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ORIGINAL ARTICLE

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Does waste feed from salmon farming affect the quality of saithe (*Pollachius virens* L.) attracted to fish farms?

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Abstract

Salmon farms attract large amounts of wild fish, which prey on uneaten feed pellets. The modified diet of the wild fish aggregating at salmon farms may reduce the flesh quality of the fish, influencing the local fisheries. We compared the quality of saithe (*Pollachius virens*) captured near (farm associated—FA) or more than 5 km away (unassociated—UA) from salmon farms in Norway. The fish were captured during summer, autumn and spring using two commercial fishing methods (jigging and bottom nets). Overall, the fillet quality of FA saithe was good, although it was clearly reduced for almost 10% of the catch. Moreover, the quality of the FA saithe was significantly reduced compared with UA saithe, but the differences were small. Our results also showed that fish caught with jigging had better quality than fish caught with nets, and that fish that died in the nets were of lower quality than fish that were alive after hauling. There was no clear variation among seasons in fillet quality. Although no major and overall differences in quality were found between FA and UA saithe, reduced quality for even a modest proportion of the fish may influence the value of the total catch.

KEYWORDS

attraction of wild fish, flesh quality, *Pollachius virens* L., salmon farming, waste feed

1 | INTRODUCTION

Salmon farming can modify ecosystems in coastal waters (Maurstad, Dale, & Bjørn, 2007; Wiber, Young, & Wilson, 2012). The large fish feed requirement results in considerable amounts of organic by-products, in terms of uneaten feed pellets falling through the cages, fragmentation of pellets during feeding, and dissolved and particulate nutrients originating from faeces (Aas et al., 2011; Dempster et al., 2011; Holmer, 2010). The amount of uneaten feed (waste feed) during commercial operation of salmon farms has to our knowledge not been measured, but it has been assumed that the loss lies in the region of 3%–5% (Otterå, Karlsen, Slinde, & Olsen, 2009; Svåsand et al., 2015). In 2015, the salmon farming industry in Norway used more than 1.7 million tons of food (Norwegian Directorate of Fisheries, 2015), suggesting that thousands of tons of waste feed are available to wild fish each year.

Attraction of wild fish to open cage fish farms, that is farms consisting of floating net cages, is a global phenomenon (Barrett, Swearer, & Dempster, 2019; Callier et al., 2018; Uglem, Karlsen, Sanchez-Jerez, & Sæther, 2014). More than 160 fish species, belonging to about 60 families, have been detected in the near vicinity of open cage farms (Sanchez-Jerez et al., 2011). In Norway, 15 fish species belonging to nine families have been observed underneath salmon farms, with the most common species being saithe (*Pollachius virens*), Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and mackerel (*Scomber scomber*) (Dempster et al., 2009). Waste feed from the farms is believed to be the primary cause for aggregation of wild fish at open cage farms (Dempster et al., 2011; Fernandez-Jover, Sanchez-Jerez, Bayle-Sempere, Valle, & Dempster, 2008; Sanz-Lazaro, Belando, Marin-Guirao, Navarrete-Mier, & Marin, 2011). The occurrence of waste feed in stomach samples from wild fish caught at salmon farms has been quantified for saithe and cod only (Dempster et al., 2011), but waste feed has also been observed in stomach samples from haddock, mackerel and pollack (*Pollachius pollachius*) I. Uglem (unpublished data). Waste feed has been found in stomach samples of 14%–92% and 11%–32% of farm associated (hereafter FA) saithe and cod respectively (reviewed in Uglem et al., 2014). In general, FA gadoids are significantly fatter and have larger energy stores than un-associated (hereafter UA) fish (Dempster et al., 2011), and have higher concentrations of terrestrial derived fatty acids and lower concentrations of docosahexaenoic acid (DHA) in muscle and liver compared with UA fish (Fernandez-Jover et al., 2011). The metabolic status of FA and UA saithe is also different and FA fish have higher levels of, for example lactate and lower levels of creatine than UA fish, both relationships indicating a potential for reduced quality of the FA fish (Maruhenda Egea, Toledo-Guedes, Sanchez-Jerez, & Uglem, 2015).

Salmon feed is designed for promoting optimal quality and growth of salmon, and may not be an optimal food for other fish species. A diet change from natural prey to salmon feed may therefore affect the flesh quality of FA gadoids (Uglem et al., 2014). Norwegian coastal fishermen and fish buyers have raised concerns on the quality of wild gadoids feeding on waste feed (Otterå & Skilbrei, 2014; Skog, Hylland, Tortensen, & Berntssen, 2003). Fillets from FA fish are claimed to be soft and with a high degree of gaping. Abnormal coloration and unappealing smell have also been reported. It can be hypothesized that the reduction in quality, in terms of soft texture, is related to both *ante-mortem* and *post-mortem* glycolysis. The former is probably related to stress and/or activity before death (Kiessling, Espe, Ruohonen, & Mørkøre, 2004). In both cases, the glycogen is broken down to lactic acid, thus making the fish muscle slightly acidic, which in turn may increase flesh softness and gaping (Bremner, 1999; Kristoffersen, Tobiassen, & Steisund, 2006). The quality may also depend on the nutritional state of the fish. Since well-fed and fat FA fish have large amounts of lipids and glycogen in liver and muscle, they will have a high glycolytic potential and possibly low ultimate post-mortem pH and reduced fillet quality (Kristoffersen et al., 2006).

The quality of FA saithe has been evaluated in several ways, but with inconsistent results (Uglem et al., 2014). Results from sensory tests of saithe that have had a diet consisting of salmon feed compared with fish that have had a more natural diet indicate slight variations, but no consistent trend, in taste and appearance (Otterå et al., 2009; Sæther et al., 2012; Uglem et al., 2017). FA and UA saithe have also been compared with different quality index assessment methods, that is evaluation and combination of several fillet properties such as smell, splitting/gaping, colour, consistency and surface appearance into an index value (Akse, Tobiassen, Midling, & Aas, 2007; Otterå et al., 2009). In the same way as for the sensory analyses, variation in fillet quality index has been relatively small, without consistent trends between either FA saithe caught in the wild or saithe fed salmon/cod pellets in captivity compared with wild-caught FA fish (Bjørn et. al., 2007; Otterå et al., 2009; Sæther et al., 2012).

However, the interpretation of the fillet index results for saithe may have been confounded by the different groups in the previous studies being caught with different fishing techniques (jigging, pots or bottom nets). In general, fish caught by jigging or in pots are expected to be of a better quality than fish caught by nets, as they are caught alive and rapidly killed and bled, while fish caught in nets might be considerably stressed or even dead at sea after having been kept trapped in the nets for many hours (Toledo-Guedes, Ulvan, & Uglem, 2016). In support of this, Sæther et al. (2012) found that the fillet quality index of saithe caught with nets (UA fish) was significantly lower compared with saithe caught alive in pots (FA fish). Other confounding factors may be that the quality depends on the amount of waste feed consumed over time and thus the condition of the fish, as well as time of capture since flesh quality in fish may vary throughout the reproduction cycle and possibly also with environmental variation. In this study, we have captured FA and UA saithe in two areas in Norway during summer, autumn and spring using two commercial fishing methods (jigging and bottom nets). This study design allowed us to compare quality directly among groups of saithe, as well as assess if the quality varied among seasons. Hence, by avoiding confounding factors, such as capture by different types of gear, the present study represents a novel approach to evaluate the influence of salmon farming on the quality of saithe. Texture measurements and two different index-based assessment methods were used to evaluate fillet quality in a way that is realistic for the first part of the distribution chain of saithe, that is fish landing facilities and wholesalers, since this would be the most relevant stage in the value chain for assessing and sorting fish with respect to quality.

2 | MATERIAL AND METHODS

2.1 | Study location and fish sampling

Saithe were collected in Ryfylke (N59°11, E05°53) and close to the island Hitra (N63°62, E08°99) in southwestern and mid-western Norway at six different occasions during summer, autumn and spring in 2013–2015 (Figure 1, Table 1). FA fish were captured less than 500 m from farms, containing salmon above 1 kg, in each of these two areas (Figure 1). Since Norwegian salmon farms are

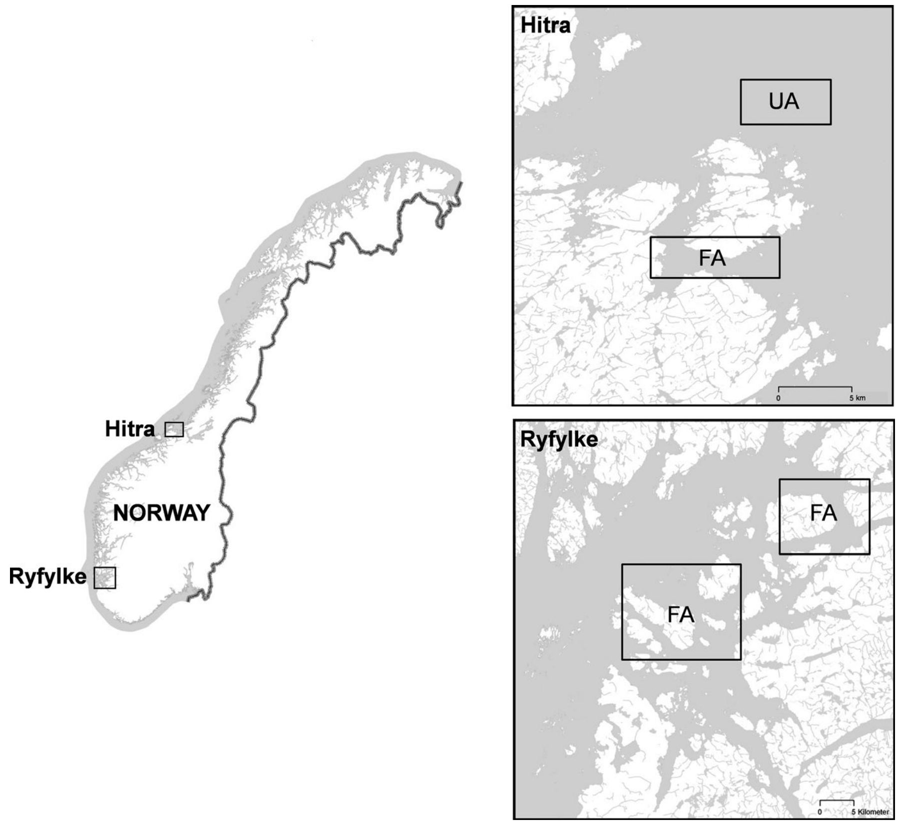

FIGURE 1 Map showing the areas in Hitra and Ryfylke where the saithe were captured. The boxes indicate where farm associated (FA) and un-associated (UA) saithe were captured

fallowed between each production cycle and the size of the farmed fish vary throughout the cycle, sampling of saithe was for practical reasons carried out at different farms within the same area throughout the study period to collect standardized samples at farms that contained larger salmon. This is the part of the production cycle when the feeding rate, and therefore the amount of waste feed available to the wild fish, is at its highest. UA fish were sampled from locations 5–10 km distant from the nearest farm (Figure 1). Nonetheless, the UA fish from Ryfylke were clearly influenced by salmon farms; between 7% and 19% of pellets, prevalence in their diet was found, while UA fish from Hitra had no pellets in their stomachs (Table 1). Thus, UA fish from Ryfylke were excluded from further analyses.

The fish were captured by commercial coastal fishermen using bottom gillnets which were soaked between 15 and 17 hr, and automatic jigging machines that hauled the fish on board in 2–3 min. After hauling, the fish that were alive were immediately euthanized with a blow to the head. The consciousness of the fish that were alive was evaluated according to Kestin, van de Vis, and Robb (2002), defined by physical responses towards handling and operculum movement prior to euthanization. Then, the fish was bled and transferred to a 500 L tank with running seawater at ambient seawater temperature where it was kept for approximately 1 hr before it was gutted and cleaned. Following cleaning and rinsing, the fish were transferred to Styrofoam boxes (BEWI. Dimensions: 22 × 39 × 79 cm) cooled with ice. The boxes with the fish were stored at low temperature (2–4°C) for 96 hr before the quality analyses. This study conforms to Directive 2010/63/EU on the protection of animals used for scientific purposes.

2.2 | Size, diet and condition indices

Upon capture and before bleeding the total length (TL) and the whole-body weight (*W*) of the fish were measured to the nearest 1 cm and 10 g respectively (Kern & Sohn, Scale model: HDB 10K 10N). Each fish was tagged with an individually coded T-bar tag (Hallprint Fish tags) to allow identification during subsequent processing. Immediately after gutting, liver (LW) and gonad (GW) weights were recorded for each fish to the nearest 1 g (Kern & Sohn, Scale model: FFN 6K 1IPN). Sex was determined by macroscopic examination of the gonads. Three morphometric indices were calculated on basis of the measurements. Fultons condition index (FCI) was calculated with the formula: $FCI = (W/TL^3) \times 100$. The hepatosomatic index (HSI) and gonadosomatic (GSI) indexes were calculated using the formulas: $HIS = (LW/W) \times 100$ and $GSI = (GW/W) \times 100$. Stomach contents from the foregut were examined and the prey identified into five broad categories (salmon feed pellets, fish, crustaceans, bivalves and other organic matter) and weighed to the nearest gram (Kern & Sohn, Scale model: FFN 6K 1IPN).

2.3 | Samples

Altogether, 554 saithe were captured during the project, 221 with jigging (50 at control sites and 171 at farm sites) and 333 with nets (147 at control sites and 186 at farm sites; Table 1). At four occasions, it was not possible to obtain control samples using jigging,

TABLE 1 Morphometric data and quality indices (mean ± standard deviations) for farm associated (FA) and un-associated (UA) saithe from Hitra and Ryfylke, captured either by jigging or in nets

Area	Season	Fishing gear	FA/UA	*N*	Length (cm)	Weight (kg)	Condition factor (K)	HSI	GSI	Pellets prevalence (%)	Pellets weight (g)	Pellet in diet (%)	QIM	IT
Hitra	Autumn	Jigging	UA	30	68 ± 4	3.05 ± 0.7	0.95 ± 0.13	6.9 ± 3.1	1.82 ± 1.52	0	–	–	1.91 ± 0.75	0.67 ± 0.71
			FA	31	60 ± 8	2.14 ± 0.97	0.96 ± 0.13	5.6 ± 2	0.93 ± 1.14	29	56 ± 77	100.0	2.73 ± 1.36	2.70 ± 1.88
		Net	UA	30	68 ± 3	2.96 ± 0.48	0.94 ± 0.1	6.8 ± 1.4	1.79 ± 1.63	0	–	–	2.39 ± 1.40	1.10 ± 1.32
			FA	30	66 ± 7	3.1 ± 0.97	1.05 ± 0.17	8.2 ± 2.4	1.27 ± 0.93	33	141 ± 163	88.8	2.96 ± 1.51	2.17 ± 2.09
	Spring	Jigging	UA	–	–	–	–	–	–	–	–	–	–	–
			FA	30	69 ± 4	3.09 ± 0.73	0.93 ± 0.16	6.1 ± 3.5	0.63 ± 1.39	60	166 ± 106	93.6	2.82 ± 1.29	2.40 ± 1.77
		Net	UA	31	66 ± 6	2.44 ± 0.63	0.84 ± 0.07	6.2 ± 4.4	0.63 ± 0.81	0	–	–	1.72 ± 0.85	1.13 ± 1.18
			FA	30	68 ± 6	3.19 ± 0.68	1.04 ± 0.18	10 ± 4.8	1.12 ± 3.09	50	89 ± 63	97.1	2.57 ± 1.10	2.03 ± 1.43
	Summer	Jigging	UA	20	62 ± 6	2.09 ± 0.64	0.86 ± 0.07	6 ± 2.2	0.25 ± 0.28	0	–	–	1.86 ± 0.57	2.42 ± 1.57
			FA	25	68 ± 7	3.18 ± 0.89	0.98 ± 0.13	10 ± 3.2	0.36 ± 0.41	88	78 ± 87	92.0	2.41 ± 0.96	2.84 ± 1.80
		Net	UA	20	69 ± 4	2.99 ± 0.47	0.9 ± 0.08	6.8 ± 2.7	0.43 ± 0.3	0	–	–	2.57 ± 1.34	2.60 ± 2.16
			FA	48	66 ± 6	2.92 ± 0.74	1.01 ± 0.13	10.7 ± 3.8	0.24 ± 0.29	23	96 ± 112	95.3	2.91 ± 1.46	3.40 ± 2.29
Ryfylke	Autumn	Jigging	UA	–	–	–	–	–	–	–	–	–	–	–
			FA	25	45 ± 2	0.9 ± 0.1	1.02 ± 0.12	11.6 ± 2	0.12 ± 0.15	72	5 ± 3	100.0	6.85 ± 1.49	6.29 ± 1.76
		Net	UA	36	59 ± 6	2.05 ± 0.73	0.96 ± 0.1	8.9 ± 2.8	3.11 ± 3.02	19	94 ± 127	87.0	4.31 ± 1.88	3.53 ± 2.02
			FA	25	57 ± 5	1.85 ± 0.7	0.93 ± 0.12	8 ± 3.8	3.44 ± 3.67	40	38 ± 75	85.5	4.70 ± 1.98	4.92 ± 1.53
	Spring	Jigging	UA	–	–	–	–	–	–	–	–	–	–	–
			FA	30	57 ± 5	2.09 ± 0.52	1.15 ± 0.14	7.2 ± 3.4	0.37 ± 0.28	70	54 ± 41	96.8	1.85 ± 0.59	1.80 ± 1.42
		Net	UA	30	62 ± 5	3.07 ± 0.85	1.26 ± 0.18	12 ± 5.1	3.52 ± 5.8	7	79 ± 67	100.0	2.25 ± 1.02	2.63 ± 2.16
			FA	30	57 ± 7	2.29 ± 0.52	1.27 ± 0.21	9.1 ± 3.4	0.77 ± 1.34	70	156 ± 73	98.1	2.35 ± 0.65	2.97 ± 1.56
	Summer	Jigging	UA	–	–	–	–	–	–	–	–	–	–	–
			FA	30	58 ± 7	1.95 ± 0.67	1 ± 0.09	9.5 ± 2.5	0.38 ± 0.3	90	32 ± 38	78.5	3.16 ± 0.81	2.59 ± 1.08
		Net	UA	–	–	–	–	–	–	–	–	–	–	–
			FA	23	65 ± 8	2.61 ± 0.94	0.9 ± 0.13	7.8 ± 3.6	0.42 ± 0.41	26	168 ± 208	100.0	2.96 ± 1.06	1.82 ± 1.11

Abbreviations: GSI, gonadososmatic index; HIS, hepatosomatic index; IT, industry test; *N*, sample size; Pellets in diet, percentage of diet that consisted of pellets; Pellets prevalence, percentage of sample with pellets in the stomach; pellets weight, average amount of pellets in stomach; QIM, quality index method.

partly due to extreme weather conditions (Hitra) or limited availability of saithe in areas away from the salmon farms (Ryfylke) (Table 1). At one occasion (Ryfylke, autumn), the fish caught by jigging close to farms were considerably smaller than the commercial size of saithe. This sample was therefore not included in the further analyses. Apart from these occasions between 20 and 48, saithe were collected for the different groups (Table 1). The fish caught at Hitra were larger than the fish caught in Ryfylke, most likely due to a general variation in the size composition of saithe in these two areas.

In general, the FA saithe from Hitra had a higher condition factor and larger livers per body mass than the UA fish (HSI: $t = 5.4$, $p < .001$, K: $t = 6.6$, $p < .001$). The HSI was slightly higher for the UA fish than the FA fish from Ryfylke ($t = -2.4$, $p = .03$), while there was no difference between FA and UA fish from Ryfylke in condition factor ($t = -1.5$, $p = .21$). None of the UA fish from Hitra had pellets in their stomach, while pellets were found in the stomachs of 19 and 7% of the UA fish from Ryfylke in autumn and spring respectively (Table 1). The findings from Ryfylke may indicate that UA fish is difficult to obtain in this region due to high farm density and a high degree of inter-farms movements (Otterå & Skilbrei, 2014; Uglem, Dempster, Bjorn, & Sanchez-Jerez, 2009).

The average GSI was low for all groups indicating that the majority of the fish were immature. Saithe should normally spawn during late winter or early spring, and it was thus expected that the GSI should be highest in the spring samples. Out of 181 fish caught during spring, only 15 (8.2%) had clearly mature or maturing gonads with a GSI above 2 (Table 1). The average prevalence and mass of pellets in stomachs from FA saithe from Hitra was 44% and 105 g (±104 g), while 61% of the saithe in Ryfylke had on average 65 g (±87 g) pellets in their stomach (Table 1).

2.4 | Fillet quality assessment

The quality of the saithe was assessed, 4 days after capture, using two quality tests: a modified quality index method (QIM) and a simple industry test (IT). Moreover, the texture of thawed loins was evaluated for a selection of the samples (stored for 4 months at −18°C). Quality index methods have been developed and used for evaluating the quality of a range of fish species (Bonilla, Sveinsdottir, & Martinsdottir, 2007 and references therein) and is recognized as a reference method in sensory research (Martinsdóttir, Luten, Schelvis-Smit, & Hylding, 2003; Olafsdóttir et al., 1997). A QIM approach has for instance been used for documenting reduced quality of bogue (*Boops boops* L.) captured in the proximity of fish farms (Bogdanovic, Šimat, & Marković, Šimat, Frka-Roić & Marković, 2012). In this study, our rationale for using a QIM approach was the need for a fast, reliable and simple method for assessing a potential alteration of quality as experienced by fishermen and wholesalers. As the purpose of this study was to detect potential differences between two groups and not to analyse fillet degradation over time or shelf life, the quality assessment was carried out 4 days after capture, that is after a sufficient period for avoiding confounding effects due to onset of rigor mortis.

The QIM test (Table 2) was based on a method developed for assessment of quality of Atlantic cod fillets (QIM; Akse et al., 2007), while the industry test (Table 2) was based on simpler test designed for rapid detection of significant texture related quality defects for salmon fillets (IT; Erikson, Bye, & Oppedal, 2009). Both methods were slightly modified after pre-observations of saithe captured in a pilot study in 2012 as they originally were developed for other species. In the QIM test, five fillet attributes (odour, gaping, colour, texture and surface) were assessed and the maximum sum was 12, while in the industry test, three attributes (inelasticity, softness and gaping) were assessed with a maximum sum of 9. The total score from both tests indicate that the fillet quality decrease with increasing value. Three trained assessors carried out the quality evaluation, and the arithmetic mean of these three independent assessments was used in the subsequent analyses.

The texture analyses followed established procedures used for evaluation of the quality of fish fillets (Larsson et al., 2012). Before analysis, the fillets were thawed at 4°C in a thermo-controlled cabinet. The analyses were performed instrumentally (TA-HDi Texture Analyser; Stable Micro Systems Ltd.) by pressing a flat-ended cylinder (12.5 mm diameter, type P/0.5) into the fillet perpendicular to the muscle fibres at 1 mm/s until the fillet thickness was reduced to 90% of original thickness. Texture was measured at three locations of each loin for fish collected at Hitra during spring 2015 and autumn 2014. The arithmetic mean of the three measurements was used in the subsequent analyses.

2.5 | Data analyses

Extreme weather conditions and low abundance of fish in some of the sampling periods, together with the presence of pellets in the diet of UA fish from Ryfylke (Section 2.1), hindered full factorial analyses. The quality of FA fish from Hitra (Farm 1) and Ryfylke (Farm 2) was therefore compared with UA fish from Hitra as a control. Since previous studies have shown that the metabolic status of UA fish from the same locations at Hitra differ significantly from FA fish (Maruhenda Egea et al., 2015), and no feed pellets were found in the stomach of these fish we assume that the UA fish from Hitra were unaffected by salmon farming. For analyses that involved comparisons of FA and UA fish between regions, the QIM and IT scores were standardized (*Z*-standardization) within each sampling season and region to control for unaccounted variation. Moreover, pairwise tests (i.e., pseudo-*t* statistic as given by PERMANOVA routine or chi-squared test; Anderson, Gorley, & Clarke, 2008) were carried out when needed to explore intergroup differences and interactions between fixed factors.

To examine potential effects of farming or fishing gear on fillet quality, standardized scores for each of the fillet quality indices (QIM and IT) were analysed with permutational multivariate ANOVAs (PERMANOVA; Anderson et al., 2008) over a similarity matrix built using Euclidean distance and performing 4,999 permutations. The

TABLE 2 Individual quality parameters and their ranges for each quality index used

Quality parameter	Description	Score
QIM		
Odour	Fresh smell of sea	0
	Neutral	1
	Fishy	2
	Ammonium	3
Gaping	No gaping	0
	Initial gaping	1
	Some, loose fillet	2
	Major, disjoint fillet	3
Colour	Normal—fresh colour	0
	Abnormal—colour	1
Texture	Firm, natural	0
	Marginally soft	1
	Soft	2
	Very soft	3
Surface	Dry and shiny	0
	Partly dissolved	1
	Very dissolved	2
IT		
Inelasticity	Folded fillet, with skin side down, straightens out quickly	0
	Somewhat elastic, the fillet straightens out slowly	1
	Inelastic, the fillet remains folded over	2
Softness	Firm, surface restored short time after approximately 1 kg pressure is applied with forefinger	0
	Reduced firmness, finger pressure leaves lasting imprint	1
	Soft fillet, the finger goes through the fillet	2
Gaping (loin, belly and tail)	No gaping	0
	Minor signs of gaping	1
	Slight gaping	2
	Moderate gaping	3
	Considerable gaping	4
	Major, disjoint fillet	5

Note: Modified after Akse et al. (2007 and Erikson et al. (2009).
Abbreviations: IT, industrial test; QIM, quality index method.

models included the fixed factors *origin* (Hitra UA, Hitra FA and Ryfylke FA) and *fishing gear* (Gillnet and Jigging). Furthermore, to analyse how the individual fillet quality parameters (Table 2) used to calculate the QIM and IT scores contributed to explain the observed variation in quality between *origin* and *gear*, SIMPER analyses were performed on standardized values of the different fillet quality parameters.

Potential influence of region and season on fillet quality was examined by using the non-standardized QIM and IT scores of FA fish with permutational univariate ANOVAs in the same way as for the analyses of quality. In this case, the two fishing methods were tested separately as the quality to some extent varied between these two methods (see Section 3). These models included the fixed factors *region* (Hitra and Ryfylke) and *season* (spring, summer and autumn). The relationships between quality (standardized QIM or IT scores), condition factor (K) and hepatosomatic index (HIS) were explored with linear regressions, where *fishing gear* were added as an independent factor, since quality varied between different gear types. To assess whether presence of pellets in the stomach content of FA fish influenced fillet quality (standardized values of QIM or IT), permutational univariate ANOVAs were performed with the fixed factors *pellets* (presence and absence) and *fishing gear* (gillnet and jigging). Likewise, permutational univariate ANOVAs were used to determine whether the quality (standardized values of QIM or IT) differed between gillnetted fish that were alive or dead when hauled aboard (Fixed factors: *dead* vs. *alive* and *origin*).

Fillet texture was measure for fish collected at Hitra during autumn 2014 and spring 2015 only. As UA saithe captured with nets were not collected during spring 2015, due to extreme weather conditions, the two samples were analysed separately. A one-way ANOVA with Tukey's post hoc tests was used to analyse the sample from spring 2015, while a univariate GLM with *origin* and *fishing gear* as fixed factors was used to analyse the autumn 2014 sample.

3 | RESULTS

The quality of the saithe was predominantly good with most of the total QIM scores being less than 3 (74.2%; Table 1). Only 25.8% of the saithe were given QIM scores above 3% and 11.6% above four. When split in different groups, 8.2% and 9.4% of the FA saithe from Hitra and Ryfylke had QIM scores at or above five, that is a sufficiently high score for the overall quality of the fish to be regarded as reduced. In comparison, 1.5% of the UA saithe from Hitra were give a QIM score at or above five. The proportion of the fish with a QIM score at or above five was higher for the FA fish compared with the UA fish (chi-square test, $df = 2$, $\chi^2 = 7.95$, $p = .02$).

The origin of the fish (FA fish from Hitra and Ryfylke and UA fish from Hitra; pseudo-$F = 13.19$, $p < .001$) was significantly associated with variation in fillet quality as estimated by the QIM test. When FA fish from Hitra and Ryfylke were compared with UA fish from Hitra, the QIM scores show that the fillet quality of the FA fish was similar between sites ($t = 2.02$, $p = .056$), but significantly reduced compared with the UA fish (FA Hitra vs. UA fish: $t = 5.17$, $p < .001$; FA Ryfylke vs. UA fish: $t = 3.04$, $p = .002$) regardless of the fishing gear used (Figure 2a). The QIM scores also indicate that the quality of the fish captured with nets was significantly reduced compared with fish captured with jigging (Figure 2a, pseudo-$F = 4.32$, $p = .035$).

Fillet quality assessments based on the IT method also differed between FA and UA fish (pseudo-$F = 16.38$, $p < .001$), but not

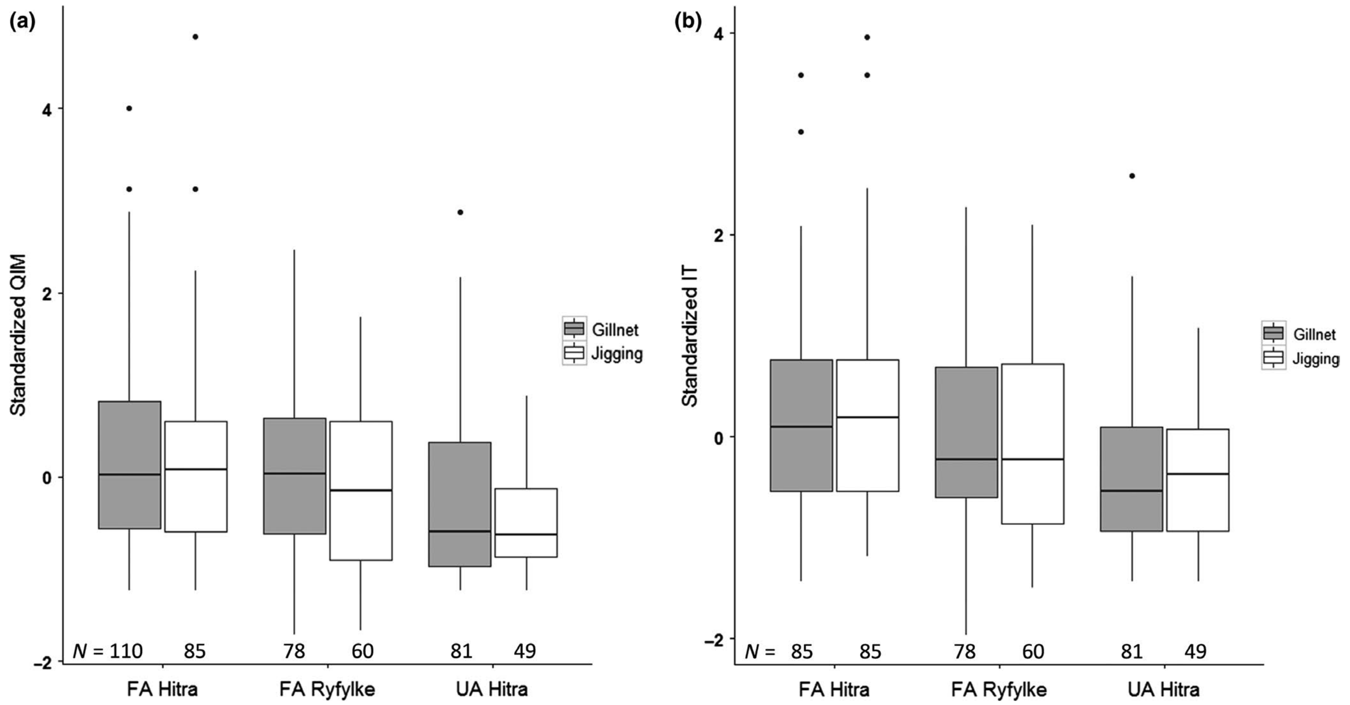

FIGURE 2 Fillet quality measured as (a) Quality index method and (b) Industry test for farm associated (FA) and un-associated (UA) saithe from Hitra and Ryfylke. The grey boxes represent saithe captured by gillnets, while white boxes indicate saithe captured by jigging. Horizontal solid lines are the median values, and the upper and lower edges on the boxes represent 75 and 25 percentiles. Vertical solid lines indicate extremal values (≤1.5 times the length of the box). Outliers are indicated with solid black circles

between fishing gear. The IT scores were different between FA fish from Hitra and Ryfylke, which both differed from UA fish (FA Hitra vs. FA Ryfylke: $t = 2.36$, $p = .022$; FA Ryfylke vs. UA fish: $t = 3.35$, $p = .001$; FA Hitra vs. UA fish: $t = 5.82$, $p < .001$). Hence, the IT scores show that the quality of UA fish from Hitra was significantly better than FA fish from both areas and that FA fish from Hitra had reduced fillet quality compared with FA fish from Ryfylke (Figure 2b).

The SIMPER analyses indicated that the contributions to intergroup dissimilarity of the five quality parameters included in the total QIM score varied between 16%–25% and 18%–22% for the quality differences related to origin (FA and UA) and fishing gear (jigging and nets) respectively (Table 3). Likewise, the contributions of the three variables included in the total IT score were also relatively similar (origin: 31%–35%, fishing gear: 32%–35%). Hence, none of the individual quality parameters was particularly important for explaining variation in fillet quality related to origin and fishing gear.

The fillet texture varied among the three groups collected at Hitra during spring 2015 (Table 4, one-way ANOVA, $F = 6.54$, $p = .002$). Tukey's post hoc tests showed that there was no difference in texture between FA and UA saithe captured in nets ($p = .95$), while the fillet of FA saithe captured with jigging was significantly firmer than saithe captured with nets ($p < .011$). The texture also varied among the groups collected during autumn 2014, but there was no significant variation between FA and UA fish when gear inflicted variation was accounted for (Univariate GLM, $F = 1.72$, $p = .19$). However, the texture varied between the fishing gears, with saithe captured by jigging being significantly softer than saithe captured in nets (Univariate GLM, $F = 5.19$, $p = .024$). Thus, saithe captured by jigging were firmer than saithe captured with nets during spring 2015, but softer compared with net caught fish during autumn 2014.

TABLE 3 Results of the two-way SIMPER routine showing the contribution percentage of each quality parameter to the intergroup dissimilarity

	FA Hitra versus UA Hitra	FA Ryfylke versus UA Hitra	FA Hitra versus FA Ryfylke	Jigging versus Gillnets
QIM				
Odour	19.6	17.5	16.9	18.8
Gaping	20.8	20.7	22.1	20.5
Colour	19.7	24.2	20.1	21.3
Texture	21.2	21.1	23.0	20.0
Surface	18.6	16.5	17.9	19.4
IT				
Inelasticity	31.1	33.1	33.2	34.9
Softness	33.5	34.5	32.6	33.2
Gaping	35.4	32.4	34.2	32.0

Abbreviations: IT, industrial test; QIM, quality index method.

The factors *Area* and *Season* interacted significantly to explain the variation in fillet quality in terms of non-standardized scores for both IT and QIM (QIM pseudo-$F = 13.77$ and IT pseudo-$F = 19.36$; $p < .001$). Pairwise comparisons indicated that there was no variation in QIM

TABLE 4 Fillet texture (mean ± standard deviations) for farm associated (FA) and un-associated (UA) saithe from Hitra captured by jigging or in nets

Season/Fishing gear	Texture (g/s)
Spring 2015	
FA saithe, Jigging (*n* = 30)	6,036 (±3,546)
UA saithe, Nets (*n* = 31)	3,869 (±2,099)
FA saithe, Nets (*n* = 30)	4,060 (±1,614)
Autumn 2014	
UA saithe, Jigging (*n* = 30)	5,050 (±3,631)
FA saithe, Jigging (*n* = 30)	3,908 (±1,477)
UA saithe, Nets (*n* = 30)	5,738 (±2,605)
FA saithe, Nets (*n* = 30)	5,543 (±2,913)

Note: The firmness increase with increasing values.

scores among seasons for saithe caught at Hitra ($0.235 < t < 0.603$; $0.553 < p < 0.812$), whereas the quality varied throughout the season in Ryfylke ($2.61 < t < 6.12$; $0.001 < p < 0.013$). The results were similar for the IT scores, except for fish captured in Ryfylke, where the IT scores differed between summer and spring ($t = 2.59$; $p = .011$).

The fillet quality was significantly associated with both K and HSI (QIM vs. K: $r^2 = .09$, $p < .001$, QIM vs. HSI: $r^2 = .07$, $p < .001$, IT vs. K: $r^2 = .07$, $p < .001$, IT vs. HSI: $r^2 = .04$, $p < .001$). The quality was reduced with increasing K and HSI, but the explanatory power was low and these relationships should thus be regarded as being marginal.

The analyses of quality in terms of IT scores showed that there was an interaction between the presence of feed pellets in the stomach of the FA fish at capture and the fishing gear ($p = .029$). Pairwise comparisons indicated that there was a difference in quality between FA fish with and without pellets in the stomach when the fish were captured by nets ($t = 2.79$; $p = .006$), but not for jigging ($t = 0.57$; $p = .58$). There were no differences in QIM scores between FA saithe with or without feed pellets in the stomach (pseudo-$F = 0.34$; $p = .551$). The variation in both QIM (pseudo-$F = 44.23$, $p < .001$) and IT (pseudo-$F = 14.60$, $p < .001$) scores indicated that the quality of gillnetted fish that were hauled on board alive was significantly better compared with fish that were dead at hauling. These results were consistent for both FA and UA saithe (Figure 3a,b).

4 | DISCUSSION

Overall, the quality of the saithe was good, but on average the quality of FA fish was slightly reduced compared with UA fish. The absence of major variation in quality between FA and UA saithe concurs with several other studies (Bjørn et al., 2007; Otterå et al., 2009; Sæther et al., 2012). Our results also concur with studies where relatively minor differences in quality parameters have been found between FA and UA fish (Bogdanović et al., 2012; Otterå et al., 2009). Although no major differences in quality were found when FA and UA fish were compared on group level, our results show that the proportion of fish with substantially reduced quality was 4–5 times

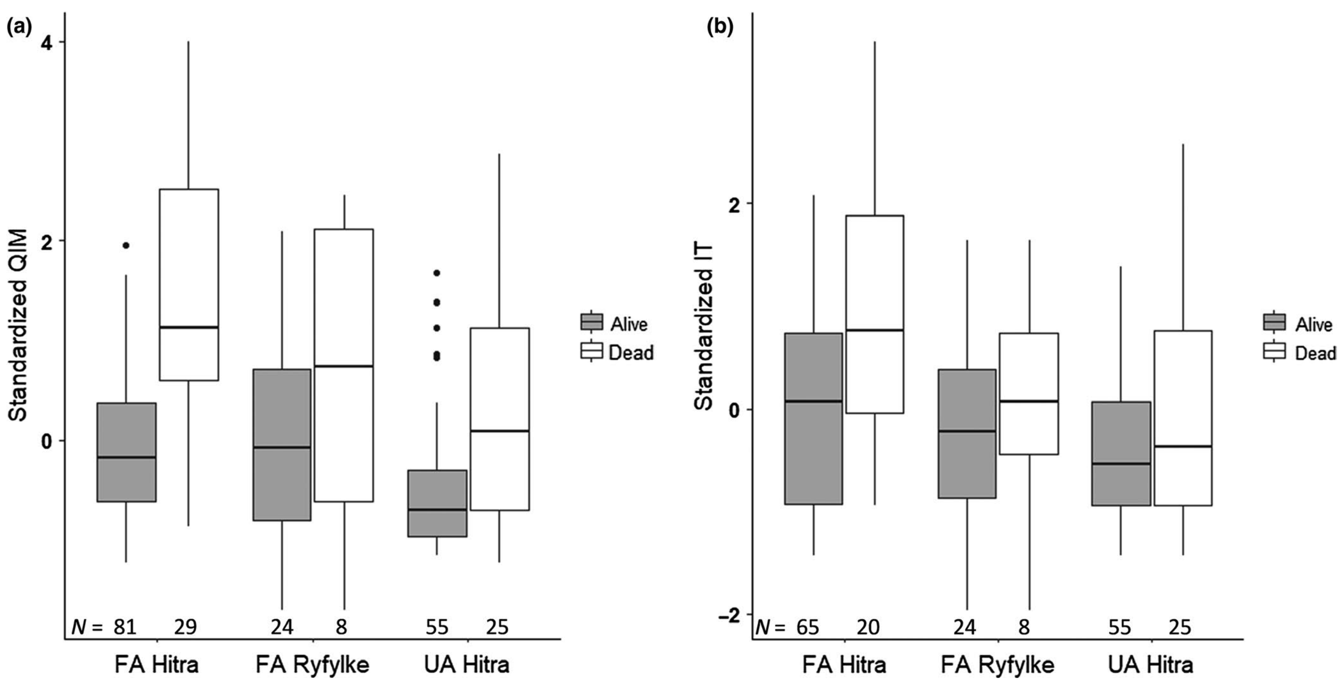

FIGURE 3 Fillet quality measured as (a) Quality index method and (b) Industry test IT for farm associated (FA) and un-associated (UA) saithe from Hitra and Ryfylke that were either alive or dead at capture in nets. The grey boxes represent fish that were alive at capture, while white boxes indicate saithe being dead. Horizontal solid lines are the median values, and the upper and lower edges on the boxes represent 75 and 25 percentiles. Vertical solid lines indicate extremal values (≤1.5 times the length of the box). Outliers are indicated with solid black circles

higher for FA saithe compared with UA saithe. This may reduce the value of the total catch, because inferior quality for a proportion of the fish may affect further industrial processing.

The methods used for evaluation of quality in the current study may, however, be regarded as being relatively insensitive as they are designed for quick industrial quality assessments. More detailed sensory analyses over a longer period after capture and until consumption could have provided more knowledge regarding the causality of the quality variation (Bogdanović et al., 2012). Nevertheless, it is reasonable to assume that major or critical quality differences that would affect the first part of the distribution chain of saithe, that is fish landing facilities and wholesalers, would be detected with the applied methodology. Moreover, the presence of pellets in the stomachs of UA fish in Ryfylke indicates the need to evaluate how distant the control locations should be to assure that the fish are not influenced by aquaculture, especially in areas with high density of fish farms.

The FA fish from both Hitra and Ryfylke had larger livers and a higher somatic condition index than the UA fish from Hitra. There was also a tendency towards quality being associated with both hepatosomatic and somatic condition indices, but the relationships were weak with low explanatory power. Thus, the difference in quality could at least in parts be caused by the FA fish having a higher glycolytic potential than UA fish, and therefore lower ultimate post-mortem pH and reduced fillet quality (Kristoffersen et al., 2006). This explanation is supported by the findings of Maruhenda Egea et al. (2015), which indicate that FA saithe have higher levels of lactate than UA fish, due to a pellets-based diet.

Our results do not support reports from local fishermen and wholesalers with respect to that the quality of FA saithe in general is substantially or critically reduced compared with UA saithe (Uglem et al., 2014). There may be several explanations for this discrepancy in perceived quality. One is that the fish farmers during the recent years have reduced the feed loss through more efficient feeding routines. It is difficult to evaluate whether this is the case as feed loss is not measured or estimated directly. Another possibility for lack of major differences in quality could be that the sampled fish were processed differently from what is done in commercial fisheries. Yet it is unlikely that the processing of fish in the current study would camouflage any major quality variation experienced by fishermen, since we used commercial boats and gear, and otherwise followed the statutory standards for fish quality in Norwegian commercial fisheries, that is the procedures that fishermen are obliged to follow by law. However, most of the commercial capture fisheries near salmon farms are based on the use of bottom nets, which may involve mortality of fish before landing. Our results show that the quality of fish that died in the nets was reduced compared with fish that were landed alive, and it is possible that higher pre-hauling mortalities than experienced in our study will further reduce the quality of the total catch. This may be a likely scenario as gillnets are often soaked for longer periods in commercial fisheries compared with our study. In addition, for this gear, a combination of higher mortalities at hauling and higher condition factor, hepathosomatic index, and lactic acid of fish around farms may exacerbate the degradation of saithe quality. It could therefore be advantageous for dead fish to be sorted out at landing and sold separately from live fish, as specified in the Norwegian injunction for quality of fish. Since our results suggest that fish caught with jigging was of better quality than fish caught with nets, most likely because of mortality in the nets, another option is to use fishing gear that ensure that the fish is alive when caught (e.g., jigging or pots) to compensate for the potential reduction in quality of FA saithe. Our results concur with other studies that have shown that different types of commercial fishing gear may affect the quality of the catch (Botta, Bonnell, & Squire, 1987; Özyurt et al., 2007; Rotabakk, Skipnes, Akse, & Birkeland, 2011; Santos, Gaspar, Monteiro, & Vasconcelos, 2002).

Although our results demonstrate significant but minor average differences in quality between FA and UA saithe, it is still possible that consumers, fishermen and wholesalers perceive a larger quality difference than would be possible to quantify with the methods applied in the current study. Perceived food quality may not only be based on sensory characteristics but also on other factors, such as previous information, past experience, as well as attitudes and beliefs (Costell, Tárrega, & Bayarri, 2010). FA saithe frequently have large amounts of partly digested salmon feed pellets in their stomach that may be punctured during gutting, which in turn will result in unappealing smell and visual impressions. Furthermore, FA saithe often have much larger livers than UA saithe, and thus an apparently abnormal body shape. In addition, FA fish has received considerable negative attention in Norwegian media during the last decade. Together, these factors could influence how the quality of FA saithe is perceived.

Commercial saithe fishing in salmon farming areas in Norway is usually carried out by local fishermen in relatively small boats with a crew of one or two people, and the daily catches can vary from a few hundred kilos to several tons per boat. To be efficient and to ensure economic viability, the processing time therefore has to be kept at a minimum and the potential for sorting the catch based on perceived quality after landing is limited. However, simple and quick sorting of the catch based on visual cues representing quality could be an alternative to avoid quality issues. In this context, mortality and abnormal body shapes could potentially be used as visual markers of fish with reduced quality. During further processing, simple industry tests or more standardized QIMs may be used on samples of the catch to get an overview of the overall quality. Such quality evaluations may be decisive for how the fish is used in the last stages of the value chain, for example if the fish is sold as fresh fillets the quality demands may be higher than if the fish is used for more processed products.

Even though we found no major differences in quality on a group level, our results show that the proportions of fish that were assessed to be of substantially reduced quality were significantly higher for the FA fish (Hitra: 8.2%, Ryfylke 9.4%) compared with the UA fish (1.5%). It would be complicated and time-consuming to sort the fish on basis of quality during industrial processing of large volumes of fish, for example if automatic filleting machines are used. Relatively low proportions of fish with reduced quality in a batch could therefore considerable reduce the value of the total catch to fishermen and wholesalers.

A high proportion of the FA fish had considerable amounts of salmon feed in their stomachs. This emphasizes the potential for wild fish to be influenced by organic waste from salmon farming, although our results do not indicate any major effects on fish quality. On one side, the nutritional content of salmon feed differs from the content in natural prey that could potentially lead to malnutrition (e.g., altering fatty acids profile; Fernandez-Jover et al., 2011), which may in turn affect gonadal development and offspring viability (Uglem et al., 2014). The abundance of feed may, however, involve increased egg production and thus increased reproductive potential (Dempster et al., 2011), as well as influencing the natural distribution of fish and the onset of reproduction (Uglem et al., 2014). Potential impacts may vary among species, seasons, gender and locations, and a broad approach is thus required to assess the total footprint due to organic waste from salmon farms.

In conclusion, our results show that the quality of most FA saithe on a diet that includes salmon feed pellets was good. However, the proportion of fish with substantially reduced quality was 4–5 times higher for FA saithe compared with UA saithe, which in turn may be sufficient to reduce the value of a catch for local fishermen targeting saithe. Apart from the origin of the fish, main drivers for the variation in quality were mortality at hauling and fishing method (nets or jigging). Although the average differences can be characterized as being minor, visual and olfactory impressions during handling and gutting of the fish may involve that quality differences are perceived as more pronounced than revealed by our quantitative assessments. In addition to reducing availability of waste feed to the wild fish, improved quality sorting of individual fish both immediately after landing and during further processing would prevent general degradation of quality and value of a catch.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHOR CONTRIBUTIONS

IU, PS-J and BSS involved in study design. IU, KT-G, PS-J, EMU and TE contributed to sampling and laboratory analyses. IU, KT-G and EMU involved in data analyses. IU drafted the paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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