SEASONAL VARIATION IN BODY CONDITION AND MUSCULAR LIPID CONTENTS IN NORTHEAST ATLANTIC MINKE WHALE *BALAENOPTERA ACUTOROSTRATA*

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Anatomical measurements and muscle samples for lipid content analysis from 225 minke whales, *Balaenoptera acutorostrata*, were sampled during scientific whaling operations in Norwegian and adjacent waters in 1992-1994. Data collected were sorted into three seasons and three areas. A linear regression analysis was used to investigate the relationship between total body length and muscle/blubber weight. To test whether there was significant differences between areas and/or seasons an ANCOVA-analysis was used. A condition index originally developed for fish based on muscle/blubber weight was fitted to test the usefulness for minke whales. The regression analysis on ln-transformed data revealed that both muscle and blubber weight vs total body length were linear. A seasonal weight increase was found and was mainly due to increase in blubber weight. The condition index based on blubber weight and total body length was found useful for minke whales. Blubber thickness increases during the feeding season both on the ventral and dorsal side of the whales. Visceral fat also shows a seasonal increase. The results from the biochemical analysis revealed that there are variable amounts of lipid stored in different muscular groups. Generally there is a seasonal increase in lipid, most clear shown by increase in lipid stored in the muscular group behind the dorsal fin.

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INTRODUCTION

The stock of minke whale Balaenoptera acutorostrata is probably the most common whale species in the Northeast Atlantic, with an abundance estimated, from sighting surveys in 1995 of 112 125 (95 % CI, 93746, 138720; Schweder & al. 1996). The northeast Atlantic minke whale is therefore an important predator and its predatory role was studied thoroughly during the period May-September in 1992-1994 in a scientific whaling programme where questions concerning the feeding ecology of the species were addressed (Haug & al. 1995a, b, 1996, 1997 in press).

As most mysticetes the minke whale is a boreo-arctic species which, in the North Atlantic, migrates regularly to feeding areas in the far north in spring and early summer, and southwards to breeding areas in the autumn (Jonsgård 1966). In mysticetes, the summer period is generally characterized by intensive feeding and consequently seasonal fattening, while feeding in the rest of the year is generally considered to be greatly reduced (Lockyer 1981). The fat deposited is probably stored as energy reserves for overwintering in lower latitudes where reproduction takes place. In the North Atlantic, both the fin whale Balaenoptera physalus and sei whale Balaenoptera borealis have been demonstrated to exhibit seasonal variation in body condition and relative amounts of body fat (Lockyer & al. 1985; Lockyer 1986; Lockyer & Waters 1986; Vikingsson 1990, 1995). The main question addressed in this paper is whether also minke whales exhibit such seasonal and potentially also geographical variation in body condition and muscular lipid contents.

Biological material for the study was collected during the 1992-1994 scientific whaling operation, and the analysis was designed to assess how the following parameters vary with season in geographical areas:

1. muscular and blubber weight as a function of total body length.
2. body condition index based on the parameters mentioned under 1.
3. various blubber thickness measurements to indicate which are most useful as indicators of seasonal variation in body condition.
4. the amount of visceral fat.
5. amount of lipid stored in various muscular groups.

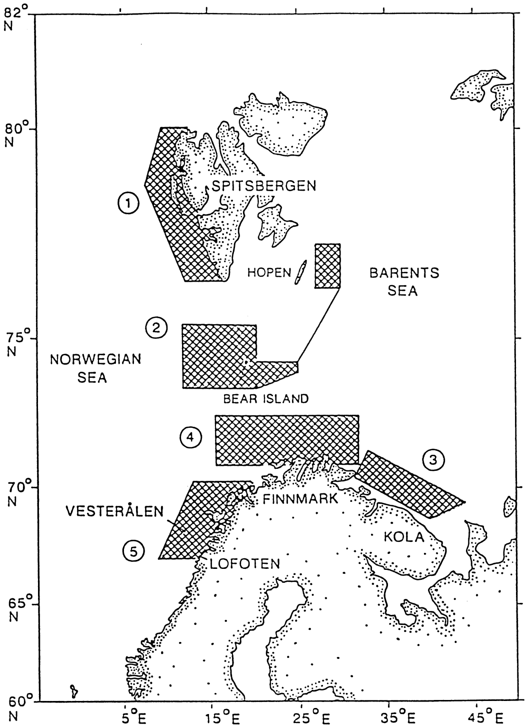

Fig. 1. Selected operational sub-areas where minke whales were sampled during the Norwegian scientific catch in 1992-1994. 1 = Spitsbergen, 2 = Bear Island and Hopen Island, 3 = Kola coast, 4 = Finnmark coast, 5 = Lofoten/Vesterålen (after Haug & al. 1997 in press).

MATERIAL AND METHODS

Sampling of whales

During the Norwegian scientific whaling program performed in the Barents Sea and adjacent waters in 1992-1994 various anatomical measurements and weights were recorded for the minke whales caught (Haug & al. 1992). From previous knowledge about spatial distribution of catches (Øien & al. 1987) and observations made during sighting surveys (Øien 1991), five separate sampling areas were defined: West of Spitsbergen, Bear Island and Hopen Island, coast of Kola, coast of Finnmark and Lofoten/Vesterålen (Fig. 1). Based on observations of similarity in feeding habits (Haug & al. 1995a, b 1996), areas were pooled into three groups in the present analysis which came to include these areas: North (West of Spitsbergen and Bear Island/Hopen Island), East (coast of Kola and coast of Finnmark) and West (Lofoten/Vesterålen).

In 1992, only the period 4 July-17 August was surveyed and sampled. In 1993, the operations were confined to three periods: 15 April-15 May, 15 June-12 July and 25 August-20 September. The 1994 operations were also confined to three periods: 30 April-6 June, 2 July-28 July and 27 August-22 September. Three seasons were defined: Spring (15 April-6 June), Summer (15 June-17 August) and Autumn (25 August-22 September). Whales from all years were pooled, and sex was not taken into consideration due to low sample size in each area/season category during the three years.

A total of 225 animals were obtained as follows: Spring (North 6, East 8, West 8), Summer (North 79, East 53, West 30) and Autumn (North 14, East 10, West 17). Anatomical measurements were recorded in all three years, while samples for biochemical analysis were collected from only 59 whales during summer and autumn of 1993.

Measurements and weights

Immediately after death, the whales were taken onboard and hauled across the fore-deck of the boat. Total body length (to the nearest cm) was measured with a non-stretching tape measure in a straight line from the tip of the upper jaw to the apex of the tail fluke notch (Fig. 2). Three half girth measurements were recorded (to the nearest cm) at the points shown in Fig. 2. Blubber thickness was measured to the nearest mm at 12 sites (Fig. 2) of which 10 were recommended by Folkow & Blix (1992). Every blubber measurement was done perpendicular from skin surface to the muscle - connective tissue interface (Slijper 1954).

Except for standardized regions around the head and the tail, blubber was stripped from the carcass in sections along the length of the body and weighed. Blubber from the ventral grooves was also included in the total blubber weight. The muscles were cut into blocks of ca. 50 kg and the total muscle weight was recorded. Blubber and muscles were weighed with a precision of ± 5 kg due to movement of the boat etc., using a Salter 300 kg weight suspended in connection with a hoist. Visceral fat was removed from the body cavity and around internal organs and weighed.

Muscle lipids

During flensing, the muscle-samples for biochemical analysis were collected. Three positions on the whale-body were selected for analysis (Fig. 2): site A - by the ventral grooves, site B - at the pectoral fin and site C - behind the dorsal fin. The samples ($5 \times 5 \times 5$ cm), were packed in plastic bags, frozen to –20 °C *in situ,* and kept frozen for subsequent total lipid-analysis.

Muscle samples were chopped and dried at 60 °C for 48 hours (or until constant weight was achieved). After drying, samples were homogenised and stored in salveglass. 6 mg of dried, homogenised muscle was weighed in 10 replicates from each sample. Lipids were extracted from dried muscle samples with methanol-chloroform (Folch & al. 1957) and transferred from glass tubes to small aluminium cups with known weight before evaporation of the methanol-chloroform. To make sure that nothing of the lipid was lost when transferred to aluminium cups, the glass tubes was washed twice with 1 ml methanol-chloroform. The lipid retrieved was weighed and expressed as a percentage of dry weight.

Statistical analysis

Weight/length relationships. The relationship between body length and weight of muscle or blubber was investigated by the formula:

$$\ln W = \ln\alpha + \beta \ln L$$

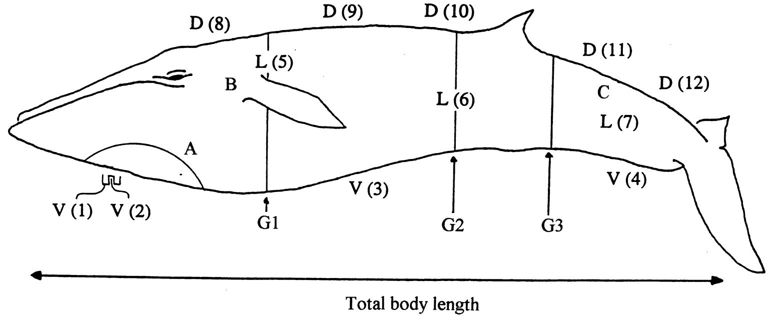

Fig. 2. Sites for morphometric measurements and tissue sampling for biochemical analysis of minke whales taken during the Norwegian scientific catch in 1992-1994. V1-V4 (ventral), L5-L7 (lateral) and D8-D12 (dorsal) = blubber thickness measurements; A, B and C = muscle tissue sampling sites; G1, G2 and G3 = girth measurements.

where W = weight (kg), L = body length (m) and α and β are constants defining the intercept and slope of the regression line.

Condition index. To test the usefulness of a condition index in studies of minke whale body condition, an index originally developed for fish (Le Cren 1951) and based on muscle/blubber weights (in kg) and body length (in m) was used:

$$\text{C.I.} = (\text{Weight}/\text{Length}^3) \times 100$$

were the weights of muscle and blubber were analysed separately to estimate individual condition indices.

Statistical tests. To investigate if the regression analysis for the whales body length and muscle/blubber weights could be different between different seasons and geographical areas, an ANCOVA (ANalysis of COVAriance) was performed.

Condition index, blubber thickness measurements and muscular lipid content are expressed graphically as mean values with .95 confidence intervals. The results are considered as significantly different if the confidence intervals do not overlap. In all statistical analysis level of significance is set to probability $p \leq 0.05$.

RESULTS

Weight/length relationships

Regression analysis of the ln-transformed data on muscle and blubber weight vs. length (n = 225) revealed a significant linear relationship (Tables 1 and 2).

An ANCOVA was applied to the regression lines in order to test whether differences could be detected between β values or α values with respect to area or season (Tables 3 and 4). No significant difference between the β values was detected either in muscle or blubber weight. Test of α values gave only significant difference where seasons were compared in area North for muscle weight (Table 3). For blubber weights however, significant differences in α values were observed between seasons in all three areas (Table 4). In addition, there is a significant difference in blubber α values between areas in the summer-season.

Seasonal and geographical variation in muscle/blubber weight as a function of length is also presented for a 'standard' whale, i.e. all data was recalculated to the developed regression lines to an average whale with mean length 7.26 m (n = 225) (Fig. 3). There seems to be a seasonal increase in muscle weight from spring to autumn in all seasons, however not significant in area East. In area North and West there are significant increases in blubber weight through all three seasons. In area East, blubber increases significantly between spring and summer, while the seasonal fattening seems to slow down between summer and autumn.

Condition index

The condition index based on muscle weight seems to exhibit an increasing tendency throughout the three seasons, although not statistically significant (Fig. 4A). The condition index calculated for blubber weight shows a significant increase throughout the season in all areas: In area North a significant difference was observed from spring to autumn. In area East there is a significant difference in blubber condition between spring and summer, while in area West a significant difference between spring and autumn was detected (Fig. 4B).

Blubber thickness

The blubber thickness measurements were sorted according to their position between snout and tail on the ventral, lateral or dorsal side of the whales (Fig. 5). An ANOVA yielded no significant differences between sampling areas (Næss 1996) which were, therefore

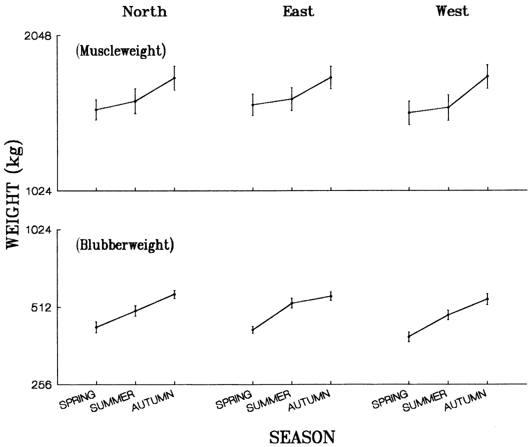

Fig. 3. Calculated weight of muscle and blubber from a 'standard' (7.26 m long) minke whale, based on the regression analysis for the three areas North, East and West sorted into three seasons.

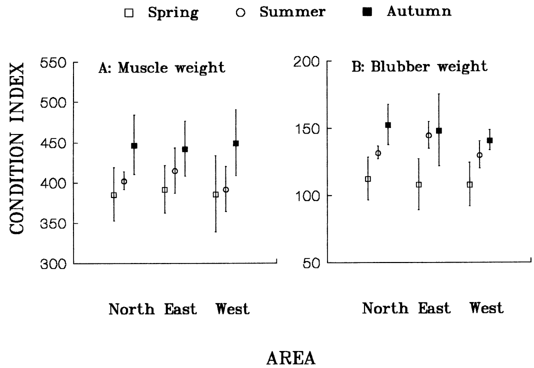

Fig. 4. Condition index calculated with muscle and blubber weights in the three whaling areas sorted into three seasons for minke whales with a 95 % confidence interval.

pooled. The blubber tends to increase in thickness toward the tail region both on the ventral and dorsal side. Laterally, the blubber has a more uniform distribution.

Ventrally, there is a significant seasonal increase in blubber thickness from spring to summer in measurement V4 (the region between anus and tail) while measurements V1 - V3 shows only small seasonal variations. Laterally, there is a significant seasonal increase in blubber thickness from summer to autumn in all three measurements. Similar increase was found on the dorsal side, particularly in measurements D9 - D12.

Visceral fat

Fig. 6 illustrates the amount of visceral fat found in the minke whales in the three seasons in question. The spring season is dominated by minke whales with less than 10 kg of visceral fat (70 %), while 30 % of the whales had between 11 and 20 kg. In the summer season minke whales with less than 10 kg fat had decreased to approximately 40 %, and whales with more than 21 kg of visceral fat now constituted more than 40 %. The amount of whales with more than 21 kg visceral fat increased further from summer to autumn (70 %) accompanied with a reduction in minke whales with less than 10 kg fat.

Muscular lipid

A general seasonal increase in muscular lipid content seems to occur (Fig. 7). For whales caught in area North, there is no significant increase in lipid content at any of the three sites, although there is an increasing trend at site C. Area East displays a similar situation, but here the lipid level in the tail region (site C) increases significantly between summer and autumn. Minke whales caught in area West increases their muscular lipid level significantly from summer to autumn at all three sites.

Comparison of the muscular groups analysed seems to indicate higher lipid levels behind the dorsal fin (site C) than at the other sites. Comparing areas season by

Table 1: Regression analysis of ln muscleweight as a function of ln length of minke whales caught during the Norwegian scientific whaling program in 1992-1994. n = number of minke whales, ln α and β = constants, SE of β = Standard error of β, r^2 = correlation coefficient, F = Fishers test value, P = level of significance.

Area	Season	n	ln α	β	SE of β	r^2	F	P
North	Spring	6	1.06	2.452	0.217	0.970	127.3	< 0.001
	Summer	79	0.61	2.995	0.115	0.898	677.9	< 0.001
	Autumn	14	0.71	2.926	0.312	0.880	87.7	< 0.001
East	Spring	8	0.91	2.636	0.266	0.942	98.1	< 0.001
	Summer	53	0.79	2.787	0.184	0.819	230.6	< 0.001
	Autumn	10	0.84	2.779	0.238	0.945	136.8	< 0.001
West	Spring	8	0.67	2.894	0.380	0.906	58.1	< 0.001
	Summer	29	0.46	3.146	0.200	0.902	247.3	< 0.001
	Autumn	17	0.71	2.924	0.383	0.795	58.3	< 0.001

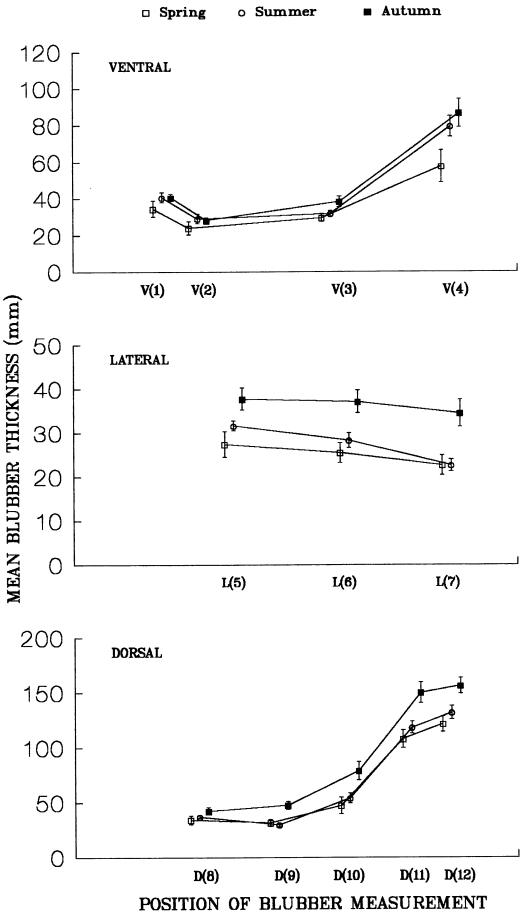

Fig. 5. The seasonal distribution of blubber measurements performed on the ventral, lateral and dorsal side of the whale. The measurements are positioned relative to a standard length from the snout (left) to the tail (right) of the whale, and a 95 % confidence interval is given for the values.

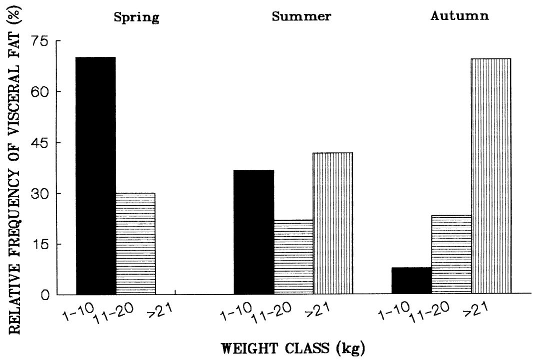

Fig. 6. Seasonal variation in relative frequency of visceral fat, categorised into three weight classes (in kg) for minke whale visceral fat caught in the Norwegian scientific whaling operation in 1992-1994.

season, there is no significant difference between areas in the summer season at any of the three sites, but there is a significant differences between area East and West at site A and between North and West at site C in the autumn season.

DISCUSSION

Earlier studies on energetics of fin whales (see LOCKYER 1987) have showed great differences between females of different reproductive status, and that this is a direct response of the extra energy requirements of reproduction. Stratification by sex and reproductive classes was not possible in this study because of low sample size when the sample was divided by area and season. This may have biased the results to some extent.

Apparently there is a significant seasonal increase in blubber weight in Northeast Atlantic minke whales. Similar seasonal fattening has been documented in fin whales (VIKINGSSON 1990, 1995), demonstrating the

Table 2: Regression analysis of ln blubberweight as a function of ln length of minke whales caught during the Norwegian scientific whaling program in 1992 - 1994. n = number of minke whales, ln α and β = constants, SE of β = Standard error of β, r^2 = correlation coefficient, F = Fishers test value, P = level of significance.

Area	Season	n	ln α	β	SE of β	r^2	F	P
North	Spring	6	0.30	2.712	0.526	0.869	26.6	~ 0.007
	Summer	78	0.51	2.541	0.141	0.811	326.3	< 0.001
	Autumn	14	1.08	1.952	0.205	0.883	90.9	< 0.001
East	Spring	8	1.15	1.706	0.363	0.786	22.1	< 0.003
	Summer	53	0.73	2.315	0.189	0.747	150.4	< 0.001
	Autumn	9	0.98	2.054	0.435	0.761	22.3	~ 0.002
West	Spring	8	0.47	2.468	0.424	0.850	33.9	~ 0.001
	Summer	29	0.73	2.362	0.150	0.902	248.2	< 0.001
	Autumn	17	0.48	2.622	0.201	0.919	170.0	< 0.001

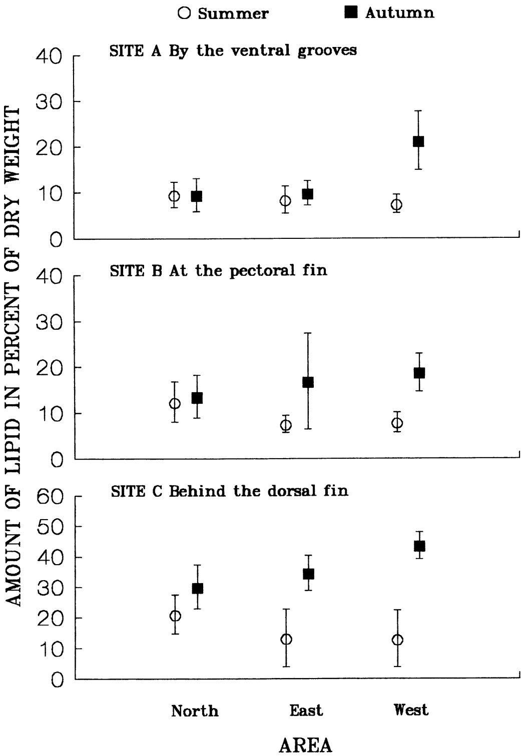

Fig. 7. The percentage of lipid stored at three different sites in the minke whale body sorted into the three areas North, East and West and the seasons summer and autumn. Lipid levels are expressed as mean values with a 95 % confidence interval.

general tendency of baleen whales to increase their fat reserves during summer feeding periods, and thereby storing energy reserves for wintering and breeding at lower latitudes. NILSSEN & al. (1997 in press) found comparable seasonal variations in blubber mass for Barents Sea harp seals (*Phoca groenlandica*). NORDØY & al. (1995) calculated that the energy deposited during summer will only last for a small part of the winter energy needs for minke whales. This minke whale study indicates seasonal fattening and it remains to be seen how minke whales manage to survive during the remaining winter months.

The lack of significant differences between β-values (slopes) in the regression analysis indicate that small and large minke whales have similar strategies for energy storing. HAUG & al. (1997 in press) has previously found that whales of all ages appear to exploit the same resources within a given area.

The condition index originally developed for fish, has been shown to be useful for other marine mammals such as Barents Sea harp seals (NILSSEN & al. 1997 in press). The condition index based on whale muscle weight did not vary significantly between seasons or areas which may indicate that it is not useful as an indicator of energetic condition in minke whales. The seasonal increase in blubber weight, however, was confirmed from the condition index based on blubber weight which showed both seasonal and area variation (Figs 3 and 4). The blubber condition index, therefore, appears useful for characterization of variation in body condition in minke whales.

There is an increase in blubber thickness from snout to tail, both on the ventral and the dorsal side of the minke whale, while on the lateral side, the blubber is more uniformly distributed (Fig. 5). This increase in blubber thickness toward the tail region, may be due to the build-up of a pronounced ridge, and is consistent with previous observations for fin and sei whales (LOCKYER & al. 1985; SLIJPER 1948).

Consistent with the observed seasonal increase in blubber weight, there seems also to be a significant seasonal variation in blubber thickness from summer to autumn, especially on the lateral and dorsal side from the middle part and towards the tail region of the whales. This hind region is probably an important energy storage region in minke whales. In addition to represent an important energy storage, the dorsal and ventral ridge also contributes to give minke whales a streamlined body shape. LOCKYER & al. (1985) suggested that blubber thickness, at its most variable site, might be the best

Table 3: ANCOVA of ln muscle weight as a function of ln length for minke whales. Df 1/Df 2 = degree of freedom between groups/within groups, F = Fishers test value, P = Level of significance.

	Test of difference between β-values			Test of height between regression lines		
	Df 1/Df 2	F	P	Df 1/Df 2	F	P
Effect Area						
Spring	2/16	0.41	0.671	2/18	0.33	0.727
Summer	2/155	1.29	0.280	2/157	0.87	0.421
Autumn	2/35	0.07	0.938	2/37	0.01	0.986
Effect Season						
North	2/93	0.60	0.550	2/95	4.54	0.013
East	2/65	0.03	0.969	2/67	1.17	0.317
West	2/48	0.22	0.801	2/50	2.68	0.078

index of body condition in fin and sei whales. In this minke whale study, there are significant seasonal variations at all three measurement sites taken laterally and in all five measurements taken dorsally, suggesting that all these measurement sites may be useful indicators of variation in body condition of the species.

There was a reduction in number of minke whales with less than 10 kg of visceral fat and an increase in frequency of whales with more than 21 kg of visceral fat from spring to autumn (Fig. 6). Visceral fat therefore seems to act as a secondary energy storage in the body cavity. Lockyer & al. (1985) observed visceral fat in large quantities in fin and sei whales which had already attained a thick blubber layer, and suggested that visceral fat deposits might be more mobile than those in blubber. Thus, minke, fin and sei whales may well have similar strategy for energy storing during the feeding season.

The results from the biochemical analysis reflect that minke whales store variable amounts of lipid in different muscular groups. Lipid level is generally low in the muscular groups underlying the ventral grooves. Similar observations were made near the pectoral fin, but there is a tendency of increased lipid levels as the season progresses. In the muscular groups behind the dorsal fin, there is a clear seasonal increase in lipid level. Lockyer & al. (1985) similarly found that both fin and sei whales had the highest lipid levels in the muscular groups located behind the dorsal fin. Seasonal trends in muscular lipid content similar to these observed for minke whales have been demonstrated in harp seals (Beck & al. 1993).

Northeast Atlantic minke whales are euryphageous, feeding on a number of prey items including both fish and crustaceans (Jonsgård 1951, 1982; Nordøy & Blix 1992; Haug & al. 1995a, b, 1996). Many fish and crustacean species exploit the large primary and secondary plankton production that takes place in the spring and summer season at high latitudes and store the lipids produced (Sakshaug & al. 1992). The results of this study show that there is a marked difference in the general body condition of the whales between the summer and autumn season. The time needed for the trophic system to transport energy upwards from primary producers to top predators (see Falk-Petersen & al. 1990), may have contributed to the more marked increase in whale condition between summer and autumn than between spring and summer and suggest that the main build-up of fat deposits for minke whales occurs late in the feeding season.

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Table 4: ANCOVA of ln blubber weight as a function of ln length for minke whales. Df 1/Df 2 = degree of freedom between groups/within groups, F = Fishers test value, P = Level of significance.

	Test of difference between β-values			Test of height between regression lines		
	Df 1/Df 2	F	P	Df 1/Df 2	F	P
Effect Area						
Spring	2/16	1.26	0.311	2/18	0.83	0.453
Summer	2/154	0.55	0.557	2/156	4.18	0.017
Autumn	2/34	1.88	0.169	2/36	0.15	0.858
Effect Season						
North	2/92	1.62	0.203	2/94	10.01	< 0.001
East	2/64	0.54	0.585	2/66	5.71	~ 0.005
West	2/48	0.34	0.714	2/50	16.91	< 0.001

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