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Utilization of feed resources in the production of Atlantic salmon (*Salmo salar*) in Norway: An update for 2016

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ABSTRACT

The utilization of feed resources in Norwegian salmon farming in 2010 and 2012 has been reported previously. The present study is an update for 2016, along with data on whole body composition of slaughter sized salmon. In 2016, in total 1,252,573 tonnes of salmon were produced. Fillet production was estimated to 814,172 tonnes. Given 'as is', 1,627,478 tonnes of feed ingredients were used (1,520,358 tonnes on dry matter basis). Marine ingredients constituted 405,921 tonnes (25%), 1,156,135 tonnes (71%) were of plant origin and 65,422 tonnes (4%) were other ingredients. The estimated retention of energy, protein, lipid, DHA + EPA and phosphorus was 41.3%, 36.6%, 49.4%, 37.3% and 18.5%, respectively, in whole salmon. In fillet, the corresponding retention values were 23.0%, 26.1%, 24.6%, 21.8% and 9.5%, respectively. Whole body of slaughter sized salmon (mean body weight 5276 g) contained 12.71 MJ/kg energy, 16.9% crude protein, 21.5% total lipids (0.44% EPA, 0.72% DHA) and 1.8% ash (0.31% phosphorus). The salmon production and use of feed ingredients in 2016 were of similar volumes as in 2012, but the use of marine protein sources was further reduced and replaced by plant ingredients.

1. Introduction

The utilization of feed resources in Norwegian salmon farming during one production year (2010 and 2012) has been described by Ytrestøyl et al. (2015). As shown in that study, feed composition has changed considerably over the last decades from mainly marine ingredients to an increasing inclusion of plant ingredients. Availability and price of feed ingredients will vary over time and this will affect dietary composition. The shift from marine ingredients to plant ingredients is beneficial from an economic point of view and it has allowed the industry to grow. However, high inclusion levels of plant ingredients in salmon diets may have negative effects on growth performance, feed utilization and fish health due to imbalanced nutrient composition and content of fiber and anti-nutritional factors in plant ingredients (Gatlin et al., 2007; Turchini et al., 2009). Farming routines, technical equipment and size of farming units have also developed over time (Nilsen, 2010; Gjedrem et al., 2012). Such changes may affect the growth and feed utilization in the salmon. Norwegian farmed salmon has now been selected for increased growth and other traits such as disease resistance and product quality for more than 12 generations. The genetic gain per generation in terms of growth is estimated to 10–14% (Gjedrem, 2010; Gjedrem et al., 2012). Whether this growth potential is fully realized in practical farming conditions is dependent on rearing conditions, diet composition, disease outbreaks and parasites. Infestation with salmon louse (*Lepeophtheirus salmonis*) is currently a challenge in some regions. Frequent delousing operations increase stress and mortality and reduce feed intake and growth in salmon (Oppedal et al., 2011; Stien et al., 2012; Øverli et al., 2014; Abolofia et al., 2017; Overton et al., 2018). Consequently, indices for feed utilization and production efficiency change over time and need to be assessed regularly in order to follow long-term trends in production efficiency.

The body composition of salmon changes during its life cycle. The composition also varies with season, and it depends on feed composition and on body weight of fish when slaughtered. It may also be affected by changes in farming routines (Shearer et al., 1994; Mørkøre and Rørvik, 2001; Roth et al., 2005). There are no available updated data available on nutrient composition of whole body of slaughter sized salmon, which is the end product in the Norwegian salmon farming industry. Such data are required for calculation of retention indices that can be used to monitor production efficiency over time. The nutrient content in whole salmon determines the amount of nutrients potentially available for human consumption. The proportion of the salmon that is actually consumed is determined by slaughter yield and further processing and use of trimmings. Fillet yield (% of whole body) is often considered as equivalent to the edible portion of the salmon. However,

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several other parts of the salmon are also used for human consumption. The official production statistics (Directory Of Fisheries, 2017) on total salmon production (round weight) is accurate and comparable over years, but accurate statistics on the fractions consumed by humans or converted to feed ingredients is not available. Salmon heads, backs, and belly cut offs are used as food and protein concentrates. Oil capsules are produced from salmon trimmings and sold as dietary supplements. The part of salmon used for human consumption is thus higher than the fillet yield. Exact statistics on the faith of different fractions is not available, because most of the salmon exported from Norway (80%) is sold gutted with head on for further processing. Blood loss is around 3% and viscera around 10% (Einen and Roem, 1997; Rørvik et al., 2018). Gutted salmon is thus around 87% of live weight. According to Fry et al. (2018a, b), the portion of farmed salmon considered as edible varied from 58 to 88%. Whether one considers fillet yield or gutted weight as edible product will have a large impact on the amount of nutrients considered available for human consumption. Fry et al. (2018a, b) ranked Atlantic salmon as the most efficient aquaculture production of nine aquaculture productions examined, with energy and protein retention of 25 and 28% in the edible portion, respectively. In general, efficient productions are characterized by a high growth rate, high feed efficiency, and that a large part of the animal is used for human consumption.

The present study is an update on the utilization of feed ingredients in the total Norwegian salmon farming in 2016. In addition, body composition of slaughter sized salmon was analyzed. The methods used, comparison with other feed production systems and global perspectives of feed resources were discussed by Ytrestøyl et al. (2015). The present study is mainly an update of data to identify potential changes in production efficiency in 2016 relative to 2010 and 2012 (Ytrestøyl et al., 2015).

2. Materials and methods

2.1. Data on feed ingredients

The data represent the total Norwegian salmon industry for feed resources spent and salmon produced in 2016. The four large feed manufacturers in Norway (BioMar, Cargill, Mowi and Skretting) provided data on ingredients used for salmon feed in 2016. After Ytrestøyl et al. (2015) published similar data for previous years, Mowi (former Marine Harvest) has started feed production. For a few ingredients from some of the feed companies, complete chemical composition was not given. Such missing data were replaced by corresponding data from the other feed producers, or by literature data.

2.2. Sampling and chemical analysis of salmon

For a representative selection of samples across geography and season, slaughter sized salmon was collected from southern (Hordaland), mid (Trøndelag) and northern (Finnmark) part of Norway, in spring (late April/early May), summer (August) and late autumn (November). Times for sampling were chosen to have approximately evenly distributed number of day degrees (number of days x temperature, ˚C) between each sampling. In the mid region, all salmon were collected from one farm. This was also the case in the northern region. In the southern region, salmon collected in summer was from a different farm than those collected in spring and autumn, due to availability of fish at the time the fish was sampled. At each sampling at each region, 10 individuals (in total 90 individuals) of similar body weight (range 4930 – 5690 g) and of average harvest size of salmon in Norway in 2016 were sampled, and weight and fork length registered. The sex ratio was close to 50:50 in all samples but harvested before sexual maturation. The sampled salmon was transported on ice to Nofima Research Station for Sustainable Aquaculture, Sunndalsøra, frozen and stored at -20 ˚C. The frozen fish was cut into slices with a meat saw before homogenization with a meat grinder. The 10 individuals from each sampling were pooled to one sample, in total 9 samples (3 regions x 3 times) and stored at -20 ˚C until freeze drying before chemical analysis.

The samples of whole salmon were analyzed for dry matter (105 ˚C until constant weight), ash (five hours at 550 ˚C), gross energy (Parr 1271 Bomb calorimeter) crude lipid (SOXTEC hydrolysing and extraction systems), nitrogen (Kjeltec Auto System, Tecator, Höganäs, Sweden) and phosphorus (by inductive coupled plasma mass spectroscopy, ICP-MS, at Eurofins, Moss, Norway). Fatty acids were analyzed as described by Mason and Waller (1964) after extracting the lipids according to Folch et al. (1957).

Amino acids were analyzed with a Biochrom 30 amino acid analyzer (Biochrom Cambridge, UK). Tryptophan was analyzed after basic hydrolysis (Hugli and Moore, 1972), and the remaining amino acids according to Davies (2002). During sample preparation for amino acid analysis, glutamine (Gln) and aspargine (Asn) are converted to glutamic acid (Glu) and aspartic acid (Asp), respectively. Therefore, Gln + Glu are given as Glx, and Asn + Asp as Asx.

2.3. Statistical analysis

Statistical analyses were carried out with SAS computer software (SAS1985, SAS Institute Inc, Cary, USA). Data on whole body composition, body weight, fork length and condition factor were tested with ANOVA. Significant differences between means were defined with Duncan's multiple range test using time of year as class variable. Normal distribution of data was tested with the 'Normal' statement in the 'Univariate' procedure. Homogeneity of variance was tested with Levene's test. For data on whole body composition, $n = 3$ (pooled samples), and for individual data on body weight, fork length and condition factor, $n = 10$ (individual data).

2.4. Calculation of feed utilization efficiency

2.4.1. Feed conversion ratio

Feed conversion ratio (FCR) is the ratio between feed eaten and salmon produced. The economic feed conversion ratio (eFCR) is the ratio between feed used and salmon produced, i.e. the uneaten feed is included. In this study, all losses of feed and feed ingredients are included in the calculation.

$$eF\mathrm{CR} = \frac{\text{Feed used (tonnes)}}{\text{Salmon produced (tonnes)}}$$

2.4.2. Retention efficiency

The retention (%) of nutrients and energy from feed was calculated as:

$$\text{Nutrient or energy retention (\%)} = 100 \bullet \frac{\text{Amount of nutrient or energy incorporated in animal}}{\text{Amount of nutrient or energy used in feed}}$$

The estimated retention data include all losses of feed and feed ingredients, and of salmon (mortality and escapees) in the production, and poor or failed productions of both feed and salmon. In fish nutrition, 'retention' commonly refers to the calculation above but is also used as a general term for any calculation of energy or nutrient utilization from feed into food product.

Protein utilization was also estimated as the protein efficiency ratio (PER):

$$\mathrm{PER} = \frac{\text{Body weight or biomass produced (kg or tonnes)}}{\text{Protein fed (kg or tonnes)}}$$

Corresponding formulae were used to estimate the lipid efficiency ratio (LER) and energy efficiency ratio (EER).

2.4.3. Fish-In-Fish-Out ratio and forage fish dependency ratio

A commonly used indicator for use of marine ingredients for production of salmon is the Fish-In-Fish-Out-ratio (FIFO; Tacon and Metian, 2008; Jackson, 2009). FIFO measures the amount of wild fish used in feed for production of one kg of farmed salmon. The yield of fish meal (FM) and fish oil (FO) from forage fish is different, and the amount of fish meal and fish oil in feed is different. FIFO is therefore estimated for fish meal and fish oil separately. The calculation of FIFO involves the reduction efficiency of forage fish into fish meal and fish oil. In this process, 90% of the water in the forage fish is condensed, and, based on a global average, 1 kg of forage fish is converted to 235 to 245 g of fish meal and 50–120 g of fish oil (IFFO, 2010). Fish vary in lipid content to a larger extent than in protein content. In the following calculation, 240 g fish meal and 93 g fish oil per kg forage fish was assumed.

$$FIFO_{(FM\ or\ FO)} = \frac{100 \cdot \left(\frac{\text{Tonnes of FM or FO used in feed}}{\text{\% Reduction efficiency for FM or FO}}\right)}{\text{Tonnes of salmon produced}}$$

The forage fish dependency ratio (FFDR) is equivalent to the FIFO, but with only fish meal and fish oil produced from forage fish included.

2.4.4. Marine nutrient dependency ratio

Marine nutrient dependency ratios (MNDRs, Crampton et al., 2010) measure the dependency of marine nutrients in feed. The marine protein dependency ratio (MPDR) is the ratio between protein of marine origin in feed and protein in the salmon produced. Marine oil dependency ratio (MODR) is the corresponding ratio for oil.

$$MPDR = \frac{\text{Tonnes marine protein sources used} \cdot \text{\% Protein in marine protein sources}}{\text{Tonnes salmon produced} \cdot \text{\% Protein in salmon}}$$

$$MODR = \frac{\text{Tonnes marine oil used} + (\text{Tonnes marine protein sources used} \cdot \text{\% Oil in marine protein sources})}{\text{Tonnes salmon produced} \cdot \text{\% Fat in salmon}}$$

Data for average amount of protein and oil in marine protein sources (fish meal) were calculated from the composition of the feed ingredients used. The fish meal contained in total 66.6% protein and 10.3% oil. The content of protein and oil in fish meal produced from forage fish was 68.2% and 10.7%, respectively. Whole body of salmon contained 16.9% crude protein (Nx6.25) and 21.5% fat, respectively.

The individual indices are further discussed by Ytrestøyl et al. (2015).

3. Results and discussion

This study describes utilization of feed resources in salmon production in a whole country during a whole year and includes all losses of feed ingredients and fish. The given estimates measure resource efficiency, not to be confused with biological efficiency. As an example, if a large volume of a feed ingredient has been discarded, it will be reflected in the retention of nutrients and energy in the produced salmon. Furthermore, the estimates are based on large scale data and do not have the same level of accuracy as a controlled study. The estimated indices such as feed conversion factor and nutrient retention should therefore not be compared to data from controlled studies or small, successful productions of salmon or other animals.

It has been debated extensively how to measure sustainability in a food production system (Fry et al., 2018a, b; Tlusty et al., 2018). None of the commonly used indices give a simple measure of sustainability, but each of them represents a calculation of use of ingredients versus production of salmon. Use of by-products for human consumption, which is not included in these indices, increases sustainability in a food production chain (Rustad, 2003; Ramirez, 2007; Newton et al., 2014; Aspevik et al., 2016b; Stevens et al., 2018; Tlusty et al., 2018). To measure the sustainability, methods such as life cycle analysis (LCA) needs to be further developed to cover detailed information on all

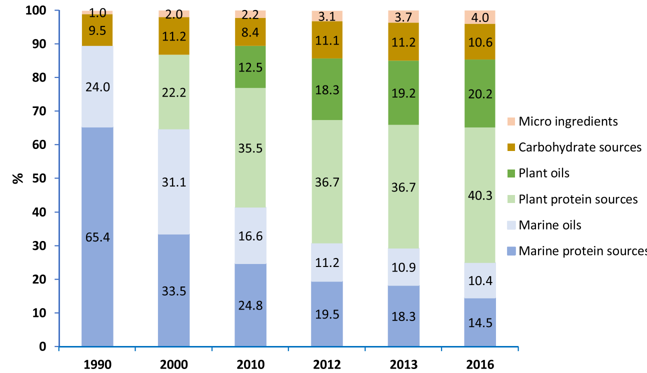

Fig. 1. Ingredient sources (% of feed) in Norwegian salmon feed in 2016 compared to previous years, which were given by Ytrestøyl et al., 2015.

inputs and outputs in the production, which differs in different parts of the world. The present study is not a measure of sustainability, but rather an account for feed resources used and salmon produced.

3.1. Feed ingredients and feed composition

Since 1990, the composition of salmon feed has changed considerably (Ytrestøyl et al., 2015), with an increasing part of marine ingredients being replaced by plant ingredients. Marine protein sources constituted 14.5% of the feed in 2016, which is a decrease since 2013. There was a corresponding increase in plant protein sources. Marine oils constituted 10.4% of the feed, which is a very slight decrease since 2013, and there was a corresponding slight increase in plant oils. Carbohydrate sources are mainly added as binders. These have been relatively stable over the years and was 10.6% in 2016. The inclusion of micro ingredients has increased gradually over the years. In 2016, micro ingredients such as vitamin and mineral mixes, phosphorus sources, astaxanthin and crystalline amino acids accounted for 4.0% of the salmon feed (Fig. 1).

The ingredients used in largest amounts in Norwegian salmon feed in 2016 were soy protein concentrate, which accounted for 19.0% or 309,711 tonnes, and rapeseed oil, which together with camelina oil accounted for 19.8% or 322,580 tonnes (Table 1). The two oils were given as a sum from one feed company and could therefore not be separated. But rapeseed oil was by far the dominating of the two oil sources. Wheat and wheat gluten summed up to 17.9%. Wheat was thus a dominating resource for salmon feed in 2016 (Table 1).

The main portion of marine protein sources and marine oil was of North Atlantic origin (Table 2). All but a small amount of undefined origin of both marine protein sources and marine oil produced from trimmings, was of North Atlantic origin. A minor part of oil was produced from trimmings from aquaculture. Of the total of 405,921 tonnes of marine ingredients used, 88,884 was from trimmings, which is a decrease compared to the previous years when this has been evaluated (Fig. 2).

A larger portion of plant protein sources and plant oil was of undefined origin. The protein sources of defined origin were from South America, Europe and Asia. All plant oil with a defined origin was produced in Europe. The aquaculture industry has achieved a high degree of traceability of marine feed resources. Such detailed traceability is at present not available as an industry standard on plant ingredients on the global market. Normal compound feed production does not demand traceability of plant ingredients back to the country of cultivation. Consequently, origin of plant ingredients is not accounted for to the same detail as the marine ingredients.

3.2. Certification of ingredients

Several certification systems for the different food production systems have been developed with the aim to ensure production according

Table 1
Ingredients used in Norwegian salmon feed in 2016, given as tonnes and percent.

	Ingredient	Tonnes	%
Plant protein sources	Soya protein concentrate	309,711	19.0
	Wheat gluten	146,274	9.0
	Corn gluten	57,973	3.6
	Faba beans	54,754	3.4
	Sunflower meal	18,548	1.1
	Pea protein concentrate	21,939	1.3
	Sunflower protein	8,691	0.5
	Other vegetable protein	37,424	2.3
Plant oils	Rapeseed and camelina oil[a]	322,580	19.8
	Linseed oil	5,625	0.3
Carbohydrate sources	Wheat	144,605	8.9
	Pea starch	12,302	0.8
	Undefined plant carbohydrate source	15,709	1.0
Marine protein sources	Marine protein sources, forage fish	190,277	11.7
	Marine protein sources, trimmings	46,362	2.8
Marine oils	Marine oil, forage fish	126,760	7.8
	Marine oil, trimmings	42,521	2.6
Other	Micro ingredients[b]	65,422	4.0
	Sum	**1,627,478**	**100**

[a] Rapeseed oil is dominating, but rapeseed and camelina oil were given as a sum from one of the feed companies, and could therefore not be separated from each other.
[b] Micro ingredients contain ingredients such as crystalline amino acids, vitamin- and mineral mixes, phosphorus sources and astaxanthin.

Table 2
Origin of marine and plant ingredients in Norwegian salmon feed in 2016 (tonnes).

Source		Origin	Tonnes
Marine protein	Forage fish	North Atlantic	115,281
		Atlantic, African	16,012
		South Atlantic	12,140
		Mexico Gulf	4,771
		South East Pacific	41,817
		Undefined	256
	Trimmings	North Atlantic	40,535
		Undefined	5,828
Marine oils	Forage fish	North Atlantic	63,534
		Atlantic, African	7,218
		Mexico Gulf	28,763
		South East Pacific	24,036
		Pacific	2,696
		Undefined	513
	Trimmings	North Atlantic	30,830
		Aquaculture	4,289
		Undefined	7,403
Plant protein		Europe	98,417
		Asia	80,741
		South America	171,371
		Undefined	304,785
Plant oil		Europe	228,884
		Undefined	99,321

to certain standards regarding environmental and social aspects. Most of the marine ingredients used in Norwegian salmon farming in 2016 were certified by IFFO RS (Table 4). The certification systems are not equally developed for plant ingredients. A smaller portion of the plant ingredients was thus certified.

3.3. Chemical composition of the feed

The average salmon feed in 2016 contained 93.4% dry matter, 35.6% crude protein, 33.5% crude lipid, 11.0% carbohydrates and 1.3% phosphorus. The average energy content was 23.7 MJ/kg (Table 3). The content of carbohydrates and crude fiber was not defined for all ingredients. Neither were data for ash, minerals other than phosphorus, or the composition of micro ingredients available. Ash content in salmon feed is typically around 8–9% (Dessen et al., 2017) and micro ingredients constituted 4.0%. This corresponds to the deviation between total dry matter and sum of given components. The dry matter content is altered during feed production, and there may have been losses of ingredients before feed production. The term ‘feed’ here reflects the sum of the feed ingredients reported by the feed companies, not the produced feed.

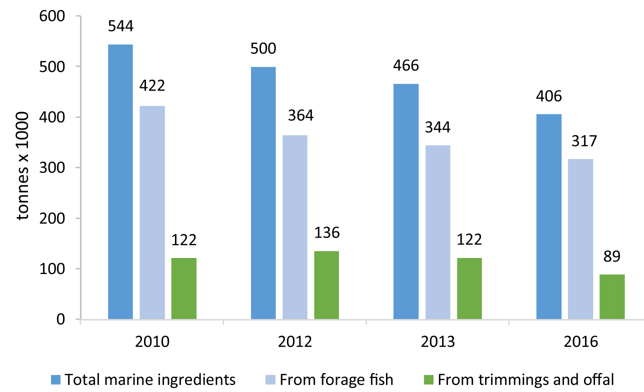

Fig. 2. Use of marine ingredients (tonnes) from forage fish and trimmings in Norwegian salmon farming in 2010, 2012, 2013 (Ytrestøyl et al., 2015) and 2016.

3.4. Total salmon production

A total of 1,233,619 tonnes of farmed salmon was traded in 2016 (Directory Of Fisheries, 2017; Statistics Norway, 2017). In addition, there was an increase in the biomass during the year. The biomass of salmon at 31st December 2015 was 721,455 tonnes. At 31st December it was 740,409 tonnes. The increase of 18,954 tonnes during 2016 was added to the amount of traded salmon, resulting in a total production of 1,252,573 tonnes in 2016. The amount of salmon traded in 2016 was slightly lower than in the three preceding years (Fig. 3).

3.5. Whole body composition of slaughter sized salmon

Salmon of similar body weight and close to the average harvest size of salmon in Norway in 2016 was sampled. Hence, there were no significant differences in body weight (Table 5). The fork length was significantly longer in salmon sampled in summer than in those sampled in spring and autumn. The corresponding condition factor was, accordingly, lowest in summer. There were no significant differences in proximate composition of whole body. There were some differences in mineral concentration during the year (Table 6). Concentrations of manganese and sodium were higher in spring and summer than in autumn. The only significant difference in amino acid concentration in whole body was found in phenylalanine. The concentration of phenylalanine was higher in spring than in autumn, with intermediate level in summer (Table 7). There was little variation in fatty acid composition throughout the year (Table 8). The fatty acid composition of the salmon reflects the fatty acids provided in the feed (Waagbø et al., 1991; Torstensen et al., 2000) The similar values of the fatty acid composition in salmon during the year indicate little variation in fatty acid composition of the feeds used throughout the year.

3.6. Nutrient content in the produced salmon

Table 9 shows the estimated total amount of dry matter, energy, crude lipids, EPA (eicosapentaeneoic acid), DHA (docosahexaenoic acid), crude protein and phosphorus in whole salmon, salmon fillet and

Table 3
Estimated average composition, total amount of nutrients used, and amount of nutrients from marine, plant and other sources in Norwegian salmon feed in 2016. Minerals (except for phosphorus), ash and micro ingredients are not included. Energy data are given as MJ/kg or GJ.

	Average composition of Norwegian salmon feed in 2016 (% or MJ/kg)	Total amount of nutrients used in Norwegian salmon feed in 2016 (tonnes or GJ)	Nutrients from marine ingredients (tonnes or GJ)	Nutrients from plant ingredients (tonnes or GJ)	Nutrients from other ingredients (tonnes or GJ)[2]
Dry matter	93.4	1,520,358	382,810	1,081,024	56,523
Energy	23.7	38,565,990	11,151,728	27,182,607	231,655
Crude lipid	33.5	545,813	193,491	349,693	2,629
EPA + DHA	2.4	38,926	38,904	0	22
Sum n-6	0.9	13,837	1,075	12,762	0
Crude protein	35.6	579,936	157,608	422,051	277
Carbohydrates[1]	11.0	179,781	0	179,156	625
Phosphourus	1.3	21,007	4,872	4,404	11,732

[1]Includes NFE (nitrogen free extract) and crude fiber.
[2]Micro ingredients such as crystalline amino acids, mineral and vitamin mixes and astaxanthin, and products from microorganisms.

trimmings produced in Norway in 2016. The data were calculated from analyzed composition of whole body of salmon (Table 6–8), public data on fillet composition (Seafood Data for data, 2017 if available), the total salmon production in 2016 (1,252,573 tonnes) and an assumed fillet yield of 65% (Marine Harvest, 2018; Nilsen et al., 2019). The fillet yield, and thus the edible part, depends on fish size, condition factor and filleting technology. The fillet yield (%) will affect all calculations where included, such as retention of nutrients and energy in the edible part of salmon. The data on fillet composition are public data and are considered to represent the nutritional content of Norwegian farmed salmon. The data are based on a large number of samples and are updated regularly. It should be kept in mind that fish for fillet analysis are not the same individuals as salmon sampled in this project for whole body analysis. Except for blood, the total amount of trimmings and offal from salmon slaughtered in Norway is used for animal feed or processed to products for human consumption (Rustad, 2003; Ramirez, 2007; Newton et al., 2014; Aspevik et al., 2016a, b; Aspevik et al., 2017; Richardsen et al., 2017; Stevens et al., 2018).

Compared to 2010 and 2012, whole salmon contained similar levels of energy, protein and lipids in 2016 (Fig. 4). The concentration of EPA + DHA was 1.2% of whole salmon in 2016 compared to 1.6% in 2012 and 3.0% in 2010. The phosphorus concentration was 0.31% in 2016 and 0.35% in both 2010 and 2012. The data for whole body composition in 2016 were based on salmon sampled particularly for the purpose of representing the average Norwegian farmed salmon. Such data were not available for 2010 and 2012. The chemical analyses of whole body (sampled and analyzed in the project) and salmon fillet (composition given by Seafood Data) represent different samples and were collected with different sampling regimes. The feed data were collected for one year (2016), whereas the sampled salmon were produced over 2–3 years and sampled in 2017. This should be kept in mind when comparing different data.

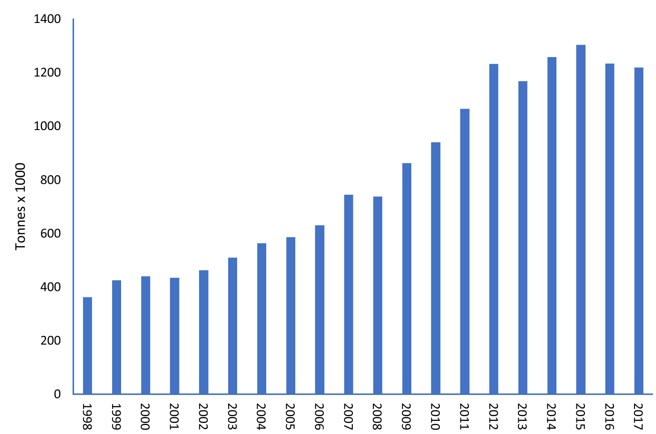

Fig. 3. The annual sale of Norwegian farmed salmon (tonnes x 1000) from 1998 to 2017 (Statistics Norway, 2017).

3.7. *Efficiency of utilization of feed ingredients*

The calculated measures of efficiency of feed ingredients include all

Table 4
Amount (%) of feed ingredients certified by the various certification systems. The same ingredient may be certified by more than one system, and the total amount of certified ingredients is therefore not equal to the sum of certified ingredients.

		MSC [1]	IFFO RS [2]	IP [3]	Non-GM [4]	ProTerra [5]	RTRS [6]
Forage fish	Marine protein sources	18	85				
Trimmings	Marine protein sources	32	78				
Forage fish	Marine oils	7	88	2			
Trimmings	Marine oils	24	53				
	Plant protein sources				37	12	7
	Plant oil				45		
	Carbohydrate sources				33		

[1] MSC (Marine Stewardship Council) certifies according to standards for sustainable fisheries and seafood traceability and is an eco-label oriented towards consumers. MSC is relevant for fish meal and fish oil.
[2] IFFO RS (Marine Ingredients Organization Responsible supply) is a business to business standard to demonstrate a standard in fishing, production and traceability of marine ingredients. The IFFO RS is relevant for fish meal and fish oil.
[3] IP (Improvers' Program) is a program launched by the IFFO RS for factories that are working towards the IFFO RS approval and is relevant for fish meal and fish oil.
[4] Non-GM is a certification for ingredients that are not genetically modified and is relevant for plant ingredients.
[5] ProTerra covers social, environmental aspects and non-GMO products, mainly soy but also other agricultural crops, and is relevant for plant ingredients.
[6] RTRS (Round Table Responsible Soy) has a standard for social, environmental and economical aspects in the production of soy. This is relevant for ingredients produced from soy, in salmon feed mainly soy protein concentrate.

Table 5
Body weight, body length and condition factor of slaughter sized salmon sampled at spring, summer and autumn. For each sampling point, 10 fish were sampled at south, mid and north of Norway. Data are given as mean ± SEM (n = 30, N = 90). Sex ratio was close to 50:50. None of the fish was sexually mature.

	Spring	Summer	Autumn	Overall mean
Body weight (g)	5 262 ± 57	5 282 ± 67	5 285 ± 57	5 276 ± 189
Fork length (cm)	73.1 ± 0.6[b]	74.6 ± 0.6[a]	73.1 ± 0.7[b]	73.6 ± 2.2
Condition factor[1]	1.35 ± 0.03[a]	1.28 ± 0.03[b]	1.36 ± 0.04[a]	1.33 ± 0.11

[a, b] Significant differences within a column are indicated with different letters.
[1] Condition factor = 100*body weight (g)/fork length^3 (cm).

losses and express the feed utilization in the total Norwegian salmon farming industry over one year (2016). The data should therefore not be directly compared to controlled trials or single productions of salmon or other species which is reported in the literature.

3.7.1. Economic feed conversion ratio, eFCR

The 1,627,478 tonnes ('as is') of feed ingredients used in 2016 and the salmon production of 1,252,573 tonnes (harvested and increase in biomass) resulted in an eFCR of 1.30 in Norwegian salmon farming in 2016. This is approximately the same as in 2012 (1.29) and somewhat lower than in 2010 (1.38). On dry matter basis of feed ingredients (1,520,358 tonnes), the eFCR was 1.21. According to public data, 1,543,000 tonnes of salmon feed was traded in 2016. This gives an eFCR of 1.23. The difference in amount of feed ingredients and traded feed is mainly explained by difference in dry matter content.

3.7.2. Retention

The retention of nutrients and energy was calculated from data for total use of feed ingredients and the total production of salmon during one year. The production cycle of salmon is more than one year. The accuracy of the estimates therefore depends on a fairly constant use of feed ingredients and production of salmon over a few years. The retention of lipid, EPA + DHA, protein and phosphorus in whole body of salmon was 49%, 37%, 37% and 18%, respectively, whereas 41% of the energy from feed was retained in whole body. In fillet, the 25%, 22%, 26% and 10% of lipid, EPA + DHA, protein and phosphorus, respectively, was retained. Also, 23% of the energy was retained in fillet (Table 10). The retention of EPA + DHA and phosphorus in whole body and fillet was somewhat lower than estimates for previous years (Fig. 4). Retention of carbohydrates is not estimated due to lack of data.

Table 7
Analysis of amino acids in slaughter sized salmon sampled in spring, summer and autumn. At each sampling, 10 fish were collected from Southern, Mid and Northern part of Norway, and analyzed as 3 pooled samples. Data (except taurine) are given as dehydrated residuals, mean ± S.E.M, g/100 g, 'as is'.

	Spring	Summer	Autumn	Overall mean
Essential amino acids:				
Arg	0.89 ± 0.01	0.93 ± 0.02	0.92 ± 0.01	0.91 ± 0.01
His	0.37 ± 0.01	0.38 ± 0.00	0.38 ± 0.01	0.38 ± 0.00
Ile	0.63 ± 0.01	0.60 ± 0.01	0.60 ± 0.02	0.61 ± 0.01
Leu	1.03 ± 0.02	1.00 ± 0.01	1.00 ± 0.03	1.01 ± 0.01
Lys	1.21 ± 0.02	1.20 ± 0.01	1.20 ± 0.04	1.20 ± 0.01
Met	0.47 ± 0.01*	0.44 ± 0.00*	0.44 ± 0.01*	0.45 ± 0.01
Phe	0.64 ± 0.01[a]	0.62 ± 0.01[ab]	0.60 ± 0.01[b]	0.62 ± 0.01
Thr	0.60 ± 0.01	0.61 ± 0.00	0.61 ± 0.02	0.61 ± 0.01
Trp	0.16 ± 0.00	0.15 ± 0.00	0.17 ± 0.01	0.16 ± 0.00
Val	0.75 ± 0.03	0.75 ± 0.02	0.77 ± 0.02	0.75 ± 0.01
Non-essential amino acids:				
Ala	0.85 ± 0.03	0.85 ± 0.01	0.83 ± 0.01	0.84 ± 0.01
Asx[1]	1.35 ± 0.02	1.32 ± 0.01	1.33 ± 0.03	1.33 ± 0.01
Cys	0.14 ± 0.00	0.14 ± 0.00	0.14 ± 0.00	0.14 ± 0.00
Glx[1]	1.98 ± 0.04	1.98 ± 0.03	1.97 ± 0.04	1.98 ± 0.02
Gly	0.84 ± 0.03*	0.98 ± 0.04*	0.92 ± 0.02*	0.91 ± 0.03
Pro	0.58 ± 0.01	0.61 ± 0.04	0.60 ± 0.02	0.60 ± 0.01
Ser	0.53 ± 0.01	0.56 ± 0.01	0.55 ± 0.01	0.55 ± 0.01
Tyr	0.47 ± 0.01*	0.47 ± 0.01*	0.51 ± 0.01*	0.48 ± 0.01
Sum of amino acids [2]	13.50 ± 0.28	13.58 ± 0.13	13.55 ± 0.25	13.54 ± 0.11
Tau [3]	0.11 ± 0.01	0.10 ± 0.01	0.11 ± 0.00	0.11 ± 0.00

[a, b] Significant differences within a column are indicated with different letters.
[1] Asx represents Asp and Asn, and Glx represents Gly and Gln. These are analyzed as Asp and Glu, respectively.
[2] Tau is not included in the sum of amino acids.
[3] Given as analyzed.
* Trend, 0.05 < P < 0.1.

Carbohydrates from feed will to a large extent be converted to lipid or end up as not retained energy. Lipids, including EPA and DHA, can be synthesized from non-lipid precursors and the term 'retention' should be used with care. In this case, retention represents the net flow of these compounds from feed ingredients to salmon.

The retention efficiency of energy and nutrients from feed to edible product depends strongly on the percentage of the animal that is used for human consumption. This is illustrated in Fry et al. (2018b, a) where production of terrestrial and aquatic species including salmon is

Table 6
Analysis of proximate composition and selected minerals in slaughter sized salmon sampled in spring, summer and autumn. At each sampling, 10 fish were collected from Southern, Mid and Northern part of Norway, and analyzed as 3 pooled samples. Data are given as mean ± S.E.M, 'as is'.

	Spring	Summer	Autumn	Overall mean
Proximate composition (MJ/kg or %):				
Energy (MJ/kg)	12.4 ± 0.6	12.6 ± 0.1	13.1 ± 0.1	12.7 ± 0.2
Dry matter (%)	39.9 ± 1.3	40.9 ± 0.5	42.1 ± 0.1	40.9 ± 0.5
Ash (%)	1.7 ± 0.1	1.8 ± 0.0	2.0 ± 0.1	1.8 ± 0.1
Lipid (%)	21.1 ± 1.8	21.0 ± 0.3	22.5 ± 0.5	21.5 ± 0.6
Nitrogen (%)	2.7 ± 0.1	2.7 ± 0.0	2.7 ± 0.0	2.7 ± 0.0
Minerals (mg/kg):				
P	3 114 ± 123	3 147 ± 57	3 042 ± 115	3 101 ± 54
Fe	20 ± 2*	27 ± 4*	15 ± 1*	21 ± 2
K	2 775 ± 152	2 741 ± 32	2 676 ± 17	2 730 ± 47
Ca	3 587 ± 160*	3 281 ± 121*	2 955 ± 182*	3 274 ± 120
Mg	262 ± 8	247 ± 3	249 ± 26	253 ± 8
Mn	1.6 ± 0.0[a]	1.6 ± 0.1[a]	1.3 ± 0.1[b]	1.5 ± 0.1
Na	824 ± 46[a]	826 ± 32[a]	676 ± 29[b]	775 ± 31
Zn	31.3 ± 3.4	34.2 ± 2.6	38.2 ± 1.0	34.6 ± 1.6

[a, b] Significant differences within a column are indicated with different letters.
* Trend, 0.05 < P < 0.1.

Table 8
Analysis of fatty acids in slaughter sized salmon sampled in spring, summer and autumn. At each sampling, 10 fish were collected from Southern, Mid and Northern part of Norway, and analyzed as 3 pooled samples. Data are given mean ± S.E.M, g/100 g, 'as is'.

	Spring	Summer	Autumn	Overall mean
C14:0	0.36 ± 0.03	0.33 ± 0.00	0.36 ± 0.02	0.35 ± 0.01
C14:1*n*-5	0.02 ± 0.00*	0.02 ± 0.00*	0.01 ± 0.00*	0.02 ± 0.00
C15:0	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
C16:0	1.60 ± 0.15	1.63 ± 0.07	1.60 ± 0.01	1.61 ± 0.05
C16:1*trans*	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
C16:1*n*-9	0.40 ± 0.04	0.36 ± 0.00	0.40 ± 0.03	0.38 ± 0.02
C16:1*n*-7	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.01 ± 0.00
C17:0	0.03 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
C16:2*n*-6	0.04 ± 0.01	0.03 ± 0.00	0.04 ± 0.00	0.03 ± 0.00
C17:1*n*-7	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00	0.02 ± 0.00
C16:2*n*-3	0.02 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.02 ± 0.00
C18:0	0.45 ± 0.05	0.47 ± 0.03	0.45 ± 0.01	0.46 ± 0.02
C18:1*n*-11	0.03 ± 0.01	0.02 ± 0.02	0.01 ± 0.01	0.03 ± 0.01
C18:1*n*-9	6.81 ± 0.03	6.87 ± 0.61	6.63 ± 0.36	6.77 ± 0.21
C18:1*n*-7	0.54 ± 0.03	0.52 ± 0.01	0.50 ± 0.03	0.52 ± 0.01
C18:2*n*-6	2.41 ± 0.23	2.50 ± 0.07	2.35 ± 0.03	2.42 ± 0.07
C18:3*n*-6	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00
C18:3*n*-3	1.14 ± 0.36	1.20 ± 0.27	1.09 ± 0.13	1.14 ± 0.14
C20:0	0.07 ± 0.01	0.07 ± 0.01	0.06 ± 0.01	0.07 ± 0.01
C20:1*n*-11	0.09 ± 0.01	0.09 ± 0.01	0.10 ± 0.00	0.10 ± 0.00
C20:4*n*-3	0.07 ± 0.00*	0.05 ± 0.01*	0.03 ± 0.01*	0.05 ± 0.01
C20:1*n*-9	0.77 ± 0.10	0.80 ± 0.10	0.64 ± 0.02	0.74 ± 0.05
C20:1*n*-7	0.04 ± 0.01	0.04 ± 0.01	0.03 ± 0.00	0.03 ± 0.00
C20:2*n*-6	0.24 ± 0.03	0.24 ± 0.02	0.20 ± 0.00	0.23 ± 0.01
C20:3*n*-6	0.05 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00
C20:4*n*-6	0.05 ± 0.01	0.04 ± 0.00	0.05 ± 0.00	0.05 ± 0.00
C20:3*n*-3	0.13 ± 0.04	0.13 ± 0.04	0.10 ± 0.01	0.12 ± 0.02
C22:0	0.03 ± 0.00	0.04 ± 0.00	0.03 ± 0.01	0.03 ± 0.00
C22:1*n*-7	0.15 ± 0.00	0.13 ± 0.01	0.14 ± 0.01	0.14 ± 0.00
C22:1*n*-11	0.31 ± 0.06	0.36 ± 0.07	0.31 ± 0.07	0.33 ± 0.03
C22:1*n*-9	0.12 ± 0.02	0.12 ± 0.02	0.08 ± 0.01	0.11 ± 0.01
C20:5*n*-3 (EPA)	0.46 ± 0.09	0.40 ± 0.03	0.45 ± 0.02	0.44 ± 0.03
C24:0	0.02 ± 0.01	0.02 ± 0.02	0.01 ± 0.01	0.04 ± 0.01
C24:1*n*-9	0.08 ± 0.01	0.08 ± 0.00	0.07 ± 0.01	0.07 ± 0.00
C22:5*n*-3	0.24 ± 0.03	0.19 ± 0.01	0.22 ± 0.01	0.21 ± 0.01
C22:6*n*-3 (DHA)	0.75 ± 0.06	0.72 ± 0.05	0.69 ± 0.01	0.72 ± 0.03
Sum EPA + DHA	1.21 ± 0.15	1.12 ± 0.08	1.14 ± 0.03	1.16 ± 0.05
Sum *n*-3 fatty acids	2.80 ± 0.58	2.71 ± 0.38	2.59 ± 0.18	2.70 ± 0.21
Sum *n*-6 fatty acids	2.82 ± 0.27	2.88 ± 0.08	2.70 ± 0.02	2.80 ± 0.08
Ratio *n*-6:*n*-3	1.05 ± 0.11	1.10 ± 0.12	1.05 ± 0.07	1.07 ± 0.05
Sum saturated fatty acids	2.59 ± 0.26	2.62 ± 0.14	2.56 ± 0.03	2.59 ± 0.09

*Trend, $0.05 < P < 0.1$.

Table 9
Composition of whole body and edible part, and total amount of nutrients in the whole body, edible part and trimmings of Atlantic salmon. Calculations of the three latter are based on a total amount of 1,252,573 tonnes of salmon produced in 2016 of which 65% is considered edible, resulting in 814,172 tonnes of salmon for human consumption. Energy data are given as MJ/kg or GJ.

	Whole body composition (% or MJ/kg) [1]	Composition of salmon fillet (% or MJ/kg) [2]	Total nutrients in whole body of salmon (tonnes or GJ) [3]	Total nutrients in edible part of salmon (tonnes or GJ) [4]	Amount of nutrients in trimmings (tonnes or GJ) [5]
Dry matter	40.9	36.3 [6]	512,694	295,219	217,475
Energy	12.7	10.9 [7]	15,925,589	8,880,259	7,045,330
Crude lipid	21.5	16.5	269,730	134,338	135,392
EPA	0.44	0.407	5,495	3,582	1,913
DHA	0.72	0.636	9,006	5,553	3,453
Crude protein	16.9	18.6	212,229	151,436	60,793
Phosphorus	0.31	0.246 [8]	3,884	2,003	1,881

[1] Data from Table 6 and 8.
[2] Data from Seafood Data (2017).
[3] Data for whole body composition multiplied by total salmon production in 2016 (1,252,573 tonnes).
[4] Data for fillet composition multiplied with the total calculated salmon fillet yield in 2016 (814,172 tonnes).
[5] Nutrients in total salmon produced minus nutrients in edible part produced in 2016.
[6] Calculated as the sum of lipid, protein and ash (16.5% + 18.6% + 1.16%).
[7] Calculated from energy content of lipid (39.5 MJ/kg) and protein (23.6 MJ/kg).
[8] Analyzed in 2013.

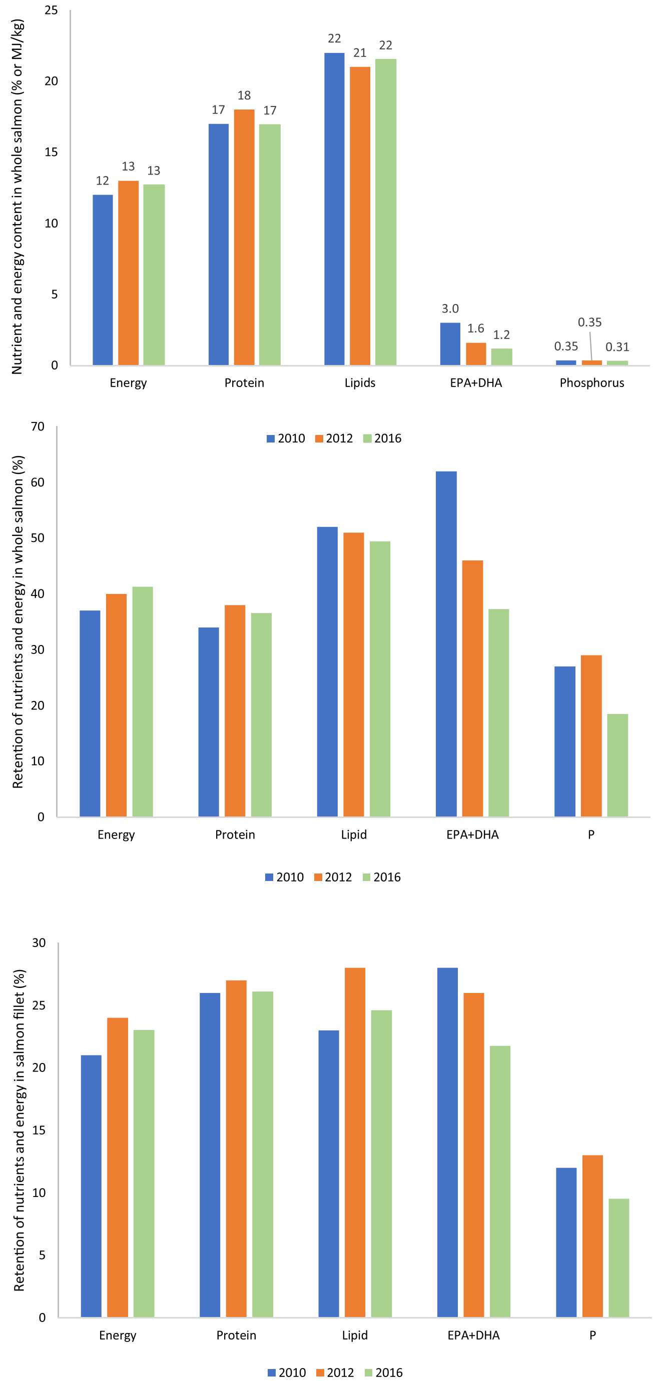

Fig. 4. Nutrient and energy content in whole salmon (upper panel), retention of nutrients and energy in whole salmon (middle panel) and retention of nutrients and energy in salmon fillet (lower panel) for salmon produced in Norway in 2010, 2012 (Ytrestøyl et al., 2015) and 2016.

evaluated. In Fry et al. (2018b) bone was included as edible part in beef cattle, pigs and chicken, with energy and nutrient content as meat. In Fry et al. (2018a), bone was excluded except for chicken where only half of the bone fraction was excluded because some of the retail chicken is sold with bone. Nutrient content in feed, fillet yield, inclusion of breeding stock or not and inclusion of losses or not are other factors that influence retention calculations. These assumptions must be taken into account when comparing values obtained in different studies. In the present study, 65% fillet yield of salmon was assumed as an average, and for comparison with previous years (Ytrestøyl et al., 2015). This resulted in 23% retention of energy and 26% of protein in fillet. Some of the salmon is sold to the consumer as gutted with head on, which may give 85% edible part, which again result in 30% of the energy and 34% of protein from feed retained in the edible part.

Table 10
Retention (%) of nutrients and energy in whole body, fillet and trimmings of salmon, and not retained (lost) nutrients and energy in Norwegian salmon production in 2016.

	Retention in whole body	Retention in fillet	Retention in trimmings [1]	Not retained – loss [2]
Dry matter	34	19	14	66
Energy	41	23	18	59
Crude lipid [3]	49	25	25	51
EPA + DHA [3]	37	22	16	63
Protein	37	26	10	63
Phosphorus	18	10	9	82

[1] Retention in whole body (%) – retention in edible part (%).
[2] 100 (%) – retention in whole body (%).
[3] Includes lipids produced from non-lipid precursors.

The retention is estimated for nutrients and energy of the whole Norwegian salmon farming industry in 2016. 'Resource economic retention' could be an adequate term for these estimates.

3.7.3. Protein-, lipid-, and energy efficiency ratios

The term 'retention' often refers to the estimates discussed in 3.7.2. It is also used as a general term for estimates of utilization of energy or nutrient from feed into food product, such as PER, LER and EER. The PER, LER and EER was estimated to 2.2, 2.3 and 3.2, respectively, for whole salmon produced in Norway in 2016. The corresponding values for salmon fillet was 1.4, 1.5 and 2.1, respectively (Fig. 5). These values were similar to corresponding values estimated for 2010 and 2012 (Fig. 5).

3.8. Dependency on marine feed ingredients

3.8.1. Fish in fish out

A commonly used indicator for use of marine ingredients for production of salmon is the Fish-In-Fish-Out-ratio (FIFO). This is simply the weight ratio between amount of wild fish used and salmon produced without taking nutrient concentration into consideration. The amount of fish meal (FM) and fish oil (FO) condensed from forage fish varies, as does the inclusion of fish meal and fish oil in feed. FIFO is therefore estimated for fish meal and fish oil separately. The FIFO for total fish meal and fish oil in Norwegian salmon farming in 2016 was estimated to 0.84 and 1.45, respectively. The FIFO has decreased considerably since 1990 when salmon feed was mainly based on fish meal and fish oil. The estimated FIFO for both fish meal and fish oil was lower in 2016 than the previous years (Fig. 6).

The FIFO is often asked for in media and among consumers since it is believed to be a simple index to relate to. However, the FIFO is a poor measure of sustainability and does not reflect the complexity of resource utilization. Fish meal and fish oil produced from offal is also included in the FIFO.

3.8.2. Forage fish dependency ratio (FFDR)

The calculation of forage fish dependency ratio (FFDR) is the same as for FIFO, except that it only includes fish meal and fish oil produced from forage fish. This FFDR in 2016 was 0.63 for fish meal and 1.09 for fish oil. Fish meal was earlier produced mainly from forage fish. The use of offal has increased, which is reflected in a difference between FIFO and FFDR for both fish meal and fish oil the last decade (Fig. 6).

3.8.3. Marine nutrient dependency

The dependency of marine ingredients is also estimated with the marine nutrient dependency ratios (MNDPs). These are the ratios

Fig. 5. PER (protein efficiency ratio), LER (lipid efficiency ratio) and EER (energy efficiency ratio) of whole salmon (upper panel) and salmon fillet (lower panel) produced in Norway in 2010, 2012 (Ytrestøyl et al., 2015) and 2016.

between protein and oil of marine origin in feed and in the salmon produced. The marine protein dependency ratio (MPDR) in Norwegian salmon farming in 2016 was 0.6, compared to 0.7 in 2012 and 2013. The marine oil dependency ratio (MODR) in 2016 was 0.5 which is the same as in 2013 (Fig. 6).

4. Concluding remarks

This is an update of the utilization of feed resources in Norwegian salmon farming with data from 2016. There were in general moderate changes compared to 2012 with regard to both amounts and type of feed ingredients used (Ytrestøyl et al., 2015). The use of marine protein sources was further reduced and replaced by plant protein sources.

Indices for use of marine ingredients in salmon production have often been used in the context of sustainability, referring to the use of marine ingredients as negative. But reductions of marine ingredients in feed must be substituted by other ingredients. These substitutes also have environmental impacts and both marine and terrestrial feed ingredients may be more or less sustainably sourced. Some ingredients are produced from wastes or by-products from other production systems. Others imply use of water and/or phosphorus, land area, deforestation and transport over long distances, and may compete with production of food for human consumption. Feed ingredients on the global market are used in many different animal productions, and the sustainability of one production system is thus related to other production systems that consumes resources from the same market. Improvement of the sustainability in the world's food production depends on using the available resources in the best possible way. The authors wish to emphasize this complexity when evaluating the sustainability of a food production system. Some of these aspects are also discussed by Ytrestøyl et al. (2015). The intention of this study is to document the status of use of feed resources in Norwegian salmon farming. It is intended to be a tool for the industry and authorities to plan and improve salmon farming and provide information relevant for media and consumers.

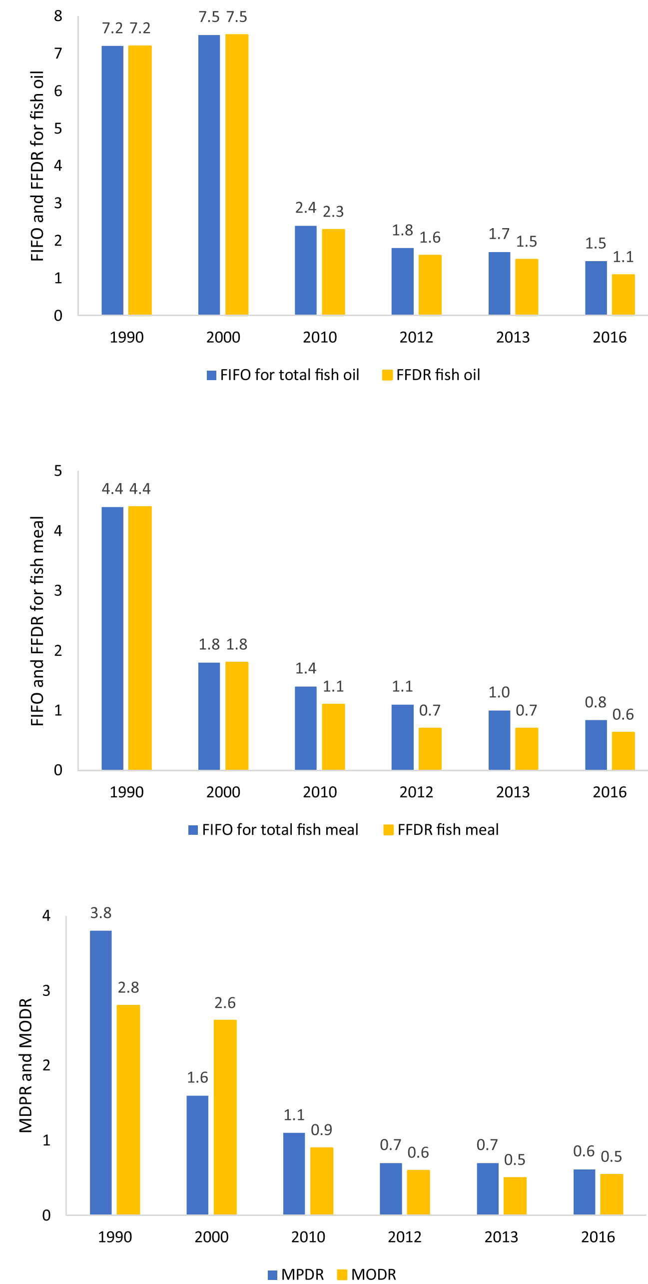

Fig. 6. Estimated FIFO (Fish-In-Fish-Out-ratio) and FFDR (forage fish dependency ratio) of fish oil (upper panel) and fish meal (middle panel), and MPDR (marine protein dependency ratio) and MODR (marine oil dependency ratio) from forage fish (lower panel) in Norwegian salmon farming in 1990, 2000, 2010, 2012, 2013 (Ytrestøyl et al., 2015) and 2016.

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