The Economics of Aquaculture with respect to Fisheries

95th EAAE Seminar
Civitavecchia (Rome), 9-11 December 2005

Edited by
Kenneth J. Thomson and Lorenzo Venzi

Review of Environmental Issues in Fish Farming: Empirical Evidence from Salmon Farming

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Abstract

Intensive fish farming has faced a number of environmental challenges both locally and globally. In this paper we review some of the most important environmental issues that has faced fish farming and then see how the industry has handled these challenges. Salmon aquaculture has probably faced more of these challenges than any other farmed species, with the possible exception of shrimp aquaculture. We concentrate on empirical evidence related to salmon, although the issues related to other farmed species are similar to that of salmon. Other environmental issues include degradation of local habitat, disruption of ecological systems, and detrimental impact on wild species. Evidence suggests that most of the local environmental problems have been resolved or minimized through industry action and governmental regulations, although a few challenges remain.

Keywords:
Jel classification:

Introduction

In the early 1990s, the Norwegian public was confronted with images of farmed salmon that died of toxic gases from organic waste under farm sites. The images showed thick layers of organic waste covering the underwater fauna. The extensive use of antibiotics also received much attention during this early phase of the industry. As these problems have receded, attention has shifted to other issues, such as the conflict between farmed and wild salmon stocks because of the impact of farmed salmon escapees on the genetic pool and sea lice proliferation around farms. In addition, the use of fishmeal and fish oil in salmon feed has raised some controversy because it potentially threatens the sustainability of reduction fisheries. The salmon industry has since striven to change its image from one of an environmental 'sinner' to one of a sustainable and environmentally friendly industry. If we compare those early days in the salmon industry's life cycle with the current situation, several issues have been resolved and the remainder substantially reduced. In this paper, we review some of the environmental issues in aquaculture, with empirical evidence from the salmon farming industry. In doing so, we try to identify

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economic factors that have contributed to improvements in environmental practices and in the cases where they are unresolved, to ask “Why so?”.

The experiences described above are not unique to salmon farming. Naylor *et al*. (2000) addressed many environmental issues in aquaculture, ascribing them, in part, to the intensive nature of industrialized aquaculture production. In this respect, the salmon and shrimp industries have received the bulk of attention, not only because of their perceived negative impact on the local environment, but also because of the extensive use of marine resources in feeds, which is considered a global environmental concern. Shrimp farming has received even more negative publicity than salmon farming in relation to detrimental environmental effects, such as destruction of mangroves, salination of agricultural areas, eutrophication, and disruptive socio-economic impacts (Boyd and Clay, 1998, Naylor *et al*., 2000). As with the salmon industry, however, the environmental problems in shrimp farming have been reduced.

Detrimental environmental effects of aquaculture not accounted for in market prices are by definition externalities. Asche, Guttormsen and Tveterås (1999) argued that internalization of externalities explains how some of the major environmental issues have been resolved in aquaculture. The arguments go along the following lines: Productivity in aquaculture depends on an environment where farmed fish thrive. Fish farms with environmental practices that damage the local environment experience negative feedback effects, where poor water quality reduces on-farm productivity. These negative environmental feedback effects are well known, and can be amply exemplified by reference to salmon and shrimp farming. The results are reduced growth of the biomass through deteriorating fish health and, in the worst of cases, disease outbreaks that wipe out entire on-farm fish stocks. For example, in shrimp farming there is a clear link between farm practices and the likelihood of a white-spot outbreak in regions where white spot is endemic. Consequently, one is concerned with cultivating management practices that avoid such negative repercussions on productivity.

The environmental issues that arose in intensive salmon and shrimp farming, during the 1980s and through the 1990s, must be seen in relation to the introduction of a new technology that uses the environment as an input. There is a time lag from an environmental issue arises before it can be resolved. First, the impact and the causes must be properly identified. Second, the solution to the problems may require modifications of existing technology or maybe entirely new technology. In both cases, pollution reduction implies some form of induced innovation. In this respect, Tveterås (2002) argues that industry growth has a positive effect on pollution, in line with the Environmental Kuznets Curve (EKC). The EKC hypothesis refers to an empirical observation that pollution tends to increase with economic growth up to a certain point, after which growth will reduce pollution (Arrow *et al*., 1995). The EKC hypothesis originally referred to country-level data. In the context of the aquaculture industry, the main argument is that the rate of induced innovation of abatement technologies increases as the market increases.

The degree to which producers internalize environmental effects suggests two different measures of environmental improvements: (1) *relative* and (2) *absolute* reductions in environmental degradation. The former indicates that industries have incentives to internalize environmental problems, where the pollution per unit produced (pollution intensity) is reduced. However, a reduction in pollution intensity may not offset the increase in pollution-generating activity (production), and hence the absolute amount of environmental degradation may still increase. Under condition (2), the industry not only has incentives to internalize, but actually improves its environmental practices to such a degree that pollution decreases, despite increased industry production.

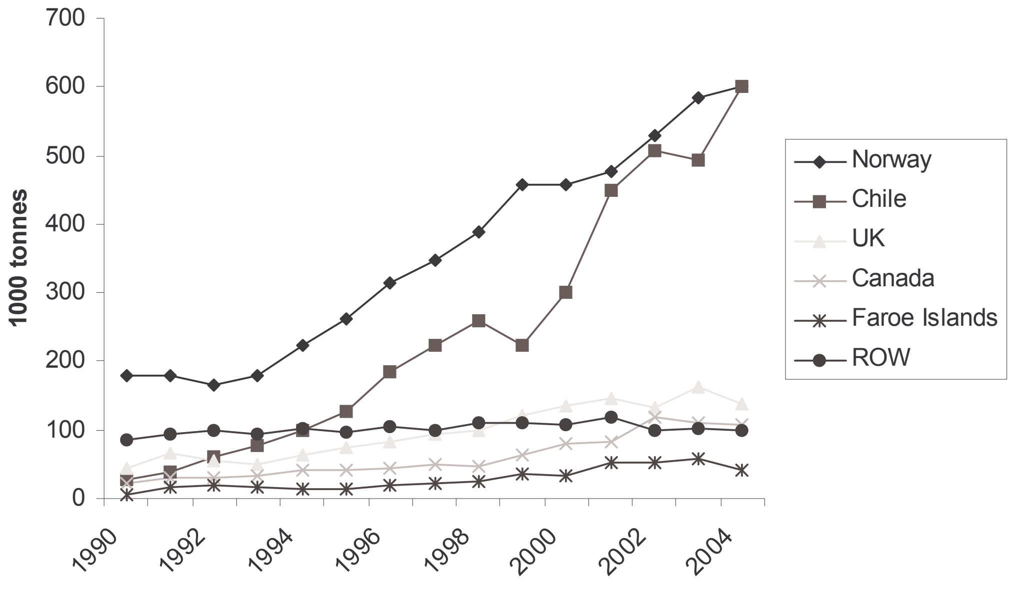
If there is no negative feedback on profitability, it is unlikely that the industry will internalize detrimental environmental effects. In this case, one has to regulate the industry. The rapid growth of global aquaculture has represented an environmental challenge for authorities. First, knowledge about the environmental effects of aquaculture has been lacking. This has called for extensive research to identify causes and effects. Second, it is desirable to have regulations that, on the one hand, are efficient in addressing the externalities and, on the other, allow the aquaculture industry to be economically sustainable. However, these two goals have not always been easy to reconcile. Consequently, if the aquaculture industry operates in a well-regulated area and the preceding goals are not possible to reconcile, the industry will most likely diminish.

The Norwegian Salmon Aquaculture Industry

The Norwegian salmon aquaculture industry has been the global market leader since the early 1980s, and has also been at the forefront of technological innovation. As Figure 1 shows, however, Chile has experienced tremendous growth and has reached approximately the same production level as Norway. These two countries dominate the global salmon supply with a production level around 600 thousand metric tonnes each. Increased efficiency in production has reduced production costs in salmon aquaculture, and market prices have followed suit (Asche, 1997). The reduction in production costs has allowed rapid expansion in salmon aquaculture, as this has led to increased demand for salmon.

A number of environmental concerns have emerged in the wake of the rapid expansion of salmon aquaculture, many of which can be attributed to the intensive nature of salmon farming. These concerns have ranged from effluent discharges, escaped farmed salmon, diseases, and the use of medicines and chemicals, to more global concerns, such as the taxation of wild fish stocks, which has been prompted by the increased consumption of fish meal and fish oil (Folke, Kautsky, and Troell 1994; Black *et al*. 1997; Asche, Guttormsen, and Tveterås 1999; Asche and Tveterås 2000; Naylor *et al*. 2000). As already indicated, the industry has faced considerable scrutiny from media and interest groups in Norway and elsewhere because of these concerns. However, most indicators of environmental quality show signs of improvement, which suggests that the Norwegian salmon aquaculture industry is addressing these concerns. It also indicates that salmon farmers have economic incentives to internalize environmental problems, as suggested by Asche, Guttormsen, and Tveterås (1999).

Figure 1: Global salmon production by countries, 1990-2004



Source: SalmonChile

The rest of this paper is organized as follows. The next section presents a theoretical framework for analyzing economic factors that affect environmental quality. The main focus in the theoretical section is the role of negative environmental feedback effects, regulation and industry growth on environmental quality. The following section investigates the development of environmental problems in Norwegian salmon aquaculture in relationship to the theoretical framework. A discussion and summary complete the paper.

Theoretical Framework

Broadly speaking, there are two main reasons for a profit-maximizing firm to address the environmental problems that arise from its activity: either legislation forces the firm to clean up, or it is profitable for the firm to do so. Both imply internalization of the environmental problem, since the firm bears the social costs that arise from its own activity. This is illustrated in Table 1, where 'Yes' indicates internalization, while 'No' implies that the environmental problem remains an externality.

Table 1: Internalization of externalities

	Negative feedback on productivity	No Negative feedback on productivity
Regulation	Yes	Yes
No regulation	Yes	No

Policy measures are usually adopted because industries themselves do not have incentives to address these issues. This is usually true in cases where costs are more dispersed, as is the case with CO_2 emissions and other airborne pollutants from which there are no feedback effects on productivity (Shafik and Bandyopadhay 1992). Local pollution tends to be the type that generates negative feedback effects on productivity. Reduced productivity provides firms with incentives to internalize the feedback effects into their decision-making given that they have property rights over the environmental resource. This can be illustrated by using the following profit-maximization problem:

$$\max_{y} \pi = py - c(y) - \mathbf{e}(y) \quad (1)$$

where *py* is income as a function of price, *p*, and the produced quantity, *y*; *c(y)* denotes production costs; and **e***(y)* is vector of negative feedback emissions of pollutants as a function of the produced quantity. We assume that $c'(y) > 0$ and $\sum_i e_i'(y) \geq 0$, so that increased production increases the cost of production, *c*, and emissions, **e**, if the sum of the feedbacks on cost is positive. Firms are indifferent to the effects of the emissions if $\Sigma e_i' = 0$. Firms have incentives to improve their environmental practices if there are negative feedback effects on productivity; i.e. $\sum_i e_i' > 0$.

Note that in equation (1) emissions are solely a function of output, *y*. In general, this will only be true if the elasticity of substitution between conventional inputs and pollution approaches zero; i.e., in the limiting case of Leontief technology. In more realistic cases, in which the elasticity of substitution is greater than zero, it is possible to reduce pollution by upgrading equipment and technology. This means that the emissions, **e**, can be reformulated as $\mathbf{e}(y, \mathbf{z})$, where *e* is now a function of output, *y*, and a vector of inputs, **z**, with $\mathbf{e}_y > 0$ and $\mathbf{e}_\mathbf{z} < 0$. This is a reasonable description of salmon aquaculture, in which an array of different inputs can be used to reduce environmental problems. These include, most importantly, industry-specific inputs, such as feeds and feeding technology, vaccines, and medicines.

Increased productivity and reduced costs are not the only reasons why firms may find it profitable to invest in more environmentally friendly practices. Such investments can also be prompted by consumer behaviour. For example, food safety issues and the demand for more environmentally friendly food products have stimulated markets for organic produce. This has influenced decision-making in food industries, since there is a belief that products, which are perceived to be more environmentally friendly are priced at a premium and, in some cases, are of a higher quality than conventional products. Studies support the notion that consumers are becoming increasingly concerned with issues relating to food safety and sustainability in relation to seafood production by signaling a willingness to pay a higher price for more environmentally friendly seafood products (see Wessells and Anderson 1995; Wessells Johnston, and Donath 1999; Johnston *et al*. 2001).

Expanding industries find it easier to attract capital simply due to the implications of growth. For investors, growth represents the prospect of good returns on capital, while suppliers see growth providing an expanding market base for their own products and services. Still, it is apparent that the scale of activity must exceed some critical threshold if suppliers and investors are to deem such investments profitable. Moreover, if the industry has incentives to internalize its environmental impacts, then it is most likely that these investments will be channeled towards abatement technologies, hence increasing the elasticity of substitution between conventional factors of production and pollution. This result can be expected whether the internalization is induced by governmental regulations, ‘green’ markets, or individual property rights, unless internalization signifies some constraint on the industry’s output. If this is the case, unsustainable practices may be causing the industry to contract.

The Environmental Concerns of the Salmon Farming Industry

Consider now the environmental issues in Norwegian salmon aquaculture. Naylor *et al*. (2000) outline two main groups of environmental problems for the salmon farming industry. The first group relates to the negative effects of salmon farming on the environment, wild fish, and the ecological basis of other living things. These are mainly local and regional concerns. Issues belonging to this group include diseases, medicine use, the impact of organic waste from farms on benthic fauna, eutrophication, the escape of farmed salmon, sea lice, and contamination of the genetic make-up of wild salmon. The second group relates to the pressure put on wild fish stocks by salmon farming’s use of large quantities of fishmeal and fish oil in the salmon feeds. This is a global issue. Other global issues include the presence of toxins, such as dioxins and PCBs in the marine inputs, and possible GMO inputs in the feed. This paper examines only local and regional environmental issues. For a discussion of global issues, see Asche and Tveterås (2000).

Organic Waste

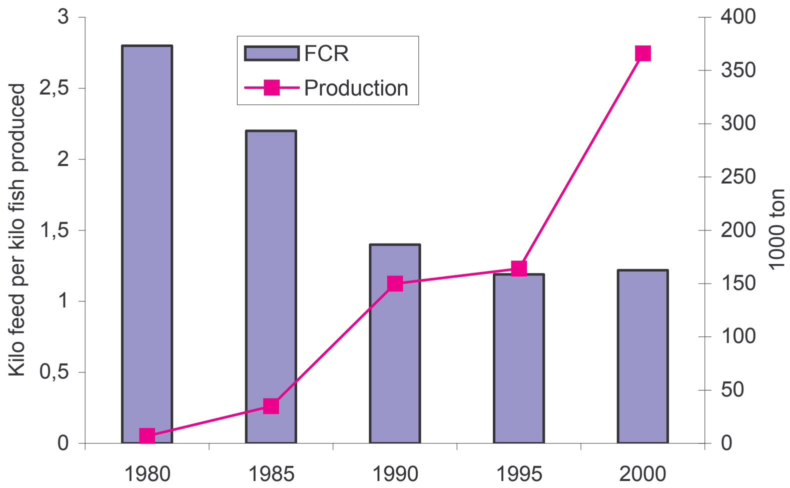
Effluence discharges are one of the major environmental concerns in salmon farming and account for most of the pollution around fish farms. The organic waste, which comes primarily from fish faeces and waste feed, can build up on the seabed if the rate of decomposition is sufficiently low, thereby damaging the local fauna. Another problem is that the waste leads to higher concentrations of nutrients in the sea, which increase the risk of eutrophication (Folke *et al*. 1994). However, Black *et al*. (1997) point out that eutrophication depends on the nutrients being discharged and on the resilience of the local environment. A strong current increases the availability of oxygen, which is needed for the decomposition of the organic matter, and also contributes to its wider dispersion. Hence, the organic load directly under the cages is reduced, thereby alleviating the challenge to the environmental resilience capacity. Since seabed topography also influences the resilience of the environment, the siting of cages is important.

However, organic waste sedimentation not only poses a problem for the local fauna, but also for salmon farmers due to negative feedback effects on productivity. The biological decomposition process for the waste reduces the availability of oxygen in the surrounding area, thus lowering the resistance of farmed fish to diseases. Moreover, depletion of the oxygen level in the decomposition process can produce toxic gases, which, if released, are harmful to farmed fish (Wallace 1993). Thus, production risk increases with higher feed use because of the negative environmental feedback (Asche and Tveterås 1999; Tveterås 1999, 2000). Therefore, risk-averse salmon farmers would minimize feed use and/or take other measures to reduce negative feedback effects on productivity. As feed costs account for over 40% of the total production costs in salmon farming, there is also a cost argument for reducing feed.

Salmon farmers have responded to these problems. First, feed and feeding technology have improved considerably over the last two decades. Figure 2 shows that the feed conversion ratio (FCR) declined between the 1980s and 1990s. It has fallen from almost three kilos of feed required to produce one kilo of salmon in 1980 to just over one kilo required in 2000. Most of this reduction is due to a greater use of lipids in the feed: a 1% increase in the inclusion rate of lipids leads to a 1% reduction in organic waste. However, new feeding systems have also contributed to reducing the FCR by lowering the feed waste.

Second, most salmon farms have moved to areas with stronger currents, deeper waters, and more suitable seabed topography, which significantly reduces the accumulation of waste sediments and negative feedback effects on productivity. In areas with unsustainable locations, salmon farms have disappeared. Thus, the combination of new sea cage technology, which allows sites to be moved to more exposed locations and enables rotation between different sites, and improved feed and feeding technology, has significantly increased the elasticity of substitution between traditional factors of production and effluence discharges. This undertaking has probably been induced by a combination of environmental feedback effects on productivity and a general effort to reduce costs. Consequently, salmon farmers have internalized many of the problems related to organic waste so that the environmental quality of the areas surrounding the salmon farms has improved since the late 1980s.

Figure 2: Feed conversion rate, 1980-2000



(Source: Austreng (1994) and Directorate of Fisheries)

There is little evidence that the capacity for resilience of the local environment is currently being challenged. Since there is a negative relationship between FCR and output, the reduction in the FCR implies that there has been a decline in relative discharges of organic waste since 1980, indicating an inverted U-shaped relationship in relative terms. It is not possible, however, to judge from the available data whether there has been an inverted U-shaped relationship between the absolute level of effluence discharges and the growth of the salmon aquaculture industry in Norway. Calculating total feed consumption by multiplying the FCR by the salmon production, we find that total feed consumption has increased, which is not surprising given the explosive growth of salmon farming. However, this does not necessarily imply that the absolute level of organic waste has increased, since the relationship between feed consumption and feed waste is not one-to-one. If the feed spill percentage declined substantially, there might be an inverted U-shaped pattern for the absolute level of organic waste relative to industry growth.

In this context, it is interesting to note that the improvements in the feed and feeding regimes have, to a large degree, been made by the feed industry, and not by the salmon farmers. Some improvements in the FCR have been due to on-farm experiments with feeds and feeding systems. However, the feed technology changed in the late 1980s and early 1990s when almost all salmon farmers abandoned wet and moist feeds in favour of dry. Dry feeds are commercially manufactured and are therefore not made on-farm. Since then, feed development has mainly been conducted by the feed industry. This indicates that, in the 1990s, the salmon farming industry enjoyed external economies of scale with respect to improved feed and feeding technology.

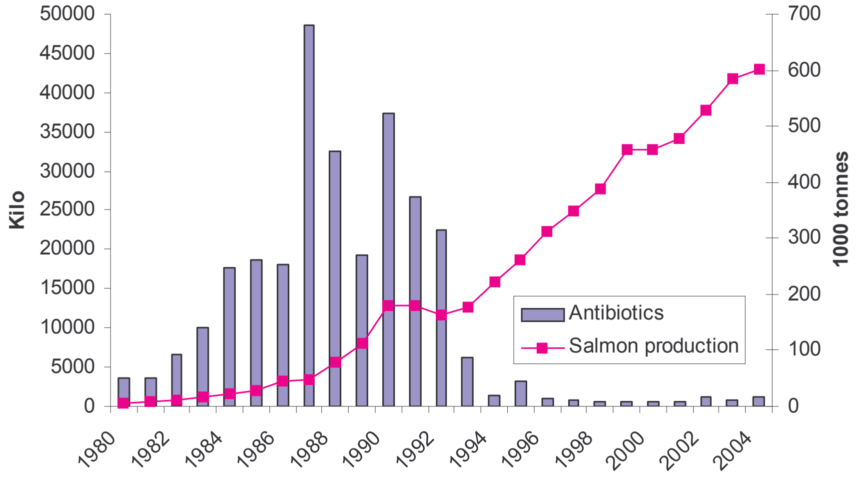
Antibiotics and Chemicals

The use of antibiotics in the treatment of diseases is another controversial issue concerning the environmental practices of salmon aquaculture. Antibiotic use can lead to antibiotic resistance in fish and other living organisms. In particular, the extensive use of antibiotics in the late 1980s provoked much criticism from consumers. Since then, the use of antibiotics has been virtually eliminated.

Figure 3 shows that the use of antibiotics forms an inverted U-shaped pattern in absolute terms. First, salmon farmers responded to the disease problem in the 1980s by increasing the use of antibiotics. The first large disease outbreaks were bacterial coldwater vibrosis in 1986 and furuncolosis in 1990-1992. Two factors were important in reversing the trend towards increasing use of antibiotics. First, the relocation of salmon farms to more suitable locations generally improved fish health. Second, the introduction in 1992of an oil-based vaccine effective against bacterial diseases made antibiotics more or less redundant. Thus, since peaking in 1987, the use of antibiotics has been on a downward trend, despite a temporary increase in usage following the furuncolosis outbreaks in 1990. This contrasts with the upward-sloping trend for production, which is shown in Figure 1. After the first vaccinations took effect in 1993, antibiotics were hardly used.

The development of the oil-based vaccine can be seen as the result of the salmon industry becoming an attractive market for industry-specific pharmacy services and products. Industry growth therefore made it profitable for the pharmacy industry to invest in the development of such vaccines, which would otherwise not have been available until much later. Thus, industry growth has helped to reduce the use of antibiotics, not only in relative terms, but also in absolute terms.

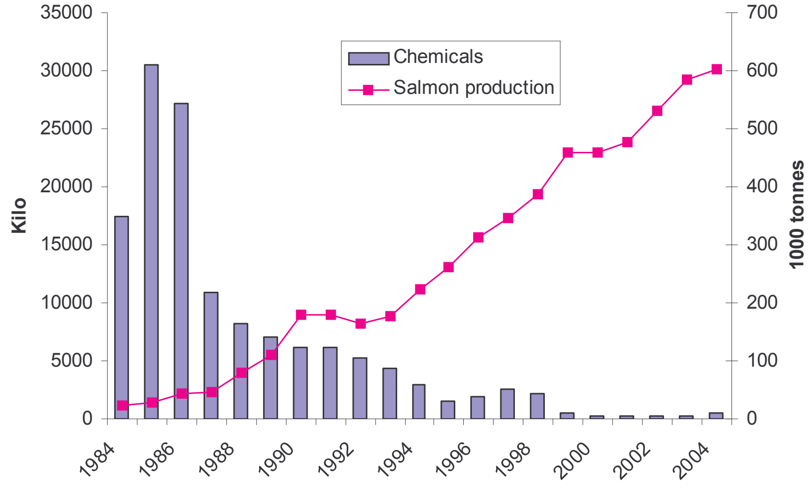
Figure 3: Use of antibiotics in the Norwegian salmon farming industry, 1980-2004



Source: Norwegian Medicinal Depot.

The same overall trends are found in the use of chemicals. Figure 4 shows that since the mid-1980s, the use of chemicals has demonstrated a downward trend. Because the time-series only dates back to 1984, we only observe the downward-sloping trend in the use of chemicals. However, we can infer an inverted U-shaped pattern for chemicals, given that their use must have been close to zero in the 1970s when intensive salmon aquaculture began. Chemicals are mainly used for cleaning cages and for treating salmon lice. Wrasses have been introduced as a more environmentally friendly method of treating sea lice because they feed on the sea lice that live on farmed salmon. On its own, this measure is not sufficient to eliminate the sea lice. Salmon farmers must still rely on chemicals to treat infected fish, but they use considerably less now than they did in the mid-1980s. Yet, as in the case of antibiotics, we observe a decline in the use of chemicals as the salmon industry expands.

Figure 4: Use of chemicals in the Norwegian salmon farming industry, 1984-2004



Source: Norwegian Medicinal Deport.

Salmon Escapees and Sea Lice

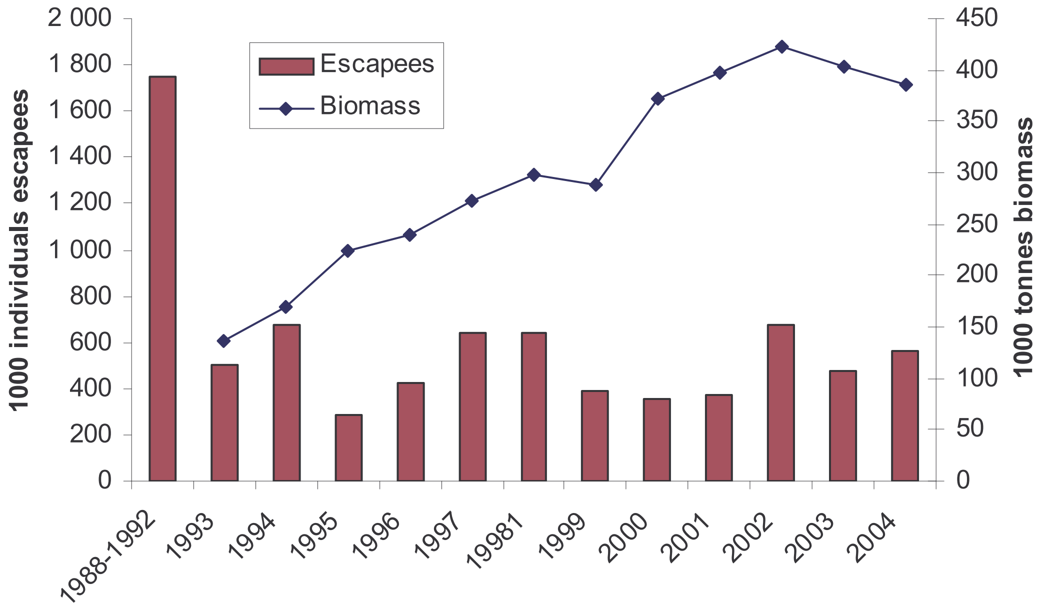
The issue of salmon escapees is controversial because of its potential negative impact on wild salmon stocks. The short-term effects of escaped farmed salmon include competition and breeding with wild salmon, the spreading of diseases and parasites to wild salmon, and hybridization with trout. Since a number of theories have tried to explain why wild salmon stocks have been reduced, the actual effects of farmed salmon on wild salmon are still open to question. Nevertheless, farmed salmon probably has a negative impact on wild salmon stocks.

The main reasons for accidental release of farmed salmon are winter storms, propeller damage, and wear and tear on equipment. In recent years, better management of these problems has led to a reduced number of salmon escapees, which contrasts with the increased number of salmon produced each year. According to the official statistics presented in Figure 5, salmon escapees have been reduced from between 1.5 and 2 million reported in 1988-1992 to about 0.5 million reported in 2004 (Norwegian Directorate of Fisheries.) Note that the figures for 1988-1992 are mean figures for this period. While the number of escapees has decreased the standing biomass in sea has increased. This indicates a fall in the number of escapees both in relative and absolute terms.

The figures of escaped farmed salmon should be treated with some caution, however, because they are probably lower than the actual number of escapees. Since escapes of salmon can generate negative publicity and may even lead to lawsuits, salmon farmers have incentives to under-report the actual number of salmon escapees. Farmers may also be unaware of escapes because damage to cages is detected late, or they may not know exactly how many fish are in the cages. However, underreporting is unlikely to affect the main trends.

Systematic fishing along the Norwegian coast and rivers provide another indicator of the escaped farmed salmon situation. Figure 6 shows that the percentage share of farmed salmon in the catches decreased from 1989 to 2003. Importantly, the share of farmed salmon in broodstock rivers for wild salmon decreased from 39% in 1989 to 13% in 2003.

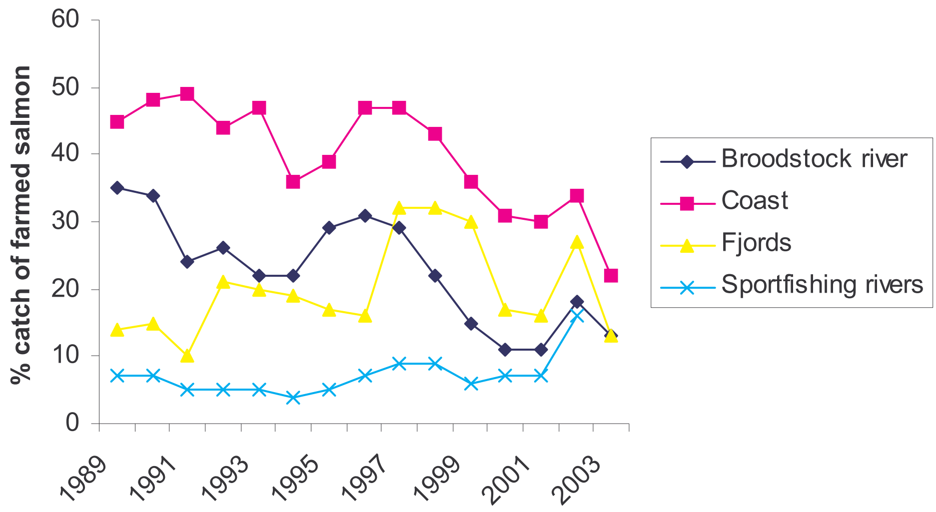
Figure 5: Number of escaped salmons 1988-2004 and standing biomass in sea.



Source: Directorate of Fisheries.

Infection by sea lice is possibly one of the most important factors that reduce the stock of wild salmon. Registrations show that the heaviest infections of wild salmon are limited to areas with a high concentration of salmon farms (Tully and Nolan, 2002; Grimnes *et al*. 1998). A plausible explanation is that the number of hosts is larger in areas with a high concentration of salmon farms, thus leading to a higher concentration of sea lice in that area. Moreover, escaped salmon are believed to be one of the major causes of spreading salmon lice to wild salmon.

Figure 6: Percentage of farmed salmon in catches in Norwegian rivers and coast, 1989-2003.



Sea lice infections and salmon escapes are probably the major remaining environmental problems in salmon farming today. Salmon farmers clearly have an incentive to limit the number of sea lice because of negative feedback effects on productivity and for marketing purposes. This involves the use of chemicals and sea wrasses. However, it is not clear that salmon farmers have an incentive to reduce the number of sea lice to a level that is significantly below the level required by the market. This means that sea lice concentrations in salmon farming areas might be relatively high even if the number of sea lice living on the farmed salmon is at an acceptable level. Thus, it is uncertain whether there has been an inverted U-shaped pattern for the level of sea lice in salmon farming areas. Research on vaccines against sea lice continues, but there has been no breakthrough to date.

Summary and Discussion

This paper has investigated environmental problems in intensive aquaculture with empirical evidence from the salmon aquaculture industry. When there are incentives to internalize, industry growth seems to act as a catalyst for environmental improvement, by changing the framework by which firms operate. Industry growth stimulates more investment, and this investment can be channeled towards the development of abatement technologies, thereby increasing the elasticity of substitution between conventional inputs and pollution. This is closely related to the induced innovation hypothesis of Hicks (1932), which states that a change in the relative prices of inputs should induce innovations directed to economizing the use of the input which has become relatively more expensive.

Here, the relatively more expensive input is pollution, provided that industry has incentives to internalize it. An empirical test of this relationship is performed, in which the independent variable is industry growth, rather than economic growth. This is used for empirical evidence of the EKC hypothesis at the country level. As dependent variables, we use measures of pollution, pollution per unit produced and total pollution. This allows us to investigate first if the industry has incentives to reduce pollution, and secondly if they are strong enough to lead to an absolute pollution reduction. Internalization is a pre-condition for industry growth to facilitate the reduction of environmental problems. Therefore, an inverted U-shape pattern of pollution in relation to industry growth will not apply to all environmental problems, since not all industries have incentives to internalize them.

Data from the Norwegian salmon aquaculture industry support the idea that industry growth has a positive relationship with environmental quality. The data cover the period from the early 1980s to the early 2000s, which has been a period of tremendous growth in the Norwegian salmon aquaculture industry. These data provide evidence of inverted U-shaped relationships between environmental indicators and the growth of the Norwegian salmon aquaculture industry. This implies that Norwegian salmon farmers have increased the degree of internalization due to negative feedback effects from pollutants as the industry has expanded. The use of antibiotics and chemicals has been reduced in absolute terms. The number of salmon escapees may have also declined. In the case of sea lice and effluence discharges, results are more uncertain given the lack of data. However, the reduction in the FCR shows that, relative to production volume, organic waste discharges have been reduced, which is important given the substantial increase in salmon production over the last two decades. To summarize, in those areas where the industry experience negative feedback on productivity or effective government regulations, environmental problems have been reduced. Escaped salmon and sea lice are major environmental issues remaining. Although the industry clearly has incentives to reduce these problems, those incentives are clearly not strong enough to eliminate these issues.

If we use these observations to generalize to other kinds of aquaculture, one may conclude that environmental issues arising in the early stages of an aquaculture industry may often be viewed as teething problems. Since aquaculture uses the environment as an input, it is likely that environmental issues will arise. However, the presence of environmental feedback on productivity, government regulation and industry growth will, to a large degree, determine whether these issues are resolved. In other words, internalization of environmental problems is positively related with those three economic factors. Industry growth is not a sufficient or necessary condition for internalization, but, in combination with one of the two other factors – negative environmental feedback and regulation – it functions as a catalyst for improved environmental quality.

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