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Utilization of feed resources in the production of rainbow trout (*Oncorhynchus mykiss*) in Norway in 2020

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ABSTRACT

The utilization of feed resources in Norwegian farming of Atlantic salmon has been reported for 2010, 2012, 2016 and 2020. The present paper is a corresponding documentation for farming of rainbow trout in Norway in 2020. 89,667 tonnes of rainbow trout were produced, which is 6 % of the amount of salmon produced. The 116,990 tonnes of ingredients used for feed sold as trout feed were produced from 13.4 % marine protein sources, 10.8 marine oils, 39.7 % vegetable protein sources, 19.9 % vegetable oils, 12.1 % carbohydrate sources and 3.9 % micro ingredients, which include vitamin and mineral premixes, crystalline amino acids and astaxanthin. In addition, was 0.2 %, or 257 tonnes, of single cell protein, insect meal, fermented products and microalgae used in trout feed. Norwegian fish meal and fish oil constituted 8.8 % of the ingredients, and the remaining 91.2 % were imported ingredients. The economic feed conversion factor (FCR) was 1.30, 1.21 or 1.44 if calculated from feed ingredients 'as is', feed ingredients on dry matter basis, or from registered traded feed, respectively. The trout retained 37 %, 43 %, 33 %, 63 % and 63 % of the feed's dry matter, energy, protein, fat and EPA+DHA, respectively, in the whole body. In fillet, the corresponding retention values were 21 %, 25 %, 23 %, 34 % and 35 %, respectively. The feed utilization in trout was slightly overestimated because of some salmon feed used in the trout production. The feed ingredients used and the feed utilization in trout farming in 2020 were similar to the data for salmon farming, but trout is produced in a smaller quantity.

1. Introduction

In Norwegian aquaculture, Atlantic salmon has become the dominating species, whereas modern, commercial fish farming in Norway started with rainbow trout. Farming of fish has ancient traditions which go back maybe 5000 years in Asia, and more than thousand years in Europe, often with wild-caught fish of freshwater species kept in ponds. In Europe, the monasteries contributed to the development of farming fish for human consumption. The first 'in vitro' fertilization and hatching of trout is assumed to be done by the German Stephan Ludwig Jacoby in the 18th century. In Norway, the first hatchery started production of fry of salmonids for releasing into rivers and lakes in the 1850 s. In the beginning of 1900 s, Norwegian farming of rainbow trout for food consumption started with fish imported from Denmark, kept in ponds in fresh water. Few years later, feeding of rainbow trout in sea was attempted, but failed. The farming of rainbow trout evolved in Europe however, and in the 1950 s, new attempts were made in Norway. Among the early pioneers were the brothers Karstein and Olav Vik who studied the whole life cycle of salmonids and showed that rainbow trout could be kept in seawater throughout the grow-out phase. I the 1960 s there were several trout farms in Norway using seawater, first on land by pumping water from the sea, and later in enclosures and sea cages. The development also went form plate-sized fish in the 1950 s to production of larger fish in the 1960 s. The aquaculture feed was initially chopped fish or fish cut-offs, shrimp waste and shrimps. (Information on history is adapted from Edwards, 1978; Gjedrem, 1993; Jensen, 1968; Osland, 1990).

The early 1970 s was the start of a fast-growing aquaculture industry in Norway. The first fish farmers in modern Norwegian aquaculture were pioneers with a bold entrepreneurship approach, and in the beginning, the aquaculture industry was developed by trial and error. Research and selective breeding started in the 1960 s. The aquaculture industry has grown continuously and is now a main industry in Norway. With rainbow trout as the main species initially, the first farmed salmon was slaughtered in 1971. In 1976, the amount of salmon and trout were 1431 and 2045 tonnes, respectively (Statistics Norway, 2019). In 1977,

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the salmon production (2137 tonnes) exceeded the trout production (1795 tonnes) for the first time, and since then Atlantic salmon has dominated in Norwegian aquaculture (Fig. 1). In 2020, the amount of sold salmon and trout was 1377,185 and 96,633 tonnes, respectively (Directory Of Fisheries, 2021). Rainbow trout is still an important farmed species in 2022, and the second largest aquaculture species in Norway.

Fish farming, as all animal farming, depends on feed with adequate composition to cover the animals' nutrient requirements. The ingredients for large scale feed production are traded on a global market. Availability and price of various ingredients for feeds and food change co-dependently on each other. Consumer expectations and climate changes may affect the choice of ingredients over time, whereas conflicts and yearly variations in weather conditions may lead to rapid changes in availability and price of feed ingredients. Rainbow trout depends on high quality feed with a high content of digestible protein, fat, and energy, and thus depends on high quality feed ingredients with high nutrient and energy density. Evaluation and further improvement of the utilization of the feed resources depend on detailed knowledge on the feed ingredients used and the fish produced.

Rainbow trout and Atlantic salmon have similar nutritional requirements (National Research Council, 2011). Some trout farmers even use salmon feed in the production of trout. The amount of trout produced in Norway is small compared to the salmon production, but documentation of the utilization of feed ingredients is still a prerequisite for increasing the sustainability of the production.

The utilization of feed ingredients in Norwegian salmon farming during one year has been documented for Atlantic salmon multiple times and was last updated for 2020 as part of the present study (Aas et al., 2019, 2022a; Ytrestøyl et al., 2015). Feed utilization, methods and indices for measurement of feed utilization, and sustainability aspects are discussed further in those papers. The present study is a corresponding documentation of the utilization of feed resources in Norwegian farming of rainbow trout in 2020. Data on amount, composition, origin and certification of the feed ingredients were collected, as well as amount of trout produced. The chemical composition of whole body and fillet of trout is published separately (Aas et al., 2022b).

2. Materials and methods

The data were collected and processed, and the results given, in the same way as has been described for the corresponding documentations of Norwegian salmon production (Aas et al., 2019, 2022a; Ytrestøyl et al., 2015). The methods, calculations and indices are discussed further in these papers.

2.1. Data on feed ingredients

There are three large producers of trout feed in Norway, namely BioMar, Cargill and Skretting, which provided data on all ingredients used for trout feed in 2020. Data on amount and chemical composition of each ingredient were used for calculations on feed utilization. In addition, information on origin and certification was provided. For a few ingredient batches, complete data on composition were not given. For such ingredients, the corresponding data from the other feed producers, or literature data, were used instead.

2.2. Chemical composition of whole body and fillet

The body composition of rainbow trout varies with body weight, time of year, geography, feed intake and feed composition. Trout for analysis of whole body and fillet was collected to achieve samples representative for all farmed trout slaughtered in Norway in 2020. Trout was sampled at early summer and early winter, and at the northern and southern part of the main area of trout production in Norway. At each sampling, ten fish were collected for whole body analysis and ten fish for fillet analysis. The ten individuals from each sampling were pooled to one sample, giving in total four samples for whole body analysis and four for fillet analysis. The sampling is described in more detail, and the chemical data on chemical composition, are shown in Aas et al. (2022b).

2.3. Calculations

The calculations of feed utilization reflect the utilization of feed resources in the whole trout farming industry in Norway during one year. All losses of feed ingredients, feed and trout are included. The data should therefore not be compared directly to the corresponding data obtained in controlled studies or successful productions of short duration, although some of the same calculations and indices are used. The calculations are discussed by Ytrestøyl et al. (2015) and Aas et al., (2019, 2022a).

FM = fish meal, FO = fish oil.

Economic feed conversion ratio, $\text{eFCR} = \frac{\text{Feed used (tonnes)}}{\text{Trout produced (tonnes)}}$

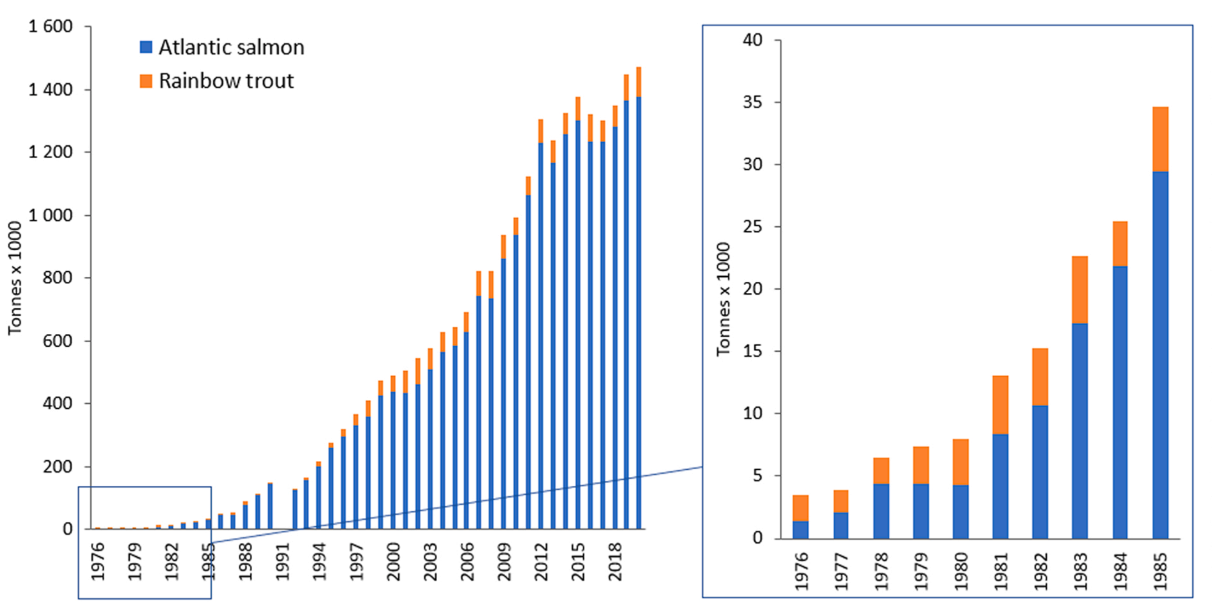

Fig. 1. Annual sale of farmed Atlantic salmon and rainbow trout in Norway in 1976–2020 (Directory Of Fisheries, 2021; Statistics Norway, 2019).

$$\text{Retention (\%)} = 100 \bullet \frac{\text{Amount of nutrient or energy incorporated in trout}}{\text{Amount of nutrient or energy in the feed used}}$$

The retention of lipid includes lipids synthesized by the fish.

$$\text{Protein efficiency ratio, PER} = \frac{\text{Trout produced (tonnes)}}{\text{Protein in feed (tonnes)}}$$

The lipid efficiency ratio (LER) and the energy efficiency ratio (EER) were calculated with the corresponding formulae as PER.

$$\text{Fish-in-fish-out ratio, } \text{FIFO}_{(\text{FM or FO})} = 100 \bullet \frac{\left(\frac{\text{FM or FO used in feed (tonnes)}}{\text{Yield in production of FM or FO (\%)}}\right)}{\text{Trout produced (tonnes)}}$$

The yield is different in production of fish meal and fish oil, and the amount of fish meal and fish oil in the feed is different. The FIFO for fish meal and fish oil is therefore different, and FIFO is therefore calculated separately for fish meal and fish oil.

22.5 % yield was assumed in production of fish meal from cut-offs, and 24 % for forage fish. The average yield in production of fish oil was estimated to be 7.6 % (Aas et al., 2022a).

Forage fish dependency ratio (FFDR) is calculated as FIFO, but only including FM and FO produced from forage fish.

$$\text{Marine protein dependency ratio, MPDR} = \frac{\text{FM used (tonnes)} \bullet \text{Potein in FM (\%)}}{\text{Trout produced (tonnes). Protein in trout (\%)}}$$

$$\text{Marine oil dependency ratio, MODR} = \frac{\text{FO used (tonnes)} + [\text{FM used (tonnes)} \bullet \text{Fat in FM (\%)}]}{\text{Trout produced (tonnes). Fat in trout (\%)}}$$

3. Results and discussion

Whereas the utilization of feed resources in Norwegian salmon farming has been documented several times the last decade (Aas et al., 2019, 2022a; Ytrestøyl et al., 2015), the corresponding documentation of trout farming has not been done previously. Rainbow trout and Atlantic salmon are both salmonids with very similar nutritional requirements. But there is a difference in body composition, the trout being higher in fat content, and a corresponding difference between the two species in the utilization of energy and macro nutrients.

Rainbow trout has a higher feed intake than Atlantic salmon, which to a larger extent reduces feed intake as a response to stress (Madaro et al., 2015; Skretting, 2012). Regulations, technology and routines are similar in farming of the two species. But in periods with stress, such as handling, delousing, suboptimal temperature or outbreak of disease, the feed intake in salmon may drop temporarily. As feed intake affects the feed utilization (Einen et al., 1999; Grisdale-Helland et al., 2013), these situations may influence the overall feed utilization differently for the two species.

Salmon feed and trout feed are practically the same, and an unknown amount of salmon feed is used for trout production. Salmon and trout are not produced at the same locations. Use of salmon feed in trout production is due to some farmer's preferences as feeds for the two species are practically the same. The use of salmon feed for trout farming, results in an underestimation of the feed utilization of the salmon, and an overestimation for trout. We have no information on the opposite, that trout feed is used for salmon. The amount of trout produced is 6 % of the salmon production, and for salmon, the error caused by some feed used for trout is negligible. For the trout production however, use of salmon feed may give a noticeable bias in the data. The feed utilization is therefore calculated both for trout alone, and in sum for the two species. In some contexts, data given for the two species as a sum will give the most correct data.

Data on feed utilization of a whole farming industry on national level for a whole year include all losses. Discarded feed ingredients or feed batches, outbreak of disease, escapees and mortality are all included in the data.

The trout feed was very similar to the salmon feed produced in 2020, and certain aspects on ingredients and resource utilization are discussed in the corresponding documentation for salmon farming in 2020 (Aas et al., 2022a).

3.1. Feed ingredients

In 2020, a total amount of 116.990 tonnes of feed ingredients ('as is') were used for production of trout feed in Norway. For comparison, this amounts to 5.9 % of the 1976,709 tonnes used for salmon feed in 2020 (Aas et al., 2022a). The trout feed was produced from 13.4 % marine protein sources, 10.8 % marine oils, 39.7 % vegetable protein sources, 19.9 % vegetable oils, 12.1 % carbohydrate sources, 3.9 % micro ingredients and 0.2 % of insect meal, single cell protein, fermented products, and microalgae, classified as 'other' (Fig. 2.). Micro ingredients include vitamin and mineral premixes, phosphorus sources, crystalline amino acids and astaxanthin. A total of 28,364 tonnes of marine ingredients were used (24.2 % of the ingredients), of which 74 % were from forage fish and 26 % from cut-offs. In this study, the term 'cut-offs' include all offal from processing of fish. The sources of ingredients used for trout feed in 2020 (Fig. 1., Table 1) was very similar to the data reported for salmon feed (Aas et al., 2022a) when given as percentage of the feed. It is common practice that the feed producer formulates the feed according to specifications given by the farmer. The small differences found between trout feed and salmon feed may reflect small differences in the farmers' preferences.

Historically, trout feed has had a different development that salmon feed. High inclusion of vegetables was used early for trout. In 1985, a standard trout feed was produced from 30 % fish meal, 30 % soybean meal, 26 % carbohydrate sources, 11 % fish oil and 3 % micro ingredients. A more expensive trout feed was produced from 40 % fish meal, 17 % soybean meal, 27.2 % carbohydrate sources, 11.5 % fish oil and 4.3 % micro ingredients (Skretting, 1984). Trout feeds were produced by cold pelleting. At the same time, salmon feed contained no soybean meal, and was produced mainly from marine ingredients (Skretting, 1984), by using extrusion technology. After this, there was a shift in feeds used for trout, which became more similar to salmon feeds.

The ingredients used were also similar to the ingredients used in salmon feed in 2016 (Aas et al., 2019), indicating minor changes in the use of feed ingredients during the last few years. Various products of single cell protein have a long history of research and use as feed ingredients (Aas et al., 2006; Agboola et al., 2020; Jones et al., 2020; Sharif et al., 2021). The research on such products along with e.g. insect meal and microalgae has been intensified recently, but the use is still moderate. The inclusion of these ingredients was 0.2 % of the total ingredients in Norwegian trout feed in 2020. In general, high cost and moderate production volumes are the main limitations for use of these products. The COVID-19 pandemic strongly affected the global supply and logistics of all types of goods in 2020. The war in Ukraine is expected to cause severe shortage in the world's supply of food and feed, accompanied with high prices. The present situation may force a rapid change in ingredient composition of feeds, and untraditional ingredients may be used to a larger extent. Several categories of ingredients, such as single cell organisms, lower trophic marine organisms, blue mussels, micro algae and insect larvae have been evaluated (Albrektsen et al., 2022; Almås et al., 2020; Eidem and Melås, 2021) and may be used in increased quantities in near future. Some aspects related to the ingredients are discussed further by Aas et al. (2022a).

3.1.1. Origin of ingredients

The origin of the ingredients is shown in Table 2. The origin was reported for all ingredients but 125 tonnes of marine oil. For marine ingredients, the origin was reported as FAO's major fishing areas (https://www.fao.org/fishery/en/area/search). The origin of vegetable ingredients was given as geographic area. The origin of micro ingredients is not reported. Micro ingredients may be produced on the lab in one country with resources originating from other parts of the world and revealing the true origin of such resources was behind the scope of this study. The marine ingredients produced from cut-offs originated to a large extent from FAO fishing area number 27, which includes the North Atlantic and the Norwegian coastline. The Norwegian feed ingredients

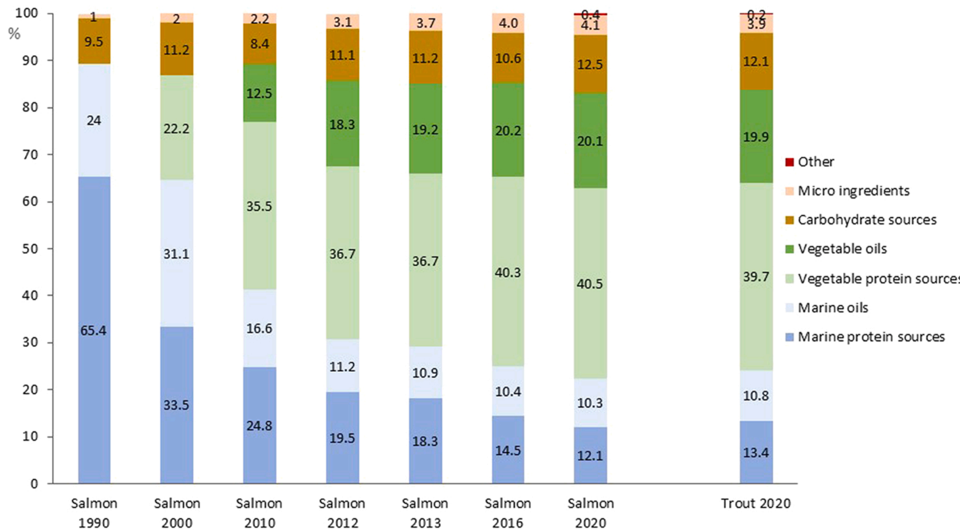

Fig. 2. Sources of feed ingredients (% of feed) in Norwegian trout feed in 2020 (at right), compared to data for salmon feed from 1990 to 2020 (Aas et al., 2019, 2022a; Ytrestøyl et al., 2015).

Table 1
Ingredients used in Norwegian trout feed in 2020, given as tonnes and % 'as is'.

	Ingredient	Tonnes	%
Vegetable protein sources	Soy protein concentrate	23,458	20.1
	Wheat gluten	11,413	9.8
	Guar protein	6018	5.1
	Sunflower	3837	3.3
	Pea protein	1686	1.4
Vegetable oils	Rapeseed oil	21,684	18.5
	Linseed oil	741	0.6
	Soybean oil	180	0.2
	Camelina oil	538	0.5
	Coconut oil	108	0.1
Carbohydrate sources	Wheat	10,002	8.5
	Faba beans	3111	2.7
	Pea flour	1070	0.9
Marine protein sources	Fish meal, forage fish[a]	11,078	9.5
	Fish meal, cut-offs	4634	4.0
Marine oils	Fish oil, forage fish	9824	8.4
	Fish oil, cut-offs	2828	2.4
Micro ingredients[b]	Micro ingredients	4522	3.9
Other[c]	Other	257	0.2
	Sum	**116,990**	**100**

[a] Includes 94 tonnes of krill meal
[b] Includes vitamin- and mineral premixes, phosphorus sources, astaxanthin, crystalline amino acids
[c] Insect meal, single cell protein, fermented products, microalgae

accounted for 8.8 % of the ingredients, all of this was marine ingredients. For vegetable proteins, soy protein concentrate from Brazil was the major contributor, but Europe was also an important producer of vegetable protein, and of carbohydrate sources. Vegetable oils used in the Norwegian trout feed in 2020 was produced in Russia and Europe (Table 2).

19,256 tonnes, or 8.8 % of the ingredients, were fish meal and fish oil of Norwegian origin. The remaining 91.2 % (106,735 tonnes) of the ingredients were imported. This is similar to the data for salmon in 2020 (Aas et al., 2022a). Norwegian aquaculture thus depends heavily on import of feed ingredients. On the other hand, the major portion of the farmed fish is exported. In 2020, Norway exported 72,109 tonnes of trout (Statistics Norway, 2022), which is equivalent to 80 % of the produced rainbow trout. Similarly, was 78 % of the salmon produced in 2020 exported (Aas et al., 2022a; Statistics Norway, 2022).

3.1.2. Environmental certification of ingredients

There are several systems with different focus areas available for certifying the marine ingredients. The main part of the marine ingredients used in Norwegian trout feed in 2020 was certified by at least one standard (Table 3). Systems and routines for certification of ingredients are not as developed for vegetable ingredients on the global market. A main environmental focus area for vegetable products is deforestation. According to the feed producers, all soy protein concentrate was certified as deforestation-free (Table 3).

3.1.3. Non-GM certification of ingredients

For soy protein concentrate, 100 % was reported as certified non-GM (non-genetically modified by the Proterra and Europe Soy/Donau Soja standards (https://www.proterrafoundation.org/, http://www.donausoja.org/). The feed producers reported all ingredients to be non-GM, whether certified or not. Use of GM products in feed is restricted by Norwegian legislation.

3.1.4. Chemical composition of the feed

The average chemical composition of the feed used in Norwegian trout farming in 2020 is shown in Table 4. These data are used in the calculations on utilization of nutrients and energy from the feed. The carbohydrate fraction of feed ingredients for many ingredients was probably not analysed and characterized as thoroughly as other components of the ingredients. The precision of the data on this fraction is therefore somewhat limited. Carbohydrates, NFE (nitrogen free extract) or crude fibre given in Table 4 all include different types of carbohydrates and are given as reported by the feed producers.

3.2. Amount of rainbow trout produced

The total amount of rainbow trout produced in Norway in 2020 was estimated from 96,765 tonnes registered traded trout (Directory Of Fisheries, 2021) corrected for a decrease in 7098 tonnes of biomass during the year (47,298 tonnes 31. December 2019 and 40,200 tonnes 31. December 2020). In comparison, the estimated production of Atlantic salmon in Norway this year was 1467,655 tonnes. The amount of trout produced was 6.1 % of the amount of salmon. The amount of traded trout varies from year to year, but there is an overall trend of increasing production. The amount traded in 2020 was the largest registered amount registered (Fig. 3).

A fillet yield of 62 % was assumed for trout. This results in 55,593 tonnes of fillet, which was used as 'edible part' in the calculations.

Table 2
Origin of the ingredients used in Norwegian trout farming in 2020. The FAO numbers refer to FAO's major fishing areas (https://www.fao.org/fishery/en/area/search). The contribution of ingredients produced in Norway is included in the table. The Norwegian coast is within FAO major fishing are number 27. The systems for reporting origin are well developed for marine ingredients. For vegetable ingredients on the global market, the origin of an ingredient may not be reported accurately to the buyer.

Ingredient	Sum (tonnes)	Origin	Tonnes	Norwegian (tonnes)	Norwegian (%)
Marine protein – forage fish	**11,078**	FAO 27	10 415	3745	34
		FAO 34	2		
		FAO 48	249		
		FAO 87	411		
Marine protein - cut-offs	**4634**	FAO 27	4 634	3580	77
Marine oil – forage fish	**9824**	FAO 27	3374	1439	15
		FAO 31	2434		
		FAO 34	1482		
		FAO 37	56		
		FAO 47	10		
		FAO 51	435		
		FAO 77	795		
		FAO 87	1112		
		Undefined	125		
Marine oil - cut-offs	**2828**	FAO 27	2381	1490	53
		FAO 31	65		
		FAO 34	22		
		FAO 67	26		
		FAO 87	15		
		Farmed fish	320		
Vegetable protein	**46,401**	Europe[a]	12,958	0	0
		Russia	4176		
		China	1330		
		India	6018		
		Canada	351		
		Brazil	21,567		
Vegetable oil	**23,251**	Europe[a]	12879	0	0
		Russia	10372		
Carbohydrate sources	**14,195**	Europe[a]	14,195	0	0
Micro ingredients[b]			4522		
Other[c]		Europe[a]	2		
		USA	232		
		Brazil	24		
Total			**116,990**	**10,256**	**8.8**

[a] Europe except Russia
[b] Includes vitamin- and mineral premixes, phosphorus sources, astaxanthin, crystalline amino acids
[c] Insect meal, single cell protein, fermented products, microalgae

Table 3
Amount (%) of ingredients in Norwegian trout feed in 2020 that originated from fisheries or companies certified by different certification standards. One ingredient can be approved by several standards and the amount certified by different standards can therefore not be summed.

	Marine trust[a]	MSC[b]	Marine trust FIP[c]	MSC FIP[d]	Certified deforestation-free[e]
Fish meal from forage fish[f]	66	85			
Fish oil from forage fish	61	45	18	9	
Fish meal from cut-offs	88	88			
Fish oil from cut-offs	73	64			
Soy protein concentrate					100

[a] https://www.marin-trust.com/
[b] https://www.msc.org/
[c] https://www.marin-trust.com/programme/improver-programme/accepted-fips
[d] https://www.msc.org/for-business/fisheries/developing-world-and-small-scale-fisheries/fips
[e] https://www.proterrafoundation.org/, http://www.donausoja.org/
[f] Includes 94 tonnes of krill meal

3.3. *Efficiency of utilization of feed ingredients*

The efficiency of the utilization of the feed resources can be expressed with different calculations and indices based on the amount and composition of feed ingredients versus the amount and composition of trout produced. Some of the calculations are the same as used in feeding trials, but since the present calculations include all losses in the production for a whole national industry, they should not be compared directly with the corresponding calculations from feeding trials.

The efficiency of utilization of the feed in animal production can be quantified with various calculations, which all express different aspects of the animal's efficiency in utilization of the nutrients and energy from the feed (Fry et al., 2018a; b). Comparison among different animal productions is complicated by the different feed compositions for the different animals, the difference in products (e.g. trout fillet, milk or eggs), and the utilization of the side streams (e.g. fish oil from cut-offs used for human consumption). Different products can be compared by using a Life Cycle Analysis (LCA) which is intended to quantify the environmental impact of the various products. There are, however, also weaknesses with the LCA method (Bohnes and Laurent, 2019; Henriksson et al., 2012; Philis et al., 2019). Using a simple measure such as feed conversion ratio (FCR) provides valuable information about resource utilization, as long as interpreted thoroughly (Tlusty et al., 2018).

The calculations and indices used have also been discussed previously (Aas et al., 2019, 2022a; Ytrestøyl et al., 2015).

3.3.1. *Economic feed conversion ratio (eFCR)*

The eFCR of trout produced in Norway in 2020 was 1.30 if calculated with feed ingredients 'as is', 1.21 if calculated with feed ingredients on dry matter basis, and 1.44 if calculated with the amount of traded feed. The corresponding eFCR's of the sum of trout and salmon was 1.34, 1.25 and 1.29, respectively. This is very similar to the eFCRs for salmon alone (Aas et al., 2022a). The eFCR for trout calculated from traded feed deviated from the values obtained when using the amount of feed ingredients used. The amount of traded feed was 129.000 tonnes, which is noticeably higher than the reported amount of feed ingredients used. We do not have access to data to reveal what causes this difference. But there is a difference in dry matter content in ingredients and feed, some feed or ingredients may be discarded, and around new year, an inconsistency between traded feed and traded fish in quantities registered on the last year or the next year may cause a deviation in the registered data for one year.

3.3.2. *Retention*

The retention expresses how much of a nutrient or energy from feed is retained in the trout. In Aas et al. (2019) we suggested using the term 'resource economic retention', since the present retention data calculate the per cent of a nutrient or energy from the total amount of feed ingredients used that are found in the produced trout. This is opposed to biologic retention, using the same formula for the calculation, but measuring how much of a nutrient or energy eaten is retained in the fish. The given data on 'retention' of fat includes lipids produced by the trout from non-lipid precursors.

Table 4
Estimated average composition, the total amount of nutrients used, the amount of nutrients from marine, vegetable, micro and other ingredients in Norwegian trout feed in 2020. Other minerals than phosphorus are not given, nor is ash and micro ingredients. Energy data are given as MJ/kg or GJ.

	Average composition of Norwegian trout feed in 2020 (% or MJ/kg)	Total amount of nutrients used in Norwegian trout feed in 2020 (tonnes or GJ)	Nutrients from marine ingredients (tonnes or GJ)	Nutrients from plant ingredients (tonnes or GJ)	Nutrients from micro ingredients (tonnes or GJ)[a]	Nutrients from other ingredients (tonnes or GJ)[b]
Dry matter	92.5	108,239	27,143	78,571	2270	255
Energy	24.9	2908	801	2064	34	10
Crude protein	37.5	43,842	10,822	31,699	1317	3.1
Crude lipid	32.0	37,493	14,034	23,215	1	242
EPA+DHA	2.0	2354	2226	0	0	128
n-6 fatty acids	4.1	4749	312	4433	0	4.6
Carbohydrates[c]	4.9	5788	2	5787	0	0.0
NFE[c]	16.1	18,814	9	18,617	181	7.5
Crude fiber[c]	2.0	2322	17	2304	0	0.6
Phosphorus	0.87	1013	365	326	321	0.1

[a] Includes vitamin- and mineral premixes, phosphorus sources, astaxanthin, crystalline amino acids
[b] Insect meal, single cell protein, fermented products, microalgae
[c] It varied among feed producers and among ingredients if data for carbohydrates, NFE (nitrogen free extract) or crude fibre were given. The table shows the data as provided from the feed producers.

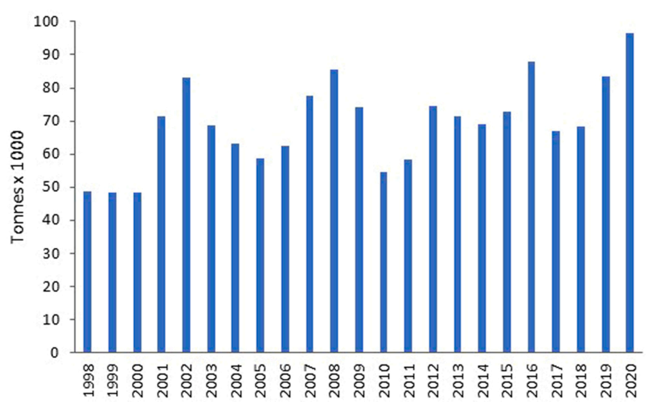

Fig. 3. Annual amount (tonnes x 1000) of traded rainbow trout in Norway in 1998–2020 (Directory Of Fisheries, 2021).

The retention data are given for both trout itself and for the sum of the trout and salmon production in Norway (Table 5). The retention of total dry matter from the feed ingredients, total fat, the fatty acids EPA (eicosapentaenoic acid, 20:5n-3) and DHA (docosahexaenoic acid, 22:6n-3) and thus of energy, was higher in whole body of trout than in the sum of trout and salmon. Some of this difference is caused by an underestimation of feed ingredients used for trout since some of the feed used for trout is registered as salmon feed. But the trout is also different from salmon in body composition, being higher in fat content (Aas et al., 2022b). In fillet, the retention data were very similar for trout and for the sum of trout and salmon, whereas the trout retained more lipid, energy, and total dry matter in the cut-offs (Table 5). For fish processed in Norway, the cut-offs are near completely recycled to products used in feed or for human consumption (Richardsen et al., 2017).

3.3.3. Protein-, lipid- and energy efficiency ratios, (PER, LER and EER)
The PER, LER and EER in whole body and fillet of trout was slightly different from that of salmon and trout as a sum (Fig. 4). This difference may be due to a difference in body fat and energy metabolism between the two species, and some trout feed registered as salmon feed. The PER, LER and EER for the sum of salmon and trout was identical to the ratios for salmon alone (Aas et al., 2022a).

Table 5
Retention (%) of nutrients and energy in whole body, fillet and cut-offs, and nutrients and energy not retained (loss). The data are given for trout, and for the sum of trout and salmon produced in Norway in 2020.

	Retention in whole body	Retention in fillet[a]	Retention in cut-offs[b]	Not retained – loss[c]
Retention in rainbow trout:				
Dry matter	37	21	16	63
Energy	43	25	18	57
Crude lipid[d]	63	34	29	37
EPA + DHA	62	35	27	38
Protein	33	23	10	67
Phosphorus	29	12	17	71
Retention in the sum of rainbow trout and Atlantic salmon:				
Dry matter	34	21	12	66
Energy	39	25	14	61
Crude lipid[d]	58	35	23	42
EPA + DHA	50	32	18	50
Protein	34	24	9	66
Phosphorus	25	12	13	75

[a] 62 % fillet yield was assumed
[b] Retention in whole body (%) – retention in edible part (%)
[c] 100 (%) – retention in whole body (%)
[d] Includes lipids produced from non-lipid precursors

3.4. Indices for use of marine ingredients

The various indices for use of marine ingredients were calculated for trout alone, and for the total production of trout and salmon in Norway in 2020. The use of marine ingredients was similar in trout production and the total production of trout and salmon (Fig. 3). This is not unexpected since feed for the two species is very similar.

The fish-in-fish-out ratio (FIFO) was 0.8 for fish meal and 1.9 for fish oil in the production of trout (Fig. 5). The corresponding FIFOs for the overall production of trout and salmon was 0.7 and 1.8, respectively. The equivalent ratios, but only including forage fish (forage fish dependency ratio, FFDR) was 0.5 for fish meal and 1.4 for fish oil in the trout production alone, and 0.5 and 1.5, respectively, in the total production of trout and salmon in Norway in 2020. The marine protein dependency ratio was 0.53, and the marine oil dependency ratio was 0.46 in the production of trout. For the overall production of trout and salmon, the corresponding ratios were 0.49 and 0.54, respectively. This

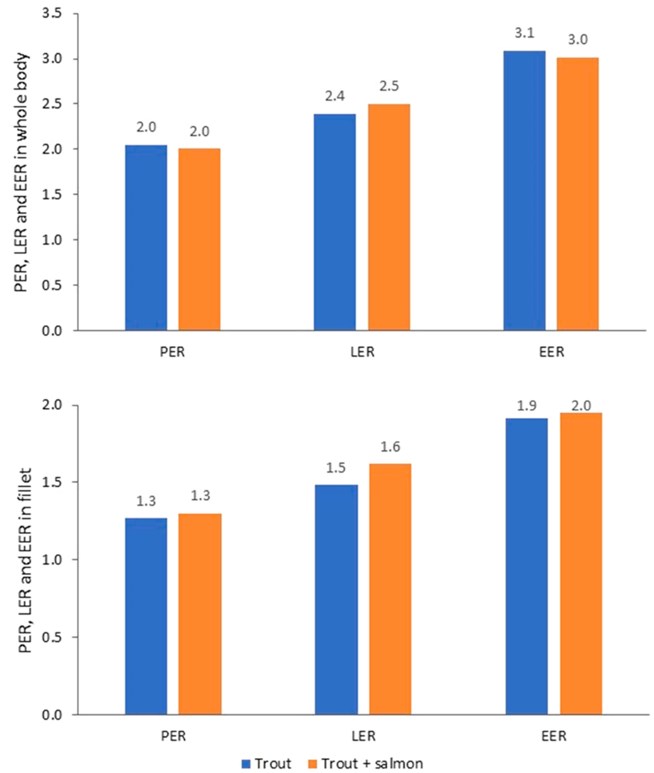

Fig. 4. Protein efficiency ratio (PER), lipid efficiency ratio (LER) and energy efficiency ratio (EER) in whole body and fillet of trout and of sum of salmon and trout produced in Norway in 2020.

difference shows that compared to salmon feed, the trout feed depended on more marine protein, and less marine oil (Fig. 5). The marine nutrient dependency ratios were calculated from fish meal and fish oil from forage fish only.

It should be noted that indices for use of marine ingredients are not a measure of the sustainability of trout farming, and the use of marine ingredients versus plant ingredients in feed is not a measure of sustainability. The sustainability of marine ingredients in comparison with other feed ingredients in salmon diets is discussed previously (Aas et al., 2019, 2022a) and in several other studies based on LCA methodology (Boissy et al., 2011; Cadillo-Benalcazar et al., 2020; Pelletier et al., 2009; Torrissen et al., 2011). Weaknesses of the FIFO calculation are discussed by Aas et al. (2022a). Evaluation of the sustainability of a food production system is very complex and requires all factors in the production to be taken into account, which is aimed for in LCA analyses.

4. Concluding remarks

The present data show that the utilization of feed resources in Norwegian trout farming is very similar to that of salmon farming. There are some differences in physiology and body composition between rainbow trout and Atlantic salmon, that cause some minor differences in the utilization of feed resources. Feeds for the two species are in practice formulated identically regardless of species. An undefined amount of salmon feed used for trout production causes an inaccuracy in the data for trout farming. This inaccuracy can be avoided by evaluating farming of the two species as a total.

The annual production of rainbow is a small fraction of the total aquaculture production in Norway, which is dominated by Atlantic salmon.

The present study documents and quantifies the utilization of feed resources in production of rainbow trout in Norway in 2020. Sustainability has not been evaluated. Sustainability in animal production involves use of resources such as energy, freshwater, phosphorus, fertilizers, and agricultural areas, and it includes emissions, deforestation and management of fisheries, as well as social and economic aspects. Sustainability is further complicated by some of the feed ingredients are by-products from other productions, and by-products from trout production are used in other productions or for human consumption directly. Feed ingredients are traded on a global market and Norwegian trout farming is thus intertwined with other feed productions.

The present study provides data that can be used as a basis for the continuous improvement of the sustainability in Norwegian trout farming and in other feed production systems as well.

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CRediT authorship contribution statement

Turid Synnøve Aas: Data curation, Project administration, Writing – original draft. **Torbjørn Åsgård**: Data curation, Validation, Writing – review and editing. **Trine Ytrestøyl:** Methodology, Writing – review and editing

Declaration of Competing Interest

The authors declare that they have no known competing financial

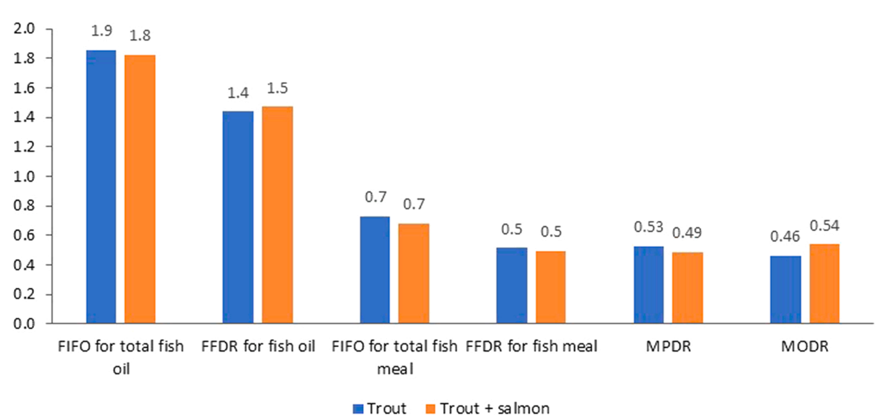

Fig. 5. Indices for use of marine ingredients in feed (FIFO, FFDR, MPDR and MODR) in production of trout and in the sum of production of trout and salmon in Norway in 2020.

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data that has been used is confidential.

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