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Assessment of the Sustainability of Organic Salmon Farming

by

Sigbjørn Tveterås

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Introduction

This paper is concerned with the sustainability of organic salmon farming, an emerging segment of salmon aquaculture. The sustainability of organic farming can not be analysed in isolation, since production practices are similar to conventional farming. Furthermore, since most of the accumulated experience is from conventional salmon farming, the reference point in this paper is conventional salmon aquaculture, which is used as a benchmark for organic salmon production.

This paper reviews sustainability issues raised by current standard and practises in the salmon farming industry. We will mainly focus on the use of inputs in salmon aquaculture, and externalities like waste emissions and salmon escapees in the sustainability assessment. However, we will also assess some solutions intended for a more environmental friendly and sustainable production, e.g. salmon feed based on fish offal and improved methods for handling organic waste.

The salmon farming industry has experienced a tremendous growth over the last twenty years. Global annual industry output growth has averaged 27% in the period from 1980 to 1998[1]. The rapid growth in output is projected in Figure 1, showing global output for farmed salmonid species from 1985 to 1998. Atlantic salmon is clearly the dominating species, accounting for more than 70% of the total farmed quantities. Figure 2 depicts the annual output by countries. Norway is the largest producer, followed by Chile, UK and Canada. Salmon and trout production has even exceeded the combined production of poultry, pork and beef in Norway: in 1997 salmon and trout production was 350,000 tonnes versus a total production of 253,000 tonnes of poultry, pork and beef.

Fishmeal and fish oil utilisation is one of the issues raised by input use in salmon farming. The large quantities of raw materials of fish that are used may have negative impact on wild fish stocks. Other issues include pollution of local environments, escaped farmed salmons, the use of GMO raw materials in the feeds, medication of the fish, waste handling etc. A Norwegian firm, Giga, started production of organic salmon in 1996. Their concept was a fish-pen where in- and output was fully controlled. This was achieved by using a waterproof “bag” as fish pen, instead of the ordinary cages with net. Fresh water was pumped into the pen from the sea, and it could be pumped from any level of the sea that was considered the most beneficial. The organic waste from feeds and faecal where collected in the bottom of the pen, where it could be pumped up and recycled.

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[1] Source: Calculated from Bjørndal (1990) and Bill Atkinson’s News Report.

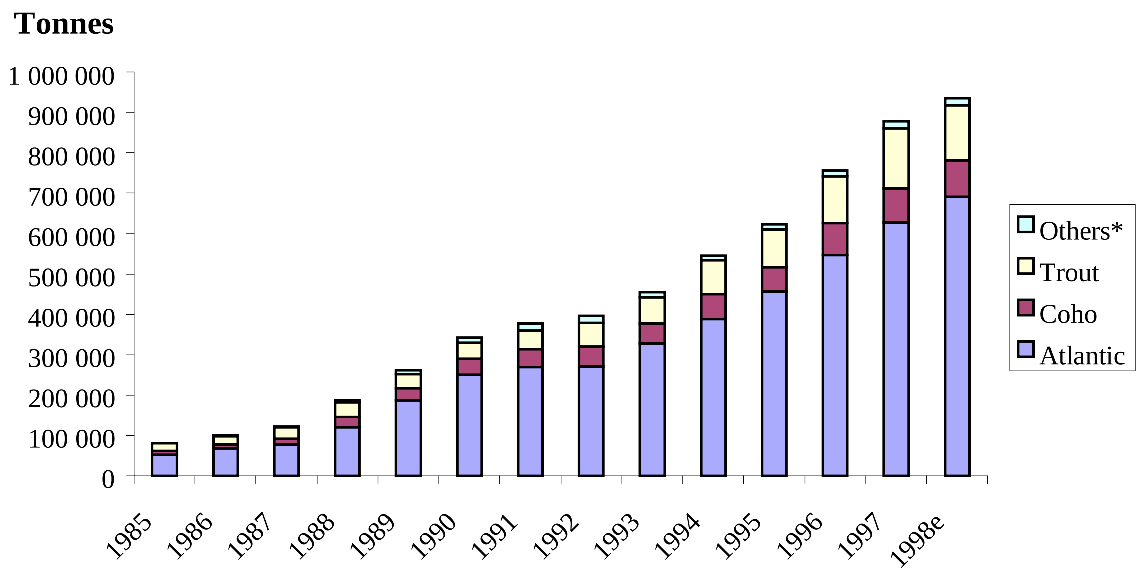

Figure 1. Farmed Salmon and Salmon Trout 1985-98.
* Others include chinook and cherry
Source: Bill Atkinson's News Report and Kontali Analyse

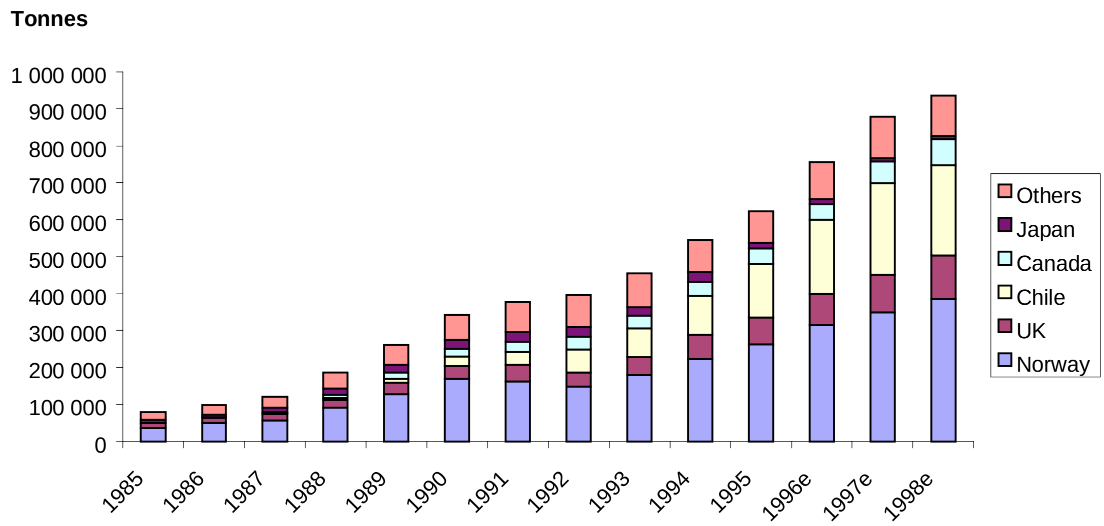

Figure 2.Main Producers of Farmed Salmon and Salmon Trout 1985-1998.
Source: Bill Atkinson's News Report and Kontali Analyse

Giga's project provides an interesting starting point for a discussion of organic production and sustainability in relation to salmon farming. Realisation of organic production in salmon farming corresponding to other organic livestock production is not very likely because of the very form of intensive aquaculture, i.e. the use of fish pens does lack some appeal in this respect. Organic production are based on a set of principles, which can be roughly summarised in four points:

I. The consumers should know what they eat, e.g. what the products contain and how they are produced.
II. The welfare of the animals should be taken into consideration in such a way that their

natural needs are attended to.

III. The production must be sustainable, i.e. an effective use of resources and minimum pollution.

IV. The food must not contain chemical compounds that are potential harmful to human beings.

This paper mainly concern itself with the third principle of organic food production since it reflect the most important aspects of sustainability, although issues concerning the other principles are also addressed. In Section 1 salmon farming is compared with agricultural production of domestic animals and other fish species in aquaculture production. Feed utilisation is addressed in particular. In Section 2 the extensive use of wild fish as raw material in salmon feeds and the subsequent pressure on these stocks is addressed. Section 3 and 4 discusses soy products as alternatives to fishmeal and fish oil in the fish feed. GMO and other ethical issues concerning soy use is also addressed in this section. Section 5 focus on some possible models for treatment of waste from fish farms and fish processing plants with special focus on sustainable solutions. Section 6 evaluates the waste output from salmon farming. An adverse effect of salmon farming, besides waste emissions, is escaped salmon. This issue is reviewed in Section 7. In Section 8 follows a brief conclusion and summary.

1. The sustainability of salmon farming an other types of livestock production

An appropriate point of departure for an evaluation of the sustainability of salmon farming is a comparison with the sustainability of meat production in the agricultural sector. The production of poultry, pigs, and ruminants are all, as salmon farming, based on intensive production systems. One of the advantages of salmon as a farmed species is that the nutritional yield is higher than any other species/animal in industrial production. Compared with pigs, which return most proteins of the domestic animals, salmons return almost twice as much (Table 1). Salmon utilises its feed more effectively than any domestic animal with respect to energy and protein retention. Thus, the waste production is correspondingly higher in agriculture meat production.

Table 1. Comparison of the yield of a given amount of feed in four common species.

	Salmon	*Poultry*	*Pigs*	*Sheep*
Protein	30	18	13	2
Energy	27	12	16	1

Source: Hillestad, Austreng and Åsgård, 1996.

The salmon farming industry has experienced a large productivity growth during the last ten years. Changes in the feed technology have reduced the economic food conversion ratio (FCR) from ca 1.75 in 1990 to near 1.35 in 1998 (Figure 3). The biological FCR is reduced from 1.25 to 1.10. The biological FCR measures the amount of dry matter necessary to produce one unit fish, while the economic FCR includes the wet matter as well. Figure 4 shows that the feed’s share of total costs and the feed consumption has increased in the same period that the FCR has decreased. Thus, even if the salmon utilises the feed efficiently feed is still getting a more pronounced role in the salmon farming cost structure. This reflects that the productivity of other inputs have increased substantially.

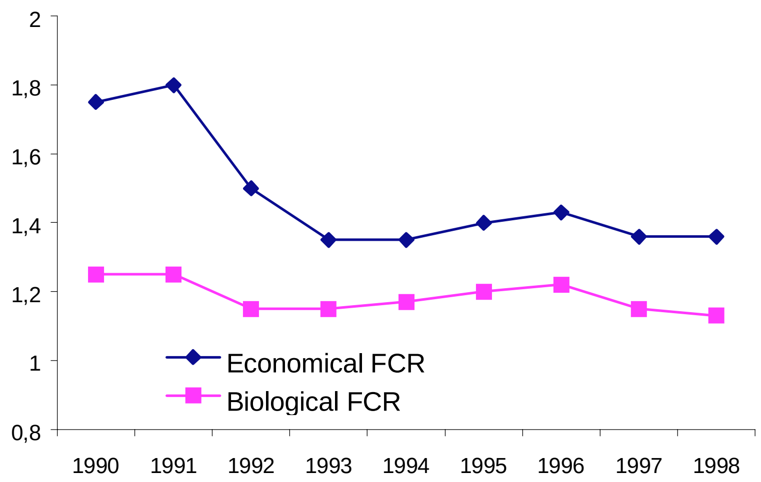

Figure 3. The FCR evolution in Norwegian salmon farming.

Source: Intrafish and Kontali Analyse

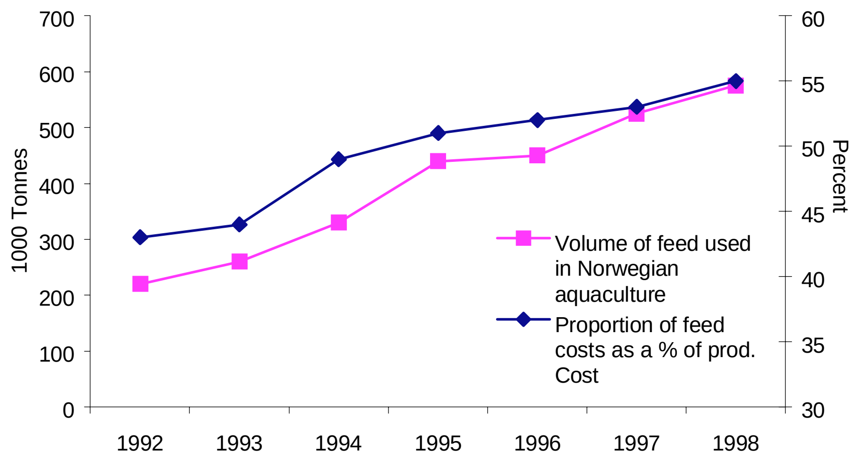

Figure 4. The evolution of feed use and feed cost in the Norwegian salmon farming industry.

Source: Intrafish and Kontali Analyse.

The efficacy of feed conversion to energy and protein in salmon is also pronounced in comparison with many other farmed species. Table 2 presents the FCR for various fish species and shrimps. The FCR is calculated as kg feed used/kilo produced. The salmonids, together with the Marine fish 2) group, have the most effective utilisation of the feed compared with the other species reported in the table. The salmonids nearly grow proportionally to the amount of feed. Other species, like carp and tilapia, need 2 kilo feed for one kilo growth. On the other hand, those two fish species are herbivore and can grow independent of high value protein. Only 25% and 40% of carp and tilapias, respectively, are farmed on commercial feed. Carp is predominantly farmed in extensive and semi-intensive production systems where the input need and monitoring requirement is marginal compared to salmon farming.

Table 2. Feed utilisation for different fish species 1999 Prediction of global aquaculture feed production in 2000 and 2010.

Species	*% on Feed*		*Feed Use per t produced*		*Feed required '000 t*	
	2000 3)	2010	2000 3)	2010	2000	2010
Carp	25	50	2	1.5	6,991	27,000
Tilapia	40	60	2	1.5	779	2,106
Shrimp	80	90	1.8	1.6	1,489	2,425
Salmon	**100**	**100**	**1.2**	**0.8**	**1,051**	**1,255**
Marine fish 1)	60	80	1.8	1.5	923	1,670
Trout	100	100	1.3	0.8	585	586
Catfish	85	90	1.6	1.4	505	761
Milkfish	40	75	2.0	1.6	303	554
Marine fish 2)	100	100	1.2	0.9	126	585
Eel	80	90	2.0	1.2	346	284
Total					**13,098**	**37,226**

Source: IFOMA.
1) Bass, bream, yellowtail, grouper, jacks, and mullets.
2) Flat fish including flounder, turbot, halibut, sole and cod, hake.
From Tacon, A., 1997 IFOMA Conference, Rome Italy.

Despite the low FCR of cultured salmon described above, the dependency on high-valued fish protein is a significant problem in salmon farming. Fishmeal and fish oil are and will continue to be limited resources. In particular, the extremely low FCRs described in salmon farming can be misleading, because the feed itself is a highly processed product. In the processing of fishmeal, up to five kilograms of forage fish are used to produce one kilogram of commercial feed (Tacon *et al.* 1997). Another important factor to consider is that the feed for most terrestrial livestock contains very low levels of fishmeal, typically around 4% inclusion (and no more than 10%), compared to around 45% for salmon (FIN, 1999).

Table 3. 1999 Prediction of global fishmeal and oil use in aquaculture in 2010.

Species	*% Fishmeal inclusion*		*Fishmeal required '000t*		*% Fish oil inclusion*		*Fish oil required '000 t*	
	2000	2010	2000	2010	2000	2010	2000	2010
Carp	5	2,5	350	675	1	0,5	70	135
Tilapia	7	3,5	55	74	1	0,5	8	11
Shrimp	25	20	372	485	2	3	27	73
Salmon	**40**	**30**	**454**	**377**	**25**	**20**	**283**	**251**
Marine fish 1)	45	40	668	668	20	15	185	251
Trout	30	25	415	147	15	20	88	117
Catfish	3	-	176	-	1	1	5	8
Milkfish	12	5	15	28	3	2	10	11
Marine fish 2)	55	45	36	263	10	12	13	70
Eel	50	40	173	114	5	10	17	28
Total			**2,115**	**2,831**			**708**	**955**

Source: IFOMA.
1) Bass, bream, yellowtail, grouper, jacks, and mullets.
2) Flat fish including flounder, turbot, halibut, sole and cod, hake.

There has recently been a transition towards vegetable proteins in the feed (see section 4). Fishmeal and fish oil admixture *per se* in salmon feed is likely to fall even more in near future, but the aggregated demand by this sector of the aquaculture industry is expected to grow (Table 3). Fishmeal as well as fish oil demand is estimated to increase with approximately 35%. Paradoxically carp, which is herbivore in nature, is estimated to have the largest increase in demand for both fishmeal and fish oil.

2. The sustainability of the fish meal and oil industry

One of the criteria for fish farming to be classed as organic is that 'When wild fish are used, the "Code of Conduct for Responsible Fisheries" (FAO, 1995) shall be followed', which generally advocate the use of sustainably managed fisheries (IFOAM, 1998). If this is to be achieved, then it is necessary to know the source of feed ingredients. Not only do we need to know whether the target species itself is being sustainably fished, but also whether it is sustainable in terms of the other resources that may be impacted by that fishery.

Traditional aquaculture has to a large extent used herbivore species with limited requirements for additional feeding. However, in intensive aquaculture production one farm carnivore species like salmon and also feeds herbivore species with fishmeal as this increase growth. This has lead to a growing concern that increased aquaculture production poses an environmental threat to the species targeted in reduction fisheries as increased demand increase fishing pressure.

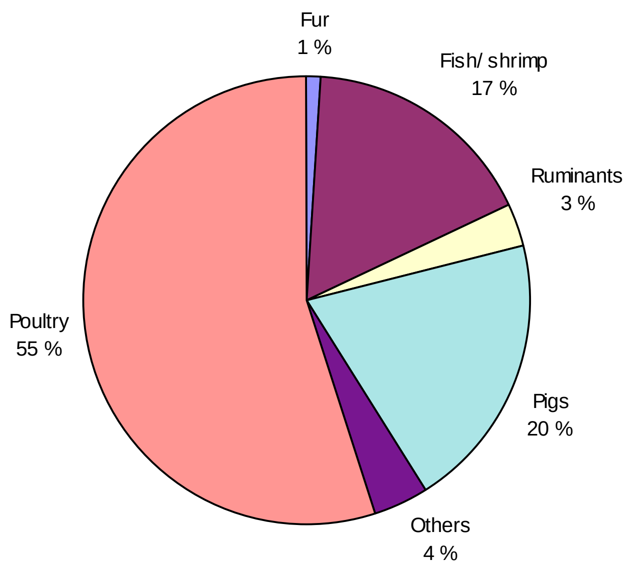

Figure 5. Estimated total use of fishmeal by farmed animals (Pike, 1996).

The world harvest of fish for fish meal and oil processing increased steadily between the 1960s and 1980s, but has stabilised at approximately 30 million metric tons (Mt) the last decade. This comprises about 1/3 of the total world harvest of 90-100 million Mt. About 6-7 million Mt of fishmeal are manufactured each year (Barlow, 1989; Rumsey, 1993a). Fishmeal processing is not expected to increase beyond this level.

The aquaculture sector consumed 15% of world fishmeal supplies in 1995, which is a 50% increase from 1989 (Pike 1996). In addition, fishmeal was used in feeds for poultry (50%), swine (25%), ruminants (5%) and other animals (5%) (Figure 5). Salmonid and shrimp farming comprised 12.5% of world aquaculture production in 1993, but consumed 60% of the fishmeal consumption of the sector.

Fishmeal production is mainly based on pelagic[2] fish. Several of these species are not fit for human consumption. Pelagic species like sprat, herring, and anchovy, on the other hand, are used for human consumption (canned, cured, etc.), in addition to being processed to fishmeal. The annual increase in the human consumption of pelagic species is increasing steadily. The excess landings are almost exclusively absorbed by the fishmeal sector (Hempel, 1999) (Figure 6).

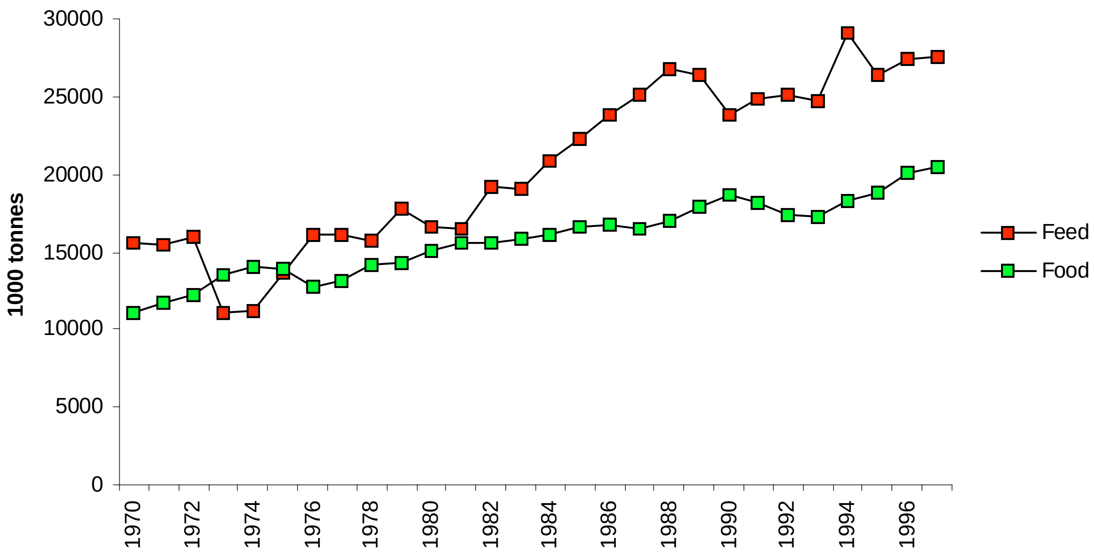

Figure 6. Pelagic species used for food and feed 1970-97 (FAO).

Chile and Peru currently land more forage fish than any other nation, and produce approximately half of the world's fishmeal (Figure 7). Although Chile does have an expanding aquaculture industry, the amount of fishmeal processed in South America far exceeds the local industries needs. The South American fishmeal industry was well established before the boom in the aquaculture industry (Landell Mills, 1983). Thus the aquaculture industry can only partly explain the current intensive fishing effort on forage fish.

Overall it seems that a growing share of the capture fisheries will be used for human consumption. In addition, fishmeal and oil demand from the aquaculture sector is estimated to increase (see Table 3). A prospect that the salmon industry may face in the future is that an increased global demand for fishmeal will lead to prohibitively high prices, and thus an incitement for the salmon industry to either search for other protein sources in its feed or to

[2] Fish that inhabit the surface waters rather than the sea floor. Are usually applied to such free-swimming species as tunas and mackerel, in addition to the smaller species like herring and anchovies.

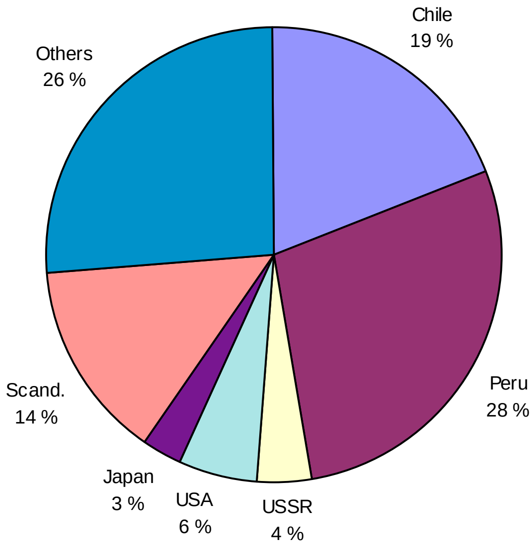

Figure 7 World fishmeal production in 1997.
Source: FEO.

limit its output. Another prospect may be that the production of poultry, swine and ruminants will switch to vegetable protein sources and, thus, leave captured fish for use in aquaculture feeds and human consumption. This will depend on the sensitivity to changes in the fishmeal prices in these sectors. If fishmeal is used because it is unique, the price of fishmeal should be determined by the demand and supply for fishmeal alone. On the other hand, if fishmeal is used mainly because it is cheap protein, one would expect a high degree of substitutability between fishmeal and other oilmeals. If the first explanation is correct, increased demand from aquaculture production for fishmeal are likely to increase prices, and therefore increase fishing pressure after poorly managed fish stocks.

Is fishmeal a unique product or is it a part of the larger market for oilmeals which includes soy meal? This is an important issue since the market structure for fishmeal is instrumental for whether increased aquaculture production may affect fishmeal prices, and thereby increase fishing pressure in industrial fisheries. There are technical possibilities to substitute fishmeal for other protein sources in the feeds for poultry, pigs and fish. The most obvious candidate is soybean meal, since it is the oilseed meal that has most similar features as fishmeal (Hempel, 1999; Torsvik, 1998). Although soybean meal has a lower protein content and not identical nutritional structure with respect to amino acids and fatty acids, it has the highest protein content of the vegetable oilseed meals.[3] Some traders in the feed market have in fact operated with a long-run equilibrium ratio of 2 between the fishmeal and soybean meal prices (Durand, 1994), and others with a slightly higher ratio (Hempel, 1999). This suggests that there exists an equilibrium price for fishmeal that is twice the size, or slightly higher, than the soybean meal price. Hence, the possibility of an equilibrium price indicates that the demands for the two products are strongly related. Soybean meal is already the major protein source in livestock feeds on a global basis, but only on a small scale in aquafeeds, which is still dominated by fishmeal.

[3] Cf. Section 4 for a technical description regarding the use of soybean products in fish feeds.

We have to examine the co-movements in the prices of fishmeal and soybean meal to judge if the markets are integrated or not. Stigler (1969) defined the market as

‘the area within which the price of a good tends to uniformity, allowance being made for transportation costs’.

If the fishmeal and soybean meal markets are integrated we can say that they constitute one market: A market for cheap proteins. In Stigler’s framework we are thus interested in testing if the prices of cheap proteins tends to uniformity. Market integration implies that the products are perceived as substitutes, thus when the price of one of the products gets too high it can be substituted for the other. Hence, fishmeal prices cannot diverge from soybean meal prices over a longer period of time due to arbitrage and substitution. This is also the basis for the *“Law of One Price”* (*LOP*). The *LOP* refers to the similar behaviour of prices of goods belonging to the same market. If the fishmeal and soybean meal prices were bound together by the *LOP* their relationship could be formulated as

$$P_{St} = \alpha P_{Ft} , \tag{1}$$

where P_{St} and P_{Ft} is the prices of soybean meal and fishmeal at point t in time. α function as a scaling parameter in case there is a price differential that has to be accounted for. Asche and Tveterås (2000) found strong evidence of market integration with cointegration estimation

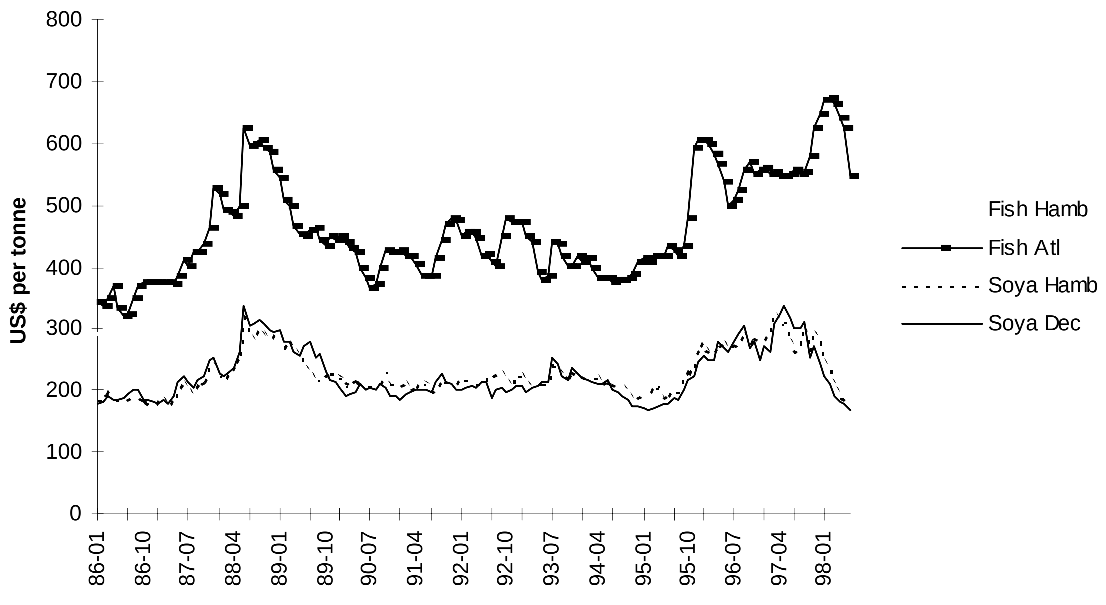

Figure 8 Monthly fishmeal and soybean meal price data from Hamburg (Hamb), Atlanta (Atl) and Decatur (Dec) in the period of 1986 to 1998.
Source: Oil World.

method of fishmeal and soybean meal prices. In Figure 8 are the price series, which were used for the estimations, plotted. The fishmeal prices are in general more volatile than the soybean meal prices, which may be caused by a generally more uncertain supply situation. However the main trends in the price series seems to correspond well with one another. The price premium fishmeal fetches is mainly due to higher protein content, but also because of its excellent balance of amino acids.

Durand (1994) came to similar conclusions regarding the relationship between these markets. The results of these studies indicate that increased demand for fishmeal cannot have led to increased fishing pressure in industrial fisheries because of the market structure for fishmeal. However, market structures can change if the aquaculture industry becomes the dominant player in this market. Thus differentiating the fishmeal market from the soybean meal market to a more specialised product aimed for the aquaculture sector. This is not, however, the case for the time being.

3. The use of soybean meal and oil in salmon feed

The share of fishmeal and -oil in salmon feeds are normally 50 % and 15 % respectively (Chamberlain, 1993). Extensive research is aimed at reducing fishmeal and -oil in feeds by substitution with vegetable alternatives, first and foremost soy products. The following review of research concerning soy products in salmon and trout feeds is mainly based on Storebakken *et al.* (1999a).

3.1 Substitution of fishmeal with soybean meal

Soy products are valuable ingredients in feeds for salmonids because of their high content of available protein with a well-balanced amino acid profile and steady supply. Adequately processed soy products have high protein digestibility in fish. Still, the upper limit for full fat or de-fatted soy meal inclusion in diets for salmonids is between 20 and 30%, even if anti-nutritional factors are eliminated (Storebakken *et al.*, 1999b). On the other hand, salmonids can grow well and utilise diets with soy protein concentrate as the major or sole protein source, provided that the diet is supplemented with the limiting amino acids.

The high protein content[4], well-balanced amino acid composition, and the reasonable protein price of soy protein products have made them important ingredients in fish feeds over the last two to three decades (Storebakken *et al.*, 1999b). But, utilisation of soy products is very dependent on the level of processing; different levels of processing lead to significantly different qualities of soy products. The heat treatment is in particular very important since it reduces the level of growth inhibitors and anti-nutritionals like phytate, trypsin inhibitors, lectins and sapponins. However, many studies have shown that feeds containing heat treated soy meal demonstrate less palatability to salmonids than fishmeal-based feeds (Fowler, 1980; Smith *et al.*, 1988; Wilson, 1992; Arndt, 1994; Kaushik *et al.*, 1995; Rumsey *et al.*, 1994a; Olli *et al.*, 1995; Refstie *et al.*, 1998). Reasons for this limited soy meal tolerance are discussed in a later section.

The substitution of fishmeal with soy meal cause reduced digestibility of fat. Decreased uptake of dietary lipids has consequences for the net energy value of the feed and probably also for utilisation of lipid-soluble nutrients.

Although soy meal cannot completely substitute fishmeal, other soy products like soy isolate or

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[4] Typically 35 to 40% for full-fat meals, 45 to 50% for de-fatted (solvent extracted) meals, 55 to 65% for various "high protein meals", 65 to 80% in soy protein concentrates.

soy protein concentrate prove to be more successful. Experiments with trout in freshwater have demonstrated that 50 to 75% of the fishmeal protein in LT-fishmeal diets may be replaced by protein from soy protein concentrate without adverse effects on growth, feed efficiency, or protein retention (Rumsey *et al.*, 1994a; Mèdale *et al.*, 1998). Similarly, feed conversion, nitrogen digestibility, and whole-body nitrogen retention were similar in Atlantic salmon fed a diet with LT-fishmeal or a diet with 75% of the fishmeal protein replaced by phytase-treated soy protein concentrate.[5] This level of dietary phytase-treated soy protein concentrate did not reduce salmon growth (Storebakken *et al.*, 1998).

Furthermore, highly processed soy products cause little or no reduction in fat absorption in salmon. In a recent study, diets with 50% of the protein from soy isolate or soy protein concentrate resulted in fat digestibilities of 96 to 98%, whereas digestibility of fat was decreased by more than 10% when 50% of the protein came from solvent extracted soy meal (Refstie *et al.*, 1999).

Diets with high amounts of soy meal or protein concentrates without phytase treatment impair the uptake of essential elements. In the initial stages, mineral deficiency symptoms can be difficult to detect by external measures in salmonids, as the fish continue to grow at a high rate in spite of poor mineralisation of bones and other hard tissues (Baeverfjord *et al.*, 1998). At later stages reduced availability of essential elements inevitably develop into pathological conditions, with reduced growth, mortality, and deformities as results. Reduced availability of Zn due to dietary phytic acid also has been shown to cause eye cataracts in Chinook salmon (Richardson *et al.*, 1985).

Soy protein products ability to trigger of immune responses in fish has been little investigated. The studies that have been undertaken have produced various results. While Kaushik *et al.* (1995) did not detect any systemic antibody responses in rainbow trout fed diets with 50% of the protein from de-fatted soy meal or 100% from protein concentrate, Rumsey *et al.* (1994b) found that a diet with de-fatted soy meal as the sole protein source increased antibody responses. This hypersensitivity response corresponded with growth depression and changes in the intestinal morphology, particularly in the posterior (large) intestine. Ingh *et al.* (1991) and Baeverfjord and Krogdahl (1996) discovered changes of the posterior intestinal epithelium induced by soy meals in Atlantic salmon.

Bjerkeng *et al.* (1997) reported that raising Atlantic salmon on a diet with 10% full fat soy meal did not compromise the flavour, texture, and overall acceptability of cooked filets when compared to salmon raised on a fishmeal diet, nor did it alter the proximate composition, colour characteristics, or fat distribution in the fish. Thus, partial replacement of fishmeal by soy protein products in fish diets seem to have little practical impact on the flesh quality of farmed fish.

Soy protein concentrate has high nutritional value in fish feeds, and the results obtained with different purification methods of soy meal and soy protein isolates indicate a large potential for development of specialised products suitable for being the major source of dietary protein for farmed carnivorous fishes.

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[5] Phytase is an enzyme which frees phosphorous and thus lead to increased phosphor utilisation. In addition phytase can have positive effect on the availability of other nutrients in the feed.

3.2 *Substitution of fish oil with soybean oil*

Dietary lipids are the source of essential fatty acids in salmon feeds. They provide a rich source of energy, and dietary phospholipids, which are vital as structural components of biomembranes. Dietary lipids also serve as carriers for the absorption of other nutrients, including the fat-soluble vitamins A, D, E and K, and natural or synthetic pigments (Kaels, *et al.*, 1999).

Fish oil is the major dietary lipid in salmon feeds, while soy oil has a rather marginal role as dietary lipid. The substitution between different dietary lipids in fish feed is more complicated than the substitution between different protein sources. The fatty acid requirements in fish are quite complex and not wholly unproblematic. Compared with fish oils, soy oil contains greater amounts of n-6 fatty acids. There are some n-3 fatty acids in soy oil, but the longer «marine» n-3 fatty acids are absent. Fish, like other animals, do not possess the de-saturate enzymes necessary for the formation of certain n-3 and n-6 fatty acids.[6] Consequently, those fatty acids are considered essential constituents of the salmon diet.[7]

Evidence that dietary fatty acid composition may affect the fish physiologically without immediate effects on growth or mortality emphasises that disease resistance and normal physiological functionality should be emphasised when defining safe inclusion levels of soy oil in feed for fish with a high requirement for n-3 fatty acids (Røsjø, *et al.*, 1994).

Substitution between different dietary lipids is not an entirely unproblematic matter. One reason is possible metabolic competition between n-6 from soy oil and n-3 in fish. High contents of essential n-6 fatty acid in dietary soy oil may inhibit the metabolism of essential n-3 fatty acid to the longer chain essential of carbon-20 and carbon-22 PUFAs (poly-unsaturated fatty acid). Thus, not only the percentage requirement for n-3 fatty acids, but also the ratio between n-3 and n-6 fatty acids must be taken into account when soy oil is used for energy in fish that have a high requirement for n-3 fatty acids and the ability to de-saturate and elongate the essential n-3 and n-6 fatty acids.

Digestibility depends on the melting point of the dietary lipid source (Austreng *et al.*, 1979). Generally, salmonids have a poorer digestibility of saturated fat, which has a relatively high melting point, than do warm-blooded animals (Austreng *et al.*, 1979). Thus fats with a low melting point are preferred in diets for salmonids. Saturated fats, such as lard, destruction fat, or hydrogenated oils should be avoided. The essential fatty n-6 and n-3 fatty acids are oxidised for energy at a much higher rate than the corresponding C 20 and C 22 fatty acids in rainbow trout (Henderson and Sargent, 1985), the same as in mammals (Leyton *et al.*, 1987). Thus, soy oil also should be a good energy source in feeds for cold water fish, both because of high availability and favourable fatty acid composition. However, there are examples that fish oil is utilised better than soy oil in diets for juvenile marine fish (Tucker *et al.*, 1997), emphasising the need to carefully evaluate the biological response to soy oil before it is fed to a new species.

Due to the high content of natural antioxidants, soy oil is more efficiently protected against

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6 Specifically it is the linoleic acids 18:2 n-6 and 18:3 n-3.

7 Not all fish species have requirements for both of these fatty acids. For example tilapias only have known requirements for n-6 fatty acids while rainbow trout only has documented needs for n-3 fatty acids.

oxidation than are fish oils (Greene and Selivonchick, 1990). A mixture of soy oil and fish oil in fish feeds thus has a potential of increasing the shelf life of the feed by protecting the long-chain n-3 fatty acids in the fish oil and protecting the fish against oxidative stress. This may have positive consequences for the health of the fish, as found by Greene and Selivonchick (1990), who fed moist diets with salmon oil, soy oil, linseed oil, chicken fat, pork lard, or beef tallow.

The effect of dietary lipids on pigmentation remains to be understood, but it is documented that the choice of dietary lipids has an effect (Thomassen and Røsjø, 1989; Hardy *et al.*, 1987). Used in combination with certain fish oils soy oil may enhance the pigmentation of salmon (Christiansen *et al.*, 1993). Considering that the carotenoid substances which provides the colour pigments to the salmonids account for up to 10% of the feed cost soy oil inclusion can be very beneficial.

Partial replacement of dietary fish oil with low- and high-erucic acid rapeseed oil or soy oil for Atlantic salmon resulted in the fish fed either of the rapeseed oils expressing a fainter "salmon odour" than the fish fed the capelin oil diet, while the salmon fed diets with soy oil had significantly less "salmon taste" than the control fish (Thomassen and Røsjø, 1989). On the other hand, Guillou *et al.* (1995) fed brook charr (*Salvelinus fontinalis*) diets with soy, canola, or menhaden oil added, without any differences among the groups in a sensory evaluation. However, the texture of the fish fed the canola oil diet was softer, and preferred over the fish fed the soy oil diet. Thus, soy oil may affect the sensory characteristics of the fish, and proper investigations must be carried out in order to define the consumer response to this product.[8]

3.3 Ethical aspects of the use of soy in salmon feed

There are four main ethical questions posed by the idea of using soy products in salmon feed. The first problem is the use of valuable marine protein for fish production (harvesting fish to feed to fish). The second point involves the ethics of feeding a mainly carnivorous fish an ‘unnatural’, vegetarian diet. Knock-on effects of the provision of such a diet are possible impacts on fish health and growth. Thirdly, there is the problem of soy-based diets and the exposure to a GMO soy meal market. Finally, we must ask whether the provision of such food to salmon will alter the quality of the final product. These points are discussed below:

(1) Fish protein is an acknowledged source of protein for industrial agriculture husbandry. Due to the match of amino acids, fish have a much better conversion rate of marine protein than terrestrial husbandry. The ethical dilemma, however, is whether fishmeal - a product of the global industrial pelagic fishery - is the appropriate source of protein for a sustainable salmon farming industry. Aquaculture is supposed to increase the output of marine proteins, not reducing it. The fishmeal is processed and transported over large distances, and consume large quantities of fossil fuel. Alternative uses of the fishmeal closer to where it is processed might, however, also raise ethical questions.

(2) The anti-nutrients in soy meal clearly raise ethical aspects. With the use of large quantities of soy in the feed the fish has to break down the phytic acids in order to avoid sublinical or sickly problems with mineralisation. The deficiency created by phytic acids may be difficult to

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8 Cf. Storebakken *et al.* (1999a) for a more thorough overview concerning the aspects of soy meal and soy oil utilisation in salmon feeds.

detect by external measures, but they will surface eventually. Poor mineralisation of the bones and other hard tissues will develop into pathological conditions, with reduced growth, mortality, and deformities as the result. Reduced availability of zinc due due to dietary phytic acid also has been shown to cause eye cataracts in chinook salmon (Richardson et al., 1985). Thus, phytase treatment procedures or pre-treatment must be optimized if soy products are to account for a major portion of the feed. Fat and protein digestibility is another problem probably caused by non-starch polysaccharides (NSPs), but the anti-nutritional actions of soluble NSP are not still fully understood.

Intestinal changes induced by soy meal also an ethical problematic aspect. A high inclusion of soy meal, but not soy protein concentrate, lead to morphological changes in the posterior intestines that may induce enteritis. It is not known if the soy-meal induced enteritis affects the ability of the posterior intestine to absorb macromolecules and regulate the ionic balance, but it is not unlikely in view of the morphological changes observed. Practical experience from Norwegian fish farming has shown that both Atlantic salmon and rainbow trout can grow fast and have a high rate of survival with soy meal in their feed, both in freshwater and in the sea. This experience indicates that the intestinal changes do not represent acute health risks for the fish. It is important, however, to find to what extent the morphological changes in the intestine have negative effects on physiology of the fish, and what inclusion rate of soy meal eventually can be tolerated.

(3) The use of GMO soy in salmon feeds is an established issue. Many of the biological implications is yet not known so at least a precautionary approach should be followed. Large soy producing nations do not require labelling of GMO soy products. All soy products are thus possibly GMO. Hence, no fish feed manufactured with the admixture of soy protein can guarantee that it is GMO free. The positive news is that DuPont has developed a soybean that is resistant against a pesticide that has similar effect as (glysofat), but is not a GMO. Classical methods are used to grow these soybeans and are today raised in large areas in the US. Presently the production goes in its entirety to human consumption, but if demand should increase there should be no problems in increasing production. The ethical implications here are the lack of information of the actual source of the soy combined with the consuming publics awareness and scepticism to GMO products and the lack of trustworthy information on this issue.

(4) Pollution may be more prominent with high soy meal inclusion in the salmon feed. High soy meal inclusion leads to increased phosphorus and nitrogen waste that may induce eutrophication. This problem is more prominent in fresh water farms than exposed saltwater farms. If it is a negligible problem in saltwater farms is another question. Soy protein concentrate utilisation does not present these problems, but is at the present to expensive to use in fishmeal, at least on a larger scale. In general, the amount of faeces increases when vegetable sources are used. This might pose a problem at some farm-sites, given the extent of many farm-operations. The ethical implications here are the possible increase of offal without an increase in the feed quota. The costs of the increased pollution will be shared by many as an increased load in the coastal commons.

Soy meals are valuable ingredients in salmon feeds because of their high content of available protein with well-balanced amino acid profile, but also reasonable price and steady supply. Still there are problems to overcome. In spite of adequate elimination of heat-labile anti-nutrients, there seems to be a limitation in dietary soy meal inclusion rates of 20 to 30% in salmonids. Soy protein concentrates and isolates can successfully supply 75 to 100% of the protein in salmonids, provided that limiting amino acids are supplemented. Soy oil is a good source of energy and n-6 fatty acids in salmon feeds, but may cause metabolic competition with n-3 fatty acids. Soy oil has beneficial effects on the growth of juvenile fish. An adverse effect is change in flavour of the fish if too much of the dietary lipids are provided by soy oil. In general, there are still much research needed to get rid of the above mentioned problems regarding the use of soy products, and also find cost-effective ways to do so.

4. Recycling of waste from fish processing facilities

Huge volumes of fish wastes, derived from fish processing plants or discarded by-catch from commercial fisheries are produced each year, a great deal of which is discarded. Efforts to address this problem began with RUBIN (Recycling and Utilisation of By-products in Norway), a government funded project running from 1991 to 1998. The aim of the project was to find commercially viable solutions to the problems regarding fish waste and recycling issues related to fish farming and fish processing industries. The background for the project was the environmental problems that the salmon farming industry struggled with (dead fish and hygiene in relation to contamination hazards), and handling of by-products from the fish processing industry including fishing vessels. Several problems have been solved during this period, by the industries themselves, by increased awareness, and by research conducted by the RUBIN foundation (RUBIN, 1998). Figure 9 presents the development that has taken place in quantities and utilisation of by-products, and Figure 10 shows the value of processing of by-products.

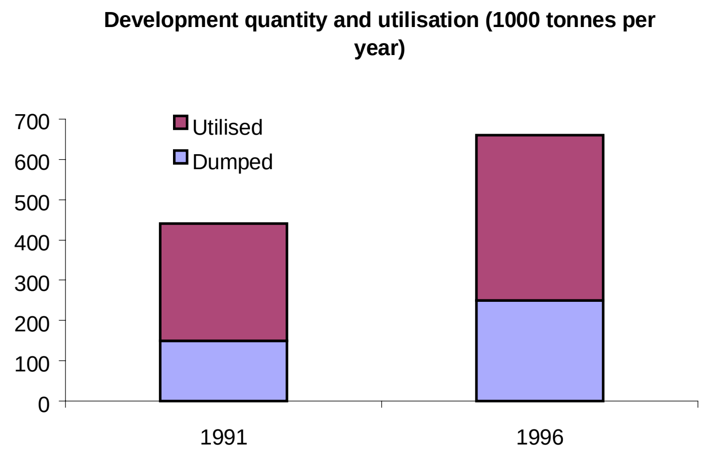

Figure 9. Development in quantities and utilisation 1991-1996.
Source: RUBIN (1998).

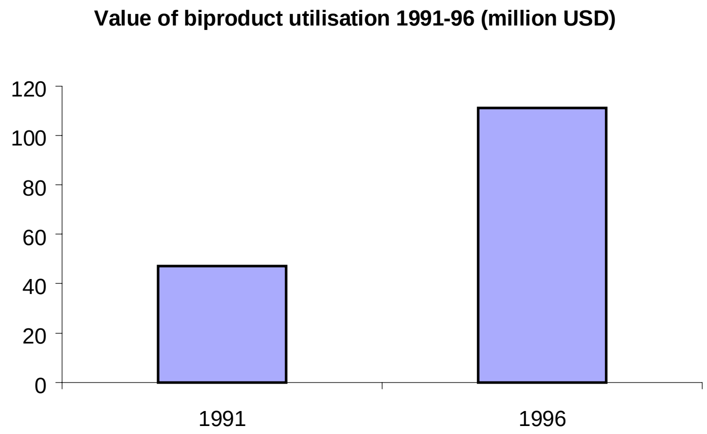

Figure 10. Sales development 1991-1996.
Source: RUBIN (1998).

4.1 Recycling and utilisation of waste from the fish processing industry

The RUBIN foundation has developed a wet-feed for salmon farming based on ensilage from the fish processing industry that has been quite successful (the Rubin feed). The production and utilisation of this feed has been successfully implemented in three fish farms, and it is estimated that 1/4 - 1/2 USD per kg salmon produced can be saved using this technology. Almost all the ensilage from onshore fish processing plants are today used as raw material in fish feeds.

Furthermore, there are still unused by-products from processing on board fishing vessels. RUBIN has conducted some preliminary projects concerning handling of ensilage onboard vessels. These projects have documented that there is a potential for vessels to improve byproducts utilisation for commercial purposes (ex. ensilage to fish feed). An example here is the development of a technology that removes bones from the ensilage.

4.2 *Recycling and utilisation of waste from the salmon farming industry*

Due to localisation of rearing sites in more exposed waters and an increased FCR in salmon farms, the problems and volume of organic waste output from rearing sites has decreased radically in Norway (cf. Section 5 for further details). The major remaining waste problems have been handling of ensilage and dead fish. Today 97% of the ensilage is used, and an industry that specialises in handling ensilage has developed.

Ensilage from salmon farms is mainly used in feeds for domestic animals like poultry and pigs, but also for ruminants and sheep.

Handling of dead fish has been one of the major waste problems for the industry. Today this problem is organised in a more responsible manner. ‘Dead fish’ is fish that dies in the pen because of diseases, algae attack, or other more or less random causes. Furthermore, dead fish can either be fresh or cadaverous. Cadaverous fish has to be handled according to appropiate procedure to avoid any contamination hazard for humans or nature. Cadaverous fish are either dumped at (refuse) disposal plants or composted. Composting prescribe an acceptabe medication level in the fish. RUBIN developed a relatively cost efficient way of testing the medication level in the fish, a test that used to be a time consuming and expensive process.

5. Waste output from salmon farming

The salmon are fed pellets either by hand or by machines. Everything that is not consumed by the salmon will drift through the pens and sink to the seabed beneath the farm. Feed is therefore the main pollutant from the farm, together with the salmon's natural discharge. A salmon farm may accordingly supply its environment with a substantial amount of organic matters. In the late 1980s it was common to use feed with an admixture of antibiotics, hence adding a substantial quantity of antibiotics to the local environment.

The feed is the dominant cost factor in salmon aquaculture. In Norway, the share of feed costs of total production costs has been increasing and is currently about 50% of total cost (Asche, 1997). Hence, for economic reasons, a fish farmer would be interested in increasing the efficiency of the feeding. Moreover, as the discharge can cause substantial local pollution problems, which again will affect productivity, there is also a direct economic incentive to reduce pollution. Einen *et al.* (1995) also indicate that reducing the quantity of feed used per produced kilo of fish might be the easiest way to reduce discharges.

5.1 Environmental problems caused by the feed

Nutrient discharges may represent a problem both for the individual farm and for the sea or fjord where the farm is located. The most common sign of an environmental problem is the accumulation of organic sediments and changes in the benthic fauna.[9] Another possible indication that there might be a problem is algae blooms, which are closely linked to increased concentration of nutrients in the sea. Several locations along the Norwegian coastline have experienced problems with toxic algae, with the consequence of substantial losses. Especially the alga blooms in 1988 and 1989 created difficulties for salmon and trout farmers. The toxic plankton algae *Prymnesium parvum* killed 750 tonnes of salmon and salmon trout in fish farms (Kaartvedt *et al.*, 1991).[10]

There are several definitions of eutrophication. Nixon (1995) provides the following definition: "Eutrophication (noun) means an increase in the rate of supply of organic matters to an ecosystem". Droop *et al.* (1982) indicate that increases in phyto plankton or attached macro algae (eutrophication) in the sea is controlled by the availability of light or nutrient in a threshold manner — whichever is least available will limit growth. Salmon aquaculture can, at least locally, make a difference to the last of these threshold factors. Nitrogen (N) and Phosphorus (P) are the two elements of the discharges from salmon farming that are of particular importance to the environment (Einen *et al.*, 1995). Discharges of nutrients in the sea will also alter the natural relationship between Nitrogen and Phosphorus. An unbalanced N/P ratio will make the phyto plankton less valuable as food for filter-feeding animals (Ryther and Officer, 1981). This will lead to reduced grazing and may thus result in higher algae biomass and plankton blooms, i.e. eutrophication.

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[9] Johannessen *et al*. (several years) has documented this in a large number of studies of salmon farm sites.

[10] It should be noted when one is able to provide a link between algae blooms and aquaculture, this is very local phenomena in areas with poor flushing (Gowen and Ezzi, 1994). While locations with poor flushing where used in the early days of salmon farming, it is rare to find a fish farm in such location today (Black *et al*., 1997).

A discussion of what extent farming of salmon leads to eutrophication or the occurrence of alga blooms in marine waters has taken place. Folke *et al.* (1994 and 1997) strongly emphasises the cost of eutrophication from salmon farming. However, Black *et. al.* (1997) reject most of their argument. Kaartvedt *et al.* (1991) linked the blooms of *Prymnesium parvum* in 1988-1989 directly to the nutrient loading from the fish farms. However, except from this single case, there is very little direct evidence of eutrophication and alga blooms from fish farms in marine areas other than in embayments with limited water exchange. Salmon aquaculture's share of total Norwegian phosphorus emissions was 24% in 1994, which also represents 2% of the total emissions to the North Sea. For nitrogen the shares were 7% and less than 1% for Norway and the North Sea, respectively.[11] It should be noted, though, that most of the emissions from Norwegian salmon aquaculture are not released into the North Sea basin, but farther north (in the Norwegian Sea), where nutrient loading problems are considerably smaller.

When there are discussions concerning to what extent fish farming causes an environmental threat to the surrounding environment and the sea, there is no doubt that nutrient discharges from fish farms can have direct consequences for the individual farmer. The supply of organic material is of importance to the level of oxygen in the water. Discharges of organic material require oxygen when being decomposed, and these discharges will compete with other organisms (i.e. fish) for the oxygen. The accumulated organic materials under the pens will consume oxygen, which leads to lower levels of oxygen beneath the pens. With an oxygen deficit this will result in a non-oxygen decomposition of the organic material. Through this process hydrogen sulphide (H_2S) will be produced (Håkanson *et al.*, 1988, p. 13). This substance will cause death for the fish if sufficient quantities are released from the sediments. In addition, the sediments will possibly act as a source of infection for fish pathogen micro-organisms. A high water exchange rate can limit the accumulation problems.

In the early days of salmon farming this was more of a problem since farms were often located at sites with limited water exchange, as the farms otherwise would be vulnerable to extreme weather conditions. For farms that are located in closed stillfjords local eutrophication is even more likely to be a problem. However, the development of more robust production plants have allowed farms to locate at more exposed sites with higher water exchange and larger depths. This has reduced the problems of organic matter accumulation and production of toxic by-products in the local marine environment surrounding the farm, (Black *et al.*, 1997). This is because sites with poor flushing capacity are not used to any extent anymore.

5.2 Improvements in feeding technology

While the potential problems related to discharge of organic matters is still substantial, several factors in addition to farm relocation have reduced the problems the last decade. As such, it is not accidental that the evidence of local alga blooms that may be attributed to salmon aquaculture dates as far back as 1988-1989. Both the feed and the feeding technology have reduced the potential problems, partly because one became aware of the environmental issues and partly because innovations that primarily targeted productivity also were good for the environment.

[11] Total Norwegian and North Sea countries phosphorus emissions were respectively 3 000 tonnes (Tjomsland and Braaten, 1996) and 34 000 tonnes (OSPAR Commission, 1998), while nitrogen emissions were 71 000 tonnes (Tjomsland and Braaten, 1996) and 1 150 000 tonnes (OSPAR Commission, 1998).

One of the most important issues has been the reduction of the feed conversion ratio (FCR).[12] The decrease in the average FCR has been substantial during the history of Norwegian salmon farming. In the early 1980s, the FCR was 3, i.e. around 3 kilo feed was needed to produce 1 kilo fish. Today the best farmers produce one kilo fish with less than one kilo feed.[13] The average FCR in 1997 was 1.19. The change in the utilisation of feed is of great importance also economically. For example, without these changes, the total feed costs in 1993 would have exceeded 6 billion NOK, which was more than the total sales revenues of the industry that year (Austreng, 1994).

The quality of the feed has improved substantially. If Norway should produce the same amount of feed for fish as they did in 1993 with the recipe used in the late 1970s, production costs would have increased by at least 15% (Austreng, 1994). Moreover, the feed that is used today has a design and weight that makes it sink much more slowly through the water. This substantially increases the likelihood that the salmon consumes the feed. Feeding technology innovations have also improved the ability to monitor that the salmon indeed is consuming the feed that is supplied into the pens, and to cut back on feeding if the feed is not consumed. Also, the utilisation of the feed is better for the bred fish than for their wild cousins (Grisdale-Helland and Helland, 1998).

6. Genetic pollution and other adverse effects of escaped salmon

Escaped salmons have been, and still are, a continuous controversial issue due to possible adverse effects on wild salmon stocks, and are also relevant in the context of sustainability of salmon farming. While the production of farmed salmon has increased considerably the last 20 years, the reproduction of wild salmon has decreased. In 1999 the Ministry of the Environment presented a study concerning the effects of salmon farming on wild salmon stocks, following up with proposals for steps to be taken such that genetic diversity and reproduction of wild salmons should be protected (NPR, 1999). Establishment of national watercourses and fjords is the most radical proposal in this study. These areas should be protected against different kinds of activities such as building of infrastructure, roads, bridges etc, and most importantly salmon farming operations. The main bulk of protected areas are proposed to be established in the North of Norway, since salmon farming is less developed here and thus has not inbreeded with wild salmon, at least not in the same degree as further south.

Salmon escapes take place both in the freshwater period and the saltwater period, but the major bulk of escapes are from saltwater farming sites due to damages, towing of pens and smaller accidents. Spot tests conducted in Norwegian rivers from 1989 to 1996 show that 19 to 35% of the salmon tested before the spawning period are escaped salmon. The variation between rivers is big. The amount of escaped salmon varies between 0-2% and 60-80%. Although escaped farmed salmon are capable of spawning in the nature, it has a lower spawning success than wild salmon.

The short-term effects of escaped farmed salmon includes competition and breeding with wild salmon, spreading of diseases to wild salmon, hybridisation with trout, and competition

[12] Influencing the FCR is easiest way to reduce discharges (see Einen *et al.*, 1995).
[13] In laboratory experiments one has been able to achieve feed conversion ratios as low as 0.6.

between natural produced offspring, farmed offspring and cross-breed offspring. It is reasonable to assume that the ecological effects will reduce the size of the wild salmon stocks. Slinde (1999) argues that for most species gene mixing is preferred to inbreeding. The result of gene mixing is not a species that disappears, but a species that is genetically strengthened. The salmon that are farmed today represents a broad compound of genetic material, and thus does not present a threat at the present. But breeding can have adverse effects. Hence, evaluation of potential long-term ecological effects should take into consideration that future farmed salmon will as individuals be poorer adapted to a life in the nature, but that they as a group still can have a large degree of influence if the escapes continues.

Sea lice are possibly one of the most important factors that reduce the stock size of wild salmon. Registrations show that the heaviest infections on wild salmon are limited to areas with a high concentration of salmon farms (Tully et al., 1993ab; Grimnes et al., 1998,1999). A plausible explanation is that the number of hosts is larger in areas with high concentration of salmon farms. Still there is a lot of insecurity regarding the connection between fish farming and the recession of wild salmon stocks. Analysis of a small sample of rivers in Scotland and Norway showed no special recession from 1987 and up till today in farming intensive areas (Hansen, L.P., 1999). In contrast to these findings Sægrov et al. (1997) found by comparing 77 different rivers, the largest recession of wild salmon in farming intensive areas.

It should be noted that there are other potential explanations for the recession in the stocks of wild salmon in Norway. Acid rain in the south of Norway killed large numbers of fish in many rivers, especially in the seventies and the eighties. However, intensive calcium treatment has restored life in many of these rivers. Overfishing, intervention in watercourses and the parasite *Gyrodactylus salaris* are other factors that have led to the decline of salmon stocks. Rotenone treatment of rivers is one measure taken against this and other parasites.

It is obvious that farmed salmon has had a negative impact on the level of the wild salmon stocks, and probably their genetic material as well. But it is not easy to quantify the various causes behind the decline of these stocks. Hence, more research is required in this area. If we wish to keep the genetic diversity of our wild salmon it is important to clarify what sort of genes it is that we wish to keep. If there was any conception of this, besides the wish to keep a broad genetic material base, we could protect the watercourses to the salmon stocks with the desirable sequences of genetic material. Anyhow, it is clear that there is a conflict of interest between salmon farming and recreational wild salmon fishing. This has, amongst other, contributed to the study from the Ministry of Environments, which concluded with a recommendation of protected watercourses for the wild salmon stocks.

Improvements at the farm sites can limit salmon escape. One solution is monitoring the pens for damages, which can be done by underwater cameras. Norwegian authorities have also introduced a rule that requires fish farms to have regular surveillance fishing for escaped salmon, but strives to get fish farmers to comply, especially the smaller agents that have limited resources for this kind of activity. Another area with potential for improvement is fish-pen technology. Some argue that the basic design and technology of the fish pens to a large degree has remained unchanged over the years. A contractor in the offshore oil sector recently announced it was on its way into the aquaculture sector, where it intended to deliver fish-pens that could endure offshore weather conditions and that was more secure against salmon escaping (Sandvik, 2000). The oil sector has attracted many of the graduated engineers in Norway, and experiences and technological spillovers from this sector may benefit the aquaculture sector.

The authorities have also addressed the salmon lice problem by introducing a new delousing programme. From the first of February 2000 fish farmers are required to delouse salmons that have more than 0.5 sexually mature female louse or 5 sea lice. The fight against sea lice has brought forward sustainable solutions in the use of wrasses. But as wrasses go into hibernation during the wintertime, other measures has to be supplemented. Chemical solutions are used, but they also suffer from being less effective in the cold water in wintertime.

7. Summary and conclusions

Salmon farming has made substantial progress towards a more sustainable production. Still, some issues remain uncertain regarding sustainability and environmental impacts. Ethical issues concerning the use of soy products in salmon feeds relates to the first two principles of organic production (cf. principles of organic food production presented in the introduction, Section 1). The use of GMO soy in fish feed is controversial, and not in line with organic production philosophy. But with respect to consumer safety it may be less controversial than GMO products that go directly to human consumption. Salmon is the intermediate receptor of the GMO soy; thus nothing should dictate that it should present a health hazard to humans. However, in organic salmon farming GMO inputs may be much more problematic.

Furthermore, extensive use of soy products in salmon feeds, not considering the GMO issue, has its ethical questions due to its impact on the physiology and health of the fish. This is a field that requires further research (Storebakken *et al*, 1999a). There exists significant variations in the response to soy inclusion between the different age groups of salmon. Moreover, there are many different kind soy products that have different benefits and adverse effects on salmons. Further research in this area should make lead to a higher inclusion of soy products, and other vegetable alternatives.

Sustainable production is the third principle of organic food production, which includes an effective use of resources and minimum pollution. Section 2 showed that salmon utilises its feed very effectively. In fact, more so than any other species reared in intensive livestock production systems. Due to the effective utilisation of its feed, the waste output is also reduced. The organic waste that still remains rarely represents a problem at the local level due the moving of farms to more exposed farming sites and less emission from each farm. Still, the organic waste that remains can be a problem on a regional level. However, compared with the waste from other industries and agricultural production it is very small.

Escaped salmon and sea lice are also externalities that fall under the second principle of organic food production. These are probably the largest “pollution” problems for salmon farming in Norway today. Both problems are, and have been addressed, but have not been adequately resolved yet. A new restriction on max level of sea lice per salmon has just been implemented this year, and it remains to be seen whether this is successful or not. Escaped salmon is still a problem, but the industry itself has started to address this problem due to outside pressure. Hydro Seafood recently reported that their farming sites in Trøndelag County has not had any salmon escapes in two years. These results are attributed to new fish-pen technology that they have developed. But as long as there are smaller agents that do not have the kind of capital to invest in improved fish-pens, escapes will continue.

On a general level, the salmon industry seems rather healthy in a sustainable context. Due to the rapid growth in the last couple of decades, where the salmon industry has acquired large areas that could have been put to other uses, it has been under strong scrutiny from different interest groups. This has probably been to the benefit of the industry, in the sense that it has disciplined producers, input suppliers and processors. Internalisation of waste problems has also contributed to a sustainable development. But there are new tasks ahead with a growing awareness among consumer of food production. The most pressing task at the moment may be dealing with the GMO issue.

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