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**Productivity in Organic and
Conventional Salmon Aquaculture**

by

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Abstract

This report provides a comparative analysis of productivity in conventional and organic salmon aquaculture. Regulations in organic salmon farming impose several restrictions on production that are not present in conventional salmon farming. We have analysed the effect of a fish density regulation on the economic performance of salmon farms. A fish density regulation has two possible consequences. First, with a given cage volume, it leads to a reduction in total production at the farm. Second, it leads to an increase in costs per kilo produced. We undertook a linear programming analysis of a conventional salmon farm and organic salmon farms with open and closed cage systems. The results from the analysis indicated strongly that the economic performance is sensitive to the maximum fish density.

Contents

1.   Introduction

This report provides a comparative analysis of productivity in conventional and organic salmon aquaculture. Regulations in organic salmon farming impose several restrictions on production that are not present in conventional salmon farming. In the regulations of the Norwegian organic certification body *Debio*, this applies, for example, to standards for fish densities and use of medication. One may ask whether standards for organic salmon farming allows profitable production. Furthermore, how large are production cost differentials between conventional and organic salmon farms? Are the cost differentials smaller or larger than the price premiums which can be obtained for organic salmon?

In this report we use a linear programming model framework to analyse the performance of organic and conventional salmon farms. Data from the Norwegian Directorate of Fisheries on conventional salmon farms and from the organic salmon producer Giga AS are utilised.

1.1.   Background

The production of organic foods has increased substantially in industrialised countries in recent years. This is probably a result of consumers' increasing concern for food safety and negative effects from large scale, intensive agricultural activities, mainly with emphasis on human health, animal welfare and the environment.

Up until now the concern of the consumers has mainly been focused on terrestrial production activities and produce, but with increasing consumption of seafood it is reasonable to expect the consumer to take greater interest in how and where their seafood is produced or caught. The first signs of response to this change or expected change in consumer attitude are already seen both in fisheries and in aquaculture. Unilever, one of the major companies in seafood, is introducing eco-labeled fish products in cooperation with the World Wildlife Foundation, and in the forthcoming EU provision on organic livestock production, legal protection of eco-labels will also include fish. Small-scale production of organic salmon was undertaken by the industrial partner of this research project, the Norwegian company Giga AS, in 1996-1997, whilst pilot projects have been undertaken in Scotland and Ireland.

Organic production is based on four principles:

I.   The consumers should know what they eat, e.g. what the products contain and how they are produced.

II. The welfare of 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.

In order to ensure a production according to these principles, a number of minimum standards and general guidelines must be imposed. In this report we examine how these constraints affect production costs, using a linear programming model developed by Tveterås (1993). We also find the optimal production, given the constraints and see how profits vary with different price levels, and how relative profitability between organic and conventional farms vary with price premiums.

Aquaculture may be said to have the characteristics of "putty-clay" technology, meaning that the producers at the time before investments have a number of choices on technology, dimensions, etc. However, after investments have been undertaken, the production is restricted to a constant ratio between the input factors and upward bounded by the chosen scale of the plant. In this report we are mostly concerned with optimisation of production for a given technology, that is, after investments in the plant have been made.

Debio, the Norwegian certification body of organic primary production, certified the products of Giga as an experiment for a limited period of time (1996/1997).[1] Their minimum standards and guidelines will be used as restrictions when simulating organic salmon production. Data from Giga will be used to calculate initial values. Optimal production of conventional and organic salmon will be simulated and compared for different technologies.

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[1] Debio terminated the certification programme for salmon aquaculture in 1997, but has recently taken it up again.

1.2. Disposition

Section two describes the general legislation concerning Norwegian aquaculture, and the standards and guidelines for organic salmon farming used by Debio. The linear programming model used to simulate the production costs is described in section three. Section four provide the different cases (model farms) to be analysed and parameter values chosen for these. The results from the different simulations are given in section five. In section six summary and conclusions are provided.

2. Regulations on Conventional and Organic Salmon Farming

In this section we discuss regulations that impose restrictions on salmon aquaculture production.

2.1. Norwegian Regulations

Conventional salmon farming is subject to many public regulations in Norway. Three laws and a number of provisions nested in these regulate the Norwegian aquaculture industry. The laws are:

- The Aquaculture Act ("Lov om oppdrett av fisk, skalldyr m.v. av 14.06.1985")
- The Animal Protection Act ("Lov om dyrevern av 20.12.1974")
- The Fish Disease Act ("Lov om tiltak mot sykdom hos fisk og andre akvatiske organismer av 13.06.1997")

The most important of these for salmon farms is the Aquaculture Act and its' provisions.

The Aquaculture Act regulates ownership, new establishments and locations. No person or firm may own or establish a new farm with out having a license. The license is given for a specific location and may not be transferred without permission from the authorities. License may not be given if the farm is a potential source for the spreading of diseases or pollution, or have unfavourable location relative to the surrounding environment and activities.

Until 1977 the licenses were given in a consecutive and liberal manner. This practice was followed by a period (1977-1981) with complete stop in the allocation of licenses. After this allocations were done in 1983, 1985, 1989 and 1998. In the last two rounds licenses were only given in Troms and Finnmark, the two northernmost counties.

Furthermore, the Aquaculture Act regulates the cage volume and the concentration of fish in the cages. The license allows for a maximum cage volume of 12.000 m^3 and a maximum density of 25 kg per m^3.

However, these restrictions may not necessarily be effective. The volume is to be measured at the surface area and five meters down, independent of the actual depth of the cage. In reality it is not unusual to have cages of 20 meters depth and with a wider circumference below 5 meter than that of the surface area. This practice makes the restrictions on cage volume and density mere formalities.

From 1st of March 1996 individual farm quotas on feed were implemented as a measure to reduce or control the production. Table 1 shows the feed quotas for the period 1996-1999 and the corresponding production, given a feed conversion factor of 1.19 and no mortality.

Table 1. Feed quotas for the period 1996-1999 (tonnes per licensed 1000 m^3) and the corresponding gross production (kg/m^3) with a feed conversion rate of 1.19 and no mortality.

Year	Dry feed	Wet/soft feed	Estimated Production
1996	43	30	36,13
1997	53	37	44,54
1998	54,2	37,8	45,55
1999	56,7	39,7	47,65

(Source: Norwegian Ministry of fisheries)

We see from table 1 that the production corresponding to the feed quotas is higher than the formally allowed concentration of 25 kg/m^3. This limit to production was, however, exceeded by ~5-9 kg/m^3 by the owners of one license and by greater numbers by owners of two or more licenses in the period 1994-1996 due to reasons explained above. The feed conversion ratio may however be to high, because when the feed quotas were implemented the feed producers developed high energy feeds, in which the water content to a high degree were replaced with lipids and proteins, probably resulting in a lower feed conversion rate. The possible net production figure in table 1 may thus be too low.

The Fish Disease Act does not give any direct restrictions on regular production, but gives detailed descriptions on how to act when there is danger of a contagious disease. In this report we shall however assume that the plant is optimally run and will not take disease into account.

The Animal Protection Act is a general law applying to all owners of animals, including fish and crustaceans. This law states that no animal should suffer unnecessary and that the animals are to be given living conditions according to their natural needs and instincts. The law does however not give any specific standards and gives thus no direct restrictions to the production of salmon.

2.2. International Agreements

In 1997 the EU and Norway signed the Agreement on a solution to the "salmon case". In this Norway has agreed to raise the export tax from 0.75% to 3%, to indicative ceilings to the Norwegian export of salmon to the EU and to floor prices on this export.

The total Norwegian export of salmon to the EU was 220,000 tonnes in 1996. According to the treaty a growth of 11% in the export was allowed in 1997 (with 1996 as the base year) and a 10% growth is allowed for the remaining years the treaty is in force, which is until 30th of June 2002. The floor price was set to 3.25 ECU per kg (26.36 NOK per kg) for fresh or frozen whole (gutted, head on) salmon. For filets the floor price was set to 4.50 ECU per kg (36.51 NOK per kg). This is a relatively high price compared to the market price and may cause problems for the Norwegian industry in terms of getting the fish sold in the EU, which has been and still is the most important market for Norwegian salmon, taking between 60 and 70% of the total export. A floor price this high may imply that the firms face increased costs due to efforts to enter new markets either in the geographical or product space. It may also force the producers to lower the production.

2.3. Restrictions on Organic Aquaculture

Debio provided a detailed set of guidelines and minimum standards to be followed in the production of organic salmon. In this part only the standards with direct implications to the production and production costs will be discussed. The complete set of standards and guidelines are however provided in appendix A1.

The most important restrictions, in terms of production costs, are probably on medication, feed and seine impregnation. The guidelines also contain restrictions on concentrations of fish in the cages, but as for conventional salmon farming the volume is only measured down to 5 meters, independent of the actual depth of the cages and is thus in reality no restrictions to the production.

No synthetic agents such as colorants, appetite or growth stimulants are allowed in the feed. A special and more expensive feed is thus required. In feed for conventional salmon synthetic colorants are normally used. In the organic feed used by Giga this was replaced by colorants extracted from the shells of krill. This feed exceeded the price of conventional feed by 1 NOK. Feed is the major component in the production cost of aquaculture. In 1997 the feed contributed to 54% of the total production costs. Also, in open systems, feed spills must be collected to the extent that is causes no harm to the macro fauna beneath the cages. This is not required in conventional farming and may be a source of increased costs, depending on the qualities of the location.

Upon the detection of a critical virus or bacteria infection, treatment or disposal of the infected fish must be undertaken immediately. Fish that are treated with chemo-therapeutic agents or antibiotics may however not be sold as organic. The producer would in such a case then, either have to tolerate a higher mortality rate, or accept a lower price.[2]

Chemicals and synthetic compounds are not allowed in the impregnation of seines. This may reduce the lasting time of the seines. All use of other input factors must be cleared with Debio prior to use. Emphasis is on environmentally friendly production equipment. Giga did, however, use closed cages made of plastic with glass fibre reinforcements, which have a life span of ~6 years, approximately twice as long as nets used in conventional farming.

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[2] Giga had a total of 14 cages, of which 7 were used for organic production, the rest for conventional farming.

3. The Model

In this section the linear programming model of Tveterås (1993) is described. The model is based on a number of assumptions on physical and biological factors such as technology, growth, prices and costs. In the first part of the section we therefor give a description of the biological and physical processes governing the production. In the second part the objective function and its' implicit functions are described, while the restrictions are listed in the third part of this section. Symbols and restrictions are also listed in appendix A2 and A3 respectively.

3.1. Biological and Physical Factors

Aquaculture has much in common with agriculture, both with respect to the dependence on the natural conditions of the specific location and with respect to the control of recruitment. The location is crucial because the production generates by-products that may influence the local environment and thereby future production. Ammonium, CO_2 and H_2S are among the most important by-products. The production of these by-products depends on the feed conversion rate, the number of fish in the pens, the density of fish and the feeding technology. Their impact depends on the specific features of a given location such as the topography of the bottom, the current and the content of oxygen. Together, all these factors determine the long-term carrying capacity of a location, which may be described by the following expression:

(1) $Y_{MAX} = f(F, \mathbf{v}, \mathbf{h}, \mathbf{r})$

where F is the minimum feed conversion rate for a given type of cage, feed quality and feeding technology, $\mathbf{r}$ is a vector of topographic features, $\mathbf{h}$ is a vector of the depth of the different layers of water beneath the cages, and $\mathbf{v}$ is a vector of the current in the different layers. The following relationships between the carrying capacity and the variables are assumed:

(2) $\dfrac{\partial f}{\partial F} \leq 0$, $\dfrac{\partial f}{\partial v_i} \geq 0$, $\dfrac{\partial f}{\partial h_i} \geq 0$

This implies that an increase in the feed conversion rate reduces the carrying capacity, while an increase in the depth or current of one of the layers of water increase the carrying capacity

of the location. However, it is not possible to determine on a general basis how a change in the topographic features influences the carrying capacity.

Ample supply of oxygen to the cages is crucial, and it is normally the first binding restriction to the production in terms of biophysical factors. In other words, if the production does not exceed what is optimal for a given level of oxygen, the production of by-products may be ignored.

The oxygen supply must be sufficient for the basic biological functions and secure growth. Determining the optimal supply of oxygen may, however, be difficult. Underestimating the oxygen requirements may lead to reduced growth and thereby economic losses. On the other hand, overestimation of the oxygen requirements may also lead to economic losses: In an open production system by under-utilising production sites, and in closed systems by requiring higher investments in pumps, lines and oxygenating equipment and higher operating costs.

The saturation of oxygen in water will vary with among other thing salinity and temperature, while the need for oxygen will vary with temperature, activity, biomass, feeding regime, etc. The biologists do however not agree on the functional form of the relationship between the variables. Forsberg (1995) explored different functional forms for modelling the oxygen consumption of Atlantic salmon in commercial-scaled land-based farms and found the following relationship:

(3)　　$O_C = 1.92 \cdot W^{-0.27} \cdot T^{0,63} \cdot 10^{0,01C}$

where the oxygen consumption is given in mg O_2 per kg fish per minute and C is the current velocity in the fish tank. This function however, suggests a lower oxygen need than that proposed by Christiansen et $al.$ (1990):

(4)　　$O_{C,g,i} = 5.5 \cdot W_{g,i}^{-0.2} \cdot \exp(0.07 \cdot T)$

In the simulation of production in an open system we will use the function of Christiansen et $al.$ in a modified form.

(5) $O_{C, g, i} = 5.5 \cdot W_{g,i}^{-0.2} \cdot \exp(0.07 \cdot T_{HIGH, i})$

where the temperature used is between the monthly average and maximum and

(6) $T_{HIGH, i} = \lambda \cdot T_i + (1 - \lambda) \cdot T_{MAX, i}, \; 0 \le \lambda \le 1$

The literature gives little advice on what temperature to choose as T_{HIGH}, but λ should probably be close to zero.

Given sufficient supply of oxygen and optimal feeding, the number of individuals at the end of month i is a function of the number at the beginning of the month, the mortality rate and the number of slaughtered fish and is described by the following expression:

(7) $n_{g,i} = n_{g,i-1} - h_{g,i} - D_{g,i}, \; g = 1,\ldots, G$ and $i = 1,\ldots,I$

where $h_{g,i}$ is the number of fish slaughtered and $D_{g,i}$ is the number of deaths. The mortality rate is assumed to be a function of age alone. The number of deaths in generation g in month i is thus expressed by

(8) $D_{g,i} = d_{g,i} \cdot n_{g,i},$

where $d_{g,i}$ is the mortality rate in generation g in month i.

The average individual growth of salmon (in grams) is described by

(9) $W_{g,i} = W_{g,i-1} \cdot (1 + w\,(T_i, W_{g,i}) / 100)^{30 \cdot i}, \; g = 1,\ldots, G$

where

(10) $w\,(T_i, W_{g,i}) = \begin{cases} 0{,}9 T_i^{0.97} W_{g,i}^{-0.34}, & 2 \le T \le 14, \quad 30 \le W < 4000 \\ 0, & W \ge 4000 \end{cases}$

is the daily growth rate. T_i is the average temperature in month i[3]. It is assumed that all individuals mature when they reach 4 kg and that no growth occurs after this. The yield from generation g in month i may then be expressed as

(11) $\quad y_{g,i} = (n_{g,i} + h_{g,i}) \cdot W_{g,i} - n_{g, i-1} \cdot W_{g, i-1}$

That is, the production in month i is equal to the biomass at the end of the month plus the biomass slaughtered, minus the biomass at the beginning of the month.

3.2. The Objective Function

When dealing with producers of products for which ethics is an important aspect, it might be reasonable to assume that the some of the producers maximise some combination of utility and profit, rather than profit alone. That is, it may be that some producers would choose what they consider the ethically correct production strategy, even if it means loss of profit. This would however be impossible, or at least very difficult to model. It may also be difficult for producers choosing such a strategy to survive in the long run. We thus assume that both the producers of conventional and organic salmon aim at maximising the net present value of the profit (NPV).

Maximising net present value of profits in aquaculture is similat to the rotation problem in forestry. When should a generation be slaughtered in order to give room to the next? NVP is maximised when

(12) $\quad \text{NPV} = \dfrac{1}{(1+r_m)^i} \sum_{i=1}^{I} \pi_i$

$$= \sum_{g=1}^{G} \sum_{i=i_g}^{I_g} \frac{1}{(1+r_m)^i} \left\{ R_{g,i}^{H} - C_{g,i}^{H} - C_{g,i}^{y} \right\} - \sum_{g=1}^{G} \frac{1}{(1+r_m)^i} C_{g}^{S} - \left[C_C + C_{CI} + FC \right] \sum_{i=1}^{I} \frac{1}{(1+r_m)^i}$$

where

r_m = monthly discount rate

G = maximum number of generations in the sea

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[3] It is assumed that all months have 30 days.

I_g = the last month fish of generation g is in the sea

$R_{g,i}^{H}$ = total revenues from generation g slaughtered in month i

$C_{g,i}^{H}$ = total costs of slaughtering related to generation g in month i

$C_{g,i}^{y}$ = variable costs related to generation g in month i

C_{g}^{S} = smolt costs for generation g

C_C = total user costs on investments dependent on the cage-volume

C_{CI} = total user costs on volume dependent capital

FC = monthly fixed costs

The endogenous or controllable variables in this model are:

- The number of cages each generation (a_g) are stored in and thus the total cage-volume (Z_c) at the plant.
- The number of smolt in every generation ($Z_{s,g}$)
- The number of fish harvested every month ($h_{g,1}$,….,$h_{g,I}$)

Total cage-volume at the plant is given by

$$(13) \quad Z_M = M_w \cdot M_d \cdot M_l \cdot \sum_{g=1}^{G} a_g$$

where M_w, M_d and M_l are the width, depth and length of the cages and G is the total number of generations. Factor costs and user costs are assumed constant over time. The length of the time horizon (I) does thus not influence the results from the model as long as the production is allowed to go through the whole cycle (2 – 4 generations in the sea at the time).

The total revenue from slaughtering, $R_{g,i}^{H}$, is a function of the price per kg (P($W_{g,i}$)), the average weight of the fish (W_g) and the number of fish slaughtered ($h_{g,i}$).

$$(14) \quad R_{g,i}^{H} = P(W_{g,i}) \cdot W_{g,i} \cdot h_{g,i}$$

Slaughtering costs are defined as

(15) $C_{g,i}^{H} = (P_H + P_T) \cdot W_{g,i} \cdot h_{g,i},$

where P_H is the cost of the actual slaughtering process per kg fish and P_T is the transportation cost. The monthly variable production costs for generation g are given by

(16) $C_{g,i}^{y} = (P_F \cdot F + P_I + P_L \cdot a_L) \cdot y_{g,i} + P_P,$

where P_F is the price per kg feed, F is the feed conversion factor, P_I the insurance cost per kg fish, P_L the wage of workers, a_L the hours of work and $y_{g,i}$ is the produced quantity of fish of generation g in month i. P_P is the pumping cost in a closed system, which is determined by the water needed, multiplied by the price of pumping pr. liter. The total costs of smolts in generation g is a function of the price per smolt (P_S) and the number of smolt bought ($Z_{S,g}$).

(17) $C_{g}^{S} = P_S \cdot Z_{S,g}$

The total user cost of volume dependent capital equipment such as cages and nets is defined as

(18) $C_M = \left(\sum_{j=1}^{J_C} \left[\frac{1}{L_{C,j}} + r \right] P_{C,j} \right) Z_C$

where $P_{M,j}$ is the price of the volume dependent capital equipment and $L_{M,j}$ is the lasting time. The user cost of volume independent capital equipment is

(19) $C_M = \sum_{j=1}^{J_{CI}} \left(\frac{1}{L_{CI,j}} + r \right) \cdot I_{CI,j},$

were $I_{CI,j}$ is the investments in volume independent capital equipment.

From (1)-(19) we see that the both production factors and prices are included in the profit function and that the producer is a price taker in both the factor and product market.

3.3. Restrictions

Due to the linear objective function, the marginal costs are continuously decreasing with increasing production. This combined with the defined price function, causes profit to increase with increasing production, until the first binding restriction is met. The restrictions are listed and explained below. The first five restrictions (20a-f) are specific for aquaculture. The last three (20e-g) are general non-negative restrictions, standard in linear programming models.

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The first restriction (20a) tells us that the density of fish in the cages must not exceed the maximum oxygen-independent capacity.

$$(20a) \ u_{max} \cdot a_g \cdot M_w \cdot M_d \cdot M_l - b_{g,\,i} \geq 0, \qquad g = 1,...., G \text{ and } i = 1,...., I$$

were $b_{g,\,i}$ is the total biomass of generation g in month i. u_{max} is the maximum oxygen-independent density, and may either be equal to a biological defined capacity or the maximum legal density, 25 kilo/m^3 for conventional and 10 kilo/m^3 for organic salmon.

Restriction (20b) limits the density based on the need for oxygen. In an open system the restriction would be

$$(20b) \ 10 \cdot 60 \cdot M_W \cdot M_l \cdot v \cdot a_g - \frac{O_{C,g,i}}{O_{INN} - O_{OUT}} \cdot b_{g,i} \cdot a_v \geq 0, \ g = 1,...., G \text{ and } i = 1,....,I$$

The first expression in (20b) is the oxygen supply to generation g per minute, in which v is the minimum current and a_v is the number of cages in the direction of the current. It is assumed that the cages are square and placed perpendicular to the current. The second expression in (20b) is the total need of water per minute by generation g in month i. O_{INN} is the level of saturated oxygen in the water as it flows in to the cage area and is given by:

$$(21) \ O_{INN} = \frac{m}{100} \cdot \left[14.6 - (0.132 \cdot \frac{S - 0.03}{1.805} \right] \cdot \exp\left[- \frac{227 - \exp(0.078 \cdot S)}{10000} \cdot T_i \right],$$

where m is the saturation of oxygen in the water and S is the salinity, both given in percent. The minimum level of saturated oxygen in the water as it flows out of the cage area is found by setting S equal to 75% (Forsberg, unpublished note).

In a closed system the restriction transforms to that the need for water must not exceed the capacity of the pumps.

$$(20b^*) \qquad PC - \frac{O_{C,g,i}}{O_{INN} - O_{OUT}} \cdot b_{g,i} \geq 0, \qquad g = 1,...., G \text{ and } 1,....., I$$

Restriction (20c) states that the total cage-volume according to the measurements rules (see section 2) must not exceed the licensed volume of the plant ($Z_{M, MAX}$).

$$(20c) \quad 5 \cdot M_w \cdot M_l \cdot \sum_{g=1}^{G} a_g \leq Z_{M, MAX}$$

Restriction (20d) limits the production in terms of the carrying capacity to the specific location.

$$(20d) \quad \sum_{i=1}^{12} \sum_{g=1}^{G} y_{g,i} \leq y_{max}$$

The standard non-negative restrictions are

(20e) $\qquad a_g \geq 0, \quad g= 1,....., G \qquad$ (number of cages)

(20f) $\qquad h_{g,i} \geq 0, \quad g= 1,....., G \text{ and } i = 1,...., I \qquad$ (slaughtering)

(20g) $\qquad Z_{s,g} \geq 0, \quad g= 1,....., G \qquad$ (smolt)

The price of salmon is defined as a linear function of the weight W:

$$(22) \quad P(W) = \begin{cases} 0, & W < W_{MIN} \\ p_0 + p_1 W, & W > W_{MIN} \end{cases}$$

We see that it is assumed that the fish must reach a certain size before a price may be achieved and that the possibility of systematic seasonal changes in price is excluded. The model does however allow implementation of seasonal changes by the use of a sinus function. It is also assumed that only one quality is produced.

4.   Cases and Choice of Parameters

The restriction on the concentration of fish in the cages in organic fish farming is based on a concern for fish welfare. High densities may stress the fish, and chronic stress may lead to reduced growth and increased exposure to diseases (Brattelid, 1999). However, the optimal density may change over the year, throughout the life and with feeding regime. There does not seem to be a scientific basis for setting the limit at 10 kilo/m^3.

We run two simulations for the organic farms, one in which the restrictions on density is set to 10 kilo/m^3 and one were it is set to 25 kilo/m^3. In both cases we use the actual volume of the cage, not the licensed volume. We also run one group of simulations in which it assumed that varying densities within the ranges described above have no negative effects, and one were it is assumed that the mortality rate increase with increasing densities of fish in the cages. The effect of reduced growth on the production costs will be the same as increasing the mortality rate.

The actual values of the low and medium mortality rates used are listed in Table 2. The Directorate of Fisheries does not routinely report on mortality in aquaculture. The values used as low mortality rates are obtained from Aaker & Wold (1990) and this together with the values used for medium mortality are approximately equal to those used for low and medium mortality in Willumsen et al. (1995).

Table 2. Values used for low and medium monthly mortality rates

Category	1st year	Rest
Low	0.6434	0.32737
Medium	1.25	0.625

The average price of conventional salmon was 20.53 NOK in 1997 and the constant term of the price function for conventional salmon was set to 20 NOK/kg. The slope of the price function was found by fitting a trend line through data on prices provided by the Norwegian Fish Farmers' Association. The same slope was used for both conventional and organic salmon while the constant term was varied to represent a price premium on organic salmon.

Each simulation for two generations over two years and it is assumed that all generations have equal growth and environmental conditions. Table 3 shows a complete list of the initial parameters.

Table 3. The initial values of parameters used in the simulations

Economic Parameters:

Parameter	Conventional open	Organic open	Organic Closed	Units	Source/ Comments
A_L	*0.0096*	*0.01206*	*0.01206*	*Hours/kg*	Directorate of Fisheries
$FC_{MANAG.}$	450 000	4500 000	450 000	NOK	
FC_{CI}	347 .650	347 650	347 650	NOK/year	Bjørndal, 1990
FC_{OTHER}	640 000	640 000	640 000	NOK/year	Bjørndal, 1990
C_C	*88.27*	*88.27*	*98.73*	*NOK/year*	Giga
P	*20.48+0.4927W*	*30.49+0.4927W*	*30.49+0.4927W*	*NOK/kilo*	
P_F	*7.44*	*8.24*	*8.24*	*NOK/kilo*	Directorate of Fisheries, Giga
P_H	2.19	2.19	2.19	NOK/kilo	Directorate of Fisheries
P_I	0.23	0.23	0.23	NOK/kilo	Directorate of Fisheries
P_L	163.75	163.75	163.75	NOK/hour	Directorate of Fisheries
P_P			$9.52 \cdot 10^{-7}$	NOK/liter	Giga
P_S	9.58	9.58	9.58	NOK/piece	Directorate of Fisheries
P_T	0.18	0.18	0.18	NOK/kilo	Directorate of Fisheries
R	7	7	7	%	

Biological parameters:

Parameter	Conventional open	Organic open	Organic Closed	Units	Source/ Comments
F	0.19	0.19	0.19	%/month	Directorate of Fisheries
$W_{g. 0}$	80	80	80	%/month	
W_M	4000	4000	4000	grams	
W_{min}	2000	2000	2000	grams	

Table 3. The initial values of parameters used in the simulations (continued)

Technological parameters:

Parameter	Conventional open	Organic open	Organic Closed	Units	Source/ Comments
a_v	2	2			
G	2	2	2		
L_F	5	5	5	Years	Directorate of Fisheries, Giga
L_N	3	3	6	Years	Directorate of Fisheries, Giga
L_O	10	10	10	Years	Directorate of Fisheries, Giga
M_B	10	10	10	Meters	
M_D	13	13	13	Meters	
M_L	10	10	10	Meters	
Z_{MAX}	31200	31200	31200	m^3	

Physical parameters:

Parameter	Conventional open	Organic open	Organic Closed	Units	Source/ Comments
S	35	35	35		
$T_1 - T_{12}$	4.46, 4.02, 3.55, 4.58, 6.83, 9.89, 11.8, 12.52, 11.63, 9.62, 7.53, 5.70	4.46, 4.02, 3.55, 4.58, 6.83, 9.89, 11.8, 12.52, 11.63, 9.62, 7.53, 5.70	4.46, 4.02, 3.55, 4.58, 6.83, 9.89, 11.8, 12.52, 11.63, 9.62, 7.53, 5.70	°C	Meteorological Institute
T_{max}	1.3	1.3	1.3		Meteorological Institute
u_{max}	80	80		kg/m^3	Holm & Søreide
V	1.25	1.25		cm/sec.	Aure, Ervik, Johannesen & Ordemann, 1988
PC			60	Tonnes/min.	Giga

5. Results

This section presents the results from the linear programming model under different restrictions. We focus particularly on the effect of fish density restrictions. Table 4 shows the average costs per kilo and cost components for the three types of salmon farms we consider. From the table we see that the organic farm with closed cages has the highest production cost, 25 NOK per kilo, followed by the organic farm with open cages (23.98 NOK/kilo). The lowest costs are achieved by the conventional farm with open cages (20.82 NOK/kilo). An examination of the cost components, reveals that fish feed has the highest cost share (around 40%). Capital costs are higher for the closed farm operation than for the two farms with open cages. All in all, the distribution of costs for the open cage farms are similar to distribution found in the annual survey of Norwegian salmon farms (Directorate of Fisheries).

Table 4. The average cost and its different components

	Organic, closed		Organic, open		Conventional, open	
Density	$25 kilo/m^3$		$25 kilo/m^3$		No restrictions	
Mortality	Low		low		Low	
	Kr/kg	%	Kr/kg	%	Kr/kg	%
Pump	0.33	1.29				
Feed	10.04	39.02	10.04	41.88	8.85	42.52
Smolt	3.25	12.63	3.26	13.61	3.79	18.22
Wages	2.72	10.57	2.72	11.35	2.09	10.03
Capital	5.67	22.03	4.22	17.61	2.68	12.85
Insurance	0.23	0.89	0.23	0.96	0.23	1.10
Other	3.49	13.57	3.50	14.58	3.18	15.27
SUM	**25.74**	**100**	**23.98**	**100**	**20.82**	**100**

Table 5 shows the results from the linear programming model under different fish density restriction (no restrictions, 25 kilo/m^3, and 10 kilo/m^3). We assume that the mortality rate is not affected by the fish density, but for an open organic farm we compare two different fish mortality scenarios. According to table 5 the density restriction has a significant effect on the optimal number of smolts to be released into the cages. The conventional farm that faces no density restriction has a maximum fish density of 42 kilo cubic meter. The harvest per generation ranges from 248 tonnes in the organic farms with the 10 kilo per cubic meter density restriction to 897 tonnes in the conventional unrestricted farm. This, of course, has a large effect on total revenue, although we assume that the organic farms obtain price premiums for their salmon. The average cost per kilo produced ranges from 20.82 NOK in the unrestricted conventional farm to 36.95 NOK in the closed organic farm that faces the 10 kilo

per cubic meter restriction. For the closed organic farm the cost per kilo is increased from 25.75 NOK to 32.59 NOK when the maximum fish density is reduced from 25kilo/m^3 to 10 kilo/m^3. Similarly, for the open organic farm the cost per kilo is increased from 23.98 NOK to 32.96 NOK when the maximum fish density is reduced from 25kilo/m^3 to 10 kilo/m^3. Hence, we see that a fish density restriction has a significant effect on production costs, and could easily increase production costs above the sales prices obtained by the farmer. Note also that a higher fish mortality does not have a very dramatic effect on production costs and profitability of the open organic farm

Table 5. Results from simulations of the production of organic and conventional farmed salmon

Farm type		Organic, open			Organic, closed		Conventional, open	
Fish density		25 kilo/m^3	25 kilo/m^3	10 kilo/m^3	25 kilo/m^3	10 kilo/m^3	25kilo/m^3	No restrict.
Fish mortality		Low	Medium	Low	Low	Low	Low	Low
Smolt release	no	205 142	220 785	82 057	205 142	82 056	205 142	344 566
Max density	kilo/m^3	25	25	10	25.00	10	25	41.99
Harvest per generation	kilo	618 368	612 605	248 340	620 850	248 339	618 368	897 829
Average price	NOK/kilo	32.57	32.65	32.58	32.59	32.59	22.30	22.19
Average cost	NOK/kilo	23.98	24.35	32.96	25.75	36.95	22.03	20.82
Profit	NOK	8 574 473	8 121 724	-603 414	7 012 611	-2 251 379	-522 068	1 051 902

We see that the density restriction has a considerable effect on profitability. Not, however, that one should not put too much emphasis on the profit figures in table 5, because they depend very much on the sales price assumptions. For the closed organic farm the profit is reduced from 7 million NOK to –2.25 mill NOK when the maximim fish density is reduced from 25kilo/m^3 to 10 kilo/m^3. Similarly, for the open organic farm the profit is reduced from 8.5 million NOK to –0.6 mill NOK when the maximim fish density is reduced from 25kilo/m^3 to 10 kilo/m^3.

6.   Summary and Conclusions

This report provided a comparative analysis of organic and conventional salmon farming production. Regulations in organic salmon farming impose several restrictions on production that are not present in conventional salmon farming. We have particularly analysed the effect of a fish density regulation on the economic performance of salmon farms. A fish density regulation has two possible consequences. First, with a given cage volume, it leads to a reduction in total production at the farm. Second, it leads to an increase in costs per kilo produced. We undertook a linear programming analysis of a conventional salmon farm and organic salmon farms with open and closed cage systems. The results from the analysis indicated strongly that the economic performance is sensitive to the maximum fish density. With the small price-cost margins that salmon farmers generally faced during the 1990s, the negative effect of a fish density restriction on production and costs per kilo should not be very large before fish farmers experienced poor profitability.

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A1. Appendix: Restrictions on Organic Aquaculture

WATER

The fish should to as great an extent as possible have an environment which favours their natural behaviour. Proper care and management plus ample continuos addition of unpolluted water is significant in preventing stress and sickness in farmed fish.

The oxygen content ought to be at the 75% saturation level.

In areas of brackish water there must be a free water area of a depth of at least 9 meters under the brackish layer.

If the fish exhibit unusual behaviour measurements should be taken and checked against the standard max. loads for:
a) Ammonia
b) Particles
c) Algae

In every fish-raising unit the following measurements should normally be taken on a daily basis:
a) Temperature: min. 1°C. max 20°C. measured in the middle of the cage at a depth of 3 m.
b) Salinity: higher than 1 measured at a depth of 1 m.
c) Oxygen: Over 50% saturation. Measured in the middle of the cage at a depth of 3 m.

HANDLING

The fish must be handled as little as possible. and then only in the most considerate manner possible.

The fish can be out of water for no longer than 30 seconds during handling. Any sort of moving must be noted in the operations logbook.

SLAUGHTERING

There shall be emphasis on avoiding situations that cause stress to the fish during transportation and slaughtering. The behaviour of the fish is a good indicator of whether this process is being carried out in a responsible and considerate manner.

The fish must be brought live and by a considerate transportation method to an approved slaughterhouse. In order to avoid unnecessary suffering the fish must be slaughtered before bleeding out. The slaughtering process must also be performed in accordance with the regulations determined by the authorities responsible.

FOREIGN SUBSTANCES IN THE WATER

Consideration to the environment takes precedence in all aspects of the production processes.

Seine impregnation with chemical or synthetic agents is forbidden.

Chemotherapy agents are forbidden. Except for H_2O_2 (hydrogen peroxide) and tapeworm treatments.

MEDICINES

The aim is to maintain the health of the fish by undertaking preventive measures in order to make it unnecessary to administer medicine to them.

If medication involving chemotherapy is used on sick fish then the fish from the unit concerned may not be sold as organic. The distance from the affected unit to the nearest unit containing organically approved fish must be a min. of 75 m. or there must be a physical barrier between the units which hinders the flow of water between them.

If any medicine is administrated. Feed spill and faeces must be collected.

Any vaccination can be done at the hatchery stage. Re-vaccination, however, is not permitted.

A logbook of any use of medicine is required to be kept.

The operations manager is required to see to it that a logbook of the use of medicines is kept.

CONTAGION HYGIENE

Leaving sick fish in the system must be avoided to the greatest degree possible.

When the mortality rate exceeds 0.5% per week. a diagnosis must be made. Dead fish must be removed every day.

ORGANIC DISCHARGES

The system must be adjusted to local conditions and managed in such a manner that unacceptable effects on the surrounding environment are avoided.

Feed spill and faeces must be collected to the degree that they will not have harmful effects on the surrounding environment.

The macrofauna at the bottom of the system must be intact. The oxygen content of the bottom-water under the system cannot diverge significantly from the natural value for the area.

ESCAPE SECURITY

It is of the highest priority to minimize the negative effects of a fish-farming system on the surrounding environment.

The system must be secured against escape as well as possible, and it must be certified with respect to strength and anchoring by an approved independent authority.

SALMON LOUSE

Use of labrids as natural predator on salmon louse is allowed to the extent that it does not otherwise cause harm to the sorrounding environment.

A count must be made at specified crucial points in time. Measures must be taken when the max. of 1 sexually mature female louse per 10 salmon is exceeded. The count must be recorded in the logbook.

INFECTIOUS MATTER

Upon the detection of a critical bacteria/virus infection, treatment or disposal of the infected fish must be undertaken immediately.

FEED

Only feed with the right quality and composition in relation to the needs of the fish may be used.

95% of the feed, calculated as solid matter, must be organically approved and/or have originated from wild fish.

The feed should consist of natural components to the greatest extent possible

Synthetic growth-regulating agents, antibiotics, synthetic antioxidants, synthetic appetite stimulants, and synthetic colouring agents must not be added to the feed. Any vitamin additives used must be noted in the operations logbook.

Allowable additives to the feed for colouring effects are shrimp shells, fungus cultures. etc.

Log-keeping of feeding practices is required

The operations manager is required to make monthly reports of the type and quantity of feed used for each raising unit.

FACTOR INPUTS

The production of the equipment and articles should be as environmentally friendly as possible. Emphasis should be placed on recycling.

All use of factor inputs must be cleared beforehand with Debio and noted in the operations logbook.

NATURAL BEHAVIOR

In order to improve quality, the fish is starved for a period before slaughter. During the starvation period, the metabolism of the fish is reduced and there is no wastage of feed. Greater concentrations are therefore allowed for a limited period, provided this does not reduce the water quality.

In an open system there can be a max. Of 10 kg fish/m^3 measured to a depth of 5 m. During the starvation period, there can be a max. of 20 kg fish/m^3 measured to a depth of 5 m. The starvation period during which this greater fish concentration is allowed is limited to at most 18 days.

For cold-blooded vertebrates. it is natural with lengthy periods of starvation.

In a closed system there must be a minimum supply of 1 litre water per kg fish per minute. Alternatively. it must be documented that there is no accumulation of harmful substances in the water.

The smallest cage size allowed is 100 m^2 with a depth of 9 m. The fish must have the possibility of forming a shoal.

Use of genetically engineered organisms is forbidden in all contexts.

	Use of triploid fish is forbidden.
SMOLT The Debio certification process also places requirements on the care and feeding of the preceding generation of fish.	Smolt can only be used when the preceding generation has not been treated with hormones or given antibiotics.

A2.   Appendix: Symbols

Variables with footnotes vary over time. The others are constant.

a_g = number of cages for generation g

a_L = hours of work per kg fish produced

a_v = number of cages in the direction of the water flow

$b_{g.i}$ = biomass of generation g at the end of month i

$b_{MAX.g}$ = maximum biomass of generation g

C_C = total user costs on investments dependent on the cage-volume

C_{CI} = total user costs on volume dependent capital

$C_{g,i}^{H}$ = total costs of slaughtering related to generation g in month i

$C_{g,i}^{y}$ = variable costs related to generation g in month i

C_{g}^{S} = smolt costs for generation g

$d_{g.i}$ = mortality rate of generation g in month i

$D_{g.i}$ = Number of salmon of generation g that died in month i

F = feed conversion ratio

FC = monthly fixed costs

g = generation of fish

G = maximum number of fish in the cages

$h_{g.i}$ = number of fish of generation g slaughtered in month i

i_g = the month generation g is released into the sea

I = the number of months used in the model

I_g = the last month the generation g is in the cages

$I_{CI.j}$ = investments in volume-independent capital equipment of type j

K = bank overdraft facilities

$L_{C.j}$ = life-span of volume-dependant capital equipment of type j

$L_{CI.j}$ = life-span of volume-independent capital equipment of type j

m = oxygen saturation in water (%)

M_d = depth of cage (m)

M_l = length of cage (m)

M_w = width of cage (m)

$n_{g.i}$ = number of salmon of generation g at the end of the month of slaughtering

$n_{g.0}$ = initial number of smolt

$O_{F.g.i}$ = oxygen use by salmon of generation g in month i (mg O_2/kg/min.)

O_{INN} = oxygen content in the water as it flows into the cage (mg O_2/liter)

O_{OUT} = oxygen content in the water as it flows out of the cage (mg O_2/liter)

P = the price of salmon (NOK/kg)

P_F = the price of feed (NOK/kg)

P_H = costs of harvesting (NOK/kg)

P_I = insurance costs (NOK/kg production)

P_M = user cost of volume-dependent capital equipment (NOK/m^3 cage volume)

$P_{M.j}$ = new price of volume-dependent capital equipment of type j (NOK/m^3 cage volume)

P_L = wages (NOK/hour)

P_S = price of smolt

P_T = transportation cost of slaughtered salmon

PC = capacity of pump

$R_{g,i}^H$ = total revenues from generation g slaughtered in month i

r = annual discount rate

r_m = monthly discount rate

S = salinity in water

T_i = water temperature in month i (°C)

$T_{high.i}$ = temperature used in calculation of the need for oxygen (°C)

$u_{g.i}$ = density in cage of generation g in month i (kg/m^3)

u_{MAX} = maximum density in cage given sufficient supply of oxygen and legislation (kg/m^3)

$u_{MAX.g}$ = maximum density in cage of generation g throughout its' life span (kg/m^3)

v = minimum current in the flow of water into the cage area (cm/sec.)

$W_{g.i}$ = weight of salmon in generation g in month i (gram)

$W_{g.0}$ = initial weight of smolt of generation g (gram)

W_{MIN} = minimum slaughtering weight

y = annual production of salmon (kg)

$y_{g.i}$ = production of generation g in month i

y_{MAX} = the annual production capacity of the locality (kg)

Z_M = total cage volume of a plant (m^3)

$Z_{M.g}$ = licensed production capacity of a plant (m^3)

$Z_{S.g}$ = initial number of smolt

π = annual profit (NOK)

π_i = profit in month i

A3. Appendix: Assumptions of Linear Programming Model

I. Physical and biological factors

1a) Diseases and algae do not influence the growth and mortality rate, nor the quality of the fish.

1b) Fish growth is a deterministic function of temperature in water and initial weight.

1c) All smolt have identical initial weight. Restriction 1b and 1c together imply that all fish in generation g have the same weight at all times.

1d) The mortality rate is constant and deterministic for all temperatures and densities.

1e) All fish is of same quality.

1f) Oxygen need is a deterministic function of weight and temperature.

1g) A temperature between the monthly average and maximum temperature is used when the need for oxygen is calculated.

1h) The minimum current is used when the water flow is calculated

1i) Oxygen is used as the limiting factor of density in cages.

1j) To obtain optimal growth a oxygen saturation of 75% in the water as it flows out of the cage area is needed.

II. Production technology

See Tveterås (1993).

III. Costs and prices

See Tveterås (1993).