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Variation in content of ω3 fatty acids in farmed Atlantic salmon, with special emphasis on effects of non-dietary factors

Yngvar Olsen[1]* and Harald Skjervold[2]

[1] *Trondhjem Biological station, Bynesveien 46, N-7018 Trondheim, Norway*
[2] *Department of Animal Science, Agricultural University of Norway, PO Box 25, N–1432 Ås-NHL, Norway*

The main aim of the present study was to examine the impact of some biological and environmental factors on the lipid and fatty acid compositions of farmed Atlantic salmon (*Salmo salar*), with special emphasis on ω3 fatty acids. Two year groups of salmon at nine fish farms distributed along the Norwegian coast were fed the same diet and were sampled every second month. The data are believed to give a representative characterization of lipid and fatty acid content of salmon farmed in Norway.

Multiple regression analysis revealed that variation in lipid content and body weight explained 80% of the variation found in ω3 fatty acids in farmed salmon, and 22:6 ω3 showed greater variation than other ω3 fatty acids. Further analysis of lipid-corrected values revealed only minor effects of latitude on the per cent content of highly unsaturated ω3 fatty acids, and hardly any effect of seawater temperature, with the exception of 22:6 ω3, which decreased slightly with increasing temperature.

The per cent 22:6 ω3 in the fillet became gradually reduced with increasing fish age and body weight, whereas the content of 20:5 ω3 and other ω3 fatty acids remained relatively constant. The per cent content of 22:6 ω3 of young salmon was higher than in the feed, but approached the feed value gradually as body weight increased. The lipid content of the salmon increased with fish age, and the absolute quantitative contents of both 22:6 ω3 and 20:5 ω3 increased meanwhile, even though the per cent content of 22:6 ω3 decreased quite pronouncedly.

The per cent 22:6 ω3 and other ω3 fatty acids was higher in wild than in farmed salmon, but the absolute quantitative content was higher throughout in farmed salmon, which had higher lipid contents. The ω3/ω6 ratio, which is important in human health evaluation, was lower in farmed than in wild salmon. The large flexibility of ω3 fatty acids and lipid content of farmed salmon leave us with the option of producing a wide variety of salmon qualities requested by the market. Both per cent and absolute quantitative ω3 contents, as well as the ω3/ω6 ratio, may readily be manipulated.

KEYWORDS: Atlantic salmon (*Salmo salar*), Body weight, Latitude, Lipid content, Temperature, ω3 fatty acids, ω3/ω6 ratio

INTRODUCTION

Cultivation of Atlantic salmon, which began in the early 1970s, represents one of the later successful attempts at domestication in human history. Marine cold-water fish are important sources of marine lipids, and cultivated salmon represents a future source of essential ω3 fatty acids, which are important for human health (Kinsella, 1987).

*Author to whom correspondence should be addressed.

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Cultivation conditions, including both feeding and environmental factors, will probably affect the fatty acid composition of farmed salmon (Lie *et al.*, 1988; Olsen and Skjervold, 1991), but several other factors may be involved as well (Viga and Grahl-Nielsen, 1990).

For male spawners of wild Atlantic salmon from Norwegian rivers, Olsen and Skjervold (1991) found a highly significant increase in per cent ω3 fatty acids (% of total fatty acids) in fillets of the fish with increasing latitude of river outlet. The increase in ω3 fatty acids was 1.1% of total fatty acids per degree latitude, and was mainly due to an increase in 22:6 ω3, which has an important role in temperature acclimation of cold-blooded animals (Farkas *et al.*, 1980). It was therefore suggested that the increased level of 22:6 ω3 was an effect of the lower temperature in the rivers at higher latitude, but dietary factors may also have been involved. In any event, the study indicated that wild salmon exhibited pronounced and systematic variation in their content of ω3 fatty acids, primarily 22:6 ω3, dependent on latitude. If temperature during ongrowing in seawater or other environmental factors were strongly involved, a similar pattern of variation could be expected also for salmon farmed along the Norwegian coast.

The aim of the present study was to establish a status for ω3 fatty acid content of Atlantic salmon produced in Norway and to examine the impact of some biological and environmental factors on lipid and fatty acid composition of farmed Atlantic salmon. We present results from a realistic field investigation where the fish were fed a standard commercial feed in nine commercial fish farms uniformly distributed along the Norwegian coast.

MATERIALS AND METHODS

One fish farm in each of the nine counties along the Norwegian coast, from the county of Rogaland in the south to Finnmark in the north (Fig. 1), participated in the experiment, which was run from April 1988 to April 1989. Two year groups of salmon were examined; one was transferred to seawater in spring 1988 when the project started (YG-1), and the other had stayed in seawater since spring 1987 (YG-2). At each fish farm, three fish from each year group were randomly sampled every second month for 1 year (324 fish in all). The youngest group (YG-1, 1988 smolt) were accordingly followed during their first year in seawater (2–12 months), whereas the oldest group (YG-2, 1987 smolt) were followed through their second year in seawater (12–24 months). In graphical representation and statistical treatment, the data have been pooled and used to describe the development of one group of salmon through 2 years in seawater (2–24 months).

The sampled fish were cooled with ice and shipped to the laboratory together with two samples of their feed. To minimize dietary effects on fish fatty acid composition, all fish farms used fish fed from the same feed producer (T. Skretting AS, Norway).

The fish and feed samples arrived at the laboratory within 24 h of sampling. Each individual was weighed, and representative lipid and fatty acid samples were taken as follows. A cross section of the fish (width 1–2 cm) was taken under the dorsal fin. Skin and bones were removed, the meat was rinsed and homogenized in a blender, transferred to small plastic tubes, and thereafter transferred to the freezer and stored in darkness at −80 °C under an N_2 atmosphere.

Lipids from fish and feed were extracted by a modified Bligh and Dyer (1959) method, and lipid content was determined gravimetrically. An internal standard (21:0 methyl ester) was added prior to lipid extraction to obtain quantitative fatty acid determinations.

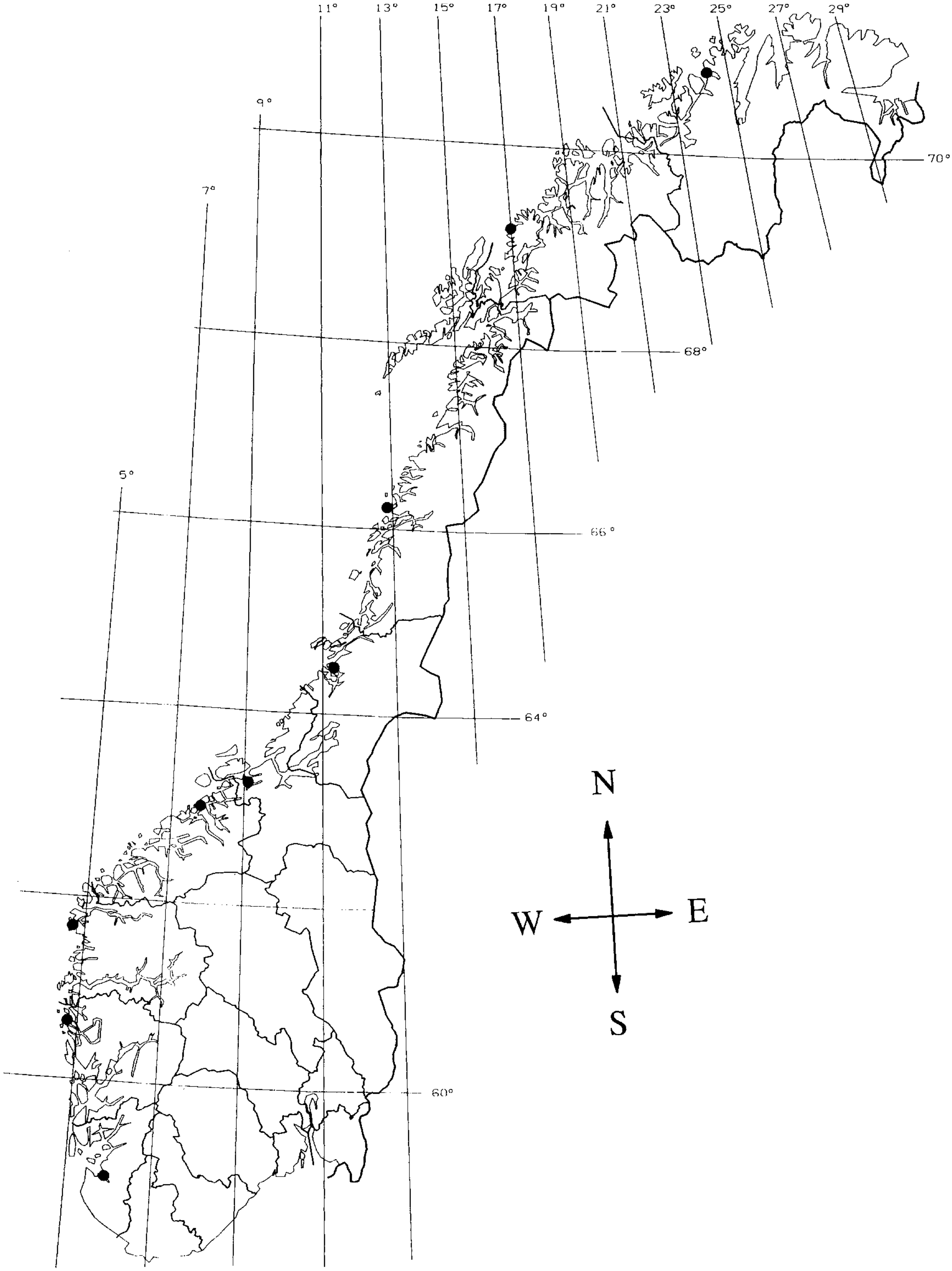

FIG. 1. Location of the nine fish farms that participated in the experiment.

The fatty acids were methylated with 12% BF_3 in methanol after hydrolysis in 0.5 M NaOH (Metcalfe *et al.*, 1966). The methyl esters were determined by capillary gas chromatography (Shimatzu, model GC 14A), equipped with an SP-2330 glass capillary column, on-column injection, and flame ionization detector. Hydrogen was used as carrier gas, and the identification and quantification were based on standard reference samples (Nu-Check Prep., Minn., USA).

The statistical treatment of the material was based on the general principles of multiple covariance. The r^2-value expresses an estimate of the variance in the Y-variable which depends on different combinations of X-variables.

RESULTS

The average total lipid content and per cent fatty acid distribution of the feed used for the two year groups are summarized in Table 1. Although specific feeds are manufactured for different age groups of salmon, only 20:1 and 22:6 ω3 showed a significant difference between the two batches of feed.

The data also showed that the fatty acid content of the feed used within each batch of salmon was almost identical in all fish farms participating in the experiment. Only one

TABLE 1. Average lipid content (% of dry weight), total fatty acid content (% of dry weight) and fatty acid distribution (% of total fatty acids) of the feed used for the two year classes of salmon (YG-1, 2–12 months in seawater; YG-2, 12–24 months in seawater)

	YG-1	YG-2	Difference[a]
Lipid, % of DW	21.9	22.6	0.66
Total fatty acids, % of DW	16.4	18.1	1.65
Fatty acids, %			
14:0	6.64	6.62	0.02
16:0	15.0	14.6	0.39
18:0	7.43	7.83	0.40
16:1	1.78	1.67	0.11
18:1[b]	13.7	14.2	0.49
20:1[b]	15.2	15.8	0.60*
22:1	13.8	13.9	0.11
18:2 ω6	4.98	4.65	0.33
20:4 ω6	0.47	0.45	0.02
18:3 ω3	1.21	1.17	0.04
20:5 ω3	8.66	8.62	0.04
22:5 ω3	0.66	0.68	0.02
22:6 ω3	10.46	9.76	0.70**
Total ω6	5.45	5.10	0.35
Total ω3	21.0	20.2	0.76

[a] *, $p < 0.05$; **, $p < 0.01$.

[b] Includes the isomers ω9 and ω7, and for 22:1 also ω11.

fatty acid, 22:1, varied significantly between fish farms, but the range of variation was small (range 12.6–14.1%) and presumably accidental. It can therefore be assumed that differences in salmon fatty acid composition between the farms must primarily originate in non-dietary factors in the present experiment.

The fish were distributed in 24 groups based on their growth period in seawater (see methods), and the variation in lipid content (% of fresh meat) and relative content of ω3 fatty acids (% of total fatty acids) are shown as functions of the growth period in seawater in Fig. 2. The figure reveals a gradual increase in lipid content with age throughout the period and a rapid decline in per cent total ω3 fatty acids during the first 6–10 months after the transfer to seawater. The reduced level of total ω3 fatty acids was mainly a result of a decline in 22:6 ω3 towards the lower per cent level found in the feed (see below and Table 1).

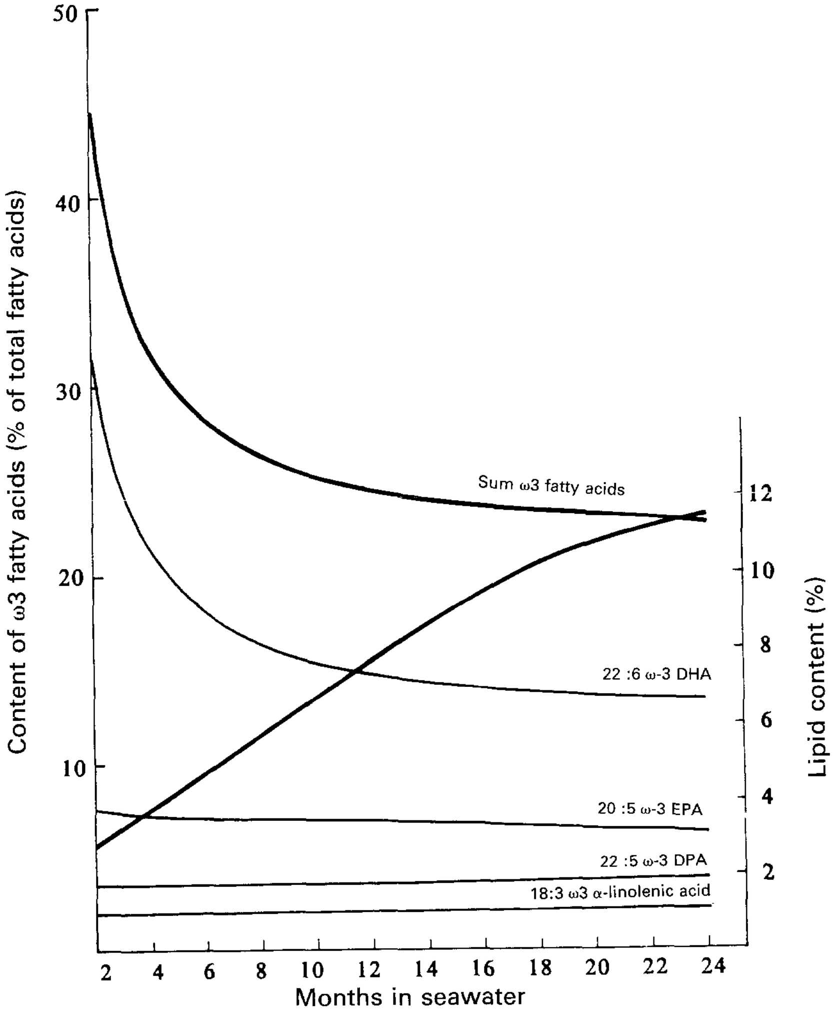

FIG. 2. Variation in lipid content (% of fresh meat) and relative content of ω3 fatty acids (% of total fatty acids) as a function of the growth period in seawater. Curves express regression lines.

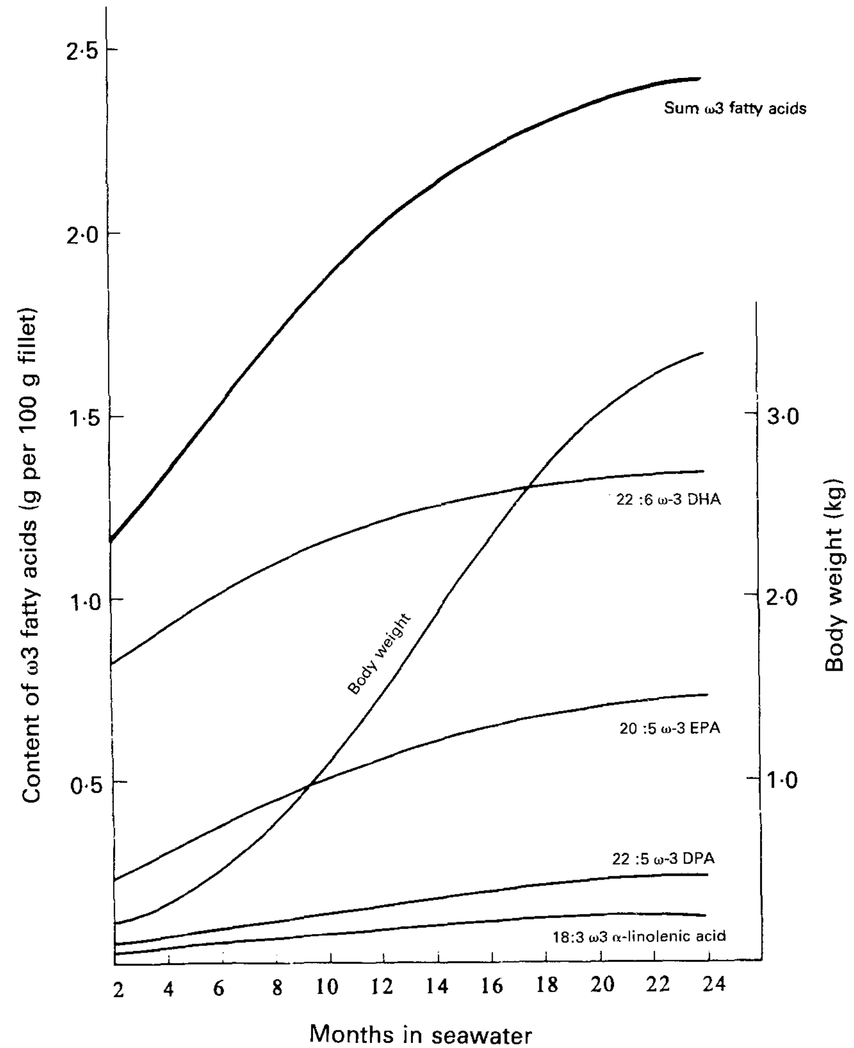

FIG. 3. Variation in absolute content of ω3 fatty acids and the average salmon weight as a function of the growth period in seawater. Curves express regression lines.

Figure 2 shows that per cent total ω3 fatty acids became reduced with increasing age and lipid content of the fish. Simple regression analysis gave a negative correlation of total ω3 vs. age of $r = -0.48$ and $r = -0.73$ for year classes YG-1 and YG-2, respectively.

Figure 3 shows the absolute content of ω3 fatty acids and the average salmon weight as a function of age or residence time in seawater. The absolute content of all ω3 fatty acids increased gradually with age, and the average total of ω3 fatty acids was twice as high in older salmon as in the younger fish. Figure 4 shows the absolute content of different ω3 fatty acids as a function of fish weight. The absolute contents of all ω3 fatty acids increased rapidly with weight up to 2–3 kg, after which the rate of increase was slower.

Multiple regression analysis was undertaken to determine the combined effect of lipid

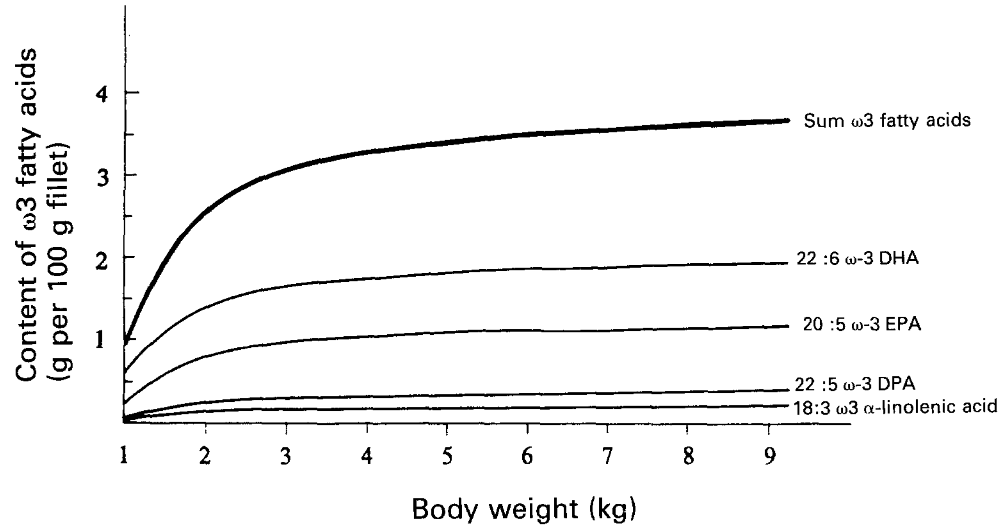

FIG. 4. Variation in absolute content of ω3 fatty acids as a function of fish weight. Curves express regression lines.

content (X_1) and weight (X_2) on the per cent content of individual fatty acids (Y). The relationship between lipid content and per cent fatty acid content was non-linear for many fatty acids, and the square of the lipid content was included as a third variable (X_3). Statistical values as well as mean contents of fatty acids derived for the two year groups are shown in Tables 2 and 3.

For the youngest year group (2–12 months, Table 2), the variable lipid content of the fish explained most of the variation in the majority of fatty acids. Some fatty acids, i.e. 18:0 and 22:5 ω3, were more sensitive to the weight of the fish than to the lipid content, but the weight could nevertheless only explain < 10% of the total variance of these fatty acids. A second group of fatty acids, including 16:0, 18:2 ω6; 18:3 ω3, 20:4 ω6, and 20:5 ω3, were only moderately affected by the weight of the fish. For the remaining fatty acids, including the important fatty acid 22:6 ω3, as much as 55–75% of the variance could be explained as a combined effect of variable lipid content and fish weight.

The increase in r^2 after including X_3 was considerable for all fatty acids except for 22:5 ω3. This showed that the second-order regression line for lipid content vs. fatty acid content gave the best representation of the data.

Both fish weight and lipid content showed less pronounced effect on the variance of most fatty acids in the older year group (12–24 months) than in the younger year group (Table 3). The variance of 18:1, 20:5, ω3, and 22:6 ω3 gave, however, more or less equal r^2 values for both year groups.

The analysis above indicated that fish weight, and to some extent also the lipid content, may affect the fatty acid distribution enough to hide minor effects of other factors. Correction of the data for the influence of fish weight may therefore be undertaken, and should preferably be done within each sampling day and fish farm to eliminate systematic variation in environmental conditions between the farms as well as seasonal variation. This procedure suffers from the low number of fish per sample at each farm (n = 6).

TABLE 2. Multiple coefficients of correlation of fish lipid content (X_1), fish weight (X_2) and the square of fish lipid content (X_3) on per cent fatty acid content (Y) of year group 1 (YG-1, 2–12 months in seawater) along with average fatty acid profile for the year group (SD, $n = 162$)

Fatty acids	Lipid (X_1) r^2	Weight (X_2) r^2	(Lipid)^2 (X_3) r^2	Y_{mean} (SD)
14:0	0.51	0.54 *[a]	0.69 ***	4.52 (1.09)
16:0	0.05	0.06	0.09 *	14.6 (1.48)
18:0	0.09	0.13 **	0.25 ***	2.58 (0.71)
16:1	0.61	0.64 **	0.79 ***	6.20 (1.60)
18:1[b]	0.47	0.50 **	0.55 ***	15.5 (3.00)
20:1[b]	0.41	0.44 **	0.61 ***	11.5 (3.22)
22:1[b]	0.45	0.50 ***	0.71 ***	9.41 (2.69)
18:2 ω6	0.10	0.14 **	0.24 ***	4.35 (0.84)
20:4 ω6	0.24	0.24	0.35 ***	0.61 (0.27)
18:3 ω3	0.11	0.14 *	0.23 ***	1.02 (0.16)
20:5 ω3	0.22	0.22	0.26 **	7.26 (1.51)
22:5 ω3	0.03	0.05 *	0.05	1.83 (0.27)
22:6 ω3	0.54	0.59 ***	0.74 ***	20.6 (9.37)
Total ω6	0.06	0.07	0.12 **	4.96 (0.76)
Total ω3	0.55	0.59 ***	0.74 ***	30.7 (10.2)

[a] Significance for increase in r^2 after successively including the X_2 and X_2 variables: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.
[b] Includes the isomers ω9 and ω7, and for 22:1 also ω11.

An attempt to correct for fish weight was nevertheless made for the oldest year group after examining various methods in advance, including the optimal approach mentioned above. Highest r^2 values were obtained when the three individuals sampled from one fish farm were weight-corrected on the basis of the regression line obtained for all the individuals sampled at the nine fish farms on the same sampling day ($n = 27$) (left column, Table 4).

Multiple regression analyses of the weight-corrected data were then used to examine the potential impact of other factors which may have affected the fatty acid distributions of the farmed salmon, including lipid content, seawater temperature 2 and 3 months before slaughter, per cent total ω6 fatty acids in the feed, and location (latitude) of the fish farm (Table 4). The weight correction resulted in an increased variance caused by lipid content. The content of ω3 fatty acids was not significantly affected by seawater temperature in the period before slaughter, but the content of the highly unsaturated ω3 fatty acids (C_{20-22}) was slightly affected by latitude. The analysis also revealed a significant relationship between variation in ω6 fatty acid content in feed and fish.

Table 5 reviews the average lipid and fatty acid profiles of feed and fish for both year groups studied. Average values obtained for wild male spawners of salmon have also been indicated (data from Olsen and Skjervold, 1991). The lipid content of large cultured salmon (YG-2) was higher than that of the smaller fish (YG-1) and approximately twice that of wild salmon. The average weight of year group 2 was lower than the average

TABLE 3. Multiple coefficients of correlation of fish lipid content (X_1), fish weight (X_2) and the square of fish lipid content (X_3) on per cent fatty acid content (Y) of year group 2 (YG-2, 12–24 months in seawater) along with average fatty acid profile for the year group (SD, $n = 162$)

Fatty acids	Lipid (X_1) r^2	Weight (X_2) r^2	(Lipid)^2 (X_3) r^2	Y_{mean} (SD)
14:0	0.24	0.29 *[a]	0.30	5.31 (0.54)
16:0	0.06	0.07	0.10 *	14.1 (1.46)
18:0	0.01	0.01	0.03	2.47 (0.34)
16:1	0.23	0.24	0.25	7.53 (1.29)
18:1[b]	0.41	0.45 ***	0.53 ***	17.7 (2.03)
20:1[b]	0.12	0.15 *	0.21 **	13.9 (1.70)
22:1[b]	0.19	0.19	0.26 **	11.6 (1.26)
18:2 ω6	0.06	0.06 **	0.06	4.52 (0.63)
20:4 ω6	0.27	0.30 *	0.30	0.46 (0.10)
18:3 ω3	0.05	0.05	0.05	1.07 (0.14)
20:5 ω3	0.23	0.28 **	0.29	6.64 (0.77)
22:5 ω3	0.05	0.13 ***	0.14	1.93 (0.20)
22:6 ω3	0.43	0.51 ***	0.59 ***	12.8 (4.01)
Total ω6	0.02	0.03	0.03	4.98 (0.60)
Total ω3	0.42	0.50 ***	0.57 ***	22.4 (4.57)

[a] Significance for increase in r^2 after successively including the X_2 and X_3 variables: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.
[b] Includes the isomers ω9 and ω7, and for 22:1 also ω11.

weight of marketed Norwegian salmon, but an independent comprehensive analysis made by Skaarfish AS in 1989–90 confirmed that the average lipid content of 3–4 kg and 4–5 kg fish was 12% and 13% of fresh weight, respectively (unpublished results).

The relationship between the fatty acid profiles in feed and fish became closer with increasing weight or age of the fish. Some fatty acids, i.e. 16:0, 18:1, 18:3 ω3, and 20:4 ω6, were found in equal amounts in feed, farmed salmon, and wild salmon. The fatty acids 14:0, 16:1, and 18:2 ω6 were found in higher amounts in feed and farmed salmon than in wild salmon. The enhanced level of 18:2 ω6 in farmed salmon reduced the ω3/ω6 ratio compared with wild salmon (4.5 and 17, respectively) (Table 5). Use of feed with 1–1.5% of 18:2 ω6 would probably have eliminated this difference between farmed and wild salmon.

The level of 22:1 was always lower in farmed salmon than in feed, but 22:6 ω3 exhibited more pronounced variation than any other fatty acid. The level of 22:6 ω3 was high in small fish, and decreased steadily with age towards the level found in the feed. This fatty acid was found in higher proportions in wild salmon (range 15–30%, Olsen and Skjervold, 1991).

DISCUSSION

In fish farming, as in all animal production, there is a need to quantify the factors responsible for the phenotypic variance of important traits. Information on phenotypic

TABLE 4. Multiple coefficients of correlation of corrected values of the fish lipid (X_1), water temperature 3 months before sampling (*T*-3, X_2), water temperature 2 months before sampling (*T*-2, X_3), sum per cent ω6 fatty acids in feed (X_4), and latitude of fish farm (X_5) on per cent fatty acid content (Y) of weight-corrected data for year group 2 (YG-2, 12–24 months in seawater, n = 162). Right column (Sum X_{1-5}) expresses regression coefficient for all *X*-variables. Values of R^2 for X_i that were not significantly higher ($p < 0.05$) than r^2 for X_{i-1} are indicated as –

Fatty acids	Lipid (X_1) r^2	*T*-3 (X_2) r^2	*T*-2 (X_3) r^2	ω6 feed (X_4) r^2	°Lat (X_5) r^2	Sum X_{1-5} r^2
14:0	0.73	–	–	–	–	0.74
16:0	0.78	0.79 ***[a]	–	–	–	0.80
18:0	0.71	0.73 *	–	–	–	0.74
16:1	0.63	–	–	–	–	0.63
18:1[b]	0.77	0.80 *	–	–	–	0.80
20:1[b]	0.79	0.80 *	0.81 *	–	–	0.81
22:1[b]	0.81	–	–	–	–	0.82
18:2 ω6	0.59	0.61 *	–	0.75 ***	–	0.75
20:4 ω6	0.70	0.71 *	–	0.74 ***	–	0.75
18:3 ω3	0.66	–	–	–	–	0.66
20:5 ω3	0.79	–	–	–	0.80 *	0.80
22:5 ω3	0.73	–	–	–	0.74 *	0.74
22:6 ω3	0.74	0.74 *	–	–	0.75 *	0.75
Total ω6	0.62	0.63 *	–	0.76 ***	–	0.80
Total ω3	0.79	0.80 *	–	–	–	0.76

[a] Significance for increase in r^2 after successively including the *X*-variables in the regression: *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.

[b] Includes the isomers ω9 and ω7, and for 22:1 also ω11.

variance, obtained under realistic production conditions, has to a great extent contributed to the progress made in cattle breeding during the last 30 years. Such knowledge enhances our possibilities to shift the phenotypic variance in certain directions to increase production efficiency, and this approach will be useful also in the further development of the aquaculture industry.

The phenotypic variance includes variance caused by genetic, environmental, and combined genetic and environmental factors. Estimation of the genetic variance requires information about the coefficient of relationship of the fish. The statistical analysis of the present material can therefore only give information on variance caused by environmental and demographic factors.

Several authors claim that the per cent content of ω3 fatty acids in fish is reflected by the per cent content of ω3 fatty acids of its feed (Lie *et al.*, 1988; Sargent *et al.*, 1988), but some have questioned this general conclusion (Viga and Grahl-Nielsen, 1990). The fish in the present study were fed for 24 months with a constant diet, and the fatty acid composition reached an apparent steady state in the large salmon (Fig. 2). At that point both the per cent content of 22:5 ω3 and that of 22:6 ω3 of the large salmon were

TABLE 5. Lipids (% of fresh weight), total fatty acids (% of fresh weight), and per cent fatty acid content in the two year groups of salmon, in their feed, and in wild male salmon (data from Olsen and Skjervold, 1991)

	YG-1 (2–12 months)		YG-2 (12–24 months)		Wild salmon
	Feed	Fish	Feed	Fish	Fish
Lipid, % of FW	21.9[a]	5.38	22.56[a]	10.51	3.5
Total FA, % of FW	16.4[a]	4.09	18.1[a]	8.48	1.8
Fatty acids, %					
14:0	6.64	4.52	6.64	5.31	3.27
16:0	15.02	14.63	14.63	14.6	14.6
18:0	1.78	2.58	1.67	2.47	3.63
16:1	7.43	6.20	7.83	7.53	2.51
18:1[b]	13.68	15.46	14.17	17.74	15.5
20:1[b]	15.22	11.54	15.82	13.85	12.2
22:1[b]	13.78	9.41	13.89	11.58	13.2
18:2 ω6	4.98	4.35	4.65	4.52	1.24
20:4 ω6	0.47	0.61	0.45	0.46	0.75
18:3 ω3	1.21	1.02	1.19	1.07	0.82
20:5 ω3	8.66	7.26	8.62	6.64	9.17
22:5 ω3	0.66	1.83	0.68	1.93	3.04
22:6 ω3	10.46	20.60	9.76	12.75	20.2
Total ω6	5.45	4.96	5.10	4.98	1.99
Total ω3	20.99	30.71	20.25	22.39	33.2

[a] Expressed as % fatty acids (FA) of dry weight.
[b] Includes the isomers ω9 and ω7, and for 22:1 also ω11.

significantly higher than in the feed ($p < 0.05$, Table 5). The enhanced level of 22:5 ω3 and 22:6 ω3 suggest that both dietary and genetic mechanisms may be involved. Phospholipids constitute a variable fraction of the total lipids of the fish muscle, and the phospholipids of fish will normally contain much higher levels of highly unsaturated ω3 fatty acids than the neutral lipids (i.e. trigycerides) (Castledine and Buckley, 1982; Olsen *et al.*, 1991). The fatty acid compositions of the phospholipids are probably controlled to a greater extent than those of the triglycerides. The fatty acid composition of the phospholipids will therefore be less influenced by dietary lipids than will the neutral lipids (Sargent *et al.*, 1988). Therefore, we should anticipate that the content of highly unsaturated ω3 fatty acids in fish total lipids will be slightly higher than that in the feed if the contents of these fatty acids in neutral lipids are exactly equal to that of the feed.

This simple interpretation of our data implies that both dietary and genetic factors determine the ω3 fatty acid contents of farmed salmon. The quantitative impact of the different mechanisms will depend on the ratio of phospholipids to triglycerides in the fillets. This conclusion implies that lean fish will exhibit higher per cent ω3 fatty acids than fat fish, in agreement with our results (Table 4, Fig. 2).

Also, the lower level of 22:1 in fish than in the feed must be explained by non-dietary mechanisms (Table 5). This is probably simply an effect of selective catabolism (Henderson *et al.*, 1982; Waagbø *et al.*, 1991).

In the present study, the dietary-mediated differences in fatty acid composition between fish farms was minimized by using feed from the same feed producer at all farms involved in the experiment. This was done to obtain better resolution in our attempts to identify other important factors which affected the ω3 fatty acid content of farmed salmon. In fact, fish weight (or age) and lipid content explained 80% of the variance found in total ω3 fatty acids in the salmon, meaning that environmental factors must have been of minor importance.

The per cent content of ω3 fatty acids in farmed Atlantic salmon showed much less variation with latitude than the content in male spawners of wild salmon (Olsen and Skjervold, 1991). A small, although systematic, geographical variation was found in the fatty acid profiles of salmon farmed along the entire Norwegian coast with use of the same feed. The content of highly unsaturated ω3 fatty acids was positively related to the latitude of the fish farm, but the effect was too small to permit further speculation (Table 4). Latitude integrates, at least to some extent, seawater temperature and light conditions, and the effect of seawater temperature was not significant ($p > 0.05$) for all fatty acids except for 22:6 ω3 ($p < 0.05$), which increased slightly with reduced temperature (Table 4). Admittedly, the gradient in average seawater temperature from the south to the north along the Norwegian coast was less (range 4 °C, Olsen and Skjervold, 1991) than the gradient in the rivers.

The per cent content of ω3 fatty acids in farmed salmon decreased steadily from > 40% in young fish to 22% after 2 years in seawater, in agreement with Lie *et al.* (1988). The reduction was mainly a result of decreased per cent 22:6 ω3 (Fig. 2). The lipid content of the salmon increased, however, by a factor of four in the same period, leading to an increase in the quantitative content of total ω3 fatty acids in the fish from 1.2 g ω3 fatty acids per 100 g fillet in small fish to 2.4 g after 24 months in seawater (Fig. 3). The quantitative increase in ω3 fatty acids with weight was mainly a result of increased contents of 20:5 ω3 and 22:6 ω3 (Figs 3 and 4). The quantitative level of ω3 fatty acids in wild salmon was 0.6 g ω3 fatty acids per 100 g fillet (Olsen and Skjervold, 1991). This shows that the farmed salmon has a high potential to deliver important ω3 fatty acids for human consumption in the future.

In this connection, it is important to emphasize the impact of the balance of individual fatty acids for human nutrition. Wild salmon exhibits ω3/ω6 ratios as high as 17 (Olsen and Skjervold, 1991), whereas farmed salmon showed values of 4.5 (Table 3). Our results indicated that the ω6 level of the salmon feed explained the difference. Both ω3 and ω6 fatty acids are essential for humans, and the balance between these groups of essential fatty acids in the dietary lipids, rather than their specific contents, is the important factor for human health. This fact should be considered by the salmon industry. The quality of a product which is uncomfortably far removed from the wild salmon in ω3/ω6 ratio may be questioned in the future market. The use of more ω6-rich vegetable oils in the salmon feed should therefore also be questioned.

The large flexibility of the fatty acid composition as well as the lipid content of farmed salmon leave us with the option of producing a wide variety of salmon qualities as requested by the market. The per cent content of ω3 fatty acids may be increased in the period before slaughter by the use of ω3-rich feed (Waagbø *et al.*, 1991), and the lipid level of the salmon, as well as the quantitative ω3 content, may by manipulated by food rations and lipid content of the feed. Such treatments may be used to produce different qualities of Atlantic salmon, ranging from a wild-type characterized by low lipid and absolute quantitative ω3 contents, but high per cent ω3 fatty acids and ω3/ω6 ratio, to a ω3-rich salmon characterized by high lipid content and more moderate per cent ω3 fatty acids. The ω3/ω6 ratio may be maintained at acceptable levels also in the fat salmon. The normal salmon produced today represents an intermediate quality in this respect.

CONCLUSIONS

1. The lipid content and the absolute quantitative contents of total ω3, 22:6 ω3 and 20:5 ω3 of farmed Atlantic salmon increased with fish age, reaching 11.5, 2.4, 1.3 and 0.7 g per 100 g fillet, respectively, after 2 years in the sea.
2. The per cent contents of most ω3 fatty acids in the fillet, and in particular 22:6 ω3, were gradually reduced with increasing fish age, approaching the respective values in the feed.
3. Variation in salmon lipid content and body weight (i.e. age) explained 80% of the variation found in ω3 fatty acids in farmed salmon, and 22:6 ω3 showed greater variation than other ω3 fatty acids. The effects of latitude and temperature were small.
4. The per cent contents of 22:6 ω3 and other ω3 fatty acids were higher in wild salmon than in farmed salmon, but the absolute quantitative contents were lower.
5. The ω3/ω6 ratio, which is important in human health evaluation, was lower in farmed than in wild salmon. The future market effect of a further increase of ω6-rich vegetable oils in the salmon feed should be questioned.
6. The flexibility of salmon lipids allows production of a wide variety of salmon qualities requested by the market. Both per cent and absolute quantitative ω3 contents, as well as the ω3/ω6 ratio, may be controlled during production.

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