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## The development of salmon and trout aquaculture

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**SUMMARY** – This paper gives an overview of the development in the global salmon and trout aquaculture industry over the last couple of decades. With the growth in production from a mere 13,000 t in 1980 to 1,105,000 t in 2000, a number of structural changes have occurred. Here we focus on the changes that have taken place on the production and market side of the industry. This includes issues such as production volume, technological changes, market structures and marketing. Moreover, lessons that can be learned from the development of salmon and trout aquaculture of relevance to the farming of other species are also discussed.

**Key words:** Salmon, trout, aquaculture, cost, markets, marketing.

**RESUME** – "Le développement de l'aquaculture du saumon et de la truite". Cet article présente un bilan du développement de l'aquaculture du saumon et de la truite sur les deux dernières décennies. La croissance de la production de près de 13 000 t en 1980 à 1 105 000 t en 2000 a été accompagnée de nombreux changements structurels. Nous traitons ici principalement des évolutions de la production et du marché. Cela couvre les évolutions en volume de production, les changements technologiques, la structure des marchés et le marketing. De plus, des leçons peuvent être tirées de l'analyse du développement de l'aquaculture de la truite et du saumon pour l'aquaculture d'autres espèces.

**Mots-clés :** Saumon, truite, aquaculture, coût, marchés, marketing.

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### Introduction

Since the early 1980s the international salmon aquaculture industry has experienced growth rates that have been surpassed by few other production sectors. Global annual industry output growth has averaged 25% in the period from 1980 to 2000. In comparison, the average annual growth in output has been 24% in Norway, the leading producer of farmed salmon species, and impressive 57% in Chile<sup>1</sup>, the world's second largest producer.

For the major producer of farmed salmon, Norway, the salmon aquaculture industry has created new employment opportunities in many coastal communities. Today the industry directly and indirectly provides 15,000 full-time jobs, partly in outlying areas<sup>2</sup>. Salmon and trout production has also exceeded the combined production of poultry, pork and beef in Norway: in 2000 salmon and trout production was 458,000 tonnes versus a total production of 261,000 tonnes of poultry, pork and beef.

There are important lessons to be drawn from salmon aquaculture. This paper analyses the evolution of salmon farming, with a particular emphasis on the Norwegian industry. The two main objectives are to provide some hypotheses on the future development of the salmon aquaculture industry, and to provide relevant lessons for other aquaculture species.

Several conditions have to be satisfied for a new aquaculture industry to become economically sustainable. Firstly, one needs to achieve a high degree of control over the biological production process from the fry stage until the fish are ready to be harvested. Technological problems at one stage of the production process will create bottlenecks and hinder expansion. Lack of technological control can also create an unacceptably high level of economic risk for private entrepreneurs. Secondly, several market demand characteristics should be satisfied. A high price-cost margin at the

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<sup>1</sup>Refers to the period 1985-97 (Bjørndal and Aarland, 1998).

<sup>2</sup>Storting (1994-1995).

early stage of the product's life, before production expands and the industry becomes competitive, may be an indication of economic sustainability, although not a sufficient one. Furthermore, the price should, at least initially, decline only moderately as the supply of the farmed species increases, implying that it is regarded as a good substitute for other fish species or other livestock meat products. Given that per-capita incomes increase over time, it is also desirable that the income elasticity is positive and high. Thirdly, when the industry has reached the stage where the price-cost margin has almost vanished, it should have reached a size which in the next phase allows the producers to exploit *external* economies of scale in research and development, (generic) advertising, veterinary services, fish processing and distribution. The ability to exploit external economies of scale can enable the industry to undertake a further profitable expansion.

The above conditions have been satisfied to a large extent for salmon aquaculture, which despite periodic variations in profitability in major producer countries can be said to have emerged as an economically sustainable industry. A potentially important factor for further expansion of the salmon farming industry, however, is the access to fish resources for use in the salmon feed. Salmon farming relies more heavily on fishmeal than most other aquaculture industries, and higher fishmeal prices in the future may represent a barrier to further expansion unless good substitutes are found.

The extent and directions of government involvement are also important factors in aquaculture industry evolution. Government certainly has a role to play in terms of introducing regulations aimed at limiting environmental externalities caused by the industry and limiting conflicts with other user interests in the coastal zone. Government intervention may also be necessary if different types of market failure lead to a socially insufficient supply of research and development and of investment capital. However, experience from the salmon aquaculture industry also suggests that governments should be careful when considering the scope and means of public interventions.

The paper is organised as follows: next section provides an overview of production and the market characteristics for salmon species. The following section examines the characteristics of salmon production and productivity growth. The following section provides a discussion of government interventions into the salmon industry. Finally, a summary and conclusions are provided, focusing particularly on relevant lessons for other types of aquaculture production.

## Overview of production and markets

This section provides a description of the development of global salmonid aquaculture production. We also discuss some characteristics of markets for salmon and salmon trout, with an emphasis on the EU market.

### The supply of salmon

The global salmonids aquaculture production has experienced a tremendous growth since the early 1980s. From an annual production of 13,000 tonnes in 1980, it was estimated at 1,105,000 tonnes in 2000. In comparison, the wild-caught quantities increased from 561,000 tonnes in 1980 to 699,000 tonnes in 2000, down from 975,000 tonnes in 1995. From 1997 the farmed quantities have been higher than the wild-caught. The joint global supply of farmed and wild salmon species has thereby more than tripled from 573,000 tonnes in 1980 to 1804,000 tonnes in 2000, and most of the growth can be attributed to aquaculture. The development in harvests for both wild and farmed salmon and also joint harvest has been plotted in Fig. 1.

According to Fig. 1, wild salmon catches almost doubled from 1982 to 1995, but have thereafter declined. A pronounced characteristic of wild salmon fisheries, however, is the large fluctuations in catches from year to year. As a simplification one can say that farmed salmon is the source of the trend growth in total salmon supply, while wild salmon is mainly responsible for year-to-year fluctuations.

Today, over 50 per cent of the world's salmon supply is farmed salmon. With a continued production growth the market share of farmed salmon can be expected to increase further over the next decade, since it is not anticipated that catches of wild salmon shall remain at the same high levels experienced in recent years.

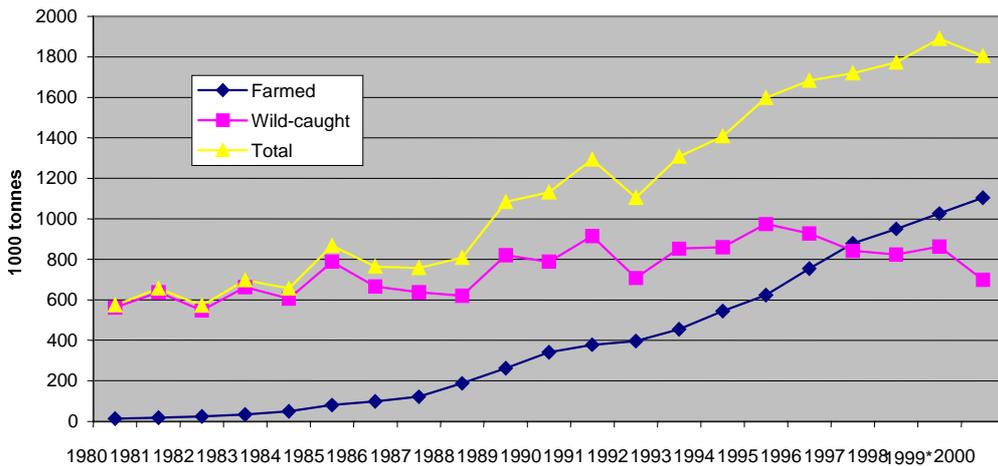


Fig. 1. Total production of salmon and salmon trout (wild-caught and farmed) 1980-2000 [source: BANF, SERNAP (Chilean National Fisheries Services), Kontali Analyse, FAO, Norway Directorate of Fisheries, DFO (Department of Fisheries and Oceans, Canada), Scottish Office].

The bulk of the catches of wild salmon are made up by the three species pink (*Oncorhynchus gorbuscha*), chum (*Oncorhynchus keta*) and sockeye (*Oncorhynchus nerka*), while the aquaculture mainly farms Atlantic salmon (*Salmo salar*), coho (*Oncorhynchus kisutch*) and salmon trout (*Oncorhynchus mykiss*). The harvest of the main species can be seen in Fig. 2 for the selected years 1986, 1992, 1995 and 1999.

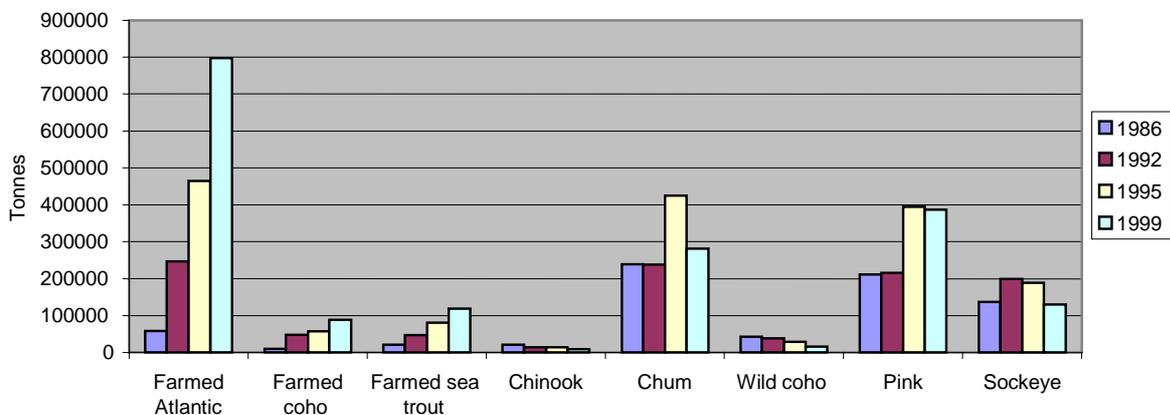


Fig. 2. Harvest of main salmon species in 1986, 1992, 1995 and 1999 (source: FAO database).

Wild salmon catches include the Pacific species pink, chum and sockeye in addition to smaller quantities of coho, chinook (*Oncorhynchus tshawytscha*) and cherry (*Oncorhynchus mason*). The three former species account for between 90% and 95% of the total harvest of wild-caught salmon. The share of the three remaining species has been declining in the period considered. The composition of the wild-caught harvest from 1980 to 2000 is shown in Fig. 3.

Only a few countries dominate the harvesting of wild salmon. The distribution of catches of wild salmon between the main harvesting countries for 1980 to 2000 can be seen in Fig. 4. The US has had the leading position, accounting for around 45% of the total global catch. However, Japan has had a rising share of the total catches and had almost as large catches as the US in 1997, but the share has decreased in the following three years. The two remaining main players are Russia and

Canada. Russia's share has varied between 15% and 25% in most years considered, while Canada has supplied between 10% and 15% of the total quantities, falling down to around 5% from 1995 onwards.

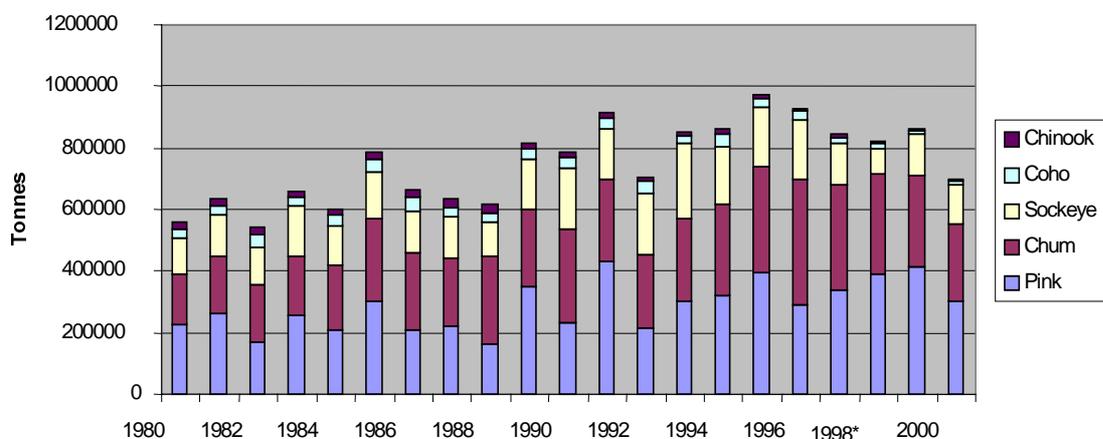


Fig. 3. Composition of Wild salmon harvest 1980-2000 [source: BANR, NMFS (National Marine Fisheries Service), Alaska Department of Fish & Game (Alaska F&G), Hokkai Keizai Shinbun, Russian Federal Institute of Fisheries and Oceanography, DFO, FAO].

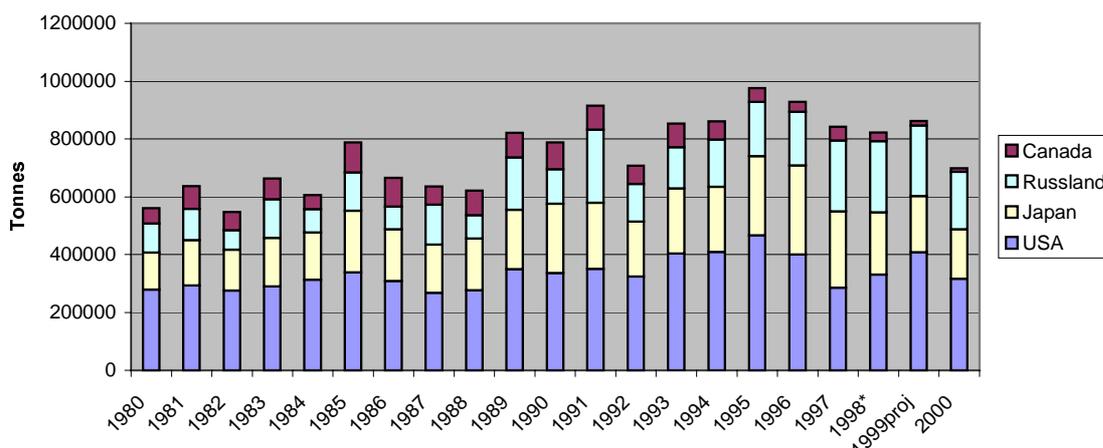


Fig. 4. Catches of wild salmon by country 1980-2000 (source: BANR, NMFS, Alaska F&G, Hokkai Keizai Shinbun, Russian Federal Institute of Fisheries and Oceanography, DFO, FAO).

The development in farmed salmonids can be seen in Fig. 5. The production of farmed salmonids is concentrated on the three species Atlantic salmon, coho and salmon trout. In addition, smaller quantities of cherry and chinook are being farmed. Atlantic salmon is the dominating species, accounting for more than 70% of the total farmed quantities. Salmon trout follows with around 15% of the total harvest, while coho accounts for around 10%.

From the very beginning, the worldwide production of farmed salmon has been dominated by a few nations. Four countries supply around 80% of the total production. These are Norway, Chile, the UK and Canada. Their production over time is illustrated in Fig. 6.

Two trends dominate the picture in Fig. 6. The first is Norway's leading position throughout the whole period. In 1981 its share in world production was approximately 70%. Its dominance has been reduced over time, though, and Norway's share had decreased to just about 47% in 1999 and 43% in 2000. As 1999 saw reduced output in Chile due to the economic crisis in Asia and in Scotland due to disease problems, Norway's share actually increased that year. The second important trend is the rise

of Chile as a major producer of farmed salmon. From a zero share in world production at the beginning of the 1980s, the production rapidly increased in the late 1980s and had surpassed that of both the UK and Canada by 1992, making Chile the second largest producer of farmed salmon in the world. In 1998 Chile's share in world production was about 22%, falling to 20% in 1999, but increasing again to 24% in 2000. The shares of Canada and the UK have been more stable.

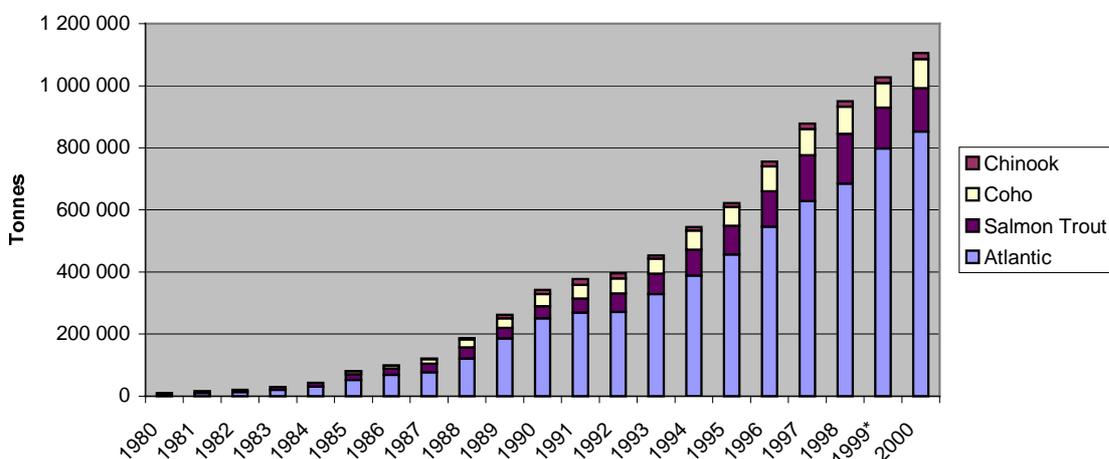


Fig. 5. Farmed salmon and salmon trout 1985-2000 (source: Bill Atkinson's News Report, Sernap, Kontali Analyse, FAO, Directorate of fisheries, DFO, Scottish Office).

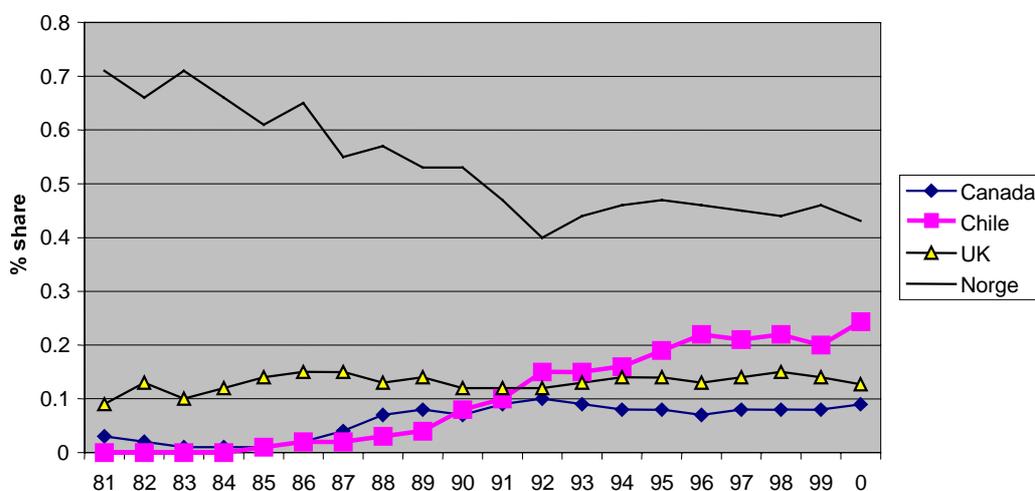


Fig. 6. Shares in World production of farmed salmon 1981-2000 (source: Bill Atkinson's News Report, Sernap, Kontali Analyse, FAO, Directorate of fisheries Norway, DFO, Scottish Office).

An important factor explaining the development in a country's production share is usually the development in its production costs relative to other countries. As noted, Norway's production share declined substantially in the period under consideration. This decline was probably bound to happen due to diffusion of best-practice technologies from Norway to other countries. Nevertheless, developments in cost of production may also have been important. Furthermore, trade measures such as those Norway has experienced in the European Union market also affect the production share.

The distribution of harvest among main producing countries can be seen in Fig. 7 for Atlantic salmon and in Fig. 8 for all farmed salmon species.

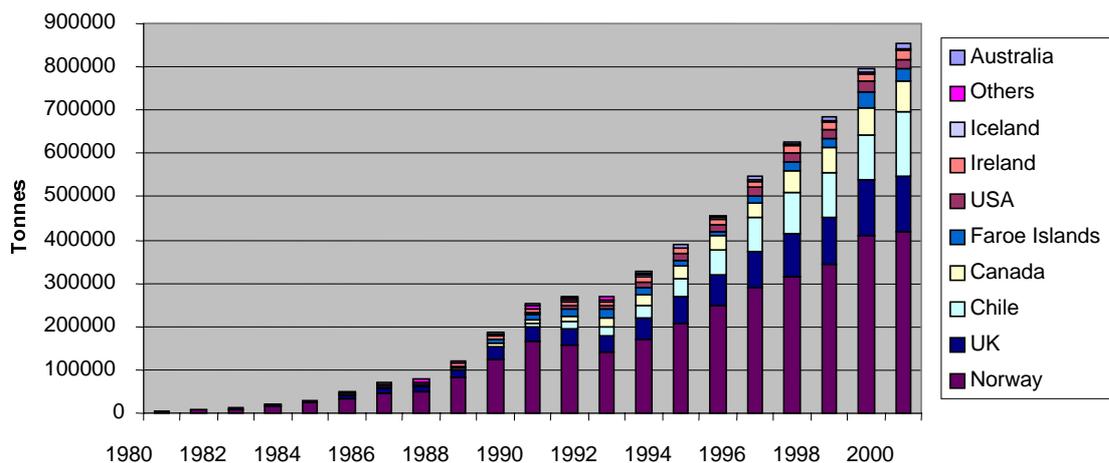


Fig. 7. Atlantic farmed salmon production 1984-2000 (source: Bill Atkinson's News Report, Sernap, Kontali Analyse, FAO, Directorate of fisheries Norway, DFO, Scottish Office).

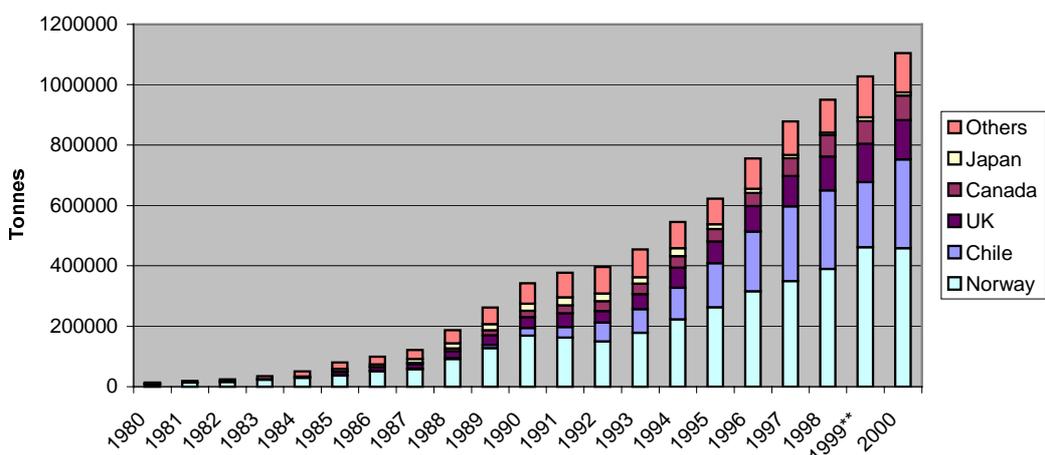


Fig. 8. Main producers of farmed salmon and salmon trout 1985-2000 (source: Bill Atkinson's News Report, Sernap, Kontali Analyse, FAO, Directorate of fisheries Norway, DFO, Scottish Office).

It is not historical coincidences that have made Norway, Chile and the UK the major producers of salmon species. The first condition for large-scale production is a long coastline with plenty of sheltered locations in areas with limited competition from other user interests (e.g. recreational users, residential areas, and other industries), but at the same time with access to infrastructure (e.g. roads and electricity). Another condition is sea temperatures during the year which fluctuate within the range conducive to salmon farming. For most countries the lack of suitable locations is the most important barrier to establishment of a large salmon farming industry. In the US, in particular, site availability seems to represent a barrier to further expansion of the industry. There are plenty of sites with appropriate biophysical conditions, but competition with other user interests is generally high. In Alaska, for example, there is a total ban on salmon farming due to concerns for wild salmon stocks. Competing user interests is also an increasing problem in Canada and the UK. On the other hand, site availability should not limit further expansion in Norway and Chile in the foreseeable future.

### The salmon markets

The world's three largest markets for salmon and salmon trout are in the EU, Japan and the US.

However, the composition of the consumption differs substantially due to traditions and production methods. In Europe most of the salmon consumed is farmed, and this is also the quickest growing market. This may not be accidental, since most of the farmed salmon is produced in Europe. Both the US and Japan have stronger salmon consuming traditions than Europe, since wild Pacific salmon is much more abundant than Atlantic salmon. However, also here the growing production of farmed salmon is making a substantial impact. In Japan, the market share of wild salmon is now less than 50%. In the US import of farmed salmon is increasing rapidly.

Not all salmon species are valued equally. A market segment for high-valued salmon species consisting of Atlantic salmon, coho, salmon trout, sockeye and chinook has been identified. Pink and chum typically fetch lower prices due to lower quality. These are also mainly used for canning or salting and therefore aim at a different market segment. In the following, this paper will focus on the high-valued species.

The markets for salmon and salmon trout have been subject to extensive econometric analysis, both demand analyses and cointegration analysis. Econometric demand analyses aim to provide quantitative estimates of the effects of changes in the own price of a good, changes in the prices of substitutes and changes in consumer income on the demand for a salmon product. Analyses of price relationships aim to provide estimates of to what extent markets for different salmon products are integrated, i.e. whether the prices of different salmon products follow each other over time<sup>3</sup>.

Most farmed salmon is sold fresh. Market delineation studies of the salmon markets have found that there is no separate market for fresh salmon in the EU or globally (Asche and Sebulonsen, 1998; Asche, 1999). Hence, there seems to be a global market for fresh salmon. The price level differs, with higher prices in Japan than the EU and the US, but the prices follow the same pattern over time. An integrated market for fresh salmon implies that changes in the price in the EU market will also affect the prices in the other major markets. Market integration studies also indicate that farmed salmon competes closely with wild salmon. In fact, the different species seem to be so close substitutes that the Law of One Price holds (Asche *et al.*, 1999). As most farmed salmon is sold fresh, while most wild salmon is sold frozen, this also implies that there is a close relationship between fresh and frozen salmon. However, market delineation studies indicate that there is little or no substitution between salmon and other fish species (Asche *et al.*, 1998).

An important issue in studies of the demand structure for salmon is the substitutability of different forms of salmon, and the substitutability of salmon with other food products e.g. other fish and meat products. For example, how many per cent will the demand for salmon increase if the price of other fish species (such as turbot or cod) increases? Substitutability has been analysed empirically by means of econometric demand models where prices of other products have been included as explanatory variables. Such models allow one to estimate the *cross-price elasticity*, which is defined as the percentage change in the demand for a product when the price of another product increases by one per cent<sup>4</sup>. Cross-price elasticity estimates for fresh and frozen salmon at the EU market suggest moderate to high degrees of substitutability between different product forms of salmon (Asche *et al.*, 1997; Asche *et al.*, 1998).

According to most studies salmon demand is fairly elastic in own price. In other words, most studies find that a one per cent decrease in the price of salmon will lead to a more than one per cent increase in salmon demand. However, there is also a tendency that the magnitude of the elasticity is becoming smaller as the supply has been increasing, and for some species or product forms it already seems to be inelastic. If supply of salmon continues to increase, it is therefore most likely only a matter of time before aggregate demand for salmon becomes inelastic. In fact, it may already be inelastic, since most studies use older data sets, and elasticities reported at the mean will contain substantial weight from data from the 1980s.

The effect of changes in income on the demand for salmon has also been estimated in the above-cited studies. In general the studies find that salmon demand is income elastic. This means that a one

<sup>3</sup>The advantage of analysing price relationships compared to demand analysis is smaller data requirements, since quantity and income data are not required. The drawback is that one obtain less information than what traditional demand analysis provides.

<sup>4</sup>The cross-price elasticity is defined as  $\eta_{ij} = (\partial X_i / \partial p_j) / (p_j / X_i)$ , where  $X_i$  is the quantity demanded of product  $i$  and  $p_j$  is the price of product  $j$ .

per cent increase in income has increased salmon demand by more than one per cent. To what extent this also will be the case in the future depends on whether salmon maintain its historical reputation as a luxury product. New distribution channels (e.g. supermarkets) and product forms may change consumers' perceptions of salmon and consequently their tendency to purchase salmon as income increases.

It can also be fruitful to make a distinction between the short and long run. Limited economies of scale both in production and distribution should preclude a high degree of concentration, and consequently the ability to exercise market power in Europe also in the future. Furthermore, the potential threat of entry from new salmon farmers and wild-caught Pacific salmon will also act as an impediment to maintaining prices above marginal costs in the long run. To summarise, the salmon market has historically been competitive and there are strong arguments for asserting that it will remain so in the future despite a somewhat higher degree of concentration.

Real salmon prices at the EU market have experienced a significant decline from the early 1980s. This is illustrated in Fig. 9, which plots the average export price for Norwegian salmon. According to Fig. 9 the exports price declined from nearly 80 NOK/kg in 1985 to less than 27 NOK/kg in 1999. This means that the export price in 1999 was a third of the 1985-price, which is a dramatic reduction. As can be seen from the figure, the decline in salmon prices has been accompanied by a decline in the production costs. We now turn to a discussion of the sources of this remarkable increase in productivity.

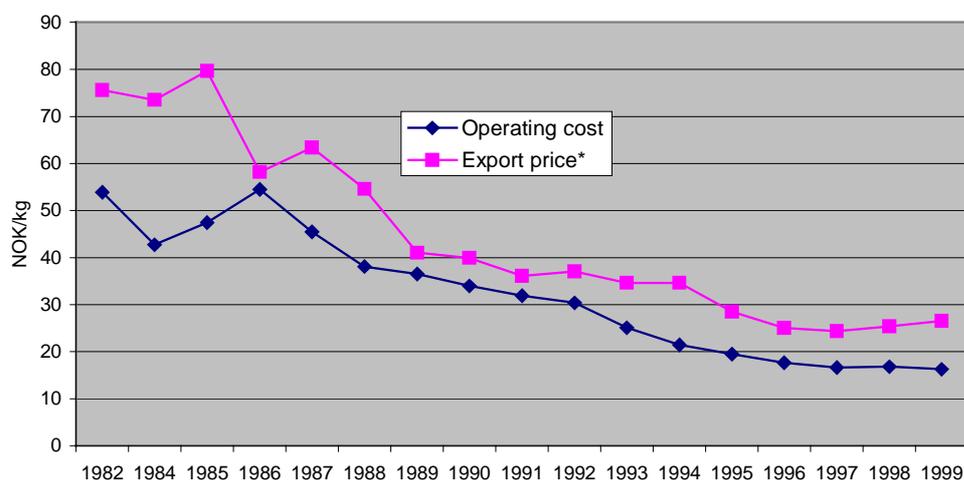


Fig. 9. Real operating costs and export price in Norwegian salmon aquaculture (\*the export price refers to whole, fresh salmon) (source: Directorate of Fisheries; Asche *et al.*, 1999).

### Salmon production, productivity growth and marketing

This section examines the structure of the salmon production technology and the productivity growth in Norwegian salmon farming since the mid-1980s.

#### The structure of production and costs

The most important input in salmon farming is the salmon feed which represented around 52% of operating costs in 1999 according to Table 1. Other inputs are smolts (15% cost share), capital (5%), labour (9%), insurance (2%) and materials (17%).

Econometric cost and production function studies suggest that economies of scale are exhausted at relatively low production volumes (Asche and Tveterås, 1999; Tveterås, 1999a; Tveterås and Heshmati, 1998). However, according to these studies the production volume at which scale economies are exhausted has also increased substantially from the early 1980s.

Table 1. Costs in Norwegian salmon farming (1985-1997) per kg of salmon produced. Values in 1997 NOK. Percentage cost shares in parentheses<sup>†</sup> (source: Directorate of Fisheries and some material used in Salvenes, 1988)

Type of cost	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Smolt	12.38 (26.1)	13.90 (25.5)	11.28 (24.8)	9.72 (25.5)	6.44 (17.6)	5.90 (17.4)	5.41 (17.0)	5.30 (17.4)	4.66 (18.6)	4.07 (19.0)	3.91 (20.1)	3.08 (17.4)	2.69 (15.8)	2.23 (13.0)	2.53 (15.2)
Feed	17.10 (36.0)	16.80 (30.9)	13.87 (30.5)	13.89 (36.5)	15.45 (42.3)	15.16 (44.7)	13.31 (41.8)	13.20 (43.5)	11.22 (44.7)	10.50 (49.0)	9.55 (49.1)	8.82 (50.0)	9.11 (53.6)	9.71 (56.5)	8.62 (51.8)
Wages	6.34 (13.4)	7.48 (13.7)	6.24 (13.7)	4.29 (11.3)	3.86 (10.6)	3.87 (11.4)	3.59 (11.3)	3.52 (11.6)	2.76 (11.0)	2.37 (11.1)	1.93 (9.9)	1.70 (9.6)	1.62 (9.5)	1.61 (9.3)	1.49 (8.9)
Net capital cost	4.32 (9.1)	6.58 (12.1)	5.78 (12.7)	4.20 (11.0)	4.22 (11.6)	3.85 (11.4)	3.72 (11.7)	2.42 (8.0)	2.01 (8.0)	1.27 (5.9)	1.01 (5.2)	0.90 (5.1)	0.74 (4.4)	0.77 (4.5)	0.87 (5.2)
Insurance	1.77 (3.7)	2.42 (4.4)	1.87 (4.1)	1.28 (3.4)	1.30 (3.6)	1.31 (3.9)	1.06 (3.3)	0.90 (3.0)	0.67 (2.7)	0.52 (2.4)	0.42 (2.1)	0.36 (2.0)	0.24 (1.4)	0.25 (1.5)	0.28 (1.7)
Other costs	5.52 (11.6)	7.27 (13.4)	6.42 (14.1)	4.69 (12.3)	5.27 (14.4)	3.87 (11.4)	4.78 (15.0)	5.02 (16.5)	3.78 (15.1)	2.71 (12.7)	2.65 (13.6)	2.79 (15.8)	2.59 (15.2)	2.61 (15.2)	2.85 (17.1)
Operating costs per kg	47.43	54.45	45.47	38.08	36.53	33.95	31.87	30.36	25.10	21.44	19.46	17.65	16.99	17.18	16.65

<sup>†</sup>Due to changes in the definition of the different types of costs, there is some uncertainty associated with comparing these over time.

This development coincides with an increase in the average production of Norwegian salmon farms, from 47 tonnes per farm in 1982 to 543 tonnes in 1996. One important factor behind the increase in the output range in which economies of scale are increasing is probably the improvement in the feed and feeding technology. This has led to a reduction in accumulation of organic material at the seabed and less consumption of oxygen for degradation of feed waste and faeces. Another factor is the gradual relocation of many farms to more exposed sites, which allowed these farms to increase their scale of operation without being constrained by biophysical limits (e.g. oxygen exchange). A third factor is the relaxation of the government's restriction on fish pen volume, which led to a misallocation of variable inputs and prohibited exploitation of economies of scale<sup>5</sup>.

The above studies found limited substitution possibilities between feed, capital and labour. This is not surprising since salmon production in the short run, after investments in capital equipment have been made, can be characterised as a technology which implies a close to fixed relative factor share in the production process. The scope for substitution is larger in the long run, when farmers have exploited changes in technology and relative prices to substitute in particular capital for labour.

An important feature of salmon aquaculture is the riskiness of the production process. Inputs have two "functions" in salmon farming; they influence both the mean (or expected) output level and the level of output risk. A marginal increase in the use of any input should increase the expected output level. However, an increase in the use of an input may increase or decrease the variance of output, too.

## Productivity growth

There are several interesting aspects of productivity growth in Norwegian salmon aquaculture. First, the relationship between productivity growth and decline in salmon prices. Second, the sources and mechanisms behind the technical change. Third, the effects of technical change on the level of production risk.

We have seen earlier (Fig. 9) that the decline in salmon prices was accompanied by a decline in production costs, although this decline was not sufficient enough to maintain the large price-cost margins that farmers enjoyed until 1985. Tveterås and Heshmati (1998) found that technical progress at the farm level, i.e. technological and organisational changes, only explains some of the price decline during the 1985-93 period. Declining factor prices also contributed to the price decline.

Table 1 shows the development of operating costs during the 1985-99 period. Total operating costs per kilogram of salmon output decreased from 47.43 NOK in 1985 to 16.65 NOK in 1999. According to the table the cost share of feed has increased from 36% in 1985 to 52% in 1992, despite a more than halving of the feed cost per kg produced. On the other hand, labour and particularly capital have experienced a decrease in cost shares. Hence, the technological change and changes in relative factor prices have led to a larger increase in the productivity of labour and capital in cost terms than is the case for feed.

There are several sources behind the productivity growth observed in Norwegian salmon aquaculture. One source is public investments in research and development, which has caused many innovations that have been diffused to salmon producers. Public R&D will be discussed in the next section. Another source is on-farm innovations and learning. Farmers have learned from their own production experiences, but they have also acquired knowledge from other farmers. An important issue is to what extent entrepreneurs that entered the industry at late stages were able to catch up with early entrants, or more generally, how rapidly initially less efficient farmers were able to catch up with more efficient farmers. This is of interest since the average observed productivity growth from one period to another will be the result of both improvements in the best-practice technology and catching-up of less efficient producers.

In Norway one can ask at a more aggregate level if coastal regions that entered into the salmon industry at later stages were able to catch up with regions that entered at earlier stages. Figure 10 shows econometric estimates of the development of regional technical efficiency in eight coastal

<sup>5</sup>The maximum licensed pen volume has gradually been increased from 3000 m<sup>3</sup> in 1981 to 15,000 m<sup>3</sup> currently.

regions from 1985 to 1995. We see that mean technical efficiency increases over time. According to the econometric estimates the regions with the highest initial technical efficiency (e.g. Rogaland) experienced the smallest increase in productivity growth during the period. The least efficient regions (e.g. Finnmark and Troms) experienced the highest rate of technical progress. However, it seems like the convergence in the rate of technical slowed down after 1990. This may be due to different biophysical conditions (e.g. sea temperature, tidal water exchange) or intra-regional external economies of scale (in industry infrastructure such as transportation, veterinary services, slaughtering, etc.), which give rise to permanent differences in productivity.

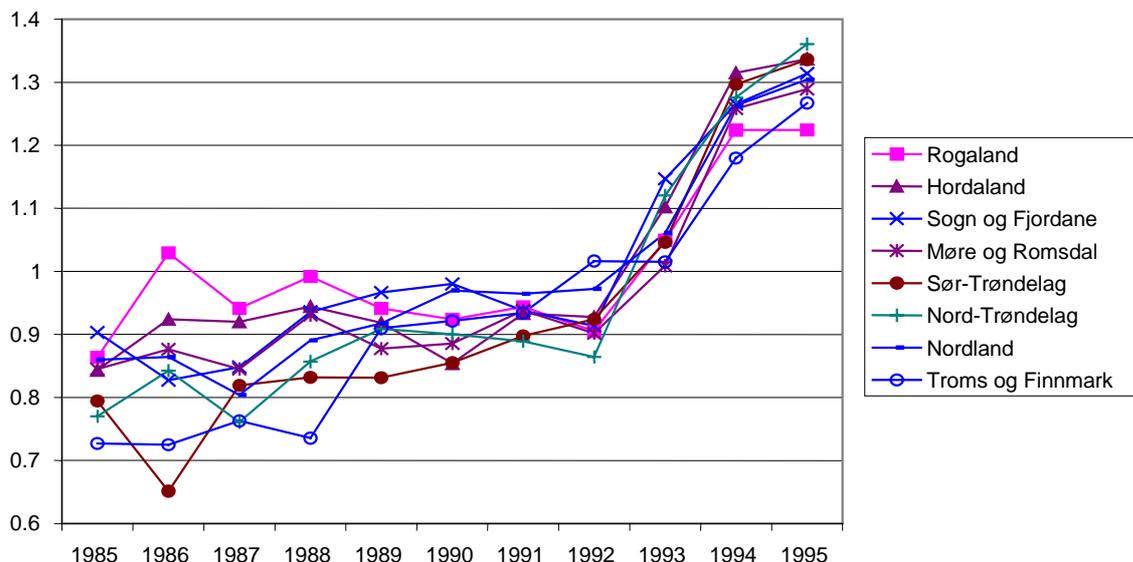


Fig. 10. Development of regional technical efficiency in Norwegian salmon farming 1985-95 (source: Tveterås, 1999b).

Given the high level of production risk in salmon farming the effects of technical change on production risk is also an issue that deserves scrutiny. Risk averse producers should be concerned about the effects of new technologies both on mean output and on output risk. Tveterås (1999a) found that although technical change has not led to a large reduction in the variance of output, the nature of the technical change has been such that all producers will prefer the 1995-production technology to the 1985-production technology.

### Marketing of salmon

When production of farmed salmon exploded in the early 1980s the industry could exploit existing distribution channels used by traditional Norwegian fisheries abroad. However, in order to find buyers for rapidly increasing volumes, a major challenge for the industry was to find new distribution channels and means of advertising to make more consumers aware of the benefits of salmon. As for other fish it has been difficult to establish strong brand names, because one supplier's investments in advertising provide positive externalities for other suppliers of salmon. This market failure led the Norwegian industry to organise generic marketing for salmon through their joint sales organisation. The effort was largely terminated in 1991, when the sales organisation went into bankruptcy. Shortly after, a fee on salmon exports was introduced, to be used mainly for generic marketing. Recently, the generic marketing has regained force due to the introduction of a 3% value tax on salmon exports to the EU in conjunction with an agreement with the EU. The tax was earmarked generic marketing, which meant it would also benefit EU-salmon producers like the UK and Ireland. Because of this tax the Norwegian Seafood Export Council, which coordinates the generic marketing effort, spent 235 million NOK on generic marketing of Atlantic salmon in the EU and other markets in the period 1997 to 1999. In 2001 290 million NOK will be used for marketing purposes.

The first priority of the Norwegian Seafood Export Council is to ensure continued growth, and also keep Norway's position in the EU market. Japan and USA have been defined as core markets with large potential, while Asia and East/Central Europe are viewed as important emerging markets.

An important trend in the marketing of salmon has been the penetration into new market segments through the distribution of increasingly cheaper fresh and frozen salmon products to supermarkets. This has opened up a new market of consumers who consider salmon as a substitute for chicken and other meat products. In the future increased concentration and vertical integration, increased traceability of the salmon through the value chain, and increased product differentiation (e.g. dinner-ready frozen products) should to a larger degree facilitate private marketing and establishment of strong private labels.

## Summary and future development

We have seen that the salmon industry has experienced an impressive growth over the last 20 years. In 1980 farmed salmon supply constituted a negligible fraction of world salmon supply, but today exceeds wild salmon catches.

Explanations for the rapid growth of the salmon aquaculture industry are found both on the supply and demand side. Since the early 1980s salmon farmers have acquired a high degree of control over all stages of the production process. Consequently, there are presently no technological bottle-necks in the production chain, and the industry has been able to reduce the production risk to manageable levels. During the same period salmon aquaculture has experienced high productivity growth rates, which has resulted in production costs that are now only one-third of the level in the mid 1980s. The sources of this productivity growth have been both technological change and exploitation of scale economies. In the largest producer country, Norway, scale economies have been exploited to an increasing degree internally at the farms, but also externally as the industry growth has allowed the development of an industry infrastructure.

The decline in production costs has been accompanied by a similar decline in salmon prices. Although the decrease in market prices is considerable, it must be viewed in light of the fact that supply has increased many times during the same period. Even though the price-cost margin is not at the high levels obtained in the early 1980s, the farming of salmon still provides a good economic return to many producers with the current price levels. From the consumers' point of view salmon is generally considered an alternative source of healthful nutrition. Despite increasing supply and availability in supermarkets it is still valued higher than many other meat products in general and fish products in particular. The intensive use of antibiotics may have represented a threat to the reputation of farmed salmon at some stage, but with other less harmful medical treatments that have become available there are no imminent serious threats to its image among consumers.

There is some evidence that salmon is a good substitute for other high-valued white fish species and that salmon demand increases with consumer income. Both these factors are important for maintaining prices at relatively high levels. As salmon prices have declined many consumers have substituted away from meat products. To some extent farmed salmon has also benefited from the relatively stagnant catches of high-valued white fish.

So far the salmon aquaculture industry has satisfied the conditions for growth and economic sustainability presented in the introduction. What about the future? In the short run market demand is the limiting factor for further expansion of production. Norwegian producers probably have the capacity to increase production two or three times with the present technology without any increase in average production costs. However, with the short-run demand curve facing them such an increase in production volume would imply a large price decline. Nevertheless, there should be room for further expansion in the long run from a market demand perspective, both in the EU and other markets. Salmon still constitutes a relatively small fraction of the meat and fish consumption for most consumers in the EU – less than two kg per capita. Innovations in the marketing of farmed salmon, both with respect to development of distribution channels and development of non-generic products, should contribute to shifting the demand curve outwards and thus mitigate the negative effect of further supply increases on market prices.

On the production side there are some factors which may limit further downward shifts of the supply curve. New vaccines have already contributed to reducing the mortality rates to low levels, and thereby exhausted to some extent the potential for future productivity growth through further decreases in mortality. Furthermore, during the last 15 years, new innovations have led to a large increase in the efficiency of the best-practice feed and feeding technology. The ratio between salmon output and feed input is now close to the theoretical limit at the most efficient farms. Further increases in average feed utilisation efficiency must therefore be due to catch-up of the least efficient farms, rather than improvement in the best-practice technology.

Also in a global perspective catch-up may be as important as improvements in the best-practice technology for increasing average productivity in the salmon aquaculture industry and hence shifting the supply curve downwards. Chile is a producer country which may have the potential for catching up further.

Salmon is a carnivorous fish species, and fish meal and fish oil are important ingredients in the salmon feed. In 1994 8% of fish meal and 17% of fish oil were used in feed for salmon and trout (Rosenlund, 1997). Until now feed manufacturers have only to a limited degree been able to use other nutritional sources as substitutes for fish raw materials. There have been some promising developments in this area recently, but there is no general consensus on the possibility of finding substitutes for fish meal that are both technologically feasible and that will be accepted by consumers. Considering the large cost share of feed, the future development of fish meal and fish oil prices may be crucial for the future salmon supply. If the salmon industry is not able to reduce its dependence on fish raw material, one could see increasing salmon prices in the long run, since fish resources are finite and salmon aquaculture competes with agriculture for fish meal and fish oil. There is a need for more research on the determinants of salmon supply, such as the factors determining the feed price, before one can provide more quantitative predictions on future development.

Protectionist measures will also determine production and price levels in the future, if major importers such as the EU and the USA continue to use these. This is because these measures may distort incentives and lead to reallocation of production from more efficient producers to less efficient producers.

Are there any important lessons from salmon aquaculture to other species? The allocation of productive resources to salmon aquaculture in Norway has been successful in economic terms. Furthermore, the study of Norwegian salmon aquaculture leads to the conclusion that the producers themselves internalise the environmental problems to a large extent in their ordinary production decisions. This means that the need for public regulation is limited, although some measures are necessary to the extent that environmental effects are not internalised by farmers. The most important role of government may be to offset market failures in research and development to ensure the socially desirable level of innovative activities. Public R&D has been an important factor in reducing production costs in salmon farming, and production would probably have been significantly smaller without the subsidisation of R&D. However, the existence of a salmon aquaculture industry can not be attributed to public R&D, since the industry itself resolved the technological obstacles to large-scale commercial production.

Considerable resources have also been spent on R&D other species. Despite the fact that other species have benefited from more government support, for example, in R&D, than was the case for salmon in the 1970s and early 1980s, one has yet to see a commercial breakthrough on a larger scale. The lack of commercial success is probably due both to technological problems at certain stages of the production process and to market demand characteristics. For some species public R&D may lead to innovations which resolve technological problems, but it may also be the case that the success of salmon farming has led to unrealistic optimism for other species. For some species, such as halibut, there are technical barriers at the hatchery stage. For other species, such as sea bass and sea bream, the market demand may represent the greatest problem.

Figure 11 shows the development in the average price of sea bass and sea bream in Italy together with the total European aquaculture production of these species. Despite the modest production volume the price has decreased substantially. This dramatic decline may suggest that consumer preferences are such that other fish products or meat products are not easily substituted with sea bass and sea bream, and that the structures of market demand therefore represents the largest

barrier to growth for these two species. However, there are indications of flattening in the price, which may suggest that the market for these species is expanding.

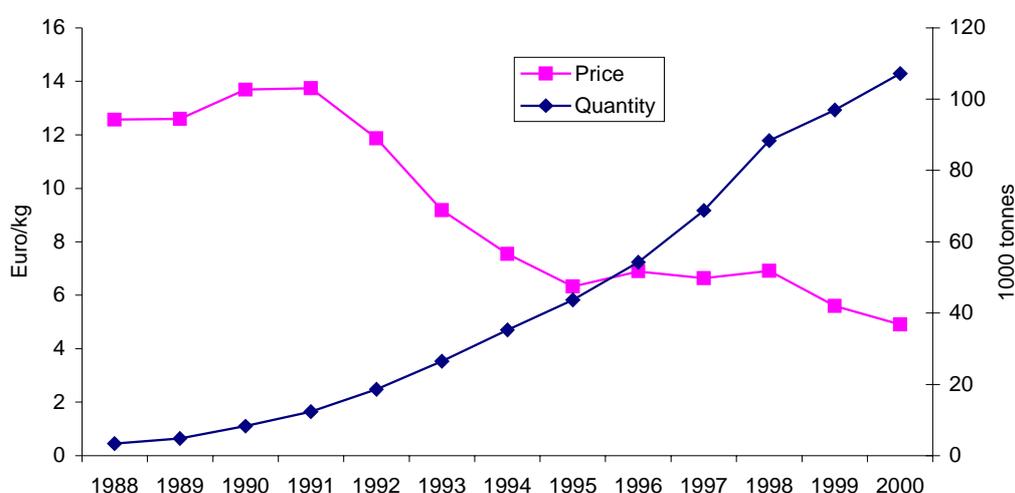


Fig. 11. European production of sea bass and bream ('000 tonnes) and real Italian import price (€/kg), 1988-2000 (source: FAO, Eurostat).

The experience with salmon farming suggests that governments should exercise care when picking certain fish species as engines for future aquaculture growth. Initial prices may be poor indicators of the market prices when much larger quantities are brought to the market. Several large companies have recently been involved in innovative activities related to new aquaculture species. Policy makers have a difficult task when they must decide if the failure of these companies in overcoming technical barriers or obtaining sufficiently high prices may be an indication that aquaculture production is not commercially viable for certain species, and that tax-payers money should not be spent on these species.

## References

- Asche, F., Bjørndal, T. and Salvanes, K.G. (1998). The demand for salmon in the European Union: The importance of product form and origin. *Can. J. Agric. Econ.*, 79: 139-150.
- Asche, F., Bremnes, H. and Wessells, C.R. (1999). Product aggregation, market litemegration and relationships between prices: An application to World salmon markets. *Amer. J. Agric. Econ.*, 81: 568-581.
- Asche, F., Gordon, D.V. and Hannesson, R. (1998). Testing for market integration in the European whitefish market. In: *Proceedings IFET 98 Tromsø*, Eide, A. and Vassdal, T. (eds.). University of Tromsø, Tromsø, pp. 746-754.
- Asche, F., Guttormsen, A. and Tveterås, R. (1999). Environmental problems, productivity and innovations in Norwegian salmon aquaculture. *Aquaculture Economics and Management*, 3(1): 19-29.
- Asche, F., Salvanes, K.G. and Steen, F. (1997). Market delineation and demand structure. *Amer. J. Agric. Econ.*, 46: 69-81.
- Asche, F. and Sebulonsen, T. (1998). Salmon prices in France and the UK: Does origin or market place matter? *Aquaculture Economics and Management*, 2: 21-30.
- Asche, F. and Tveterås, R. (1999). Modeling production risk with a two-step procedure. *Journal of Agricultural and Resource Economics*, 24(2): 424-439.
- BANF (various issues). *Bill Atkinson's News Report*.
- Bjørndal, T. and Aarland, K. (1998). *Salmon aquaculture in Chile*. Working Paper No. 47/97. Foundation for Research in Economics and Business Administration, Bergen.
- Directorate of Fisheries (1985-97). Profitability survey for fish farms (in Norwegian: "Lønnsomhetsundersøkelse for matfiskanlegg"). Annual Report.

- FAO (2000). *FAO Fisheries Database. Fishstat+ v 2.30*. FAO, Rome.
- Kontali Analyse (various issues). *Monthly Report* (in Norwegian: "Månedsrapport")
- Rosenlund, G. (1997). *Feed and feed additives* (in Norwegian: Fôr og fôrtilsetninger). Paper presented at the Workshop on Gene technology and aquaculture, Tromsø (Norway), 23 April 1997.
- Salvanes, K.G. (1988) *Salmon aquaculture in Norway: An empirical analysis of cost and production properties*. Ph.D. Dissertation, Norwegian School of Economics and Business Administration, Bergen.
- Storting (1994-95). *Aquaculture – A driving force in Norwegian coastal industries* (in Norwegian: "Havbruk – en drivkraft i norsk kystnæring"). Report to the Storting (St. meld.) No. 48.
- Tveterås, R. (1999a). Production risk and productivity growth: Some findings for Norwegian salmon aquaculture. *Journal of Productivity Analysis*, 12(2): 161-179.
- Tveterås, R. (1999b). Learning and knowledge spillover: Regional productivity convergence in Norwegian aquaculture. In: *The Annual International Conference and Exposition of the World Aquaculture Society*, Sydney (Australia), 26 April - 2 May 1999.
- Tveterås, R. (2000). Flexible panel data models for risky production technologies with an application to salmon aquaculture. *Econometric Reviews* (in press).
- Tveterås, R. and Heshmati, A. (1998). Patterns of prices and productivity growth in the Norwegian salmon farming industry. In: *Proceedings IFET 98 Tromsø*, Eide, A. and Vassdal, T. (eds). University of Tromsø, Tromsø.