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Resource utilization of Norwegian salmon farming in 2016

Professional final report

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Report

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Sammendrag/anbefalinger:

Utnyttelse av fôrressurser i norsk lakseoppdrett gjennom ett år har tidligere vært beregnet for 2010 og 2012. Dette er en oppdatering for 2016.
I 2016 ble det produsert 1,25 millioner tonn laks i Norge. Det ble totalt brukt 1,62 millioner tonn fôrrråvarer i 2016, eller 1,52 tonn på tørrstoffbasis. Den økonomiske fôrfaktoren, beregnet fra mengde fôrråvarer brukt, var 1,30 (1,21 på tørrstoffbasis).
Soyaproteinkonsentrat utgjorde 19 % av total mengde fôringredienser, hvete og hvetegluten utgjorde til sammen 17,9 % mens rapsolje og kamelinaolje til sammen utgjorde 19,8 %. Marine proteinkilder utgjorde totalt 14,5 % av fôringrediensene og marine oljer 10,4 %.
Helkropp av laks med slaktestørrelse ble analysert for kjemisk sammensetning. Laksen ble samlet inn ved vår, sommer og høst, og fra Nord-, Midt- og Sør-Norge for å få prøver som er representative for norsk oppdrettslaks. Analysedata ble brukt for beregning av retensjon av energi og næringsstoff fra fôr.
Indikatorer på retensjon og utnyttelse av fôrråvarene ble beregnet. Det var noe redusert bruk av fiskemel, og en liten reduksjon i mengde fiskeolje. Ellers var det moderate endringer i ressursutnyttelsen i 2016 sammenlignet med 2012.

English summary/recommendation:

This report is an update on the utilization of feed resources in Norwegian salmon farming industry in 2016.
In 2016, 1.25 million tonnes of salmon were produced in Norway, using 1.62 million tonnes feed ingredients 'as is' or 1.52 million tonnes on dry matter basis. This gives an economic feed conversion ratio of 1.30 (or 1.21 on dry matter basis).
Soy protein concentrate accounted for 19 % of the feed ingredients, wheat and wheat gluten summed up to 17.9 % and rapeseed and camelia oil 19.8 %. Marine protein sources accounted for 14.5 % of the feed ingredients and marine oils 10.4 %.
Salmon of harvest size was sampled and analyzed for whole body composition for use in retention estimates.
Indices of retention and utilization of feed resources were calculated and showed some reduction in use of fish meal and a small reduction in use of fish oil. Otherwise, there were small changes in the utilization of feed resources in 2016 compared to 2012.

Forord

Prosjektet 'Ressursutnyttelse i norsk lakseoppdrett i 2016' er finansiert av FHF (Prosjektnummer FHF: 901324).

Data for bruk av fôrmidler i 2016 er gitt av BioMar AS, Cargill, MOWI ASA og Skretting AS.

Fisk for helkroppsanalyse ble gitt av Blom Fiskeoppdrett AS, Erko Seafood AS, Grieg Seafood ASA og Lerøy ASA.

Innhold

1 Sammendrag

Utnyttelse av fôrressurser i norsk lakseoppdrett gjennom ett år har tidligere vært beregnet for 2010, 2012 og til dels 2013 (ikke fullstendige data tilgjengelig for 2013). Dette er en oppdatering for 2016. I tillegg ble laks av slaktestørrelse analysert for kjemisk sammensetning av helkropp.

Total mengde laks produsert i 2016 ble beregnet fra tall i offentlige statistikker (Fiskeridirektoratet og Statistisk sentralbyrå). Data for forbruk av fômidler ble gitt av de fire store norske fôrselskapene (BioMar AS, Cargill, MOWI ASA og Skretting AS). Fisk til helkroppsanalyse ble gitt av Blom Fiskeoppdrett AS, Erko Seafood AS, Grieg Seafood ASA og Lerøy ASA.

I 2016 ble det produsert 1,25 millioner tonn laks i Norge, hvorav mengde filet ble beregnet til 0,81 millioner tonn.

Det ble totalt brukt 1,62 millioner tonn fôrrråvarer ('as is') i 2016, som gir en økonomisk fôrfaktor på 1,30. På tørrstoffbasis ble det brukt 1,52 millioner tonn fômidler, som gir økonomisk fôrfaktoren 1,21. Den registrerte mengden omsatt fôr i 2016 var 1,54 millioner tonn, som gir økonomisk fôrfaktor på 1,23.

Sammensetningen av norsk laksefôr har endret seg betydelig over de siste tiårene, fra å være hovedsakelig basert på fiskemel og fiskeolje, til å inneholde en betydelig andel planteingredienser. I 2016 var soyaproteinkonsentrat den fôringrediensen som ble brukt i størst volum, og utgjorde 19 % av total mengde fôringredienser. Hvete og hvetegluten utgjorde til sammen 17,9 % og rapsolje og kamelinaolje til sammen 19,8 %. Marine proteinkilder utgjorde totalt 14,5 % av fôringrediensene og marine oljer utgjorde 10,4 %. Størstedelen av de marine ingrediensene var av Nord-Atlantisk opprinnelse. Videre var størstedelen av de marine ingrediensene godkjent under sertifiserings-/standardiseringsordninger som har bærekraft blant hovedpilarene. Hverken sporbarhet eller sertifiseringsordninger/standarder er like utviklet for planteråvarer som for de marine råvarene, og følgelig var en mindre del av planteråvarene som ble brukt i 2016 av kjent opprinnelse, eller med sertifisering/standardisering.

Laks med gjennomsnittlig slaktestørrelse ble analysert for kjemisk sammensetning av helkropp. Laksen ble samlet inn ved vår, sommer og sein høst, og fra Sør-, Midt- og Nord-Norge for å få prøver som er representative for norsk oppdrettslaks. Analysedata ble brukt for beregning av retensjon av energi og næringsstoff fra fôr. Helkropp av laks inneholdt i gjennomsnitt 12,7 MJ/kg energi, 40,9 % tørrstoff, 21,5 % fett, 16.9 % råprotein (Nx6.25), 0,.31 % fosfor og 1,8 % aske. Innholdet av EPA og DHA var henholdsvis 0,44 % og 0,72 %.

Total retensjon av energi fra fôret i den produserte laksen var 41 %. Retensjon av EPA+DHA var 37 %, protein 37 % og fosfor 18 %. Under forutsetning av 65 % filetutbytte og filetsammensetning basert på NIFES' Sjømatdata, ble retensjon av energi i filet estimert til 23 %, EPA+DHA 23 %, protein 26 % og fosfor 10 %.

Såkalt 'Fish-in-fish-out'-ratio ble beregnet til 0,8 for fiskemel og 1,5 for fiskeolje. Tilsvarende ratio, men der fiskemel og -olje fra avskjær er tatt ut av beregningen, såkalt 'forage fish dependency ratio' ble beregnet til 0,6 for fiskemel og 1,1 for fiskeolje.

Forholdet mellom marint protein i fôr og protein i laks, såkalt 'marine protein dependency ratio' ble beregnet til 0,75 totalt, eller 0,61 når bare villfanget fisk brukt i fôret var inkludert. Tilsvarende ratio for fett, 'marine oil dependency ratio' var 0,72 totalt og 0,55 for villfanget fisk brukt til fôr.

Indekser for fôrutnyttelse og bruk av marine råvarer gjelder den totale lakseproduksjonen i Norge gjennom et år og inkluderer alle tap (fôr og laks). De beregnede verdiene kan derfor ikke sammenlignes direkte med verdier fremskaffet i kontrollerte forsøk eller mindre produksjoner av begrenset tid eller omfang.

Generelt er det moderate endringer i ressursbruken og lakseproduksjonen de siste årene, men bruken av marint protein har gått ytterligere ned og er erstattet at planteråvarer, og det var også en liten tilsvarende endring i bruk av marine oljer.

For marine råvarer er det høy grad av sporbarhet og oversikt. Tilsvarende oversikt kunne vært ønskelig også for andre råvarer.

Hovedfunn

- I 2016 ble det totalt brukt 1,62 millioner tonn fôrråvarer og produsert 1,25 millioner tonn laks i Norge, som gir økonomisk fôrfaktor 1,30.
- Soyaproteinkonsentrat utgjorde 19 % av total mengde fôringredienser. Rapsolje og kamelinaolje utgjorde til sammen 19,8 % mens hvete og hvetegluten utgjorde 17,9 % av fôringrediensene.
- Hoveddelen av marine råvarer som ble brukt var under en sertifiseringsordning eller standard med bærekraft som en av hovedpilarene. Tilsvarende system er ikke utviklet i samme grad for planteråvarer.
- Marine proteinkilder utgjorde totalt 14,5 % av fôringrediensene og marine oljer 10,4 %.
- Total retensjon av energi fra fôret i hel laks var 41 %, retensjon av EPA+DHA var 37 %, protein 37 % og fosfor 18 %.
- Fish-in-fish-out-ratio var 0,8 for fiskemel og 1,5 for fiskeolje. Tilsvarende ratio men med bare villfanget fisk (avskjær trukket fra) var 0,6 og 1,1 for henholdsvis fiskemel og fiskeolje.
- Det var noe lavere bruk av marine proteinkilder enn foregående år, og en mindre reduksjon i bruk av marine oljer. Ellers var endringen i ressursutnyttelsen i 2016 moderat i forhold til 2012.

English summary

The utilization of feed ingredients has previously been reported for 2010, 2012 and partly for 2013 (not all data were available for 2013). This report is an update on the utilization of feed resources in Norwegian salmon farming industry in 2016. Besides, salmon of average harvest size was analyzed for chemical composition of whole body.

Public data were used for calculation of total salmon production (Norwegian Directorate of Fisheries and Statistics Norway). Data for use of feed ingredients were provided by the four large Norwegian feed companies (BioMar AS, Cargill, MOWI ASA and Skretting AS). Fish for whole body analysis were provided by Blom Fiskeoppdrett AS, Erko Seafood AS, Grieg Seafood ASA and Lerøy ASA.

In 2016, 1.25 million tonnes of salmon were produced in Norway, and fillet yield estimated to 0.81 million tonnes.

A total of 1.62 million tonnes feed ingredients 'as is' was used, which gives a feed conversion ratio of 1.30. On dry matter basis, 1.52 million tonnes feed ingredients were used, which corresponds to a feed

conversion ratio of 1.21. The registered amount of traded feed was 1.54 tonnes, resulting in feed conversion ratio 1.23.

The composition of Norwegian salmon feed has changed considerably over the last decades, from mainly marine ingredients to inclusion of a substantial part of plant ingredients. In 2016, soy protein concentrate was the largest single feed ingredient, accounting for 19 % of the feed ingredients used, wheat and wheat gluten summed up to 17.9 % and rapeseed oil and camelia oil 19.8 %. Marine protein sources accounted for 14.5 % of the feed ingredients and marine oils 10.4 %. The main portion of marine ingredients originated from the North Atlantic. Furthermore, the main part of the marine ingredients used were approved by a certification or standardization system which has sustainability as one of the main pillars. The same degree of traceability and certification-/standardization systems is not developed for plant ingredients. Consequently, the share of ingredients with defined origin and with certification was lower among the plant ingredients used in 2016.

Salmon of average harvest size was sampled and analyzed for whole body composition. The salmon were sampled in spring, summer and late autumn, from south, mid and north of Norway for samples representative for Norwegian farmed salmon. The data were used for estimation of retention of energy and nutrients. The average whole body of salmon contained 12.7 MJ/kg energy, 40.9 % dry matter, 21.5 % fat, 13.5 % protein (sum of amino acids), 0,.31 % phosphorus and 1.8 % ash. The content of EPA+DHA was 0.44 % and 0.72 %, respectively.

The total retention of energy from feed ingredients was 41 % in whole salmon. The salmon retained 37 % of EPA+DHA, 37 % of protein and 18 % of phosphorus. Assuming 65 % fillet yield and fillet composition as given in Seafood Data (2017) retention of energy in fillet was estimated to 23 % of the energy, 23 % of EPA+DHA, 26 % of protein and 10 % of phosphorus from the feed ingredients.

The estimated Fish-In-Fish-Out-ratio was 0.8 for fish meal and 1.5 for fish oil. The corresponding ratio, but with fish meal and -oil produced from trimmings left out of the calculation, was 0.6 for fish meal and 1.1 for fish oil (Forage Fish Dependency Ratio).

The ratio between marine protein in feed and protein in the produced salmon, the Marine Protein Dependency Ratio was 0.75 for total marine ingredients, or 0.61 when only including forage fish. The corresponding ratio for fat, the Marine Oil Dependency Ratio, was 0.72 in total and 0.55 when only including forage fish.

Indices for feed utilization and use of marine ingredients were calculated for the total production of salmon in Norway during one year and included all losses of feed and salmon. These values should not be compared directly to similar values obtained in controlled studies or productions of limited scale or duration.

Overall, the data showed minor changes in utilization of feed ingredients and production of salmon over the last few years, but the amount of marine protein sources was further reduced and replaced by plant protein sources, and a small corresponding reduction in the use of marine oils.

A high degree of traceability and transparency is developed for marine ingredients. A similar transparency could also be desirable for plant ingredients.

Main findings

- In total, 1.62 million tonnes of feed ingredients were used and 1.25 million tonnes of salmon were produced in Norwegian salmon farming in 2016, which gives an economic feed conversion ratio of 1.30.
- Soy protein concentrate constituted 19 % of the total amount of feed ingredients used, rapeseed and camelina oil summed up to 19.8 % whereas wheat and wheat gluten summed up to 17.9 %.
- The major part of the marine ingredients was approved by a certification system or standard which emphasizes sustainability. The same degree of such systems is not developed for plant ingredients.
- Total retention of energy from feed in whole salmon was 41 %, retention of EPA+DHA was 37 %, protein 37 % and phosphorus 18 %.
- Marine protein sources accounted for 14.5 % of the ingredients used, and marine oils 10.4 %.
- The Fish-In-Fish-Out-ratio was 0.8 for fish meal and 1.5 for fish oil. The corresponding ratio when only including forage fish was 0.6 and 1.1 for fish meal and fish oil, respectively.
- The use of marine protein sources was somewhat reduced since 2012, and there was also a minor reduction of marine oils. Except for this, there were moderate changes in the utilization of feed ingredients in 2016 compared to 2012.

2 Innledning

Kunnskap om den totale utnyttelse av fôrressurser i norsk lakseoppdrett er viktig for vurdering og forbedring av industriens bærekraft. Dette er viktig kunnskap for næringen selv, for forbrukeren og for allmenheten. Sammensetningen av fôret har endret seg betydelig over tid, og i dette prosjektet er det redegjort for ressursutnyttelsen i 2016.

I tillegg har man manglet representative data på kjemisk sammensetning av helkropp av laks av slaktestørrelse. I dette prosjektet ble det samlet inn laks for kjemisk analyse til bruk ved beregning av effektiviteten i utnyttelse av energi og næringsstoff fra fôr i produsert laks.

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3 Objective

All food production has an impact on the environment, using area, water, phosphorus, energy and other resources, and emitting CO_2 and nutrient discharges. In sustainability of food production, the resource economy aspect is important and the effectiveness of the utilization of resources and minimal emissions is central. The utilization of feed resources of Norwegian salmon farming during one year has been presented previously (Ytrestøyl *et al.*, 2015). The present report is an update on the utilization of feed resources in Norwegian salmon farming in 2016.

There are limited data available on the composition of the whole body of large salmon. The composition varies with body size, time of year, location of farm, composition of feed and several other factors. The accuracy of estimates of production efficiency depends on representative data on the final product. In this project, average harvest-size salmon was collected from southern, mid and northern Norway in spring, summer and late autumn for chemical analysis of whole body composition.

To our knowledge, Norwegian salmon farming is the only system for production of animal protein where data on input (feed used) and volume produced for the total production in the whole country over a year are available. Such data is a measure of the effectiveness of the whole production systems, including all losses such as discarded batches of feed or feed ingredients, mortality and escapees. The data should therefore not be compared directly to controlled studies or production periods of limited time or scale.

In this update on resource utilization for 2016, commonly used indexes for resource utilization are used. The methods used are described and discussed previously (Ytrestøyl *et al.*, 2015).

4 Project implementation

Data for use of feed ingredients were provided by the four large feed manufacturers in Norway (BioMar AS, Cargill (Ewos), MOWI ASA (Marine Harvest) and Skretting AS).

Total production of salmon was calculated from public data (Directory of Fisheries and Statistics Norway).

Salmon of average harvest size were collected for chemical analysis of whole body. Salmon were collected from south (Sotra, Hordaland), mid (Hitra, Trøndelag) and north (Alta, Finnmark) of Norway in spring, summer and late autumn to represent salmon produced in the whole Norwegian coastline and slaughtered during the whole year.

Indices for measurements of retention and utilization of energy, nutrients and feed ingredients were calculated. The methods are discussed previously (Ytrestøyl *et al.*, 2015).

5 Results, discussion and conclusions

5.1 Feed ingredients used in 2016

5.1.1 The total use of feed ingredients

Data for all consumed feed ingredients for salmon feed in 2016 were provided by the four large feed companies in Norway (BioMar, Cargill (Ewos), MOWI Feed (Marine Harvest) and Skretting). In total, 1,627,478 tonnes of feed ingredients ('as is') were used for production of salmon feed in Norway in 2016. Given on dry matter basis, this corresponds to 1,520,358 tonnes.

The registered amount of traded feed in 2016 was 1,543,000 tonnes (Akvafakta.no, 2017). The dry matter content of the ingredients ranged from 47 % to 100 % (oils) whereas the dry matter content of salmon feed is typically around 93-95 %. Due to differences in dry matter content, the amount of feed ingredients used is not identical to that of the produced feed.

Corresponding estimates for Norwegian salmon farming was done in 2010 and 2012 (Ytrestøyl *et al.*, 2015), and the figures for both total use of feed ingredients and for production of salmon 2016 were similar to the figures for 2012, and somewhat higher than in 2010 (Figure 1).

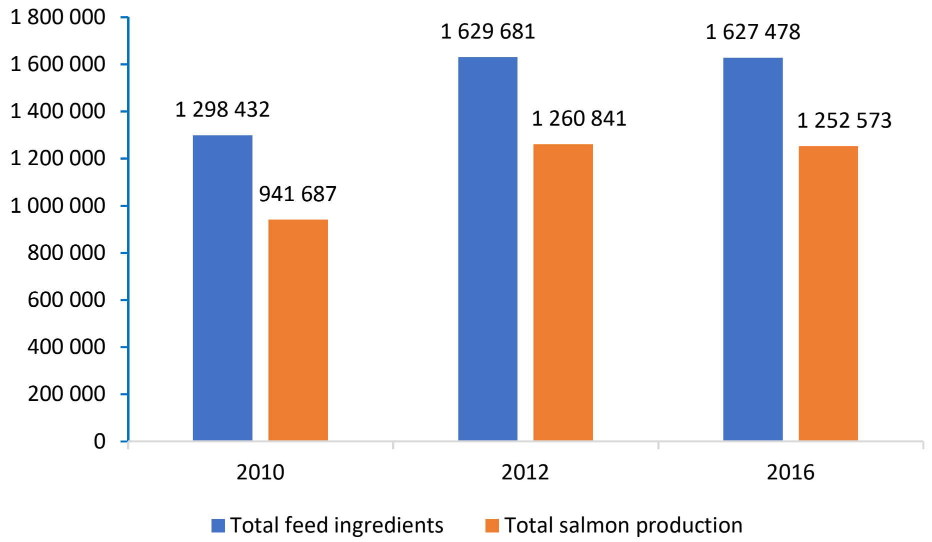


Figure 1 The total use of feed ingredients and production of salmon (tonnes) in Norway in 2010, 2012 and 2016.

The feed ingredients used in Norwegian salmon farming in 2016 is shown in Table 1 and compared with 2010 and 2012 in Figure 2. The reduction of the level of marine ingredients over the last years has been replaced by an increase in levels of plant ingredients, mainly soy protein concentrate and rapeseed oil (Figure 2). In 2016, soy protein concentrate was the main protein source, constituting 19 % of the feed. The second most abundant plant protein source was wheat gluten (9 % of the feed), and wheat was also used as a binder (8.9 % of the feed), making wheat an important feed resource in salmon feed. The main oil source was rapeseed oil.

Rapeseed and camelina oil were given as one sum from one of the feed companies and could therefore not be separated from each other, but rapeseed is the main contributor and camelina oil is a minor oil source in comparison.

The feed contained 14.5 % marine protein sources, of which 2.8 % was from fish trimmings. The inclusion of marine oils was 10.4 %, of which 2.6 % was from trimmings.

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[1]	322,580	19.8
	Linseed oil	5,625	0.3
Carbohydrate sources	Wheat	144,605	8.9
	Pea starch	12,302	0.8
	Unknown 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[2]	65,422	4.0
	Sum	**1,627,478**	**100**

[1] 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.

[2] Micro ingredients contain ingredients such as crystalline amino acids, phosphorus sources and astaxanthin.

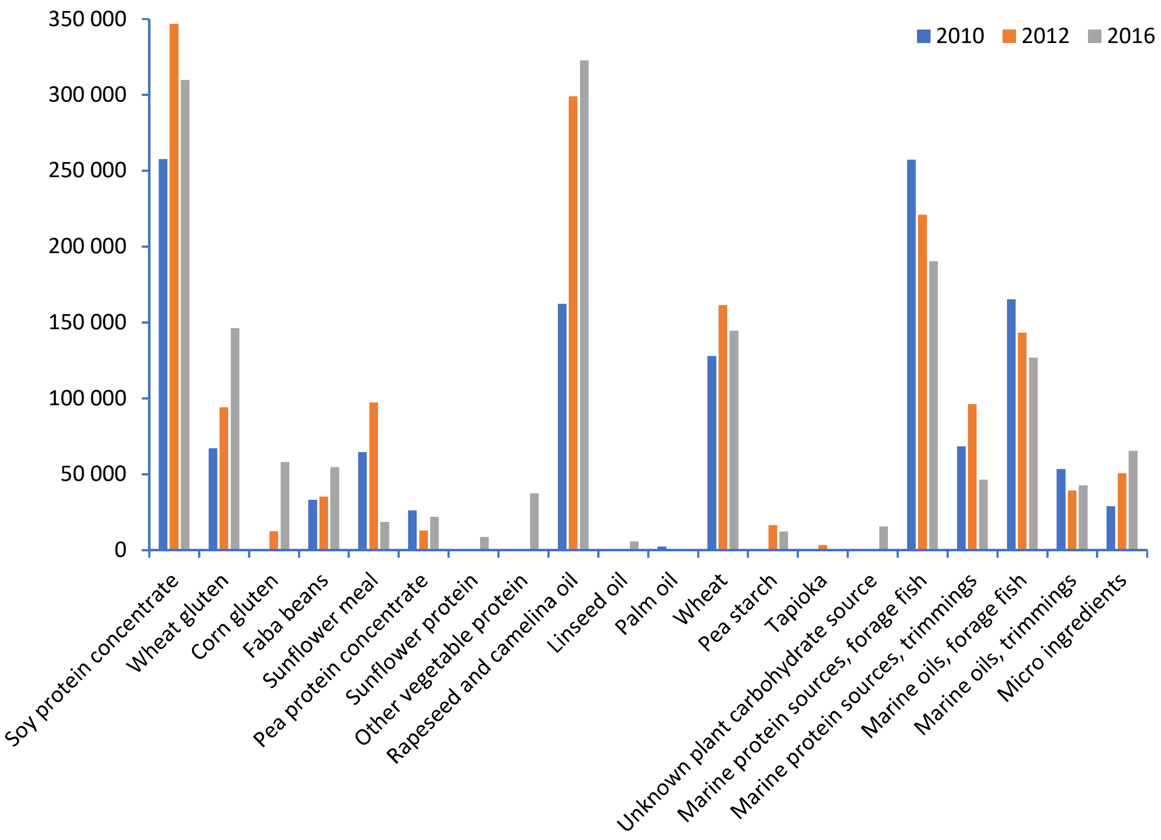


Figure 2 Feed ingredients (tonnes) used in 2010, 2012 and 2016.

In 2016, the salmon feed contained 14.5 % marine protein sources, 10.4 % marine oils, 40.3 % plant protein sources, 20.2 % plant oils, 10.6 % carbohydrate sources and 4.0 % micro ingredients (Figure 3). Compared to 2013, the portion of marine protein sources in the feed was reduced in 2016 and replaced by plant protein sources.

The portion of marine oils was almost the same as in 2013. Since 1990, the portion of marine ingredients in salmon feed has declined, being replaced by plant ingredients.

The share of micro ingredients has increased gradually since 1990. This is explained mainly by increased addition of crystalline amino acids to balance the amino acid profile when using plant ingredients and addition of functional compounds.

The amount of carbohydrate sources, which are mainly used as binders has been kept stable at around 10 % (Figure 3).

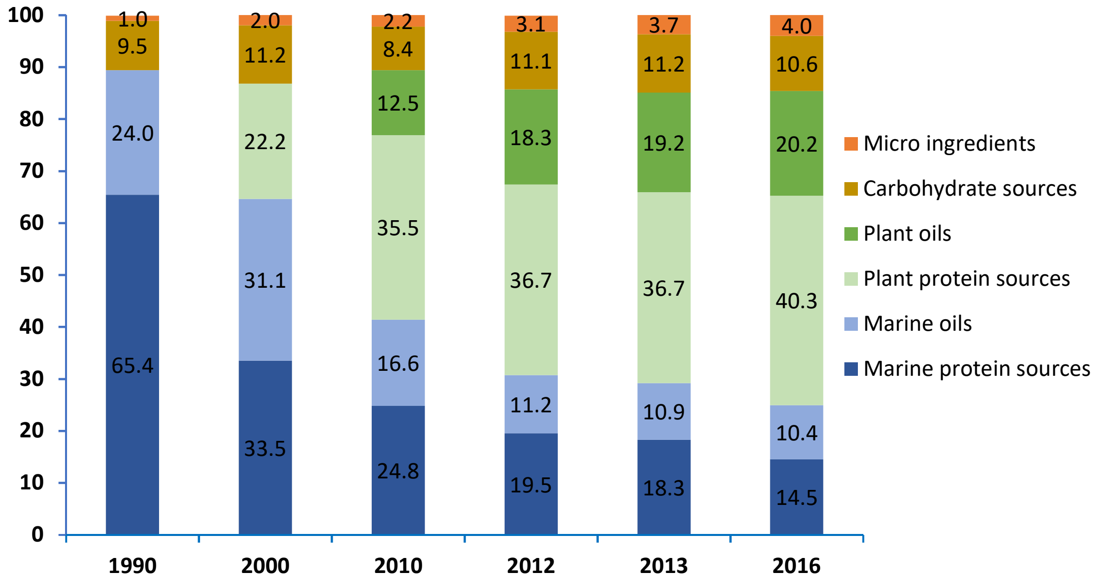


Figure 3 Ingredient sources in Norwegian salmon feed from 1990 to 2016 (% of feed).

The use of marine ingredients in feed was lower in 2016 than in the previous years the data have been compiled, both when given as % of the feed (Figure 3) and as total amount in tonnes (Figure 4). Compared to 2010, 2013 and 2013, the use of marine ingredients from forage fish was reduced to 317,037 tonnes, but the use of marine ingredients from trimmings was also reduced to 88,884 tonnes in 2016 (Figure 4).

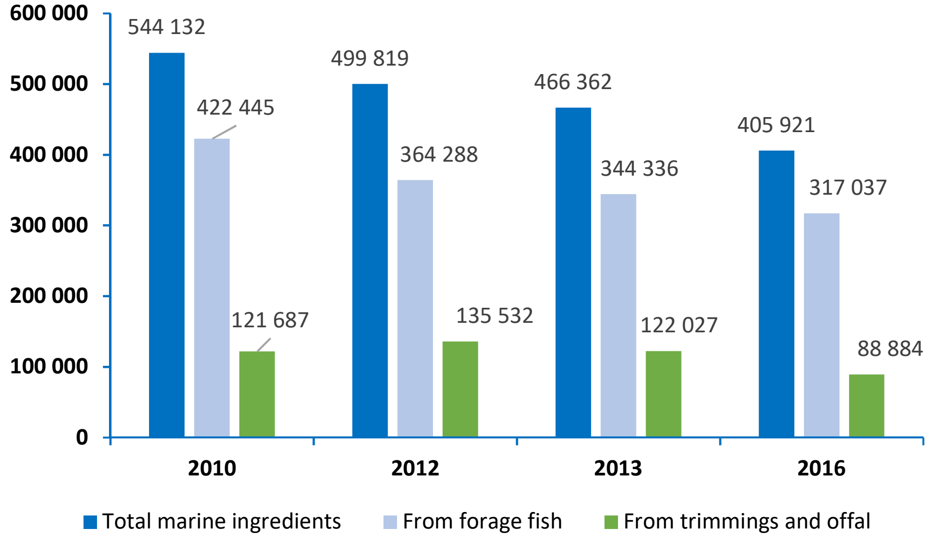


Figure 4 Use of marine ingredients (tonnes) from forage fish and trimmings in Norwegian salmon farming in 2010, 2012, 1013 and 2016.

5.1.2 Origin of feed ingredients

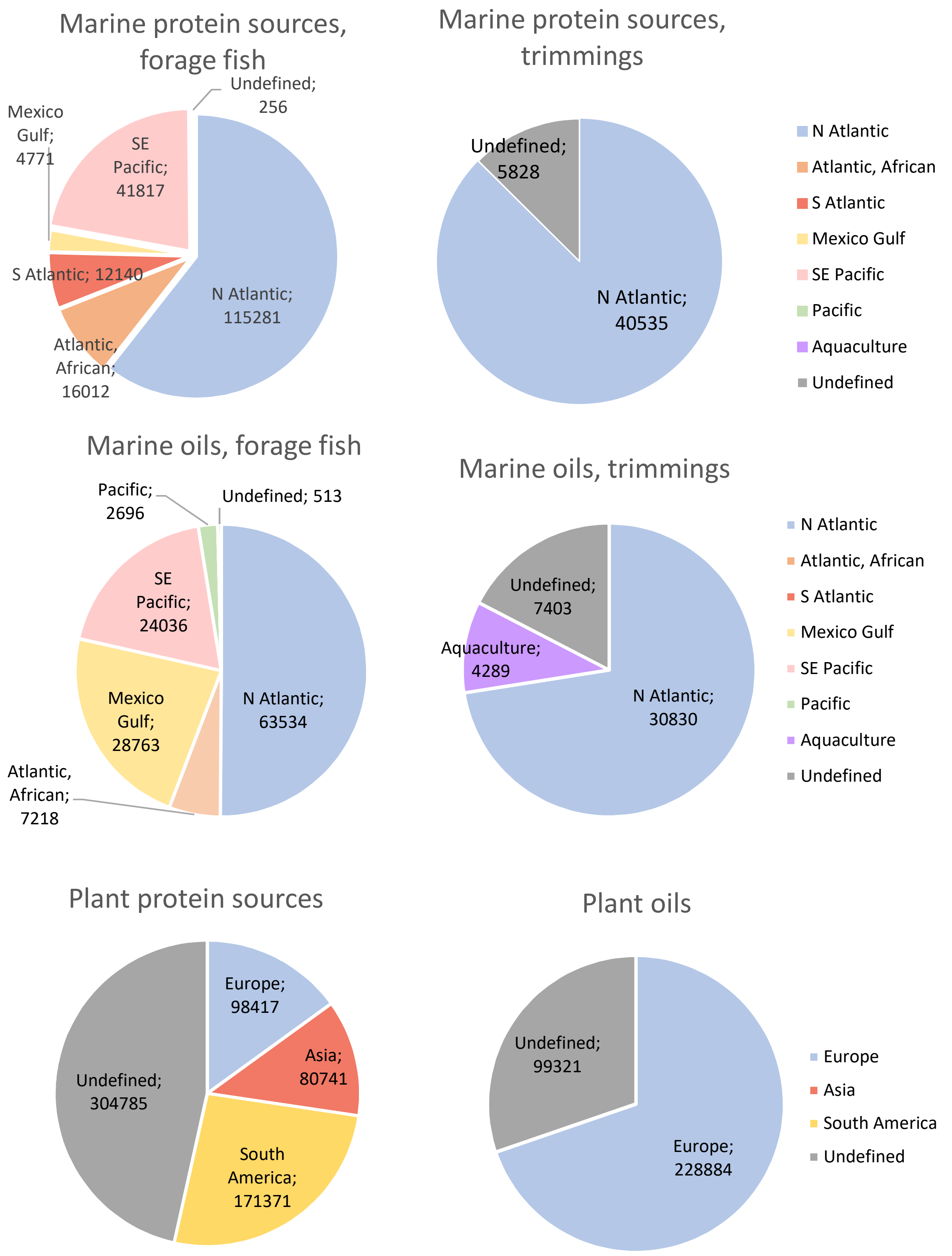


Figure 5 Origin of marine and plant ingredients in Norwegian salmon feed in 2016 (tonnes).

The marine protein sources were mainly of North Atlantic origin (Figure 5). Marine protein sources made from trimmings were all from the North Atlantic, except for one batch of undefined origin. The marine protein sources made from forage fish were also mainly from the North Atlantic, but also some originated from the South East Pacific, African Atlantic and South Atlantic, a small amount from the Mexico Gulf, and a very small part of undefined origin.

The marine oil made from trimmings was also mainly North Atlantic, and some was from offal from farmed fish (Figure 5). A certain part was of undefined origin.

Approximately half of the fish oil from forage fish used in salmon feed in 2016 originated from the North Atlantic. There was also oil originating from the Mexico Gulf and the South East Pacific, a smaller amount from the African Atlantic, and a very small amount of undefined origin (Figure 5).

The plant ingredients used in salmon feed in 2016 contained larger fractions of ingredients of undefined origin. The protein sources that were accounted for, originated from South America, Europe and Asia, whereas all plant oil with a defined origin was produced in Europe (Figure 5). The aquaculture industry has developed a high degree of traceability of ingredients of marine origin. The same detailed traceability is presently 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. This is the reason for that the origin of plant ingredients is not accounted for to the same detail as for the marine ingredients.

5.1.3 Certification of feed ingredients

There are several certification and standardization systems and for the different food production systems to ensure that the products have been produced according to certain standards regarding environmental and social aspects. The relevant systems and bodies for salmon feed ingredients are briefly described below.

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.

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.

IP (Improvers' Programme) 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.

Non-GM is a declaration for ingredients that are not genetically modified and is relevant for plant ingredients.

ProTerra has auditable scheme and infrastructure against which to issue certificates that covers social, environmental aspects and non-GMO products, mainly soy but also other agricultural crops, and is relevant for plant ingredients.

RTRS (Round Table Responsible Soy) is a civil organization that promotes responsible production, processing and trading of soy on a global level.

The amount (% of each type of feed ingredients) of certified or declared ingredients used in Norwegian salmon feed in 2016 is given in Table 2. The major part of the marine ingredients was certified by IFFO RS. For plant ingredients, the certification systems are not equally developed and accordingly, a lower portion of the plant ingredients was certified. One ingredient can have two certifications and the data can therefore not be summed to the total amount of certified ingredients.

Table 2 Amount, given as % of each ingredient type, that is certified and authorized by the various certification and standardization -systems and bodies. 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	IFFO RS	IP	Non-GM	ProTerra	RTRS
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		

5.1.4 Chemical composition of the feed

The chemical composition of the feed ingredients was reported by the feed companies. For missing values, assumptions were made based on values given by the other feed companies, or literature data. From the given composition data, the average salmon feed in 2016 was calculated to contain 93 % dry matter, 23.7 MJ/kg gross energy, 33.5 % crude lipid, 35.6 % crude protein, 11 % carbohydrates and 1.3 % phosphorus (Table 3). Data for content of ash, minerals other than phosphorus, and the composition of micro ingredients were not available. However, the feed contained 4.0 % micro ingredients, and ash content is typically around 8-9 % (Dessen *et al.*, 2017), which corresponds to the deviation between the sum of the components and the total dry matter in the average feed composition (Table 3). The dry matter content is altered during feed production, and the term 'feed' here reflects the sum of the feed ingredients used, not the produced feed.

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.

	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)**
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*	11.0	179,781	0	179,156	625
Phosphourus	1.3	21,007	4,872	4,404	11,732
Sum	80.2	1,305,530	351,098	950,900	3,532

*Includes NFE (nitrogen free extract) and crude fiber

** Micro ingredients such as crystalline amino acids, mineral and vitamin mixes, astaxanthin and products from microorganisms

5.2 Salmon production in 2016

5.2.1 Total amount of salmon produced

A total of 1,233,619 tonnes of Norwegian farmed salmon was sold in 2016 (Statistics Norway, 2017, Directory of Fisheries, 2018). The livestock at 31st December 2015 was 721,455 tonnes, and at 31st December 2016 the livestock was 740,409 tonnes. This is an increase of 18,954 tonnes during 2016 and adding this to the amount of sold salmon gives a total production of 1,252,573 tonnes in Norway in 2016. As shown in Figure 6, the amount of salmon sold in 2016 was slightly lower than the two preceding years (Directory of Fisheries, 2018).

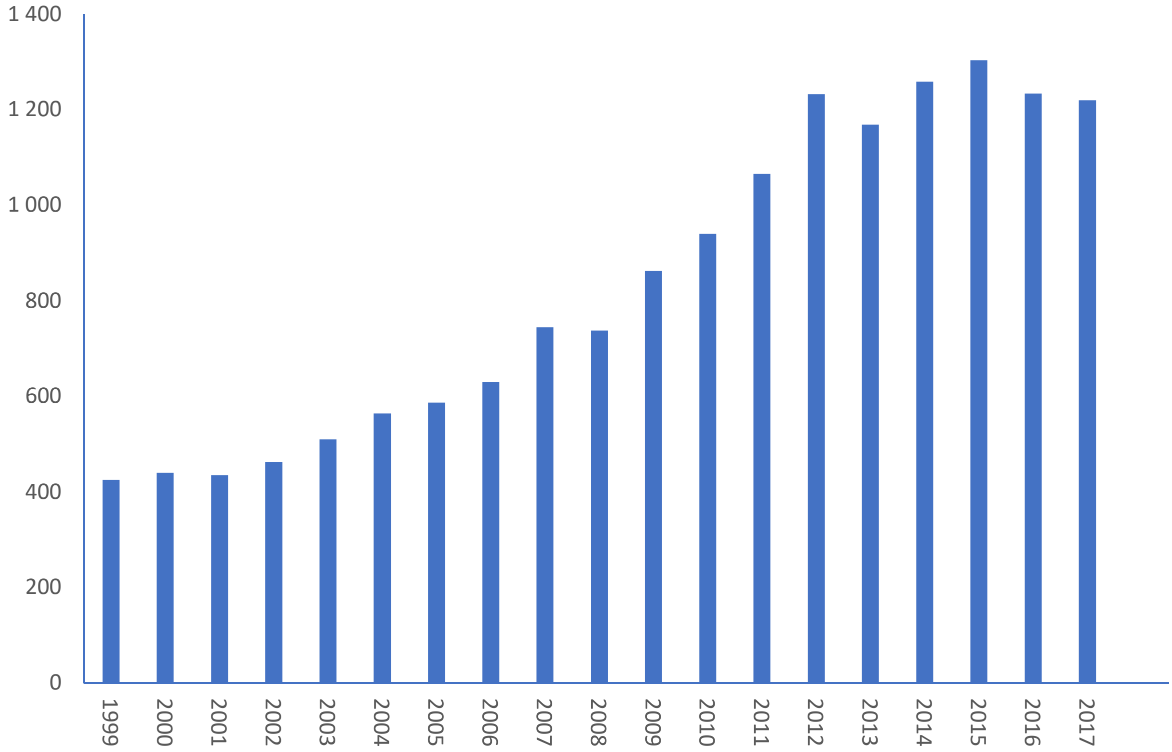


Figure 6 The annual sale of Norwegian farmed salmon (tonnes x 1000) from 1998 to 2017 (Directory of Fisheries, 2018).

5.2.2 Chemical composition of salmon

The chemical composition of whole salmon has changed over the years due to breeding, but also due to changes in feed and development of the farming systems. The composition also changes during the salmon's life cycle, during season, and varies among different geographical locations along the Norwegian coast.

Available data on chemical composition of harvest-size salmon is often measured on fillet or the NQC (Norwegian quality cut) whereas data on whole body are not available. To update the knowledge of the final product in salmon farming, and to increase the accuracy of retention calculations, salmon of average harvest size was analyzed.

For a representative selection of sample, salmon of similar size (range 4930-5690 g) was collected from processing plants in the southern (Sotra, Hordaland), mid (Hitra, Trøndelag) and northern (Alta, Finnmark) part of the Norwegian coast. Ten fish were collected at each sampling (N=90; Table 4).

Table 4 Time (date) for sampling of salmon of harvest size (n=10) for whole body analysis.

	Region	Sampling date
Spring	South	25.04.2017
	Mid	20.04.2017
	North	03.05.2017
Summer	South	24.08.2017
	Mid	16.08.2017
	North	29.08.2017
Autumn	South	16.11.2017
	Mid	30.11.2017
	North	23.11.2017

Body weight and fork length of the sampled salmon were registered (Table 5). Individual data on body weight, body length and condition factor were tested with ANOVA and Duncan's multiple range test with time of year as class variable. (All statistical analyses were carried out with SAS computer software, SAS1985, SAS Institute Inc, Cary, USA.) Since salmon were sampled with similar body weight, there were no significant differences in body weight. However, the body length in summer was significantly longer than in spring and autumn, and the corresponding condition factor was lowest in summer.

Table 5 Body weight, body length and condition factor of salmon of harvest size sampled in spring, summer and autumn. For each sampling point, 10 fish were sampled in outh, mid and north of Norway. Data are given as mean ± SEM (n=30, N=90).

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

[1] Condition factor = 100*body weight (g)/fork length^3 (cm)

[a, b] Significant differences within a column are indicated with different letters

The sampled salmon was transported to Sunndalsøra and stored at -20 ˚C. The frozen fish was cut into slices with a meat saw and homogenized with a meat grinder. The homogenized material from the 10 salmon from each sampling point was pooled into one sample and stored at -20 ˚C until freeze drying prior to chemical analysis.

The samples of whole salmon were analyzed for dry matter (105 ^{o}C until constant weight), ash (five hours at 550 ^{o}C), gross energy (Parr 1271 Bomb calorimeter) crude lipid (SOXTEC hydrolyzing and extraction systems), nitrogen (Kjeltec Auto System, Tecator, Höganäs, Sweden) and minerals (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; Table 6).

Amino acids were analyzed with a Biochrom 30 amino acid analyzer (Biochrom Cambridge, UK). Tryptofan 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 and aspargine are converted to glutamic acid and aspartic acid, respectively. Therefore, Gln+Glu are given as Glx, and Asn+Asp as Asx (Table 7).

There were no significant differences in proximate composition, whereas there were some significant differences in mineral concentration during the year (Table 6). Concentrations of manganese and sodium were higher in spring and summer. For amino acids (Table 7), the only significant difference among concentrations in whole body was found in phenylalanine, which was higher in spring than in autumn, and with intermediate levels in summer.

There were also small differences in fatty acid composition in whole body of salmon sampled at different times throughout the year (Table 8). The fatty acid composition of salmon reflects that of the feed, and the variations present may be due to differences in the feeds used rather than time of year itself.

Table 6 *Chemical analysis of dry matter, energy, ash, lipid, nitrogen, and selected minerals in harvest-size salmon sampled in spring, summer and autumn. For each sampling point, 10 fish were sampled in south, mid and north of Norway, and each analyzed sample was analyzed as a pooled sample of the 10 salmon. Data are given as mean ± SEM, 'as is', n=3, N=9.*

	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

*Trend, 0.05<P<0.1

[a, b] Significant differences within a column are indicated with different letters

Table 7 *Chemical analysis of amino acids in harvest-size salmon sampled in spring, summer and autumn. For each sampling point, 10 fish were sampled at south, mid and north of Norway, and each sample was analyzed as a pooled sample of the 10 salmon. Amino acids are given as dehydrated residuals, % 'as is'. Data are given as mean ± SEM, n=3, N=9.*

	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

[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

[a, b] Significant differences within a column are indicated with different letters

Table 8 *Chemical analysis of fatty acids in harvest-size salmon sampled in spring, summer and autumn. For each sampling point, 10 fish were sampled at south, mid and north of Norway, and each sample was analyzed as a pooled sample of the 10 salmon. The n-3 fatty acids are shaded. Data are given as mean ± SEM, 'as is', n=3, N=9.*

	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

5.2.3 Nutrient content in salmon produced in 2016

The estimated total amount of dry matter, energy, crude lipids, EPA, DHA, crude protein and phosphorus in whole salmon, salmon fillet and trimmings in salmon produced in Norway in 2016 is shown in Table 9. The data are calculated from analyzed composition of whole salmon (Table 6 - Table 8), public data on nutrient content in salmon fillet (SeafoodData, data for 2017 if available), the total salmon production in 2016 (1,252,573 tonnes) and an assumption of 65 % of the salmon is edible. Fillet yield, and thus edible part, varies with several factors such as fish size, condition factor and filleting technology. There are to our knowledge no data on this that represent all salmon produced in Norway today, and the figure 65 % for the edible part is used as an assumption.

Chemical analysis of whole body (sampled and analyzed in the project) and fillet (composition given by Seafood Data) is performed on different samples, collected with different sampling regimes. Furthermore, the feed data is collected for 2016, whereas the sampled salmon was produced also from feed in 2016 but was sampled in 2017. There may thus be discrepancies in the data.

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 production.

	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
Ratio *n*-3:*n*-6	1.07	1.04	-	-	-
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 Table 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 salmon fillet production 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

Compared to 2010 and 2012, whole salmon contained similar levels of energy, protein and lipids in 2016 (Figure 7). 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.

Except for blood, the total amount of offal from salmon slaughtered in Norway is processed further (Richardsen *et al.*, 2017), either by silage or hydrolysis into protein products or oils that are used in feeds, pet food or for human consumption (Aspevik, 2016, Aspevik *et al.*, 2016a, Aspevik *et al.*, 2017, Aspevik *et al.*, 2016b).

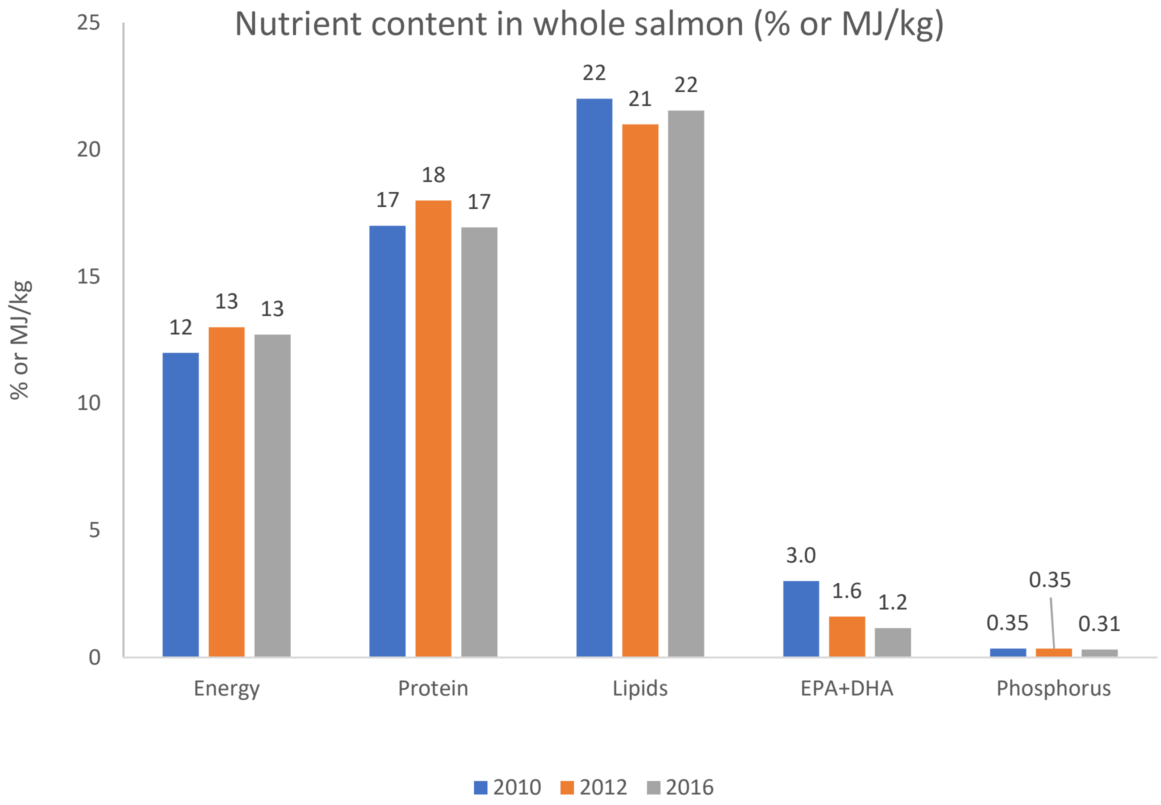


Figure 7 Nutrient content in whole salmon produced in Norway in 2010, 2012 and 2016.

5.3 Efficiency of utilization of feed ingredients

The efficiency of the utilization of feed ingredients and nutrients is important for estimation of the sustainability of all animal production systems, including salmon farming, and for evaluation of how well feed resources are managed. There are several ways to express feed utilization, which all measure different factors and with different accuracy.

5.3.1 Feed conversion ratio (FCR)

The simplest way to express feed utilization is by the feed conversion ratio (FCR), which is simply the ratio between feed eaten and salmon produced. When using 'feed used' in the calculation, i.e. including uneaten feed, the ratio is termed the economic feed conversion ratio, eFCR:

$$\text{eFCR} = \frac{\text{Feed used (tonnes)}}{\text{Salmon produced (tonnes)}}$$

Equation 1

Calculated from the 1,627,478 tonnes (as is) of feed ingredients used in 2016 and the 1,252,573 tonnes of salmon produced (harvested and increased biomass), the FCR in Norwegian salmon farming in 2016 was 1.30. Using the dry matter value for feed ingredients (1,520,358 tonnes dry matter), the FCR was 1.21. According to official statistics, 1,543,000 tonnes of salmon feed was traded in 2016, resulting in an FCR of 1.23.

The economic FCR in 2016 (1.30, based on feed ingredients, as is) was approximately the same as in 2012 (1.29) and somewhat lower than in 2010 (1.38; Figure 8).

FCR is a commonly used measure of feed utilization both in controlled trial and in larger productions. The FCR calculated above includes all losses and expresses the feed utilization in the total Norwegian salmon farming industry over one year (2016) and should not be compared to FCR-values obtained in controlled studies or productions of limited duration or scale.

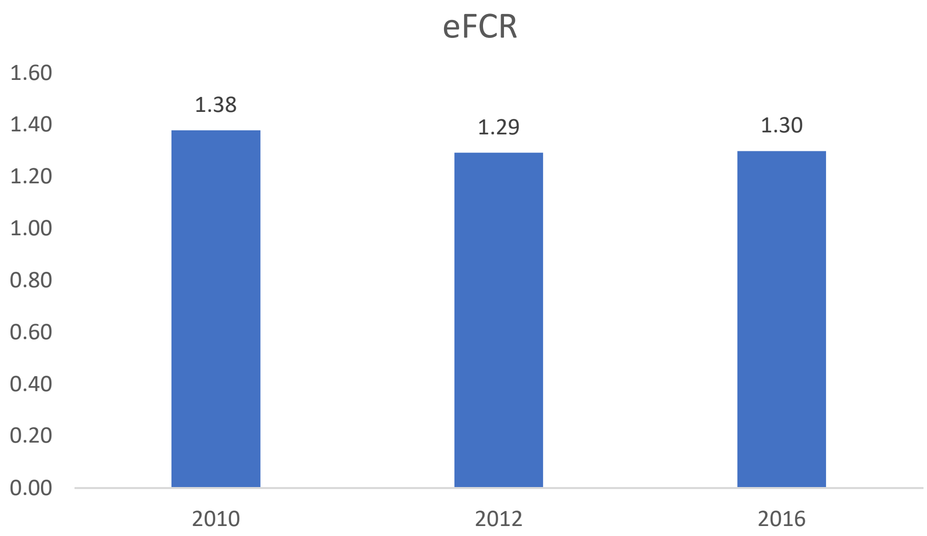


Figure 8 Economic FCR in Norwegian salmon production in 2010, 2012 and 2016.

5.3.2 Retention of energy and nutrients in Norwegian farmed salmon

The amount (%) of nutrients and energy from feed that is retained in the salmon was calculated as

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

Equation 2

Retention is calculated from data for total use of feed ingredients and total salmon production during one year. However, the production cycle of salmon is more than one year, and the accuracy of the estimation assumes a constant feed use and salmon production over a few years.

These retention data include all losses of feed ingredients, feed and salmon (mortality and escapees), and poor or failed productions of both feed and salmon. The data show the retention of nutrients and energy of the whole Norwegian salmon farming industry in 2016, and the term 'resource economic retention' could be used for the retention estimates. These retention data should not be compared directly to values from controlled trials or single productions of salmon or other species which is reported in the literature.

The estimated values for lipids, EPA and DHA includes the salmon's own synthesis of these compounds. Fatty acids can be synthesized from non-lipid precursors and 'retention' is therefore not a strictly correct term for lipids. For simplicity, it is still used here since it shows the net flow of these compounds from feed to salmon fillet.

The estimated retention of nutrients and energy is shown in Table 10. Carbohydrates are not included in the table due to lack of data. Most of the carbohydrates from feed will either be transformed to lipid or end up as not retained energy.

Comparison of retentions from 2010, 2012 and 2016 in whole salmon and in fillet is shown in Figure 9.

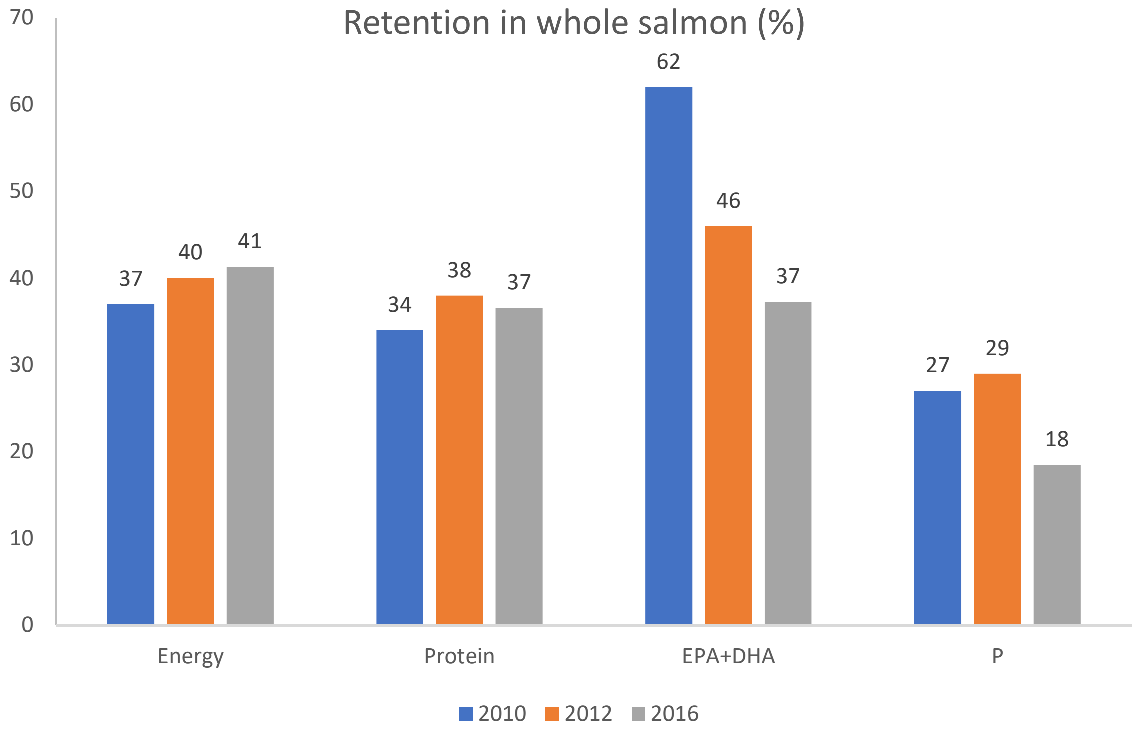
Table 10 Retention (%) of nutrients and energy in whole body, fillet and trimmings of salmon, and not retained (lost) nutrients and energy in Norwegian salmon production in 2016.

	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	23	14	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



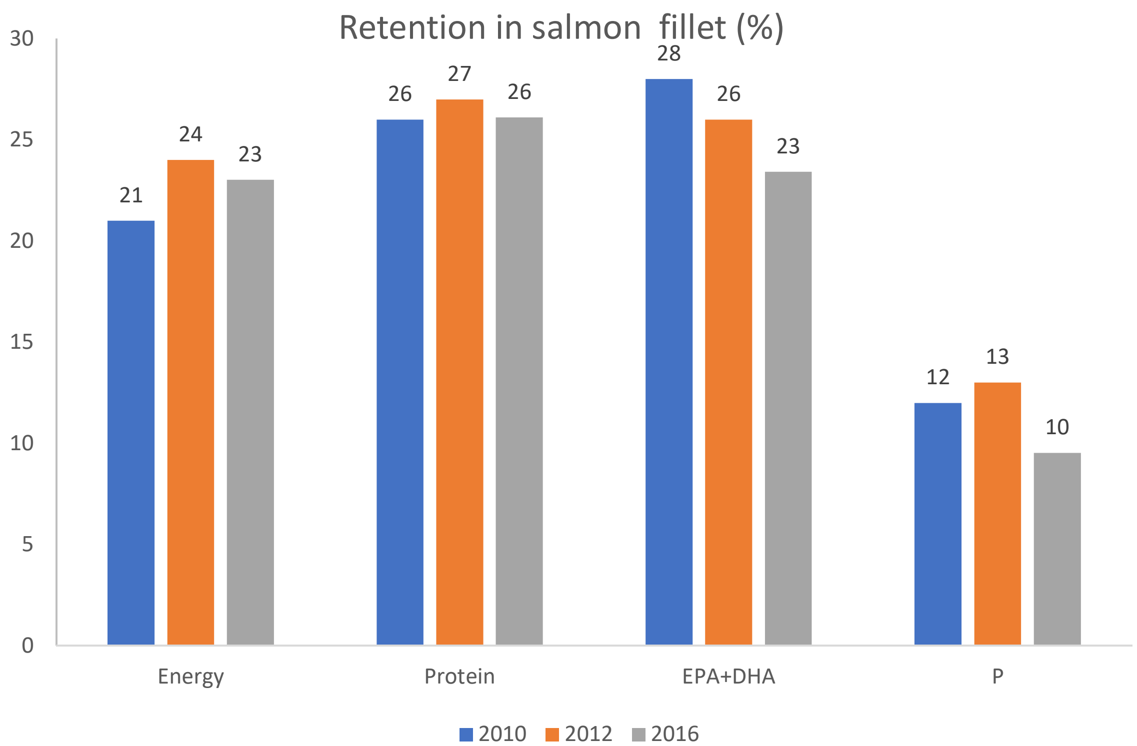


Figure 9 *Retention of nutrients (% of content in feed ingredients) in fillet and whole salmon produced in Norway in 2010, 2012 and 2016.*

In fish nutrition, 'retention' commonly refers to the calculation above (Equation 2) but is also used as a general term for any calculation of energy or nutrient utilization from feed into food product. One other common estimate of protein utilization is the protein efficiency ratio (PER), which is the ratio between weight increase (growth) and amount of protein used in feed:

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

Equation 3

The corresponding formula can be used to calculate lipid efficiency ratio (LER) and energy efficiency ratio (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. For fillet, the PER, LER and EER was estimated to 1.4, 1.5 and 2.1, respectively.

Figure 10 PER, LER and EER of whole salmon (upper panel) and salmon fillet (lower panel) produced in Norway in 2010, 2012 and 2016.

5.3.3 Dependency on marine feed ingredients

Fish in fish out

One indicator often used for utilization of marine ingredients for production of salmon is the Fish-In-Fish-Out-ratio (FIFO). This is a measure of the amount of wild fish used (kg) to produce one kg of farmed salmon without taking nutrient concentration into consideration. The amount of fish meal (FM) and fish oil (FO) produced from one kg of forage fish is different, as is the amount of fish meal and fish oil in salmon feed. Thus, the FIFO is estimated for fish meal and fish oil separately. The calculation of FIFO is based on two conversion ratios: 1) 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 turned into 235 to 245 g of fish meal and 50-120 g of fish oil (IFFO, 2010, Péron *et al.*, 2010, Jackson, 2009). The variation in lipid content in fish is larger than in protein content. In the following calculation, 240 g fish meal and 93 g fish oil per kg forage fish was assumed. 2) The economic feed conversion ratio (eFCR) which is the ratio between feed used and salmon produced (tonnes). In this case, the total use of feed ingredients was used as a measure of feed consumption, which resulted in an eFCR of 1.30 in Norwegian salmon farming in 2016.

$$\text{FIFO}_{(\text{FM or FO})} = \left[\frac{\text{FM or FO in feed (g/kg)}}{\text{FM or FO reduction efficiency (g/kg)}}\right] \cdot \text{eFCR}$$

Equation 4

Equation 4 can be simplified:

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

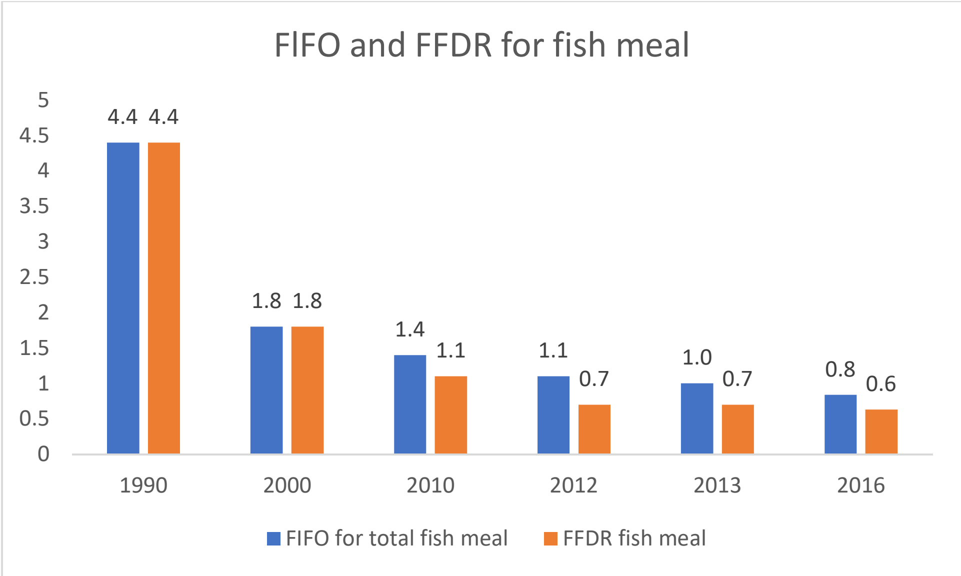
Equation 5

The FIFO for total fish meal and fish oil in Norwegian salmon farming in 2016 was estimated to 0.79 and 1.45, respectively. The FIFO has been considerably reduced since 1990 when salmon feed was mainly based on fish meal and fish oil, and the FIFO for both fish meal and fish oil was lower in 2016 than in the previous measurements (Figure 11).

In the calculation above, fish meal and fish oil produced from offal is included. The corresponding ratio, but without offal is expressed in the forage fish dependency ratio.

Forage fish dependency ratio (FFDR)

The forage fish dependency ratio (FFDR) is equally as the FIFO (Equation 4), but only fish meal and fish oil produced from forage fish are included. This resulted in FFDR of 0.63 and 1.09 for fish meal and fish oil, respectively. Whereas fish meal earlier was mainly produced from forage fish, the increasing use of offal is reflected in a difference between FIFO and FFDR for both fish meal and fish oil the last decade (Figure 11).



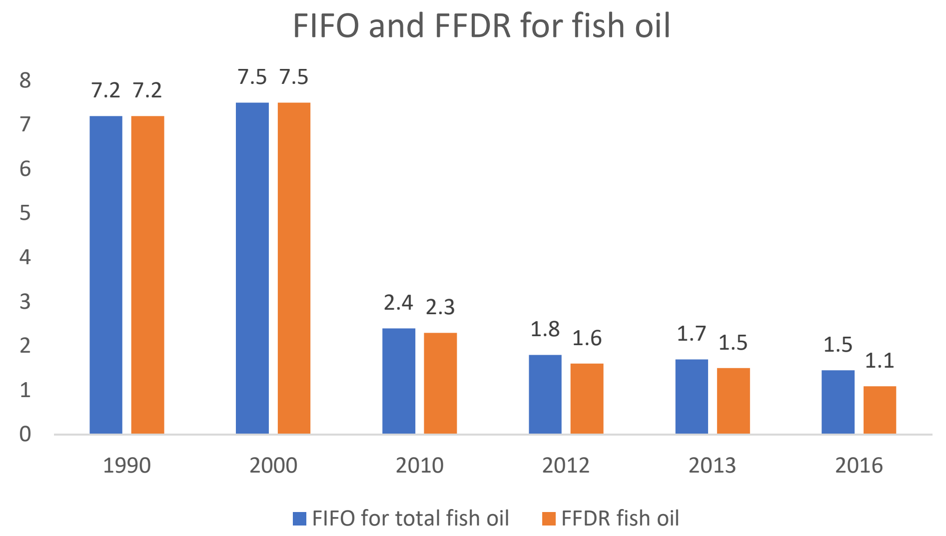


Figure 11 Estimated FIFO and FFDR of fish meal and fish oil in Norwegian salmon farming in 1990, 2000, 2010, 2012, 2013 and 2016.

Marine nutrient dependency

Another suggested measure of dependency of marine ingredients is the marine nutrient dependency ratios (MNDPs). The marine protein dependency ratio (MPDR) is the ratio between protein of marine origin in feed and protein in the salmon produced, and the corresponding ratio for oil is the marine oil dependency ratio (MODR).

$$\text{MPDR} = \frac{\%\ \text{marine protein source in feed} \cdot \%\ \text{protein in marine protein source} \cdot \text{kg feed eaten}}{(\text{final body weight} \cdot \%\ \text{body protein}) - (\text{initial body weight} \cdot \%\ \text{body protein})}$$

Equation 6

$$\text{MODR} = \frac{[\%\text{ marine oil in feed} + (\%\text{ marine protein source in feed} \cdot \%\text{ oil in marine protein source})] \cdot \text{kg feed eaten}}{(\text{final body weight} \cdot \%\text{ body fat}) - (\text{initial body weight} \cdot \%\text{ body fat})}$$

Equation 7

Equation 6 and Equation 7 can be simplified:

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

Equation 8

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

Equation 9

Data for average amount of protein and oil in marine protein sources (fish meal) was calculated from the composition given by the feed manufacturers. The total amount of fish meal contained 66.6 % protein and 10.3 % oil. In fish meal produced from forage fish, the content of protein and oil was 68.2 % and 10.7 %, respectively. The analyzed values of crude protein (Nx6.25) and fat in whole body of salmon was 16.9 % and 21.5 %, respectively (Table 6).

When calculated for the total amount of fish meal and fish oil used, the MPDR in Norwegian salmon farming in 2016 was 0.75 and the MODR was 0.72. When only including fish meal and fish oil produced from forage fish in the calculation, the MPDR and MODR was 0.61 and 0.55, respectively. The MPDR for forage fish was slightly lower than in 2013, whereas MODR was unchanged (Figure 12).

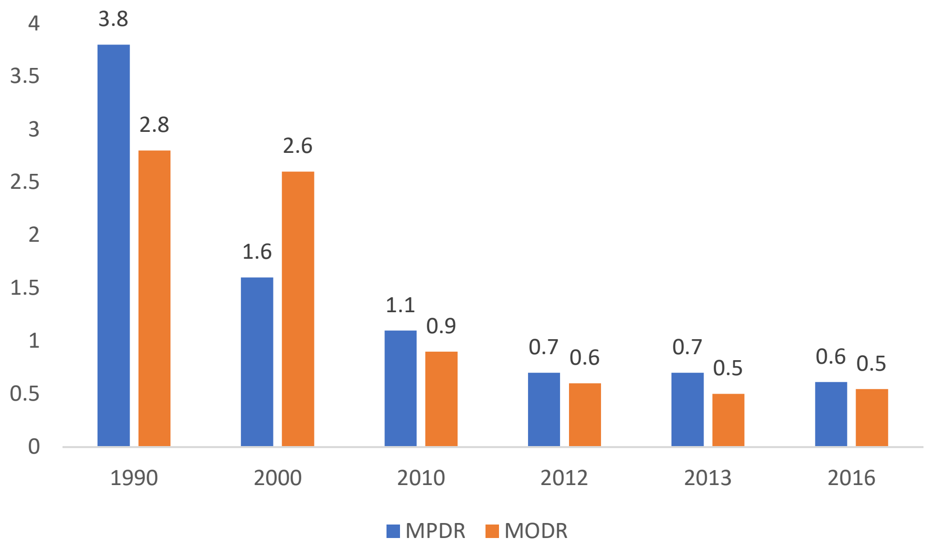


Figure 12 MPDR and MODR from forage fish in Norwegian salmon farming in 1990, 2000, 2010, 2012, 2013 and 2016.

5.4 Concluding remarks

The utilization of feed resources in Norwegian salmon farming is in this report updated with figures from 2016. Overall, there are small changes compared to 2012 both regarding total volumes and the feed ingredients used. However, the use of marine protein sources has been further reduced and is replaced by plant ingredients.

Indices for dependency of marine ingredients are often used in evaluation of sustainability. However, reduction in marine ingredients must be replaced by other ingredients, and whether ingredients are of marine or other origin is not itself a measure of sustainability. The sustainability of a food production system depends on optimal use of all feed resources, and how the feed resources themselves are produced. This report is meant as a documentation of the status of use of feed resources in Norwegian salmon farming and is meant to be a tool for the industry and authorities to plan and improve the salmon farming. Besides, it provides information sought for by media and consumers.

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7 Leveranser

6.4.2017 Skypemøte med referansegruppe

19.4.2017 Skypemøte med referansegruppe

13.9.2018 Skypemøte med referansegruppe

9.1.2019 Skypemøte med referansegruppe

Muntlig presentasjon på internasjonal konferanse:

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Poster på internasjonal konferanse:

Åsgård, T., Aas, T.S., Ytrestøyl, T. (2018) Whole body proximate, amino acid, fatty acid and elemental composition of Atlantic salmon (*Salmo salar*) at harvest size from commercial farming in Norway. ISFNF 2018. International Symposium on Fish Nutrition and Feeding, 3.-7. juni 2018, Las Palmas, Gran Canaria.

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Aas, T.S., Åsgård, T., Ytrestøyl, T. (2018) Fôrressurser og deres utnyttelse i norsk lakseoppdrett. Nfexpert nr. 2 2018, s. 40-41.

Faglig sluttrapport (denne)

PowerPoint-presentasjon med hovedfunn/resultater fra arbeidet

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