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Resource utilisation of Norwegian salmon farming in 2012-2013

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Report

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Summary:

This project follows up the work on resource utilisation and eco-efficiency of Norwegian salmon production in 2010 and the work was done in collaboration between Nofima, Sintef and Institutet för Livsmedel och Bioteknink (SIK). This report contains a resource budget for the Norwegian salmon production in 2012, showing the flow of major nutrients from feed to whole body and edible product. The retention of protein, fat and energy, as well as the retention of the essential ω 3 fatty acids EPA and DHA and phosphorus, are calculated in whole salmon and fillet. The marine sustainability indicators often used to evaluate aquaculture productions (FIFO, marine protein dependency ratio, forage fish dependency ratio) is also calculated for the Norwegian salmon production.. In 2012, 1.26 million tons of Atlantic salmon was slaughtered in Norway. The salmon industry has been criticized for the use of fish meal and oil in the production of salmon feed. At present, 20 % of the global fish meal production and 53 % of the fish oil production is used in feed for salmonid fishes worldwide (FAO 2012). Two decades ago, the main ingredients for Norwegian salmon feed were fish meal and fish oil. However, in 2013 only 30% of the ingredients were of marine origin. The forage fish dependence ratio (FFDR) is the amount of forage fish used to produce the amount of fish oil and meal in salmon feed required to produce 1 kg of salmon. This ratio has decreased from 7.2 to 1.5 for fish oil and from 4.4 to 0.7 for fish meal between 1990 and 2013. The marine protein dependency ratio has decreased from 3.8 to 0.7 in the same period.

Information of ingredients used for feed production in 2012 was provided by BioMar, Ewos and Skretting. Chemical composition of the feed ingredients was partly provided by the feed producers, and partly based on literature values. Lerøy Seafood provided data on nutrient content in salmon fed diets from BioMar, Skretting and EWOS in 2012. Based on this information, the flow of energy, protein, dry matter, phosphorous and the important marine fatty acids EPA and DHA in Norwegian salmon farming was estimated. In 2012, 1.63 million tons of feed resources, with an energy content close to 40 million GJ, and 579 000 tons of protein and 530 000 tons of lipid were used in Norwegian salmon feed production. In total, 820 000 tons of salmon fillet, containing 9.45 million GJ, and 156 000 tons of protein was produced. Salmon is still an important source of the nutritionally important fatty acids EPA and DHA, and of the 43 000 tons of EPA+DHA in the feed ingredients, around 11 000 tons were retained in the edible part of salmon. This amount is sufficient to cover the recommended daily intake of EPA and DHA of more than 120 million people for a whole year (recommended daily intake of 0.25 g). The retention of EPA and DHA was 46 % in the whole salmon and 26 % in the fillet. The retention of protein and energy were 27 and 24 % in the edible part, respectively. The retention data obtained in the present study can however not be compared to controlled studies, since all losses during the production of feed and salmon are included in the data.

Sammendrag:

Denne rapporten følger opp arbeidet med kartlegging av ressursutnyttelse og øko-effektivitet av norsk lakseproduksjon i 2010 og har vært et samarbeid mellom Nofima, Sintef fiskeri og havbruk og Institutet för Livsmedel och Bioteknink (SIK). Rapporten inneholder et ressursbudsjett for norsk lakseproduksjon i 2012 som viser flyt av næringsstoffer fra fôrråvarene til hel laks og spiselig produkt. Retensjon av protein, energi og fett, inkludert de essensielle omega-3 fettsyrene EPA og DHA, samt fosfor er beregnet både i hel laks og i fillet. Indikatorer på marin ressursbruk, som ofte brukes til å evaluere marin ressursbruk av akvakulturproduksjoner (FIFO, marine protein dependency ratio, forage fish dependency ratio) er også beregnet for norsk lakseproduksjon. I 2012 ble det slaktet 1,26 millioner tonn laks i Norge. Laksindustrien har vært kritisert for bruken av fiskemel og olje i produksjonen av laksefôr. 20 % av verdens produksjon av fiskemel og 53 % av fiskeoljen brukes i dag i fôr til laksefisk (FAO 2012). For to tiår siden var fiskemel og olje de viktigste råvarene i laksefôret. I 2013 var kun 30 % av råvarene i fôret fra marine kilder. Mengden villfanget fisk som går med for å produsere fiskemelet og oljen som brukes i laksefôret til produksjon av 1 kg laks betegnes av de såkalte «forage fish dependency ratio (FFDR)». Fra 1990 til 2013 har denne ratioen blitt redusert fra 7,2 til 1.5 for fiskeolje og fra 4,4 til 0,7 for fiskemel. Marint protein fra villfisk brukt i produksjonen av laks (Marine protein dependency ratio) er redusert fra 3,8 til 0,7 i samme tidsrom.

Informasjon om ingrediensene brukt i laksefôret ble gitt av de tre største fôrselskapene i Norge (BioMar, EWOS og Skretting). Kjemisk sammensetning av fôringrediensene er til dels oppgitt fra fôrleverandørerene, og ellers er det brukt verdier fra litteraturen. Lerøy Seafood har bidratt med data på næringsinnhold i laks fôret med fôr fra de tre fôrselskapene i 2012. Basert på denne informasjonen ble strømmen av energi, protein, fett, fosfor og de viktige omega-3 fettsyrene EPA og DHA gjennom norsk lakseproduksjon beregnet for 2012 og sammenlignet med tallene for 2010. Det ble brukt 1,63 millioner tonn fôrråvarer i 2012, med et energiinnhold på 40 millioner GJ. Totalt ble det brukt 579 000 tonn protein og 530 000 tonn lipid i fôrproduksjonen i 2012. Av dette ble det produsert rundt 820 000 tonn laksefilet med et estimert energiinnhold på 9,45 millioner GJ og et proteininnhold på 156 000 tonn. Laks er fortsatt en viktig kilde til EPA og DHA, av de rundt 43 000 tonn som ble brukt i fôrråvarene var om lag 11 000 tonn retinert i det spiselige produktet. Dette er nok til å dekke anbefalt daglig inntak av disse fettsyrene til mer enn 120 millioner mennesker i et helt år (gitt et anbefalt daglig inntak på 0,25 g). Retensjonen av EPA og DHA var 46 % i hel laks og 26 % i filet. Retensjonen av protein og energi i filet var henholdsvis 27 og 24 %. Disse retensjonstallene kan ikke sammenlignes med dem man oppnår i forsøk under kontrollerte betingelser, ettersom alle tap i produksjon av fôr og laks er inkludert i datagrunnlaget for retensjonsberegningene.

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1 Introduction

The Food and Agricultural Organization (FAO) projects that 70 % more food need to be produced globally within 2050 to feed a population of 9 billion people and calls for urgent action in developing food systems that uses less energy and emits less greenhouse gases (FAO 2011a). The global food sector is responsible for around 30 % of the world's energy consumption and contributes to more than 20 % of the global greenhouse gas (GHG) emissions (FAO 2011b). In addition, land use changes contribute (mainly deforestation) to another 15 % of GHG emissions. The increased food production must come through improvements in efficiency of food producing systems in converting natural resources into food and also through reducing waste. 30 % of the world's cereal production is currently used to feed livestock and livestock productions also consume large amounts of freshwater, both for irrigation of feed crops and for drinking. Freshwater is becoming increasingly scarce and the livestock sector is probably the largest source of water pollution (FAO 2011b). The expansion and intensification of the livestock production sector the last decades has led to degradation of 20 % of the world's pastures due to overgrazing. Deforestation to grow animal feed crops has led to extinction of many plants and animals and released large amounts of carbon dioxide into the atmosphere. The global food production is also heavily dependent on the use of Phosphorus fertilizer. However, the current use of P is not sustainable due to losses at all stages from mining to crop field to human consumption. P is not cycled at present, but moves through an open one way system where the final losses end up in the ocean.

Several indicators and methods for measuring sustainability and eco-efficiency of aquaculture production systems have been developed, such as the simple fish-in-fish-out-ratio, forage fish dependency ratio, marine nutrient dependency ratio and various nutrient retention ratios. More extensive methods such as the ecological footprint model and life cycle analysis (LCA) are also applied for assessing the sustainability of food production systems. These methods have their strengths and weaknesses, and the outcome of an analysis will depend on which impacts are included in the analysis and how the impacts are allocated between co-products in production processes that generate several products. Evaluation of sustainability of aquaculture is complicated, and different aspects have to be addressed in order to evaluate the sustainability of Norwegian salmon production. For tracking of nutrient flow and estimating the nutrient retention efficiency mass balance models are more suited than LCA models, and the assimilation efficiency of nutrients in a food production system could also be used as a sustainability indicator.

1.1 The worlds fishery and aquaculture production

Aquaculture is the fastest growing animal food producing sector with an annual growth rate of 8.8 % between 1980 and 2010 (FAO 2012). Aquaculture now accounts for almost half of the total food fish supply and the percentage is increasing every year (Figure 1). Capture fisheries and aquaculture supplied the world with 154 million tons of fish in 2011 of which 131 million tons were used as human food, resulting in a per capita food fish supply of 18.8 kg in 2011, and fish accounted for 16,6 % of the global intake of protein. In 2011 the world aquaculture production was 63.6 million tons and was dominated by China who accounted for more than 60 % of the global production by volume (FAO, 2012).

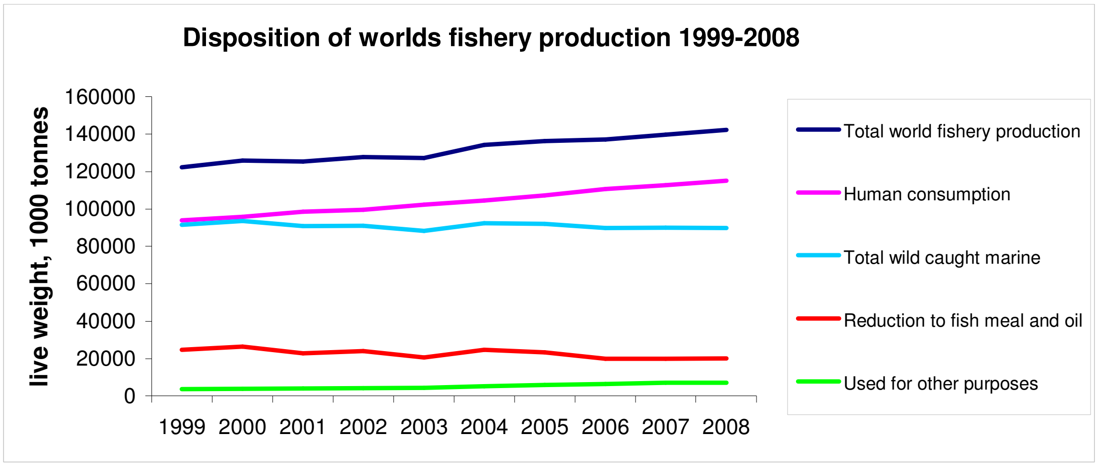


Figure 1 *Disposition of the total world fishery production (freshwater and marine, including aquaculture production (data from FAO).*

The production of fish oil has been fairly stable at around 1 million tons per year for the last 50 years while the production of fish meal has been declining in the last decade after reaching a peak of 7.5 million tons in 1995. The current production is around 4.5 million tons of which 25 % originates from trimmings and by-products (IFFO). Between 1999 and 2008, the amount of the marine catch that was reduced to fish meal and fish oil decreased from 27 to 22 %. Of the world's total fishery production in 2010, 86 % was used for human consumption, 14 % was used for non-food purposes, including fish meal and oil production (FAO, 2012). The global capture fisheries production has been relatively stable at around 90 million tons in the last decade and around 15 million tons was used for fish meal and fish meal and oil production in 2010. Although somewhat uncertain, unreported by-catch and discards are estimated to be around 38 million tons (Davies et al., 2009). Of the total production of fish meal and oil in 2006, between 56-68 % of the fish meal and 83-89 % of the fish oil produced were consumed by the aquaculture industry (Jackson, 2006, 2007, Tacon and Metian 2008, FAO 2012). The production of Atlantic salmon has been more than doubled worldwide since 2000 and around 2.07 million tonnes were produced in 2012 (Figure 2), with Europe as the major salmon producing region (1.26 million tonnes were produced in Norway in 2012).

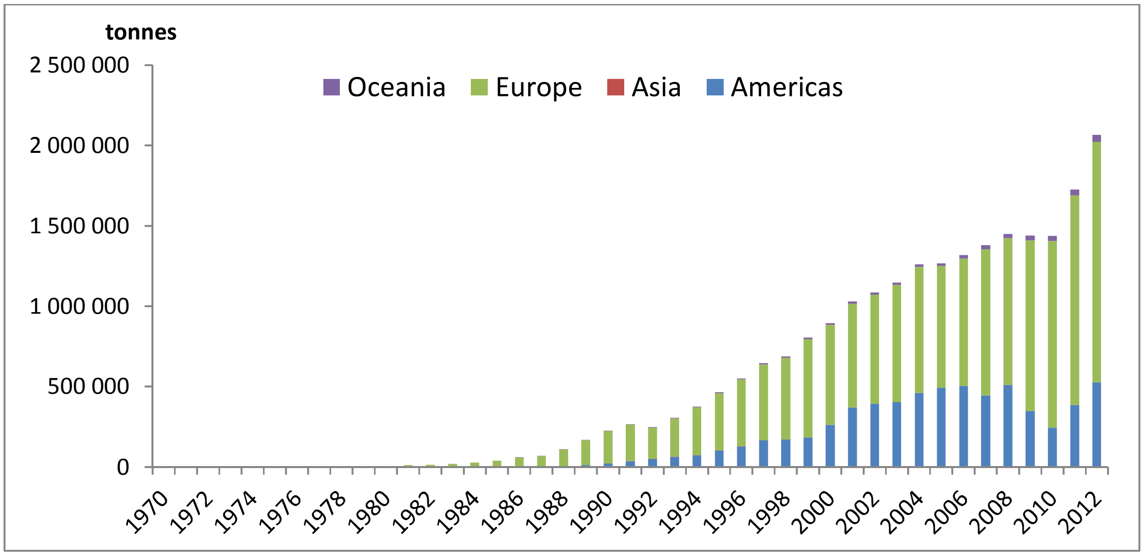


Figure 2 The worlds salmon production per continent from 1970 – 2012 (data from FAO).

In 2012, 53 % of the fish oil and 20 % of the fish meal used in aquaculture was consumed by the salmon industry (figure 3). Some fish oil was also used for human consumption and around 5 % of the fish oil production was used for other industrial purposes. Fish oil used for direct human consumption is mainly in the form of concentrated EPA and DHA omega-3-fatty acid products and food products fortified with these essential fatty acids (functional food). The market for human consumption of fish oil is growing rapidly. It was estimated that 63% of the world production of fish meal in 2009 was used in various aquaculture productions (data from IFFO). The remaining fish meal was used in terrestrial animal feed production, mainly pig (25 %) and poultry production (8 %).

Figure 3 Use of fish meal (left) and fish oil (right) in different aquaculture productions in 2012 (data from FAO 2012).

1.2 Sustainable food production

The report from United Nations Brundtland commission (WCED 1987), defines a sustainable development as “a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs” (WCED, 1987:43). Included in this definition is not only a development that secures the global resource base and the environment, but also includes a social and economic aspect with responsibility for securing the basic needs of the present and future population. Access to sufficient food with a satisfactory nutritional quality is a basic human need, and one of the major challenges in the next 30-40 years will be to increase the world’s food production to support a population of 9-11 billion people on earth in 2050 at the same time as coping with the increase in global temperature.

At the United Nations 2005 World Summit it was noted that this requires the reconciliation of environmental, social and economic demands - the "three pillars" of sustainability (Figure 4). This view has been expressed as an illustration using three overlapping ellipses indicating that the three pillars of sustainability are not mutually exclusive and can be mutually reinforcing. The three pillars have served as a common ground for numerous sustainability standards and certification systems in recent years, in particular in the food industry. The ecological, social and economic development is restricted by the limits set by the environment, which consist of available resources and the capacity of the environment to absorb waste and emissions.

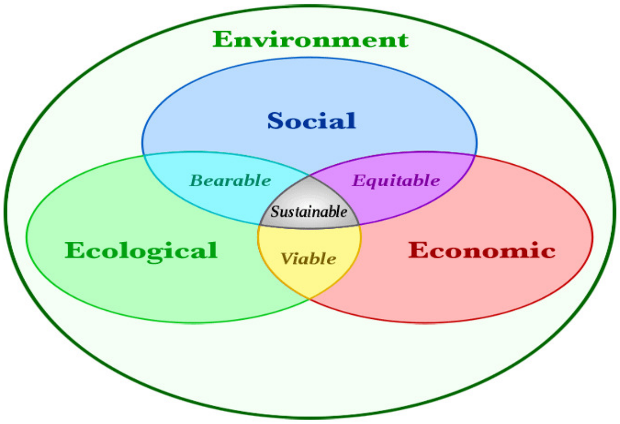


Figure 4 Development can be classified as sustainable, viable, bearable and sustainable and has elements of social and economic aspects in addition to ecological aspects.

In several recent reports it is concluded that the current use of P is not sustainable due to losses at all stages from mining to crop field to human consumption (Smit et al., 2009, Schröder et al., 2009,van Enk et al., 2011). Less than 20 % of the mined P is consumed by humans, and the majority of what is eaten is excreted, around 3 Mt P/y is present in human excreta and 12 Mt P/y is present in animal excreta (Smit et al., 2009). P is not cycled at present, but moves through an open one way system where the final losses end up in the ocean. Only a very small amount of the 16 Mt of P lost to the oceans is recovered (0.3 Mt/y in fish harvests), the rest ends up in ocean sediments where the P becomes unavailable for millions of years until tectonic movements lifts the ocean floor to dry land and erosion makes the P accessible to plants. Thus there is a need to reduce the global use of P and increased recycling of the P that is used. Table 1 shows how long the P reserves will last with different scenarios for growth in production of food and biodiesel.

Table 1 *Calculated phosphate rock consumption in 2050 and sufficiency of reserves available with current phosphorous prices (= reserves) with zero, low, intermediate and high annual growth in food and biodiesel production between 2010 and 2050. Future reserves that may become available with new technology (=resource base) are not included (from Van Enk et al., 2011).*

Growth scenario	% annual increase in food production	% annual increase in biodiesel production	Consumption in 2050 (Mt/y)	Year of depletion of reserves
Zero	0	0	167	2100
Low	1.5 %	12.3 %	356	2060
Intermediate	2.7 %	12.3 %	511	2050
High	4.4 %	15.7 %	1093	2040

The growth in the aquaculture industry has raised concerns about the environmental impacts and sustainability of fish farming among consumers, retailers, non-governmental organisations (NGO's) and authorities. In particular, the use of marine ingredients in the fish feed has been subject for debate. Forage fish are often small pelagic fish at lower trophic levels that are important prey for species higher up in the food chain (Fréon, 2005). Farming of carnivorous finfish such as Atlantic salmon has been considered as negative due to the use of small pelagic fish used in production that could potentially be used as human food, thus presumably reducing the amount of marine protein available for human consumption (Naylor et al., 2000, Naylor and Burke, 2005, Naylor et al., 2009).

However, it is not only the aquaculture production that is growing rapidly, the production of pork and poultry is growing at a similar rate (Figure 5) and increasing amount of feed ingredients are required to sustain these livestock productions. In 2007, 750 million tons of cereals, (35 % of the world's total production) were used as animal feed (FAOSTAT 2009). Maize is the dominating feed commodity, 60 % of the world production of maize in 2009 was used as animal feed (Figure 5).

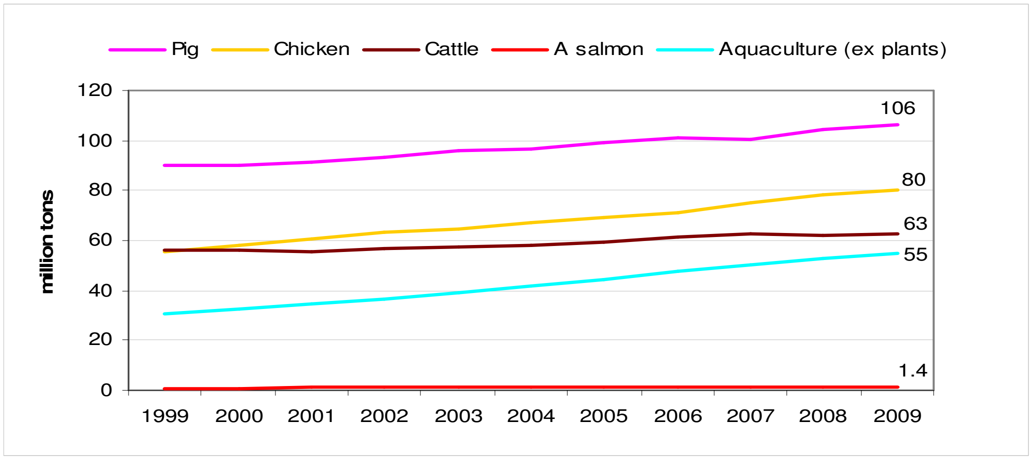


Figure 5 *Increase in world production of cattle, pig, chicken, Atlantic salmon and world aquaculture meat production from 1999 to 2009.*

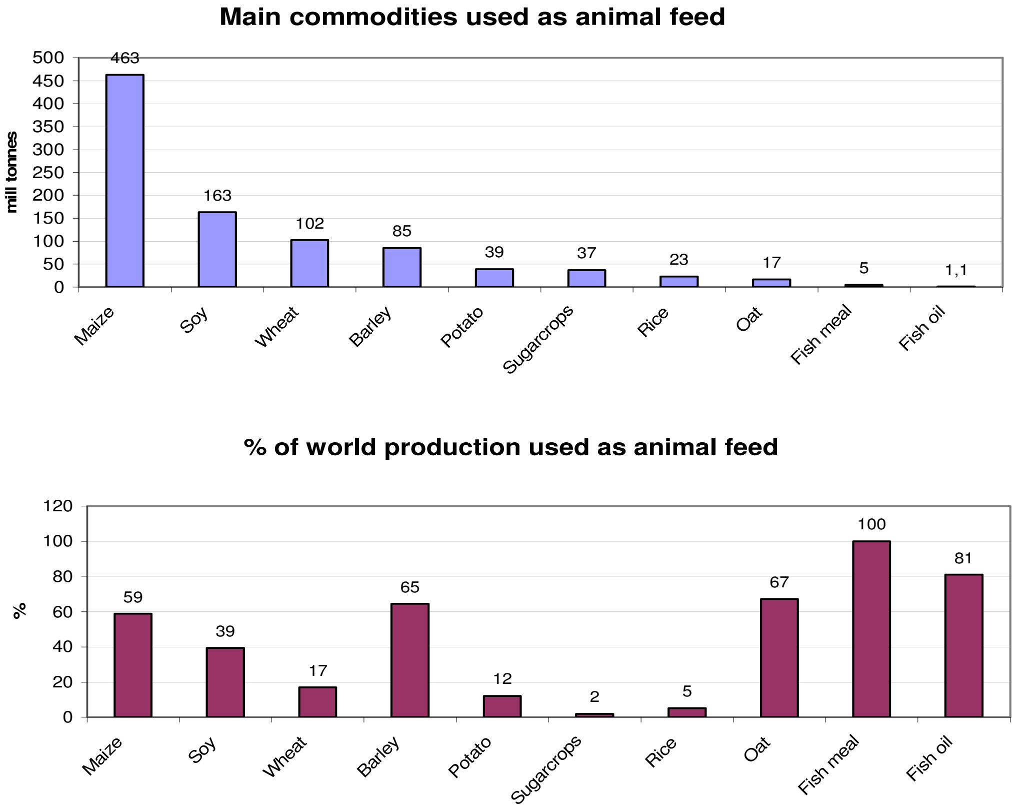


Figure 6 Upper panel: The volume of the major commodities used as animal feed in 2009. Lower panel: The % of the total world production of each commodity used as animal feed.

1.3 Marine resources

Growing food in the ocean may be a viable and sustainable alternative when farm land, phosphorous and fresh water becomes limiting resources. Aquaculture now accounts for almost half of the total food fish supply and the percentage is increasing every year (FAO, 2012). Capture fisheries and aquaculture supplied the world with 154 million tons of fish in 2011 of which 128 million tons were used as human food, resulting in a per capita food fish supply of 18.6 kg (FAO 2012). The dependence of the aquaculture feed industry on fish meal and fish oil and the consequences this may have for wild fish stocks is often used as an argument against sustainability of salmon production (Naylor et al., 2000, Deutch et al., 2007, Tacon and Metian 2008). In 2008, 53 % of the world's fish stocks were fully exploited, 28 % were overexploited, 3 % depleted and 1 % were recovering from depletion and the remaining 15 % were underexploited or moderately exploited (FAO, 2010). Thus, a further growth in the production of salmon and aquaculture cannot depend on an increase in the catch volume of wild fish beyond sustainable limits, but must rather rely on a further increase in the use of alternative sources of lipid and protein. Plant ingredients have so far been the most cost efficient alternative, and between 1990 and 2013, the diet of Norwegian farmed salmon has changed from a marine based diet (90 % marine ingredients) to a plant based diet (30 % marine ingredients) (Figure 7). The dominating plant ingredients used in Norwegian salmon feed are soy protein concentrate and rapeseed oil, but a substantial amount of wheat is also used (Figure 8). There is however still a potential for increased utilisation of discards and by-products from processing of fishery products. Worldwide, approximately 25 % of the fishmeal produced originates from trimmings, but the potential is larger considering that around 120 million tons of fish are consumed by humans, and if the edible portion is around 50 %, there are roughly 60 million tons of trimmings and by-products potentially available for production of fish oil and fish meal. In addition there are 38 million tons of unreported by-catch that can potentially be utilized for human consumption or for production of fish meal and oil. Improved management and regulation of the capture fisheries is necessary for a sustainable utilisation of the wild fish resources.

Marine products such as fish and seafood are a major source of the long chain unsaturated fatty acids EPA and DHA. These fatty acids, also known as omega-3 fatty acids, are indicated to possess several positive health effects, hence, humans are advised to consume more marine fish and less meat for health benefits. The nutritional requirement of these fatty acids is uncertain, but is assumed to be between 0.25-0.5 mg per day for healthy adults (EFSA, ISSFAL). These requirements can be fulfilled in several ways. Marine fish and seafood contain variable amounts of these fatty acids, so consumption of seafood, either from fisheries or from aquaculture is the main source of EPA and DHA in human nutrition. Salmon and trout are effective in retaining these fatty acids from their diet, and recent studies suggest that they may even be net producers of long chained omega 3-acids (Turchini et al., 2010, Sanden et al., 2011). Alternatively, omega 3 rich concentrates made from marine fish or by-products can be ingested in the form of capsules or in liquid form or used to fortify other food products with omega-3 (functional food).

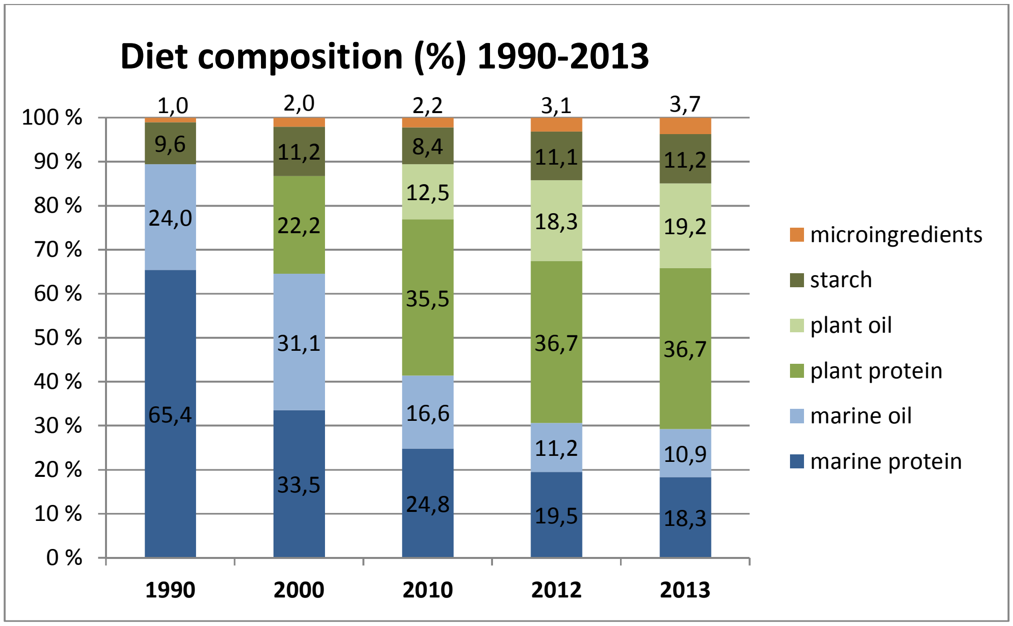


Figure 7 Development of salmon feed in Norwegian salmon farming from 1990 to 2013.

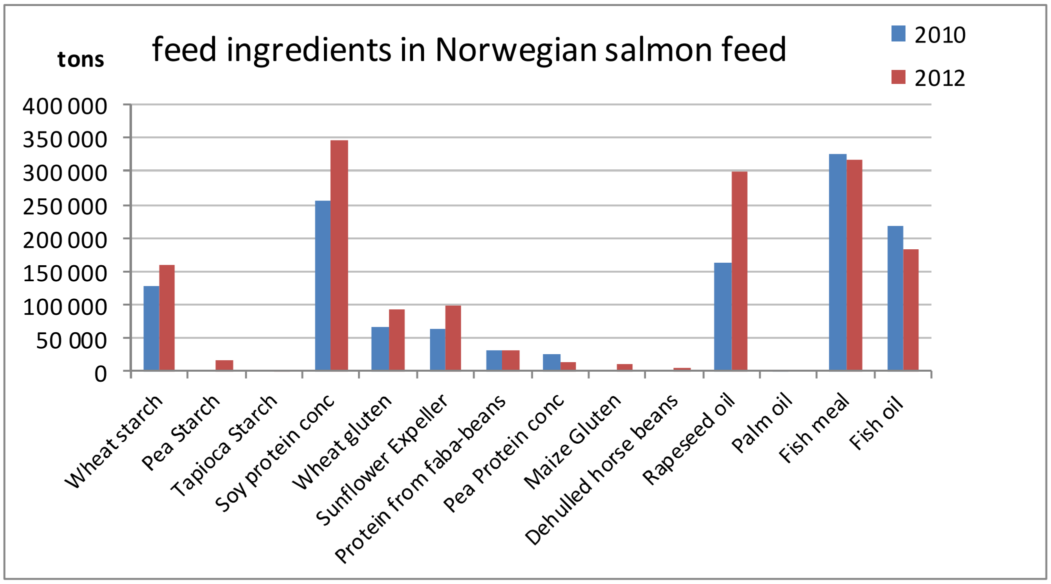


Figure 8 Feed ingredients in Norwegian salmon feed in 2010 and 2012.

1.4 Methods and indicators for measuring sustainability

There are several indicators and standards for what can be defined as sustainable food production, but an indicator does not measure the sustainability of a production unless a reference value or threshold for sustainability is defined (Lancker and Nijkamp, 2000). Thus, there is a need to develop models, metrics and tools to decide whether an activity is sustainable or not. Sustainability indicators and composite indicators are recognised as a useful tool for policy making and public communication in environmental performance (Singh et al., 2009). The main purpose of environmental indicators is to summarise, focus and condense the complexity of our environment to a manageable amount of meaningful information. This will then provide decision-makers with a tool to determine which actions should or should not be taken to move society in a sustainable direction (Kates et al., 2001). To be able to make strategic decisions on how to produce enough food in the future in a safe and sustainable way it is useful to be able to assess and compare how different food producing systems utilize biotic and abiotic resources and generate waste. Methods for comparing the environmental cost of aquatic and terrestrial food production systems include cost-benefit analysis, material and energy flow analysis, human appropriation of net primary productivity, life cycle analysis, ecological footprint analysis, risk analysis and environmental impact assessment. To be useful for comparison, the methods should be scientifically based and comparable across different sectors, expandable to different scales, practical to implement and easily understood by managers and policy-makers (see review by Bartley et al., 2007). Any human activity, including aquaculture productions, can be evaluated in terms of its biophysical performance, meaning the influence it has on the environment and how much resources that are consumed in the process. The methods used to assess performance differ in methodology and focus on different aspects of biophysical performance. No single method is currently robust enough to capture all environmental impacts and costs associated with food production. Thus, the information derived from using these tools is complementary and should be interpreted together to obtain the broadest possible understanding of the eco-efficiency of a production system.

A major problem in the current public debate is the lack of defined criteria and reference points for sustainable food production. Several indicators are currently being used to measure environmental performance of seafood products. However, some of the methods are developed for land based production systems and industrial production systems, and the impact categories chosen are not always suited to address important environmental issues that are unique to the aquaculture industry, such as use of pelagic fish species for production of fish meal and oil and potential transmission of parasites and genetic material to wild populations (see Pelletier et al. 2007 for a review). Both local impacts such as eutrophication and global impacts (e.g. climate change) should be taken into account, and it is also necessary to focus on the management of the reduction fisheries. There are currently several independent certification schemes for sustainable fisheries, the Marine Stewardship Council (MSC) has developed a standard with principles and criteria for sustainable fishing and FAO also has a Code of Conduct for Responsible Fisheries. The International Council for Exploration of the Sea (ICES) also provides scientifically based advice on the status and sustainable quotas on fish stocks in the North Atlantic Ocean.

1.5 Nutrient flow models

Nutrient flow model track the use of materials from extraction to manufacturing, to final use and disposal of emissions and waste and has a life cycle perspective. Energy flow analysis is used to account for the energy throughput of socio-economic systems based on energy content of all flows in and out of the defined system. However, the materials released at the different stages are not converted into impact categories like in the LCA methodology, so the environmental effects are not quantified as in LCA's. However, nutrient flow models can be used to quantify material requirements and release of substances from specific production systems, and may thus generate information about the environmental impact a production system has on its surroundings. The flows are measured in physical units, usually metric tonnes per year. Efficiency in the production system (conversion of feed to edible product) is highly important for the amount of biological material that is released to the surrounding environment. Nutrient flow models based on bioenergetic models have been used for estimating outputs of phosphorus, nitrogen and suspended solids (Einen et al., 1995, Kaushik, 1998, Papatryphon et al., 2005, Roque d'Orbcastel et al., 2008, Hua et al., 2008). Recently, a comprehensive report on the flow of phosphorous in the EU region was released (Schröder et al., 2009).

Fish are generally more efficient converters of feed energy to bodyweight than warm blooded animals. In nature, homeotherms have a low production efficiency compared to poikilotherms due to high maintenance and respiratory costs. On average, only 2 % of the consumed energy is used for biomass production in homoetherms whereas poikilotherms convert on average 17 % of the consumed energy to biomass (Smith, 1992). Aquatic living animals have some advantages compared to land living animals in terms of energy conservation, as they excrete ammonia directly into the environment and thus spend less energy on protein metabolism than terrestrial animals that excrete urea or uric acid. Buoyancy in water also saves energy and reduces the need for a heavy skeleton, thus increasing the edible portion of the aquatic animals as compared to the terrestrial. Being a poikoilothermic aquatic carnivore, Atlantic salmon is a very efficient converter of consumed nutrients and energy into edible flesh and potentially a very efficient food producer. Culture production of animals generally improves the energy conversion since food is more available. This results in a higher feed intake and a reduction in activity which improves the growth and retention of nutrients (Bergheim and Åsgård, 1996). However, it is not only the conversion efficiency from feed to edible product that must be considered when evaluating different meat productions. The total amount of resources that are utilized in the production and the waste that is generated must also be considered. A high energy feed is more costly to produce in terms of resource use and energy consumption compared to a low-energy feed, and in industrial food productions the feed is the major impact factor in terms of energy and resource demand.

Nutrient flow analysis can provide information on the environmental impacts of the food producing activity and efficiency of resource utilisation. The efficiency is affected by feeding routines and diet composition. Efficiency in the production system, measured as conversion of feed to edible product, is highly important for the amount of biological material that is released to the surrounding environment. The feed conversion ratio (FCR) is the amount of feed (kg) required to produce a kg of fish (round weight). The biological feed conversion factor is based on feed eaten whereas the economic feed conversion (eFCR) also include production losses (uneaten feed, mortalities, escapees) and is therefore higher than the biological FCR. The assimilation efficiency of nutrients is also important for the waste output; both the amount of nutrients digested and the amount of the digested nutrients that are retained in the fish. An optimal energy/protein ratio and covering the requirements of essential amino acids and fatty acids and minerals are crucial for obtaining maximum growth and feed utilisation. The retention efficiency of nutrients is normally calculated in % of the amount eaten. Fish retain around 30 % of the protein in the feed they eat whereas chicken and pork retain around 25 and 13 % respectively (Åsgård and Austreng, 1995, Åsgård et al., 1999, Bjørkli, 2002). The ratio of total industrial energy invested in food production relative to the edible protein energy return has been used as a measure of the energy efficiency of food production systems, and is also suggested as a sustainability indicator (Troell et al., 2004, Table 2). However, the energy produced in the form of fat should also be accounted for because not only protein, but also lipid is produced and contribute to the energy output of food productions. An alternative would be to use input and output ratios for protein, lipid and energy to assess the efficiency of food productions.

Table 2 *Ranking of industrial energy input/per protein energy output in capture fisheries, agriculture and aquaculture productions (data from Troell et al., 2004).*

Food production	**Industrial energy input/ protein energy output (J/J)**
Herring (purse seine, North Atlantic)	2-3
Vegetable crops	2-4
Tilapia (extensive, Indonesia)	8
Sheep	10
Beef (rangeland farming)	10
Cod fisheries (trawl and long line, North A tlantic)	10-12
Milk (USA)	14
Catfish culture (ponds, USA=	25
Eggs (USA)	26
Broiler production	34
Atlantic salmon (Pens, Canada)	40-50
Intensive shrimp culture (Thailand)	70

2 Resource budget for Norwegian salmon production in 2012

2.1 Ingredients used in 2012 and 2013

In 2012, the three major feed companies in Norway, BioMar, Ewos and Skretting, used around 1 630 000 tons of ingredients to produce aquaculture feed in Norway. 500 000 tons (31 %) were of marine origin and 1 079 000 (66 %) were crop derived (Table 3). There was a 15 % reduction in the % content of marine ingredients in the Norwegian salmon diet between 2010 and 2012. Micro ingredients accounted for 3.1 % of the total ingredients in 2012 and 3.7 % in 2013 (Figure 9). In total, the Norwegian salmon feed industry consumed 182 579 tons of fish oil and 317 241 tons of fish meal in 2012 (Figure 10) which is 22 and 6 % of the global production of fish oil and meal in 2012, respectively. There was only a minor reduction in the use of marine ingredients between 2012 and 2013. 25 % of the fish meal and 27 % of the fish oil used in 2013 came from fish silage and trimmings in 2013.

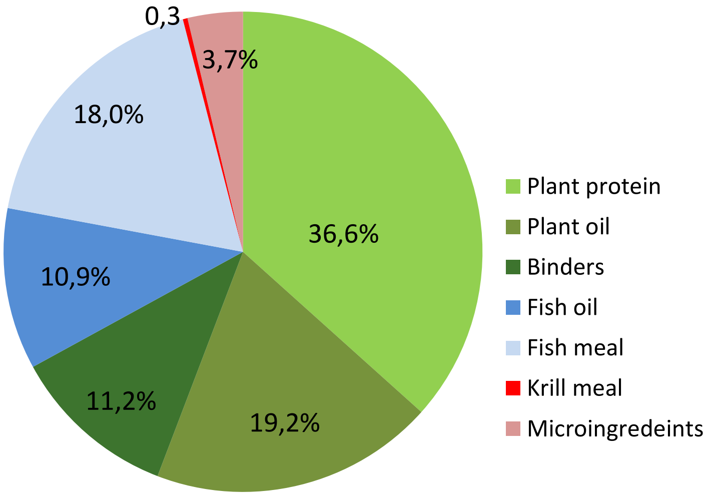


Figure 9 *Composition of salmon feed in Norway in 2013. Values are % of the total amount of ingredients used.*

Fish meal and oil from reduction fisheries made up 19.6 and 12.5 % of the salmon diet in 2010, respectively. These numbers were reduced to 13.5 and 7.9 % of the diet in 2013. In 2010, 52 % of the fish oil and the 47 % of the fish meal was of North Atlantic origin. However, since 2010 the proportion of fish meal and oil from forage fisheries from South America had increased and in 2012 only 35 % of the fish meal and 29 % of the fish oil came from the North Atlantic (Figure 11). A detailed overview of the marine forage fish species used in production of fish meal and oil used in salmon feed production in Norway in 2012 is shown in table 4. There were no major changes in species used between 2012 and 2013.

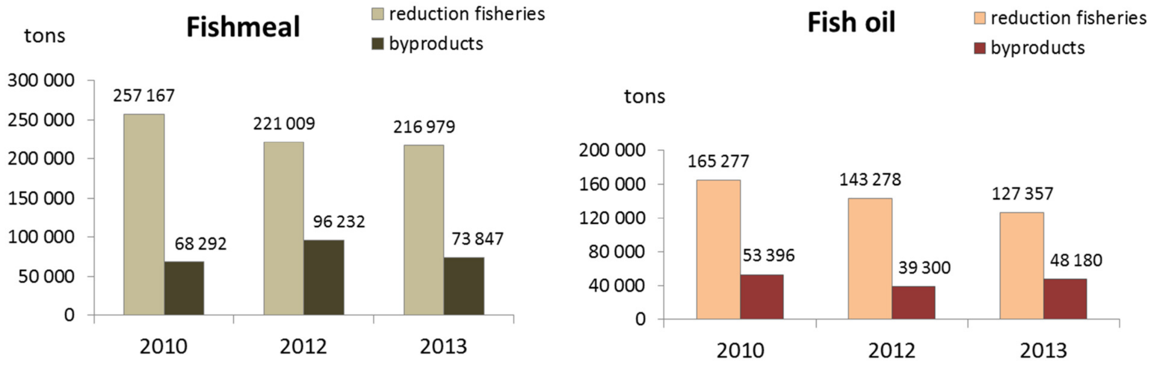


Figure 10   Fish meal and oil use in Norwegian salmon farming in 2010, 2012 and 2013.

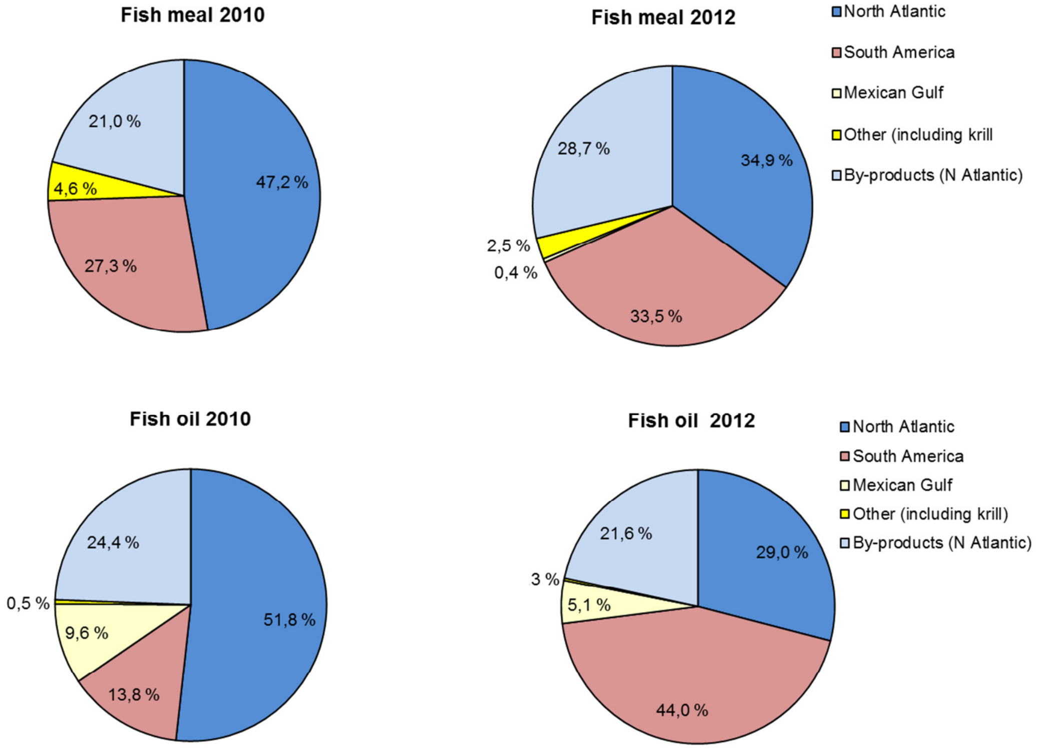


Figure 11   Origin of fish meal and oil used in the production of salmon feed in Norway in 2010 and 2012. Values are given as % of total amount of fish meal and oil respectively.

Table 3 *Plant ingredients used in Norwegian salmon feed production in 2012 and 2013. The data are the sum of ingredients used by BioMar, EWOS and Skretting.*

Plant ingredients (tonnes)		**2012**	**2013**
Protein sources	Soy protein concentrate	346 730	364 980
	Wheat gluten	94 137	99 348
	Sunflowermeal	97 137	65 039
	Peaprotein concentrate	12 936	7917
	Fababeans	30 753	24 971
	Dehulled horse beans	4442	
	Maize	12 509	28 640
Sum plant protein sources		*598 861*	*590 896*
Oil sources	Rapeseed oil	298 991	309 497
	Other plant oils	0	0
Sum plant oil		*298 991*	*309 497*
Binders	Wheat	161 432	158 992
	Pea	16 466	22 055
	Tapioca	3396	
Sum plant ingredients		**1 079 146**	**1 081 439**

Table 4 *Species used for fish meal and oil used in Norwegian salmon feed in 2012.*

Forage fisheries	**Fish meal (tons)**	**Fish oil (tons)**	**Sum**	**% of marine ingredients**
Capelin	53 926	20 418	74 343	15.3
Sprat	22 518	23 852	46 370	9.6
Sandeel	8 018	2 280	10 298	2.1
Blue whiting	5 786	501	6 287	1.3
Atlantic herring	4 220	5 113	9 332	1.9
Atlantic mackerel	516	0	516	0.1
Norway pout	94	554	648	0.1
Anchoveta	101 358	78 209	179 567	37.0
Chilean jack mackerel	507	0	507	0.1
Gulf menhaden	1 463	9 202	10 665	2.2
South American pilcard	615	1 795	2 410	0.5
Boar fish	3 448	540	3 988	0.8
Krill	2 946	0	2 946	0.6
other/unknown species	1 947	0	1 947	0.4
Sum forage fisheries	*207 361*	*142 463*	*349 824*	*72.0 %*
Trimmings/silage				
Herring	55 857	28 530	84 387	17.7
Capelin	12 723	1 278	14 000	2.9
Mackerel	2 818	640	3 459	0.7
Whitefish	3 387	1 725	5 113	1.1
Fish protein concentrates	17 442			
Unknown/other	4 004	7 127	11 131	2.3
Sum marine ingredients	**303 592**	**181 763**	**485 356**	**100.0**

2.2 Nutrient flows in Norwegian salmon farming in 2012

Nutrient-to-nutrient ratios are a measure often used to evaluate the efficiency of food production systems. Such conversion efficiency ratios measure the proportion of the dietary nutrients and energy that is retained in the animal product. These calculations are commonly given for a specific study or a single production. For evaluation of the sustainability of an entire food production industry however, all relevant data must be available. Norwegian aquaculture has a thorough system for reporting production data which is open to the public (www.fiskeridir, www.ssb.no, akvafakta.no). These data, and data provided by the three largest feed companies in Norway (BioMar, EWOS and Skretting) on feed composition and nutrient content of ingredients, have been used to calculate the nutrient flow and retention in Norwegian salmon production in 2012 as has previously been done for the Norwegian salmon production in 2010 (Ytrestøyl et al., 2011).

2.2.1 Nutrient content in Norwegian salmon feed

An estimate of nutrients used in Norwegian salmon production in 2012 and the average composition of Norwegian aquaculture feed in 2012 are given in Table 5. Of the 1 584 786 tons of feed used in 2012 in Norwegian aquaculture, 1 451 908 tons, or 91.6 %, was fed to Atlantic salmon (Akvafakta, 2013). When including the 90 000 tons feed used for rainbow trout (salmon and trout feeds are very similar in nutrient composition) the share fed to salmonids constitutes 97.3 % of the feed used (Akvafakta, 2013). Also, the three feed companies that have provided the feed ingredient data have a market share of approximately 90 % (Nordic Innovation). Thus, the estimated average composition of the total lot of aquaculture feed is considered to be representative for the average composition of Norwegian salmon feed in 2012.

Based on this, the total use of nutrients used for salmon production in Norway in 2012 (Table 5) can be estimated by multiplying the average feed composition with the total of 1 451 908 tons of salmon feed registered (Akvafakta, 2012). All batches of ingredients are not analysed, and therefore, the same chemical composition of similar ingredients is assumed. Also, not all microingredients, such as crystalline amino acids, pigment, vitamin and mineral mixes, are included. The average dry matter content of feed ingredients was 93.8 %, and the same dry matter content was assumed for the feeds (dry matter content of feeds are normally close to this value). In addition, the feed ingredient data was only collected from the tree largest feed companies, and ingredients used for all aquaculture feeds were included, as described above. Thus, it is likely that there is a minor inaccuracy in the figures of the total amount of nutrients used and all calculations based on these. However, the data includes all losses, discarded feed batches, failed productions etc, and thus represents the total use of nutrients in Norwegian salmon farming industry in 2012.

Table 5 Estimated average feed composition, total amount of nutrients used, and amount of nutrients from marine and plant origin in Norwegian salmon feed in 2012.

	Average composition of Norwegian salmon feed in 2012 (% or MJ/kg) [1]	**Total amount of nutrients used in Norwegian salmon feed 2012 (Tons or GJ)** [2]	**Nutrients from marine ingredients (Tons or GJ)** [3]	**Nutrients from plant ingredients (Tons or GJ)** [4]
Dry matter	93.8	1 528 961	469 233	1 009 013
Energy	24.5	39 930 108	13 519 644	26 365 196
Protein (Nx6.25)	35.5	578 994	212 586	364 615
Lipid	32.5	529 904	212 940	316 964
EPA	1.5	24 903	24 903	0
DHA	1.1	18 106	18 106	0
Phosphorus	0.90	15 011	6 747	4 645

[1] Calculated from all ingredients used in 2012 and their chemical composition, reported by the three largest Norwegian feed companies (BioMar, Ewos and Skretting)

[2] Calculated from average composition and the total of 1 451 908 tons of feeds used in 2012 (Akvafakta, http://akvafakta.fhl.no/fhl_statistikk/SRL/2013/Akvafakta%2013-01.pdf

Average dry matter content in feed ingredients was 93.8%, and the same average dry matter content was assumed for feed.

[3] Fraction of nutrient of marine origin in the feed ingredients multiplied by the total amount of nutrient used in feed in 2012

[4] Fraction of nutrient of plant origin in the feed ingredients multiplied by the total amount of nutrient used in feed in 2012

2.2.2 Nutrient content in Norwegian farmed salmon

In 2012, 1 232 094 tons of salmon were harvested in Norway (Statistics Norway, 2013). The additionally produced salmon that year is calculated as the difference in biomass from 31th December 2012 to 31th December 2011 (28 747 tons). Thus the total production in 2012 was estimated to 1 260 841 tons. The 1 452 000 tons of feed registered for production of this volume equals an estimated feed conversion factor of 1.15.

The composition of whole body and fillet of Atlantic salmon, and the estimated total amount of nutrients in whole body, edible part and trimmings of farmed salmon produced in Norway in 2012 is shown in Table 6. These data are based on results on fish nutrient content composition obtained in bench mark trials in 2012-13 where salmon were fed diets from BioMar, EWOS and Skretting. Furthermore, it is assumed that 65 % of thesalmon body mass is utilized for human consumption (Matvaretabellen, 2006). The fillet yield will vary depending on several factors, and here the figure for edible part from Matvaretabellen is used. This represents a high fillet yield, and thus, the “true” amount of nutrients in fillet is somewhat lower than the calculated figures, and correspondingly, the amount of nutrients in trimmings higher. A corresponding error will be present in all calculations based on these figures.

The composition of the salmon fed the 2012 diets was comparable to the nutrient content found in salmon fed the 2010 diets for fat, protein, energy and phosphorous (Figure 12). Minor differences in fat content could be caused by different time of slaughter in the two bench mark trials (September and July in the 2010 and 2013 trial respectively). The salmon in 2010 had a higher fat content in whole salmon, but lower in fillet compared to in 2013. Thus, more fat was found in the abdominal cavity in the salmon slaughtered in early September 2010 compared to the fish slaughtered in early July 2013. This is most likely a seasonal effect and not reflecting a change in the diet composition between 2010 and 2012. There was however a reduction in EPA and DHA content in both whole body and fillet due to the reduction of marine ingredients in the diet between 2010 and 2012 (fig 12). There has been concern that the decreasing level of EPA and DHA in farmed salmon would reduce the health benefit of consuming salmon. The European Food Safety Authority (EFSA) recommends a daily intake of 0.25 g EPA and DHA per day for healthy adults to prevent cardiovascular disease. The Norwegian farmed salmon in 2012 still contained 1.36 g EPA+DHA per 100 g of fillet. According to the EFSA recommendations, 130 g of Norwegian farmed salmon per week would be sufficient to supply the recommended intake of EPA and DHA for healthy adults. The 11 159 tons EPA and DHA in the salmon fillets produced in Norway in 2012 would accordingly cover the recommended intake for 122 million people for one year.

Table 6 *Composition of whole body and edible part of Atlantic salmon, and total amount of nutrients in the whole body, edible part and trimmings of Atlantic salmon produced in Norway in 2012. Data on nutrient composition are obtained from a bench mark trial with salmon fed diets from BioMar, EWOS and Skretting in 2013. Calculations of the three latter are based on a total amount of 1 260 841 tons of salmon produced in Norway in 2012 of which 65 % is considered edible (Matvaretabellen, 2006) resulting in 819 546 tons of salmon for human consumption.*

	Whole body composition [1)] (% or MJ/kg)	**Composition of salmon fillet [2)] (% or MJ/kg)**	**Total nutrients in whole body of salmon [3)] (tons or GJ)**	**Total nutrients in edible part of salmon [4)] (tons or GJ)**	**Amount of nutrients in trimmings [5)] (tons or GJ)**
Dry matter	41.2	38.3	519 466	314 050	205 416
Energy	12.6	11.5	15 886 592	9 449 370	6 437 222
Protein (Nx6.25)	17.5	19.1	220 647	156 226	64 421
Lipid	21.3	18.4	268 559	150 797	117 763
EPA	0.60	0.52	7520	4 222	3 297
DHA	0.98	0.85	12 354	6 937	5 417
EPA+DHA	1.58	1.36	19 873	11 159	8 714
Phosphorus	0.35	0.25	4 357	2 012	2 345

[1)] Mean values of salmon (5 kg) fed 3 different commercial diets. Data from Lerøy, not published.
[2)] Mean values of NQC of salmon (5 kg) fed 3 different commercial diets. Data from Lerøy, not published
[3)] Data for whole body composition multiplied by total salmon production in 2012 (1 260 841 tons)
[4)] Data for fillet composition multiplied by total salmon fillet production in 2012 (819 546 tons fillet)
[5)] Nutrients in total salmon produced minus nutrients in edible part produced in 2012.

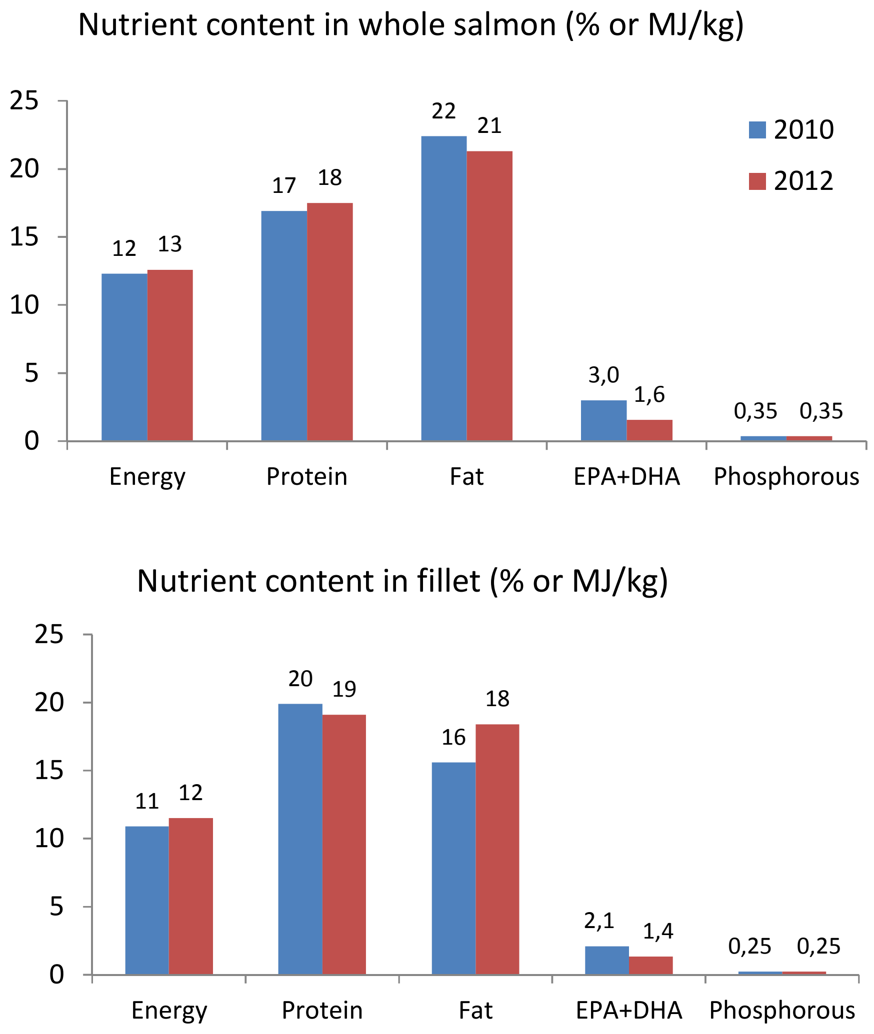


Figure 12 *Nutrient content in whole salmon and fillet in salmon fed commercial diets from BioMar, EWOS and Skretting in bench mark trials in 2010 and 2013 (run by Nofima) The fish were slaughtered in September in 2010 and in July 2013 respectively. Energy content is given in MJ/kg, other nutrients in % (mean values for fish fed the three diets)*

2.2.3 Retention of nutrients in Norwegian farmed salmon

The amount (%) of nutrients and energy from the feed used that is retained in the animal (whole body or edible part) product can be calculated as

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

(Equation 1)

The retention data for Norwegian production of Atlantic salmon in 2012 is shown in Table 7.

The calculation is based on figures from Table 5 and 6. The sources of inaccuracy described for the total amount of nutrients used and fillet yield (above) also apply for the retention data. Furthermore, the retention data are based on feed consumption during one year and salmon production during one year. Thus, the calculation of retention assumes a constant use of feed and production of salmon over a few years, since the production cycle of salmon is more than one year. The retention data includes, in addition to all loss of feed and feed ingredients, all loss of fish (mortality and escapees) and poor and failed productions of both feed and salmon. Thus, the data show the retention of the total amount of nutrients in Norwegian salmon production in 2012. Consequently, these retention data cannot be compared to data from controlled, single productions of salmon or other species which is reported in the literature.

It should be noted that the given retention values for lipids, including EPA and DHA, incorporates the salmon's production of these from non-lipid precursors. Since fatty acids can be produced from carbohydrates and amino acids, 'retention' of lipids, with the given calculation is not a strictly correct term. For simplicity however, the term is still used here since it shows the net flow of these nutrients from feed to salmon fillet. The retention of protein and lipid is sometimes referred to as protein productive value (PPV) and lipid productive value (LPV).

Table 7 Retention (%) of nutrients and energy in whole body, edible part (fillet) and trimmings of Atlantic salmon, and not retained (lost) nutrients in Norwegian salmon production in 2012.

	Retention in whole body of salmon	**Retention in edible part of salmon**	**Retention in trimmings [1]**	**Not retained – loss [2]**
Energy	40	24	16	60
Protein (Nx6.25)	38	27	11	62
Lipid [3]	51	28	22	49
EPA[3]	30	17	13	70
DHA[3]	68	38	30	32
EPA+DHA [3]	46	26	20	54
Phosphorus	29	13	16	71

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

Carbohydrates are not included in the overview of the nutrient flow, partly due to lack of data from analyses. Most of the carbohydrates from feed will either end up as part of the lipid fraction or as energy not retained. It should be noted however, that the increased use of protein ingredients of vegetable origin, which contain indigestible carbohydrates, results in decreased energy retention compared to the previously used fish meal based feeds.

Retention of protein and energy

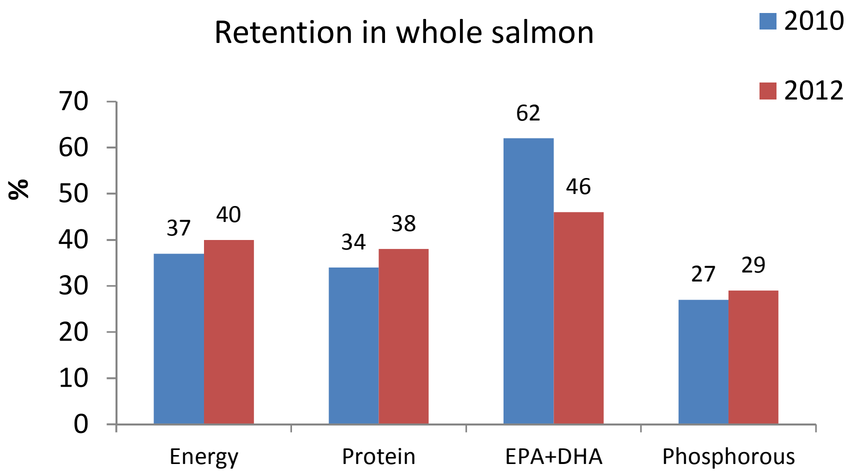
As the data in Table 7 show, 24 % of the energy and 27 % of the protein (nitrogen) in the feed ingredients used in Norwegian salmon farming in 2012 was incorporated into the edible part of salmon to be used for human consumption. This is comparable to what was found for the 2010 salmon production (Figure 13). A direct comparison of the retention values for 2010 and 2012 is not possible, because the fillet retention values in 2010 were based on data on fillet fat and protein content from Matvaretabellen and analysis at NIFES (NIFES Sjømatdata 2010) whereas the retention values from 2012 was based on analysis of fillet of salmon fed diets from EWOS, BioMar and

Skretting in a bench mark trial. The nutrient retention values in whole salmon from 2010 and 2012 are based on analysis of fish from bench mark trials run by Nofima in 2010 and 2013. The fish in these two feeding trial were slaughtered at around 5 kg in the beginning of September 2010 and July 2013, and seasonal effects on fat deposition pattern could have influenced the results and makes it difficult to draw firm conclusions regarding development in nutrient retention between 2010 and 2012. However, there were not any large differences in retention of protein and energy between 2010 and 2012, and the data used in the present study are the most relevant data available. To be able to monitor the production efficiency in Norwegian salmon production over time it is important that data are obtained in a standardised way with respect to final body weight and time of the year that the salmon are slaughtered. The challenge is the availability of data, particularly on the nutrient composition in whole salmon, which is laborious and thus expensive to obtain. However, new methodology such as Nuclear Magnetic Resonance (NMR) and Near Infrared Spectroscopy (NIR) could be used to obtain nutrient content of salmon to a lower cost compared to chemical analysis. Due to the change in protein/fat ratio with season it would be best to include samples taken throughout the year at different locations (for example southern, northern and mid Norway).

It is difficult to find comparable data for other animal productions. Austreng (1994), Åsgård and Austreng (1995), Åsgård et al., (1999) and Bjørkli (2002) have compared the retention of protein and energy in Atlantic salmon, chicken and pig. The data from Bjørkli (Table 8) deviates from the data shown above due to a different method of calculation. However, Bjørkli's calculations are the same for all species, and can be used to compare the different animal productions to each other. According to Bjørkli (2002), protein and energy is most efficiently retained in salmon, whereas chicken retain more protein but less energy than pig.

Table 8 Comparison of the retention of energy and protein in Atlantic salmon, chicken and pig by Bjørkli (2002).

	Retention in salmon fillet	**Retention in chicken, edible part, skin included**	**Retention in chicken, edible part, no skin**	**Retention in pig, edible part**
Energy	23.0	12.1	10.2	14.1
Protein (Nx6.25)	31.4	21.2	20.7	17.9



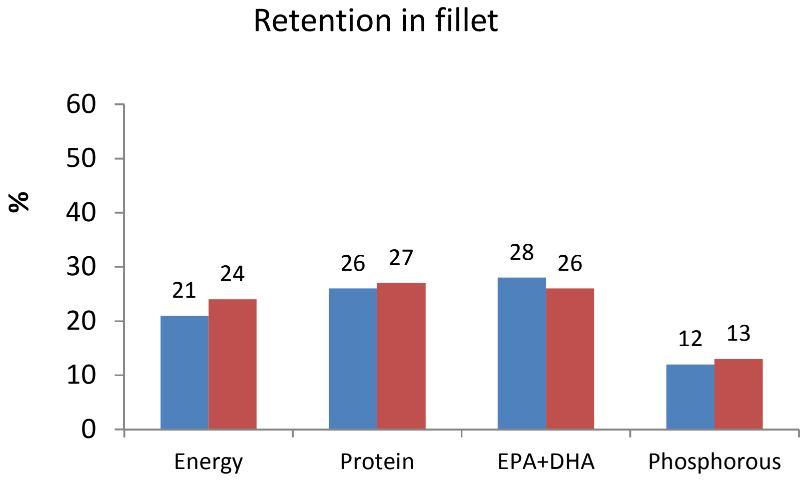


Figure 13 *Estimated retention of nutrients and energy (% of content in feed ingredients) in fillet and whole salmon produced in Norway in 2010 and 2012. The retention values in 2010 and 2012 are calculated on the basis of nutrient and energy content in salmon fed commercial diets from BioMar, EWOS and Skretting in bench mark trials run by Nofima in 2010 and 2013. The fish were slaughtered in September 2010 and in July 2013 respectively.*

Although the concept ‘retention’ is often referred to in the calculations above, it is also used as a collective term for any calculation of efficiency of energy or nutrient utilisation from feed into food product. Another commonly used way to describe protein utilization, is the protein efficiency ratio (PER), which is a measure of weight increase per amount of protein fed:

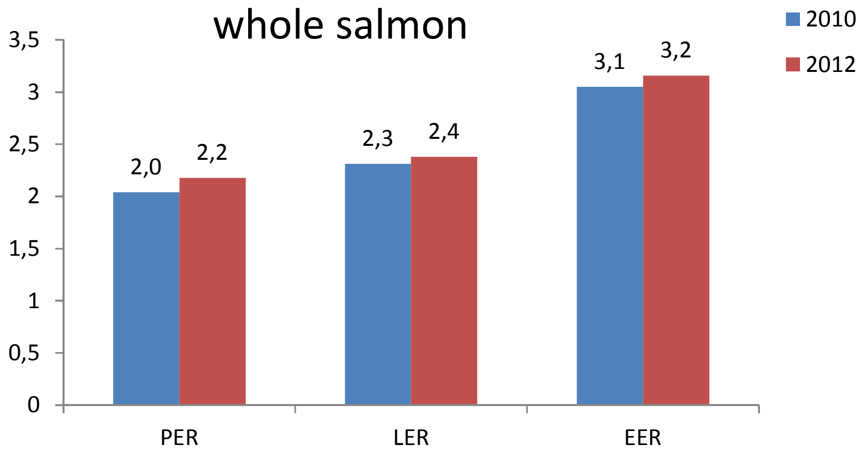
$$\text{PER} = \frac{\text{Body weight or biomass produced (kg or tons)}}{\text{Protein fed (kg or tons)}}$$

(Equation 2)

Producing 1 260 841 tons of salmon from 578 994 tons of protein (Nx6.25) result in a PER value of 2.2 in Norwegian farmed salmon in 2012 (2.0 in 2010). Using the same calculation for the 819 546 tons of edible part of salmon produced, the PER value for the edible part of salmon in 2012 was 1.4 (1.3 in 2010).

The similar calculation for energy efficiency ratio (EER) gives an EER in whole salmon of 3.2 and 2.1 in fillet.

The corresponding estimate can be given for lipid efficiency ratio (LER). For whole salmon and salmon fillet the LER values are 2.4 and 1.5 (2.3 and 1.5 in 2010, respectively). Although the calculation uses the amount of nutrient (protein or lipid) in feed, the increase in body weight is used for measurement of utilisation. The PER (and EER and LER) does not distinguish between differences in body composition between species. Besides, protein and lipid retention and PER and LER are expressions of total protein and lipid retention, and do not separate between origin of the feed ingredients such as marine or vegetable ingredients, or offal. These calculations of PER and LER can, as the retention data, not be compared to PER and LER data obtained for single productions or in studies.



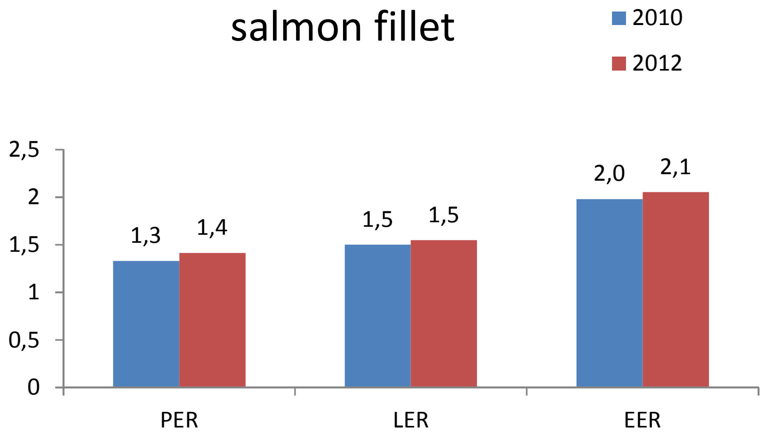


Figure 14 Nutrient productive values in fillet and whole salmon produced in Norway in 2010 and 2012. The efficiency ratios of protein, lipid and energy are calculated on the basis of nutrient and energy content in salmon fed commercial diets from BioMar, EWOS and Skretting in bench mark trials run by Nofima in 2010 and 2012. The fish were slaughtered in September 2010 and in July in 2013 respectively.

Whereas the health benefits of consumption of Atlantic salmon are often ascribed to its high content of long-chain polyunsaturated fat, the protein in fish is also beneficial for human health (Wergedahl *et al.*, 2004, Bergeron and Jacques, 1989, It-Yahia *et al.*, 2003, Liaset *et al.*, 2009). A general increase in fish consumption is recommended in Norway, although no specific recommendations on weekly intake are given (Anonymous, 2010). Recommended daily protein intake in Norway is 15 % (10-20 %) of the energy intake (Anonymous, 2010). Assuming a person's daily energy intake is 10,000 kJ, and the energy content in protein is 23.7 kJ/g, the recommended daily protein intake is 63 g per day. Given a protein content in salmon of 19.9 % and in 18.6 % in chicken (whole chicken with skin included; Matvaretabellen, 2006), 63 g protein corresponds to 317 g salmon fillet or 339 g of chicken. Edible parts of both salmon and chicken with skin is 65 % (Matvaretabellen, 2006) resulting in 487 g salmon or 521 g chicken produced to yield 63 g protein.

Globally, sufficient protein production for the world's growing population is a challenge, and protein intake is suboptimal in certain parts of the world (Muller and Krawinkel, 2005). Therefore, the protein retention in aquaculture and other food production is an important factor when assessing sustainability. During a nine month period, Torstensen et al. (2008) found similar protein retention and PER in Atlantic salmon fed a pure marine feed and feeds with up to 80 % of the fish meal and 70 % of the fish oil replaced by vegetable ingredients (and some krill meal). The protein retention given for salmon fed the marine-based feed was 50 %, and the PER given for three separate periods was 2.80, 3.03 and 2.81 (Torstensen *et al.*, 2008). In accordance, Bendiksen et al. (2011) found no significant difference in PER in Atlantic salmon fed diets containing from 10 % to 20 % fish meal, and 50 % of the oil from vegetable origin. In that study, the PER for the salmon fed the highest fish meal inclusion was 2.73. Both these studies show that Atlantic salmon can be produced with feeds containing high inclusion of ingredients of vegetable origin, and only low amounts of marine ingredients. However, the sustainability of exchanging marine ingredients (fish meal and fish oil) with plant ingredients should be assessed thoroughly, since production of plant ingredients requires water, fertilizers, phosphorus, pesticides, land area and transportation and contributes to depletion of the soil. Most plant ingredients can also be used for human consumption, and the benefit of substituting marine ingredients produced from well managed fisheries is not obvious.

Retention of EPA and DHA

EPA and DHA are nutritionally important for human consumption, and salmon is an important dietary source of these fatty acids in Norway. From a consumer perspective, high concentration of EPA and DHA in salmon, and thus in feed, is desired. Marine ingredients were the sources of EPA and DHA in Norwegian salmon feed in 2012, and since fish meal and fish oil are limited resources, both retention of EPA and DHA and the utilisation of these from offal are important aspects. As shown in Table 5, 24 903 and 18 106 tons of EPA and DHA, respectively, were used in Norwegian salmon feed in 2012. In whole salmon 46 % of EPA+DHA was retained, in fillet 26 % was retained, and 20 % was retained in trimmings, whereas 54 % of EPA+DHA in the feed were not retained by the salmon. These retention values include the salmon's production of EPA+DHA.

There fillet retention of EPA and DHA was similar in 2010 and 2012, whereas there was apparantly a lower retention of these fatty acids in whole salmon in 2012 than in 2010.(Figure 13). However, the lower retention of EPA and DHA in whole salmon in 2012 is most likely an effect of different time of slaughter (July in 2013 versus September in 2010) of the salmon used as reference with respect to nutrient composition. The decrease in EPA and DHA in the feed between 2010 and 2012 would be expected to increase the retention of EPA and DHA in the salmon. However, there may be seasonal variations in salmon in the utilisation and retention of omega-3 fatty acids. A better understanding of the environmental and physiological factors that affect the retention and the nutritional requirements of EPA and DHA in salmon will make it possible to optimise the content of these valuable fatty acids in the salmon diet so that as much as possible is retained in the fillet.

The retention of DHA was higher than the retention of EPA both in whole salmon and in fillet. The retention of omega-3 fatty acids in whole salmon and trimmings was lower in 2012 compared to in 2010. This was particularly evident for EPA, where 70 % of the EPA in the feed ingredients is "lost" whereas 32 % of the DHA in the feed ingredients was not retained in the salmon. The retention of DHA was also higher in all body compartments than the retention of EPA (Table 7). This may reflect a higher metabolism of EPA, being a precursor of DHA. It is also worth mentioning that the sources of fish oil changed between 2010 and 2012. In 2012, 75 % of the fish oil in the diet came from the North Atlantic, whereas in 2012, fish oil from South America accounted for almost half of the total fish oil (Figure 11). Fish oils from the North Atlantic have a lower concentration of EPA compared to South American oils, so the ratio of EPA:DHA in the feed was higher in 2012 than in 2010 (1.4 and 1.2 respectively).

Retention of phosphorus

Phosphorus is a required nutrient for both plants and animals, and is therefore added in both agricultural fertilizers and animal feeds. The world's currently available phosphorus sources are limited and phosphorus is considered to be a limited resource for food production in near future. The ingredients used by the three feed companies BioMar, Ewos and Skretting for aquaculture feed production in 2012 contained 15 011 tons of phosphorus, of which 6 747 tons (45 %), originated from marine ingredients, 4 645 tons (31 %) originated from plant ingredients, and the remaining 3 620 tons (24%) was added as crystalline mineral compounds. The 1 451 908 tons of feed that was used in

2012 contained 0.9 % P, in total 13 070 tons of phosphorus. 30 % of the dietary phosphorus was retained in the salmon (Table 7), meaning that 70 % of the feed's phosphorus was released to the sea. Thus, of the 13,070 tons of phosphorus in the feed, 70 % loss amounts to 9 278 tons. This is more than what originate from the marine ingredients in all aquaculture feed used. Consequently, much of the phosphorus used for growing crops for feed ingredients is transferred to the sea, and therefore, increased use of plant ingredients in fish feed increases the drain of phosphorus from land to sea. Furthermore, some plant ingredients contain components such as phytic acid which decrease phosphorus absorption in the salmon's intestine, thus increasing the need for added phosphorus. From a phosphorus sustainability perspective, plant ingredients are therefore not beneficial unless phosphorus discharged from aquaculture is effectively captured and reused. Improving availability of phosphorus from the marine ingredients in particular and all sources in general, would improve the resource balance of phosphorus.

2.3 Indicators of marine resource use

One of the main concerns raised against the increase in salmon production is the use of wild fish stocks for production of fish meal and oil. The concern is based on the assumption that aquaculture production is consuming large amounts of pelagic fish for feed that could have been used as human food, and therefore that the salmon industry is reducing the amount of marine protein available for human consumption (Naylor et al., 2000, 2009, Naylor and Burke, 2005). Other authors claim that the use of marine resources in aquaculture feeds are a sustainable way of providing marine nutrients for human consumption (Shepard et al., 2005, Welch et al., 2010). To quantify the use of marine resources in aquaculture productions several indicators for the use of forage fish in aquaculture productions have been developed.

2.3.1 The fish in-fish out ratio (FIFO)

The fish in-fish out ratio transforms the amount of fish meal and oil that is used to produce one weight equivalent of farmed fish back to wild fish weight equivalents (usually a kg or ton), and it is often used as a measure of the amount of marine resources that is consumed in the production of farmed fish. The calculation of the FIFO ratio is based on two conversion ratios. The first is the conversion ratio of forage fish into fish meal (FM) and fish oil (FO). 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 225 g of fish meal and 50-120 g of fish oil (IFFO, 2010). The second conversion ratio is the amount of feed (kg) consumed to produce one kg of salmon (economic feed conversion ratio, eFCR):

$$\mathrm{FIFO} = \left[\frac{\text{Diet FM (g/kg)}}{\text{FM reduction efficiency (g/kg)}} + \frac{\text{Diet FO (g/kg)}}{\text{FO reduction efficiency (g/kg)}}\right] \cdot \mathrm{eFCR}$$

(Equation 3)

However, because the relationship between meal and oil yield from reduction fish is approximately 5:1, it is the amount of fish oil in the diet that will determine the dependency of reduction fish and the FIFO ratio, so the FIFO ratio should be calculated separately for fish oil and fish meal:

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

(Equation 4)

Improvements in production technology has led to a greater protein recovery from whole fish and the latest yield figures from the industry range from 23.5-24.5 % fish meal from whole fish (Jackson, 2009, Péron et al., 2010).

The FIFO ratio is very sensitive to oil yield. Thus, using herring and capelin with high fat content in fish oil production will reduce the FIFO ratio whereas using oil from leaner species such as anchovies (5 % oil yield) will increase the FIFO ratio for fish oil. The oil yield is dependent on the fat content of the forage fish that vary a lot between species and also within the same species during the year (Figure 15). Doubling the oil yield from the forage fish will reduce the FIFO ratio for fish oil by half (Figure 16).

Using Equation 4, the FIFO for fish meal and oil in Norwegian salmon production in 2012 and 2013 was estimated. For fish meal a mean yield of 22.5 % was used (IFFO) and for fish oil a yield of 7.5 % was used based on a weighted mean of the oil yield of the species used for production of fish meal in 2012 and 2013. The economic feed conversion ratio was 1.15 in 2012 and 1.23 in 2013

$$\text{FIFO}_{(\text{FO 2012})} = [\ 112\ (\text{g/kg}) / 75\ (\text{g/kg})\ ]\ *\ 1.15 = \underline{1.79}$$

$$\text{FIFO}_{(\text{FM 2012})} = [\ 195\ (\text{g/kg}) / 225\ (\text{g/kg})\ ]\ *\ 1.15 = \underline{1.02}$$

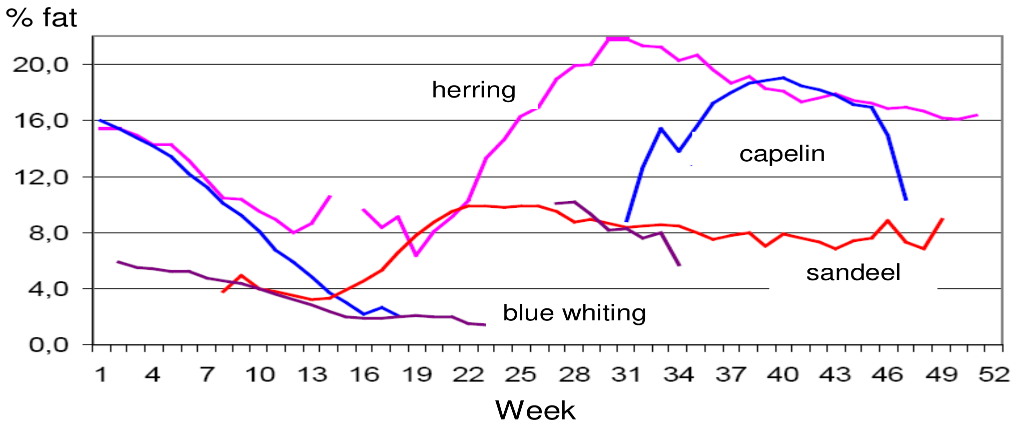


Figure 15 Variation in mean fat content by season in some of the species used in fish meal and oil for production of Atlantic salmon in Norway in 2012 and 2013.

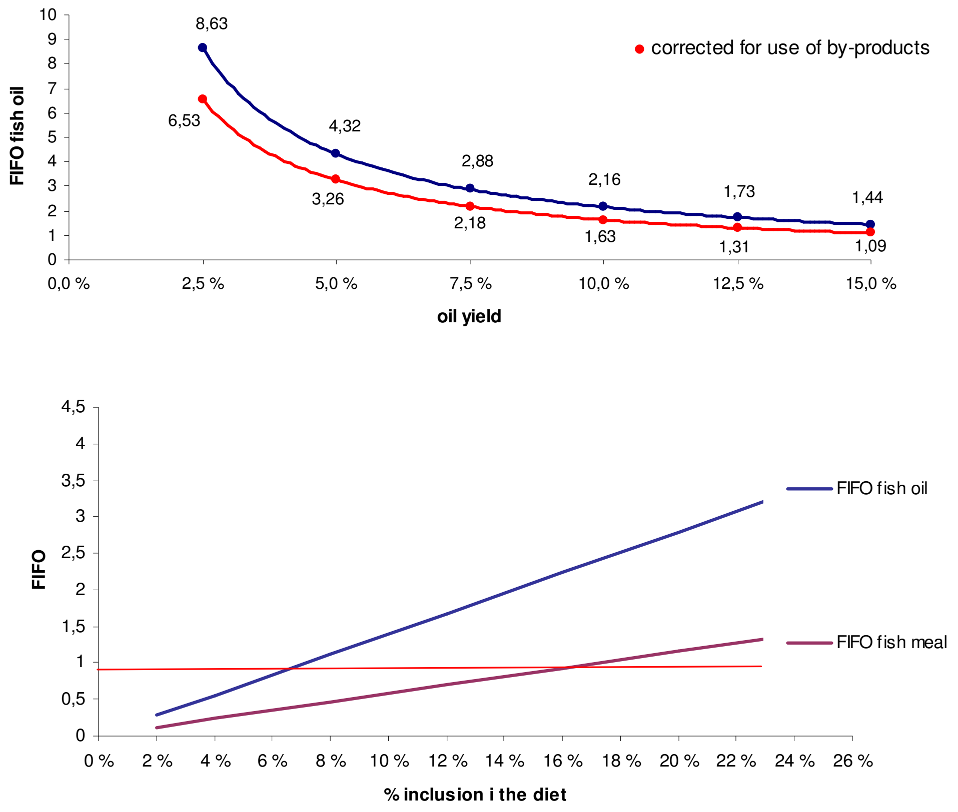
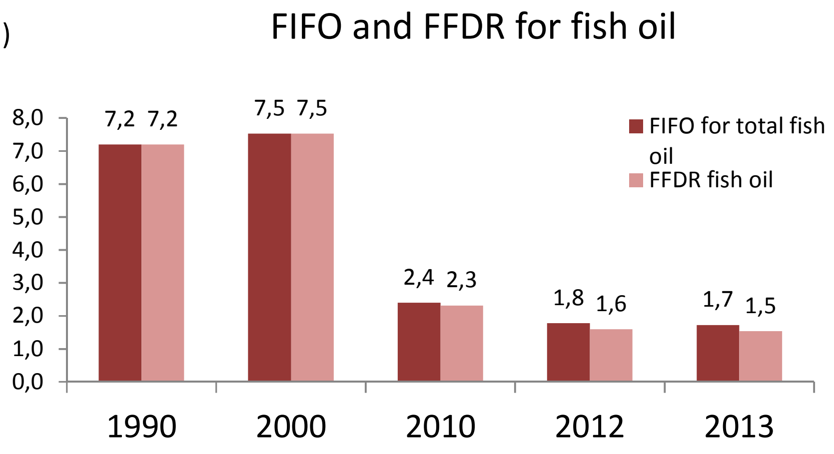


Figure 16 *a) FIFO as a function of the conversion efficiency of reduction fish into fish oil. b) FIFO ratio as a function of the inclusion level of fish meal and oil in the diet. Data from 2010 are used in the calculations (FCR = 1.3, inclusion level of fish oil was 16.6% of which 24 % came from trimmings and by products. The fish meal and oil yield from forage fish is 22.5 and 9.3 % respectively).*

a)



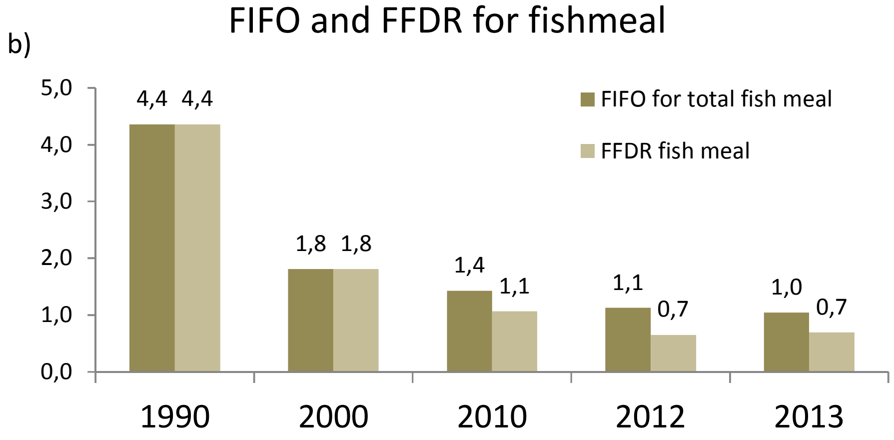


Figure 17 FIFO for total amount of marine ingredients and forage fish dependence ratios (FFDR) in Norwegian salmon farming between 1990 and 2013 (a) fish oil, (b) fish meal.

The FIFO ratio is often used and published FIFO values for salmon production during the last decade range from less than 2 to 8.5 (Tacon and Metian, 2008, Jackson, 2009, Naylor et al., 2009, Bendiksen et al., 2011). The development of FIFO for fish oil and meal in Norwegian aquaculture over the past two decades is shown in Figure 17 a) and b) respectively. The variation in reported FIFO values is a result of different inclusion levels of marine ingredients, different feed conversion ratios and different conversion efficiencies of industrial fish into fish oil and meal. There are also currently several ways of calculating the FIFO ratio. Kaushik and Troell (2010) calculate a FIFO based on either fish meal or oil in accordance with what is done in the present report. Tacon and Metian (2008) also calculate a separate FIFO for fish oil in a similar way, but subtract the possible fish oil yield from the fish meal transformation. However, Naylor et al. (2009) calculate one reduction fish equivalent for meal ($RFE_{(FM)}$) and one for additional fish oil used ($RFE_{(AO)}$) and sum up these values to give a combined FIFO required to produce a kg of farmed fish. Neither Tacon and Metian (2008) or Naylor et al. (2009) subtract the amount of fish meal and oil made from trimmings and by products from the total budget. The increasing use of trimmings and by products from aquaculture productions in feeds for aquaculture makes the use of FIFO ratios less reliable as a measure of the amount of marine resources that is consumed by the aquaculture industry.

Jackson (2009) proposed another approach to address this issue in a more global perspective for several aquaculture productions with different demand for fish oil and fish meal. Thus, a FIFO ratio is calculated for a combination of several aquaculture productions with different dependencies on fish meal and oil. The argument for this is that the surplus of fish meal from the production of salmon feed is used in the aquaculture production of other species such as shrimp or carp that have a higher requirement for fish meal than fish oil in the diet. In theory, this way of calculating a FIFO ratio for an aquaculture production will reflect what is actually consumed of marine ingredients. When this calculation method is used on the total global aquaculture production, the estimated volume of wild fish consumed as fish meal and oil is in agreement with what is estimated by FAO (20.2 million tons of wild fish in 2006). Thus, this method gives a more realistic estimate of the amount of wild fish that is used in an aquaculture production than the calculation used by Naylor et al. (2009).

Irrespective of what calculation method is used to estimate FIFO, the FIFO ratio is not an indicator of sustainable use of marine resources, because sustainability must be based on a responsible harvest of fish species that are used for fish oil and fish meal according to international fishery regulations.

2.3.2 Forage fish dependency ratios according to the ASC standards

The Aquaculture Stewardship Council (ASC) has included the Forage Fish Dependency Ratios for fish meal and oil as one of its indicators of performance. These ratios calculate the quantity of forage fish required to produce the amount of fishmeal and oil used to produce a unit of farmed fish. Fishmeal and fish oil that originate from trimmings are excluded from the calculation as long as they do not originate from species that are endangered or vulnerable in the IUCN Red List of Threatened species. The amount of fish meal in the diet is calculated back to live fish weight by using a yield of 24 % (Péron et al., 2010). The amount of fish oil in the diet is calculated back to forage fish live weight by using a 5 % yield of fish oil for fish originating from Peru, Chile and the Gulf of Mexico and a 7 % oil yield for fish originating from the North Atlantic.

$$FFDR_{FM} = \frac{\text{(\% Fishmeal in feed from forage fisheries)* eFCR}}{\text{Meal yield (24 \%)}} \qquad \text{(Equation 5)}$$

$$FFDR_{FO} = \frac{\text{(\% Fishoil in feed from forage fisheries)* eFCR}}{\text{Oil yield (5 or 7 \%)}} \qquad \text{(Equation 6)}$$

The ASC standards for $FFDR_{FM}$ and $FFDR_{FO}$ are <1.35 and <2.95 respectively (http://www.asc-aqua.org/)

In 2012, 28.7 % of the fish meal and 22 % of the fish oil came from trimmings and byproducts. In 2013, 25 % of the fish meal and 27 % of the fish oil came from trimmings. In 2010, the majority of the marine ingredients came from the North Atlantic. However, in 2012 a larger fraction of the marine ingredients came from South America (figure 11), so a weighted mean of 6.1 % for oil yield was used to calculate the forage fish dependence ratio according to the ASC standards.

$$FFDR_{FM2012} = (13.6 * 1.15) / 24 = \underline{0.7}$$

$$FFDR_{FO2012} = (8,8 * 1.15) / 6.1 = \underline{1.6}$$

For 2013 the corresponding Forage fish dependence ratios are 1.54 and 0.69 for fish oil and meal respectively (weighted mean for oil yield of 6.3 due to more forage fish originating from the north Atlantic and FCR of 1.23 for 2013). The Norwegian salmon industry is thus well below the ASC standards for dependency of forage fish, both for fish meal and oil.

2.3.3 Marine nutrient dependency ratios

The amount of marine resources consumed in relation to marine nutrients produced can be expressed more accurately by calculating nutrient-to-nutrient ratios. Crampton et al. (2010) suggested to use a "Marine nutrient dependency ratio" (MNDR) as an alternative to the FIFO ratio. The Marine nutrient dependency ratio (MNDR) is the ratio of each marine-derived nutrient used to feed salmon divided by the amount of each marine nutrient produced as a result of salmon farming (Crampton et al., 2010). Thus, it estimates the amount of marine protein and oil produced in salmon farming relative to how much marine protein and oil that is consumed in the form of forage fish. Dietary protein sources and oils or lipids from all capture fish, shellfish or zooplankton are classified as marine sources. The lipids contained in fishmeal and other marine sources are counted as part of the dietary marine oils. Marine Protein Dependency Ratio (MPDR) and Marine Oil Dependency Ratios (MODR) are calculated as:

$$\text{MPDR} = \frac{(\%\,\text{MP in feed}) \cdot (\%\,\text{protein in MP}) \cdot (\text{kg feed eaten})}{(\text{BW(f)} \cdot \%\,\text{body protein}) - (\text{BW(i)} \cdot \%\,\text{body protein})} \qquad \text{(Equation 7)}$$

$$\text{MODR} = \frac{[\%\,\text{FO in feed} + (\%\,\text{FM in feed} \cdot \%\,\text{fat in FM})] \cdot (\text{kg feed eaten})}{(\text{BW(f)} \cdot \%\,\text{body fat}) - (\text{BW(i)} \cdot \%\,\text{body fat})} \qquad \text{(Equation 8)}$$

Where MP is the marine protein sources (e.g. fishmeal) in the feed and FO is the fish oil, BW(f) is the slaughter weight of salmon and BW(i) is the initial bodyweight.

The mean protein and fat concentration in the fish meal is 70 % and 10% respectively. Whole body lipid and protein concentration was 21 and 18 % and the initial protein and lipid concentration in the fish was assumed to be 18 and 10 % respectively.

The MPDR and MODR for the salmon production in Norway between 1990 and 2013 are shown in Figure 18.

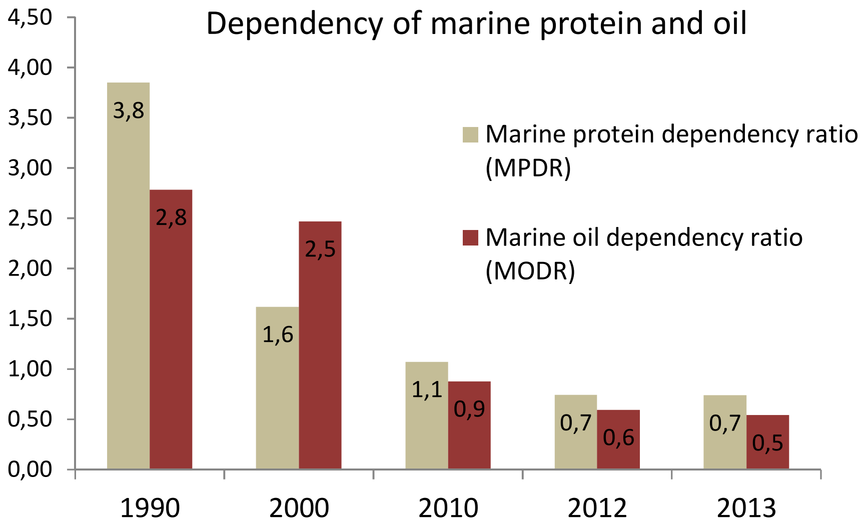


Figure 18 Marine nutrient dependency ratios for marine protein and oil for the Norwegian salmon production between 1990 and 2013 (Data are corrected for inclusion of fish meal and fish oil from trimmings and by-products).

3 Concluding remarks

When assessing the environmental efficiency of food production systems it is vital to identify the processes that consume most of the energy and resources and generates most of the emissions. Life cycle assessment methodology (LCA) has been most widely used to study the efficiency of food production systems. However, the LCA methodology has its limitations, in its current form it does not track the flow of nutrients in food production systems and there is no consensus in how the environmental impacts should be allocated between co-products in a production with multiple outputs. Recycling of nutrients from agro-industrial by-products back into animal productions is a key factor in increasing the environmental efficiency of food production, and is positive for the overall productivity and efficiency. For tracking of nutrient flow and estimating the nutrient retention efficiency mass balance models are more suited than LCA models. It is essential to be able to track the major flows of protein, lipid, minerals and fatty acids in food production systems, and knowing how efficiently the nutrients are utilised. Availability of representative data on nutrient composition of the feed, final product and, particularly in the parts of the salmon that are not consumed by humans, is vital for tracking the nutrient flows when making a resource budget for a food production system. It must also be mentioned that an increasing amount of the offal from salmon production is used for production of health products for human consumption, both protein concentrates and omega-3 products. So the total amount of nutrients from the Norwegian salmon production that are utilised by both humans and for other food productions should be included in the resource budget for Norwegian salmon production in the future.

Finally it is important to have in mind that when assessing the resource utilisation in a food production system one have to look at the entire chain from harvesting of feed ingredients and production at the farm to how much of the final product that is actually consumed by humans. FAO has estimated that 30 % of the food produced in the world is not consumed by various reasons (FAO 2011a). In the developed world, retailers and consumers are responsible for most of the waste whereas in developing countries, losses occur mainly during harvest and storage of food. Avoiding these losses will reduce the demand for land, water, energy and reduce the GHG emissions. Thus, more focus should be directed towards reducing food losses after the product leaves the farm gate when the goal is to provide food for human consumption in the most efficient way from a resource utilisation perspective.

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