Geographic, temporal and size segregation of sexes of the common minke whale (*Balaenoptera acutorostrata*) in Icelandic waters based on catch data from 1974 to 2009

Erlingur Hauksson, Gísli Víkingsson and Jóhann Sigurjónsson

Program for Whale Research, Marine Research Institute, P.O.Box 1390, Skúlagata 4, 121 Reykjavík, Iceland

Abstract

In the early whaling period, 1974-1985, there were found significant differences in the catch of males (M) and females (F), between spring, summer and autumn. More females were generally caught in the spring, but more males were caught in the summer and autumn. During spring there were significantly more males caught in the northern part and females in the southwest part of Icelandic waters. During the summer significantly more males were caught in southwest, west and northwestern waters, but more females were caught off the east coast. In the Scientific whaling period, 2003-2007, in the summer, there were a significant more males caught in the southern waters and more females caught elsewhere. In the commercial whaling after 2007, the whaling was almost all done off the southwest coast, during spring and summer, and there was observed a predominance of males in the catch; 125/30 M/F.

Results of a binomial GLM analyses of F/M ratio (F = 1 and M = 0) and available predictor variables, showed that seasons, years, areas and the interactions; seasons×longitude, years×longitude and years×length of animals were significant. The females were increasingly dominating in the catch (P = 0.01) as the season progressed, however there was observed a significant interactions between season and latitude (P = 0.001). Also the F/M ratio was highly significantly different between the East and West area of Icelandic waters (P < 0.001), divided by the western 18° degree longitudinal arch. The F/M ratio increased with latitude, but this was dependent on the season (P = 0.01). There was observed a increasing F/M ratio in relation to length of animals, but here again was a significant interaction between years and length of animals observed (P = 0.002). This indicates that F/M was different in the two areas West and East of Iceland, the ratio decreased with time but that was influenced by longitude and length of animals. There was a negative relation between F/M and length of animals and some interaction between seasons and latitude. We conclude that not only was observed a complicated geographic and temporal segregation of minke whales, but also size dependent one.

Introduction

Whales are evolutionary related to Artiodactyla and one common trade of the even toed ungulates is the segregation of sexes, seasonally. The whales' closes living terrestrial relatives are probably hippopotamuses, where females seem to form schools with their young, and around the bulls which are settled according to the hierarchy, the dominant adult bulls being the nearest, probably being responsible for the whole group (Dorst and Dandelot 1993). The cause of this segregation is not always known, but it has been explained with male altruism, e.g. males taking care of not to compete with the mothers of their offspring and their offspring themselves for limited resources, such as food. The formation of sexually mature male-groups seasonally, which are found distant from the females, juveniles and caws groups, is observed for several species of even toed mammals, e.g. reindeer (*Rangifer tardanus*) (Forbes et al. 2006).

Segregation of sexes has been clearly demonstrated by researchers studying the gray whale (*Eschrichtius robustus*) which shows long-distance fasting migrations to low latitude in winter months for calving and mating. Near-term pregnant females depart the Bering Sea at the start of the southbound migration two weeks before other gray whales do. Non-pregnant adult females start moving southward later in company with adult males. These late-arriving whales are also the first to leave the Mexican calving lagoons, where the female gray whales give birth and mate, after about 30 days. While in the lagoons and adjacent coastal areas, most lactating cows with newborn calves maintain a spatial separation from other age and sex groups. The early arriving females, accompanied by their calves, are the last to leave the calving grounds the following spring, after about 80 days (Berta et al. 2006).

Female-male segregation by common minke whales (*Balaenoptera acutorostrata*) in Icelandic waters, has not been studied as thoroughly as in case of the gray whale. Recent satellite tagging in Icelandic waters has provided some information on autumn migrations although without information on sex of those animals (Víkingsson & Heide-Jørgensen 2006, Víkingsson 2005, SC/F13/SP18.). 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 been clearly 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 hypothezised that female minke whales move farther north in warmer years. Sea temperature 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) find probable that pregnant females may separate socially to avoid niche overlap with males or to avoid them. General northward movement of pregnant females would result in an increasing proportion of males in the SW part of the Greenland Sea and probably also in the waters west of Iceland. Laidre et al. (2009) rule out the potential effect of selective harvesting because observed changes in the proportion of females were limited to specific areas and not occurring in the entire range of the population. Also sex-selective hunting by whalers was not possible, because sexes cannot be distinguished at sea.

Migrations in Icelandic waters are not well documented. However, 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 the species is most abundant off the coast of Iceland in the months May to September, with high abundance spots in Faxaflói and off the Southeast-coast. Segregation by sex has been observed by studying whalers logbooks, the early catch-data indicating males arriving later than the females, and females migrating further north than males, towards the ice-edge, migrating even as far north as to western Greenlandic waters.

(Sigurjónsson 1982). Horwood (1990) in his monograph on the minke whale's biology and exploitation, points out that studies of blubber thickness may reflect a complicated spatial and temporal segregation and migration of the different sex 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.

This paper deals with the catch-data from the common minke whaling in Icelandic waters in which we try to explain the catch record of males and females, with the possible segregation of the sexes and sizes, in three periods; early commercial whaling (1974-1985), the scientific whaling period (2003-2007) and late commercial whaling (after 2007).

Material and methods

The catch data from the common minke whaling in Icelandic waters was divided into three periods; the early commercial whaling occurring in the period 1974-1985 (E), the scientific whaling in the period 2003-2007 (V) and the late commercial whaling period after 2007 (C). Available information on the catch was separated into the sexes and placed into the Bormicon areas of the Icelandic waters (Fig. 1). -Areas 8 and 9 were combined into one and named SA. Using Chi-squared (X^2_{df}) test for independence of two categorical variables, the distribution of females and males between the Bormecon areas, during the spring (March – May), summer (June – August) and autumn (September – November) were tested, as far as was possible with the available data (Tables 1). The three whaling periods were analyzed separately.

For investigating segregation of sexes further (F females and M males) and standard length (L) in relation to latitude (in decimal degrees; Lat), years (years – 1973; Y), standard length of animals and months (month – 6; M), as predictor variables, 1 = females were taken as a response variable and 0 = male, and the three catching periods (E, C and V; P), and two coastal areas (A) of Icelandic waters (East and West areas divided by the -18° Longitude) taken as factors. The two way interaction terms of predictor variables such as; Lat, Y, M and L, were also included. The model being;

$$Ln[P(\mathrm{F})/P(\mathrm{M})] = k_o + k_1\mathrm{M} + k_2\mathrm{Y} + k_3\mathrm{A} + k_4\mathrm{Lat} + k_5\mathrm{L} + k_6\mathrm{Y}\times\mathrm{M} + k_7\mathrm{M}\times\mathrm{Lat} + k_8\mathrm{M}\times\mathrm{L} + k_9\mathrm{Y}\times\mathrm{Lat} + k_{10}\mathrm{Y}\times\mathrm{L} + k_{11}\mathrm{L}\times\mathrm{Lat},$$

the parameters k_i being the log odds of a female catch. Trends in the sex ratio of minke whales catches were investigated by fitting standard logistic regression models using General Linear Models (GLM). Statistical analyses were performed with R (R Development Core Team 2010; Verzani 2005; Everitt and Hothorn 2010).

Results

Distribution of the catch in the early whaling period is presented in Fig. 2, there were found significant differences in the total catch of males and females, between spring, summer and autumn ($X^2_2 = 51.16$, $P < 0.001$). More females were generally caught in the spring, but more males were caught in the summer and autumn. During spring there were significantly ($X^2_5 = 22.40$, $P < 0.001$) more males caught in the areas in the northern part of Icelandic waters (Bormecon areas 2, 4, 5; areas SA and 10 had to be excluded due to no data) and females in Bormecon area 1. During the summer significantly ($X^2_5 = 21.62$, $P = 0.001$) more males were caught in most of the areas, e.g. Bormecon areas 1, 2 and 4. More females than males were caught in area 6, but that was not significant (Table 1). During the autumn there was not a significant difference between catch of males and females in the areas SA and 10, area 3 had to be excluded, due to lack of catch-data (Table 1). During the Scientific whaling period, 2003-2007, distribution of the catch is presented in Fig. 3, there were not found any significant differences in the total catch, between the seasons, spring, summer and autumn (Table 1). In the spring and the autumn there were not enough whales caught for a meaningful analyses. However, in the summer, there were significant more males caught, in areas 1 and 10 and more females caught in areas 2, 4, 5 and 6; $X^2_7 = 34.22$, $P < 0.001$ (Table 1). In the commercial whaling after 2007 there was not found any significant difference in relation to seasons in the total catch. This period the whaling was almost all done in area 1 (Fig. 4), during spring and summer, and there was observed a predominance of males in the catch 125 males against 30 females, a highly significant difference ($X^2_1 = 58.23$, $P < 0.001$). Other comparisons were not possible due to lack of data (Table 1).

Results of the GLM analyses showed that month-6, year-1973, areas, the interactions; month-6×longitude, year-1973×longitude, and year-1973×Standard length, were significant. The "full two terms interaction model" had AIC = 3183.4. The intercept of the model (k_0) was not significantly different from zero. The F/M ratio increases significantly ($P = 0.01$), as the season progresses, log odds 0.125 (odds ratio = 1.13), however there were significant interactions between month-6 and latitude (P = 0.001), so this happened differently at higher and lower latitudes (Fig. 6). Also the F/M ratio was highly significantly different between the East and West area of Icelandic waters (P < 0.001) the area West being proportionally higher in females than the area East (Fig. 5). The F/M ratio increased somewhat with latitude, but not significantly, this was however dependent on the season (significant interaction; P = 0.008). An increasing F/M ratio in relation to standard length of animals was observed, however not significant, but here again there were observed a significant interaction between year-1973 and standard length (P = 0.002), so this change in sex ratio in relation to size of whales was dependent on time.

The significant terms and interactions were included in the minimial "best two term interaction model" (SE in parentheses), which was;

$$Ln[P(\mathrm{F})/P(\mathrm{M})] = -11.61(9.854) + 8.71(3.780)\mathrm{M} - 1.98(0.421)\mathrm{Y} - 0.44(0.103)\mathrm{A}[=\mathrm{West}] + 1.99(0.147)\mathrm{Lat} - 0.002(0.001)\mathrm{L} - 0.14(0.057)\mathrm{M}\times\mathrm{Lat} + 0.03(0.006)\mathrm{Y}\times\mathrm{Lat} + 0.0002(0.000)\mathrm{Y}\times\mathrm{L},$$

where the intercept and latitude was not significantly different from zero, but latitude was included in the model because it being a member of a significant interaction terms. Other predictors, factors and interaction terms were significant; month-6 (P = 0.02), year-1973 (P < 0.001), area (P < 0.001), standard length (P = 0.008), M×Lat (P = 0.012), Y×Lat (P <0.001) and Y×L (P = 0.001). AIC = 3179.5 or only 0.12% lower than the AIC of the "full" model.

This indicates that, the ratio of females to males were different in the two areas West and East of Iceland (Fig. 6). The ratio decreased with time but that was influenced by longitude of the caching site and standard length of animals caught (Fig. 7). There was negative relation between ratio and standard length of caught animals and some interaction between month of year and latitude of caught animals.

Discussion

Looking at Table 1, a potential bias concern was how unbalanced the data on the common minke whale catch was when comparing these different periods and whaling operations. The results have to be viewed with that in mind. Unbalanced data can often lead to "fake" interactions between variables and predictors, and there could be associations between the observations (Zuur et al. 2009). Females were on average longer than males in the catch, however the mean standard length of caught animals was lower in the early commercial whaling, than the scientific whaling and late commercial whaling possibly due to smaller boat size in the early whaling years than in the later years of whaling, that probably was the cause of the observed significant interaction between year-1973 and standard length (P = 0.002).

The observed pattern in the catch-data of common minke whales in Icelandic waters, could be explained with males arriving later from the south to Icelandic waters, because their spring and summer distributions were observed to be more southerly (areas 1, SA and 10) than the distribution of females. Later in the summer and the autumn they have arrived to the northern part of Icelandic waters, dominating in the catch there too. One could speculate that the females may by then have left the Icelandic whaling area and moved even more northerly or to West and East Greenlandic waters. There was observed a difference between the West and East coastal areas in this respect. Perhaps, the males were much more vulnerable to be caught by the whaling boats than the females, which is also not known, but was unlikely according to Laidre et al. (2009). We feel though that segregation of the sexes of the common minke whale, in Icelandic waters, were real, and based on males arriving later to the feeding grounds in Icelandic waters than the females. These findings are quit similar to the views of the whalers and earlier description by Sigurjónsson (1982) and also in accordance to sex-ratio differences in minke whales in Greenland waters (Laidre et al. 2009). The conclusion was therefore, that there was evidence for segregation by sex and size in Icelandic waters, for the periods commercial or scientific whaling have been operating. Similarly as discussed by Jonsgård (1951) and Christensen (1974), which found that during the northward migration common minke whales, in Norwegian, Barents Sea and Greenlandic waters, was segregated by size and sex.

Segregation by size in the catch in Icelandic waters has not been thoroughly analyzed before. Such analysis has been hampered by low numbers of whales caught in most of the periods and limitesd spatial distribution of the commercial whaling. The scientific sampling programme has improved the data set with representative sampling although sample size is still small. The low proportion of immatures in the sample might indicate a segregation by length/age out of the reach of the study area which was confined to Icelandic EEZ (200 nutical miles). However the significant interaction term of year-1973 and standard length points strongly toward such segregation, size selection of waling boats through the years taking into consideration. For explicit studies on segregation of sexes and sexual maturity of common minke whales a longitudinal research plan, probably is the best approach, marking animals of known sex with satellite tags and following their migration routes through Icelandic waters. Although minke whales have so far proved to be especially difficult to instrument with satellite tags (SC/F13/SP18) such a tagging programme continues at the Marine Research Institute.

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Tables

Table 1. Catches of female (F) and male (M) common minke whale (*Balaenoptera acutorostrata*) in relation to months and oceanic areas, in Icelandic waters, during the early whaling period of 1974-1985, the scientific whaling period 2003 – 2007 and the commercial whaling period after 2007.

Periods	Spring			Summer			Autumn			Total		
Areas	F	M	*P*(F)	F	M	*P*(F)	F	M	*P*(F)	F	M	*P*(F)
Early whaling period 1974 - 1985												
1	6	20	0.23	100	206	0.33	13	46	0.22	119	272	0.30
2	13	5	0.72	144	181	0.44	26	64	0.29	183	250	0.42
3	1	0	1	45	48	0.48	-	-	-	46	48	0.49
4	111	48	0.70	364	419	0.46	51	75	0.40	526	542	0.49
5	10	6	0.62	14	15	0.48	2	6	0.25	26	27	0.49
6	4	2	0.67	59	55	0.51	2	1	0.67	65	58	0.53
	145	81	0.64	726	924	0.56	94	192	0.33	965	1197	0.45
Scientific whaling period 2003 - 2007												
1	1	3	0.25	9	28	0.24	0	7	0	10	38	0.21
2	3	0	1	7	3	0.70	2	1	0.67	12	4	0.75
3	-	-	-	9	5	0.64	-	-	-	9	5	0.64
4	-	-	-	11	3	0.79	1	0	1	12	3	0.80
5	-	-	-	8	2	0.80	1	0	1	9	2	0.82
6	2	0	1	13	6	0.68	1	1	0.50	16	7	0.70
SA[1]	1	0	1	12	15	0.44	2	1	0.67	15	16	0.48
10	-	-	-	2	16	0.11	1	1	0.50	3	17	0.15
	7	3	0.70	71	78	0.48	8	11	0.42	86	92	0.48
Commercial whaling period after 2007												
1	4	17	0.19	26	108	0.19	-	-	-	30	125	0.19
2	-	-	-	1	1	0.50	3	0	1	4	1	0.80
6	-	-	-	0	1	0.00	0	1	1	0	2	1.00
10	-	-	-	1	2	0.33	0	1	1	1	3	0.25
	4	17	0.19	28	112	0.20	3	2	0.6	35	131	0.21
Total	156	101	0.61	825	1114	0.42	105	205	0.34	1086	1420	0.43

[1] Bormecon areas 8 and 9 combined (see Fig. 1).

Figure

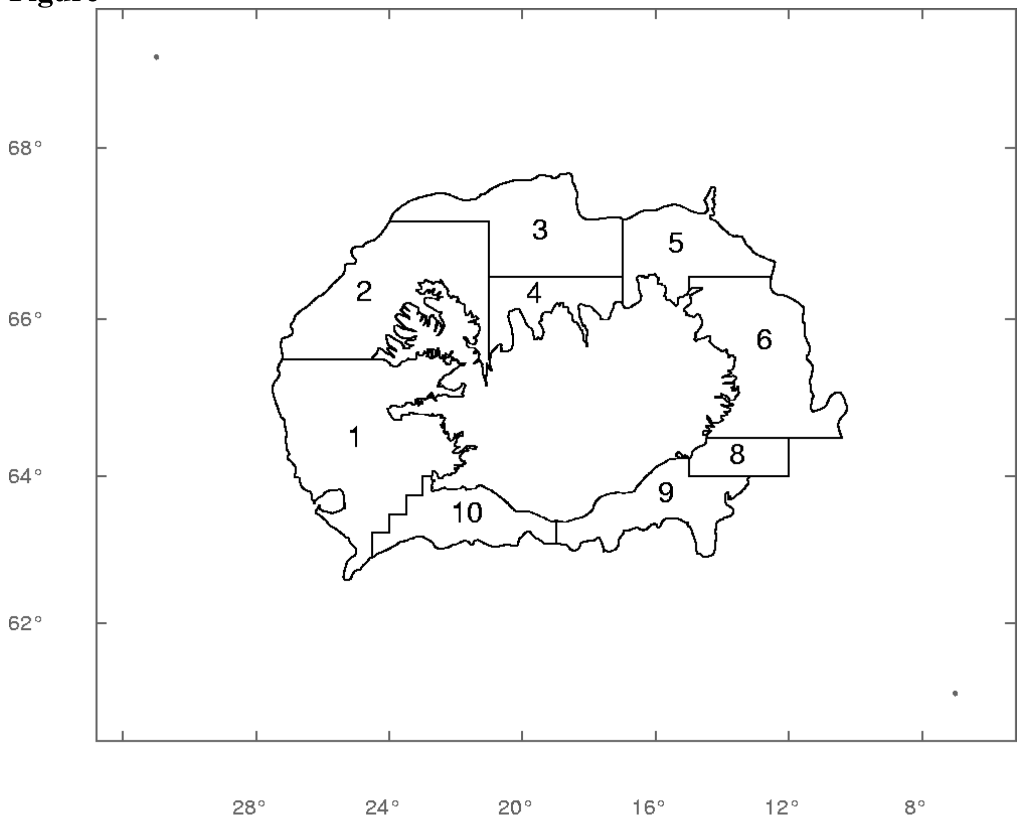

Fig. 1. Information about the division of the sea around Iceland into coastal and oceanic areas –Bormecon areas (no area 7 shown). Areas 8 and 9 combined into area SA.

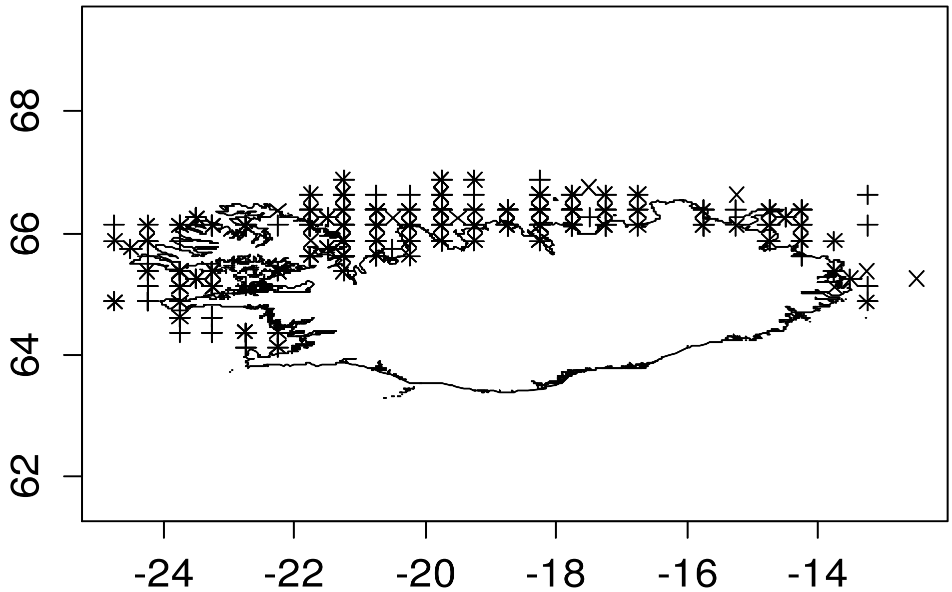

Fig. 2. Catching sites for the common minke whale (*Balaenoptera acutorostrata*), in Icelandic waters, during the period of the early commercial whaling, period 1974-1985, degrees latitude and longitude on the ordinate and abscissa respectively, + males and x females.

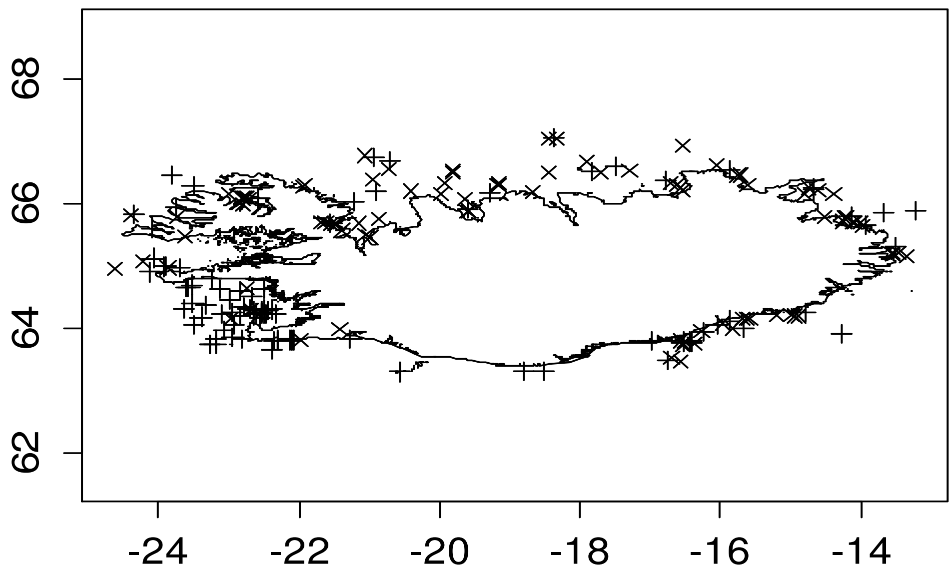

Fig. 3. Catching sites for the common minke whale (*Balaenoptera acutorostrata*), in Icelandic waters, during the period of scientific whaling, 2003-2007, degrees latitude and longitude on the ordinate and abscissa respectively, + males and x females.

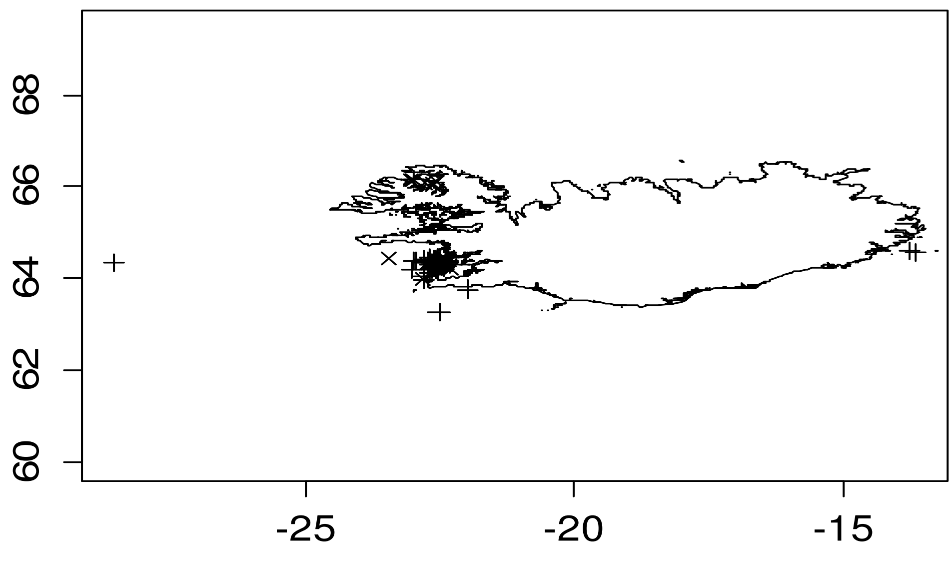

Fig. 4. Catching sites for the common minke whale (*Balaenoptera acutorostrata*), in Icelandic waters, during the period of later years commercial whaling, after year 2007, degrees latitude and longitude on the ordinate and abscissa respectively, + males and x females.

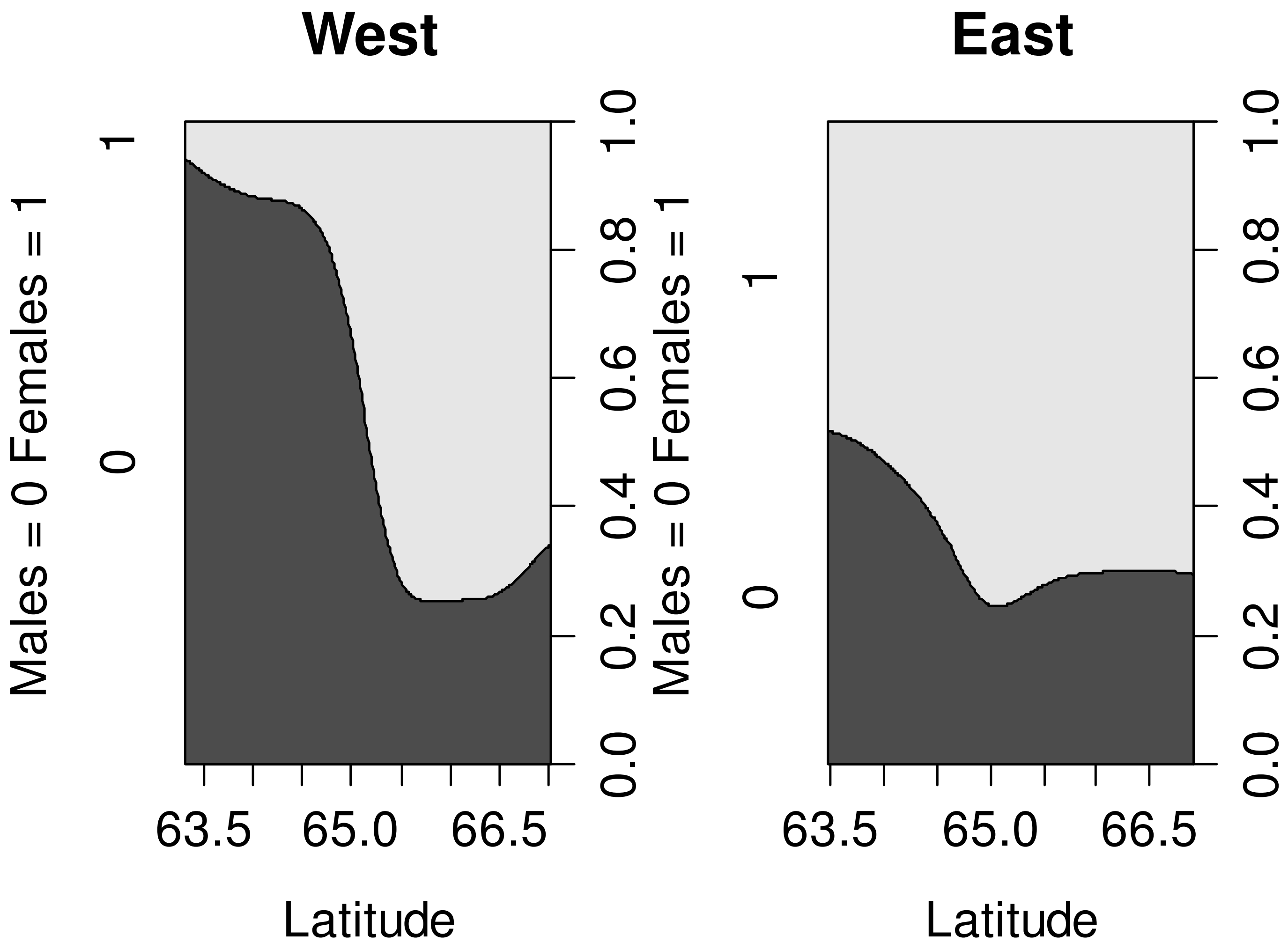

Fig. 5. Conditional density plot of the female/male ratio (second Y-axis to the right on each graph) of common minke whale (*Balaenoptera acutorostrata*) in relation to decimal latitude west and east of the 18° longitudinal arch W, in Icelandic water, during the period of scientific whaling, 2003-2007.

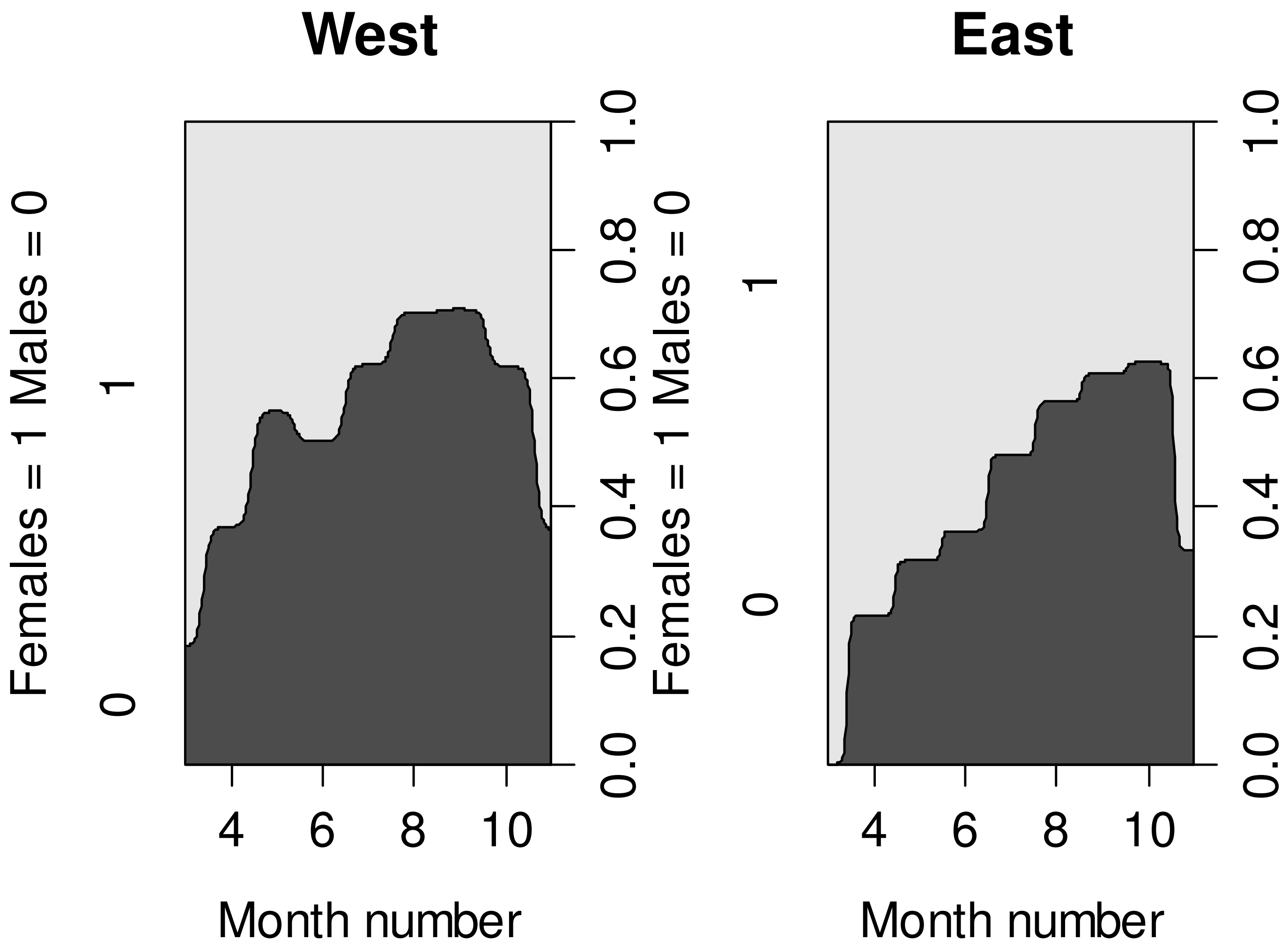

Fig. 6. Conditional density plot of the female/male ratio (second Y-axis to the right on each graph) of common minke whale (*Balaenoptera acutorostrata*) in relation to months west and east of the 18° longitudinal arch W, in Icelandic water, all whaling periods combined.

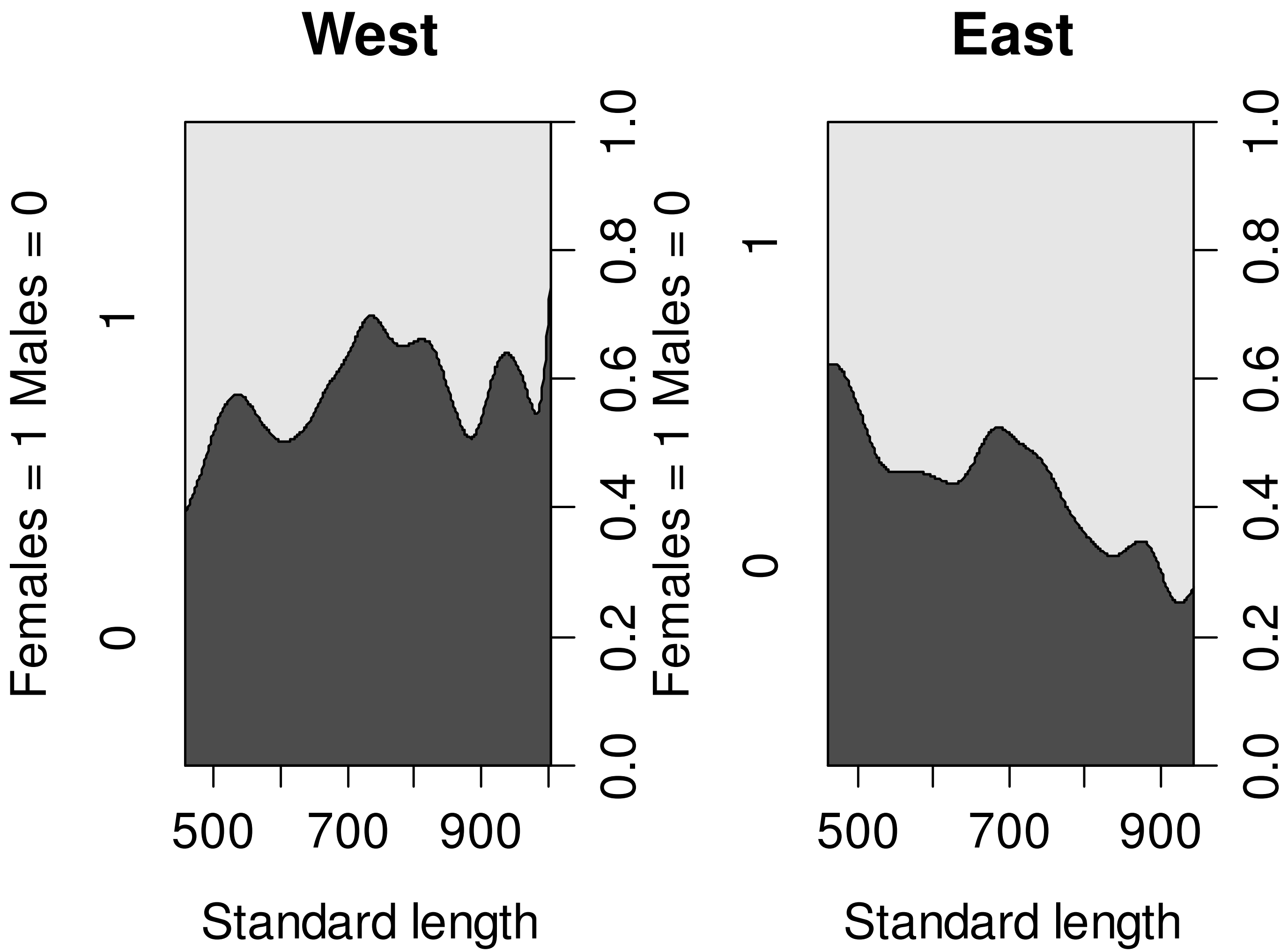

Fig. 7. Conditional density plot of the female/male ratio (second Y-axis to the right on each graph) of common minke whale (*Balaenoptera acutorostrata*) in relation to Standard length west and east of the 18° longitudinal arch W, in Icelandic water, all periods combined.