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Utilisation of feed resources in production of Atlantic salmon (*Salmo salar*) in Norway

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ABSTRACT

In 1990, 90% of the ingredients in Norwegian salmon feed were of marine origin, whereas in 2013 only around 30%. The contents of fish meal and fish oil in the salmon feed were 18% and 11%, respectively, in 2013. Between 2010 and 2013, salmon production in Norway increased by 30%, but due to a lower inclusion of marine ingredients in the diet, the total amount of marine ingredients used for salmon feed production was reduced from 544,000 to 466,000 tonnes. Norwegian salmon farming consumed 1.63 million tonnes of feed ingredients in 2012, containing close to 40 million GJ of energy, 580,000 tonnes of protein and 530,000 tonnes of lipid. 1.26 million tonnes of salmon was produced. Assuming an edible yield of 65%, 820,000 tonnes of salmon fillet, containing 9.44 million GJ, and 156,000 tonnes of protein were produced. The retentions of protein and energy in the edible product in 2012 were 27% and 24%, respectively. Of the 43,000 tonnes of EPA and DHA in the salmon feed in 2012, around 11,000 tonnes were retained in the edible part of salmon. The retentions of EPA and DHA were 46% in whole salmon and 26% in fillets, respectively. The *fish in/fish out ratio* (FIFO) measures the amount of fish meal and fish oil that is used to produce one weight equivalent of farmed fish back to wild fish weight equivalents, and the *forage fish dependency ratio* (FFDR) is the amount of wild caught fish used to produce the amount of fish meal and fish oil required to produce 1 kg of salmon. From 1990 to 2013, the forage fish dependency ratio for fish meal decreased from 4.4 to 0.7 in Norwegian salmon farming. However, weight-to-weight ratios such as FIFO and FFDR do not account for the different nutrient contents in the salmon product and in the forage fish used for fish meal and fish oil production. *Marine nutrient dependency ratios* express the amount of marine oil and protein required to produce 1 kg of salmon oil and protein. In 2013, 0.7 kg of marine protein was used to produce 1 kg of salmon protein, so the Norwegian farmed salmon is thus a net producer of marine protein.

Statement of relevance

This manuscript shows the retention efficiency of nutrients from feed resources to final product in the Norwegian salmon production, including limiting resources such as the omega-3 fatty acids EPA and DHA and phosphorous. It is highly relevant to compare the efficiency in commercial scale with experimental data, and this is to our knowledge the first attempt to make such calculations for an entire commercial aquaculture production.

1. Introduction

The world's population is currently increasing by 80 million each year, and is expected to reach 9 billion by the year 2050. The Food and Agricultural Organization of the United Nations (FAO) has predicted that 70% more food must be produced globally by 2050 to meet the increase in demand. The population growth, combined with increased urbanisation and higher *per capita* income in large parts of the world, changes consumption habits and puts pressure on the available resources. The *per capita* meat consumption was 15 kg in 1982, when the world population was 4.5 billion, and is expected to reach 37 kg in 2030. This will have a large impact on the environment and the available resources of land area, fresh water, and phosphorus, and urgent action to develop food systems that use less energy and emit less greenhouse gases is required (FAO, 2011a). The global food sector is currently responsible for around 30% of the world's energy consumption and contributes more than 20% of the global greenhouse gas emissions (FAO, 2011b). In addition, land use changes, mainly through deforestation, contribute another 15% of greenhouse gas emissions.

Any method of food production can be evaluated in terms of the influence it has on the environment and how much natural resources are consumed in the process (Bartley et al., 2007; Kates et al., 2001; Singh et al., 2009). Eagle et al. (2004) defined *ecologically sustainable*

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food production as production that maintains the natural capital on which it depends, and that in principle can continue indefinitely. Well-managed fisheries where the catch is regulated based on stock assessment fulfil this definition. However, no industrial food production is truly sustainable today, because all such productions depend on non-renewable energy sources such as oil and gas, as well as non-renewable phosphorous sources. Industrial food productions may be evaluated in terms of energy produced in relation to the input of industrial energy (Tyedmers et al., 2007). When the sustainability of food productions is evaluated, the goal should be to maximise the nutritional output for human consumption and minimise the input of resources (organic and inorganic), with the lowest possible impact on the environment. The nutritional content of food products is easy to calculate, but it is more challenging to quantify the use of natural resources and to assess the environmental effects of different food production systems (Schau and Fet, 2008).

All food production has environmental consequences. Agriculture is the main source of water pollution by nitrates, phosphates and pesticides, and livestock production is a major source of greenhouse gases. Livestock production uses large amounts of fresh water and land areas. The global meat consumption is increasing by around 3.6% per year and has nearly doubled between 1980 and 2004. It is expected to double again by 2030 (FAO, 2011b). There is also a shift from extensive grazing systems to more intensive production systems that depend on more concentrated feeds and feed ingredients that are traded internationally. More than 30% of the world cereal production is currently used in feed for livestock. Global food production is also heavily dependent on the use of phosphorus fertilizer. The low phosphorous concentration in soil in large parts of the world makes it a limiting factor for plant growth on entire continents such as Africa and Australia, and in many large countries such as Brazil and India. Phosphorus is thus essential for global food production, and agriculture consumed almost 90% of the P used in 2010, 82% was used in fertilizers and 7% was used in animal feed supplements (Schröder et al., 2009). However, the current use of phosphorus is not sustainable. Phosphorus is not recycled at present, but moves through an open one-way system in which the phosphorus ends up in the ocean. A meat-rich diet consumes three times as much P as a vegetarian diet, and for a world population of 7.7 billion people, a 20% increase in phosphorous-fertilizer would be required without changes in the world diet, whereas a 64% would be required if the complete world population were to have a diet that resembles the diet in developed countries (Smit et al., 2009).

With less space and water resources available on land, growing food in the ocean is an attractive option. Aquaculture now accounts for almost half of the total food fish supply and the percentage is increasing every year (FAO, 2012). The rapid growth in the aquaculture industry has raised concerns among consumers, retailers and non-governmental organisations about the environmental impact and sustainability of fish farming. The dependence of the aquaculture feed industry on fish meal and fish oil and the consequences for wild fish stocks are often used as arguments against the sustainability of salmon production (Deutch et al., 2007; Naylor et al., 2000; Tacon and Metian, 2008). Forage fish are often small pelagic fish at lower trophic levels that are important prey for species higher up in the food chain (Fréon et al., 2005). The majority of the world's fish resources are fully exploited or overexploited (FAO, 2012). A further growth in aquaculture must therefore rely on an increase in the use of alternative sources of lipid and protein. There is, however, still a potential for an increased utilisation of discards and by-products from the processing of fishery products for human consumption. Approximately 25% of the fish meal produced worldwide originates from trimmings, but the potential is larger, considering that around 120 million tonnes of fish are consumed by humans. If the edible portion is around 50%, there are roughly 60 million tonnes of trimmings and by-products available for the production of fish oil and fish meal. This is three times the amount of forage fish used for this purpose today. Improved regulation and management of the capture fisheries are necessary for a sustainable and optimal utilisation of the marine production systems.

Farming of Atlantic salmon has been seen as negative due to the use of small pelagic fish in the feed, and it has been claimed that salmon farming reduces the amount of marine protein available for human consumption (Naylor and Burke, 2005; Naylor et al., 2000, 2009). In common with all food production, aquaculture has environmental consequences, and feed production is a major input factor in salmon production (Ellingsen et al., 2009; Pelletier et al., 2009). An understanding of the environmental impact of different feed formulations and how they affect resource utilisation is thus important for making strategic decisions about food production regimes (Åsgård and Austreng, 1995; Åsgård and Hillestad, 1998; Åsgård et al., 1999; Einen et al., 1995; Torrissen et al., 2011). Several indicators and methods for measuring the sustainability and production-efficiency of aquaculture productions have been developed, such as the simple fish in/fish out ratio, forage fish dependency ratio, marine nutrient dependency ratio and nutrient retention and nutrient flow models (Einen et al., 1995; Papatryphon et al., 2005; Roque d'Orbcastel et al., 2008). More extensive methods such as the ecological footprint model and life cycle analysis (LCA) are also used to assess the sustainability of aquaculture and other food production systems. These methods are complementary and cover different aspects of biophysical performance and resource efficiency. Evaluating the sustainability of food production methods is complicated, and many aspects must be addressed. There is currently no single method that is robust enough to cover all environmental impacts related to food production, and several methods must be used to evaluate eco-efficiency and sustainability.

2. Methods

Nutrient flow analysis can provide information about the environmental impact of food-producing activities and the efficiency of resource utilisation. The efficiency of a production method is affected by many factors, such as feeding routines and diet composition. The efficiency can also be improved by selective breeding for improved performance (Gjedrem, 2010; Grisdale-Helland et al., 2013; Thodesen et al., 1999). The conversion of feed to edible product determines the amount of biological material that is released to the surrounding environment. The *feed conversion ratio* (FCR) is the amount of feed (in kilograms) required to produce 1 kg of farmed animal (round weight). The *biological feed conversion ratio* is based on the feed eaten, whereas the *economic feed conversion ratio* (eFCR) includes also production losses (uneaten feed, mortalities, escapees), and is therefore higher than the biological FCR. The assimilation efficiency of nutrients is also crucial for the waste output — both the amount of nutrients digested and the amount of the digested nutrients that are retained in the fish. A high feed intake and an optimal energy/protein ratio are necessary for obtaining maximum growth and feed utilisation, as is also satisfying the requirements for essential amino acids, fatty acids and minerals. The retention efficiency of nutrients is normally calculated as a percentage of the amount eaten. The ratio of the total industrial energy invested in food production to the edible protein energy return has been used as a measure of the energy efficiency of food-production systems, and has been suggested also as a sustainability indicator (Troell et al., 2004). However, the energy produced in the form of fat should also be accounted for, because not only protein, but also lipid is produced and contributes to the energy output of the food production methods. An alternative is to use input and output ratios for protein, lipid and energy to assess the efficiency of food production methods.

Nutrient flow models were used to estimate the nutrient retention efficiency in Norwegian salmon production in 2012. Representative data for the nutrient content of the feed, salmon fillets and the parts of the salmon that are not utilised for human consumption must be available in order to track the nutrient flows in a resource budget for salmon. The Norwegian aquaculture industry is required to report detailed