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Salmon farming affects the fatty acid composition and taste of wild saithe *Pollachius virens* L.

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Abstract

There is an ongoing controversy on whether fish farming affects the quality of wild fish in fjords. In northern Norway, local people prefer not to eat saithe, *Pollachius virens* L., from areas in the vicinity of fish farms because they say the taste is inferior to saithe from other areas. To address this issue, saithe were collected in the vicinity of a salmon fish farm in a fjord in northern Norway and in two reference areas: one site 6 km away from the nearest fish farm in the same fjord, and the other in a fjord nearby with no fish farms. The objective of this study was to clarify whether the physiology or taste of saithe near fish farms differs from saithe in areas with no or limited influence from fish farms. The fish collected near farms were larger than those from control sites of the same age and had been eating pellets. Analysis of fatty acid composition of the fillet indicated that fish collected near the farms had fatty acid profiles that resembled that of pellets more than fish from reference sites. The results suggest that there were individual differences in the time spent near cages for saithe collected near the farm, and that saithe collected at the reference area in the same fjord had also been eating pellets, i.e. had visited at least one of the fish farms in the fjord. In a sensory test, the test panel found that saithe from the fjord without fish farms tasted better than saithe collected near the cages. The test panel found no clear differences in taste between saithe collected near the fish farm and saithe from the same fjord, but 6 km from the nearest fish farm.

Keywords: diet, fish farming, sensory quality, fatty acid composition, saithe

Introduction

Saithe, *Pollachius virens*, is one of the most common fish in northern European inshore waters. It is economically the second most important gadiid in Norway, only surpassed by cod, *Gadus morhua*. Saithe is the most active of the gadiids and is most commonly found at depths of 80–300 m; however, it is also found closer to the surface. Saithe mainly feeds on zooplankton, fry and yearlings of different species of fish (Nedreaas 1987).

Salmon farming has been suggested to affect fat content, chemical composition, growth and the taste of wild saithe in the vicinity of fish farms (Carss 1990). The increase in salmon farms in Norwegian fjords has been associated with the decreased quality and taste of wild fish. Especially in northern Norway, local people claim that fillets of saithe from fjords with salmon farms disintegrate during cooking and the taste is inferior to saithe from other areas. Saithe are often observed in the vicinity of sea cages in salmon farms and are known to feed on excess food pellets (Carss 1990). Commercial salmon feeds differ from the natural diet of saithe. The use of corn or soya in pellet production gives a high proportion of oleic acid (18:1n-9), linoleic acid (18:2n-6) and linolenic acid (18:3n-3) in commercial diets. Salmon and cod fed on diets based on plant oils have been shown to have elevated levels of 18:2n-6 and 18:1n-9 in their tissue (Lie, Lied & Lambertsen 1986; Bell, Ashton, Secombes, Wetzel, Dick & Sargent 1996; Torstensen, Lie & Frøyland 2000; Bell, Henderson, Tocher, McGhee, Dick, Porter, Smullen & Sargent 2001). The fatty acid composition in cod fillet and liver is known to change gradually in the direction of the fatty acid composition of the diets (Lie *et al.* 1986; Dos Santos, Burkow & Jobling 1993; Kirsch, Iverson, Bowen, Kerr & Ackman 1998). It should therefore be possible to use the fatty acid signature as a biochemical 'fingerprint' for long-term foraging of wild saithe on commercial pellets from salmon culture.

The aim of this study was to clarify whether there are sensory (taste) differences between saithe near fish farms and saithe in areas with limited or no influence from fish farms. One location was chosen adjacent to the cages of one of the farms, the second about 6 km away from the nearest farm in the same fjord, and the third in an adjacent fjord without farms. Food selection from the different locations was assessed semi-quantitatively by macroscopic examination of gut contents and fatty acid composition of diets and saithe fillet. The taste of saithe fillets from the three locations was assessed by a calibrated test panel.

Materials and methods

Locations

Sørfold is a fjord system in northern Norway (Fig. 1). It cuts 40 km into the land, stretching southeast, and has a side fjord to the northeast. Water exchange is good in the fjord system and the fjord sustains a high production of phytoplankton due to a stable supply of nutrients. A fish farm in this fjord was chosen for study (Kines). One reference site was chosen in the same fjord, 10 km away from the fish farm at Kines, and 6 km away from other farms in the fjord (Kalvik). Because of the high mobility of saithe, a second reference site (Saltfjord) was chosen in a different fjord with no fish farms.

Sampling and physiological parameters

Thirty saithe were collected at each of three locations: near the fish farm (Kines), and at two reference sites (Kalvik and Saltfjord) using a trailing line on 14, 5 and 17 July 1999 respectively. The fish were removed from the line and transferred directly to a tub with seawater, where they were kept alive until sampling. None of the fish were in the tub for more than 2 h and there were no mortalities. The fish were terminated by a blow to the head, weighed, the length measured, the liver weighed, sex determined and gonads weighed. The gut was then dissected open, and its contents were categorized into pellets, crustaceans, fish and unknown. The fish were thereafter split into two and each part was stored in a −20 °C

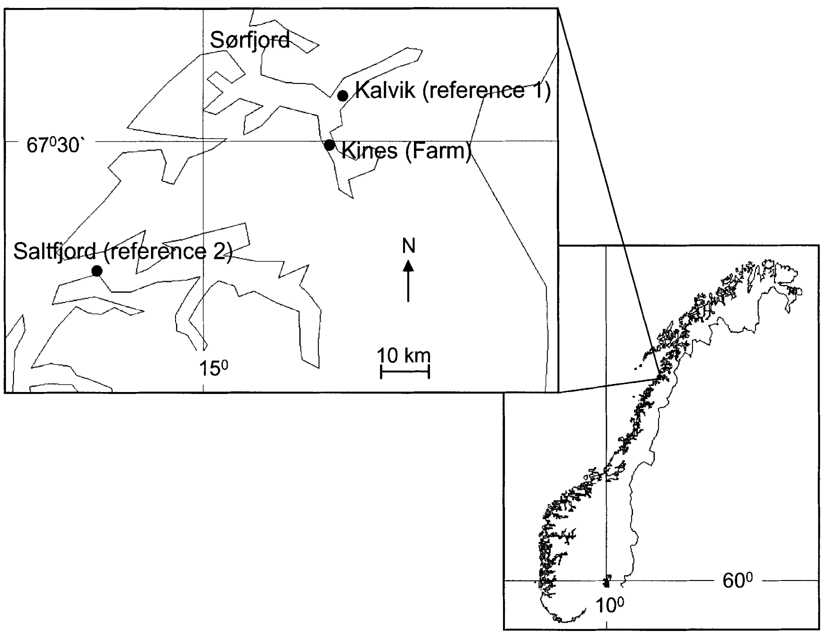

Figure 1 Maps of the study area. The lower map is an overview map of Norway. The top map shows the two investigated fjord systems: one with fish farming (Sørfjord) and one without farming activity (Saltfjord). Sample localities are indicated with dots on the map including (a) a site near a fish farm (Kines), (b) a site 10 km away from a fish farm within the same fjord system (Kalvik, reference 1) and (c) a site in a nearby fjord system free of fish farming (Saltfjord, reference 2).

freezer. The anterior part was used for sensory analyses and the fillet from the back of the fish was used for fatty acid analyses. Otoliths were taken, cleared in glycerol, cut in two and used for age determination.

The condition factor (CI) and liver somatic index (LSI) were calculated as described by Le Cren (1951). For both indices, the weight of the gonads was subtracted, as the content of the gonads will be lost during spawning, and usually cannot be utilized by the individual (Le Cren 1951).

Fatty acid composition

The fatty acid composition in fillet was determined according to Lie & Lambertsen (1991). Briefly, lipids were extracted from approximately 0.4 g of fillet from 10 randomly chosen fish from each of the three locations by adding chloroform:methanol (2:1) and kept at −20 °C overnight. The samples were filtered, saponified and methylated using 12% BF_3 in methanol. The methyl esters were separated on a Carlo Erba gas chromatograph using 'cold on column' injection, heated at 69 °C for 20 s, increased by 25 °C min^{-1} to 160 °C for 28 min, increased by 25 °C min^{-1} to 190 °C, held at 190 °C for 17 min, finally increased by 25 °C min^{-1} to 220 °C and then held at 220 °C for 9 min. The chromatograph was equipped with a 50-m-CP-Sil88 fused silica capillary column (i.d. 0.32 nm; Chromopack, Middelburg, The Netherlands). The fatty acids were identified against the retention time of a standard mixture of methyl esters (Nu-Chek-Prep, Elysian, MN, USA).

Sensory analyses

The sensory tests took place in the evening on 26 July 1999 in the local community hall canteen. Local volunteers were picked randomly. Persons in the test panel were aged from 17 to 82 years, 55% were males. The tasting ability of the taste panel was calibrated by the use of standard solutions with basic tastes (sweet, salt, sour, bitter and water) based on the method described by Lea, Rodbotten & Naes (1995). Two of the original test persons had to be removed from the panel because of too low a discerning ability for these tastes.

In the tasting test, sensory differences were tested in two ways: by difference and by ranking. The difference sensory test was conducted to assess the ability of test persons to taste the difference between fish from the three different locations. This was designed as a triangle test as described by Lea *et al.* (1995). Each participant was given three plates of fish. Two of the plates contained fish fillets from the same location. The participants had to determine which fish fillet was dissimilar to the two others. In the ranking test, the panel participants were asked to rank the fish from the three different locations. They were handed three arbitrarily numbered plates with fish. Each plate contained fish from one of the locations. They were asked to grade the taste of the fish from 1 ('very bad taste') to 9 ('very good taste').

Statistical analyses

The size and condition comparisons were performed using one-way analysis of variance (ANOVA), followed by Tukey's test for pairwise comparisons (Sokal & Rohlf 1981; Day & Quinn 1989). Levene's test was used to assess the homogeneity of variances prior to ANOVA (Glaser 1983). When variables could not be transformed to yield homogeneous variances, the Kruskal–Wallis test was used, followed by Mann–Whitney's test for pairwise comparisons (Sokal & Rohlf 1981).

Principal component analysis (PCA) was used for selected fatty acids to clarify the extent to which the fatty acid profiles in saithe fillet differed between the three locations and how they compared with the profiles from pellets and mackerel (see e.g. Brodtkorb, Rosenlund & Lie 1997). This analysis was carried out on arcsin-transformed data as the original data were on a percentage basis. Data were normalized and rotated before the analysis.

In the sensory tests, there were two outcomes of the tests: either picking the correct plate or one of the two other plates. In each test, the number of participants was 18. The probabilities of different outcomes from this test are binomially distributed, with $n = 18$ and $P = 1/3$ (picking the correct plate) (Lea *et al.* 1995). The ranking test was analysed using the Kruskal–Wallis test when comparing all locations, and Mann–Whitney's test for pairwise comparisons. The relationships between the age of the participants and taste preferences were analysed using regression analysis (Sokal & Rohlf 1981).

Results

Length, weight, CI and LSI

There were differences in the length, weight, CI and LSI for 2- and 3-year-old saithe between the fish farm

Table 1 Length, weight, condition (CI), and liver somatic index (LSI), and year-class distribution of saithe caught at Kines, Kalvik and Saltfjord, mean ± SD, $n = 30$

Location	Age group	Length (cm)	Weight (g)	CI	LSI	Proportion (%)
Kines	All	37.20 ± 7.0^a	648 ± 23^a	1.16 ± 0.09^a	8.54 ± 2.78^a	100
	2+	33.24 ± 2.77^b	460 ± 128^b	1.21 ± 0.07^a	8.27 ± 1.83^a	13
	3+	36.30 ± 2.69^b	569 ± 137^b	1.17 ± 0.05^a	7.83 ± 1.65^a	77
Kalvik	All	32.90 ± 2.32^a	366 ± 63^a	1.02 ± 0.09^b	4.38 ± 1.39^b	100
	2+	30.33 ± 1.11^a	295 ± 35^a	1.05 ± 0.07^b	5.33 ± 1.60^b	33
	3+	34.26 ± 1.48^a	403 ± 41^a	0.99 ± 0.06^b	3.90 ± 1.01^b	63
Saltfjord	All	30.15 ± 4.46^a	340 ± 131^a	1.17 ± 8.71^a	8.71 ± 2.62^a	100
	2+	30.15 ± 1.09^a	327 ± 51^a	1.18 ± 0.11^a	8.85 ± 3.01^a	43
	3+	34.27 ± 0.86^a	472 ± 32^a	1.17 ± 0.05^a	7.71 ± 1.94^a	37

Values in columns with the same superscripts are not significantly different ($P > 0.05$).

Table 2 Gut diet content (% pellets, crustacean and unknown) of saithe collected from a location near a fish farm (Kines) and from saithe collected in a nearby fish farm-free fjord system (Saltfjord)

	Pellets (%)	Fish (%)	Crustacean (%)	Unknown (%)
Kines	45.8 ± 17.2^a	0 ± 0^a	41.6 ± 18.6^a	13.4 ± 9.16^a
Saltfjord	0 ± 0^b	9.85 ± 2.54^b	41.6 ± 25.3^a	35.8 ± 22.1^a

A total of 30 fish per location were sampled (mean ± SD). Values in rows with the same superscript (or no superscript) are not significantly different ($P > 0.05$).

(Kines) and the two reference sites (Kalvik and Saltfjord). No significant differences were found between the two reference sites (Table 1).

Diet

As a result of technical problems, only the gut contents of saithe caught at Kines (the fish farm) and of saithe caught in the reference fjord (Saltfjord) were assessed. All fish caught near the fish farm had full guts, whereas the guts of 13% of the saithe caught in Saltfjord were empty. The diet of saithe from Kines and Saltfjord also differed. The gut contents of saithe from Kines consisted mainly of pellets (46%) and no fish, whereas some saithe from Saltfjord had eaten fish (10%, mostly mackerel *Scomber scomber*). Pelagic crustaceans were major food items in both areas, mostly *Calanus finmarchicus*, although some krill, *Thysanoessa inermis*, were also found (Table 2).

Fatty acid composition

The fatty acid composition differed between saithe from a fish-farm-free fjord (Saltfjord) and saithe from a fjord with farm sites (Kines and Kalvik). The concentration of 16:0 increased and 18:3n-3 and 18:2n-6 decreased with increasing distance from the fish farm (Table 3). Saithe from Saltfjord had significantly lower concentrations of 18:2n-6 and 18:3n-3 and significantly higher levels of 16:0 than the other two locations. The total amount of unsaturated fatty acids and the ratio between n-3:n-6 also increased significantly with increasing distance from the fish farm. Saithe from Kalvik had significantly lower concentrations of 22:1n-11 than saithe from the other two locations (Table 3). The commercial pellets contained higher levels of 18:2n-6, 18:1-9 and 18:3n-3 compared with fish (mackerel), whereas mackerel was characterized by higher concentrations of 20:5 and 22:6.

A plot of the data (including all fatty acids) split up in three PCA axes showed that the fatty acid profile of saithe from Kines was more variable than profiles for saithe from Kalvik and Saltfjord (Fig. 2a, b). Saithe from Kalvik was most aggregated. The first axis, accounting for 67% of the total variability, separated mackerel/pellets from saithe from the three stations. Saithe from Kines distributed more towards the pellet grouping, and saithe from Saltfjord more towards the mackerel grouping. This differentiation was clearer in the plot of PCA axes 2 and 3, which separated mackerel and pellets. In that plot (Fig. 2b), saithe from Saltfjord was more concentrated towards the mackerel

Table 3 Relative fatty acid concentrations (%) in commercial pellets ($n = 3$), natural pray (mackerel) ($n = 6$) and saithe fillet ($n = 30$) from saithe collected from a location near a fish farm (Kines) and from saithe collected in a nearby fish farm-free fjord system (Saltjord) (mean ± SD)

	Pellets	Mackerel	Kines	Kalvik	Saltjford
14:0	4.6±0.2	4.2±0.1	2.2±0.2	2.1±0.3	2.2±0.2
16:0	12.8±0.2	13.6±0.4	23.9±1.7[a]	23.4±0.2[a]	32.1±1.1[c]
18:0	2.2±0.1	2.4±0.1	5.9±0.3	6.4±0.4	6.0±0.5
Total saturated	19.6±0.1	20.2±0.2	32±1.6[a]	31.9±0.3[b]	40.3±1.0[c]
16:1n-7	5.2±0.1	5.5±0.3	1.7±0.4	1.3±0.1	1.4±0.3
18:1n-7	2.3±0.2	3.1±0.7	3.2±0.4	3.2±0.3	3.1±0.5
18:1n-9	14.8±0.1	9.2±0.7	7.1±0.2[a]	6.8±0.2[a]	6.1±0.4[b]
18:1n-11	1.0±0.1	0.5±0.1	1.6±0.1	1.5±0.1	1.7±0.2
20:1n-9	7.2±0.2	8.0±0.5	3.2±0.8	2.9±0.1	4.1±0.8
20:1n-11	0.5±0.2	0.7±0.4	0.5±0.1	0.5±0.2	0.6±0.1
22:1n-11	9.5±0.1	11.1±0.8	1.7±0.3[a]	0.9±0.1[b]	1.2±0.2[a]
Total monounsaturated	40.5±0.2	38.1±0.5	19.0±3.2	17.1±2.5	18.2±3.1
18:2n-6	10.2±0.1	1.5±0.1	1.9±0.2[a]	1.6±0.1[a]	1.3±0.1[b]
18:3n-3	2.4±0.1	1.4±0.1	1.6±0.2[a]	1.3±0.1[a]	1.0±0.2[b]
18:4n-3	2.6±0.1	2.7±0.1	1.1±0.4	0.8±0.1	1.0±0.2
20:4n-6	0.2±0.1	0.4±0.3	1.6±0.1	1.6±0.1	1.4±0.2
20:4n-3	0.4±0.1	0.8±0.1	0.8±0.1	0.7±0.1	0.8±0.1
20:5n-3	7.2±0.1	7.5±0.2	12.1±0.7	13.0±0.4	12.2±1.3
22:5n-3	0.5±0.1	0.3±0.2	1.2±0.1	1.2±0.1	1.2±0.2
22:6n-3	6.7±0.1	13.5±0.4	23.9±1.2	25.1±2.1	24.2±0.6
Total polyunsaturated	30.2±0.1	28.1±0.2	44.2±2.4	45.1±2.9	42.1±2.1
Total	64.6	93.4	92.2	94.7	91.5
Total n-3	19.8±0.1	26.2±0.3	40.7±2.4	39.3±2.6	40.4±2.1
Total n-6	10.4±0.1	1.9±0.2	3.5±0.8	3.2±0.4	2.7±0.5
Ratio n-3/n-6	1.9±0.1	13.78±0.2	11.6±0.5[a]	12.3±0.6[b]	14.9±0.4[c]

Values in rows with the same superscript (or no superscript) are not significantly different from each other (pellets and mackerel not tested due to low n; ANOVA, Tukey's test, $P > 0.05$).

grouping, whereas saithe from Kines concentrated towards the pellet grouping. Saithe from Kalvik was found to be in between in both plots. It should be noted that axis 1 accounted for as much as 67% of the total variability.

Sensory tests

The results from two members of the sensory panel were excluded from the data analysis since they were not able to separate the basic tastes. The difference test showed a significant difference between fish from the three localities. The results from the ranking test show that fish from the fish-farm-free fjord (Saltfjord) were rated significantly highest compared with saithe from Kines and Kalvik (Fig. 3). No significant differences were observed between fish from Kines and Kalvik. There was no significant correlation between age of the participants and the marks they gave to fish from the different locations ($P > 0.68$).

Discussion

The differences in size between year-classes of saithe from near the fish farm (Kines) and saithe from other ares (Kalvik and Saltfjord) indicate differences in growth rate. A similar observation was made by Carss (1990) for saithe in western Scotland, where the 0-group near the farms was significantly longer than the 0-group from a reference area. The availability of high-energy salmon pellets from the cages is an obvious explanation for the relatively larger size of saithe collected near fish farms compared with saithe from other areas. The results also indicate that this saithe was more or less resident in this area, at least until 3 years of age. The CIs and LSIs for all three locations were higher than those found in saithe from the North Sea by Storozhuk (1978), indicating that feeding conditions were good at all three locations in this study. Saithe collected at the reference site in a fjord with fish farms (Kalvik) had

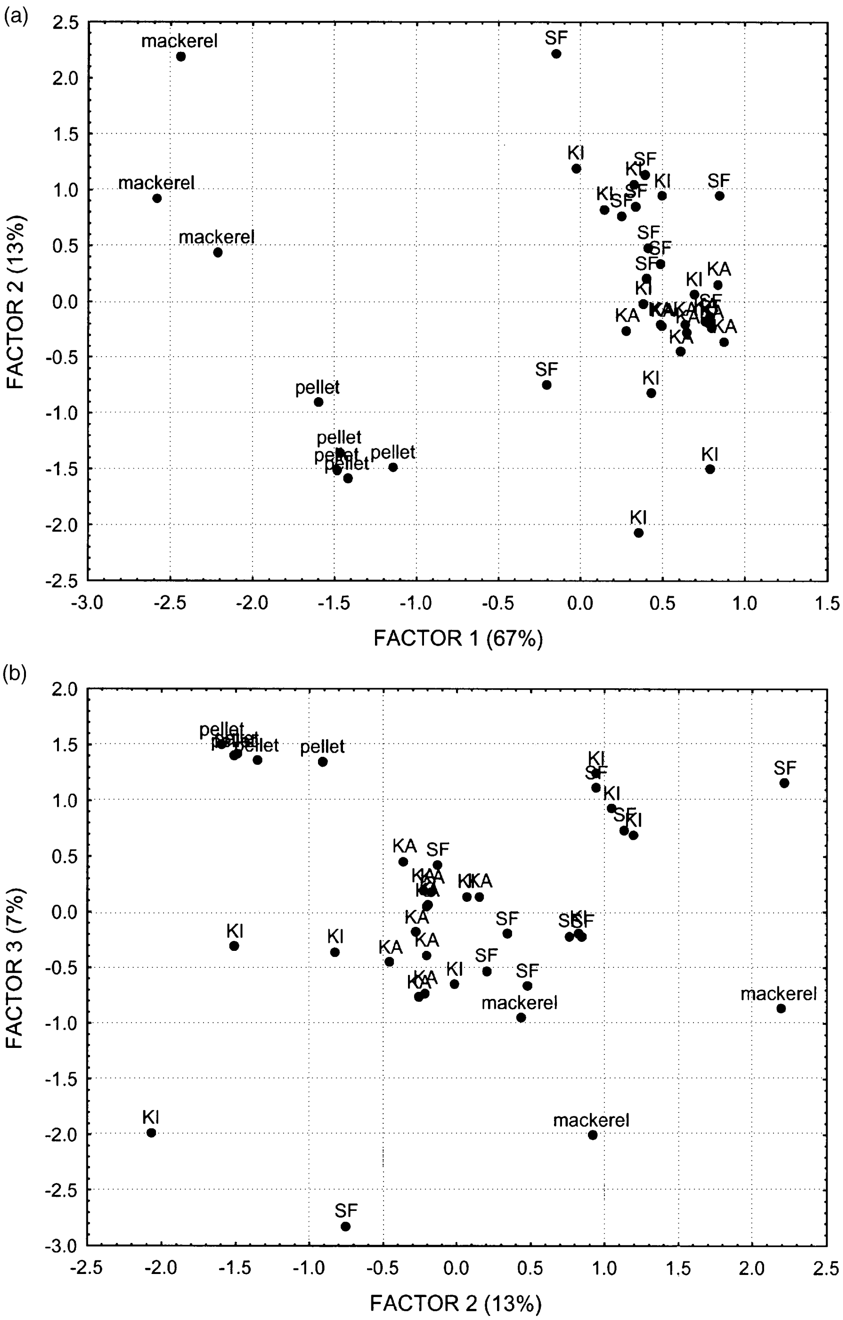

Figure 2 Score plots of the fatty acid composition of pellets, mackerel and saithe collected from Kines, Kalvik and Saltfjord. Dots are single fish from Kines (KI), Kalvik (KA) or Saltfjord (SF), $n = 10$, or analyses of single mackerel or pooled pellets: (a) PCA axes 1 and 2; (b) PCA axes 2 and 3.

significantly lower CI and LSI compared with the other two locations. It is generally thought that gadiids accumulate fat in their liver during growth, and Dos Santos *et al.* (1993) found that LSIs tended to increase with increasing growth rate in a feeding experiment with cod. The results found here thus indicate a lower growth rate in saithe from Kalvik compared with saithe from Kines and Saltfjord. It is more difficult to explain the difference in size of 2- and 3-year-old saithe at Kines and Saltfjord, since both areas appear to have good conditions for growth. Most probably, the difference is associated with modes of

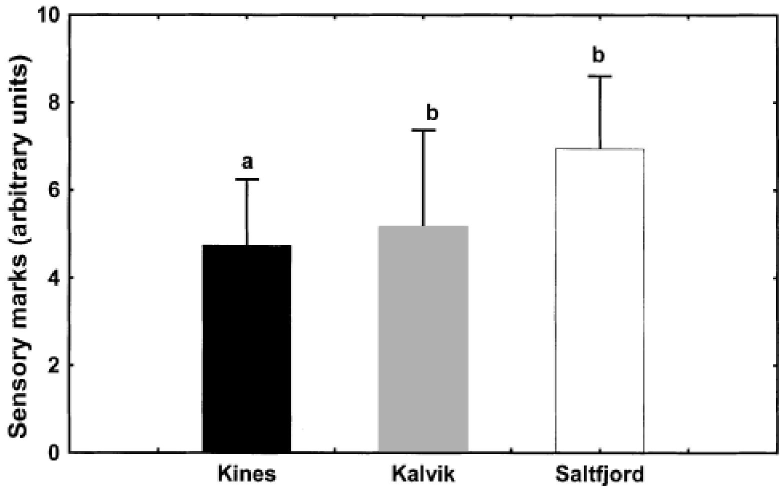

Figure 3 Sensory ranks (arbitrary units) given to saithe from the different locations. For all locations, $n = 18$ (mean ± SD). Columns with the same superscript are not significantly different from others (Kruskal–Wallis $P > 0.05$).

feeding, the Saltfjord saithe being more active. The minor differences in age distribution at the three locations were probably due to different depths of the catches. The saithe tend to live deeper with increasing age (Bergstad, Jørgensen & Dragesund 1987). At Kines, the saithe was collected mostly at 35 m depth, in Kalvik mostly at 25 and 40 m depth, and in the Saltfjord mostly at 15–20 m depth. Saithe longer than 30 cm are rarely found inshore near Nova Scotia, according to Clay, Stobo, Beck & Hurley (1989). It could be that some 2- and 3-year-old saithe preferred to stay in the fjord rather than moving to the open coast because of the availability of food near the fish farms. This would explain the larger fraction of older saithe caught near the fish farms compared with the other two areas.

The results for gut contents indicate that the saithe forage on whatever is available, but with a focus on pelagic food items. Crustaceans were present in the gut contents of nearly half the saithe at Kines and Saltfjord. The copepod *C. finmarchicus* is a known natural dietary item for saithe (Nedreaas 1987). *C. finmarchicus* is known to be abundant in the fjord systems during the summer when the study was performed (Skreslet, Olsen, Mohus & Tande 2000). Other natural prey for saithe, such as juvenile fish, was only found in the guts of saithe from Saltfjord. None of the saithe collected near the fish farm had eaten juvenile fish, but nearly all (93%) had pellets in their guts. The results are in accordance with the findings of Carss (1990), who observed that saithe was the only wild fish species that was found to eat pellets near fish farms and that saithe caught away from farms did not have pellets in their guts.

The relative concentrations and composition of fatty acids in the fillets of saithe from Kines and Saltfjord were generally in accordance with the profiles of their main dietary items. Commercial feeds have more fatty acids such as 18:2n-6, 18:1n-9 and 18:3n-3 compared with natural food. These fatty acids were significantly elevated in the fillet of saithe caught near fish farms compared with saithe from a fish-farm-free fjord (Saltfjord). Furthermore, the comparatively low ratio of n-3:n-6 found in commercial pellets compared with natural food was reflected in the fillet of saithe from near the fish farm compared with saithe from Saltfjord. The results are in accordance with findings from feeding studies on cod, in which a marked increase was observed in the typical vegetable fatty acids in muscle, especially 18:2n-6, and a decreased 18:n3 to 18:n6 ratio when fed on formulated diets rich in vegetable fatty acids under experimental conditions (Lie *et al.* 1986). In the present field study, the differences in muscle vegetable fatty acids content, especially 18:2n-3, were relatively low, although there was a clear trend in decreasing content of muscle vegetable fatty acids with increasing distance from fish farms. Saithe primarily stores its energy reserves in the liver as fat, and muscle fat mainly consists of phospholipids (Jensen 1979). Although experimental diets based on vegetable oils are also known to affect phospholipid fatty acid composition in fish (Bell *et al.* 1996), the most profound changes are expected to be in the storage fat, which for saithe is in the liver. In the present study, however, the main focus was on whether diet selection from different locations affected composition and taste in the edible part of the saithe, the fillet (muscle). The relative increase in 16:0 in saithe collected in reference areas (both Kalvik and Saltfjord) indicates *de novo* synthesis of these acids (Henderson & Sargent 1985). Such *de novo* synthesis might be attributed to the relative lower fat content and/or the presence of natural prey compared with the readily high-energy pellets available near fish farms. The present results indicate that the fatty acid 'fingerprint' of long-term foraging of saithe on commercial pellets decreases with increasing distance from fish farms.

The PCA analyses show that although there are relationships between saithe collected near farms and pellets, there is a closer relationship between pellets and mackerel (along the first PCA axis). Unfortunately, no data are available on the fatty acid composition of the third main food item, copepods. The grouping of saithe from the three areas shows that saithe collected at both Saltfjord and Kines are heterogeneous. This suggests that there is individual variation in the time spent near the cages (Kines). It is not clear why saithe from Saltfjord have such variable fatty acid profiles. A possible explanation is the availability of a wider range of food items at that location. Saithe have been found to show two different behaviour patterns in relation to fish farms: one group had a home range with the cages as the core area, and the other group had a core area in deeper water further offshore and visited the fish farm site on a daily basis. Some of the fish also visit adjacent fish farms, but generally return to their core area by nightfall. It has been found that saithe spend from 1 to 7 months in the vicinity of fish farm cages. The most obvious explanation for the variability of profiles from Saltfjord saithe is the diversity of food items available at that location (fish, copepods). In contrast, saithe from the third location, Kalvik, appeared to be very homogeneous in the PCA analysis, indicating limited dietary variation.

The results from the difference test indicate that there were differences in taste between saithe from the three locations. The mean size varied between fish from the different locations. The variation in size between year-classes was, however, larger than between saithe of the same year-class from different locations, and the age of the saithe that served as the participants was random. The tasters could therefore not use the size of the fish as an indicator of its origin. Hence, differences in fish size did not influence the results. The ranking test indicated that the panel thought that fish from the fjord without farms, Saltfjord, had the best taste.

In conclusion, the results of the study indicate that wild saithe caught near a fish farm forage on commercial fish feed, as seen from the gut content and changed fatty acid signature of muscle. These fish were also found to have inferior taste compared with fish from an adjacent fjord with no fish farms.

Acknowledgments

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References

Bell J.G., Ashton I., Secombes C.J., Wetzel B.R., Dick J.R. & Sargent J.R. (1996) Dietary lipid affects phospholipid fatty acid compositions, eicosanoid production and immune function in Atlantic salmon (*salmo salar*). *Prostaglandins, Leukotrienes and Essential Fatty Acids* **54**, 173–182.

Bell J.G., Henderson R.J., Tocher D.R., McGhee F., Dick J.R., Porter A., Smullen R.P. & Sargent J.R. (2001) Substituting fish oil with crude palm oil in the diet of Atlantic salmon (salmo salar) affects muscle fatty acid composition and hepatic fatty acid metabolism. *Journal of Nutrition* **132**, 222–230.

Bergstad O.A., Jørgensen T. & Dragesund O. (1987) Life history and ecology of the gadoid resources of the Barents Sea. *Fisheries Research* **5**, 119–161.

Brodtkorb B.T., Rosenlund G. & Lie G. (1997) Effects of dietary levels of 20:5n-3 and 22:6n-3 on tissue lipid composition in juvenile Atlantic salmon, Salmo salar, with emphasis on brain and eye. *Aquaculture Nutrition* **3**, 175–187.

Carss D.N. (1990) Concentrations of wild and escaped fishes immediately adjacent to fish farm cages. *Aquaculture* **90**, 29–40.

Clay D., Stobo W.T., Beck B. & Hurley P.C.F. (1989) Growth of juvenile pollock (*Pollachius virens* L.) along the Atlantic coast of Canada with inferences of inshore–offshore movements. *Journal of Northwestern Atlantic Fisheries Science* **9**, 37–43.

Day R.W. & Quinn G.P. (1989) Comparisons of treatments after an analysis of variance in ecology. *Ecological Monographs* **59**, 433–463.

Dos Santos J., Burkow I.C. & Jobling M. (1993) Patterns of growth and lipid deposition in cod (*Gadus morhua* L.) fed natural prey and fish-based feeds. *Aquaculture* **110**, 173–189.

Glaser R.E. (1983) Levene's robust test of homogeneity of variances. In: *Encyclopedia of Statistical Sciences* (ed. by S. Kotz & N.L. Johnson), pp. 608–610. John Wiley & Sons, New York, USA.

Henderson R.J. & Sargent J.R. (1985) Fatty acids metabolism in fish. In: *Nutrition and Feeding in Fish* (ed. by C.B. Cowey, A.M. Mackie & J.G. Bell), 253pp. Academic press, London, UK.

Jensen A.J. (1979) Energy content analysis from weight and liver index measurements of immature pollock (*Pollachius virens*). *Journal of the Fisheries Research Board of Canada* **36**, 1207–1213.

Kirsch P.E., Iverson S.J., Bowen W.D., Kerr S.R. & Ackman R.G. (1998) Dietary effects on the fatty acid signature of whole Atlantic cod (*Gadus morhua*). *Canadian Journal of Fisheries and Aquatic Science* **55**, 1378–1386.

Lea P., Rodbotten M. & Naes T. (1995) Measuring validity in sensory analysis. *Food Quality and Preference* **6**, 321–326.

Le Cren E.D. (1951) The length–weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *Journal of Animal Ecology* **20**, 201–219.

Lie Ø. & Lambertsen G. (1991) Fatty acid composition of glycerophospholipids in seven tissues of cod (*Gadus morhua*), determined by combined high-performance liquid chromatography and gas chromatography. *Journal of Chromatography* **56**, 119–129.

Lie Ø., Lied E. & Lambertsen G. (1986) Liver retention of fat and of fatty acids in cod (*Gadus morhua*) fed different oils. *Aquaculture* **59**, 187–196.

Nedreaas K. (1987) Food and feeding habits of young saithe, Pollachius Virens (L.), on the coast of Western Norway. *Directorate of Fisheries Series* **18**, 263–301.

Skreslet S., Olsen K., Mohus A. & Tande K. S. (2000) Stage-specific habitats of *Calanus Finmarchicus* and *Calanus helgolandicus* in a stratified northern Norwegian fjord. *ICES Journal of Marine Science* **57**, 1656–1663.

Sokal R.R. & Rohlf F.J. (1981) *Biometry* , 2nd edn. W.H. Freeman, New York, USA.

Storozhuk A.Y. (1978) Age-related features of the metabolism of the coalfish (*Pollachius virens*). *Journal of Ichtyology* **18**, 655–665.

Torstensen B.E., Lie Ø. & Frøyland L. (2000) Lipid metabolism and tissue composition in Atlantic salmon – effects of capelin oil, palm oil, and oleoc acid-enriched sunflower oil as dietary lipid sources. *Lipids* **35**, 1–12.