Morphometric comparison of common minke whales *Balaenoptera acutorostrata* from different areas of the North Atlantic, including animals from Icelandic waters

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Abstract

This paper is an "extension" of the paper of Christensen et al. (1990), including Icelandic data, from 2003 – 2009,. Multivariate statistical analyses of 17 morphometric characters were performed in order to evaluate potential heterogeneity between predefined common minke whales stock unit areas in the North Atlantic (West Greenlandic, East Greenlandic, and Icelandic waters, North Seas and Norwegian and Barents Sea. Results from principal component analyses (PCA), multivariate analyses of variance (MANOVA), linear discriminating analyses (LDA) and cluster analyses (CA), suggest that data cannot be regarded as random samples drawn from one uniform distribution. Males could best be divided into two clusters, eastern and western N-Atlantic common minke whales, however, females could best be divided into three groups; eastern, central and western N-Atlantic common minke whales. The overlap between groups was too substantial, however, to allow a firm conclusion concerning the question of isolated breeding stocks versus a large common breeding pool. It is important to note that common minke whales are caught in their feeding areas during the summer in northern waters and their breeding areas are not well documented. Therefore breeding segregation is unknown, even so segregation in relation to sex and size has been observed on the feeding grounds.

Key words: common minke whale, *Balaenoptera acutorostrata*, stock identification, morphometry, principal component analyses, discriminating analyses, cluster analyses, North Atlantic

[1] Retired.

Introduction

The minke whale (*Balaenoptera acutorostrata* Lacepède, 1804) is the smallest species of rorqual or balaenopterid whale (Plate 1). According to (Brinkmann 1967) the minke whale was first described by Fabricius in 1780 and he assigned it to *Balæna rostrata* (Horwood 1990).

The common minke whale is generally easy to distinguish from the larger rorquals. The head is extremely pointed and the median head ridge is prominent. The dorsal fin is tall, recurved, and located about 2/3 of the way back from the snout tip. There are 30 - 70 moderately short ventral pleats (often extending just past the flippers) and 231 - 360 pairs of white to grayish baleen plates. The color is dark grey dorsally and white beneath, with streaks or lobes of intermediate shades on the sides or both. Across each flipper is brilliant white band (Jefferson et al. 1993).

Víkingsson (1990), did morphometric analyses on sei whales (*Balaenoptera borealis*) caught in Icelandic waters in 1986-87, and the results indicated a relative isometric growth, with slight tendency towards positive allometry of the head region. The Icelandic data showed more resemblance to North-Pacific data on sei whales, than to Southern Hemisphere data. Víkingsson (1992) used discrimination analyses to show morphometric differences in fin whales (*Balaenoptera physalus*) caught In Icelandic waters and off Spain, supporting Jover (1986) conclusion on the same issue that they did differ in some morphologic traits.

Segregation by sex has, however, been observed by studying whalers logbooks, the early catch-data indicating males arriving later than the females, and females migrating further north than males,(Sigurjónsson 1982). From catch data Jonsgård (1951) and Christensen (1974) found that in the Norwegian Sea and Barents Sea minke whales are segregated by size and sex. In Greenlandic waters sexual segregation of minke whales has clearly been described by Laidre et al. (2009), indicating the positive influence of latitude and/or temperature on female/male ratio, where they rule out effect of demography and whaling, but suggested hypothetically that female minke whales move farther north in warmer years. Sea-temperature, however, unlikely being the driving factor of observed changes in sex ratio directly, but may be a proxy for temperature-driven large-scale ecological conditions that stimulate prey abundance and/or prey species composition. Further Laidre et al. (2009) found probable that pregnant females may separate socially to avoid niche overlap or to avoid males. Horwood (1990) in his monograph on the minke whale's biology and exploitation, points out that studies of blubber thickness have revealed a complicated spatial and temporal segregation and migration of the different sexual classes, and elucidates several factors influencing segregation of the sexes, e.g. inter-specific relationships with other whale species, population size, reproductive status, sexual condition and maturity, and also environmental factors as surface temperatures.

The distribution of minke whales is generally closer to coast than that of larger rorquals. Migrations in Icelandic waters are not well documented, although recent satellite telemetry studies have provided some information on movements, including a single autumn migration from Iceland to the waters off West Africa (SC/F13/SP18, Víkingsson 2005). Minke whales have been observed in all parts of Icelandic waters in all seasons and caught as late as in November some years, even though it seems most abundant off the coast of Iceland in the months May to September (Sigurjónsson & Víkingsson 1997), with high abundance spots in Faxaflói and off the Southeast-coast. There is also a recent evidence for vagrant Antarctic minke whales (*B. bonaerensis*) occurring in the N-Atlantic (Glover et al. 2010).

Morphology of minke whales have been studied in the southern seas, in the Sea of Japan and in the North-Atlantic, for population identification purposes (Van Beek and van Biezen 1982; Kato et al. 1992; Christensen et al. 1990). As a part of the Marine Research Institute's research programme on minke whales (Marine Research Institute 2003) a total of 35 morphologic dimensions were measured on 172 common minke 0+ whales and 33 on 39 foetus. This paper describes the "reanalyzes" of Christensen et al. (1990) data, by including those new morphometric measurements of common minke whales from Icelandic waters caught in 2003-2007 (Fig. 1).

Material and Methods

In total 324 common minke whales males from the five areas were included in the analyses (Table 1). The number of females studied was 592, from western and eastern Greenlandic waters, Icelandic waters and from the Barents Sea. Unfortunately the female material from the areas around the United Kingdom was too small to be included in the analyses (Christensen et al. 1990).

The morphometric data used by Christensen et al. (1990) was from minke whales collected in the period 1972-1988 in four different areas of the North-Atlantic, for collecting and processing methods see figure 1 in Christensen et al. (1990). Totally, were 18 morphologic dimensions measured (in cm) on zero and older (0+) whales. The Icelandic material from animals of age where measurements from common minke whales caught, in the period of 2003-2009 (Table 1) and were included in the new analyses (Fig. 1). Methods of measurements and processing of data is available in Hauksson et al. (2012a). Definitions of the dimensions measured in both studies are given in Table 2, and their placement on the whale see figure 1 in Christensen et al. (1990). Because of occasional missing values in the morphometric measurements database, particularly missing females in The North-Sea, and also due to sexual differences in size, each dimension was analyses separately for each sex. Average, standard deviation (SD) and range (min – max), were calculated (Table 3).

Principal Component Analyses (PCA) was performed on the data, which transforms the original variables into new variables that have zero inter-correlation, so that the new axes define independent patterns of variation. Frequently the first axes has high and positive correlation and is interpreted as representing the size or growth variation in the material, while other components have correlation of different signs and magnitude and are interpreted as representing shape variation (Zuur et al. 2007). Multivariate homogeneity of within-group covariance was tested with the betadisper function from the R's vegan package (Oksanen et al. 2010). The scores from the PCA were then subjected to a multiple analyses of variance (MANOVA), which was further analyzed within groups, and also a linear discriminant analysis (LDA), to assess variation between areas, and finally a cluster analyses (CA) to define possible groupings in the data. Statistical analyses were performed with R packages: MASS**,** lattice and scatterplot3d (R Development Core Team 2010; Verzani 2005; Everitt and Hothorn 2010; Borcard et al. 2011), Venables, and Ripley 2002; Sarkar 2009; Ligges and Mächler 2003). Group means, standardized discriminant function coefficients, the canonical eigenvalue, classification of the object, posterior probabilities of the objects to belong to the groups, table of prior versus predicted classifications and proportion of correct classification were calculated. Generalized distance of Mahalanobis (D^2), which estimates the multivariate distance between the compared groups, was computed, it has Chi-squared distribution (Rousseeuw and Leroy 1987), and was used to estimate the percent overlap of the data, by calculating the percentage of the D^2 values that were lower than the reference Chi-squared value for degrees of freedom (df) equal to 17 (number of groups – 1). The cluster analysis was performed with the R package mclust (Fraley et al. 2009), which is model based clustering, which uses classification maximum likelihood, based on Bayesian Information Criterion (BIC) (Everitt and Hothorn 2010). The analyses were performed using only complete cases, i.e. when the data values were available for all variables for any case included in the computation.

Results

There were observed size differences in the common minke whale samples from the different areas. Females and males were largest in W-Greenlandic waters. This size difference also applied to all other dimension measured, whales from other coastal areas taking the second place (Table 3). Correlation of the variables with the first two principal components, together with the percentage accounted for by each component, is shown in Table 4. In both sexes the correlations of PC1 were high and positive. Thus the PC1 reflects the probably the growth or "size" of the dorsal fin and PC2 probably its shape. The other components have correlations of different signs and magnitude and were interpreted as mainly representing shape variation (PC3 – PC17) are not tabulated. Height (M28) and basal length (N13) of the dorsal fin were the two morphometric variables which characterized the common minke whales from the different unit stock areas the most, other size and shape morphometric variables had similar and less characterizing effect (Fig. 2).

MANOVA were run with component one and two ("size and the shape of the dorsal fin") scores included or excluded. Significant differences between the areas were detected from both analyses in both sexes (Table 5). Further within group analyses indicated that minke whale females and males pair-wise were highly significantly different in most all areas. Males from the North-Sea were just marginally significantly (at the 5% level) different from males from the East-Norwegian and Barents Sea, and males from the North-Sea were only significantly different from males caught in East Greenlandic waters (at the 1% level). And at that significance level also, females from east and west Greenlandic waters differed from each other. Generalized difference of Mahalanobis D^2 indicated that all whales from all sampled areas, were highly significantly different from each other (Table 6). Controversially the overlaps between whales from all areas interchangeably were very high, greater than 85% in all cases.

LDA classified correctly males and females respectively about 60 and 65 percent to their group of origin. The worse classification cases were E-Greenlandic and North-Sea males (25.0% and 26.3% respectively) and E-Greenland and Icelandic waters females (10.0% and 22.2% respectively) (Table 7). No clear grouping was readable from the distribution of individual whales in the coordinate system of first and second canonical variates for either females (4 groups) or males (5 groups), centroids of each area were quite close to each others and the samples forming one dens cloud with "outliers" on the periphery (Fig. 3).

Cluster analyses revealed that in case of the common minke whale males the best model was an ellipsoidal, unconstrained model with two components (groups). The first one was composed of 233 and the second of 76 males, In case of the female common minke whale samples in the North-Atlantic, the best model was an ellipsoidal, equal shaped model with three components (groups), with 414, 90 and 50 female common minke whales in group 1, 2 and 3 respectively, Table 8 gives the classification criteria. Males are generally bigger in group 2 so that refers to the westward areas of the Atlantic. Females were smallest in group 1, biggest in group 2 and intermediate in group 3. Group 1, therefore referring to the eastern part of the N-Atlantic, group 2, to the western area and group 3, to the central part.

Discussions

It is important to note that the Icelandic material, used here was much more recent, than the material that Christensen et al. (1990) paper was based on, which was from 1972 – 1988. Any temporal or evolutionary changes in morphology of the common minke whale, during 1988 to 2003, would therefore have effect. Even this period was a quarter of a century, evolutionary changes in morphology during that time period were found improbable. Standard length was not the most size related component, causing the most difference among the whale groups, the basal length (N13) and the height of the dorsal fin (M28) scored much higher in absolute value (Fig. 2 and Table 4). Standard length was about equally important as most other size and shape related components, after the Icelandic data had been incorporated. Basal length and height of the dorsal fin were more correlated to each other than other variables, especially in the females. The other variables were highly correlated, but with similar variance as the variables N13 and M28 (Fig. 2). However Christensen (1990) found standard length ("size") to be the most important component in the older data. His exclusion of it from the analyses did however not change his results. Excluding the basal length and the height of the dorsal fin, in the present study resulted in that males from different areas were not as significantly different as in the full model, however significant still, the females turned out to be as significantly different as before (Table 5). The reason for excluding N13 and M28 from the multivariate analyses, and reanalyzing, was that possible bias in the material caused by different age and/or size distribution may be isolated in this component, and different methods could have been employed by researchers from Iceland and Norway, when measuring the height and base length of the dorsal fin. This however, did not alter the main results, probably because the dorsal fin was not the only morphometric dimension which matters in characterizing common minke whales. As the first two component were a general size component (length and height of the dorsal fin), this means that the whales from West Greenland tend to have larger dorsal fin than the whales from other areas (Table 3). Christensen (1990) did also observe the dorsal fin being higher, in relation to Standard length, in the whales from West Greenland than from elsewhere in the N-Atlantic. The extra importance of the size of the dorsal fin observed after incorporating Icelandic samples, could point to that methods of measuring basal length and height of it were different, among Icelandic and Norwegian whale researchers? Measured dorsal fin height of the Icelandic common minke whales was not totally equal to no. 12. The basal length of the dorsal fin was calculated as; Tip of upper jaw to posterior end of dorsal fin base – Tip of upper jaw to anterior edge of dorsal fin in Icelandic common minke whale data, but the Norwegian way was to measure basal length of dorsal fin directly.

Christensen et al. (1990) described the interrelationship between samples, except the Icelandic, which were not available to him. It was therefore important to investigate the interrelationship between the Icelandic sample and other samples specifically. Do the minke whales caught in Icelandic waters differ significantly from their nearest-neighbor minke whales caught off East-Greenland? Samples of female and male minke whales from that area were similar in total number (Table 1). Females and males caught in Icelandic waters seem to be longer (Table 3) than animals caught off East-Greenland, more similar in size as animals caught off West-Greenland. Result of pair-wise comparison indicates that overall Icelandic common minke whales are significantly different from those caught in Greenlandic waters, east or west. There were, however observed big overlaps, about and over 90%, the highest overlaps among areas in this study (Table 6). A low proportion of the common minke whales caught in Icelandic waters were correctly classified to that area, about 67% and 22%, for males and females respectively. The other common minke whales caught in Icelandic waters and which were not correctly classified to that area were some classified to Greenlandic waters, especially E-Greenland in case of the males and W-Greenland in case of the females (Table 7). Most of the males caught in Icelandic waters therefore probably belong to the west-component of the common minke whale males. However, the females probably belong to a more central-component of the common minke whale females.

The results from the multivariate analyses indicate that the external morphology of the common minke whales was, on the average, different between most of the areas after size variation and effects of biases in growth stages between the areas have been removed. This means that the material cannot be interpreted as random samples from a common, uniform population. There was, however, no indication in the present analyses that the whales (females and males) caught in the Barents Sea were totally different from those caught in Icelandic waters. Both these samples may, therefore, represent the same population. Large overlap values between all samples mean that the established differences do not exclude the possibility of intermixing between all areas. In working with fish-stocks overlap levels of less than 25% was taken as evidence for separate groups (Christensen et al. 1990). Using all these criterions, it became evident that the present results from comparisons of external morphology were not adequate to support the view that the minke whales in the sub-regions of the North Atlantic can be treated as completely isolated populations or stocks.

Conclusions similar to those above were previously obtained in the Antarctic where several attempts have been made to identify minke whale stocks by external morphological characters (Doroschenko 1979; Wada and Numachi 1979). Extensive statistical analyses of these morphological data revealed no clear discrimination between groups separated by the current IWC Area boundaries (van Beek and van Biezen 1982). Similar to the Antarctic, the high degree of overlap among groups in the North-Atlantic prevents any firm conclusions as to whether the minke whales there constitute one large or several small, independent breeding units. The results from the cluster analyses point to east – west trends in morphological differences. Recent studies on sex and size related segregation among minke whales, may indicate that observed differences in size and shape of minke whales in the waters of the North Atlantic may be caused mainly by behavioral traits (Laidre et al. 2009; Hauksson et al. 2012b). Investigations on genetic is needed to answer questions about unit stocks (Andersen et al. 2003; Árnason and Spillaert 1991; Daníelsdóttir et al. 1992 and 1995; Pampoulie et al. 2008). It is important to note that common minke whales are caught in their feeding areas during the summer in the high North and their breeding areas are not well documented. Therefore breeding segregation is unknown, even so segregation in relation to sex and size has been observed on the feeding grounds in the North Atlantic where the common minke whales forage. Antarctic minke whales (*B. bonaerensis*) may also visit the N-Atlantic as vagrants and interbreed with common minke whales (*B. acutorostrata*) in the breeding area (Glover et al. 2010).

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Tables

Table 1. Number of minke whales sampled during 1972 – 1988, at West and East Greenland, around UK, and in Norwegian and Barents Seas, and in Icelandic waters in 2003 – 2009, and used in multivariate comparisons between geographic areas (Fig. 1). Map references refer to figure 1 in Christensen (1990).

Geographic area	Number of males	Number of females	Total
West-Greenland	29	146	175
East-Greenland	72	70	142
Around UK	19	0	19
Norwegian and Barents Seas	119	293	412
Icelandic waters	85	83	168
Total	324	592	916

Table 2. Description of the dimensions measured on the common minke whale (*Balaenoptera acutorostrata*), caught in North-Atlantic waters in 1978-1988 and in Icelandic waters in the period 2003-2009 (Hauksson et al. 2012a).

Nr	Description	Comparable and used or calculated with given formula
1	Tip of upper jaw to notch of flukes (standard length)	+ Tip of upper jaw to notch of flukes (standard length)
2	Tip of upper jaw to center of anus	+ Standard length – Notch of flukes to center of anus
3	Tip of upper jaw to center of genital aperture	+ Standard length – Notch of flukes to center of genital aperture
4	Tip of upper jaw to center of umbiliculus	+ Standard length – Notch of flukes to center of umbiliculus
5	Tip of upper jaw to tip of flipper in its natural position alongside the body	-[2]
6	Tip of upper jaw to posterior end of dorsal fin base	+ Tip of upper jaw to posterior end of dorsal fin base
7	Tip of upper jaw to anterior end of blowhole	+ Tip of upper jaw to anterior end of blowhole
8	Tip of upper jaw to middle of eye	+ Tip of upper jaw to middle of eye
9	Tip of upper jaw to angle of gape	+ Tip of upper jaw to angle of gape
10	Tip of upper jaw to external auditory meatus	+ Tip of upper jaw to external auditory meatus
11	Distance between the eye and ear	+ Tip of upper jaw to external auditory meatus - Tip of upper jaw to middle of eye
12	Dorsal fin height	+ Dorsal fin height [3]
13	Basal length of dorsal fin	+ Tip of upper jaw to posterior end of dorsal fin base – Tip of upper jaw to anterior edge of dorsal fin
14	Flipper maximum width	+ Flipper maximum width
15	Flipper length, posterior insertion to tip	+ Flipper length, posterior insertion to tip
16	Flipper length, anterior insertion to tip and onward to humerus joint	+ Flipper length, anterior insertion to tip [4]
17	Length of tail fluke	+ 2 × Notch of flukes to tip of fluke
18	Width of the tail fluke	+ Notch of flukes to nearest point of leading edge of flukes [5]

[2] Not measured on Icelandic common minke whales and not possible to calculate.
[3] Seemes to be a different method in measuring between Norwegian and Icelandic whale researchers. Hardly comparable measurement of this dimension.
[4] Hardly comparable measurements on this dimension, the Norwegian must be longer, because the Icelandic method was to measure only to the tip.
[5] The Icelandic measured dimension was Notch of flukes to nearest point of leading edge of flukes so this was hardly comparable.

Table 3. Average, (standard deviation) and range (min –max) of the measurements used in the morpometric comparison of minke whales (*Balaenoptera acutorostrata*) caught in different areas of the North Atlantic. Females and males are in separate tables and they were analyzed separately (there were no females from the North Sea and UK-waters).

Coastal areas in The North Atlantic	Standard length	Tip of jaw – anus	Tip of jaw - genital opening	Tip of jaw - navel	Tip of jaw - tip of dorsal fin	Tip of jaw - blowhole	Tip of jaw - eye	Tip of jaw - corner of mouth	Tip of jaw - external ear opening	Eye – ear	Height of dorsal fin	Basal length of dorsal fin	Length of flipper (tip to axial)	Length of flipper (tip to humerus joint)	Width of flipper	Length of tail fluke	Width of tail fluke
Females																	
West-Greenland	765.2 (66.60) 554-900	581.8 (53.61) 418-696	551.8 (51.96) 398-650	422.2 (41.00) 306-520	567.1 (53.06) 408-660	104.7 (12.97) 73-190	137.4 (12.25) 104-164	133.9 (13.76) 100-170	177.2 (19.40) 85-220	42.5 (4.46) 26-53	31.2 (3.87) 23-52	58.3 (10.12) 39-96	76.6 (9.0) 38-100.0	118.1 (11.78) 83-176	29.0 (3.02) 20-35	209.7 (22.73) 126-253	53.8 (5.55) 35-64
East-Greenland	737.5 (97.42) 461-903	551.7 (74.39) 349-671	525.3 (70.20) 332-641	399.0 (52.80) 251-484	538.0 (73.32) 342-655	100.8 (14.55) 63-135	131.0 (15.78) 84-171	127.1 (15.23) 79-155	168.9 (21.82) 93-207	40.2 (5.81) 27-58	30.0 (7.28) 7-77	56.7 (13.87) 27-96	75.2 (11.1) 48-100	112.5 (14.29) 75-140	27.7 (4.25) 17-37	200.4 (31.95) 121-248	51.8 (8.28) 32-69
Norwegian and Barents Seas	719.2 (96.59) 500-907	538.7 (75.63) 362-770	512.7 (72.67) 345-735	388.6 (57.51) 253-540	521.9 (79.20) 114-746	99.2 (19.03) 60-220	126.9 (16.77) 75-182	122.6 (17.06) 74-190	164.2 (21.66) 107-235	38.6 (5.56) 23-60	29.0 (4.10) 18-41	46.8 (12.24) 23-105	71.1 (12.6) 39-138	107.9 (16.14) 70-182	26.9 (4.56) 18-50	196.2 (29.53) 132-298	50.8 (8.44) 12-71
Icelandic waters	763.8 (87.71) 461-871	575.5 (69.12) 347-712	549.5 (63.36) 336-623	418.5 (51.40) 251-498	561.6 (64.61) 340-650	93.2 (12.97) 64-122	134.6 (14.62) 88-157	129.5 (14.30) 86-153	174.7 (20.34) 105-244	39.2 (5.60) 17-48.5	28.9 (5.43) 20-55	54.9 (11.57) 32-90	74.7 (8.9) 45-91.5	118.5 (14.57) 68-143	28.5 (2.86) 20-35	207.9 (24.72) 140-250	52.4 (7.59) 34-95
Total	739.0 (91.23) 461-907	556.0 (72.17) 347-770	529.0 (68.74) 332-735	402.3 (54.47) 251-540	540.2 (73.60) 114-746	100.0 (16.34) 60-220	131.1 (15.96) 75-182	126.9 (16.37) 74-190	169.4 (21.67) 85-244	39.8 (5.57) 17-60	29.7 (4.77) 7-77	51.9 (12.95) 23-105	73.5 (11.4) 38-138	112.4 (15.47) 68-182	27.7 (4.08) 17.0-50	201.6 (28.26) 121-298	51.9 (7.76) 12-95

Males																	
West-	750.0	577.1	516.1	412.9	553.6	103.0	135.6	134.8	176.4	41.8	31.7	57.9	75.9	116.2	29.1	202.2	52.4
Greenland	(60.98)	(61.01)	(41.93)	(37.09)	(47.90)	(7.72)	(10.33)	(17.39)	(14.44)	(4.31)	(3.16)	(10.36)	(5.8)	(9.04)	(3.04)	(25.97)	(6.18)
	605-820	455-780	420-573	320-460	450-620	83-117	105-150	103-190	143-194	31-47	24-37	40-84	64-85	93-128	23.0-38.0	122-240	33-62
East-	710.5	537.0	487.9	389.0	521.7	93.2	127.3	122.0	163.0	38.6	28.4	48.8	74.1	109.4	26.8	191.7	49.6
Greenland	(100.97)	(80.45)	(74.01)	(64.27)	(78.71)	(13.63)	(18.84)	(18.08)	(22.69)	(5.28)	(4.31)	(12.03)	(12.2)	(16.67)	(3.90)	(31.00)	(7.16)
	490-847	360-660	325-619	255-520	355-652	62-118	85-176	83-158	107-200	27-49	15-36	30-81	50-120	73-176	18.0-34.0	82-249	21-61
Around	727.8	545.7	496.7	393.9	525.9	99.4	127.4	121.7	167.7	40.5	27.5	41.2	72.0	113.7	27.5 (379)	194.7	52.4
UK	(83.58)	(63.85)	(60.40)	(44.32)	(67.30)	(14.61)	(15.16)	(14.76)	(21.73)	(10.08)	(2.48)	(5.41)	(11.2)	(16.75)	20.0-34.0	(19.28)	(5.93)
	525-835	396-626	351-571	290-459	388-613	74-125	94-150	89-149	122-214	28-78	23-32	32-50	53-90	86-150		160-218	38-61
Norwegian	705.9	530.2	476.6	379.3	505.9	97.4	124.7	121.2	162.4	38.0	29.4	45.2	72.8	105.6	26.7	189.9	50.2
and	(79.15)	(66.89)	(63.95)	(47.84)	(63.45)	(21.38)	(14.90)	(15.84)	(19.03)	(5.75)	(4.36)	(9.99)	(13.6)	(13.78)	(4.26)	(22.53)	(6.57)
Barents Seas	523-870	384-688	322-672	268-531	240-660	68-250	86-190	81-190	110-220	12-58	15-43	21-82	39-130	69-140	20.0-46.0	131-230	30-65
Icelandic	735.2	550.9	500.2	400.5	540.8	89.9	129.4	124.3	167.0	38.6	29.0	49.2	72.3	115.1	28.2	196.0	49.9
waters	(78.17)	(59.36)	(56.15)	(44.94)	(64.41)	(9.90)	(14.24)	(14.88)	(18.66)	(6.44)	(4.68)	(11.08)	(10.0)	(13.62)	(3.68)	(24.48)	(5.26)
	474-870	355-660	324-654	257-471	259-640	60-111	83.5-175	79-187	109-232	24-61	17.5-42	27-90	44-100	73-138	16.5-39.5	98.2-230	33-62
Total	719.8	542.3	490.0	390.9	523.9	95.1	127.6	123.4	165.3	38.8	29.2	48.0	73.2	110.4	27.4	193.3	50.3
	(84.08)	(68.65)	(63.50)	(51.16)	(68.11)	(16.56)	(15.61)	(16.54)	(19.25)	(6.12)	(4.33)	(11.23)	(11.8)	(14.82)	(3.97)	(25.41)	(6.35)
	474-870	355-780	322-672	255-531	240-660	60-250	83.5-190	79-190	107-232	12-78	15-43	21-90	44-130	69-176	16.5-46	82-249	21-65

Table 4. Scores, on the first two components (PC1 and PC2) from a PCA of 17 external measurements of female and male common minke whales (*Balaenoptera acutorostrata*) from different areas in the North Atlantic. Percentage variations accounted for by the two components are also given.

Measurement (code no. in Table 2)	Females		Males	
	PC1	PC2	PC1	PC2
Tip of upper jaw to notch of flukes (standard length)	0.272	-0.054	-0.282	0.085
Tip of upper jaw to center of anus	0.270	-0.094	-0.276	0.128
Tip of upper jaw to center of genital aperture	0.268	-0.089	-0.263	0.174
Tip of upper jaw to center of umbiliculus	0.265	-0.132	-0.268	0.219
Tip of upper jaw to posterior end of dorsal fin base	0.262	-0.055	-0.265	0.135
Tip of upper jaw to anterior end of blowhole	0.219	0.009	-0.204	-0.100
Tip of upper jaw to middle of eye	0.260	-0.128	-0.262	0.075
Tip of upper jaw to angle of gape	0.244	-0.160	-0.248	0.080
Tip of upper jaw to external auditory meatus	0.252	-0.164	-0.268	0.131
Distance between the eye and ear	0.236	-0.108	-0.208	0.165
Dorsal fin height	0.172	0.530	-0.205	-0.454
Basal length of dorsal fin	0.150	0.767	-0.139	-0.738
Flipper length, posterior insertion to tip	0.238	0.021	-0.224	-0.214
Flipper length, anterior insertion to tip and onward to humerus joint	0.251	0.002	-0.243	0.016
Flipper maximum width	0.240	0.052	-0.241	-0.111
Length of tail fluke	0.256	0.031	-0.252	-0.038
Width of the tail fluke	0.231	0.081	-0.233	-0.042
Variance	75.66%	5.37%	68.71%	5.90%

Table 5. Multivariate analysis of variance between samples of common minke whales (*Balaenoptera acutorostrata*) from the North Atlantic based on principal component scores. The analysis was run with the all principal component included and excluding *Dorsal fin height* (DFH) and *Basal length of dorsal fin* (BLDF). F-values are approximate estimated with Pillai's trace.

Sex	Components included	df	F	P
Females	All	17,536	11.06	< 0.001
	All except DFH and BLDF	15,538	6.44	< 0.001
Males	All	17,291	2.40	0.002
	All except DFH and BLDF	15,293	1.85	0.028

Table 6. Multivariate analysis of variance between samples of common minke whales (*Balaenoptera acutorostrata*) from the North Atlantic based on principal component scores, with results of pair-wise comparisons of females and males within areas. F-values are approximate estimated with Pillai's trace, *** *P* < 0.001, ** 0.001 < *P* < 0.01, * 0.001 < *P* < 0.05, ^{ns} not significant, overlap calculated with the Mahalanobis D^2 statistics of difference in parentheses.

	East-Greenland	North-Sea	East-Norwegian waters and Barents Sea	Icelandic waters
Females				
West-Greenland	$F_{17,198} = 2.54^{**}$ (85.7%)	-	$F_{17,421} = 13.61^{***}$ (89.1%)	$F_{17,173} = 5.94^{***}$ (91.1%)
East-Greenland		-	$F_{17,345} = 3.63^{***}$ (89.8%)	$F_{17,97} = 6.51^{***}$ (91.1%)
North-Sea		-	-	-
East-Norwegian waters and Barents Sea			-	$F_{17,320} = 6.70^{***}$ (88.9%)
Males				
West-Greenland	$F_{17,83} = 3.70^{***}$ (83.2%)	$F_{17,30} = 3.73^{***}$ (89.5%)	$F_{17,130} = 6.46^{***}$ (83.2%)	$F_{17,81} = 7.01^{***}$ (91.4%)
East-Greenland	-	$F_{17,75} = 2.36^{**}$ (89.5%)	$F_{17,173} = 3.69^{***}$ (84.0%)	$F_{17,124} = 4.43^{***}$ (92.9%)
North-Sea		-	$F_{17,120} = 1.80^{*}$ (85.7%)	$F_{17,71} = 4.49^{***}$ (90.0%)
East-Norwegian waters and Barents Sea			-	$F_{17,171} = 8.02^{***}$ (90.0%)

Table 7. Percent correct *a posteriori* classification of common minke whales (*Balaenoptera acutorostrata*) to areas based on morphometric classification function in full discriminant analyses.

	No. of whales classified into area					
Area of origin	W-Greenland	E-Greenland	Around UK	North- and Barents Sea	Icelandic waters	Percent correct
			Males			
W-Greenland	15	3	0	6	5	51.72
E-Greenland	3	18	0	35	16	25.00
Around UK	0	1	5	11	2	26.32
North- and Barents Sea	2	9	2	100	6	84.03
Icelandic waters	3	6	0	14	47	67.14
Total						59.87
			Females			
W-Greenland	87	2	-	53	4	59.59
E-Greenland	19	7	-	43	1	10.00
Around UK	-	-	-	-	-	-
North- and Barents Sea	26	6	-	258	3	88.05
Icelandic waters	11	0	-	24	10	22.22
Total						65.34

Table 8. Mean vectors for clusters of male and female minke whales (*Balaenoptera acutorostrata*) in the North Atlantic, as estimated by Bayesian approach for maximum likelihood classification.

Sex	Males		Females		
Groups	1	2	1	2	3
Tip of upper jaw to notch of flukes (standard length)	733.1	742.9	729.6	758.4	744.9
Tip of upper jaw to center of anus	551.5	558.2	548.1	572.2	561.7
Tip of upper jaw to center of genital aperture	524.2	533.2	522.0	543.6	533.0
Tip of upper jaw to center of umbiliculus	398.6	404.9	396.2	414.8	407.4
Tip of upper jaw to posterior end of dorsal fin base	536.0	543.5	534.8	548.2	545.3
Tip of upper jaw to anterior end of blowhole	99.7	101.6	98.2	104.6	108.9
Tip of upper jaw to middle of eye	130.0	132.3	129.2	135.0	134.2
Tip of upper jaw to angle of gape	125.6	129.0	125.2	131.8	128.0
Tip of upper jaw to external auditory meatus	168.3	170.0	168.1	175.1	162.2
Distance between the eye and ear	39.6	40.2	39.4	41.7	39.6
Dorsal fin height	29.6	30.1	29.5	30.8	29.7
Basal length of dorsal fin	51.1	52.8	51.6	50.2	53.2
Flipper length, posterior insertion to tip	73.3	72.9	72.0	74.8	79.8
Flipper length, anterior insertion to tip and onward to humerus joint	111.4	113.1	110.8	114.0	116.4
Flipper maximum width	27.5	27.8	27.2	28.5	29.4
Length of tail fluke	199.7	203.4	198.8	206.7	205.5
Width of the tail fluke	51.4	52.8	51.5	51.9	53.4
Total number of whales	233	76	414	90	50
Percentage whales	75.4%	24.6%	74.7%	16.2%	9.1%

Figures

Plate 1. The common minke whale (*Balaenoptera acutorostrata* Lacepède, 1804), illustration by Jón Baldur Hlíðberg.

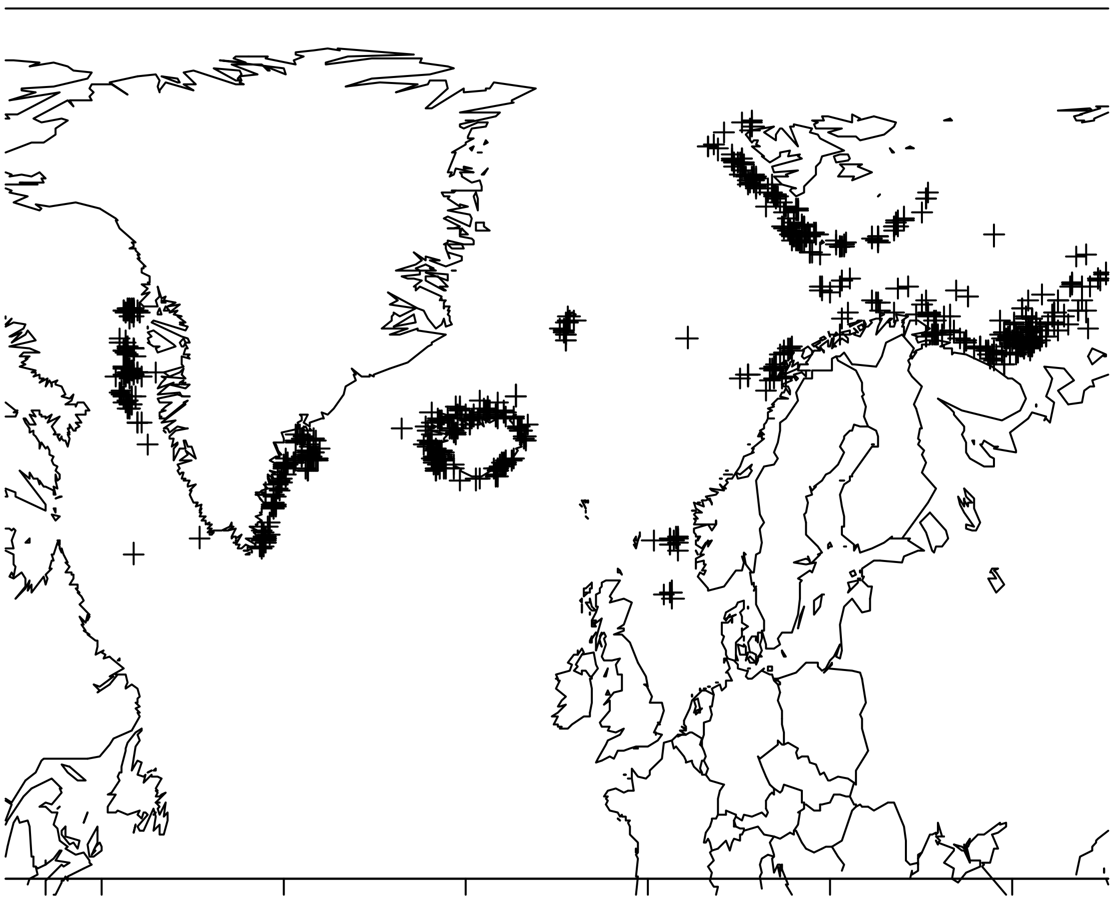

Fig. 1. The North Atlantic, with the sites where the common minke whales were caught, used in the morphometric study.

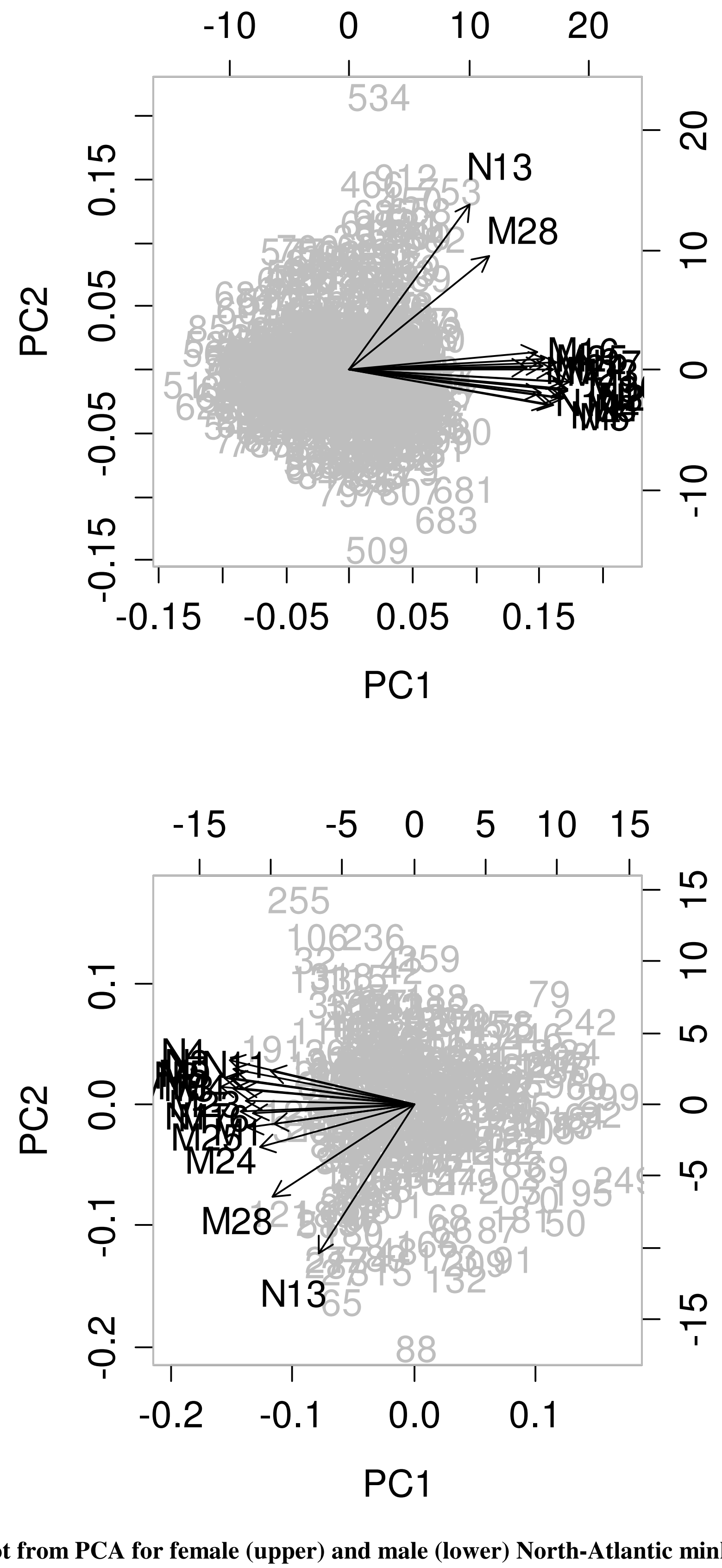

Fig. 2. Biplot from PCA for female (upper) and male (lower) North-Atlantic minke whales, showing scatter of individuals in relation to the two first principal components (PC1 and PC2) and vectors for dimensions, incorporated into the analyses.

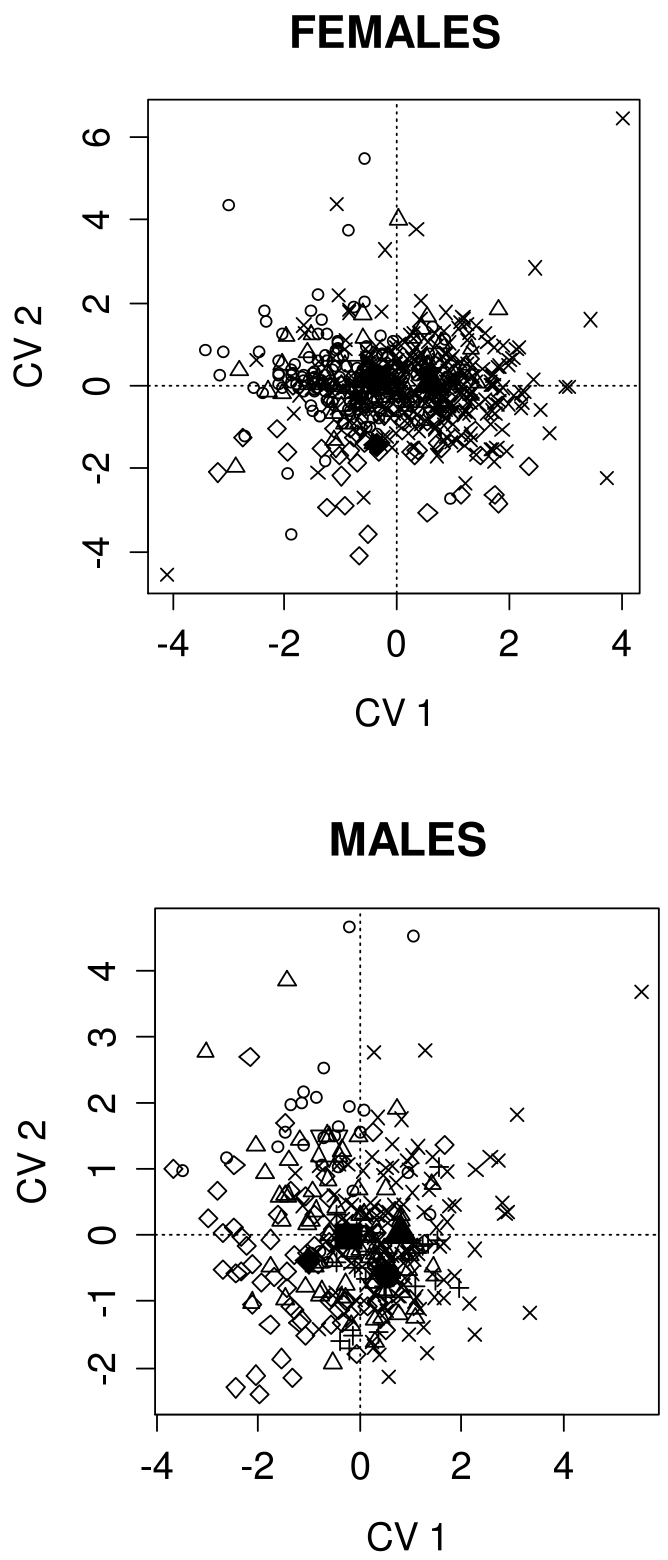

Fig. 3. Minke whale females (upper graph) and males (lower graph). Centre of the five groups based on plots of the first (x-axis) and second (y-axis) canonical varieties as determined by discriminant analyses. Small points indicate the placements of individual whales in the coordinate system (o) W-Greenland, (Δ) E-Greenland, (+) Around UK, (x) Norwegian and Barents Sea, (◊) Icelandic waters and bigger symbols indicate the group means (۞) W-Greenland, (•) Around UK, (▲) Norwegian and Barents Sea, (■) E-Greenland, (♦) Icelandic waters.