RMP variant applied requires that individual catches are specified by location and sex. Otherwise, these statistics provide information required under the IWC Schedule (International Convention for the Regulation of Whaling, 1946). Biological data, especially on reproductive parameters, are collected by scientists onboard whaling vessels at irregular intervals. These data are not required as input to the RMP per se but are useful when conditioning the models in *Implementations* and their *Reviews*.

In addition to the catch history, the RMP also requires the input of fishery independent data in the form of a series of abundance estimates with associated variances. Additional variance due to the multi-year collection of abundance data is taken into account in the Operating Models used for testing. The abundance estimates are provided through a survey program which gives a new abundance estimate for minke whales typically every six years, which in principle coincides with the time interval between *Implementation Reviews* in the IWC Scientific Committee. The surveys have been planned and conducted according to "Requirements and guidelines for conducting surveys and analysing data within the revised Management Scheme" (International Whaling Commission, 2012a, b, c). The survey procedures are described in Øien (1995) and the analyses in Skaug et al. (2004).

The Norwegian sighting surveys are conducted as annual surveys in a mosaic pattern such that the Northeast Atlantic (in practice Medium Area E and Small Management Area CM in the RMP terminology, see Figure 1) is covered over a six-year period, which coincides with the *Implementation Review* intervals. The abundance estimates calculated based on these surveys are presented to the IWC SC and discussed extensively there. The most recent estimate from a survey cycle and which has been approved by the IWC SC for use (in principle) in the RMP, is that based on the survey period 2014–2019 (Solvang et al., 2021; International Whaling Commission, 2022).

Management

The basis for the minke whale management is Norway's variant of the RMP which has been used for minke whales since 1993. The input data to this management procedure are (i) the catch history and (ii) a series of abundance estimates with variance-covariance matrix. In addition, it is necessary to decide on the tuning level for the catch limit algorithm (CLA) which is the core process within the RMP; this is the 100-year depletion target for the underlying population model. During the IWC SC's development of the RMP, all simulation tests were carried out for tuning levels 0.60, 0.66 and 0.72, and yielded scientifically acceptable results (International Whaling Commission, 1992). These numbers have a historical background from the properties of the yield curve of the NMP. The NMP classified stocks into Initial Management Stocks ($0.72 < \text{depletion} < 1$); Sustained Management Stocks ($0.54 < \text{depletion} < 0.72$) and Protected Stocks ($\text{depletion} < 0.54$). The MSYL was assumed to be at a depletion of 0.60, i.e., 60% of the pre-whaling level. The catch limit from the RMP was approximately linearly decreasing over the tuning level interval [0.60, 0.72]. The IWC (i.e., the Commission) instructed the IWC Scientific Committee to use a tuning level of 0.72, while the Norwegian catch limit calculations use tuning level 0.60. This corresponds to the optimal MSY level implied by the NMP used previously. The values were also tested during the Implementation Review of North Atlantic common minke whales in 2017 (International Whaling Commission, 2018).

To apply the generic CLA to an actual harvest situation, the *Implementation* process was developed to allow it to be applied to specific baleen whale species in specific regions. For each relevant species and area, the IWC SC conducts this process in order to be able to provide advice on safe catch limits, taking into account all knowledge about the populations of the species, and addresses specific uncertainties, in particular different scenarios for stock structures on the whaling grounds. Several combinations of possible stock structure hypotheses and possible segregations by sex and age and the spatial and temporal distribution of catches generate many scenarios and computer runs.

The outcome of the application of RMP is a catch limit which is the annual allowable catch over a six-year period. This catch limit is used for advice to the governmental authorities deciding on final limit and regulations. Some annual flexibility is allowed provided the six-year total is not exceeded, and the RMP guidelines allow for transfer of unused portions of limits within the six-year period (International Whaling Commission, 2012a).

The long-term goal for the population (tuning level) is 0.60 for an MSYR1+ rate (Maximum sustainable yield rate applied to the population one year and older) of 1% in the Norwegian management regime.

ECOSYSTEM ASPECTS

In the Northeast Atlantic, minke whales are mostly associated with coastal and continental shelf waters but are also regularly observed offshore. Their diets vary from year to year with changes in the resource base in different feeding areas. Thus, the regional consumption of different prey items is highly dynamic. As observed by Haug et al. (2002) the Barents Sea ecosystem has varied considerably over the past 30 years, presumably with the increases and decreases of the stocks of the dominant pelagic, species capelin (*Mallotus villosus*) and herring (*Clupea harrengus*) as the most prominent. Based on data sampled regularly every year, the effects of these ecological changes on the diet and food consumption of the minke whale were studied for the period 1992–1999 by both Lindstrøm et al. (2001) and Haug et al. (2002). These investigations showed that the whales fed on several species and sizes of fish and crustaceans, that they seemed to prefer capelin, herring and occasionally krill (*Thysanoessa* spp. and *Meganyctiphanes norvegica*), and that they could easily switch to other prey in years of low densities of herring and capelin.

When the capelin stock collapsed in 1992–1993, Haug et al. (2002) observed that minke whales occurring in the northern parts of the Barents Sea changed diet from primarily capelin to almost exclusively krill. For Norwegian spring spawning herring the southern parts of the Barents Sea are important nursery areas, and good recruitment to this stock result in strong cohorts of young, immature specimens (0–3 years old) that serve as the main food for minke whales feeding in that area (Lindstrøm et al., 2001; Haug et al., 2002). There is also a strong effect on young capelin in that herring preys principally on capelin larvae, with the presence of young herring, and the causal relationship between species has also been influenced from recent climate change (Solvang & Subbey, 2019). When herring recruitment is low, leading to weak cohorts in the southern Barents Sea, the reduced availability of immature herring seems to force the minke whales to switch to other prey items such as krill, capelin and, to some extent, gadoid fish (Haug et al., 2002).

Baleen whales, minke whales included, increase their fat deposits during the intensive feeding period at high latitudes, and thereby store energy reserves to be used at lower latitudes during the breeding period in winter when their feeding activity is probably reduced. Haug et al. (2002) compared the body condition of minke whales in years when the abundance of immature herring was high and low and observed that animals occurring in the southern Barents Sea, particularly immatures and adult females, were in better condition in years with high abundance of immature herring.

Later studies, conducted in 2000–2004 (Windsland et al., 2007), 2010–2011 (Meier et al., 2016) and 2016–2020 (Haug et al., 2024), have confirmed previous findings of major differences in diet composition between areas and years in the Barents Sea. The krill component increased in importance with latitude and dominated the Spitsbergen diet. Capelin was the most eaten prey item around Bear Island and contributed considerably to the diet in coastal waters of northern Norway. In the latter area, herring and haddock (*Melanogrammus aeglefinus*) also contributed importantly to the diet. Windsland et al. (2007) observed a considerable size range of prey the consumed (0.2–78 cm) and concluded, as in previous findings, that minke whales are not particularly size selective. The size of prey seems to reflect the availability of different size classes, and not selectivity by the whales (Lindstrøm & Haug, 2001; Windsland et al., 2007).

By combining data on energy requirements, diet composition, stock size and residence time (mid-April to mid-October), the total consumption by minke whales of various prey species per year in the northeast Atlantic were estimated by Folkow et al. (2000). During 1992–1995, a stock of 85,000 minke whales consumed more than 1.8 million tons (95% CI: 1.4–2.1 million tons) of prey per year: 602,000 tons of krill, 633,000 tons of herring, 142,000 tons of capelin, 256,000 tons of cod (*Gadus morhua*), 128,000 tons of haddock and 54,500 tons of other fish species, including saithe (*Pollachius virens*) and sand-eels (*Ammodytes* spp.).

The available information on minke whale foraging habits has proved very useful in setting up models that contain multiple species and ecological interactions. Thus, Skern-Mauritzen et al. (2022) assessed and compared prey consumption by the entire marine mammal community and fisheries removals in the Nordic and Barents Seas, and gave advice on how the results might indicate how marine mammals should be included in fisheries management strategies in a multispecies ecosystem context. In this study the overall consumption from minke whales in the Barents Sea was estimated to be 1.7 million tons per year with 95% CI: 0.7 – 3.1 million tons. Based on the same data sets, and to quantify past dynamics in interactions for the period 1988–2021, Planque et al. (2024) developed a food-web assessment model for marine mammals, fish and fisheries in the Norwegian and Barents Sea as a contribution to future ecosystem-based management.

The cetacean sightings surveys conducted since the late 1980s (North Atlantic Sightings Surveys, *NASS*) have demonstrated distributional changes for migrating baleen whales in the northeast Atlantic (Skaug et al., 2004; Vikingsson et al., 2015). For minke whales the observed reduction of minke whale abundance on the Icelandic continental shelf is especially illustrative of these processes; the abundance on this shelf decreased from 44,000 minke whales in 2001 to 20,000 in 2007 and 10,000 in 2009 (Vikingsson et al., 2015). These changes are likely to be functional feeding responses to changes in the marine environment, as a major change has been observed in the minke whale diet there with decreases in euphausiids, capelin and sand-eel abundance.

From body condition data (blubber thickness and girth) collected from Norwegian catches over the period 1993–2013, the conclusion was reached that the overall trend in the data over these two decades suggested a decrease in common minke whale condition, indicating a shortage of prey availability (Solvang et al., 2017). As was the case for minke whales, harp seals also showed a negative trend in body condition over this period (Øigård et al., 2013). As the cod abundance was record high in the period in question, Bogstad et al. (2015) suggested that cod may have outperformed the whales (and seals) in competition for common food resources. Recruitment to the cod stock in more recent years has been low with a subsequent continuous decrease in the total stock after 2015 to a current level which is considered to be approximately 60% of the 2015 level. Interestingly, the common minke whale body condition observed was at its lowest in 2015, whereafter it has increased (Solvang et al., 2022). This suggest that there may be a connection between the abundance of cod and the feeding possibilities for other top predators such as common minke whales.

While the minke whale distributional changes may reflect impact of changes in the ecosystem on the whales, less is known on the impact of whaling on the ecosystem. Nevertheless, Skern-Mauritzen et al. (2022) concluded that current removals in all marine mammal harvests in the Northeast Atlantic are unlikely to have had any detectable impacts on marine mammal prey consumption or on interactions with fisheries.

METHODOLOGICAL ISSUES AND KNOWLEDGE GAPS

Monitoring

As described above, the management of minke whaling in Norwegian waters is based on use of a variant of the RMP, and the aim of our monitoring program is to accommodate the requirements involved. While the catch history is recorded through a license system where whalers submit data, the use of chartered, dedicated vessels to obtain abundance estimates in visual sightings surveys with double observer platforms is costly and not economically viable in the light of the current, very limited commercial harvest of minke whales. Alternatives based on simpler shipborne sighting surveys or other approaches are discussed under *Possible ways forward* below.

Management

When applying the RMP in practical harvest situations, computer modelling is essential to both the CLA and the *Implementation Review*. Whales live long and it would probably take decades to assess empirically whether a proposed management approach is feasible, and the consequences if it does not work could be severe. Modelling permits testing of possible effects of alternative management strategies on simulated whale populations, including scientific uncertainty about whales as well as their habitat and future changes. This enables scientists to examine the potential effects of various scenarios, and to forecast future best- and worst-case consequences in order to provide robust advice. Such use of computer simulation and testing in light of scientific uncertainty was ground-breaking in its field and is becoming widely used in fisheries and other wildlife management.

As previously noted, the RMP does not use any biological data as input. Data on sex and reproductive parameters are collected from the common minke whales hunted in Norway and could be valuable in developing models for trials and for the monitoring of the population, in combination with age data. Assessing age in baleen whales has proved to be difficult, however.

During the Norwegian research program on marine mammals in the years around 1990 the use of *tympanic bullae* (ear bones), trying to reveal deposition layers related to annual life cycle (see Christensen, 1981), was found to be very inaccurate (Olsen & Sunde, 2002).

The relatively recent method of using amino acid racemisation has been tested and found to be a promising tool (Olsen & Sunde, 2002) and will be applied in an upcoming project to update reproductive parameters for northeastern Atlantic minke whales. The racemisation method has been widely used in baleen whale studies in recent years. Epigenetic age determination of whales, as presented by Polanowski et al. (2014), is another possible method.

POSSIBLE WAYS FORWARD

Future surveys

As stated above, the current line transect surveys with chartered vessels with double observer platforms is costly and needs to be simplified and economically sustainable. One possible solution is to use IMR vessels with double or single platforms. IMR vessels are conducting routine resource surveys in the Barents, Norwegian and North Seas and can in principle be combined with whale sighting surveys. Placing dedicated whale observers on routine resource surveys on board IMR vessels can generate large economic savings compared to the current line transect sighting surveys on chartered, dedicated vessels. However, the cabin capacity on IMR vessels may place constraints on the number of observers needed for double platforms. Running the survey with a single platform is an option but requires changes in the estimation procedure. The primary reason for using double platforms has been to estimate the detection probability on the transect line, known as g(0). It has been reported that g(0) varies between 0.25–0.75, depending on environmental conditions (Skaug et al., 2004). Hence, assuming g(0) = 1 would lead to a substantial bias in the abundance estimate. However, over the period 1995–2023 during which yearly double platform surveys have been conducted, we have acquired a large dataset from which g(0) could be estimated as a function of environmental covariates such as Beaufort and visibility. A limitation of this approach is that g(0) has been found to also depend on vessel type and individual observer effects, which are not easily extrapolated to

Table 1. Alternative approaches to abundance estimation based on dedicated double platform visual surveys of common minke whales in Norwegian and adjacent waters. Abbreviations: IMR = Instituted of Marine Research of Norway; g(0), PAM and DNA register: see text for explanations.

METHOD	PRACTICAL IMPLEMENTATION	ADVANTAGE	DISADVANTAGE
Opportunistic double platform surveys	IMR resource surveys. Reduce charter costs.	Routine resource surveys in Barents, Norwegian and North Seas. Will also add valuable ecosystem data.	Limited cabin space on board will require a reduced number of whale observers and consequently reduced efficiency for double platform mode.
Opportunistic single platform visual surveys	IMR resource surveys. Reduce charter costs.	Same as above.	Substantial bias for minke estimates if not corrected for g(0). G(0) may be estimated from the long series of dedicated double platform surveys.
Passive acoustics	PAM equipment, stationary buoys and towed hydrophones	Passive acoustics is widely accessible and used for several purposes	Not yet practically implemented for abundance estimation, seems more promising for odontocetes
Active acoustics	Echosounders	Available on fish resource surveys	Needs additional species identification, deterrent effects on cetaceans
Satellite-based imagery	Automatize detection by machine learning	Synoptic coverage of larger areas	Images are expensive for now; development may be long-term perspective
Genetic mark-recapture	Biopsy sampling and DNA register	All caught minke whales in DNA register	Collecting biopsies is costly and must be accumulated over years; Will only give data for minke whale abundance
Close-kin mark-recapture	DNA register	Samples available	Require age determination; Will only give data for minke whale abundance

future surveys. A summary of the issues met with when leaving the dedicated double platform visual surveys for minke whales, as well as a list of possible alternative methods for abundance estimation which will be discussed below, are summarised in Table 1.

Alternative methods for estimation of absolute abundance

Use of passive and active acoustics

Cetaceans, especially odontocetes but also mysticetes, produce sounds either for communication or while searching for food. These sounds can be detected through Passive acoustic monitoring (PAM) from a diversity of platforms including stationary buoys and towed hydrophones. Many experimental studies have been conducted, but so far practical implementations based on this methodology alone have not been yet achieved. An overview is given in Mellinger et al. (2007), and possible theoretical solutions to the challenges are presented in Whitehead (2009) where comparisons are made to conventional line-transect sampling through simulations. Generally passive acoustics seem more promising for odontocete species.

Passive acoustics may also be combined with other methods, for example visual line-transect surveys, to estimate the availability bias in the latter (Sigourney et al., 2023). This may be especially useful for deep-diving cetacean species.

It is also possible to detect cetaceans with active acoustics. Godø et al. (2013) used moored split-beam echosounders at 38 kHz to study the diving behaviour of large cetaceans and even to get estimates of the size of the animals involved. However, without additional visual or passive acoustic observations the species identification could only be speculative. Anecdotally, active sonars have been argued to have a scaring effect on cetaceans, but Knudsen et al. (2008) found in their experiments that scientific sonars and echosounders did not affect the behaviour of killer whales (*Orcinus orca*). Because of the species identification problem, we consider that active acoustics will likely not provide a way forward.

Satellite-based data with associated interpretation using machine learning

Proposals have been made to detect cetaceans from satellite imagery, see for example Kapoor et al. (2023). The process will be heavily dependent on detection of objects by machine learning to automate detection. The current status is that this methodology may be a possible way forward in a longer time perspective. For now, there are limitations in the availability of datasets, and images are expensive; there will also be a large investment necessary in learning to identify the right objects in the images.

Genetic mark-recapture experiments

Discovery tags were deployed on 333 minke whales in the Barents Sea in 1974–1978. Additionally, 18 whales were tagged prior to 1974, and 15 after 1978. 33 of the 366 tags attached were recovered in the commercial minke whale catches, and these data formed the basis for a mark-recapture estimate of minke whale abundance (Christensen & Rørvik, 1978; Beddington et al., 1984). A modern version of this study would be to collect biopsy samples, and subsequently obtain DNA profiles, from number of minke whales. This would correspond to the tagging/marking stage, and the required number of individuals sampled would be in the same range as in the Discovery study. Then the DNA-profiles would be matched against the Norwegian minke whale DNA-register (Glover et al., 2010), which contains the DNA-profiles from virtually all minke whales harvested since 1997, and matches found would constitutes the recaptures. This would then provide a basis for a new mark-recapture abundance estimate for minke whales, provided that random sampling (in tissue collection) can be ensured. There are, however, certain practical difficulties that must be overcome. These are addressed in separate paragraphs below.

Collecting biopsies from minke whales is difficult and costly, but as with the Discovery tags implanted earlier, samples can be collected in different years to obtain a sufficient number. Spatial randomization would be an advantage, but if impractical, can be compensated by mathematical modelling at the analysis stage.

It takes time to accumulate matches against the DNA-register. Since catch numbers now are much lower than they were in the late 1970's, a larger number of biopsy samples may be required. Hence, unlike the sighting surveys currently conducted, biopsy sampling will not immediately provide an abundance estimate with sufficiently low variance.

An alternative method based on DNA profiles is Close-kin mark-recapture (Bravington et al., 2016). It differs from ordinary mark-recapture in that close relatives, e.g., parent-offspring pairs, count as "recaptures". The main advantage of the method is that it does not require biopsy sampling and can be applied to the DNA register directly. Direct application of the method would require age determination of individual minke whales, but this information is currently not included in the DNA register. However, epigenetic age determination has been applied successfully to other whale species (Polanowski et al., 2014), and this gives hope that the collection of tissue samples that underlies the DNA register can be used for age determination.

Future alternatives to the current *Implementation Reviews*

The use of computer simulation and testing in light of scientific uncertainty in RMP was ground-breaking in its field, but it is also extremely complicated – known and performed by a few IWC scientists only. We would like to learn about the management of minke whales in a wider context to look for possible simplifications of the implementation process. For this purpose, a simulation study using Gadget (the Globally Applicable Area-Disaggregated General Ecosystem Toolbox) could be considered (Begley & Howell, 2004). While Gadget has been developed for fisheries stock assessment, with evaluation and validation in management, the abundance indices from standardised government surveys can be used in the model. It is a feasible alternative for the simulation trials for taking into account several hypotheses discussed in the *Implementation Review* from the IWC SC (see International Whaling Commission, 2018).

Gadget is not restricted to single-species models and possible for implementation of models including predator-prey interactions, e.g., a model of the Barents Sea of cod, capelin, herring and minke whales (Lindstrøm et al., 2009) and combining this with other simulation models as seen in and harvest control simulation (Howell & Bogstad, 2010). Gadget was also used as the basis for a simulation study to consider competing stock structure hypotheses for North Atlantic fin whales (*Balaenoptera pysalus*) given stock overlap on the feeding grounds (Elvarsson, 2015a). Applying multiple observations of other relevant species and environmental parameters per whale, similar approaches could be possible for the cases of minke and humpback (*Megaptera aeglefinus*) whales. Furthermore, the approach could demonstrate the effect of stock migration as seen from mark-recapture experiments and satellite tracking methods. But it is usually difficult for large cetaceans to track individual movements longer than few months.

Habitat and ecosystem importance

Several approaches have been applied to investigate the habitat and ecological role of minke whales: stomach content data of minke whales were analyzed to investigate the feeding behaviour (Haug et al., 1997; Skaug et al., 1997), the variation of diet composition in different time and areas (Haug et al., 2002; Windsland et al., 2007) and the relationship between food consumption and body condition (Haug et al., 2002). For the updated recent data for 2016–2020, the temporal and geographical variation of stomach contents could be investigated by spatiotemporal modelling such a "varying coefficient" model which was applied by Solvang et al. (2017) to investigate variations in minke whale body condition by year/area and to interpret covariate effects by visualization. It would be useful to follow this up regularly by using updated, recent data to understand current status for the feeding grounds and the possible changes of predator-prey interactions.

Based on data from abundance estimation of minke whale and on the status of cod and other commercially exploited marine resources, Elvarson (2015b) performed simulation studies of the mature biomass of cod with/without predation and consumption by minke whales. Furthermore, large whale occurrence and relevant biotic /abiotic data are collected in the annual ecosystem surveys. Skern-Mauritzen et al. (2011) explored the spatial associations between minke, fin, and humpback whales and their prey in the Barents Sea. In similar analysis, "varying coefficient" modelling and categorical data analysis using conditional probability (Solvang et al., 2021, 2024) are also useful to investigate recent data. In addition, the habitat condition and community structure for large whales seen in niche divergence could be investigated to assess the climatic environment in the Barents Sea.

If satellite tracking data can be obtained consistently, even for a few months, migration including feeding and movements would become estimable by using a Bayesian approach based on state-space modelling (Jonsen et al., 2003). The original method has been implemented as a R package called *bsam* package 1.1.2 in R, applied to estimate the Antarctic minke whales' (*Balaenoptera bonarensis*) migration to Antarctic waters to forage along the ice edge (Konishi et al., 2020).

CONCLUSION

The past history of over-exploitation of the large whales was the background leading to the IWC Scientific Committee developing the Revised Management Procedure, RMP, and its component Catch Limit Algorithm, CLA. Thereby, the SC developed a very safe management procedure to ensure sustainable harvests of whale resources. The current procedures have proven successful in managing harvests for sustainability, but they are very technical and complex. The current line-transect sighting surveys for abundance estimation are not economically viable considering the current limited commercial harvest of minke whales. There is therefore a need to simplify both the assessment and monitoring procedures without compromising the sustainability of the harvest. Any change in procedures should be submitted to the IWC Scientific Committee for comment before being applied to actual management of the common minke whales in the Northeast Atlantic.

ADHERENCE TO ANIMAL WELFARE PROTOCOLS

Animal welfare protocols are not applicable for this review article.

AUTHOR CONTRIBUTION STATEMENT

Bjørge, Haug & Øien: Conceived the study, contributed to text writing, final compilation and editing. **Skaug** & **Solvang**: Contributed to text writing, final compilation and editing **Biuw, Nilssen:** Contributed to text writing.

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REFERENCES

Beddington, J. R., Cooke, J. G., Christensen, I., Øritsland, T., & Øien, N. (1984). Assessments of the northeast Atlantic stock of minke whales. *Report of the International Whaling Commission, 34*, 285 –291.

Bravington, M. V., Skaug, H. J., & Anderson, E. C. (2016). Close-kin mark-recapture. *Statistical Science, 31*(2), 259–274. https://doi.org/10.1214/16-STS552

Begley, J., & Howell, D. (2004). *An overview of Gadget, the Globally applicable Area-Disaggregated General Ecosystem Toolbox* [Conference Contribution]. 2004 ICES Annual Science Conference, Vigo, Spain. CM 2004/FF:13. https://doi.org/10.17895/ices.pub.25349308

Bogstad, B., Gjøsæter, H., Haug, T., & Lindstrøm, U. (2015). A review of the battle for food in the Barents Sea: cod vs. marine mammals. *Frontiers in Ecology and Evolution, 3*, 29. https://doi.org/10.3389/fevo.2015.00029

Christensen, I. (1981). Age determination of minke whales (*Balaenoptera acutorostrata*) from laminated structures in the tympanic bulla. *Report of the International Whaling Commission, 31*, 245–253.

Christensen, I., & Rørvik, C. J. (1978). Preliminary results from recent markings of minke whales in the North East Atlantic. *Report of the International Whaling Commission, 38*,183–184.

Cooke, J. G. (1995). The International Whaling Commission's Revised Management Procedure as an example of a new approach to fishery management. In A. S. Blix, L. Walløe, & Ø. Ulltang (Eds.), *Developments in Marine Biology* (volume 4, pp. 647–657). Elsevier Science B. V. 1995. https://doi.org/10.1016/S0163-6995(06)80064-8

Cooke, J.G. (2018). *Balaenoptera acutorostrata*. *The IUCN Red List of Threatened Species 2018*. e.T2474A50348265. https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T2474A50348265.en

Elvarsson, B. Þ. (2015a). Evaluating stock structure hypotheses using genetically determined close relatives: a simulation study on North Atlantic fin whales. *ICES Journal of Marine Science, 72*(2), 661–669. https://doi.org/10.1093/icesjms/fsu140

Elvarsson, B. Þ. (2015b). *Statistical models of marine multispecies ecosystems* [PhD thesis, University of Iceland]. Skemman. https://hdl.handle.net/1946/21560

Folkow, L. P., Haug, T., Nilssen, K. T., & Nordøy, E. S. (2000). Estimated food consumption of minke whales (*Balaenoptera acutorostrata*) in north-east Atlantic waters in 1992–1995. *NAMMCO Scientific Publications*, *2*, 65–80. https://doi/10.7557/3.2972

Glover, K. A., Haug, T., Øien, N., Walløe, L., Lindblom, L., Seliussen, B. B., & Skaug, H. J. (2011). The Norwegian minke whale DNA register: a data base monitoring commercial harvest and trade of whale products. *Fish and Fisheries, 13*, 313–332. https://doi.10.1111/j.1467–2979.2011.00447.x

Godø, O. R., Sivle, L. D., Patel, R., & Torkelsen, T. (2013). Synchronous behaviour of cetaceans observed with active acoustics. *Deep–Sea Research II, 98*, 445–451. https://doi.org/10.1016/j.dsr2.2013.06.013

Haug, T., & Biuw, M. (2023). Harp Seal *Pagophilus groenlandicus* (Erxleben, 1777). In K. Hackländer & F. E. Zachos (Eds.), *Handbook of the Mammals of Europe.* (pp. 21). Springer Nature Switzerland. https://doi.org/10.1007/978-3-319-65038-8_144-1

Haug, T., Gjøsæter, H., Lindstrøm, U., & Nilssen, K. T. (1995). Diets and food availability for northeast Atlantic minke whales *Balaenoptera acutorostrata* during summer in 1992. *ICES Journal of Marine Science, 52*, 77–86. https://doi.org/10.1016/1054–3139(95)80017–4

Haug, T., Lindstrøm, U., Nilssen, K. T., Røttingen, I., & Skaug, H. J. (1996). Diet and food availability for northeast Atlantic minke whales *Balaenoptera acutorostrata. Report of the International Whaling Commission,* *46*, 371–382. https://archive.iwc.int/?r=50&k=20e95dcbb7

Haug, T., Nilssen, K. T., Lindstrøm, U., & Skaug, H. J. (1997). On the variation in size and composition of minke whale (*Balaenoptera acutorostrata*) forestomach contents. *Journal of Northwest Atlantic Fishery Science, 22,* 105–114. https://doi.org/10.2960/J.v22.a9

Haug, T., Lindstrøm, U., & Nilssen, K. T. (2002). Variations in minke whale *Balaenoptera acutorostrata* diet and body condition in response to ecosystem changes in the Barents Sea. *Sarsia, 87*, 409–422. https://doi.org/10.1080/0036482021000155715

Haug, T., Bjørge, A., Øien, N., & Ziryanov, S. V. (2011). 7. Marine mammals – 7.1 Marine mammals of the Barents Sea. In T. Jakobsen, & V. K. Ozhigin (Eds.), *The Barents Sea - Ecosystem, resources, management; Half a century of Russian–Norwegian cooperation* (pp. 395–430). Tapir Academic Press. http://hdl.handle.net/11250/109444

Haug, T., Biuw, M., Kovacs, K. M., Lindblom, L., Lindstrøm, U., Lydersen, C., MacKenzie, K. M., & Meier, S. (2024). Trophic interactions between common minke whales (*Balaenoptera acutorostrata*) and their prey during summer in the northern Barents Sea. *Progress in Oceanography, 224*, 103267. https://doi.org/10.1016/j.pocean.2024.103267

Howell, D., & Bogstad, B. (2010). A combined Gadget/FLR model for management strategy evaluations of the Barents Sea fisheries. *ICES Journal of Marine Science, 67*, 1998–2004. https://doi.org/10.1093/icesjms/fsq135

International Convention for the Regulation of Whaling (1946). International Convention for the Regulation of Whaling, Washington, 2 December 1946, *United Nations, Treaty Series*, 161, 74-75.

International Whaling Commission (1977). Report of the Scientific Committee. *27th Report of the Commission* (pp. 36– 70). International Whaling Commission.

International Whaling Commission (1988). Report of the Scientific Committee. *38th Report of the Commission* (pp. 32–61). International Whaling Commission.

International Whaling Commission (1992). Report of the Scientific Committee. *42nd Report of the Commission* (pp. 51–79). International Whaling Commission.

International Whaling Commission (1994). Report of the Scientific Committee. *44th Report of the Commission* (pp. 41–68). International Whaling Commission.

International Whaling Commission (2011). Report of the Scientific Committee. *Journal of Cetacean Research and Management, 12 (Suppl.)*, 1–75.

International Whaling Commission (2012a). The revised management procedure (RMP) for baleen whales. *Journal of Cetacean Research and Management 13 (Suppl.)*, 485–494.

International Whaling Commission (2012b). Requirements and guidelines for Implementations under the Revised Management Procedure (RMP). *Journal of Cetacean Research and Management, 13 (Suppl.)*, 495–506.

International Whaling Commission (2012c). Requirements and guidelines for conducting surveys and analysing data within the Revised Management Scheme (RMS*). Journal of Cetacean Research and Management, 13 (Suppl.),* 507–517.

International Whaling Commission (2018). Report of the Scientific Committee, Annex D. Report of the sub–committee on the Revised Management Procedure. *Journal of Cetacean Research and Management, 19 (Suppl.),* 115–182.

International Whaling Commission (2022). Report of the IWC Scientific Committee.

Jonsen, I. D, Myers, R. A., & Flemming, J. M. (2003). Meta–analysis of animal movement using state–space models. *Ecology, 84*(11), 3055–3063. https://doi.org/10.1890/02–0670

Jonsgård, Å. (1966). The distribution of Balaenopteridae in the North Atlantic Ocean. In K. S. Norris (Ed.), *Whales, Dolphins and Porpoises* (p. 114–124). Berkely, University of Calfornia Press. https://doi.org/10.1525/9780520321373-009

Jonsgård, Å. (1992). *Den norske vågehvalfangsten*. Sandefjordmuseene, Sandefjord.

Knudsen, F. R, Gammelsæter, O. B., Kvadsheim, P. H., & Nøttestad, L. (2008). Evaluation of fisheries sonar for whale detection in relation to seismic survey operations. *Bioacoustics, 17*, 327–328. https://doi.org/10.1080/09524622.2008.9753864

Kapoor, S., Kumar, M., & Kaushal, M. (2023). Deep learning based whale detection from satellite imagery. *Sustanable Computing: Informatics and Systems*, *38*, 100858. https://doi.org/10.1016/j.suscom.2023.100858

Konishi, K., Isoda, T., Bando, T., Minamikawa, S., & Kleivane, L. (2020). Antarctic minke whales find ice gaps along the ice edge in foraging grounds of the Indo–Pacific sector (60°E and 140°E) of the Southern Ocean. *Polar Biology, 43*, 343–357. https://doi.org/10.1007/s00300–020–02638–x

Lindstrøm, U., & Haug, T. (2001). Feeding strategy and prey selectivity in minke whales (*Balaenoptera acutorostrata*) foraging in the southern Barents Sea during early summer. *Journal of Cetacean Research and Management*, *3*, 238–249. https://doi.org/10.47536/jcrm.v3i3.876

Lindstrøm, U., Smout, S., Howell, D., & Bogstad, B. (2009). Modelling multi-species interactions in the Barents Sea ecosystem with special emphasis on minke whales and their interactions with cod, herring and capelin. *Deep-Sea Research II, 56*, 2068–2079. https://doi.org/10.1016/j.dsr2.2008.11.017

Meier, S., Falk–Petersen, S., Gade–Sørensen, L. A., Greenacre, M., Haug, T., & Lindstrøm, U. (2016). Fatty acids in common minke whale (*Balaenoptera acutorostrata*) blubber reflect the feeding area and food selection, but also high endogenous metabolism. *Marine Biology Research, 12*, 221–238. https://doi.org/10.1080/17451000.2015.1118513

Mellinger, D. K., Stafford, K. M., Moore, S. E., Dziak, R. P. & Matsumoto, H. (2007). Fixed passive acoustic observation methods for cetaceans. *Oceanography, 20*(4), 36–45. https://doi.org/10.5670/oceanog.2007.03

Øien, N. (1988). Length distributions in catches from the Northeastern Atlantic stock of minke whales. *Report of the International Whaling Commission, 38*, 289–295.

Øien, N. (1995). *Norwegian independent line-transect survey 1995* (Internal note, No. 8). Institute of Marine Research, Norway.

Øien, N., Jørgensen, T., & Øritsland, T. (1987). A stock assessment for Northeast Atlantic Minke Whales. *Report of the International Whaling Commission*, *37*, 225–236.

Øigård, T. A., Haug, T., & Nilssen, K. T. (2014). From pup production to quotas: Current status of harp seals in the Greenland Sea. *ICES Journal of Marine Science*, *71*, 537–545. https://doi.org/10.1093/icesjms/fst155

Øigård, T. A., Lindstrøm, U., Haug, T., Nilssen, K. T., & Smout, S. (2013). Functional relationship between harp seal body condition and available prey in the Barents Sea. *Marine Ecology Progress Series, 484*, 287–301. https://doi.org/10.3354/meps10272

Olsen, E., & Sunde, J. 2002. Age determination of minke whales (*Balaenoptera acutorostrata*) using aspartic acid racemization technique. *Sarsia*, *87*, 1–8. https://doi.org/10.1080/003648202753631686

Planque, B., Bas, L., Biuw, M., Blanchet, M. A., Bogstad, B., Eriksen, E., Drouineau, H., Hansen, C., Husson, B., Mousing, E. A., Mullon, C., Pedersen, T., Skogen, M. D., Slotte, A., Staby, A., & Lindstrøm, U. (2024). A food–web based model for marine mammals, fish, and fisheries in the Norwegian and Barents Seas. *Progress in Oceanography*, *229*, 103361. https://doi.org/10.1016/j.pocean.2024.103361

Polanowski, A. M., Robbins, J., Chandler, D., & Jarman, S. N. (2014). Epigenetic estimation of age in humpback whales. *Molecular Ecology Resources*, *14*(5), 976–987. https://doi.org/10.1111/1755–0998.12247

Quintela, M., Skaug, H. J., Øien, N., Haug, T., Seliussen, B., Solvang, Pampoulie, C., Kanda, N., Pastene, L. A., & Glover, K. (2014). Investigating population genetic structure in a highly mobile marine organism: the minke whales *Balaenoptera acutorostrata acutorostrata* in the north east Atlantic. *PLoS ONE, 9*(9), e108640. https://doi:10.1371/journal.pone.0108640

Sigourney, D. B., Deangelis, A., Cholewiak, D., & Palka, D. (2023). Combining passive acoustic data from a towed hydrophone array with visual line transect data to estimate abundance and availability bias of sperm whales (*Physeter macrocephalus*). *Peer Journal, 11*, e15850 https://doi/10.7717/peerj.15850.

Skaug, H. J., Gjøsæter, H., Haug, T., Nilssen, K. T., & Lindstrøm, U. (1997). Do Minke Whales (*Balaenoptera acutorostrata*) exhibit particular prey preferences? *Journal of Northwest Atlantic Fishery Science, 22*, 91–104. https://doi.org/10.2960/J.v22.a8

Skaug, H. J., Øien, N., Schweder, T., & Bøthun, G. (2004). Abundance of minke whales (*Balaenoptera acutorostrata*) in the Northeast Atlantic: Variability in time and space. *Canadian Journal of Fisheries and Aquatic Science, 61*, 870–886. https://doi.org/10.1139/f04–020

Skern–Mauritzen, M., Johannesen, E., Bjørge, A., & Øien, N. (2011). Baleen whale distributions and prey associations in the Barents Sea. *Marine Ecology Progress Series, 426*, 289–301. https://doi.org/10.3354/meps09027

Skern–Mauritzen, M., Lindstrøm, U., Biuw, M., Elvarsson, B., Gunnlaugsson, T., Haug, T., Kovacs, K. M., Lydersen, C., McBride, M. M., Mikkelsen, B., Øien, N., & Víkingsson, G. (2022). Marine mammal consumption and fisheries removals in the Nordic and Barents Seas. *ICES Journal of Marine Science, 79*, 1583–1603. https://doi.org/10.1093/icesjms/fsac096

Solvang, H. K., & Subbey, S. (2019). An improved methodology for quantifying causality in complex ecological systems. *PLoS ONE, 14*(1), e0208078. https://doi.org/10.1371/journal.pone.0208078

Solvang, H. K., Yanagihara, H., Øien, N., & Haug, T. (2017). Temporal and geographical variation in body condition of common minke whales (*Balaenoptera acutorostrata acutorostrata*) in the Northeast Atlantic. *Polar Biology, 40,* 667–683. https://doi/10.1007/s00300–016–1992–0

Solvang, H. K., Skaug, H. J., & Øien, N. (2021). *Abundance estimates of common minke whales in the Northeast Atlantic based on survey data collected over the period 2014–2019* [Meeting paper]. 2021 IWC 68th Scientific Committee Meeting. SC/68c/ASI/04.

Solvang, H., Haug, T., & Øien, N. (2022). Recent trends in temporal and geographical variation in blubber thickness of common minke whales (*Balaenoptera acutorostrata acutorostrata*) in the northeast Atlantic. *NAMMCO Scientific Publications, 12*. https://doi.org/10.7557/3.6308

Solvang, H. K., Imori, S., Biuw, M., Lindstrøm, U., & Haug, T. (2024). Categorical data analysis using discretization of continuous variables to investigate associations in marine ecosystems. *Environmetrics*, e2867. https://doi.org/10.1002/env.2867

Stewart, B. S., & Leatherwood, S. (1985). Minke Whale, *Balaenoptera acutorostrata* (Lacépède, 1804). In S. H. Ridgway, & S. R. Harrison (Eds.), *Handbook of Marine Mammals - Volume 3: The Sirenians and Baleen Whales* (pp. 91–136). Academic Press.

Víkingsson, G. A., Pike, D. G., Valdimarsson, H., Schleimer, A., Gunnlaugsson, T., Silva, T., Elvarsson, B. Þ., Mikkelsen, B., Øien, N., Desportes, G., Bogason, V., Hammond, P. S. (2015). Distribution, abundance, and feeding ecology of baleen whales in Icelandic waters: have recent environmental changes had effect? *Frontiers in Ecology and Evolution, 3*(6). https://doi/10.3389/fevo.2015.00006

Whitehead, H. (2009). Estimating abundance from one–dimensional passive acoustic surveys. *Journal of Wildlife Management, 73*(6), 1000–1009. https://doi/10.2193/2008–303

Windsland, K., Lindstrøm, U., Nilssen, K. T., & Haug, T. (2007). Relative abundance and size composition of prey in the common minke whale diet in selected areas of the northeastern Atlantic during 2000–04. *Journal of Cetacean Research and Management, 9*(3),1–12. https://doi.org/10.47536/jcrm.v9i3.665