Recent changes in the diet composition of common minke whales (*Balaenoptera acutorostrata*) in Icelandic waters. – Consequence of climate change?

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Abstract

The common minke whale (*Balaenoptera acutorostrata*) is the most abundant mammalian top predator in Icelandic continental shelf waters. Although Icelandic waters are among the most important feeding grounds of common minke whales in the North Atlantic, no systematic research has previously been conducted on the species' feeding ecology in this area. Here, an account is given on the first systematic research programme into the feeding ecology of common minke whales in Icelandic waters based on analysis of minke whale stomach contents data collected in Icelandic waters during 2003-2007. The results show pronounced spatial and temporal variation in the diet. The temporal changes include a decrease in the proportion of sandeel in the diet over the study period and a corresponding increase in herring and gadoids. The diet also differed markedly from the limited previously available data from Icelandic waters. These changes in diet composition are consistent with recent changes in the Icelandic continental shelf ecosystem including high sea temperatures and changes in distribution of several fish species including

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sandeel and capelin. Although natural fluctuations cannot be ruled out at this stage, these dietary changes, together with decreased abundance in coastal waters, may reflect the responses of minke whales to a changed environment possibly driven by global warming.

Introduction

The common minke (*Balaenoptera acutorostrata*) whale is the most abundant whale species in Icelandic coastal waters with mean densities up to 0.07 animals/nm.^{2} in the continental shelf area in recent decades (Pike et al. 2009). The species is generally regarded as the most ichtyophagous of baleen whales and also, the most opportunistic with regard to feeding habits (Tomilin 1967, Horwood 1990). Skaug et al. (1997) concluded that despite being quite flexible in feeding habits, minke whales off Norway show some preference for fish over krill.

In the Northern Hemisphere, minke whale diet varies considerably among areas and large temporal variations have also been demonstrated for the species (Jonsgard 1982, Horwood 1990, Klinowska 1991, Haug, Gjösæter, et al. 1995, Haug, Nilssen, et al. 1995, Haug et al. 1996, Neve 2000, Tamura & Fujise 2002). Although hunting of minke whales in Iceland dates back to 1914, knowledge on feeding habits of the species in Icelandic and adjacent waters has been very limited. During the 20th century, only 68 minke whale stomachs were examined, thereof 56 from the commercial fishery during 1977-1978, one caught in 1984 and 11 stranded or by-caught animals (1988-1997). Most of these animals were sampled off North Iceland in June and July. Thus, large parts of the distribution area and residence period of minke whales in Icelandic waters were virtually unexamined. Based on frequency of prey occurrence, this limited data indicated that approximately 65% of the diet consisted of fish while the remaining 35% were Euphausiid crustaceans

(Sigurjónsson et al. 2000). Among the identified fish species were capelin (*Mallotus villosus*), sandeel (*Ammodytidae*), and cod (*Gadus morhua*), while the identified krill species were *Thysanoessa raschii* and *Meganyctiphanes norvegica*.

Preliminary investigations into the ecological role of minke whales in Icelandic waters have indicated that the species may have a significant effect on the long-term yield from fisheries, in particular cod and capelin (Sigurjónsson & Víkingsson 1997, Stefánsson et al. 1997). There was however, large uncertainty associated with these estimated effects. Limited knowledge on the diet of minke whales in Icelandic waters was among the most important identified sources of uncertainty (Stefánsson et al. 1997). Considering the large spatial and temporal variations in the diet of minke whales species observed in other areas, there is clearly a need for further studies into the feeding ecology of the species in Icelandic waters.

The Icelandic continental shelf constitutes the most important feeding ground of the Central North Atlantic population of minke whales judging from the NASS series of large scale sightings surveys (Gunnlaugsson & Sigurjonsson 1990, Borchers et al. 2009, Pike et al. 2009). Abundance in this area has though varied considerably since systematic monitoring of abundance began in 1986 with a maximum estimate of 43,633 (30,148 - 63,149) animals obtained in 2001 (Borchers et al. 2009) The most recent surveys (2007-2009) have shown considerably lower densities (Pike, Gunnlaugsson, Elvarsson, et al. 2011). While the reasons for the decline are unclear, the limited minke whaling during this period (a total of 207 whales taken during 2003-2007) cannot have caused a decline of this magnitude (NAMMCO 2009). This sudden change in minke whale density in coastal Icelandic waters seems more likely to represent a shift in distribution than a crash in population size. However, due to poor coverage of offshore areas, particularly to the north and west of Iceland, such a shift in distribution cannot be demonstrated from the survey data and hence a real population decrease can not be excluded. A potential explanation for such a shift in distribution of minke whales could be a shift in the distribution of important prey species that may be related to appreciable changes in the physical and biological environment observed in Icelandic waters in recent years (Astthorsson et al. 2007, NAMMCO 2009). Given the euryphagous nature of the minke whale, such a shift in prey species would likely be reflected in the diet of minke whales. This paper presents a study on the diet composition of minke whales in Icelandic coastal areas. The results are discussed in connection with the limited previously available data, spatial variation and in relation to recent changes in the marine environment of Icelandic coastal waters.

Material and methods

Sampling

The minke whale material used in this study was collected during 2003-2007 as a part of a comprehensive research programme (Marine Research Institute 2003).

The whales were caught using five minke whale catching boats hired by the Marine Research Institute (MRI). Cruise leaders from the MRI were in charge of the operation onboard each vessel and up to four scientist in total. In most cases, dissection and sampling took place onboard the vessels within three hours *post mortem*.

To ensure representative sampling, searching effort was distributed temporally and spatially in proportion to densities of minke whales as known from previous surveys (Borchers et al. 2009). The sampling was designed according to an established delineation of the Icelandic continental shelf area into nine sub-areas (Fig.1), as defined by

(Stefansson & Palsson 1997), based on ecological and hydrographical characteristics. To avoid selective sampling exhaustive attempts were made to catch the first whale sighted within a given subarea and period. Whales were taken onboard immediately after death for detailed dissection and sampling for the various sub-projects (Marine Research Institute 2003).

Analysis of stomach contents

Based on comparison between contents of different stomach compartments, (Lindstrøm et al. 1997) concluded that the fore-stomach contents are sufficient to describe the diet of minke whales. Therefore this study is confined to the analysis of the fore-stomach.
The contents of the stomach were transferred to a special container for measuring it's total volume. Preliminary identification of dominant prey species and identification of stomach fill was conducted at sea by visual inspection. Then the liquid was removed by a series of sieves (20mm, 5mm and 1mm) separating differently sized particles as described by Haug et al. (1995a). Sub-samples were taken from stomachs with large contents of uniform prey and preserved frozen (see Haug et al., 1996) while stomachs with diverse contents were sampled in whole. In the laboratory, food remains were identified to the lowest possible taxonomic level. For undigested fish prey, up to 50 measurements were made of length and weight for each species and the age determined from growth zones in sagittal otoliths. Most of the stomach contents were, however, too digested for such measurements. In these cases, otoliths were used for species identification, counted and then measured under a microscope using a stereo-microscope with a graticule scale in the eyepiece.

In addition to whole undigested fish, the number of fish in each stomach was calculated by dividing the total number of sagittal otoliths by two or, in the case of larger otoliths, by counting the number of otolith pairs. The number of cephalopods was defined as the more numerous of upper or lower beaks. It was not possible to estimate the number of highly digested small crustaceans. For this group, the measured volume was used to estimate it's contribution to the diet as done in previous studies (Tamura & Fujise 2002, Windsland et al. 2007). The stomach volume and weight was analysed using generalized linear model with a Gamma link function as described by Stefansson & Palsson (1997). The parameters considered were area, year, month, sex and maturity. The best model was selected on the basis of the Akaike Information Criterion (AIC), as discussed in Akaike (1974), by stepwise removal of the above parameters.

The results are expressed as frequency of occurrence (FO) and reconstructed weight, (RW) feeding indices traditionally used in analyses of stomach content (Hyslop 1980, Pierce & Boyle 1991, Víkingsson et al. 2003). In addition a weighted frequency index (WFO) was used for comparison with a previous Icelandic study (Sigurjónsson et al. 2000). Comparions between major prey groups with respect to digestion (undigested versus other digestion states) and also comparisons of whether one or more prey species were found in the stomachs varied based on geography was made using a χ^2-test.

For calculating fish size from the size of sagittal otoliths, formulae based on Icelandic published (Vilhjálmsson 1994, Víkingsson et al. 2003) and unpublished measurements were applied if available. In the absence of Icelandic data, formulae from other areas (Härkönen 1986), were used. Otoliths that were noticeably eroded by digestion ,corresponding to digestion state 3 and above as in (Recchia & Read 1989), were not used in calculations of fish size. Some stomachs containing large amounts (>50) of otoliths were subsampled for measurements and in few cases also for counting of prey items. Further details on laboratory techniques and methods are given in Vikingsson et al., (2003)

Length dependant prey selection was analysed using a linear regression model for prey length where prey species within individual whales were treated as a random effect. The best model was selected, as in the case of stomach volume, on the basis of AIC.

Results

The spatial and temporal distribution of the sampling is shown in Figure 1 and Table 1 respectively. A total of 190 minke whales (96 males and 94 females) sampled during April-September 2003-2007 were examined with respect to stomach contents.

Total volume and weight of stomach contents

Most (97.4 %) of the stomachs contained some food remains. The median and mean volume of the unfiltered fore-stomach contents was 32 l (95% quantiles. : 0 – 132.28) and 42 l respectively with a maximum of 200 l in a 8.1 m long female. The median and mean weight of stomach contents after removal of fluid was 7.82 kg (95% quantiles : 0.03–79.53) and 14.83 kg respectively with a maximum weight of 106.25 kg in a 7.85 m long male.

The best models of stomach volume and weight, in terms of AIC, were both based on the whale length and geographic area (Table 2). Other variables such as sex, month, year and time of the day did not offer a significant improvement to the model. Two sampling areas, 2 and 10 (see Fig. 1) were significantly lower than the other 7 in terms of weight of stomach contents. Whales caught in areas 2, 5, 9 and 10 had significantly lower stomach volumes than those in other areas (Table 3).

Overall diet composition

In total 14 prey species were found in the stomachs including 10 species of fish and 2 species of euphausids (Table 4). In addition two species of crabs (*Pagurus bernhardus* and *Hyas coarctatus*) found in one stomach each were considered secondary prey ("prey of prey") and thus not included in further analyses. Most (56%) of the stomachs contained only one prey species while the maximum number of species in a single stomach was six. Sandeel was the most frequently encountered prey, occurring in 110 (58%) of the stomachs. It was not possible to distinguish between the three species of sandeel occurring in Icelandic waters. While it seems likely that the bulk of the sandeel prey is *Ammodytes marinus*, the overwhelmingly dominant species in these waters (Bogason & Lilliendahl 2009), the large size of some individuals shows that *Hyperoplus lanceolatus* was also included to some extent. Other frequently occurring prey types include haddock (*Melanogrammus aeglefinus*), herring (*Clupea haerengus*), capelin and krill found in 23%, 20%, 19%, 15% and 18% of the examined stomachs respectively (Table 4).

Figure 2 shows the the diet composition in terms of weighted frequency of occurrence (WFO) and reconstructed weight (RW) of different prey species pooled for the research period 2003-2007 compared to the previously available data (Sigurjónsson et al. (2000). The two measures of diet composition (WFO and RW) show remarkably similar results (Fig. 2). The diet was primarily composed of fish, with krill contributing only 8.6% in terms of WFO and 8.2% in terms of RW to the diet. Sandeel was the single most important prey type overall with 45% and 47% prevalence in terms of WFO and RW, respectively. Other common prey species were herring, capelin, haddock and cod. Together, large benthic fish (gadoids) constituted 24% and 23% of the diet respectively according to these measures.

Geographical and temporal variation

Although the previous data were limited, it seems clear that significant changes have occurred in the diet of minke whales in Icelandic waters between the two periods. Thus, in the more recent period (2003-7), the proportion of large, benthic fish (notably cod and haddock) was much higher while planktonic crustaceans accounted for much smaller proportion of the diet. Overall, there were similar levels of pelagic fishes although the composition of this group was quite different between the two periods with capelin dominating this prey category in the earlier period and herring more prevalent in the latter period.

Figure 3 shows the diet composition in terms of FO (Fig. 3a) and RW (Fig. 3b) by year and area for the period 2003-2007. These two measures show generally similar results although invertebrates have a somewhat higher score in terms of FO. The diet composition varied considerably with geographic location. Sandeel dominated the diet in the southern and western areas, while the diet was more diverse off northern and eastern Iceland. The dominance of sandeel was particularly striking in the beginning (2003) when it's proportion of the diet in terms of reconstructed weight amounted to 94 and 51 % in the southern and northern areas respectively (Fig. 3b). This proportion decreased steadily throughout the research period in both areas and was 18 and 12 % in respectively in 2007.

Of the pelagic fish prey capelin appeared to form a steady part of the diet in the northern area throughout the observation period while being hardly deteced in the southern area (Fig. 3). The importance of herring in the diet however increased from being non-existent in the stomachs from 2003 to constituting nearly 80% of the diet in the southern area during 2007 (Fig. 3).

Figure 4 shows the contribution of gadoid species (and other large bony fishes) in more detail. Overall, haddock and cod were the most important gadoids, contributing 9.77 and 7.93 % of the reconstructed weight respectively. Cod consumption was largely confined to the northern area where it constituted up to 29% of the diet. Haddock was only a minor component of the diet in 2003-2004, but thereafter it was an important part of the diet in both areas (Fig. 4). Other gadoid species such as saithe (*Pollachius virens*), whiting (*Merlangius merlangus*) and blue whiting (*Micromesistius poutassou*) appeared in the diet to a lesser extent.

Prey length and age.

The reconstructed size range of fish prey for the minke whale was 1 - 93 cm in total length (Fig. 5). Among the fish species taken in considerable numbers, sandeel and capelin had the lowest mean length of 12.8 and 9.3 cm respectively, although individuals up to 36.7 and 16.2 cm were found. All age classes (0 to 4 years) of capelin were consumed by the minke whales, although a large majority was less than three years (Fig. 6).

The age of sandeel ranged between 0 and 6 years with year classes 0-3 dominating in the diet.

The herring consumed varied from 0 to 41 cm in length and 1-14 years in age.

The size range for cod was 0 to 92.51 cm with a mean size of 61.99 cm. The age of cod prey ranged from 0 to 14, with a mean of 6 years. The mean length of haddock was 41.63 cm, ranging from 2.6 to 91.78 cm, and mean age was 3.9 years, ranging from 0 to 9 years.

Discussion

Potential sources of bias

Minor sampling constraints were imposed by exclusion of whale watching areas and generally worse weather in offshore areas may have caused some sampling bias. However, the limited search effort that was possible in offshore areas, together with information from a simultaneous sightings survey, as well as information from fishing vessels further offshore indicated that the distribution of minke whales in the area was indeed, very coastal during this period. Therefore, we conclude that the sampling distribution was representative of the distribution of minke whales within the Icelandic continental shelf area.

Differential digestion rates of different prey items is a potential source of error in stomach contents analysis (Hyslop 1980, Pierce & Boyle 1991). For example the proportion of small planktonic crustaceans in the diet may be underestimated due to higher rates of digestion (Gannon 1976). One way to address this problem is to compare the overall results to those of a subsample of stomachs containing only virtually undigested food. Comparison of stomachs containing fresh prey (n=51) with those containing digested prey (n=177) did not reveal significant differences in diet composition ($\chi^2(4)=6.5967$, $p=0.1588$). This indicates that differential digestion rates of prey species did not introduce any appreciable bias in the study although some underrepresentation of krill cannot be ruled out. The close similarity in the results using different measures (RW or WF) for diet composition also indicates absence of significant bias due to differential digestion rates.

Overall diet composition

The median volume of stomach contents in this study is within the range reported off Norway (Nordoy & Blix 1992) and the small proportion of empty stomachs is similar to studies of minke whales from other areas (Mitchell 1974, Larsen & Kapel 1981, Kasamatsu & Hata 1985, Haug, Nilssen, et al. 1995, Tamura & Fujise 2002). The maximum amount of food remains retrieved from a single fore stomach (106 kg) is to our knowledge the highest reported for this species.

Not unexpectedly, length of the whale appeared to have the largest predictive power for the magnitude of stomach contents but significant geographical variation was also detected The geographical variation might however be confounded by temporal changes in food availability as the sampling years were not evenly distributed on sampling areas..

This study confirms earlier findings on the euryphagous and predominantly piscivorous nature of northern hemisphere minke whales (Larsen & Kapel 1981, Jonsgard 1982, Tamura & Fujise 2002, Haug et al. 2002, Pierce et al. 2004, Windsland et al. 2007). While the range of species taken by minke whales was large, the majority of the whales (59%) had recently fed on only one prey species. This differed significantly according to a north-south division ($\chi2(1) = 15.97$, $p < 0.001$), where proportion of whales with only one prey species was 70% in the south while 43% in the north. Low diversity of prey found in individual stomachs is typical for the so called swallowing type of baleen whales (Nemoto 1959) feeding on swarming zooplankton and schooling fish and several variations of this methods have been described for minke whales in Icelandic waters (Bertulli 2010).

The prey diversity reported here is somewhat higher than that reported from Norway and Japan, where 69% and 90% respectively of the minke whales had only one prey species in their forestomachs (Tamura & Fujise 2002, Windsland et al. 2007).

Sandeel was the most important prey species overall contributing nearly 50% to the diet. Pelagic fish (herring and capelin) and gadoids each accounted for over 20% of the diet, Although gadoids have been reported as prey of minke whales in several other areas of the North Atlantic (Sergeant 1963, Larsen & Kapel 1981, Horwood 1990), their contribution to the diet is usually less than that reported here, particularly off north Iceland. However, comparable and even higher values for gadoids have been observed in some areas off northern Norway (Jonsgard 1982, Haug & al 1995, Windsland et al. 2007).

According to this study, the prey of minke whales varies in size from few millimetres (planktonic crustaceans and fish fry) to 92cm long gadoids. Similarly wide ranges have been documented for this species from Norway (Windsland et al. 2007) where gadoids upto 85cm were found in minke whale stomachs. Prey of this size contradicts the general idea of baleen whales feeding primarily on planktonic crustaceans and small schooling pelagic fish species and it could be argued that these large codfish are taken "accidentally" together with other targeted prey. However, no evidence for this could be detected in the present study. Thus in 36 % of the stomachs where gadoids were found, they constituted the main prey and in 25 % the only prey group including a stomach containing over 100 adult cods, mainly 5 to 7 years old. This clearly shows that these large gadoids are targeted by minke whales rather than engulfed accidentally.

The absence of 0-group herring in the diet off Iceland is in contrast to results from Norwegian waters where they constitute an appreciable part of the diet in some areas (Haug, Gjösæter, et al. 1995). This can be explained by the difference in spawning times of the two herring stocks. Off Norway, herring spawns in late winter and spring, while in Icelandic waters herring spawns in mid summer not reaching a consumable size until winter.

The pronounced geographical variation in prey species composition is broadly consistent with the known distribution of the prey species in Icelandic waters. Thus, sandeel is most abundant off the south- and southwest coast while capelin is mostly restricted to northern Icelandic waters during summer. Gadoids are distributed throughout Icelandic coastal waters. Their relatively low proportion in the diet in the southern areas during the first half of the period (when sandeel was abundant) could indicate a preference for sandeel when both are available.

Higher diversity of the diet in the northern Icelandic areas is similar to that found for harbour porpoises in Icelandic waters (Víkingsson et al. 2003). In both these cases low prey diversity in the southern areas seems to be related to the cetaceans' utilization of the seasonally abundant fish species capelin and sandeel.

Temporal changes in the ecosystem

The present results differ considerably from those obtained in the only previous study on minke whale diet in Icelandic waters conducted during 1977-1997. The proportion of capelin and krill in the diet was much higher in the earlier period. Capelin seems to have been largely replaced by herring and a higher incidence of sandeel and gadoids in the more recent period.

The difference in sampling strategies might contribute to the difference in diet composition between the present study, which was designed to be representative of real distribution, and the previous one (Sigurjónsson et al. 2000) which was based on commercial catches upto 1985 and strandings. However, considering only comparable areas, the frequency of krill in the stomachs of whales caught north of Iceland is still only half of that observed in the previous study. In this area the importance of capelin was similar in the two periods, while the contribution of gadoids and other large teleost fish have grown from low levels to be found in roughly half of the stomachs.

Tore Haug et al. (2002) and Tamura & Fujise (2002) described temporal dietary changes in minke whales off Norway and Japan, respectively which they attributed to changes in the ecosystem. The sampling scheme in the present study was not designed to study inter-annual variation or trends and thus, the seasonal distribution of the samples was somewhat different between years. However, this is unlikely a source of bias in this respect as no indications were seen from the data of within-season variability in the diet. The results of this study, therefore suggest that in recent years appreciable changes have occurred in the diet composition of minke whales in Icelandic coastal waters. Explanations of these changes may be found in other components of the ecosystem.

Iceland is located at a dynamic front between warmer and saline Atlantic water masses coming from the south and cold Polar water masses originating in the Arctic Ocean. While the area is in general highly productive, there is also considerable variability in environmental conditions particularly over the shelf north of Iceland where the Polar

Front separates the contrasting Atlantic and Polar water masses. During the past decade, environmental conditions in Icelandic waters have been characterized by unusually high temperatures and salinity (Marine Research Institute 2012a). This warming of the marine environment during the last decade appears to have led to pronounced changes in distribution and abundance of several fish species in Icelandic waters. Thus, southern gadoids such as saithe (*Pollachius virens*), whiting (*Merlangius merlangus*) and haddock as well as monkfish (*Lophius piscatorius*) have shown increase in abundance and extended distribution to the waters north of Iceland (Astthorsson et al. 2007, Solmundsson et al. 2010). Corresponding changes have also occurred for pelagic fish with the advancement of warm water species such as mackerel (*Scomber scombrus*) and blue whiting (*Micromesistius poutassou*) into Icelandic waters (Marine Research Institute 2012b). Haddock is noteworthy in this respect, as in addition to the northward expansion of the species' distribution, the estimated biomass in Icelandic waters increased threefold between 2000 and 2007 (Marine Research Institute 2012b). This increased availability of haddock is clearly reflected in the diet of minke whales (Figure 4).

Concomitant with these environmental changes, the cold-water species capelin appears to have retreated to a significant extent from Icelandic continental waters. Capelin was major component of the minke whale diet according to the samples collected during 1985-1997, but its contribution to the diet was much less during 2003-7. This is in accordance with changes in distribution and abundance of capelin in Icelandic and adjacent waters according to fish surveys in recent years (Astthorsson et al. 2007, Pálsson et al. 2009, Marine Research Institute 2012b). The summer distribution has shifted away from the Icelandic continental shelf towards north and to the coast of East Greenland. Unfortunately, the coverage of this area in the most recent cetacean sightings survey

(TNASS) was very poor and insufficient to test the hypothesis whether minke whales have, to some extent followed this retreat of capelin from the shelf area.

Sandeel was the single most important prey type overall during 2003-7. It also constituted a significant proportion of the diet according to the pre-2000 data where it was probably underestimated because of skewed sampling towards the northern areas. Unfortunately, specific research into sandeel abundance in Icelandic waters was not initiated until 2006. Indirect evidence (fish stomach samples, seabird breeding success) had then suggested a decline in abundance over the previous two decades, though with large inter-annual variations (Bogason & Lilliendahl 2009). The proportion of sandeel in the diet of minke whales decreased markedly during the sampling period (2003-2007) as did the number of sandeel detected in the stomachs of cod and haddock according to MRI's groundfish surveys (Bogason & Lilliendahl 2009).

Available data on minke whale and sandeel abundance in Faxaflói, SW Iceland, indicate that there might be a connection between the densities of the two species, although the nature of the sandeel data does not allow a statistical comparison. Thus, up to around 2002-3, densities of both species were considerably higher than in subsequent years and fluctuations in recent years appear to be synchronous. The variation in sandeel abundance, has been particularly pronounced in Faxaflói Bay where the highest values have been obtained. Abundance was particularly low in Faxaflói in 2007, considerably higher in 2008, but decreased again in 2009. . Aerial surveys conducted in Faxaflói Bay in 2007, 2008 and 2009 (Pike, Gunnlaugsson, & Víkingsson 2011), show similar pattern with considerably higher densities of minke whales in 2008 than in 2007 and 2009. Also, the decline to very low levels of sandeel abundance in Ingólfshöfði, SE Iceland, could explain the drastic decline in minke whale abundance in this area in the recent surveys (2007-

2009).

The summer distribution and abundance of two species of krill in northern and eastern Icelandic waters in recent years was described by (Skúladóttir et al. 2009). The distribution pattern seems to reflect whale densities to some extent. In particular, high abundance of humpback whales in the 1995 and 2001 surveys (Paxton et al., 2009) might be explained by krill abundance in those areas. Two other predominantly krill eating cetaceans have changed distribution around Iceland in recent years. A recent northward shift in distribution has been observed for blue whales (*B. musculus*) in Icelandic coastal waters (MRI unpublished data) and a change in distribution of fin whales (*B. physalus*) has been attributed to a change in enviromental conditions in the Irminger Sea (Víkingsson & Valdimarsson 2006). In general, the krill densities were considerably lower in 2007 than in 2001 and 1995 which may help explain its decreased importance in the diet and possibly also the decreased minke whale abundance in 2007.

Conclusion

After the turn of the century, large changes have occurred in the Icelandic continental shelf ecosystem. Many of these changes appear to be unfavourable to minke whales, notably less abundance of important prey species such as sandeel, capelin and krill. Although there is evidence of minke whales having reacted to this by switching to other prey species, s.a. haddock, cod and herring, minke whale abundance has also decreased significantly during this period. Detailed examinations of body condition of 190 minke whales sampled during 2003-2007 have not revealed any instances of severe malnutrition. Such instances would be expected if the decline in abundance was due to a real population decline, as a result of food shortage. Thus, it seems more likely that the decline is the result of a shift in distribution from Icelandic coastal waters as a result of declined availability of preferred food types.

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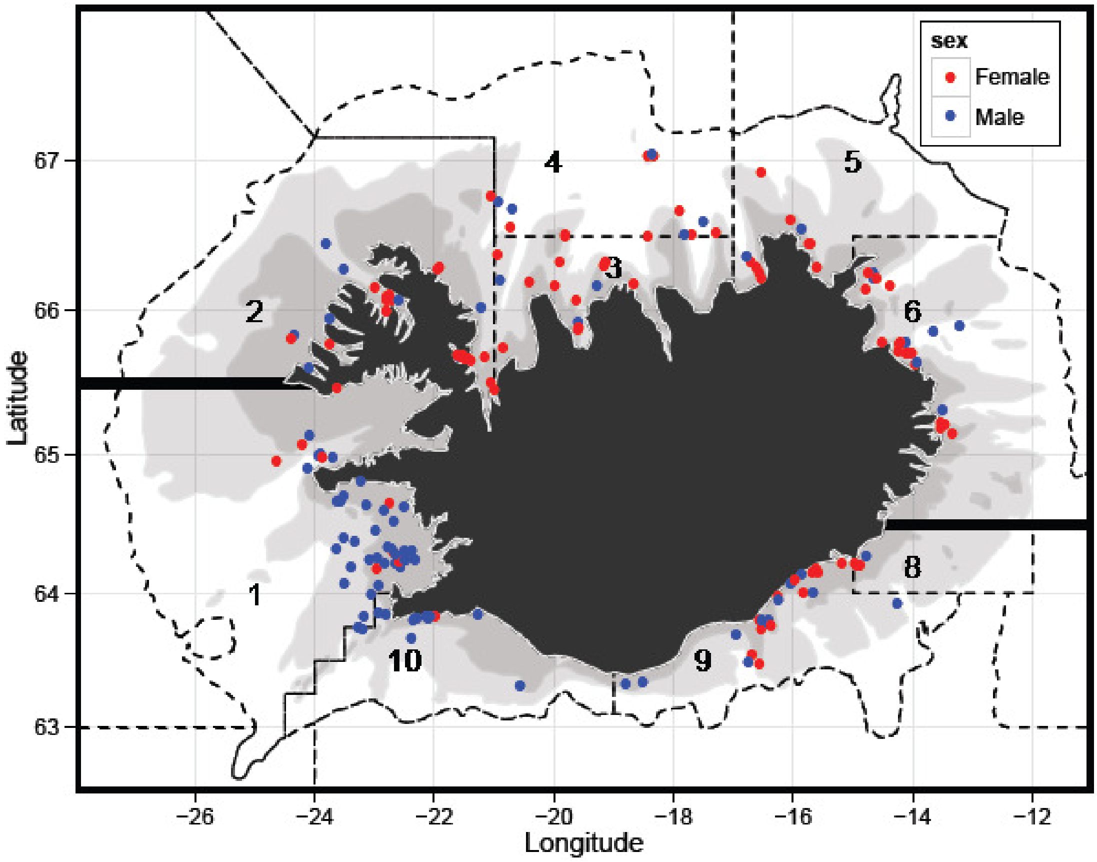

Figure 1. Catch distribution of the minke whales caught in 2003 -2007. Numbers refer to the Bormicon area division. In analysis areas 2-6 were combined to form the northern area and the remaining subareas (1, 7-10) are referred to as the southern area.

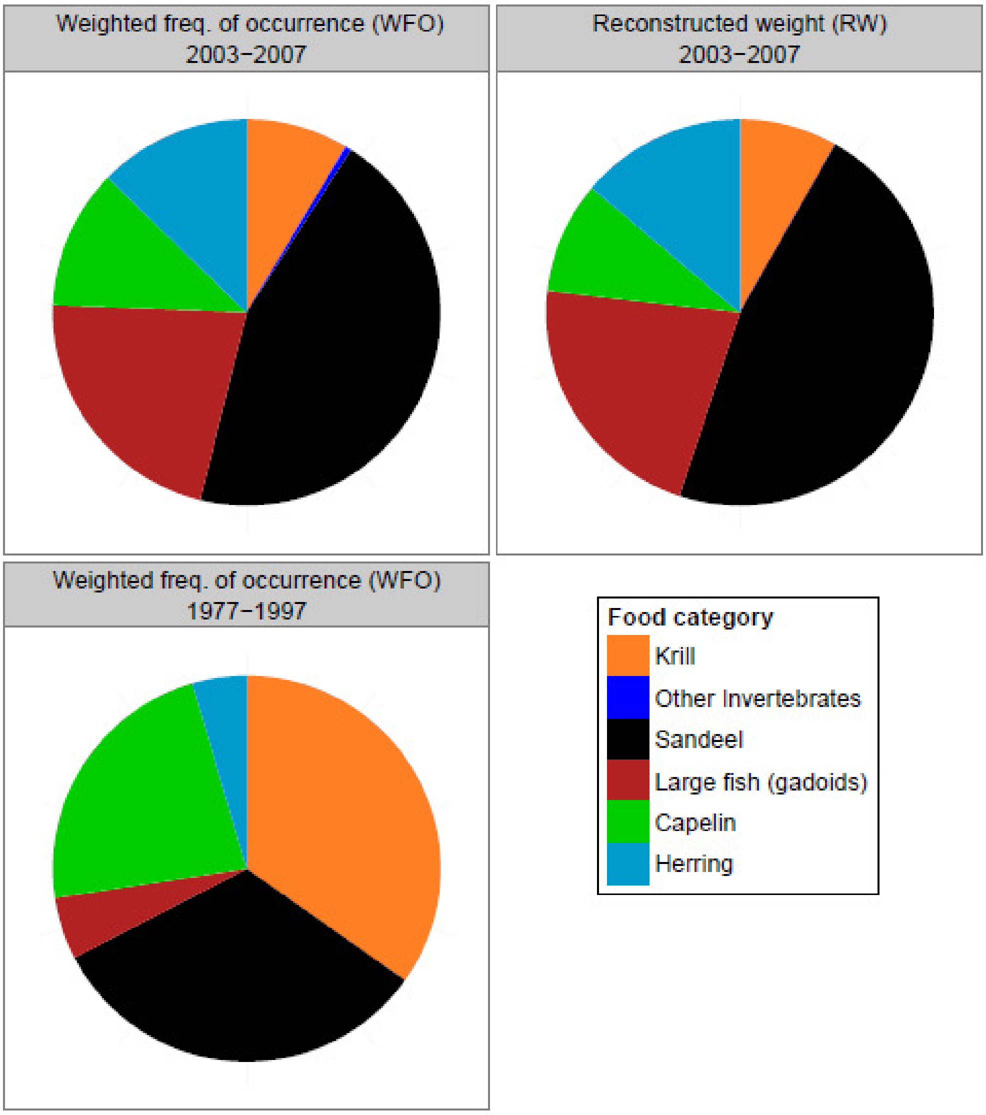

Figure 2. Diet composition of minke whales sampled in Icelandic waters 2003-2007 shown as reconstructed weight (RW) and as weighted frequency of occurrence (WFO) for comparison with previous data (1977-1997).

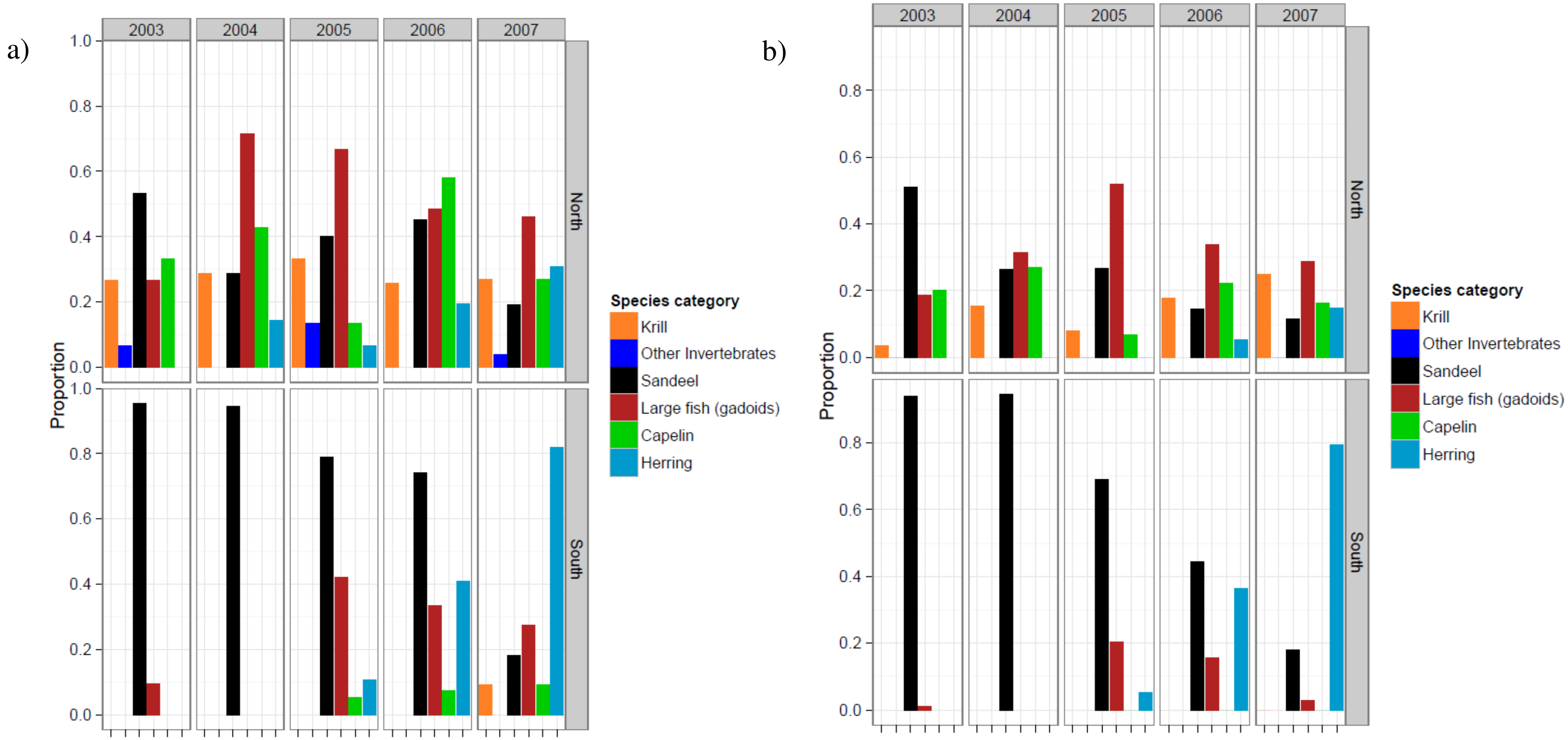

Figure 3. Spatial and temporal variation in diet composition of minke whales expressed as **a)** frequency of occurrence (FO) and **b)** reconstructed weight. (RW). Area division (North-South) as in Figure 1.

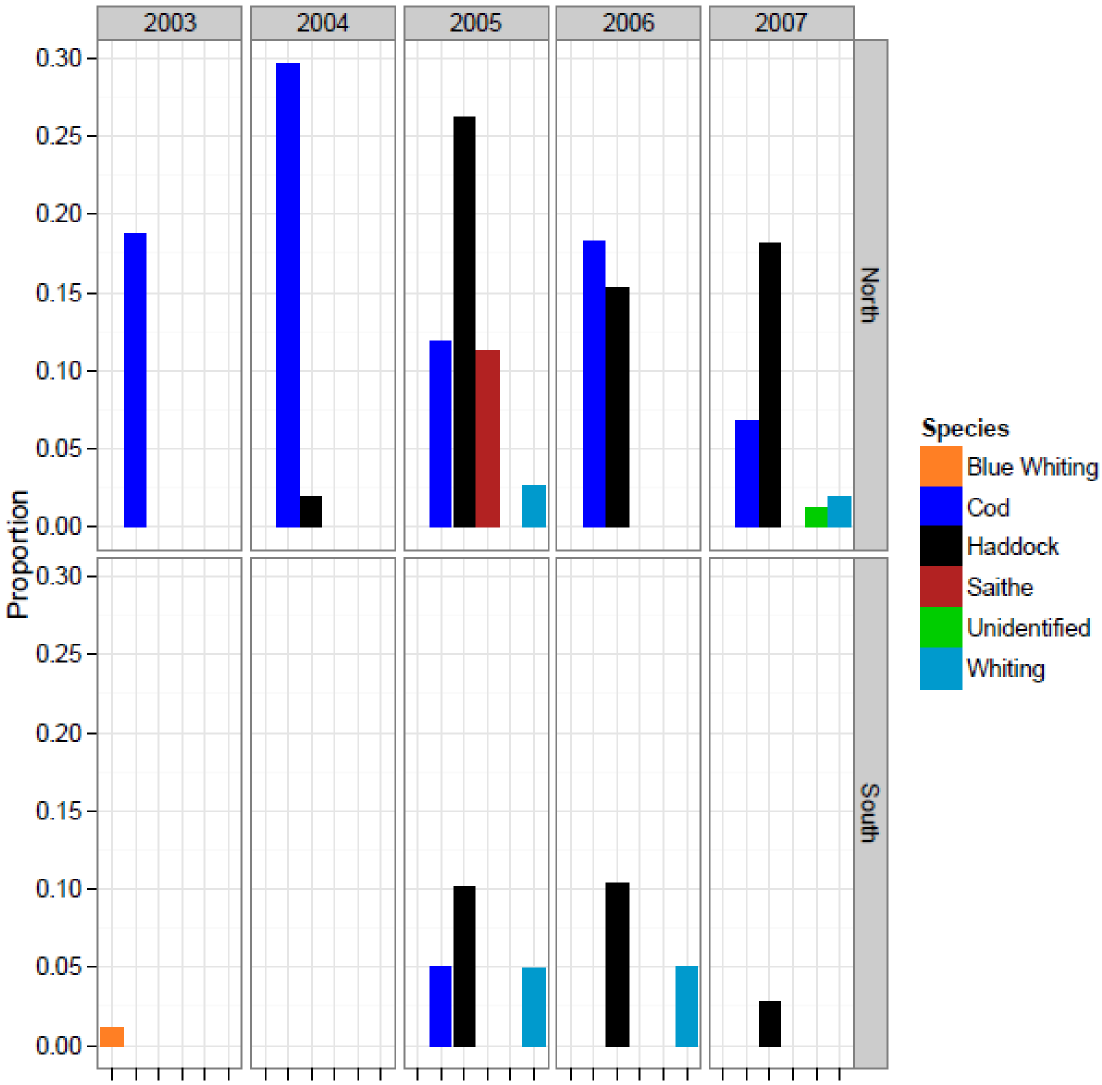

Figure 4. Spatial and temporal variation in the contribution of the most important species of gadoids to the diet composition of minke whales (RW).

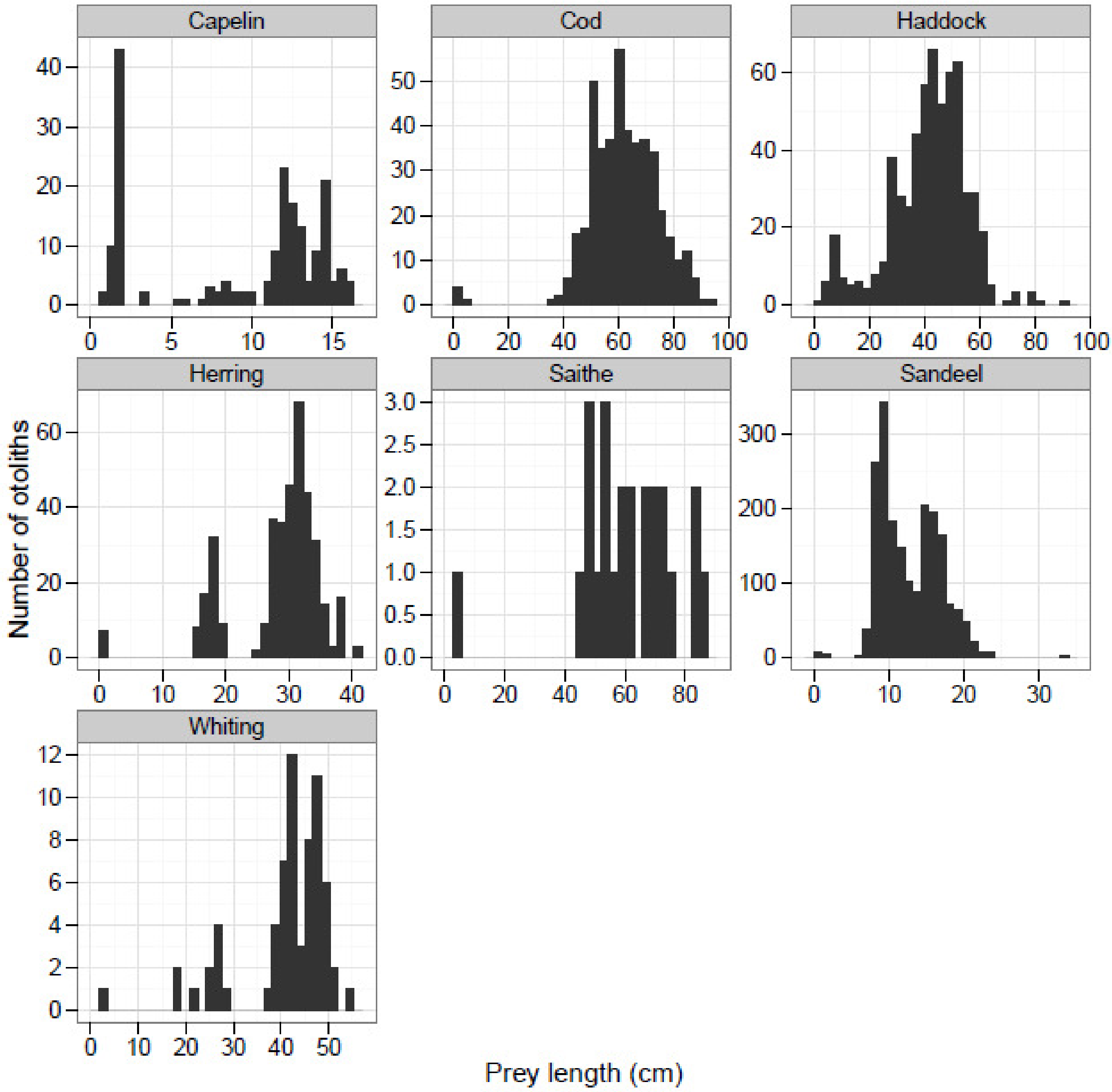

Figure 5. Length distributions of the most common fish species identified in the forestomachs of minke whales sampled in 2003-2007 according to direct measurements (undigested fish) and calculations from otolith lengths.

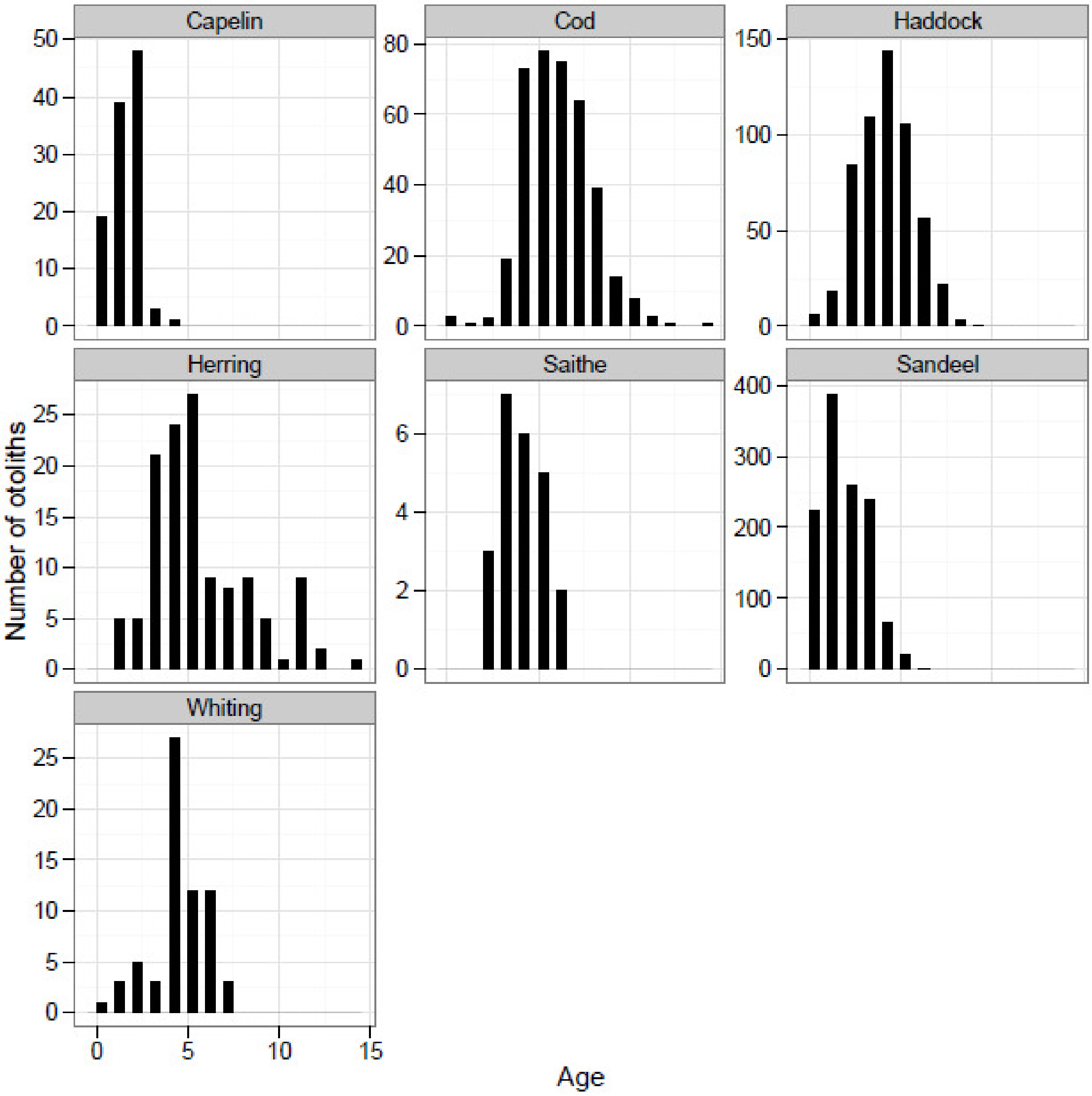

Figure 6. Age distributions of the most common fish species identified in the forestomachs of minke whales sampled in 2003-2007.

Table 1. Temporal distribution of the samples obtained during 2003-2007.

	April	May	June	July	August	September	Total
2003		0	0	0	18	18	36
2004		0	16	9	0	0	25
2005		0	0	18	16	0	34
2006		0	13	25	20	0	58
2007	3	7	22	0	4	1	37
2003-2007	**3**	**7**	**51**	**52**	**58**	**19**	**190**

Table 2. Overview of AIC scores for the fitted GLM models for weights and volume of stomach contents. Full model includes the variables whale length, geographic area, month, year, sex and maturity. D.f.: Degrees of freedom.

	Step	D.f.	Deviance	Resid. D.f.	Resid. Dev.	AIC
Weight of stomach contents						
1	Full model			169.00	329.70	1388.87
2	- month	5.00	0.80	174.00	329.50	1379.44
3	- year	4.00	5.32	178.00	334.82	1375.21
4	- sex	1.00	0.20	179.00	335.02	1373.35
Volume of stomach contents						
1	Full model			160.00	242.40	1815.17
2	- year:month	5.00	1.39	165.00	243.80	1806.46
3	- month	5.00	1.86	170.00	245.66	1798.17
4	- year	4.00	2.17	174.00	247.84	1792.16
5	- maturity	4.00	2.38	178.00	250.22	1786.32
6	- sex	1.00	0.33	179.00	250.55	1784.62

Table 3. Summary of the variables of the best model, in terms of AIC, for the weight and volume of stomach contents. The intercept value represents the model fit for length 0 whales in Area , the t-value and the corresponding p value represent the results from a Wald's test for a single parameter difference from zero.

	Estimate	**Std. Error**	**t value**	**Pr(> |t|)**
Weight of stomach contents				
(Intercept)	0.1853	0.0741	2.50	0.0133
Length	-0.0001	0.0001	-1.38	0.1681
Location: Area 2	-0.0379	0.0189	-2.00	0.0466
Area 3	0.0177	0.0377	0.47	0.6389
Area 4	-0.0043	0.0314	-0.14	0.8916
Area 5	0.0099	0.0416	0.24	0.8122
Area 6	0.0404	0.0371	1.09	0.2771
Area 8	0.0566	0.0996	0.57	0.5710
Area 9	-0.0281	0.0209	-1.34	0.1813
Area 10	-0.0442	0.0200	-2.21	0.0285
Volume of stomach contents				
(Intercept)	0.1110	0.0176	6.30	0.0000
Length	-0.0001	0.0000	-4.51	0.0000
Location: Area 2	-0.0139	0.0045	-3.11	0.0022
Area 3	0.0002	0.0075	0.03	0.9779
Area 4	-0.0082	0.0063	-1.31	0.1928
Area 5	-0.0146	0.0061	-2.41	0.0172
Area 6	-0.0059	0.0058	-1.02	0.3113
Area 8	0.0102	0.0173	0.59	0.5554
Area 9	-0.0125	0.0048	-2.62	0.0097
Area 10	-0.0146	0.0050	-2.92	0.0039

Table 4. Identified prey species of minke whales and the number of stomachs in which they occurred stratified by sampling year and area. N: Northern areas S: Southern areas (see text). n: sample size.

	2003		**2004**		**2005**		**2006**		**2007**		**All years**	
Area :	N	S	N	S	N	S	N	S	N	S	N	S
Sample size:	15	21	7	18	15	19	31	27	26	11	94	96
Crustacea												
Euphausiacea												
Thysanoessa rasci	1		1				6		6		14	
Meganychtiphanes norwegica	2				1		2				5	
Krill (unidentified)	3			1	4		3		3	1	13	2
Copepoda (unidentified)	1										1	
Decapoda												
Pandalus borealis					1						1	
Vertebrata												
Gadidae												
Gadus morhua	3	1	2	2	4	1	8	3	4		21	7
Melanogrammus aeglefinus				1	7	4	10	8	10	3	27	16
Pollachius virens					2			1	1		3	1
Merlangius merlangus	1		1		3	1	1	3	1		7	4
Micromesistius poutassou	1	1			1	1	1	1			3	3
Trisopterus esmarki	1										1	
Unidentified. large fish	1				1	2	1		4	1	7	2
Clupeidae												
Clupea harengus			1		1	2	6	11	8	9	16	22
Osmeridae												
Mallotus villosus	4		3		2	1	17	2	7	1	33	4
Ammodytidae												
Ammodytes marinus/ Hyperoplus lanceolatus	9	20	2	17	6	15	13	21	5	2	35	75