Fatty acids in the blubber and blood of common minke whales (*Balaenoptera acutorostrata*) and relation to their diet in Icelandic waters.

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Abstract

Fatty acid (FA) profiles of the total lipids of 23 minke whales (*Balaenoptera acutorostrata*) were analysed in tissues of outer blubber, inner blubber and blood and in some of the minke whales potential prey the years 2003, 2004 and 2006 in the waters around Iceland. The main objective was to study how FA profiles reflect the diet of minke whales around Iceland. These three tissues were tissue-specific (i.e. samples from each tissue group together in multivariate analysis) and the inner blubber best reflected diet. The FA profiles did not reflect the stomach contents of the minke whales. However, the large variance in FA composition of the inner blubber indicates a diverse diet of the minke whales in agreement with the stomach contents. The FA profiles indicated that before the collapse of the sandeel stock around 2005 the food variety of minke whales was more diverse than in the year 2006 when the sandeel stock had collapsed. In 2006 the *Calanus* based food-web was of higher importance than in 2003. The use of FA analysis in trophic studies of whales are promising but must be interpreted with care and with their limitations in mind.

Introduction

Common minke (*Balaenoptera acutorostrata*)whales are generally regarded as the most ichtyophagous species of baleen whales and also the most opportunistic with regard to feeding habits (Tomilin 1967; Horwood 1990). In the Northern Hemisphere minke whale diet varies considerably among areas and large temporal variations have also been demonstrated for the species (Jonsgård 1982; Horwood 1990; Klinowska 1991; Haug *et al*. 1995, 1996; Barner Neve 2000; Tamura and Fujise 2002). The diet of Antarctic minke whales (*Balaenoptera bonarensis*) is, however, much more uniform, krill (*Euphausia superba*) being the overwhelmingly dominant food (Kawamura 1994).

Sigurjónsson *et al.* (2000) studied feeding habits of minke whales in Icelandic waters. Based on frequency of prey occurrence the 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, while the identified krill species were *Thysanoessa raschii* and *Meganyctiphanes norvegica*. A more extensive recent study indicated considerably higher proportions of fish and proportionally less crustaceans (SC/F13/SP2). The most important fish species included sandeel, herring (*Clupea haerengus)*, haddock (*Melanogrammus aeglefinus)* and cod (*Gadus morhua*).The results also showed pronounced spatial and temporal variation in the diet.

The most common method for estimation of the prey of marine mammals is identification of undigested food items from the digestive tract (Pierce and Boyle 1991). This method is generally believed to give the most reliable and detailed information on recent food prior to sampling. The main disadvantages of this method are related to differential digestion rates of prey species. Thus, small hard parts of the diet such as otoliths and squid beaks may accumulate in the predator stomach and consequently cause overestimation of these prey species. On the other hand, soft and easily digested prey may be underestimated. Sampling of stomachs from marine mammals is often restricted to small areas and short catching season. In such cases investigations of stomach contents may merely provide a narrow window of the foraging in both temporal and spatial sense. For predators with wide range in prey selection this method may give limited information on seasonal and regional variation in the feeding if sampling is restricted temporally and spatially. It is therefore important to take account of

possible seasonal and geographical variation in diet when designing a sampling scheme for analysis of stomach content.

New techniques in foraging studies have received increased attention recently. One of these methods is based on the principle that the Fatty acid (FA) composition in animal's diet will be reflected in its tissues (Ackman and Eaton 1966). This analysis has the potential to provide information on the average composition of the diet weeks and even months prior to sampling, whereas the traditional stomach content analyses give a snapshot of the animal's last meal(s). Primary producers and some zooplankton species can be characterized by their specific FA profiles. Some of these FAs can be transferred relatively unchanged trough trophic levels (Lee et al., 1971b; Graeve et al., 1994; Dalsgaard et al., 2003). Diatoms are known to have relatively high amounts of 20:5n3, 16:1n7 and C16 polyunsaturated fatty acids (PUFAs), whereas elevated amounts of 22:6n3 and C18 PUFAs are characteristic for dinoflagellates and Phaeocystis (Dalsgaard et al., 2003). *Calanus* copepods biosynthesize de novo large amounts of C20 and C22 long-chain, high energy, monounsaturated FAs and alcohols (Dalsgaard et al., 2003 for review). All these FAs are regarded as good trophic markers, i.e. are transferred relatively unmodified into neutral lipids of consumers. Multivariate statistical methods have been introduced in FAprofile analysis (Grahl-Nielsen & Mjaavatten, 1991). Such methods allow comparison not only of single fatty acids but of all FA profiles derived from animal tissues. This makes it possible to detect relationships and patterns within complex data.

Whale blubber and skin are frequently used in the FA analyses. These samples may be obtained by biopsies and the most optimistic aspect is that these methods may replace the traditional and lethal stomach and intestine content analyses (e.g. IWC 2004). The applicability of this method is however highly controversial and results of FA signatures must be interpreted with caution (Anon. 2002). Some studies on the FA profiles have indicated positive correlation between the predator and its prey (Kirsch *et al.* 1998; Hooker *et al.* 2001) while others have revealed small or no such correlation (Grahl-Nielsen *et al.* 2000). The FAcomposition often shows some stratification in the animal's blubber (Lockyer *et al.* 1984; Koopman *et al.* 1996; Møller 1999; Olsen and Grahl-Nielsen 2003).

The present study is a part of the Marine Research Institute's (MRI) research programme on minke whales (Marine Research Institute 2003). The main objectives of this study were to observe how FA analyses reflect the diet of minke whales around Iceland and compare the results with stomach contents (SC/F13/SP2). The intensive sampling from each whale offered

a rare opportunity to compare different methods (SC/F13/SP2, SC/F13/SP3) using the same sample

The specific aims were to observe:

1) the relationships among the different tissues (inner blubber, outer blubber and blood) of minke whales
2) the relationships among different tissues of minke whales and their potential prey
3) the relationship among the inner blubber layer and the potential prey and
4) to observe whether there is a variability in the inner blubber layer of minke whales around Iceland by comparing different areas (north and south), males and females and the years sampled (2003, 2004 and 2006).

Materials and methods

A total of 23 minke whales were sampled in June to September, 2003, 2004 and 2006 (Figure1, Table 1). All of them were analyzed for FA profiles of the inner and outer blubber and eight of the blood tissue. Samples of potential prey of the minke whales were taken around Iceland in June to September 2003-2007.

Three full cores, 2x5 cm in diameter were taken from each blubber sample. Three 2x2x2 cm pieces were taken from each core; the inner (next to muscle, called inner blubber), mid- and outer region (next to skin, called outer blubber) of the core and analysed separately for FA concentration. One litre of blood was collected as soon as possible post mortem and preserved frozen after centrifugation.

Each of the main suspected food items were analysed for comparison to the profiles of the whale blubber and blood.

Lipids were extracted by chloroform/methanol extraction system based on the method of by Bligh and Dyer (1959) as modified by Hanson and Olley (1963), but with some alterations. To prevent oxidation of the lipids, all samples were treated in ice bath, BHT (butylated hydroxytoluene) (50-100 mg/l) was added to all solvents and care was taken to eliminate as much light as possible. The extract was centrifuged at 1000 x *g* for 20 min at 0-5 °C in a refrigerated centrifuge (Sorvall Superspeed RC5-B, DuPont Instruments, Stockholm, Sweden). The lower layer containing the chloroform with the lipids was filtered by vacuum through a glass filter (Watman GH/D).

For determination of the lipid concentration the extract, portion of the chloroform layer was pipetted in to a pre weighted beaker and the chloroform is evaporated to dryness at 60 °C for 30 min. Afterwards the beaker was cooled inside a desiccator and weighed. The remaining weight was taken as the lipid content in mg/ml.

FA analysis was performed on the lipid extracts obtained from lipid extraction according Bligh and Dyer. Portion of the chloroform lipid extract (1-5 ml) was evaporated to dryness under a stream of nitrogen gas. Saponification, methylation and gas chromatography was applied for the analysis (AOCS 1998c). The FA methylesters were separated and quantified by gas chromatography (GC) and FID detection. Results are expressed as percentage of total fatty acids in the lipid.

Multivariate statistical analyses were performed on FA compositional data due to the high number of variables (fatty acids) describing each tissue. Samples with low amounts of fatty acids (<0.5%) were excluded from the analyses as the precision of their determination was too low. The remaining percentage was subjected to principal component analysis (PCA). The multivariate statistical analyses were performed in CANOCO 4.5 for Windows. The PCA presents multivariate data in a reduced number of axes of greatest variability. The relationships among different samples could be determined by applying PCA to the FA compositions. Twenty six PCAs were analysed examine the relationships among different tissues of minke whales and how well they reflect their diet.

Results

In the inner and outer blubber and the blood tissue, 37 fatty acids were found (Tables 2, 3, 4). In all the tissues the fatty acids 16:0 and 18:1n9 were in high levels and in addition 20:5n3 were in high levels in the blood tissue. The *Calanus* FAs (20:1, 22:1) were found in relatively high numbers in all the tissues as well and highest in the inner blubber samples.

The relationships among different tissues (inner blubber, outer blubber and blood) of minke whales sampled in 2003, 2004 and 2006 are shown in Figure 2. The first two axes explained 87.5% of the total variance in FA composition (Axis 1: 56.6%, Axis 2: 30.9%). It is evident that samples from the different tissue type group together. The main gradient along axis 1 distinguished all the tissues with the blood and outer blubber being most different. The blood had relatively higher amounts of the phytoplankton originated 20:5n3 than the other tissues

while the reverse was true for the *Calanus* FAs. The gradient along axis 2 separates part of the inner blubber samples from the other samples with much higher amounts of the *Calanus* originated FAs (20:1 and 22:1) in these inner blubber samples.

The relationships among different tissues (inner blubber, outer blubber and blood) of minke whales sampled in 2003, 2004 and 2006 and their potential prey are given in Figure 3. The first two axes explained 79.6% of the total variance in FA composition (Axis 1: 46.3%, Axis 2: 33.3%). Axis 1 separates the three tissue types. The diet samples ordinates on the lower right panel with the blood samples and along the inner blubber samples and on the upper right panel along the inner blubber samples. Axis 2 separates part of the diet and inner blubber samples (upper panel) from the other samples (lower panel).

Figure 4 shows the relationships among the inner blubber layer of minke whales sampled in 2003, 2004 and 2006 and the potential prey The first two axes explained 82.4% of the total variance in FA composition (Axis 1: 57.9%, Axis 2: 24.5%). The main gradient along axis 1 separates samples (some inner blubber and diet samples) that have relatively high levels of *Calanus* fatty acids (e.g. capelin, herring, sandeel) on the left panel from the gadoids and some inner blubber samples which have lower levels of *Calanus* fatty acids (right panel). Axis 2 separates the diet (upper panel) from the inner blubber samples (lower panel).

PCA for each individual whale and its potential diet were applied (23 analyses not shown). No pure trends were observed. The FA profiles were compared to stomach content analyses (Table 1). No relationships were detected between the FA profiles and the observed diet from stomach content analyses.

The relationships of the minke whales around Iceland based on the inner blubber layer are given in Figure 5. The first two axes explained 82.4% of the total variance in FA composition (Axis 1: 61.7%, Axis 2: 20.7%). Axis 1 ordinate samples with relatively high amounts of *Calanus* fatty acids on the left and the ones with lower amounts of these fatty acids on the right. Axis 2 ordinate samples with relatively high amounts of phytoplankton originated fatty acids (lower panel) and samples with lower amounts of these fatty acids (upper panel). No separation or trends were observed between samples from the North and South of Iceland (Figure 5A) or between males and females (Figure 5B) i.e. the samples are evenly mixed together. Samples from 2003 had greatest variability along axis 1 (Figure 5C) while samples from 2006 had smaller variability (left part).

Discussion

The three minke whale tissues studied, the inner blubber, outer blubber and the blood are tissue-specific i.e. samples from each tissue group together on a PCA plot (Figure 2). The inner blubber had greatest variance in FA composition of these tissues (Figure 2) and grouped along the potential prey (Figure 3). This, confirms that the inner layers reflect diet better than the outer layers. Several studies of the blubber of marine mammals have also found stratification in the FA composition the blubber (Olsen & Grahl-Nielsen 2003; Fehn, 1996; Ackman *et al*., 1965). The inner layers of the whale blubber appear to be more metabolically active than the outer layers in some species and extraction and storage of lipids is likely to occur mainly in the inner layers of these species. Usage of biopsies that only reflect the outer layer may therefore give misleading information on the diet composition both with respect to stomach contents (short-term) and FA composition from other tissues.

Large variance in FA composition of the inner blubber (Figures 4 and 5) indicates a diverse diet of the minke whales which is in line with data from stomach content analyses (Sigurjónsson *et al*., 2000, SC/F13/SP2).

No clear relationships were between the FA profiles and the stomach contents of the minke whales, further enforcing the diverse diet. It is important, however, when comparing FA data with other trophic studies based on stomach content analyses that FA analyses reflect the diet over longer periods than traditional stomach content analyses, which provide information about the last meal(s). Thus, the prey in the stomach of the whale when captured is not expected to show up in the FA composition of the whales until later. The stomach samples of the present study were distributed over the period June-August, the resulting diet composition thus reflecting that period. Furthermore, in the broader diet study covering the period April-October, no seasonal variation was found in the diet (SC/F13/SP2. The lack of relationship between the FA analysis and stomach contents therefore indicates that the former method primarily reflects diet prior to main summer feeding season for the animals captured early in the season.

The FA composition of the inner blubber samples of whales sampled does not vary geographically (north and south of Iceland; Figure 5A). This is in contrast to the concurrent study (SC/F13/SP2) that found clear difference in their diet in these two areas with sandeel

contributing most in the diet south of Iceland. The much larger sample size in the stomach content analysis could explain the dissimilarity between these two studies, especially the extremely low sampling size south west of Iceland in this study (area 1 in Figure 1) i.e. in the area where sandeel were in highest numbers in their stomachs. In 2003 the minke whales had greater variability in their diet as observed by their higher fatty acids variance, than in the year 2006 (Figure 5C). This agrees with the drastic changes in their prey availability around Iceland caused by the collapse of the sandeel stock around 2005 Samples from 2004 could not be used in this comparison due to low sampling size.

The *Calanus* FA trophic markers were found in all samples (Table 3) thus indicating *Calanus* based food webs in all areas. The importance of *Calanus* in the diet (indirectly, through other species, see below) was relatively higher in 2006 than 2003. *Calanus* was not among the species identified in the stomachs of minke whales (SC/F13/SP2). Their prevalence as trophic markers can be explained by indirect effects, i.e. that the prey of minke whales (or even the prey of that prey) had fed on *Calanus.* In the case of the common minke whale, a top predator with a wide range of prey, it is problematic to evaluate the diet composition from FA analysis alone.

In addition to tissue specificity as mentioned above, there are several uncertainties involved when using these methods to study trophic interactions among species. The turnover times of the fatty acids can be species-specific and are often related to the metabolic conditions and reproductive status of the animals (Dalsgaard *et al*., 2003; Graeve *et al*., 2005). Some essential fatty acids such as 20:5n3 and 22:6n3 may become more elevated at higher trophic levels than at lower levels since they might be selectively retained (Graeve *et al*., 2005). When the diet of the consumer constitutes a mixture of prey with similar FA profiles the interpretation becomes more challenging. Nevertheless, FA analyses can be efficient tool in food web studies combined with available knowledge about stomach contents, ecology of the species and the use of multivariate statistical analyses, as they reflect dietary assimilation over longer time periods than the more traditional stomach content analyses. However, the results must be interpreted with care and their limitations in mind.

References

Ackman, R.G., Eaton C.A., Jangaard P.M. 1965. Lipids from the fin whale (*Balaenoptera physalus*) from north Atlantic waters, I. Fatty acid composition of whole blubber and blubber sections. *Can. J. Bioch.* 43: 1513-1520.

Ackman, R.G. and Eaton, C.S. 1966. Lipids of the fin whale (*Balaenoptera physalus*) from north Atlantic waters, III. Occurrence of eicosenoic and docosenoic fatty acids in the zooplankter *Meganyctiphanes norvegica* (M. Sars) and their effect on whale oil composition. *Can. J. Bioch.* 44:1561-1566.

Anon. 2002. Report of the NAMMCO scientific working group marine mammals:from feeding behaviour or stomach contents to annual consumption – what are the main uncertainties? Annex 1. *NAMMCO Annual Report 2001*. pp191-212

Barner Neve, P. 2000. The diet of minke whale in Greenland - A short review. *NAMMCO Sci. Publ.* 2:92-96.

Bligh, E.G. and Dyer, W.J. 1959. A rapid method of total lipid extraction and purification. *Can. J. Biochem. Physiol*. 37:911-917.

Dalsgaard, J., St John, M., Kattner, G., Muller-Navarra, D., and Hagen, W., 2003. Fatty acid trophic markers in the pelagic marine environment. Advances in Marine Biology, 46: 225-340.

Fehn, T.H. 1996. Fatty acids in minke whales (in Norwegian). Master Thesis. University of Bergen, Bergen, Norway.

Grahl-Nielsen, O., Hammill, M.O., Lydersen, C. and Wahlstrøm, S. 2000. Transfer of fatty acids from female seal blubber via milk to pup blubber. *J. Comp. Physiol B.* 170:277-283

Grahl-Nielsen, O., Andersen M., Derocher, A.E., Lydersen, C., Wiig Ø., Kovacs, K.M. 2004. Reply to comment on Grahl-Nielsen et al. (2003): sampling, data treatment and predictions in investigations on fatty acids in marine mammals. Mar Ecol Prog Ser 281: 303-306.

Graeve, M., Hagen, W., and Kattner, G. 1994. Diet-induced changes in the fatty acid composition of Arctic herbivorous copepods: experimental evidence of trophic markers. Journal of Experimental Marine Biology and Ecology, 182: 97-110.

Graeve, M., Albers, C., and Kattner, G. 2005. Assimilation and biosynthesis of lipids in Arctic *Calanus* species based on 13C feeding experiments with a diatom. Journal of Experimental Marine Biology and Ecology, 317: 109-125.

Hanson, S.W.F and Olley, J. 1963. Application of the Bligh and Dyer method of lipid extraction to tissue homogenates. *Biochem. J*. 89:101-102

Haug, T., Gjøsæter, H., Lindstrøm, U. and Nilssen, K.T. 1995. Spatial and temporal variations in Northeast Atlantic minke whale *Balaenoptera acutorostrata* feeding habits. *In:* Blix, A.S., Walløe, L. and Ulltang Ø. (eds), *Developments in Marine Biology 4. Whales, seals, fish and man*. Elsevier, Science, B.V. Amsterdam, the Netherlands. pp225-239

Haug, T., Lindstrøm, U., Nilssen, K.T., Røttingen, I. and Skaug, H.J. 1996. Diet and food availability for Northeast Atlantic minke whales, *Balaenoptera acutorostrata*. *Rep. Int. Whal. Commn.* 46:371-382

Horwood, J. 1990. Biology and exploitation of the minke whale. CRC Press, Inc., Boca Raton, Florida. 238pp.

Hooker, S.K., Iverson, S.J., Ostrom, P. and Smith S.C. 2001. Diet of northern bottlenose whales inferred from fatty-acid and stable-isotope analyses of biopsy samples. *Can. J. Zool.* 79:1442-1454

Jonsgård, A. 1982. The food of minke whales (*Balaenoptera acutorostrata*) in northern North Atlantic waters. *Rep. Int. Whal. Commn.* 32:259-262.

IWC (International Whaling Commission) 2004. Report of the Scientific Committee. Annex O. Report of the standing working group on scientific permit proposals. J. Cetacean Res. Manage. 6 (SUPPL): 350-366.

Kawamura, A. 1994. A review of baleen whale feeding in the Southern Ocean. *Rep. Int. Whal. Commn.* 44:261-271

Kirch, P.E., Iverson, S.J., Bowen, W.D., Kerr, S.R. and Ackman, R.G. 1998. Dietary effects on the fatty acid signature of whole Atlantic cod (*Gadus morhua*). *Can. J. Aquat. Sci.* 55:1378-138.

Klinowska, M. 1991. *Dolphins, porpoises and whales of the world. The IUCN red data book.* IUCN, Gland, Switzerland and Cambridge, U.K.

Koopman, H.N., Iverson, S.J. and Gaskin, D.E. 1996. The influence of phylogeny and age-related differences in blubber fatty acids of the male harbour porpoise (*Phocoena phocoena*), *J. Comp. Physiol. B*. 165:628-639

Lee, R.F., Nevenzel, J.C. and Paffenhöfer, G.A. 1971. Importance of wax esters and other lipids in marine food chain: phytoplankton and copepods. Marine Biology, 9: 99-108.

Lockyer, C. 1984. Age determination by means of earplug in baleen whales. *Rep. Int. Whal. Commn.* 34:692-696 and 683-684(refs)

Marine Research Institute 2003. A programme for a two year feasibility study on cetaceans in Icelandic waters. IWC SC/55/O2-revised. Reykjavik, 63 pps

Møller, P. (MS) 1999B. Evidence of a defined shift in the fatty acid composition along the blubber profile of harbour porpoise (*Phocoena phocoena*): The physiological significance. Univestity of Aarhus, Denamark

Olsen, E. and Grahl-Nielsen, O. 2003. Blubber fatty acids of minke whales: stratification, population identification and relation to diet. *Marine Biologi.* 142:13-24

Pierce GJ, Boyle PR (1991) A Review of Methods for Diet Analysis in Piscivorous Marine Mammals. Oceanogr Mar Biol Annu Rev 29:409–486

Sigurjónsson, J. Galan, A. and Víkingsson, G.A. 2000. A note on stomach contents of minke whales (*Balaenoptera acutorostrata)* in Icelandic waters. *NAMMCO Sci. Publ.* 2:82-9

Tamura, T. and Fujise, Y. 2002. Geographical and seasonal changes of prey species of minke whale in the Northwestern Pacific. *ICES J. Mar. Sci.* 59:516-528

Table 1. Overview of the sampled minke whales. Identity of the whales, day of sampling, sex, length, sampling area (N: North, S: South) and stomach contents (Marine Research Institute unpublished data provided by Bjarki Elvarsson).

Number	Day	Month	Year	Sex	Length (cm)	Area	Stomach content (% weight)
B0301	18	August	2003	M	520	S	sandeel (100%)
A0302	23	August	2003	F	797	N	sandeel (71%), krill (29%)
A0304	26	August	2003	M	508	N	sandeel (99.5%), capelin (0.5%)
A0306	29	August	2003	M	739	N	capelin (100%)
B0305	31	August	2003	F	861	S	sandeel (100%)
A0308	31	August	2003	M	697	N	b.whiting (20%), cod (20%), n. pout (20%), whiting (20%)
C0307	6	Sept.	2003	F	730	N	cod (99%), capelin (1%)
C0308	8	Sept.	2003	F	810	S	sandeel (100%)
A0311	16	Sept.	2003	F	526	N	sandeel (100%)
A0313	30	Sept.	2003	M	567	N	sandeel (100%)
A0403	22	June	2004	F	858	N	capelin (88%), cod (12%)
A0405	26	June	2004	F	761	N	sandeel (100%)
A0406	4	July	2004	F	819	N	krill (100%)
A0604	17	June	2006	M	606	N	krill (100%)
B0601	22	June	2006	M	797	S	herring (99%), sandeel (1%)
B0602	24	June	2006	M	700	S	herring (100%)
A0601	24	June	2006	M	775	N	krill (52%), haddock (36%), capelin (10%)
A0607	19	July	2006	F	461	N	krill (75%), northern krill (25%)
C0610	20	July	2006	F	858	N	capelin (100%)
B0608	21	July	2006	F	805	S	na
D0604	26	July	2006	M	750	S	herring (100%)
D0609	18	August	2006	M	789	S	sandeel (100%)
D0610	20	August	2006	M	740	S	haddock (99%), saite (1%)

Table 2. FA composition (mass %) in the total lipid of the outer blubber of minke whales around Iceland the years 2003, 2004 and 2006

	A0302	A0304	A0306	A0308	A0311	A0313	A0403	A0405	A0406	A0607	B0301	B0305	B0601	B0602	B0608	C0307	C0308	C0610	D0604	D0609	D0610	A0604	A0601
Fatty acids (%)																							
12:0	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1
14:0	4.1	4.4	3.9	3.7	3.9	4.1	3.5	3.5	3.6	4.2	4.5	3.8	4.2	4.3	3.6	3.5	4.3	3.6	4.3	4.1	4.2	3.4	3.6
14:1	0.7	0.5	1.0	1.0	0.6	0.9	0.9	0.9	0.9	0.6	0.8	0.9	0.8	1.1	1.0	1.0	0.9	1.1	1.2	1.0	0.8	0.7	1.1
15:0	0.3	0.4	0.3	0.2	0.3	0.4	0.2	0.3	0.2	0.3	0.5	0.3	0.3	0.3	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.3
16:0	10.4	10.5	7.6	7.3	8.8	7.2	7.1	8.4	8.5	8.6	9.0	7.5	7.1	6.1	6.2	6.4	7.4	6.1	6.7	6.7	8.1	7.2	6.5
16:1n9	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.2	0.3	0.3	0.3
16:1n7	12.1	12.6	12.9	15.3	12.4	13.4	13.7	15.2	13.5	14.1	11.5	12.4	10.9	10.2	11.2	14.8	12.8	13.2	12.0	9.3	9.8	12.9	12.7
16:2n4	0.9	0.7	0.8	0.8	0.7	0.8	0.8	0.9	0.8	0.6	0.8	0.9	0.9	0.8	0.8	0.9	0.9	0.7	0.9	0.8	0.9	0.8	0.8
16:3n4	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0
17:0	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.3	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.2
18:0	2.5	2.4	1.8	1.5	2.0	1.4	1.8	1.9	2.0	1.6	1.8	2.0	2.2	1.7	1.6	1.5	1.7	1.3	1.5	1.9	2.2	1.9	1.7
18:1	2.2	2.0	2.7	2.8	2.9	3.0	3.2	1.9	2.3	3.4	1.8	2.9	3.4	4.2	3.6	3.3	3.0	3.5	4.0	3.8	3.3	2.7	3.2
18:1n9	22.6	18.0	24.2	22.8	18.6	20.4	23.6	25.1	25.3	17.5	21.5	20.4	23.5	21.2	24.1	24.7	17.8	24.4	20.7	21.5	22.2	21.1	25.6
18:1n7	5.7	5.2	4.9	5.4	4.3	4.1	5.4	6.3	6.1	4.4	4.9	3.9	3.4	2.9	4.1	5.2	3.4	4.7	3.8	3.0	3.4	4.2	3.9
18:1n5	0.4	0.5	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.6	0.4	0.4	0.4	0.3	0.4	0.5	0.4	0.4	0.3	0.3	0.3	0.5	0.4
18:2n6	1.6	1.7	1.9	1.6	1.3	1.5	1.7	1.7	1.8	1.6	2.2	1.5	1.6	1.7	1.5	1.7	1.4	1.6	1.4	1.5	1.5	1.6	1.6
18:3n6	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18:3n3	0.7	0.7	0.9	0.7	0.6	0.6	0.7	0.7	0.8	0.7	0.7	0.7	0.8	0.9	0.7	0.7	0.7	0.7	0.6	0.8	0.7	0.8	0.8
18:4n3	0.7	0.9	0.8	0.7	0.7	0.7	0.6	0.5	0.6	1.1	1.0	0.7	0.7	0.8	0.5	0.5	0.9	0.7	0.5	0.7	0.7	0.7	0.6
20:0	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.2
20:1n11	1.8	1.8	2.6	2.8	3.0	2.7	2.8	1.9	2.0	3.0	1.7	2.4	3.2	4.4	3.4	3.1	3.0	3.6	3.6	4.3	3.1	2.5	3.0
20:1n9	5.8	8.2	8.0	8.7	10.4	10.0	8.9	5.7	6.8	11.1	7.2	7.7	9.1	11.2	9.7	8.1	9.6	11.3	11.3	10.6	9.5	10.3	8.4
20:1n7	0.3	0.4	0.3	0.5	0.5	0.6	0.4	0.4	0.4	0.6	0.4	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.4
20:2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
20:3n6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
20:3n3	0.8	1.0	0.9	1.0	1.2	1.3	1.0	0.8	0.7	1.3	1.1	0.9	0.9	1.0	0.9	0.9	1.0	1.0	1.1	1.0	1.2	1.2	0.9
20:4n3	0.9	1.0	1.0	1.1	0.9	0.8	0.7	1.0	0.8	1.3	1.1	0.8	0.8	0.8	0.7	0.9	0.7	0.7	0.6	0.7	0.8	1.1	0.8
20:5n3	3.5	4.2	3.5	3.9	3.8	3.4	2.7	3.4	3.0	3.6	3.8	3.8	2.5	2.3	2.0	3.3	4.1	2.2	2.4	2.0	2.7	3.2	2.6
21:0	0.2	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.0	0.1	0.2	0.2	0.1	0.2	0.0	0.1	0.1	0.2	0.2	0.1	0.1	0.1
22:0	0.2	0.1	0.0	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
22:1n11	5.5	5.0	5.5	5.5	7.1	5.7	6.4	3.9	4.1	7.2	2.9	6.5	7.2	7.9	7.2	4.9	7.8	6.8	9.6	8.7	8.1	5.6	5.2
22:5n3	2.8	2.8	2.4	2.3	2.3	2.3	2.1	2.6	2.5	1.8	2.6	2.9	2.0	2.2	2.2	2.5	2.5	1.4	1.7	2.1	2.3	2.4	2.2
22:6n3	4.6	6.2	4.1	3.2	4.8	5.8	3.4	4.2	4.2	3.8	8.7	6.1	4.0	4.2	3.9	3.4	5.2	2.8	2.7	4.4	4.4	6.0	4.7
23:0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.2	0.1	0.1	0.0	0.1	0.0	0.1	0.2	0.1	0.0	0.1
24:1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.3	0.3	0.2	0.1
unknown	7.3	7.2	6.6	5.9	6.9	7.2	6.6	7.0	7.2	6.0	7.4	8.2	7.8	7.3	8.1	6.4	8.3	6.2	7.0	8.3	7.5	7.0	7.7
20:1+22:1	13.5	15.5	16.4	17.4	21.0	18.9	18.5	11.9	13.2	21.9	12.1	17.1	19.8	23.9	20.6	16.4	20.7	22.1	24.8	23.9	20.9	18.9	17.0

Table 3. FA composition (mass %) in the total lipid of the inner blubber of minke whales around Iceland the years 2003, 2004 and 2006

	A0302	A0304	A0306	A0308	A0311	A0313	A0403	A0405	A0406	A0607	B0301	B0305	B0601	B0602	B0608	C0307	C0308	C0610	D0604	D0609	D0610	A0604	A0601
Fatty acids (%)																							
12:0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
14:0	5.3	5.2	5.6	6.2	5.0	5.3	5.4	5.4	4.5	5.0	5.8	5.1	6.1	3.9	6.0	5.4	6.4	5.6	6.0	3.5	6.3	6.1	4.7
14:1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.7	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.3
15:0	0.4	0.4	0.3	0.3	0.4	0.7	0.2	0.3	0.3	0.3	0.7	0.4	0.3	0.2	0.3	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.2
16:0	16.8	14.0	11.5	10.8	14.6	16.1	10.0	10.7	13.9	14.8	16.5	13.8	11.4	6.6	10.6	10.8	14.6	12.5	11.2	13.2	13.6	17.6	7.2
16:1n9	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2
16:1n7	7.4	6.2	6.6	6.5	6.5	4.1	5.4	6.2	7.4	5.5	5.2	5.5	4.8	7.9	4.7	5.8	6.4	4.9	4.9	4.1	5.2	6.1	5.0
16:2n4	0.8	0.5	0.7	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.7	0.5	0.5	0.6	0.6	0.6	0.7	0.5	0.5	0.5	0.6	0.7	0.3
16:3n4	0.2	0.0	0.2	0.2	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.2	0.2	0.1	0.1	0.0	0.1	0.1	0.0
17:0	0.3	0.4	0.2	0.1	0.4	0.9	0.2	0.2	0.2	0.2	0.7	0.4	0.3	0.2	0.2	0.2	0.3	0.2	0.3	0.5	0.3	0.3	0.2
18:0	3.5	3.2	2.7	1.7	3.3	4.2	2.5	2.4	2.8	3.1	3.7	3.4	2.9	2.6	2.6	2.2	3.2	2.2	2.5	4.7	2.9	3.4	2.4
18:1	0.9	0.8	1.5	1.9	1.0	0.8	2.1	1.7	1.5	2.9	0.5	1.2	2.4	3.7	2.8	2.0	1.2	1.8	1.9	2.5	1.6	1.1	2.1
18:1n9	15.8	12.9	11.6	10.2	13.9	19.1	14.9	15.9	18.7	18.2	18.2	13.5	13.5	18.3	11.0	12.7	10.7	12.2	13.0	19.0	10.8	14.4	19.6
18:1n7	4.9	2.2	2.4	2.4	2.4	3.4	3.0	3.8	5.1	6.1	4.0	2.3	2.7	2.6	2.4	2.9	2.4	3.2	2.6	3.4	2.0	6.2	3.2
18:1n5	0.3	0.3	0.3	0.5	0.4	0.3	0.4	0.4	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.4
18:2n6	1.0	1.4	1.0	0.9	1.5	1.8	1.1	0.9	0.9	1.5	1.8	1.2	0.9	1.5	0.9	1.0	0.9	1.1	0.9	1.3	1.2	1.4	1.2
18:3n6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.0
18:3n3	0.5	0.8	0.6	0.6	1.1	0.8	0.5	0.4	0.5	0.5	0.8	0.7	0.5	0.6	0.5	0.6	0.5	0.5	0.5	0.9	0.7	0.6	0.4
18:4n3	1.2	1.9	1.6	1.8	1.9	1.4	1.1	0.9	1.1	0.9	1.6	1.6	0.6	0.6	1.0	1.8	1.5	2.5	1.1	1.1	2.1	0.9	0.6
20:0	0.2	0.2	0.2	0.1	0.2	0.3	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.3	0.2	0.1	0.2	0.2	0.2	0.3	0.2	0.2	0.3
20:1n11	0.7	0.7	1.4	1.6	0.9	0.8	2.2	1.7	1.2	3.8	0.4	1.0	2.9	4.7	2.8	1.8	1.1	2.0	1.9	2.2	1.4	1.5	2.4
20:1n9	3.7	4.6	10.0	14.2	5.0	3.5	14.3	13.5	6.2	11.7	2.5	5.4	11.7	12.0	11.5	12.9	8.2	12.3	11.4	7.2	8.3	7.8	15.6
20:1n7	0.4	0.2	0.3	0.5	0.2	0.3	0.7	0.8	0.3	0.8	0.4	0.3	0.3	0.3	0.3	0.6	0.3	0.4	0.4	0.4	0.2	0.4	0.9
20:2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.6	0.3	0.2	0.2
20:3n6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
20:3n3	0.7	1.0	1.4	2.1	0.9	0.9	1.9	1.8	1.0	1.4	1.0	0.9	1.2	1.6	1.2	1.8	1.2	1.5	1.5	1.2	1.3	1.2	2.3
20:4n3	0.7	1.1	0.9	0.8	1.1	1.1	0.6	0.5	0.8	0.6	1.0	1.0	0.4	0.5	0.9	0.9	0.7	0.9	0.7	1.1	1.2	0.6	0.4
20:5n3	7.3	6.9	6.6	5.3	5.2	3.9	3.0	3.1	6.2	4.7	4.5	6.9	2.3	1.9	3.6	5.5	6.5	4.9	4.0	3.1	5.8	6.2	1.4
21:0	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.0	0.1	0.4	0.5	0.1	0.3	0.1	0.1	0.1	0.2	0.2	0.0	0.0	0.2
22:0	0.5	0.3	0.1	0.1	0.3	0.3	0.1	0.2	0.2	0.0	0.2	0.3	0.3	0.2	0.3	0.1	0.2	0.1	0.3	0.2	0.1	0.1	0.1
22:1n11	3.9	6.5	11.5	15.9	7.5	2.7	11.6	11.9	6.7	5.7	1.6	6.3	16.8	10.8	14.6	13.0	9.8	11.7	14.3	7.0	12.0	8.7	13.3
22:5n3	2.9	2.6	2.4	1.4	2.5	3.3	2.3	2.0	2.8	1.6	3.0	4.0	1.6	1.4	3.0	2.0	2.7	1.8	2.3	1.9	2.3	1.7	1.6
22:6n3	7.9	14.5	8.3	4.3	10.9	11.5	5.9	5.2	7.2	2.7	12.9	11.6	3.9	2.4	6.6	5.3	7.8	6.3	6.8	5.9	9.8	3.4	3.9
23:0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.0	0.1	0.3	0.5	0.1	0.2	0.0	0.1	0.0	0.2	0.4	0.0	0.0	0.1
24:1	0.4	0.5	0.6	0.4	0.6	0.3	0.7	0.5	0.3	0.1	0.3	0.6	0.5	0.9	0.5	0.5	0.6	0.6	0.5	0.8	0.6	0.3	0.7
unknown	10.2	9.3	8.4	7.8	10.0	10.3	8.1	7.8	7.8	5.8	10.1	10.1	8.9	11.7	9.2	7.8	9.9	8.2	8.3	11.2	7.6	7.5	8.2
20:1+22:1	8.7	12.0	23.3	32.2	13.7	7.3	28.9	27.8	14.5	21.9	4.9	12.9	31.7	27.7	29.1	28.2	19.5	26.4	28.0	16.8	21.9	18.4	32.2

Table 4. FA composition (mass %) in the total lipid of the blood tissue of minke whales around Iceland the years 2003 and 2004.

	A0302	A0306	A0308	C0313	A0405	A0406	C0307	C0304
Fatty acids (%)								
12:0	0.1	0.1	0.2	0.5	0.1	0.1	0.1	0.1
14:0	2.3	4.7	2.7	1.9	2.1	2.3	4.2	3.2
14:1	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.0
15:0	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3
16:0	16.4	11.9	11.9	11.4	12.7	15.0	11.3	13.8
16:1n9								
16:1n7	3.2	5.9	4.6	1.9	2.8	3.4	5.0	3.3
16:2n4	0.5	0.6	0.6	0.5	0.5	0.5	0.6	0.5
16:3n4	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1
17:0	0.5	0.3	0.3	0.7	0.6	0.4	0.3	0.4
18:0	7.1	5.2	6.7	10.5	7.8	8.1	5.0	8.2
18:1	0.6	1.4	3.1	0.6	1.6	0.7	1.5	1.0
18:1n9	23.8	8.0	13.6	11.7	19.3	15.6	9.7	14.3
18:1n7	3.6	1.9	3.0	2.1	4.0	5.4	2.2	2.2
18:1n5	0.2	0.4	0.5	0.2	0.3	0.2	0.3	0.2
18:2n6	0.9	1.5	1.3	1.5	0.8	0.9	1.5	1.0
18:3n6	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0
18:3n3	0.3	0.6	0.5	0.5	0.4	0.3	0.6	0.3
18:4n3	0.4	1.6	0.6	1.0	0.5	0.6	1.7	0.8
20:0	0.6	0.4	0.4	1.1	0.7	0.6	0.3	0.5
20:1n11	0.4	1.6	2.6	0.6	1.2	0.6	1.4	1.0
20:1n9	1.3	5.4	4.4	1.1	3.2	1.0	5.8	2.7
20:1n7	0.2	0.1	0.2	0.2	0.4	0.3	0.2	0.2
20:2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
20:3n6	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
20:3n3	1.6	2.3	1.9	4.2	2.3	2.3	2.1	2.3
20:4n3	0.5	0.8	1.1	1.5	0.7	0.6	1.0	0.6
20:5n3	8.8	17.4	12.5	13.6	10.0	14.8	16.9	13.4
21:0	0.2	0.0	0.1	0.1	0.3	0.0	0.0	0.1
22:0	0.7	0.1	0.1	0.4	0.6	0.1	0.1	0.2
22:1n11	1.1	7.2	3.6	1.0	2.3	1.0	6.8	3.4
22:5n3	3.5	1.6	3.5	3.5	2.9	3.8	1.9	4.0
22:6n3	7.0	5.8	6.7	9.7	4.7	5.0	6.3	7.1
23:0	0.2	0.0	0.0	0.2	0.3	0.0	0.0	0.1
24:1	0.8	1.0	0.8	1.4	1.1	0.9	0.9	1.2
unknown	12.2	10.9	12.0	15.3	15.1	14.6	11.5	13.3
20:1+22:1	3.0	14.3	10.8	2.9	7.0	2.9	14.2	7.2

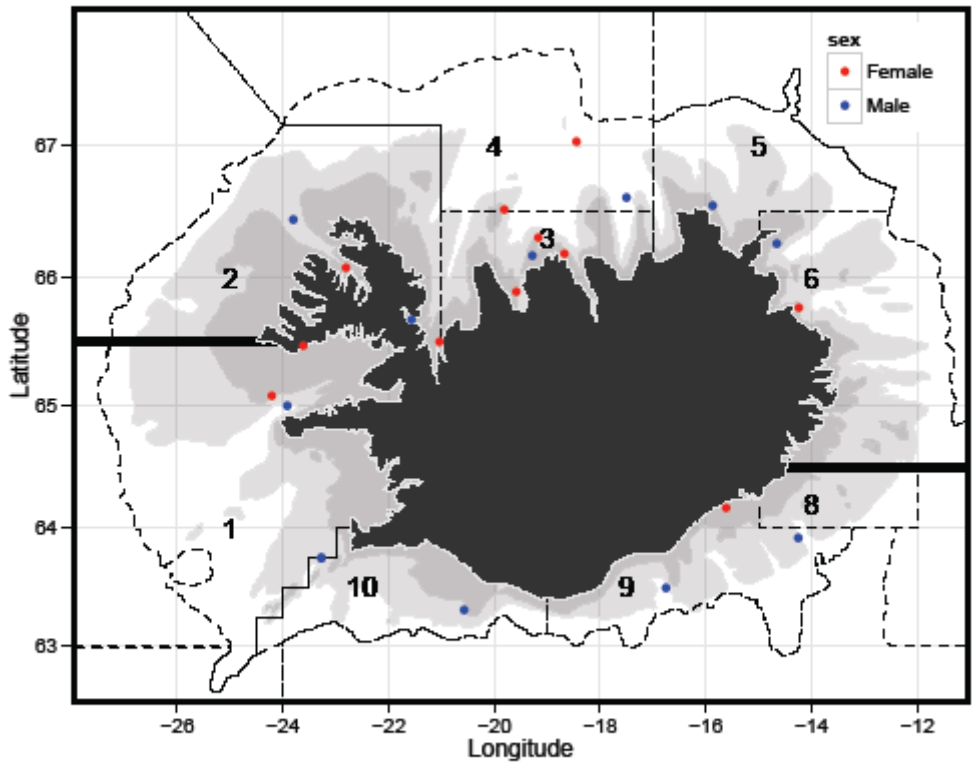

Figure 1. Map showing catch positions for 23 minke whales, which were analysed for fatty acids, the years 2003, 2004 and 2006.

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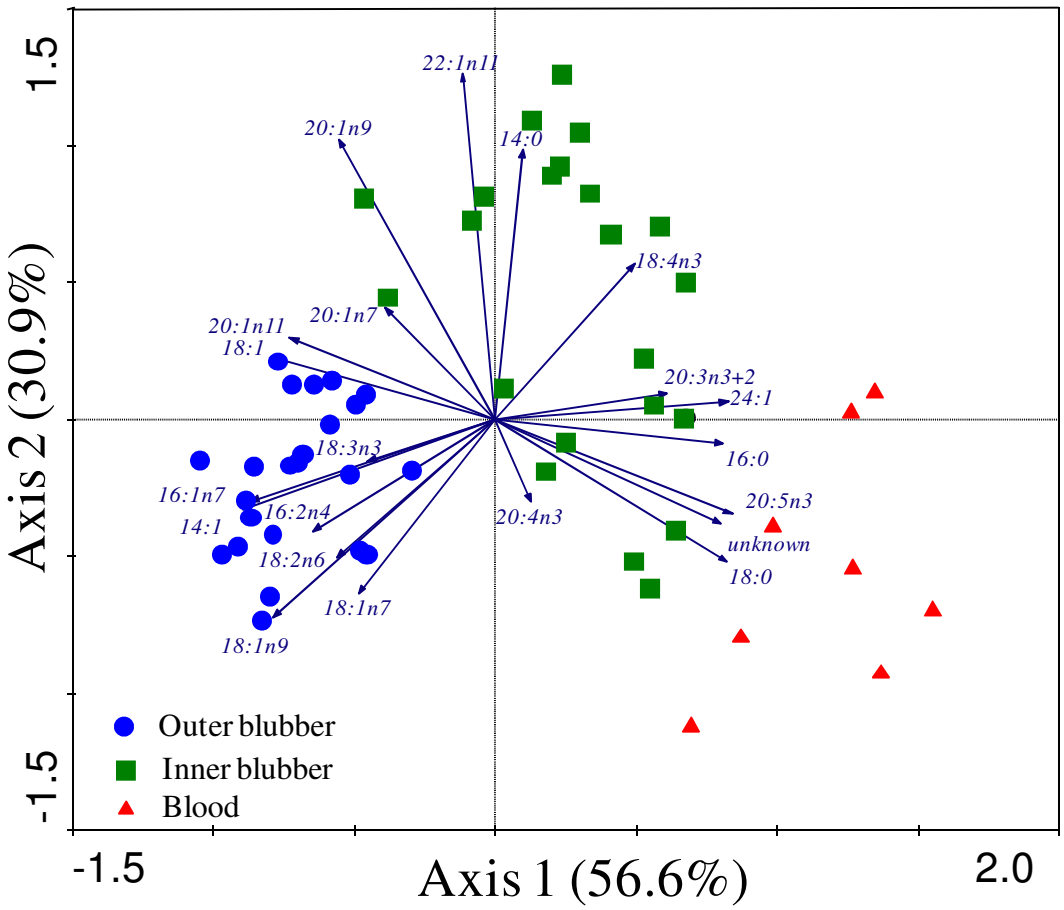


Figure 2. Total lipids of minke whales: principal component analysis (PCA) of relative FA composition of outer blubber, inner blubber and blood tissue of minke whales around Iceland 2003, 2004 and 2006. Arrows point in the direction of steepest increase of respective fatty acid. The percentage of FA variance explained by each axis is given in parenthesis

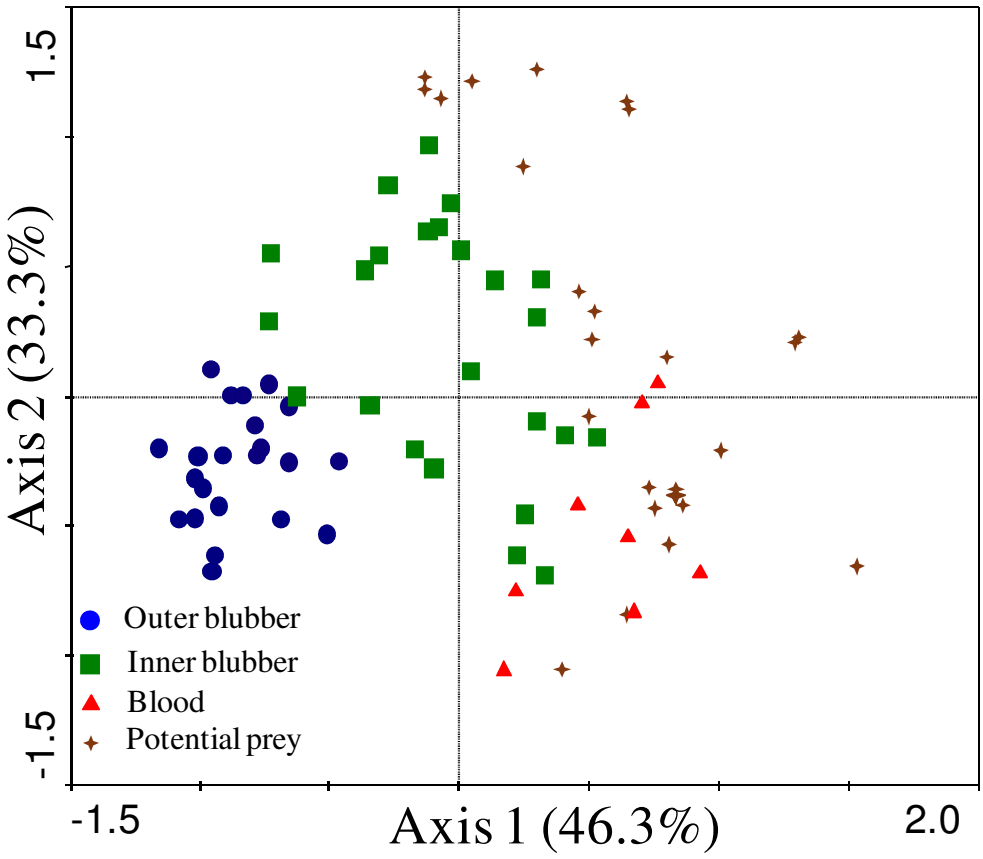


Figure 3. Total lipids of minke whales: principal component analysis (PCA) of relative FA composition of outer blubber, inner blubber, blood tissue and the potential prey of minke whales of minke whales around Iceland 2003, 2004 and 2006. The percentage of FA variance explained by each axis is given in parenthesis.

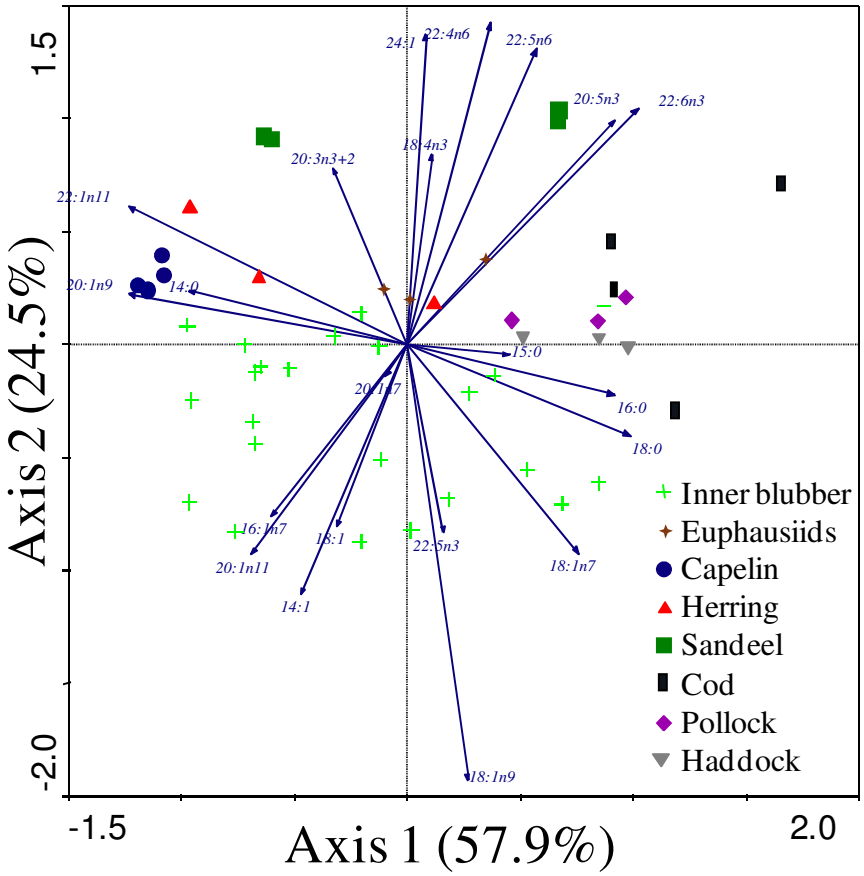
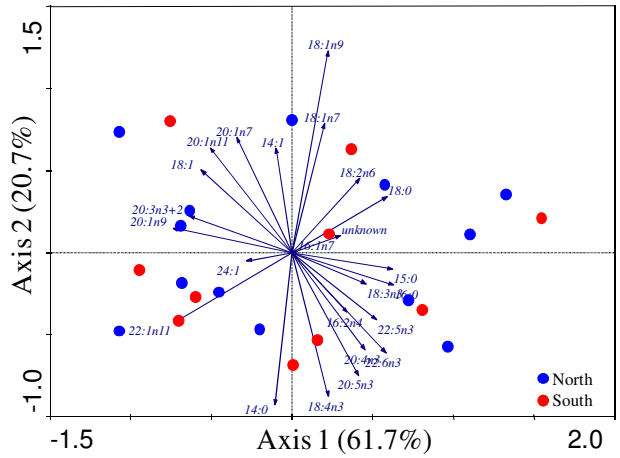
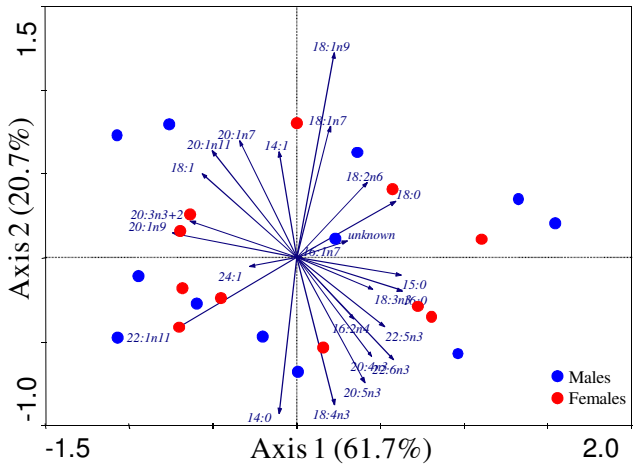


Figure 4. Total lipids of minke whales: principal component analysis (PCA) of relative FA composition inner blubber and the potential prey of minke whales around Iceland 2003, 2004 and 2006. Arrows point in the direction of steepest increase of respective fatty acid. The percentage of FA variance explained by each axis is given in parenthesis.

A)



B)



C)

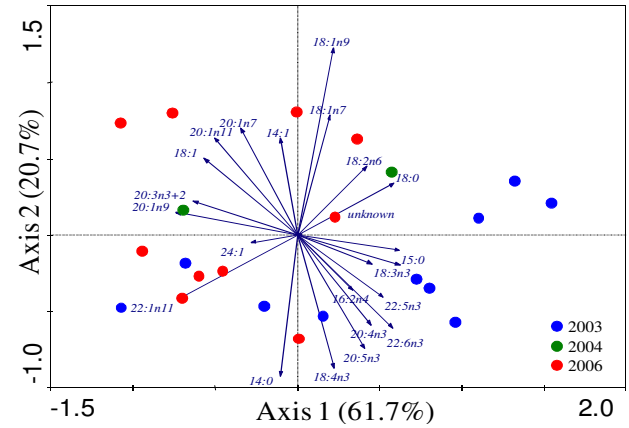


Figure 5. Total lipids of minke whales: principal component analysis (PCA) of relative FA composition in the inner blubber of minke whales around Iceland 2003, 2004 and 2006. Comparisons between A) North and South B) Male and Females and C) the years sampled, 2003, 2004 and 2006.Arrows point in the direction of steepest increase of respective fatty acid. The percentage of FA variance explained by each axis is given in parenthesis.