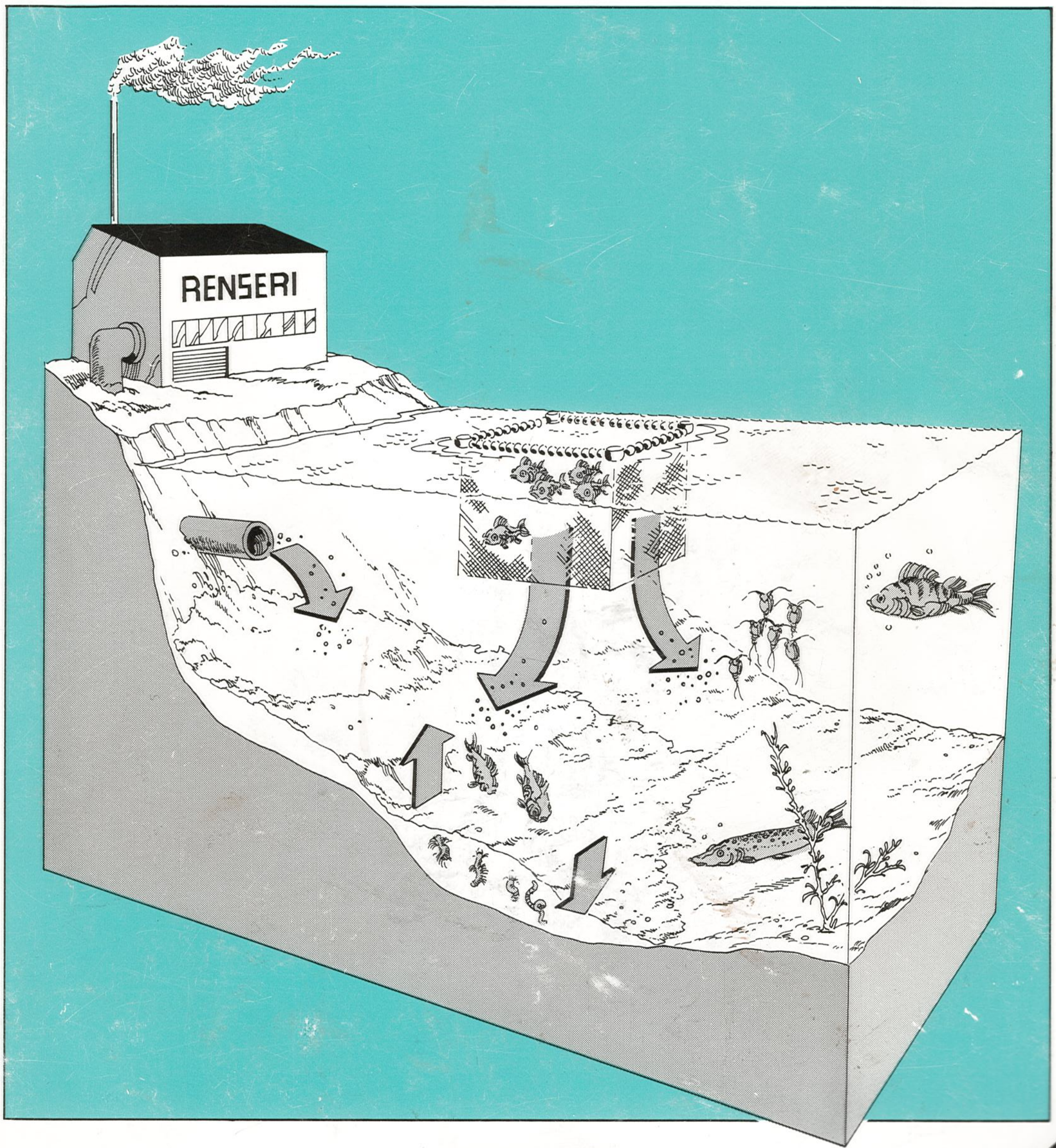
THE ENVIRONMENTAL IMPACT OF AQUACULTURE



FORSKNINGSRÅDSNÄMNDEN
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in cooperation with
The National Marine Resources Commission

Report 83:5

The environmental impact of aquaculture

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THE ENVIRONMENTAL IMPACT OF AQUACULTURE

Report from the working group on environmental effects to the Steering Committee on Aquaculture

Styrgruppen för vattenbruk

"And when the timorous Trout I wait
To take, and he devours my bait,
How poor a thing, sometimes I find
Will captivate a greedy mind:
And when non bite, I praise the wise
Whom vain allurements ne'er surprise."

Izaak Walton
"The Compleat Angler"

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FORSKNINGSRÅDSNÄMNDEN
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The National Marine Resources Commission

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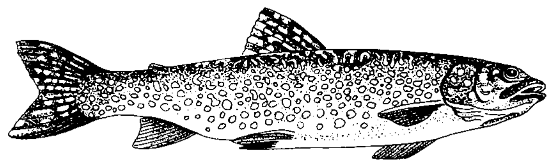
Foreword



Since the mid 1970s, interest in fish and mussel farming has increased greatly. The number of applications for farming permits has in some years been more than double that of the previous year. There are now a few hundred farms in Sweden.

On the initiative of the National Resources Delegation of the Swedish Council for Planning and Coordination of Research (FRN), in1979 a working group was appointed to determine the possibilities for the commercial farming of fish, shellfish and algae in Sweden. In spring 1980 the group presented a report* which illustrated the prospects for aquaculture along with a background description of international developments. In order to examine related problems within biology, technology and economy more thoroughly, the Natural Resources Delegation of the FRN and the Marine Resources Delegation appointed a steering committee whose task was to investigate in more detail the possibilities for the development of Swedish aquaculture operations in lakes and coastal areas.

In February 1981 the steering committee appointed various working groups in order to study biological, technical and economic topics more closely. One of these groups was given the task of illustrating environmental problems in connection with the establishment of farming installations. The group was to review various problems connected with the environmental consequences of aquaculture and suggest measures to reduce them.

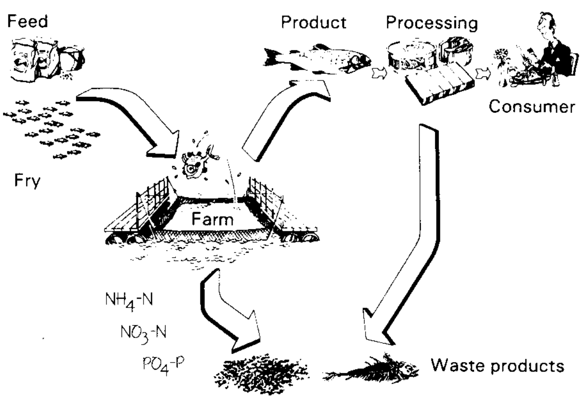


Fig. 1. Flow diagram showing the various processes within aquaculture. This report deals mainly with the wastes and their impact on the environment. (Diagram by Nils Peterson, after Clas Norell.)

* Svensk Akvakultur — Näringsgren för framtida försörjning och sysselsättning. Swedish Council for Planning and Coordination of Research, report no. 28-N, 1980, ISSN 0348-3991. Compiled by Hans Ackefors.

All human activities exert an influence upon the surrounding environment. The cultivation of organisms in ponds, lakes, rivers and coastal areas is naturally no exception in this respect. The extent to which the natural ecosystem is altered depends, among other things, on whether the farming methods are intensive or extensive. Intensive farming means that fry and feed/fertilizers are added to a limited water volume in which the organisms are to be farmed. The metabolism of the organisms results in increased amounts of wastes and by-products in the farming environment. In extensive types of farming, no foodstuffs are added, but even here metabolic products are released into the surrounding water. Organic wastes sediment underneath operations in which the organisms are concentrated, as in net bags or mussel farms. The report illustrates the importance of different kinds of farming, their location and the volume of production with respect to the status of the recipient.

The environmental problems connected with aquaculture result largely from the phosphorus which is discharged into recipients. Phosphorus, which is a component of fish feed, reaches the water via waste feed and excrement. The result is an increased supply of nutrients, which may cause changes in the environment.

Although the waste products are composed of naturally occurring substances which are considerably less harmful than the effluents discharged by sewage plants, aquaculture is today classified in Sweden as an "environmentally dangerous industry" by the Environment Protection Act.

This report is intended for farmers as well as for administrators and decision-makers. It is our hope that it will provide a broad background to questions relating to the environmental consequences of farming operations, a subject which has received surprisingly little attention overseas. For this reason, it has not been easy to find answers to all the questions which have arisen during the course of this work. Therefore, many important problems will only be solved once the relevant scientific fieldwork has been carried out. The working group has tried to identify neighbouring problems, such as conflicts with other interests over the usage of water areas, diseases, genetics and technology. Questions within these areas have, however, only been treated superficially, as they have been dealt with by other working groups.

This working group, which was appointed in consultation with the National Swedish Environment Protection Board (SNV) and the Swedish Water and Air Pollution Research Institute (IVL), was composed of the following members:

Anders Södergren, chairman	Institute of Limnology, Lund
Per-Erik Larsson, secretary	Swedish Water and Air Pollution Research Institute, Aneboda
Hans Ackefors	The Swedish Council for Planning and Coordination of Research, Stockholm

Wilhelm Dietrichs

Siegfried Fleische

Staffan Holmgren

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Wilhelm Dietrichson	National Swedish Environment Protection Board, Solna
Siegfried Fleischer	Halland County Administration, Halmstad
Staffan Holmgren	Jämtland County Administration, Östersund
Åke Häggström	National Swedish Board of Fisheries, Göteborg
Rutger Rosenberg	National Swedish Board of Fisheries, Institute of Marine Research, Lysekil
Eva Ölundh	National Swedish Environment Protection Board, Solna

A special section was written by Edna Granéli, Dept. of Marine Botany, University of Lund, on the effects of nutrient discharges in sea areas.

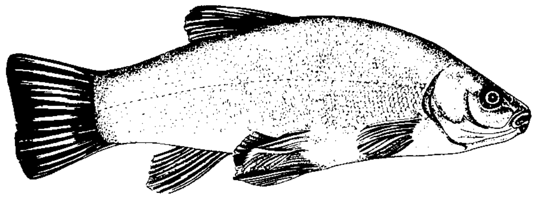
The working group has also been in contact with fish farmers who have provided their opinions. The report was compiled by an editorial group composed of Anders Södergren (chairman), Per-Erik Larsson (secretary), Hans Ackefors and Staffan Holmgren.

This report is based on a Swedish report published in 1982. The Swedish version is one of ten reports covering the whole area of aquaculture (Ackefors 1983). Two of the reports, the present one and the report about fish breeding and aquaculture, were translated into English, after being slightly revised by the working group. The translation was made by Catherine Hill. The Swedish reports have got English summaries. In the reference list the titles are translated.

The Steering Committee on Aquaculture wishes to extend sincere thanks to all the members of the working group, especially to the chairman, the secretary and Staffan Holmgren as well as to Edna Granéli and Catherine Hill.

Hans Ackefors
Chairman of the Steering Committee

Summary



This report is an investigation of the environmental consequences of the farming of fish, mussels and algae in water bodies and coastal areas. The surroundings are affected to various degrees, depending on the location of the operations, the volume of production, the techniques used and on whether processing takes place in the vicinity of the operations. The report deals with the composition and properties of by-products and wastes which result from different kinds of cultivation operations as well as the type of environmental effects which can be predicted. In general, the wastes consist of naturally occurring and easily degradable substances, which are quickly recycled in the ecosystem. Compared with other activities utilizing Swedish waters, the contribution from farming operations is, from a quantitative viewpoint, very small at present.

The report presents means of reducing the environmental effects of aquaculture. These include the alteration of feed composition, the collection and recycling of wastes, the combination of different forms of cultivation and the use of so-called trash fish from the recipient for feeds. In addition, an investigation has been carried out into the environmental effects which occur when fish production in natural waters is altered as a result of fertilization, lime treatment, the stocking of other organisms, and so on.

The environmental consequences may constitute a limit for the exploitation of water bodies and coastal areas for aquaculture. Therefore, finally, a number of research areas are identified as being able to provide a more detailed examination of the environmental effects of different forms of aquaculture and result in methods to decrease these effects.

The environmental effects which can arise as a result of discharges from operations, or altered production in natural waters can be summarized as follows:

- All cultivation operations result in a release of nutrients and organic matter.
- The phosphorus thus released is responsible for the greatest effects in inland waters, while nitrogen is usually of most importance in coastal areas.
- The amounts of waste are dependent on the volume of production and the waste treatment measures.
- The amounts of waste which are released determine the location of aquaculture activities.

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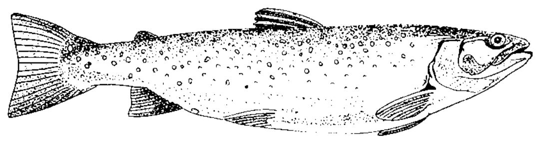
- With regard to cultivation techniques and discharges, net bag cultivation should primarily be located in coastal areas or in nutrient-poor lakes which are able to accept an increased nutrient load.
- Improved feeding techniques (better feed coefficients) and/or the development of techniques for collecting feed wastes will enable the utilization of a larger number of lakes.
- Net bag cultivation should be located so that the wastes do not reach the deep areas of lakes.
- Sedimenting wastes constitute a resource which should be collected and utilized.
- A combination of different cultivation techniques may reduce environmental effects, as in the combination of fish farming with the cultivation of algae.
- The effects of discharges from land-based cultivations may be reduced by means of waste treatment measures.
- The fertilization of lakes in order to improve fish production should only be practised in badly damaged waters or when the effects of other activities can be mitigated or counteracted by the addition of nutrients.
- The treatment of lakes with lime is necessary to counteract acidification, but is of little use as regards cultivation.
- Additional stocking of existing species should only be considered when natural reproduction does not occur, or when fish recruitment is poor.
- The stocking of foreign and for the ecosystem new fish species should be practised with restraint, as such introductions can often be regarded as irrevocable actions.
- The stocking of food organisms may have a positive effect on fish production in badly damaged reservoirs, but it is a measure of doubtful value in normal, unaffected waters.
- The stocking of fish in fish-free lakes should be avoided as a rule, as such lakes have become more and more uncommon and are valuable for other organisms.
- Aquaculture is often "self regulating", as negative environmental consequences also damage the farming activities.
- Aquaculture can be integrated with other methods of utilizing water resources.
- Aquaculture techniques of the future must be adapted to environmental demands.

Aquaculture in relation to other usage interests



Lakes and oceans have long been used by man as a food source and a medium of transport. With the breakthrough of industrialization our waters began to be used more and more for the dilution and transport of pollutants and wastes. The nutritional aspect, which was most important in the beginning, has been pushed into the background, while the function of waters as recipients (i.e. receivers of various wastes) has been exploited more intensively.

In Sweden, until not long ago, lakes and running waters were regarded as nearly inexhaustible and unalterable resources. This led to neglect of their management and supervision. However, unlike many other countries in Europe, Sweden still has many bodies of water which are nearly unaffected by human activities. Some of these may be suitable for certain forms of cultivation. Depending on the degree to which they have been affected some already exploited bodies of water could probably be used. The prerequisites for farming are, however, different in different parts of the country. The factors affecting the scope of operations are the natural character of the recipient, the type of present usage and the farming method.

The effects of the discharge of pollutants into waterways are wellknown and range from encroaching vegetation in lakes to the "blacklisting" of fish as food. Discharges from municipal outlets and industries, combined with the diffuse effects of agriculture and forestry have thus altered many waterways so that they can hardly be used for any other purpose than as recipients. As the problems and costs of restoration of the waterways have become apparent, a more restrictive view has emerged as to the use of both exploited and unexploited waters. Therefore, there is a much more restrained approach to new activities which may result in undesirable effects, or compete with the "self cleaning capacity" of recipients. However, at a regional level, it should be possible to specify waters that are suitable for aquaculture and identify areas in which such operations should not take place. Even small bodies of water such as unused marl pits, clay pits, and limestone quarries can be of interest for farming. Apart from the yield gained, farming in these waters means that they are preserved and tended, which can in many cases be advantageous to the landscape.

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Aquaculture should lead to a more effective utilization of waters for beneficial production. Such operations can be carried out in land-based installations with running water, in lakes, water courses or coastal areas.

Even though aquaculture is based on a natural exploitation of water resources, it results in effects on the environment, e.g. via the increased load of nutrients and organic matter. If these are major effects, the results will be negative, not only for the environment, but even for the cultivation. Thus, aquaculture is "self regulating" to a certain extent, and depends on the maintenance of good water quality. In addition, as aquaculture is a new field, it is often forced to adapt itself to the space left over by other established interests. It is obvious that conflicts can arise in such cases. If, at an early stage, the nature and extent of likely effects are documented and the environmental impact is estimated, it should be possible to make a well balanced judgement. Moreover, operations are regulated by law, for example by the Fisheries Act and the Environmental Protection Act. These issues are discussed in detail in the juridical working group's report "Aquaculture and the law".

A workshop of the European Fisheries Advisory Commission (EIFAC) has collated and evaluated information on the nature and extent of problems which are caused by the discharge of effluents from fish farms in order to prepare guidelines for formulating standards for effluent quality (Alabaster 1982).

Based on information from several countries the workshop concluded that fish farms (net bag farming was excluded from consideration) may change the levels of certain constituents of the water that was passed through them, although this did not necessarily cause pollution problems. It was noted that some chemicals present in the effluents, including antibiotics, were perhaps potential causes of problems in water intended to be used as potable supply.

The workshop identified several environmental problems arising from the discharge of fish-farm effluents, but did not quantify their extent. It was concluded that the problems were clearly important and increasing in several countries, in some cases to an extent that they were the main factor limiting expansion of the industry. It was agreed that much remained to be learned about the relationship between the farming system, e.g. the feed input, and the wastes produced although there was sufficient empirical information to formulate rough guidelines. There was a need to develop feed with particularly low content of fibre and phosphorus, while adopting designs that facilitated the removal of suspended solids, e.g. by avoiding the use of systems that resuspend material that has already settled. The workshop recommended that potential and actual problems arising from the discharge of effluents from fish farms should be kept under review and that EIFAC should formulate guidelines and advise on appropiate methods for their control.

Aquaculture should have as a clearly stated aim the development of products free from additives and contaminants. This means that some waste can be regarded as a resource if it is collected or otherwise utilized. Consequently, it should be recycled for use in production, as it has a high organic content and is also rich in nutrients. In China, the production of fish has long been linked with other activities. In Sweden it should be possible to carry out farming in cooperation with other activities in order to exploit the long coastline and the hundreds of thousands of lakes to the best advantage.

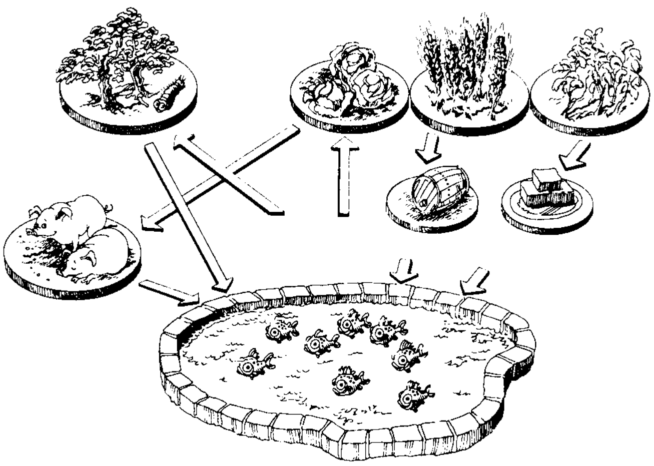

Fig. 2. In China, fish production is integrated with other activities. All wastes are utilized. The fish ponds are fertilized with agricultural by-products and other refined products. The sediment from the fish ponds is used in its turn for fertilizing arable land.

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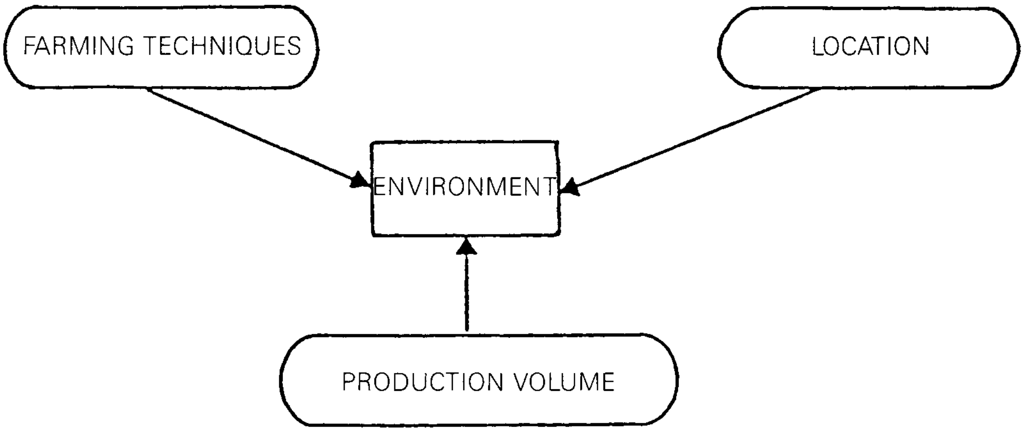

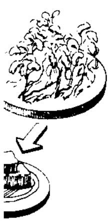

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The techniques used to farm organisms are of importance for how much the environment is affected. Intensive farming, in which growth is dependent upon supplied food, usually results in greater effects on the environment than extensive forms, in which the natural production of a water body is utilized.

In basins, ponds or recirculating farming systems situated on land the waste water can be treated before it reaches the recipient. Farming in net bags placed in lakes or running waters affects the surroundings directly. If techniques can be developed to reduce the wastes and/or recover the sedimented matter produced by this method, there are good chances of reducing the environmental effects.

The environmental effects of aquaculture also depend on the extent of the operations, and on the size and capacity of the recipient. A small farm, located near a large body of water naturally implies fewer consequences for the environment than a large farm in a small body of water.

When deciding on the location of a farm and estimating its influence on nearby water areas, the size of the discharges must be related to the hydrology, nutrient status and production conditions of the recipient. Nutrient-poor (oligotrophic) lakes and running waters can quickly change character even with the addition of relatively small amounts of nutrients, especially phosphorus. Using theoretical calculations, Karlgren (1981) estimated that in such waters, a surface area of at least 30 ha is required for every ton of fish farmed in order to avoid undesirable effects resulting from increased nutrient loads. The National Swedish Environment Protection Board and the Fisheries Board of Sweden (1982) recommend a lake area of 15—30 ha.

In nutrient-rich (eutrophic) lakes, the visible effect of increased nutrient loading may be less than in oligotrophic lakes. The amount of nutrients is, however, already so large that further additions should be avoided. Otherwise there is a risk of serious environmental effects arising, e.g. as a result of oxygen depletion and the formation of hydrogen sulphide in the bottom water. This can damage the farming operations. Therefore, farms should not be located in eutrophic waters without careful consideration. However, the extent of the effects which can be permitted in each case can only occasionally be subject to general judgement. Local considerations in combination with broad plans for the usage of water areas can become factors of vital importance for the final decision. Farming methods which use large areas also risk coming in conflict with other interests (recreation, nature conservation, commercial fishing, shipping etc.). To a certain extent, this even applies to methods used to raise the natural production in a water body (fertilization, lime treatment etc.).

Compared with the farming method and the location of operations, the volume of production is of great importance for the extent of the environmental effects. In addition, large farms run a greater risk than small ones of coming into conflict over the physical exploitation of a water area or its use as a recipient. Moreover, it is likely that larger farms will introduce processing steps (filleting, smoking etc.) which can increase the load on the environment. Therefore, special attention should be paid to large farms which are to be located in inland waters or coastal areas.

All forms of farming give rise to by-products and wastes which have a similar composition and consist of naturally occurring substances. The burden on the recipient thus depends more upon the size of the installation and the amount of wastes than upon the type of farming techniques which are used or the organisms which are farmed.

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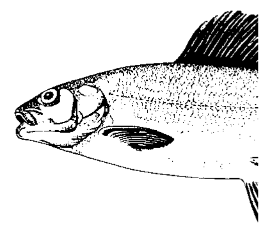

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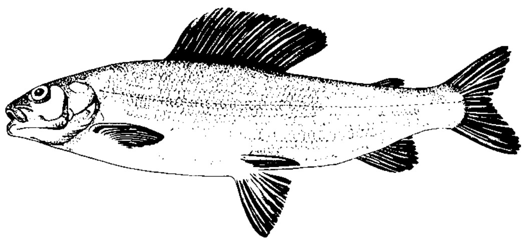
Intensive farming



In intensive farming, food or other forms of energy are supplied by man. The organisms (fish, crustaceans, algae etc.) are concentrated in a small area. Farming is carried out in ponds, troughs, tanks, silos etc. on land or in net pens, cages etc. in lakes or coastal areas.

Composition and properties of feed

The amount and composition of the by-products leaving a farm depend largely upon the properties of the feed. From an environmental point of view, the choice of feed is therefore of great importance.

The types of feed which are at present used for fish farming can be divided into three main groups; dry feeds, semi-moist feeds and wet feeds.

Dry feed consists of fishmeal, binding agents etc. and has a low water content. The semi-moist feed consists of roughly equal proportions of ground fish and binding agents, while the wet feed is largely composed of fish with a smaller proportion of binding agents.

Table 1. Example of "dry feed" composition (Ewos T51).

Protein	36%
Fat	17%
Carbohydrate	28%
Ash	10%
Water	9%
Phosphorus	1.1%

The use of wet feeds can increase the release of nutrients and oxygen consuming materials by 100% compared with dry feeds, partly due to a larger feed wastage (Markman 1978), (Table 2). Wet feeds give rise to a by-product that forms less sediment than dry or semi-moist feeds (Solberg and Bregnballe, in Alabaster 1982).

Table 2. Proportion of feed wastage associated with different types of feed (Vandkvalitets-institutet & Jydsk Teknologisk Inst. 1976).

Type of feed	Feed waste, %
Dry feed	1—5
Semi-moist feed	5—10
Wet feed (minced fish)	10—30

The method of feeding the fish also affects the amount of waste products leaving the farm. A large number of small portions result in less waste than a few large portions. Manual feeding has in some cases been shown to cause less waste than automatic feeding.

Feed wastage has a large influence on the feed coefficient, which is the proportion between the amount of feed used and the amount of fish produced. A feed coefficient of 1.5 means that 1.5 kg of dry feed were used to produce 1 kg fish (wet weight).

Dry feeds are at present the most common feeds in Sweden and during 1980 they were used in 80% of the total production of fish aimed for the commercial market (Larsson 1980). Research is being carried out into feed composition and feeding techniques, so the amount of waste from feeds can be expected to decrease.

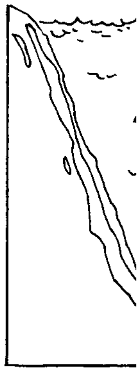
In the future, ensilaged feeds may be used in fish farming. Ensilage is a process of preservation by means of the addition of acid or acid-forming bacteria (fermentation). During this process parasites and bacteria are killed, which makes it possible to use so-called trash fish and fish offal without risk.

Techniques for producing protein from different kinds of offall or oil are being developed rapidly at present. Protein can be manufactured by culturing algae, yeasts or bacteria. This so-called single cell protein has been combined with fish-meal protein in different feeding experiments with good results for atlantic salmon (Bergström 1979).

Cage farming

This technique consists of the fish being farmed in net cages (bags). These are attached to a floating frame and placed in lakes, running water or in the sea.

In Sweden, cage operations are the most commonly used methods for the farming of food fish at present. The dominating fish species is rainbow trout but other salmonid species are also farmed in net cages. In the future it is probable that even flatfish will be farmed in this manner.



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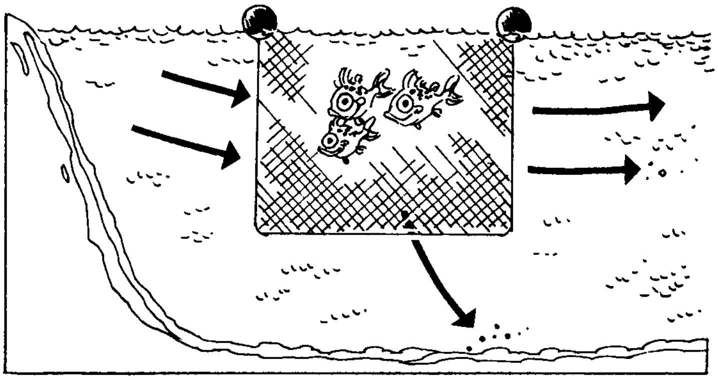

Fig. 3. Cage farming is carried out in floating net bags which vary in volume from 50 to 500 m^3.

In most cage farming, dry feeds are used. However, semi-moist or wet feeds are used in some farms.

This method results in wastes from farming operations being released directly into the recipient. There is as yet no practical technique for collecting feed wastes and faeces*. A method for removing sedimented wastes from net bag cultures by means of sedimentation basins followed by biofiltration has been presented by Lewis and Wehr (1976). However, it is not known to which extent this reduces the environmental effects of a fish farm. Due to the manner in which rainbow trout farming is carried out in Sweden, the amount of effluents increases greatly during the farming season. It is greatest in the autumn when the fish populations and the resultant feed portions are large. Nutrients and organic matter are released from the net pens into the water. Even various medicines and other foreign substances may occasionally be released into the surroundings.

* A Swedish company demonstrated in spring 1983 a technique for collecting faeces and feed wastes.

Discharges of nutrients

Among the nutrients which are released from farming operations phosphorus and nitrogen are at present considered to cause the greatest effects. In coastal sea areas nitrogen loading can cause significant increases in production, while in lakes and running waters phosphorus usually limits growth. *Theoretical calculations* of the amounts of phosphorus released from farms using dry feeds show that during a season with a production of 1 ton of fish and a feed coefficient of 1.5, 15 kg of phosphorus are released (Karlgren 1981). If the feed coefficient is 2.0, the same calculations show that 18 kg of phosphorus are released. During maximal loading, for several weeks in the autumn, 120—185 g of phosphorus are released per day and per ton of seasonally produced fish.

There is very little information based on *direct measurements*, on quantitative discharges from net pen farming. Dickson (1980) estimates the release of phosphorus into the surrounding water to be about 10 kg per ton of seasonally produced fish. Enell (in press) found that 8.5—9 kg phosphorus per ton seasonally produced fish was incorporated into the sediment below the net bag and that only a minor amount was released to the overlying water. Calculations of the nutrient discharge from circular trough systems (round basins with slightly conical bottoms) have given similar values for the release of phosphorus (Warrer-Hansen 1981). For the production of 1 ton of fish with a feed coefficient of 2.0, 13 kg of phosphorus were released per season. The maximal discharge per day was found to be 80 g of phosphorus. The nitrogen release was estimated to be 108 kg per season. Organic matter is not collected and recycled in circular trough systems, so these values should be comparable with those from net bag farming.

When estimating the burden of human communities on recipients, it has been calculated that each person contributes 2.5 g of phosphorus per day (= 1 population-equivalent). Disregarding all other differences, on a yearly basis the production of one ton of fish corresponds to about 11—16 population-equivalents, if the discharge of phosphorus is 10—15 kg. There are ecological reasons for calculating the release of phosphorus on a yearly basis, as the effects last longer than a farming season.

Discharges of organic matter

The material that is released from net pen farmings consists mainly of organic matter and is easily degraded if oxygen is available. The amount of oxygen used in this process is given as BOD (biochemical oxygen demand) or UOD (ultimate oxygen demand). UOD includes BOD as well as oxygen consumption due to the oxidation of nitrogen compounds, and respiration by fish. It should be noted that the oxygen demand resulting from fish respiration can be of the same order of magnitude as the biochemical oxygen demand (Markman 1978).

For a feed coefficient of 1.5, the theoretical BOD is estimated to be ca. 4.5 kg of oxygen per day and ton seasonally produced fish (Table 3).

BOD production from rainbow trout, fed 0.6 to 1.7 percent body weight/day by hand with dry food showed that the total production of BOD is directly proportional to the BOD of the food (Butz and Vens-Cappell, in Alabaster 1982). The BOD production was 117 g/kg food in addition to a basal rate of 485 g BOD/kg fish. Faeces production was 259 g dry matter/kg food. Increases in digestibility did not reduce the organic load, although the amount of faecal dry matter dropped.

BOD in circular trough systems may differ considerably. For a feed coefficient of 2.0 the oxygen demand is about 2.0 kg per day and ton seasonally produced fish (Table 3).

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Table 3. Estimation of oxygen demand for the cultivation of 1 ton of fish/season with different feed coefficients.

	Estimated oxygen demand (kg/day)		
	Karlgren 1981		Warrer-Hansen 1981
Feed coefficient	1.5	2.3	2.0
BOD average	4.5	10.9	2.0
BOD maximum loading	6.0	17	
UOD average	11.0	19	
UOD maximum loading	16.5	29.5	

It should be pointed out that Karlgren's estimates of theoretical oxygen demand in Table 3 are based upon the assumption that all oxygen consuming organic matter released from the fish cultivation is incorporated into the body of water. However, it has been shown that both excrement and feed wastes fall to the bottom underneath the net cages and form a layer of sediment (c.f. p. 30). Therefore, the figures presented for oxygen demand should be regarded as maximum values. The calculations do, however, show the importance of the feed coefficient for the amounts of organic wastes released. Efficient cultivation with a supply of feed well suited to the size and appetite of the fishes, as well as to the water temperature will reduce the release of wastes.

Farming in net cages results in an accumulation of waste products such as excrement and feed in a limited area. Therefore, the formation of sediment can increase underneath a cultivation. In an inland lake in southern Sweden the upper layer of sediment below a net pen operation contained visible remains of feed and was 10 cm thick at the end of a year's farming season. During the following year, the supplies of feed were halved and the upper sediment layer measured only 1 cm. Compared to the situation outside the farm the rate of sedimentation (dry matter/m^2, day) was 5 times greater below the net pens (Enell and Löf 1983). The increased sedimentation was localized to the immediate vicinity of the net bags as no effect was noted 25 m from the farm.

The accumulation of sediment depends on the hydrological conditions in the area. This means that large variations in the patterns of deposition of excrement and feed can be found, even within a single lake.

Pond culture

In this type of culture earthen ponds are used. Most pond culture in Sweden is on a small scale and has a relatively small production of salmonid fishes.

In Denmark the pond farming technique is highly developed and completely dominates the production of rainbow trout. The environmental effects of this sort of farming are quite wellknown and are to a certain extent applicable to Swedish conditions. A survey of the composition and amounts of effluents from pond farming and their environmental effects in several european countries have been compiled by Alabaster (1982).

As a result of this farming technique, the water leaving the ponds has been affected to some degree by various self-purification processes. Sedimenting excrement and feeds are whirled up by fish and bottom fauna, speeding up their degradation. The extent to which this resuspension occurs depends upon the shape of the pond, water renewal, the fish species, the type of feeds and so on.

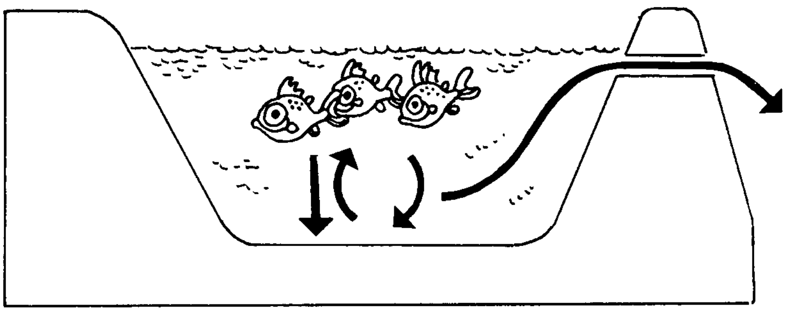

Fig. 4. The use of excavated or natural earthen ponds was previously the main cultivation technique in Sweden. In Denmark in 1981, 19,000 tons of rainbow trout were produced in earthen ponds.

If necessary, the sediment which is formed can be removed from the ponds. This should not result in any negative effects if the sludge is properly disposed of.

Discharges of nutrients and organic matter

Biochemical oxygen demand and phosphorus release from earthen ponds in Denmark are similar to or lower than those from cage operations or circular trough systems (Tables 4 and 5).

Table 4. Oxygen demand and nutrient release in earthen ponds (kg/day and for a fish stock of 1 ton) (Vandkvalitetsinstitut 1976).

	8 portions/day		3 portions/day	
	Dry feed	Wet feed	Dry feed	Wet feed
BOD_5	1.4	2.8	1.8	4.7
Tot-P	0.06	0.12	0.096	0.17
Tot-N	0.32	0.48	0.36	0.78

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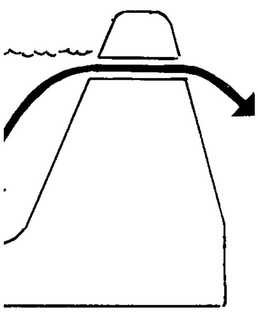

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Dry feed	Wet feed
1.8	4.7
0.096	0.17
0.36	0.78

Table 5. Yearly oxygen demand and nutrient release from earthen ponds in which rainbow trout were farmed using dry feed (kg per ton fish production) (Vandkvalitetsinstitutet & Jydsk Teknologisk Inst. 1976, Warrer-Hansen 1976, Warrer-Hansen in Alabaster 1982, Warrer-Hansen & Simonsen 1978).

	kg/year, ton
BOD_5	300
Tot-P	10
Tot-N	81

In Denmark, efforts to reduce the amount of pollutants from pond cultivation have been in progress for some time. Due to the fact that faeces from the farmed fish sediment out relatively quickly, sedimentation basins can be utilized. However, conventional basins require quite a large area. This area can be reduced by using a so-called whirlpool separator (Fig. 5).

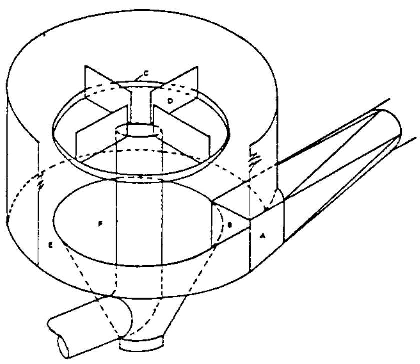

Fig. 5. The use of a so-called whirlpool separator can reduce the amount of wastes from pond operations.

This consists of a round tank with a tangential inflow. Particles sediment to the bottom in the middle of the tank, from where they are removed. The biological oxygen demand and the total amount of nitrogen are reduced by about 30%. The total amount of phosphorus is reduced by 15% (Table 6).

Water sampled from the surface in the middle of the whirlpool separator is more or less free of particles. The method concentrates the particles so that the water drained from the bottom is only about 1—5% of the total water flow.

Table 6. Effect of a whirlpool-separator (Warrer-Hansen 1981).

	Before treatment in whirlpool separator (kg/day and ton prod. fish)	Proportion removed by the whirlpool separator in %
BOD_5	1.70	30
Tot-N	0.45	30
Tot-P	0.06	15
Suspended matter	2.50	60

Tank culture

This form of farming is mainly used for compensatory farming operations near hydroelectric plants. It is mostly used for the production of juvenile salmon and brown trout.

Dry feed is the main foodstuff. The feed coefficient is 2.2 for the whole process of producing two year old fingerlings. As these operations are confined to the production of small fishes, the biomass and the resultant effluent are relatively small, even in large installations with a yearly production of 200,000—500,000 juveniles.

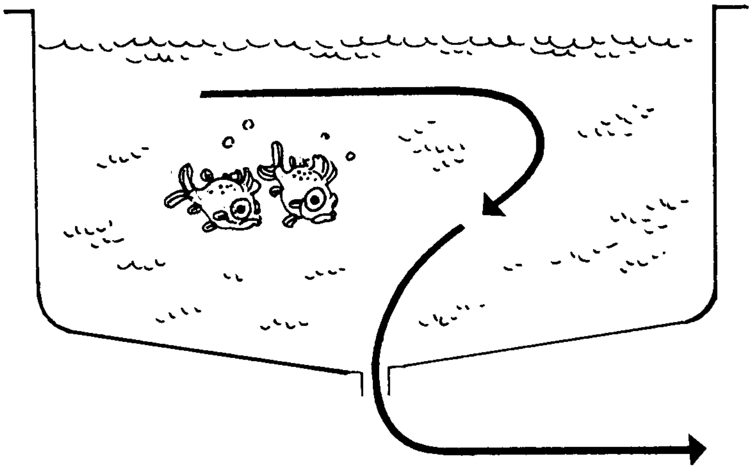

Fig. 6. When salmon smolt are produced in tanks (or troughs) the extremely dilute effluent is usually discharged directly into the recipient without being treated.

Most operations are located near large watercourses, which means that the released wastes are greatly diluted. Therefore, most effluent flows untreated into the recipient. The environment may, however, be affected locally.

In the future, the number of tank and pond operations utilizing warm process water, for example from industries, can be expected to increase.

Recirculating systems

In a recirculating system the water is recycled once or several times. This is made possible by coupling a water treatment process to the farming operations. Recirculation improves the heat budget if heated water is used. In such systems, the temperature can be regulated in order to achieve optimal growth for various species. The degree of recirculation and the purification process vary from case to case; usually there is a more or less continuous inflow of clean water.

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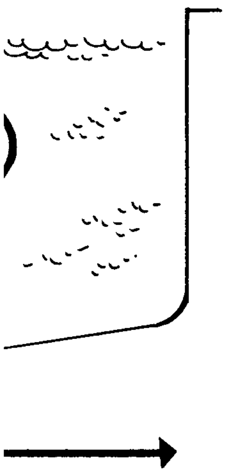

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A reduction of the amount of organic matter is brought about by sedimentation and/or filtration. Nitrogen compounds are oxidized microbially by means of the active sludge technique or biological beds.

The amounts of pollutants and water which are released vary greatly, depending upon feed type, purification techniques and the degree of recirculation. Therefore, in order to obtain information on the release of effluents, measurements must be made for different combinations of these factors. As the recirculation systems only release a limited amount of waste water, the treatment procedures will be easy to supervise. The effects on the environment are therefore likely to be small.

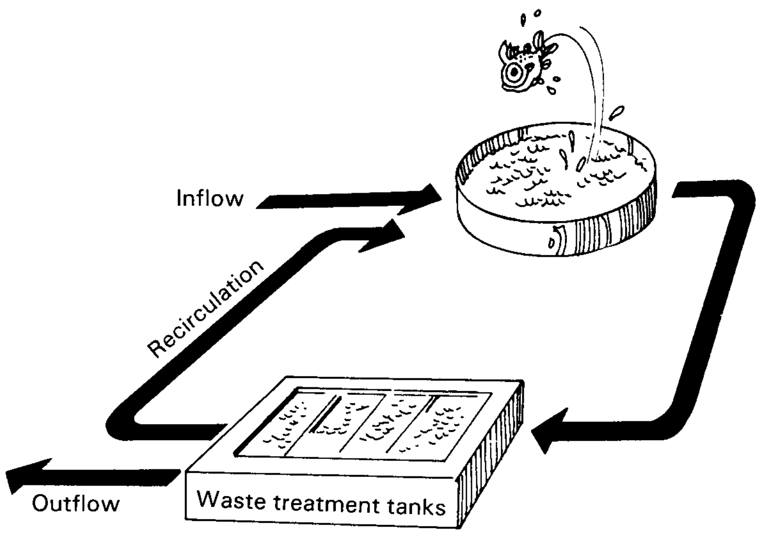
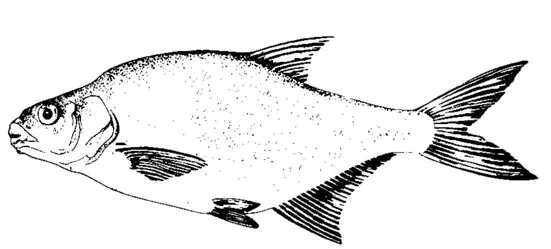


Fig. 7. In a recirculating system the biological, physical and chemical aspects of the process are under complete control and the water is recycled to various degrees (90—100%). The toxic ammonium compounds in the excrement are oxidized through nitrite to nitrate by the bacteria in the waste treatment tank. Nitrate may then be transformed into nitrogen gas by various means.

Extensive farming



In extensive farming *no food or other energy* is supplied by man. Only naturally produced food is utilized. In subtropical and tropical countries extensive cultivation of fish and shrimps is carried out in large areas and at low organism densities. The extensive farming of mussels at high population densities as practised in this country is of a completely different nature.

Mussel farming

The cultivation of blue mussels in Sweden is at present confined to the county of Bohuslän on the west coast. In southern Kattegatt and in the Baltic Sea, the mussels have a slower growth rate and do not reach the same size. Farming operations are expanding. In 1981, 500 tons of mussels were harvested in Sweden. The harvest is estimated to be about 1500 tons in 1982, and about 2400 tons in 1983. However, this production does not completely supply the demand.

The mussels are cultivated on vertical bands which hang from the surface to a depth of 6—8 metres. The bands are attached to horizontal anchored ropes which are supported by floats. The cultivation period is 1.5—2 years, at the end of which the mussels are 6—7 cm in length.

Each farm is usually dimensioned to yield about 100 tons of mussels, including the shells. Such an operation requires an area of 1,500—2,000 m^2. The theoretical yield from cultivation in the Bohuslän county archipelago has been estimated to be around 50,000 tons (Rosenberg 1981). However, other calculations give substantially larger possible yields (Haamer 1977).

There is no commercial cultivation of other mussel species or oysters in Sweden. Formerly, oysters were collected from oyster beds in the sea for further cultivation in tanks. The natural recruitment of oyster larvae is uncertain in Sweden, due to low summer temperatures which inhibit the oysters' reproduction. The blue mussel, on the other hand, reproduces at lower temperatures than the oyster and produces large numbers of larvae along the Swedish west coast.

Mussels feed by filtering phytoplankton from the water. The excretory products largely end up on the sea bed beneath the farm. The strength of the currents in the vicinity of the farm is probably of vital importance for the dispersal of the wastes and therefore for the environmental effects on the sea bed.

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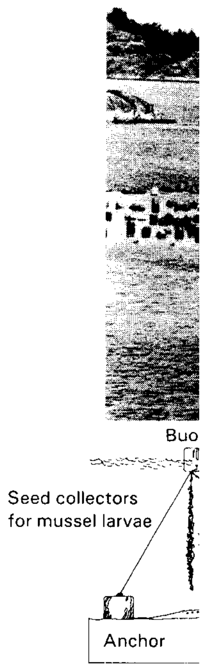

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The results from ecological studies carried out at a 100 ton mussel operation at the Swedish west coast (near Strömstad) show that during a farming period the deposition underneath the mussels is about 7 kg of dry matter per m^2 (the equivalent of 1 kg carbon per m^2). The daily sedimentation rate (3 g C/m^2) under the operations was nearly three times higher than at a nearby reference station (Dahlbäck and Gunnarsson 1981). Thus, for a farm covering an area of 1500 m^2, the sedimentation of dry matter would amount to about 10 tons. The growth of the sediment is estimated to be about 10 cm per farming season.

One future use for the sediment resulting from mussel farming could be the cultivation of animals which feed on sediment. The sediment could even be used as fertilizer.

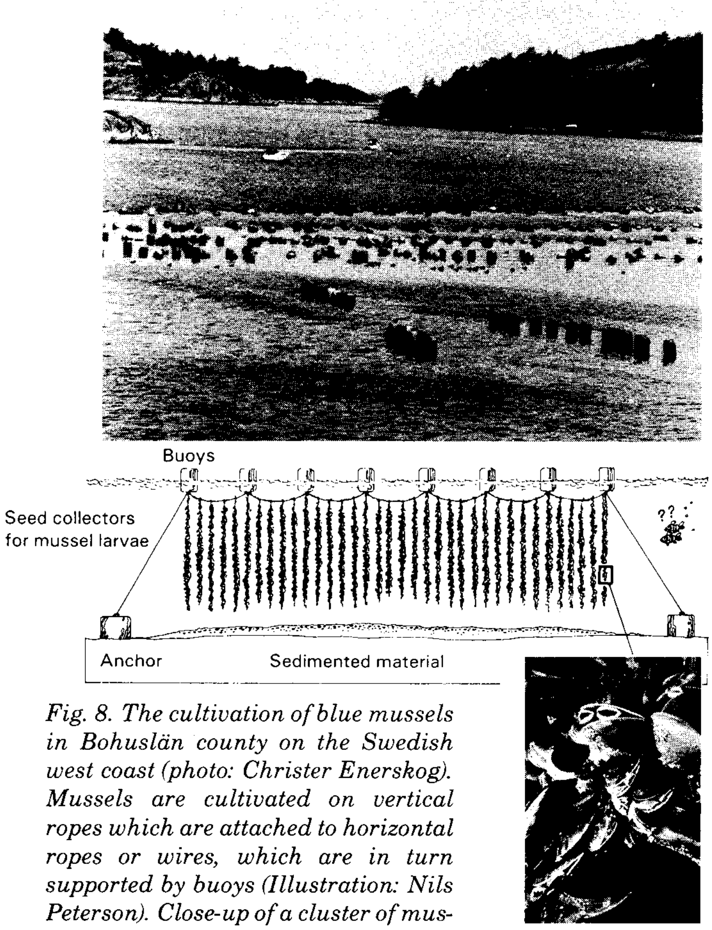
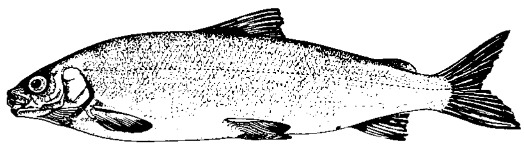


Fig. 8. The cultivation of blue mussels in Bohuslän county on the Swedish west coast (photo: Christer Enerskog). Mussels are cultivated on vertical ropes which are attached to horizontal ropes or wires, which are in turn supported by buoys (Illustration: Nils Peterson). Close-up of a cluster of mussels underwater (photo: L.-O. Loo).

Farming of algae



The algae found in water are microscopic as well as macroscopic. Both of these groups are cultivated or harvested in their natural environments. The aim is to utilize them as raw products in the manufacture of foodstuffs, animal feeds, fertilizer, chemicals and medicines, as well as to use them as a source of energy. In addition, algae can be used in the treatment of effluents. On the whole, the production of macroalgae (seaweed) is of most importance. The total world harvest, including farming, amounts to about 3 million tons, but it is considered that the yield can be expanded to 18 million tons per year.

In Asia, the farming of algae is an ancient tradition. Its purpose has been to provide raw materials for food preparation. During the twentieth century, interest in the utilization of algae for the extraction of various chemical components has become very great. The supplies of naturally occurring algae are smaller than

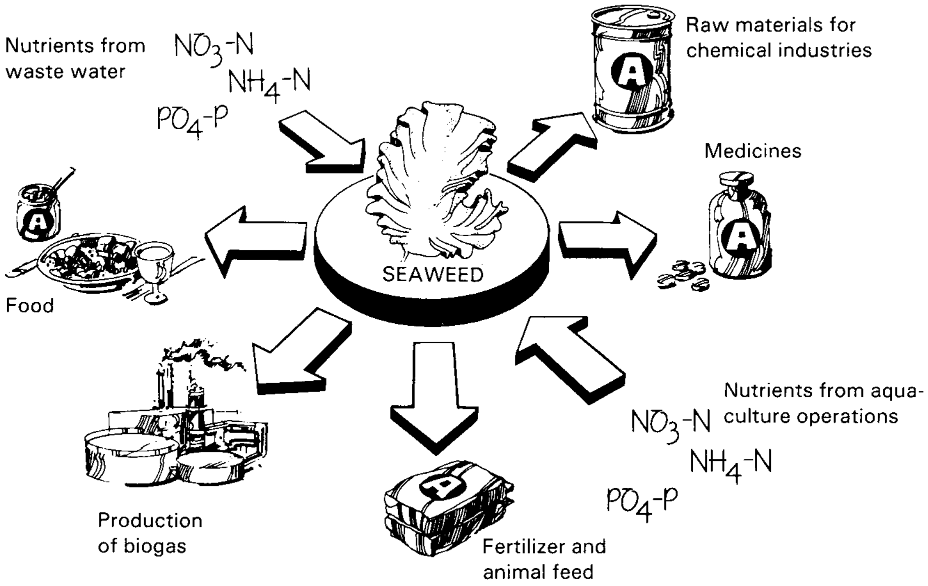


Fig. 9. Macroalgae (seaweed) are used for the manufacture of foodstuffs, animal feed, fertilizer, chemicals and medicine, as well as for the extraction of energy. In addition, algae can be used to purify effluents and to recycle nutrients from fish cultivations.

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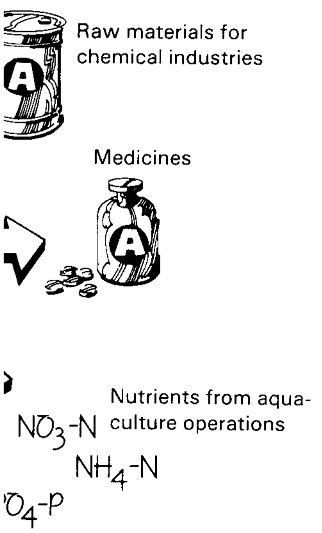

of foodstuffs, animal feed, fertil-
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the demand for them. Therefore, the supervision and care of these natural resources will become necessary. For these reasons, farming is becoming more important as a means of supplying the demand. Such operations are often situated along coasts, in many cases in areas where conflicting interests compete for the available space. Conflicts have also arisen in Asia, for example between farmers of algae and oysters. Large areas are covered by rafts from which nets containing algal sporophytes hang down into the water.

The production of biogas by the fermentation of macroalgae results in vast areas being occupied by such operations. The most wellknown of these are the experimental farming of kelp, an alga of the genus *Macrocystis,* which is located off the coast of California in the U.S.A. Each cultivation unit is about 200 m in diameter and thus occupies a large area.

All farming of algae requires relatively high levels of nutrients in the water in order to maintain a high growth rate. In many cases, the water is fertilized so as to obtain the required levels of nutrients such as nitrate. When nori *(Porphyra)* is cultivated in Japan, many farmers add pellets containing 90% nitrogen and 10% potassium. For the cultivation of kombu *(Laminaria)* it is estimated that 1 kg of fertilizer is used in the production of 3.75 kg of algae (Mathiesen 1975).

A clay cylinder containing fertilizer is attached to each raft, to enable slow diffusion of the nutrients into the water. The sporophytes may be dipped into a solution of ammonium nitrate before being placed into the water for cultivation.

Positive results are obtained when algae are cultivated in effluents from sewage plants, or in combination with fish and mussel farming. Instead of expanding a sewage plant in Denmark to include a third process for nutrient reduction, the green algae *Ulva lactuca* was cultivated in the effluent. Calculations show that the algae remove all phosphate and most of the nitrogen from the effluent (Wachenfeldt, pers. comm.). Plants other than algae are also able to absorb large quantities of nutrients. For example, the water hyacinth has been shown to absorb the following elements from water (Table 7).

Table 7. Absorption of mineral elements from water by the water hyacinth (Anon. 1976).

Element	Absorption kg/ha day
Nitrogen	22—44
Phosphorus	8—17
Potassium	22—44
Calcium	11—22
Magnesium	2—4
Sodium	18—34

In addition, it is known that potentially dangerous substances such as cadmium, nickel, mercury and phenol can be concentrated from 4,000 up to 20,000 times by various aquatic plants.

Algae are currently being used experimentally in various fish and mussel farms to investigate the possibility of eliminating substances such as nitrogen compounds from the water. The integrated farming of algae and mussels or fish is therefore a feasible future alternative.

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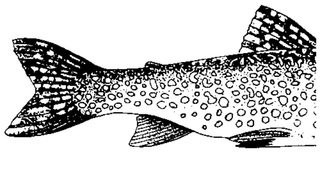

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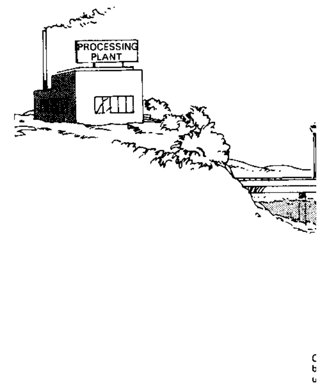

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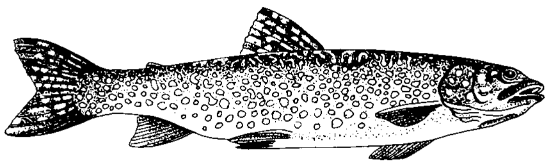

Fish farms release a large number of substances into the water. Those which are most important as regards the environment are nutrients (for example phosphorus and nitrogen) and organic matter. These substances, as well as discharges of chemicals, medicinal residues and odorous compounds from the farms can cause environmental effects (Fig. 10).

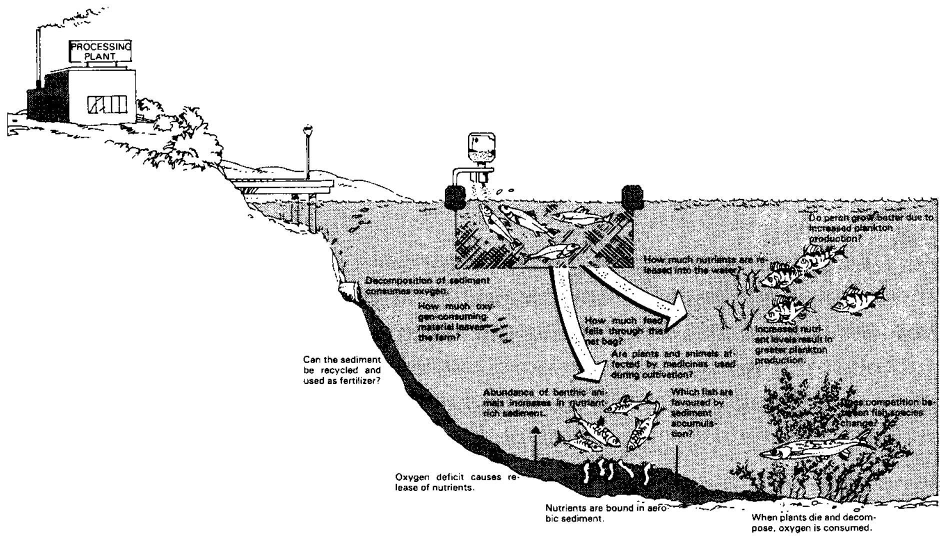

Fig. 10. Examples of environmental effects caused by aquaculture. Cultivation may increase the productive capacity of an aquatic ecosystem and induce direct or indirect changes in the environment.

The inputs of phosphorus and nitrogen fertilize the water and lead to an increased production of plants and animals. In lakes, the addition of nitrogen is usually of less importance. In ocean coastal areas, however, inorganic nitrogen is generally the limiting nutrient. The discharge of nitrogen from a fish farm can periodically be expected to cause increases in primary production.

The increased amounts of attached algae, phytoplankton and higher plants result in the consumption of large amounts of oxygen when these die and decompose. The oxygen depletion can be considerable in unfavourable conditions and may lead to an oxygen deficit in the water.

Appreciable alterations in the ecosystem of a watercourse occur when the phosphorus load exceeds a certain level, above which the usefulness of the waters is generally reduced. On the basis of experience it has been possible to determine an approximate limit for this level. In order to calculate this limit, the total supply of phosphorus is related to the rate of water turnover (Vollenweider 1975).

Some of the nutrients which are added to running waters are transported to lakes situated downstream. An estimate of the environmental effects of nutrients in watercourses must therefore also consider water areas to which excess nutrients are transported.

As the discharge of phosphorus varies greatly during the cultivation season, it is difficult to evaluate its effects. The phosphorus added to a recipient during the autumn is utilized to a lesser extent by the aquatic vegetation than an equivalent amount added during spring and summer. In such cases the effects of the autumn discharge are delayed until the following year.

In addition to the organic matter which arises as a secondary effect of phosphorus loading, matter is obtained in the form of excrement and feed from farming operations. These wastes generally fall to the bottom and form a nutrient-rich sediment. In the long term, this results in an acceleration of the lake's ageing process.

The decomposition of organic matter requires oxygen. The rate of oxygen depletion and the nutrient content of the sediment and of the sediment-water interface lead to a number of changes in the biological and chemical conditions near the bottom. Investigations carried out in a Norwegian lake showed that sediment containing a large amount of feed residues had reducing properties and a higher pH than unaffected sediment (Fig. 11).

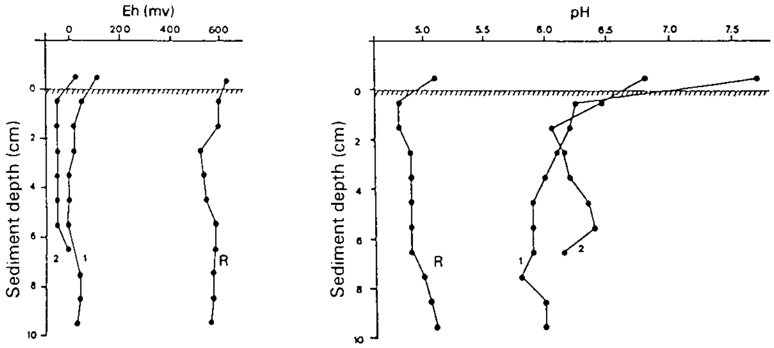

Fig. 11. Redox potential (a measure of the oxygen content) and pH of the sediment from a Norwegian lake. Points 1 and 2 are areas under the net bags and R is the reference area (Nilsen et al. 1981).

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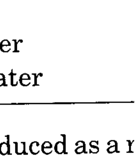

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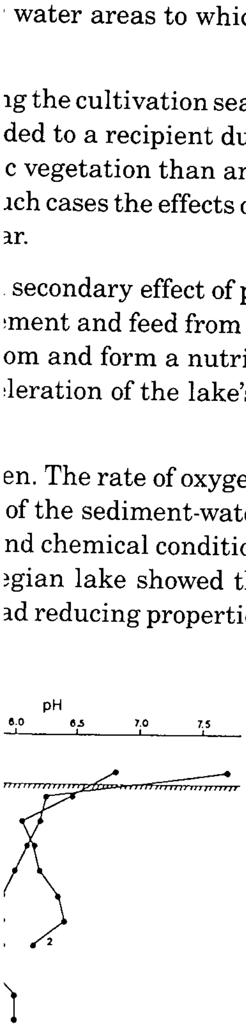

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When the oxygen content at the sediment-water interface is high, a chemical "barrier" hinders the transport of nutrients from the sediment to the overlying water. As a result, nutrients can be accumulated and bound in the sediment over long periods of time. An oxygen deficit at the sediment-water interface changes the chemical conditions so that phosphorus ceases to be bound in the sediment. The phosphorus thus freed from the sediment is released into the water above, and consequently the eutrophication process is accelerated.

Even under aerobic conditions, phosphorus has been shown to be liberated from sedimented material underneath net pen operations (Fig. 12).

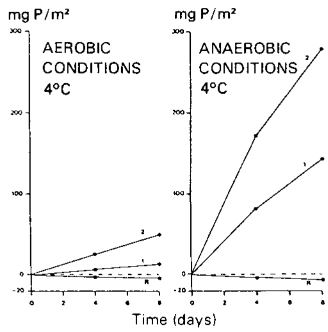

Fig. 12. The liberation of phosphorus from the sediment into the water under aerobic and anaerobic conditions in lake Liervatn, Norway. Points 1 and 2 are areas under the net bags and R is the reference area (Nilsen et al. 1981).

Matter which consumes oxygen can cause an oxygen deficit in the water and lead to the disappearance of certain animals that require high oxygen concentrations, for example, salmonid fishes and crustaceans. The latter group is, in turn, prey organisms for other more hardy species.

The oxygen deficit is balanced to a certain extent by the diffusion of atmospheric oxygen and the production of oxygen by aquatic plants. Diffusion from the atmosphere is dependent on wind exposure, water temperature and the oxygen deficit in the water (Table 8).

Table 8. Oxygen diffusion from the atmosphere to water with a temperature of 20°C and 80% oxygen saturation.

	$g\ O_2/m^2$ day
small lake	0.3
large lake	1.0
running water	1.8
cascading water	5.0

The oxygen produced as a result of photosynthesis by plants (phytoplankton, attached algae, macrophytes) helps to counteract the depletion of oxygen in the water. However, at the end of the vegetative season, most of the oxygen thus produced is used when the plants decompose. When the oxygen consuming processes from cage operation are at their greatest (summer and autumn) the production of oxygen by plants may, nevertheless, be important.

If there is a lack of oxygen in the water inside the net cages, large numbers of fish may die as a result. Even oxygen depletion occurring in the sediment can be of importance for a cultivation. Anaerobic conditions in the sediment cause the formation of hydrogen sulphide gas, which can kill the fish if it reaches the cultivation. Nor can the problem be avoided by moving the operation to deep water. In Norway, experience has shown that even with a water depth of 20 m these risks are not minimized.

With regard to the recipient, it is generally not advisable to locate operations in deep water. The oxygen-consuming organic sediment then accumulates beneath the thermocline, greatly affecting the oxygen content of the water near the bottom.

The increased supply of nutrients in the sediment causes a steady increase in the biomass of the bottom fauna, while at the same time the species composition is altered (Öhrn 1980). Totally anaerobic conditions lead to the formation of dead zones. However, when oxygen becomes available once again, a recolonization takes place. So far, observations suggest that the effects on the bottom fauna in the vicinity of farming operations are of a local nature. In running water, the effects on the bottom fauna decrease a relatively short distance downstream from the farm, provided that it is suitably dimensioned in relation to the water flow (Ekström and Öhrn 1980). However, little is known about how quickly and to what extent conditions return to normal after farming ceases.

The increased amounts of bottom animals and plankton as well as feed wastes and excrement affect the natural fish populations near the farm. Fish which feed mainly on bottom animals, or those able to utilize waste matter from farms are favoured, as are plankton eating fish which are able to take advantage of the increased plankton production.

If most of the feed could be supplied by the recipient, for example in the form of so-called trash fish, changes in the trophic levels of the recipient would in principle be very small, as nutrients would not be supplied from outside the ecosystem.

Effects of mussel farming

The effects described here are based on observations from a 100 ton mussel farm situated near Strömstad on the Swedish west coast.

No reduction in oxygen concentrations was observed, neither in the bottom water nor in the water surrounding the farm.

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In marine sediment, anaerobic conditions are usual at a depth of several centimetres. However, underneath the farm, the anaerobic layer extended all the way up to the sediment surface during the autumn. During the spring, oxygen conditions in this layer improved.

Parts of the bottom underneath the farm were periodically covered by a white carpet of sulphur bacteria. The number of species of macrofauna (animals $\geq$ 0.5 mm) was reduced during slightly more than a year so that only 20% of the original species remained. The number of species in an area 25 m away was reduced by 50%. The species composition underneath the cultivation was completely altered as a result of the sedimentation of matter. A few species of small polychaetes were periodically favoured and were present in large numbers. Otherwise, the number of individuals was greatly reduced. The biomass varied with the seasons but no clear trend was apparent.

Significant numbers of mussels and other animals fall down from the cultivation to the sea bed. After nearly one year of cultivation, there were 2,800 live mussels per m^2 on the bottom. This settling has positive effects foremost on fish, which gather around the cultivation. Periodic concentrations of cod, eels and flatfishes were observed.

Of the nitrogen and phosphorus which the mussels ingest via food particles, some is bound in mussel flesh, some sediments together with the excretory products and the remainder is recycled in inorganic forms which stimulate new primary production.

Mussel cultivations should be harvested within 2 years. If the cultivation period is extended there is increased competition with other species and a risk that large numbers of mussels will fall to the bottom.

Effects of foreign substances

Substances which are foreign to the surroundings can be spread from farming activities. Possible sources are feed, feed supplements and various forms of medication. The risks of affecting the environment are greatest in connection with net bag cultivation, as dosage and treatment usually take place directly in the net cages.

The substances discussed here can be expected to produce effects which differ from the eutrophication problems mentioned in previous chapters. It is at present unknown if and how these substances can affect resources such as water supplies.

The dry feed which is commonly used is required to be free from harmful additives. Therefore, no environmental effects can be expected to arise solely from the use of dry feeds. If wet feed is used, fish from "blacklisted" or otherwise unsuitable localities must not be incorporated.

As feeds usually have a high fat content, the possibility of contamination by fat-soluble environmental poisons such as DDT and PCB cannot be excluded. In this respect, the choice of raw materials for feed is of the greatest importance. If, for instance, there is a large proportion of fish from the Baltic Sea in the final product, great attention should be paid to possible contaminants, especially PCB.

If the feed contains persistant fat-soluble environmental poisons, these can become enriched in the cultivated organisms (Rosenthal et al. 1981, Sommer et al. 1982, Crisetig et al. 1982, Winchester and Keating 1980). This is especially the case if farming concentrates on organisms with a high fat content (eel, salmon etc.). The accumulation of chlorinated environmental poisons in particular can cause reproductive problems in breeding stocks of fish. Even if no effects are apparent during cultivation, under unfavourable conditions the final product risks being classified as unsuitable for human consumption, due to excess levels of poisons.

Any by-products of the feeding process which eventually leave the farm may be concentrated as they pass through the aquatic food chains, providing another reason for keeping feeds free from all undesirable substances.

Formalin, copper sulphate and malachite green are used to combat diseases and parasites. In addition, sodium hypochlorite is sometimes used in the cleaning and disinfection of tanks and the like.

Of these chemicals, formalin is the one most commonly used in Sweden (5—10 tons/year). Its main application is in the treatment of breeding stocks of fish in tanks, and fry in small troughs, during which the fish are "bathed" in a dilute solution of the chemical. In net pen operations, the treatment is carried out directly in the net pen, which is isolated from the surrounding water by plastic sheeting. Copper sulphate is used little in Sweden. Its main application is for the treatment of certain infections in fish fry, at concentrations of 0.1—0.3 mg/l.

Malachite green is at present used to a very small extent. Use of this preparation is not likely to increase, as it is suspected of being a mutagen.

The chemicals are more or less poisonous to both plants and animals. Copper sulphate is acutely toxic to fish (at concentrations of 0.1—1.0 mg/l) and even to phytoplankton at relatively low concentrations (0.5—2.0 mg/l) (Laveskog et al. 1976). Previously, it was used as a means of controlling unwanted algal growth in lakes and ponds. The treatment solution should therefore by greatly diluted before being discharged into the recipient.

Even formalin can be poisonous at low concentrations, above all to phytoplankton and zooplankton. It is, however, degraded relatively quickly and is only active for a limited period of time. Assuming that dosage and treatment are carried out properly, only greatly diluted solutions will reach the recipient and the effects on the ecosystem are likely to be insignificant. These chemicals are not expected to produce any long-term effects.

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In addition to the above-mentioned chemicals, antibiotics (oxytetracycline, furazolidone and various sulfa preparations) are used to combat certain diseases. During 1980, about 100 kg oxytetracycline were used in Swedish aquaculture. Only insignificant amounts of other antibiotics were used. The antibiotic preparations are dosed by being added to the feeds or injected into the fish.

The antibiotics which eventually reach the surrounding environment come from unconsumed feed. When this is broken down some hours after feeding, the antibiotics dissolve into the water. However, at normal summer water temperatures, the rate of decomposition of most antibiotics is so high that their effects wear off relatively quickly. Oxytetracycline is oxidized in an aqueous solution and loses its activity after several hours or days, depending on the temperature and composition of the water (Litorin, pers. comm.).

The antibiotics which are at present used in Swedish aquaculture are not expected to result in serious consequences for the environment, either in the short term or in the long term. In order to avoid possible health risks associated with the use of antibiotics, farms located in waters used for supply purposes should not be placed in the vicinity of the water intake.

In the report "The problems of disease in aquaculture", these and other similar topics are dealt with in more detail.

Effects of nutrient discharges in coastal areas

Extensive algal blooms in the Kattegat and Skagerrak seas in the 1980s have been interpreted as the initial stages of the eutrophication of the marine areas bordering Sweden (Fig. 13). The algal blooms and oxygen depletion in the Laholm Bay were given much publicity. As such apparently local eutrophication problems could not be explained by the release of phosphorus from municipalities or industries, two alternative hypotheses were advanced. The first is that eutrophication is dependent on the increased availability of nitrogen rather than phosphorus, as there is a relative overabundance of phosphorus (as regards the requirements of phytoplankton) in most of the Baltic, Kattegat and Skagerrak seas. The second hypothesis is that eutrophication is not caused by municipal and industrial discharges of nutrients, but mainly by runoff from agriculture and by the atmospheric deposition of nitrogen.

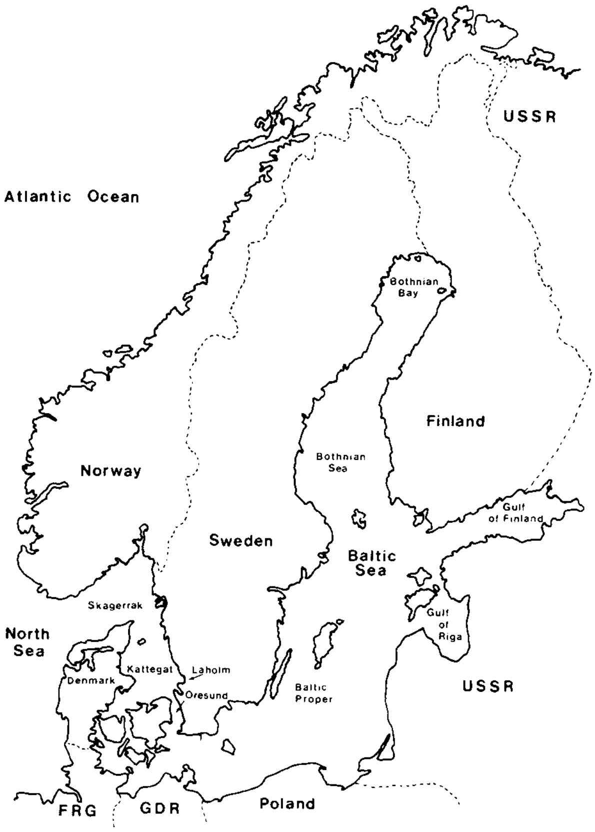

Fig. 13. The Baltic Sea and its different basins.

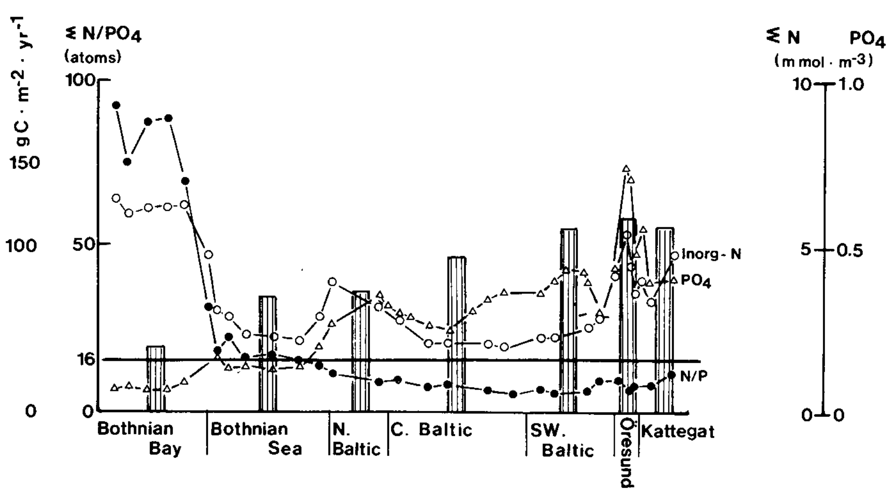

Fig. 14. Inorganic nitrogen, phosphate and N/P ratios during winter, and annual phytoplankton primary production in the Baltic Sea, the Öresund and the Kattegat (data from Ærtebjerg 1981). The solid line illustrates a balanced ratio of N/P for phytoplankton. (From Granéli and Granéli, in press).

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Before	Tot-P
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Present	Tot-P
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Primary production is very low in the Bothnian Bay but it increases rapidly towards the Baltic Proper (Ackefors et al. 1978). There is no further rapid increase in primary production as one moves towards Öresund and the Kattegat Sea (Granéli & Granéli, in press). Compared with lakes, the Baltic Proper is mesotrophic, that is, of medium productivity and on the border to being eutrophic. Increased discharges of nutrients can be expected to increase primary production and thus worsen oxygen conditions in deep water.

It should be pointed out that there is no statistical proof for the eutrophication of the Baltic, Kattegat and Skagerrak seas, in the form of increases in the biomass and production of algae due to human influence. However, in the case of the Baltic Proper, there are clear indications. The biomass of the bottom fauna above the halocline has increased significantly since the beginning of the 1900s, which can be interpreted as the effect of an increase in nutrients. Even if there is no proof of large scale eutrophication, it is difficult to believe that the enormous anthropogenic discharges of nutrients into the Baltic, Kattegatt and Skagerrak seas do not affect the open waters. There is, naturally, sound evidence of local eutrophication in the vicinity of communities and industries.

The Baltic consists of a number of separate basins: the Bothnian Bay, the Bothnian Sea and the Baltic Proper (Fig. 13). There are considerable differences in salinity, the concentrations of nutrients and primary production between these basins (Fig. 14). Therefore, the discharges and large-scale effects of aquaculture with regard to the nutrients in the Baltic should be discussed separately for each main basin.

Estimates have been made of the influx of nutrients to the Baltic, both of the "natural" load prior to man's influence on nutrient transport, and of the present day situation (Tables 9 and 10). Human activity has increased the load of nutrients in the Baltic many times. The present phosphorus load is probably 8 times higher than it was before human activities influenced the area, and during the same period the nitrogen load has increased about 4 times.

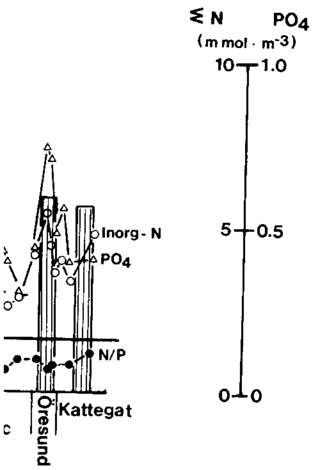

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Table 9. Estimated discharges of nutrients into the Baltic Sea before the area was influenced by man compared to the present situation (tons/year). (From Larsson and Elmgren 1983).

		Rivers	Aerial deposition	Nitrogen fixation	Total
Before	Tot-P	7 900	2 400	—	10 300
	Tot-N	148 000	79 000	67 000	294 000
Present	Tot-P	51 900	5 500	—	84 400[1]
	Tot-N	589 000	322 000	134 000	1 193 000[1]

[1]Includes municipal and industrial effluents.

Table 10. Estimated discharge of total-P and total-N into the different basins of the Baltic (tons/year). (From Larsson and Elmgren 1983).

		Tot-P	Tot-N
Bothnian Bay	Municipal effluents	100	1 600
	Industrial effluents	200	1 500
	Rivers	2 600	41 900
	Aerial deposition	700	19 000
	Nitrogen fixation		20
	Total	3 600	64 000
Bothnian Sea	Municipal effluents	300	3 100
	Industrial effluents	300	2 000
	Rivers	1 900	37 000
	Aerial deposition	1 300	43 000
	Nitrogen fixation		3 700
	Total	3 800	88 800
Gulf of Finland	Municipal effluents	10 200	53 800
	Industrial effluents	300	14 500
	Rivers	4 200	65 900
	Total	14 700	134 200
Baltic Proper	Municipal effluents	12 000	55 100
	Industrial effluents	600	5 800
	Rivers	42 100	436 200
	Aerial deposition	3 500[1]	260 000[1]
	Nitrogen fixation		130 000[1]
	Total	58 200	887 100
Öresund, Belt Sea	Municipal effluents	3 000	10 700
	Industrial effluents		500
	Rivers	1 100	7 700
	Total	4 100	18 900
Baltic	Grand total	84 400	1 193 000

[1]Includes the Gulf of Finland and Öresund.

The Bothnian Bay and the Bothnian Sea receive large amounts of relatively nutrient-poor river water. Municipal discharges in these areas are small, while the forestry industry releases large amounts of oxygen-consuming material. In the Bay of Finland as well as in the Baltic Proper and the straits (Öresund and the Belt Sea) municipal discharges are an important source of phosphorus. Municipal and industrial discharges of nitrogen are of little importance in the Bothnian Bay, the Bothnian Sea and the Baltic Proper. In these areas, the contributions from rivers and atmospheric deposition dominate. In the Baltic Proper (but not in the Bothnian Bay or the Bothnian Sea), pelagic nitrogen fixation by

blue-green algae is quantitat
has probably increased as a r
the open sea. It is only in the
municipal discharges contri
nitrogen.

The Swedish contribution to
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Most of the phosphorus origi
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as to a combined population
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(Table 11). The contribution
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from agriculture. Recent esti
Baltic Sea differ only slightly

Table 11. Contributions (%) to c
various countries (tons/year). (F

	Municipal effluents	
	Phosphorus	Nitrogen
Sweden	0.8	1.3
Finland	0.5	0.9
West Germany (FRG)	0.5	2.3
Denmark	3.5	1.2
Total	5.3	5.7
USSR	15.0	8.0
Polen	11.2	4.7
East Germany (GDR)	0.4	0.3
Total	26.6	13.0

Nutrient flow into the Ka

An evaluation of the eutrop
is being carried out at prese
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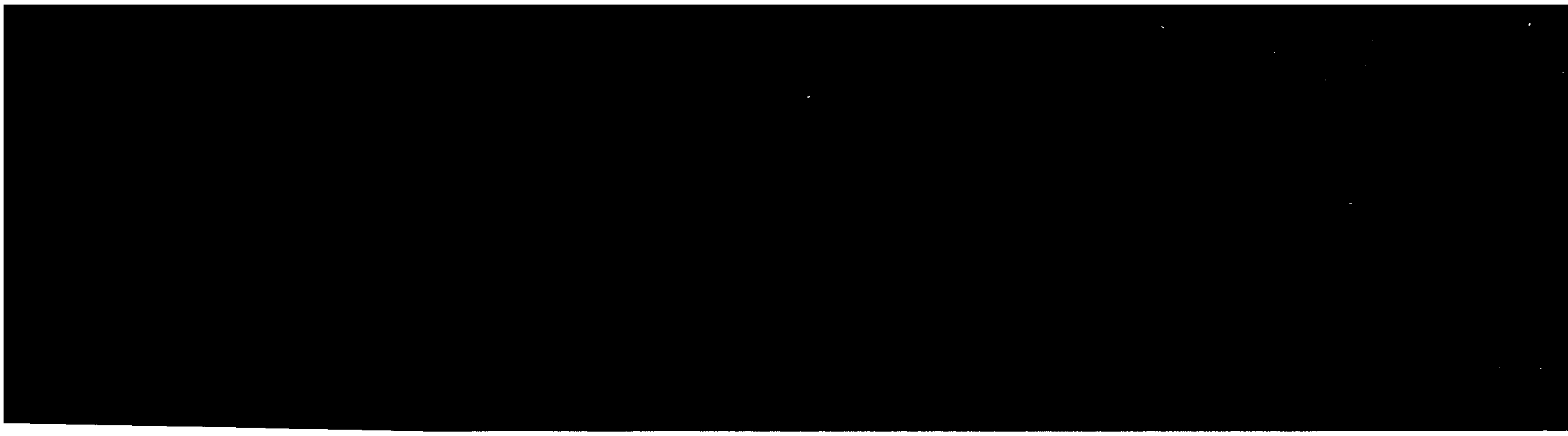

ıto the different basins of the Baltic

Tot-P	Tot-N
100	1 600
200	1 500
2 600	41 900
700	19 000
	20
3 600	64 000
300	3 100
300	2 000
1 900	37 000
1 300	43 000
	3 700
3 800	88 800
10 200	53 800
300	14 500
4 200	65 900
14 700	134 200
12 000	55 100
600	5 800
42 100	436 200
3 500[1]	260 000[1]
	130 000[1]
58 200	887 100
3 000	10 700
	500
1 100	7 700
4 100	18 900
84 400	1 193 000

large amounts of relatively
these areas are small, while
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ninate. In the Baltic Proper
pelagic nitrogen fixation by

blue-green algae is quantitatively of great importance. This nitrogen fixation has probably increased as a result of increased concentrations of phosphorus in the open sea. It is only in the Bay of Finland and in Öresund/the Belt Sea that municipal discharges contribute a large proportion of the total influx of nitrogen.

The Swedish contribution to the total discharge of phosphorus into the Baltic is 5.6%, of which 1.4% consists of municipal and industrial effluents (Table 11). Most of the phosphorus originates from Poland and the Soviet Union. However, this is not so much due to inadequate purification techniques in these countries as to a combined population which is much larger than that of Sweden. In the case of nitrogen, Sweden contributes about 12.8% of the land-based sources (Table 11). The contribution by rivers dominates (11%). The anthropogenic component of the nitrogen transported by rivers is significant and originates mainly from agriculture. Recent estimates of the input of phosphorus and nitrogen to the Baltic Sea differ only slightly from those presented here (Larsson et al., in press).

Table 11. Contributions (%) to discharges of phosphorus and nitrogen into the Baltic by various countries (tons/year). (From Larsson 1983).

	Municipal effluents		Industrial effluents		Rivers		Total	
	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen
Sweden	0.8	1.3	0.6	0.5	4.2	11.0	5.6	12.8
Finland	0.5	0.9	0.3	0.3	3.2	5.5	4.0	6.7
West Germany (FRG)	0.5	2.3	0	0	3.2	2.7	3.7	5.0
Denmark	3.5	1.2	–	–	1.2	0.4	4.7	1.6
Total	5.3	5.7	0.9	0.8	11.8	19.6	18.0	26.1
USSR	15.0	8.0	0.8	2.4	8.5	11.7	24.3	22.1
Polen	11.2	4.7	0.1	0.1	42.8	46.5	54.1	51.3
East Germany (GDR)	0.4	0.3	0	0	1.6	0.4	2.0	0.7
Total	26.6	13.0	0.9	2.5	52.9	58.6	80.4	74.1

Nutrient flow into the Kattegat and Skagerrak seas

An evaluation of the eutrophication process in the Kattegat and Skagerrak seas is being carried out at present, as is being done for the Baltic. Therefore, it can be expected that more reliable figures on nutrient inflows will become available in the near future. The discharges of nitrogen and phosphorus from water courses, industries and municipalities into the Kattegat and Skagerrak seas are presented in Table 12. Nitrogen fixation is probably of little significance. There is no data concerning the atmospheric deposition of phosphorus and nitrogen. However, it is assumed that the deposition of nitrogen is large. In general there is not enough material available to reach any definite conclusions.

Table 12. Discharges of nutrients into the Kattegat and Skagerrak seas (tons/year).

	Kattegat		Skagerrak	
	P	N	P	N
Watercourses				
Denmark	480	9 276	247	10 596
Norway	—	—	882	15 195
Sweden	1 670	22 400	77	1 010
Industries				
Denmark	30	456	143	2 140
Norway	—	—	431	12 581
Sweden	24	90	0.2	2
Municipalities				
Denmark	490	1 824	910	7 964
Norway	—	—	733	4 128
Sweden	450	3 400	30	400

(From Nordic Council and Nordic Council of ministers 1981).

Limiting nutrients and primary production

In the oceans, there is often a balanced relationship between the input of nitrogen and phosphorus, which mainly occurs via the upwelling of deep water. In coastal areas, however, it has often been noted that there is a nitrogen deficit in relation to the needs of primary producers. This seems to apply to both unpolluted and polluted coastal waters. The reasons for the nitrogen deficit are not completely clear. It should be noted that in freshwater and brackish water, e.g. in the Baltic Proper, a nitrogen deficit can be compensated for by the fixation of atmospheric nitrogen via blue-green algae and bacteria. On the other hand, in water of higher salinity, blooms of nitrogen-fixing blue-green algae do not occur.

In the waters surrounding Sweden, nitrogen seems to be the limiting nutrient, except in the Bothnian Bay (Fonselius 1978). There is a lack of information about the situation in the Skagerrak sea. In the Bothnian Bay, phosphorus concentrations are, in general, very low, and even during summer, when production reaches a peak, the water contains an excess of inorganic nitrogen.

A discharge of nitrogen *only* would be expected to raise primary production in all of the basins, except the Bothnian Bay. If phosphorus alone was discharged into the Bothnian Bay, there would be an increase in primary production, while the discharge of an equivalent amount into Kattegat would probably not result in any eutrophication. Conditions in the Baltic Proper are more complicated, as it has been shown experimentally that the addition of phosphorus stimulates both growth and nitrogen fixation in certain blue-green algae which can appear in enormous blooms in late summer.

The eutrophic effects of aq

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kagerrak seas (tons/year).

Skagerrak	
P	N
247	10 596
382	15 195
77	1 010
143	2 140
131	12 581
0.2	2
910	7 964
'33	4 128
30	400

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The eutrophic effects of aquaculture in the marine environment

Theoretically, the combined addition of nitrogen and phosphorus always increases the biomass of primary producers, regardless of their proportions. Naturally, this occurs only if the water does not already contain high concentrations of nutrients. However, the effects of a low N/P ratio will be greater when phosphorus is the primary limiting nutrient than in waters where nitrogen is limiting. Thus, if aquaculture primarily releases nitrogen, the eutrophic effects in the Baltic and Kattegat seas can be expected to be more extensive than if phosphorus was the main nutrient released.

A more profound discussion of this subject, based on limiting nutrients and the composition of discharges from aquaculture would become far too theoretical and removed from reality. The eutrophic effect of aquaculture can at present only be judged on the total amounts discharged. These can then be compared with various local sources of nutrients, or with the total or anthropogenic discharges of nitrogen and phosphorus into the various basins of the Baltic, Kattegat and Skagerrak seas. As regards Sweden, the estimated discharges from aquaculture can be compared with Swedish anthropogenic nitrogen and phosphorus loads.

It has been estimated that aquaculture in Sweden will produce about 9000 tons of fish in 1990 (Ackefors, Grip & Holmström-Dhejne 1982). About 4000 tons of fish will be produced in Baltic coastal waters. Assuming the feed coefficient to be 1.8, 64 ton of phosphorus and 314 tons of nitrogen will be released according to *theoretical* calculations (cf. p. 17). These amounts can be compared with the total inflow of nutrients into the Baltic, leading to the conclusion that the total effect should be small (Table 13). Moreover, it has been shown that much of the nitrogen and phosphorus is released in the form of particulate matter. As these particles primarily sediment in the vicinity of the farms, the short-term effect on primary production is less than the full effect of the same amount of dissolved nutrients (Enell, in press).

Naturally, aquaculture can result in serious local eutrophication. The size of individual farms and their capacity to recycle wastes and limit discharges of nutrients will determine the extent of the environmental effects in their vicinity. Therefore, it is not possible to draw any general conclusions about the scale of these effects.

Table 13. Discharge of phosphorus and nitrogen from Swedish aquaculture into the Baltic in 1990, compared to other sources. (From Larsson & Elmgren 1983 and Ackefors, Grip & Holmström-Dhejne 1982).

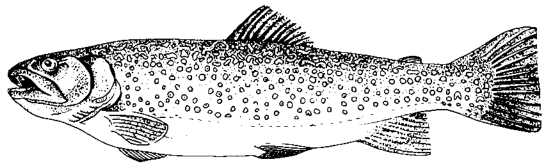
	Tot P (tons)	Discharge from aquaculture compared to other sources (%)	Tot N (tons)	Discharge from aquaculture compared to other sources (%)
Swedish aquaculture 1990	64	–	314	–
Total discharge	84 400	0.08	1 193 000	0.03
From municipalities and industries around the Baltic	26 786	0.24	147 059	0.21
Total Swedish discharges (nitrogen fixation and aerial deposition not included)	4 491	1.43	96 154	0.33
From Swedish municipalities and industries	1 123	5.7	13 470	2.33

vedish aquaculture into the Baltic mgren 1983 and Ackefors, Grip &

ı	Tot N (tons)	Discharge from aquaculture compared to other sources (%)
	314	–
	1 193 000	0.03
	147 059	0.21
	96 154	0.33
	13 470	2.33

The environmental effects of altered fish production in natural waters

Fertilization



The addition of nutrients in order to raise fish production in natural waters has so far been most successful in arctic and sub-arctic waters. In large oligotrophic lakes in Canada the number of migrating salmon increased 5—7 times after nutrient enrichment (Manzer 1976, Labrasseur et al. 1978, Stockner & Shortered 1978, Northcote 1972, and others).

In Scotland (Pyefinch 1960) and in Jämtland in northern Sweden (Fagerström 1966) the yield of brown trout increased considerably after fertilization, and even the production of arctic char has been observed to increase (Filipsson et al. 1968, Schindler & Fee 1974). In Lake Langvatn in Norway arctic char was most favoured by nutrient addition (Langeland et al. 1977) and a slight growth increase was noted in brown trout. However, after several years, the number of sticklebacks increased explosively and the increase in production was linked with this species. The growth of brown trout and arctic char regressed in connection with the increase of sticklebacks. A similar development took place in Great Central Lake, Vancouver Island in Canada, where the threespine stickleback effectively outcompeted juvenile sockeye salmon (Manzer 1976 b). This shows that an investigation of the species composition of the fish population and the ecology of the individual fishes is necessary before adding nutrients to increase the fish yield.

Fig. 15. Lake reservoirs become nutrient-poor as a result of the large fluctuations in the water level. Experiments with fertilization are being carried out in order to increase the production in these bodies of water (Photo: Magnus Fürst).

In order to mitigate the negative effects that man-made reservoirs have on fish production, experiments with partial fertilization have been carried out in Lake Anjan, Jämtland in northern Sweden (Milbrink & Holmgren 1981). The large fluctuations in water level usually cause reservoirs to become nutrient-poor. The result of this is, among other things, an increase in the number of arctic forms of bottom animals and a low primary production. This can be counteracted by a balanced supply of phosphorus and nitrogen salts. Besides a general increase in production to the same levels as in unregulated waters, growth increases were observed for arctic char, brown trout and grayling.

Nutrient enrichment in lakes always alters the natural conditions. It should therefore only be practised in badly damaged waters or in cases where the effects of other operations can be mitigated or counteracted by fertilization.

Lime treatment

In Sweden, lime has been used since the early 1900s to improve fish production in ponds (Nordquist 1922, Neess 1946). During the 1950s lime treatment was carried out in order to create conditions for sport fishing in acid lakes, above all in humic bog lakes (Hasler et al. 1951, Johnson and Hasler 1954, Waters 1956, Waters and Ball 1957, Stross 1958 and Berzins 1960).

During the last few decades, the acidification of lakes and running waters has made extensive lime treatment necessary in order to preserve the original fish fauna. A relatively comprehensive experimental program was initiated in Sweden in 1977. A proposal for extended lime treatment measures has been submitted and will form the basis for a proposition to be presented to the Swedish Parliament in 1982.

Acidification inflicts substantial damage upon aquatic ecosystems. A general account of the effects of different pH values on fish has been given by Lind (1980).

The application of lime in acidified waters is a relatively powerful intervention in the environment. The chemical composition of the water is altered during a relatively short period of time. Some of the effects which have been observed are presented below (The Swedish National Board of Fisheries and The Swedish National Environment Protection Board 1981).

- The pH of the water increases and the buffer capacity is improved.
- The salinity and the ion content increase.
- Nutrients become more available for biological production.
- Noxious metals such as aluminium become adsorbed to the sediment or form complexes which are less harmful to fish.

The biological changes which take place in the ecosystem after lime treatment are often slower than the chemical changes. However, some groups such as micro-

organisms may react quickly.
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Supplementary

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organisms may react quickly. An evaluation of several lime treatments showed that in general, the measures resulted in a return to the conditions which prevailed before acidification (The Swedish National Board of Fisheries and the Swedish National Environment Protection Board 1981).

Supplementary stocking of existing species

There is a considerable body of evidence which shows that the stocking of fish fry in waters where the species is already found does not produce any demonstrable increase in production. Even when very large amounts of spawn or fish fry are stocked, the fact remains that these are insignificant compared with the amounts of offspring produced by the lake's own fish populations. Consequently, it is not the amounts of spawn or fry that limit fish production, but various environmental factors such as water temperature, access to food, competition, predation, biotope conditions etc. In some cases, the fish used for stocking possess different genetic characteristics and may have a completely different origin than the naturally occurring species. Hybridization with the local population may then lead to the loss of valuable original characteristics. Therefore, in waters containing particularly valuable and unadulterated fish populations, especially salmonids, it is currently only permitted to stock fry originating from the same body of water.

In recent years, the practice of stocking great numbers of juveniles or nearly adult individuals of a species has been used to increase the yield of organisms in ponds or small lakes. Little is known about the effects that such mass stocking of, for example, juvenile eels for extensive cultivation, could have on the ecosystem.

In most cases, the supplementary stocking of existing species does not lead to increased yields of fish, unless large juveniles or adult fish are used. Therefore, such stocking practices should only be considered when natural reproduction does not occur, or when fish recruitment is poor.

Stocking of new fish species

The more species of fish that occur in a lake, the smaller the populations of each fish species are (Carlander 1955). This means that if a new species establishes itself in a body of water, the total fish biomass may certainly increase, but the numbers of the original species decrease.

The stocking of new fish species is an old practice and the choice of species has varied, according to changing values. At the end of the 1800s and the beginning of the 1900s the aim was to produce as much fish as possible, in order to improve the national food supply. Therefore, effective and competitive species such as white fish and perch were chosen for stocking in waters where they had not previously occurred. White fish often completely outcompeted arctic char and even populations of brown trout were negatively affected. However, the total fish yield increased.

In recent years, the field of sport fishing has become more important and the aim has been to increase the numbers of predatory fishes such as pike, brown trout, arctic char and grayling, which are suitable for this purpose. Consequently, this type of fishing has contributed to the domination of a greater number of water bodies by secondary or tertiary consumers such as lake trout, pike and brown trout. This leads to losses in energy and means that the capacity of the waters is utilized less efficiently.

In many lake reservoirs the original fish populations have either been badly damaged or completely exterminated. As a result, attempts have been made to introduce other species of fish which are able to adapt to the distinctive environment provided by impounded lakes. These species must not be dependent upon running water for their reproduction. Two such fish species, lake trout and sockeye salmon, have been stocked in Swedish lake reservoirs. Sockeye salmon has not lived up to expectations, while lake trout has been able to make itself at home in certain bodies of water with suitable prey fish species.

If a new fish species which has been introduced to a water system establishes itself, but is later found to be unsuitable for some reason, it is often very difficult and expensive to exterminate it. Therefore, each introduction of a new species must be regarded as an irrevocable step. For this reason, restraint should be practised when stocking new and foreign species.

Stocking of grass carp for vegetation control

Since the early 1970s, investigations have been carried out in order to determine whether grass carp can be used to control vegetation in Swedish lakes and water courses (Martin 1978a, 1980 a, b).

Grass carp can not reproduce by natural means in Swedish waters. Consequently, there is no risk of the species spreading.

By the time the grass carp have reached a suitable size for stocking they are mainly vegetarian. They are not particular in their choice of food, but they prefer tender plants to leathery ones. The smaller the grass carp are, the greater is their preference for filamentous plant species.

By stocking a suitable number and size of fish, the desired effects have been obtained after about three years. The submersed vegetation has been reduced and the growth of reeds checked.

Fig. 16. Grass carp are used for ve
Larsson).

Grazing of vegetation by gras
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Stunted perch populations hav
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Stocking of food

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Fig. 17. The mysid **Mysis relicta**
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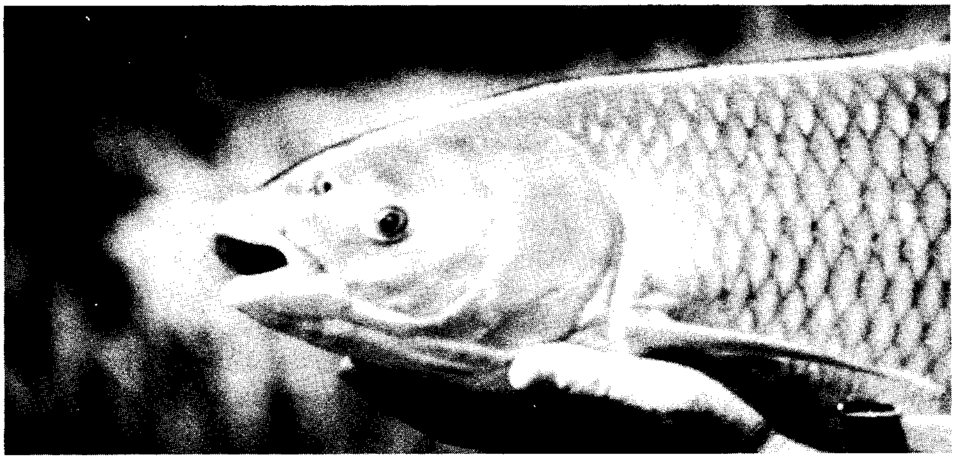


Fig. 16. Grass carp are used for vegetation control in weed infested lakes (Photo: Per-Erik Larsson).

Grazing of vegetation by grass carp causes changes in the composition of the plankton. However, these have turned out to be less drastic than expected. The changes have led to an increased food supply for bottom fauna and small fish. Stunted perch populations have, for example, been replaced after a short period of time by populations with a different size structure.

Stocking of food organisms

The introduction of various prey organisms into new bodies of water in order to improve fisheries is a relatively recent practice in Sweden. The usual procedure is to transfer so-called glacial relicts which, due to difficulties in dispersing, remained in bodies of water located below the highest shorelines of the former Baltic Sea. In Sweden, the crustaceans *Mysis relicta, Pallasea quadrispinosa* and *Gammaracanthus lacustris*, and the fish *Osmerus eperlanus*, smelt, have been introduced into new waters (Fürst 1981). In the Soviet Union, similar experiments have been carried out with no fewer than 42 different kinds of invertebrates (Fürst 1964).

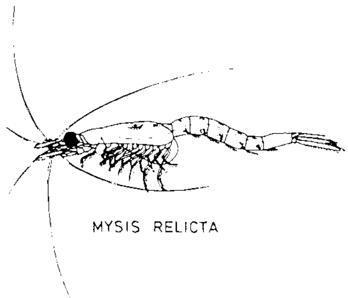


Fig. 17. The mysid **Mysis relicta** *is introduced as a prey organism in order to increase the production of fish, e.g. arctic char (Illustration: Per-Erik Larsson).*

Mysis and *Pallasea* were first introduced into the impounded lake Blåsjön in Jämtland, central Sweden, in 1964 and by 1970—1972 their populations reached maximal levels. Since 1970 these two organisms have made up about half of the diet of brown trout. During most of the year, *Mysis* was the only prey organism for arctic char. The growth and quality of the fish improved, but the cladoceran zooplankton nearly disappeared completely, as they were the most important prey item for *Mysis*. In lake Selbusjön in Norway, the introduction of *Mysis* resulted in decreased growth and *increased parasitic infection in arctic char*, while the population of burbot increased. The reason was that the numbers of cladoceran zooplankton decreased and the arctic char failed to utilize *Mysis* as a food organism but mainly preferred copepods (Langeland 1981). A positive effect of the altered diet habits of the fish in lake Blåsjön was, on the other hand, that *the number of parasites in the fish decreased noticeably*.

The introduction of *Mysis* adds a new link to the food chain in a lake's ecosystem. This involves a loss of energy, as the zooplankton are not directly utilized by the arctic char but are instead transformed via *Mysis*. However, as *Mysis* also consumes detritus and bacteria, which are an insignificant component of the original food chain, new energy is supplied to the food niche of the arctic char.

The introduction of *Mysis* and *Pallasea* may benefit the fish production in a badly damaged lake reservoir with a greatly altered ecosystem. On the other hand, the introduction of new food organisms into normal, unaffected waters is of uncertain value. The risk of damage is greater than the prospect of improved fisheries.

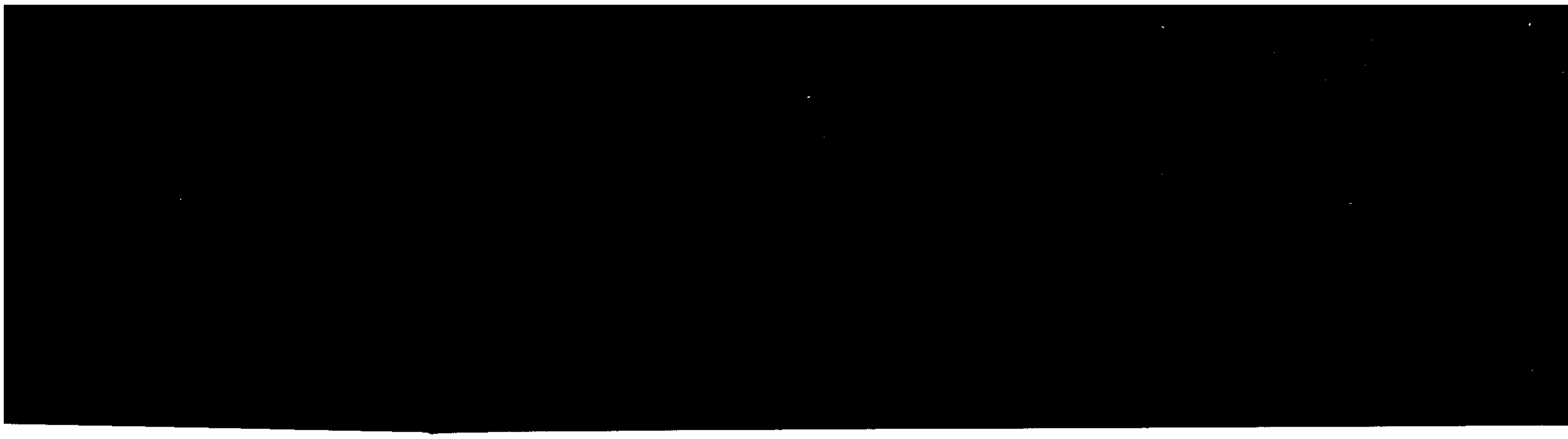
Alteration of the fish fauna

In Sweden, rotenone has been used since 1955 in about 3000 lakes to control "undesirable" fish species. However, in about 20% of the lakes treated, the original fish species have returned (Tobiasson 1979). In general, lakes containing original populations of pike, perch and roach have been treated with rotenone.

Thus, in most cases, the intended effects of rotenone treatment have been obtained, and following the stocking of fish, waters have been made attractive for sport fishing. The disadvantage of such treatment is that natural populations of fish are exterminated and along with them, possibly even valuable genetic material.

Antimycin is a still unapproved fish poison which has been tested in small acid spring lakes in Sweden (Schnick 1976). Little is known about its effects on other organisms.

In many lakes and running waters, the mass occurrence of less valuable fish species impedes the development of types of fishing attractive to man. The removal or reduction of these species can be achieved without resort to chemical means by using fishing gear such as bottom nets, trawls, fyke nets etc. The effects of such measures do not, however, last for long. Moreover, as selective fishing means that



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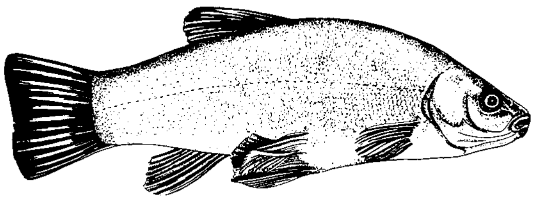
ıt resort to chemical means by
e nets etc. The effects of such
s selective fishing means that

the balance in the ecosystem is disturbed, it may be difficult to predict the final results.

Stocking of fish in fish-free waters

There is often a large nutritional potential in waters which are, for various reasons, lacking in fish. The stocking of fish in such lakes or waterways therefore results in very rapid initial growth. However, after a while the supply of food organisms which has been accumulated during previous years becomes exhausted, resulting in a decrease in the growth of the fishes. Accordingly, the improved production in such waters is of short duration. Fish-free lakes may be habitats of great value for other species of the Swedish flora and fauna. Examples of such species are the crustaceans *Branchionecta* and *Lepidurus*, and young long-tailed ducks.

Environmental effects of processing plants



The cultivated fish is treated and processed in various ways in separate plants. Processing may involve gutting, filletting, freezing, smoking, packing and so on.

A comparison of processing plants using mechanical and manual slaughter methods shows that the discharge of wastes is significantly lower when manual treatment is employed (Table 14).

Table 14. Comparison between mechanical and manual slaughter of rainbow trout (Scandiaconsult Ltd. 1980).

Type of waste	Mechanical slaughter	Manual slaughter
Waste water m^3/ton fish	6.8[1]	1.6
Susp. matter g/m^3	840	795
BOD_7	830	1 035
COD	1 650	3 150
Tot-P	5.6	11.6
Tot-N	56.5	54.5
Fat	805	630
Susp. matter kg/ton fish	5.6	1.2
BOD_7	5.6	1.6
COD	10.0	5.0
Tot-P	0.034	0.016
Tot-N	0.38	0.096
Fat	5.5	1.1

[1] 40—45% is used for cleaning purposes.

As it is not possible to measure all of the wastes from the manual slaughter method, the values for the discharges from this process are probably too low. The discharges from the mechanical process also include the cleaning of machines, floors etc., which accounts for the larger water usage. The water usage does vary, however, depending upon which types of machines are used.

The gutting and filletting of fish
wastes consist of entrails, which
fish. If the fish are filletted, an a
ton of fish. Bleeding of the fish
10—20 kg of blood/ton fish.

The discharge of effluents from
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should be installed. Moreover,
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Internal measures can be adop
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The gutting and filletting of fish produces both solid and liquid wastes. The solid wastes consist of entrails, which in the rainbow trout amount to about 150 kg/ton fish. If the fish are filletted, an additional 150 kg of wastes are produced for each ton of fish. Bleeding of the fish, which is carried out before gutting, produces 10—20 kg of blood/ton fish.

The discharge of effluents from processing plants should be connected to municipal sewage works. If this is not possible, and if the operations take place on a relatively large scale, a flotation process with or without the addition of chemicals, should be installed. Moreover, it is assumed that most of the resultant wastes will be dealt with in the same manner as other abattoir wastes. This means that the environmental effects will be less extensive and not dissimilar to those resulting from cultivation, as described in chapter 6.

Internal measures can be adopted in order to reduce effluents and limit the amounts of pollutants at their source as far as possible. Examples of such measures are:

— The installation of machines which use water economically.

— Automatic suspension of the water supply to machines during breaks in production.

— The use of self-closing nozzles on hoses used for spraying and cleaning.

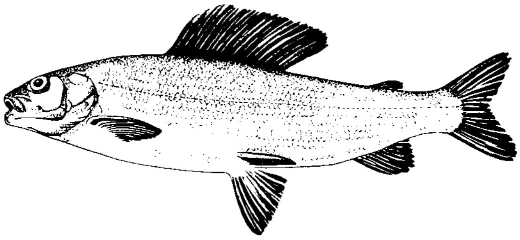
— The use of high pressure sprays to clean equipment and premises.

— Bleeding the fish in such a manner that blood does not become added to waste water.

— The collection of offal from the vicinity of each machine used.

— Sweeping, scraping etc. before spraying with water.

Localization and the development of techniques



Competition for the use of our water resources will become greater in the future. As a result, water usage will be more diversified than at present. In order to satisfy the demands of various interests, as well as to reduce environmental effects, careful planning is necessary at both regional and local levels, to evaluate the various claims made on water areas. Aquaculture must be recognized as making some of these claims.

Water resources can be schematically classified into four different categories, in order to illustrate the factors which can determine the localization of aquaculture operations, especially net pen farming.

Exploited waters	Unexploited waters		
Municipal outlets Water supplies Industry Agriculture and forestry Hydroelectricity Available for aquaculture etc.	Merit protection	Available, but unsuitable for aquaculture	Available for aquaculture etc.

Exploited waters

Aquaculture can be coordinated with other means of utilizing water resources. Operations are, however, often required to adapt to the space left over by other interests which are already established. Nevertheless, even aquaculture makes demands on the water quality. Therefore it is important not to judge water quality separately, but in relation to its users, as well as to evaluate the total effects on the ecosystem. In this way, it is likely that unwanted effects on the environment and the cultivation can be prevented.

The immediate and locally observed environmental effects usually result from the release of oxygen-consuming materials, whose influence is, to a large extent, dependent on the localization of cultivation. The most important factor for the long term evaluation of the environmental consequences is, however, the size of the nutrient input in relation to the nutrient status, size and hydrology of the recipient. This nutrient input is in turn related to the production volume of the farm, as well as to the water purification measures which are applied. Within certain limits, the effects can be expressed in general terms and used for making prognoses. The extent to which aquaculture and other interests are permitted to

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influence the environment in individual cases can, however, only sometimes be subject to a general evaluation. Local considerations, combined with the overall utilization of a water area become factors of vital importance for the final evaluation.

The qualitative contributions from aquaculture operations are at present small compared with those of other interests which utilize Swedish lakes and watercourses as recipients. In contrast to industrial or municipal effluents, substances such as environmental poisons or organisms pathogenic to humans are as a rule not released into the environment. In this respect, aquaculture does not hinder other means of utilizing water resources.

Unexploited waters

Among the waters which are worth protecting are those with a particularly interesting flora, fauna or water chemistry and those which are of value for scientific conservation. Other such waters may be lakes or watercourses which are to a large extent used for recreation or other outdoor activities. Naturally, no exploitation should be allowed if it poses a threat to the conservation of valuable bodies of water.

Certain waters are unsuitable for aquaculture due to poor water quality. The localization of operations must therefore be preceded by an evaluation of the water body as regards its quality for this purpose. Consequently, it is equally important to investigate factors that affect the result of farming as it is to establish the environmental effects of farming operations.

Waters which are suitable for farming should be able to produce high quality fish, crustaceans etc., and in addition be able to withstand the effects of farming activities. Such waters include coastal bays with a high water turnover, oligotrophic lakes and lake reservoirs. It is at present uncertain to what extent waters which are acid, or threatened with acidification can be used for cultivation.

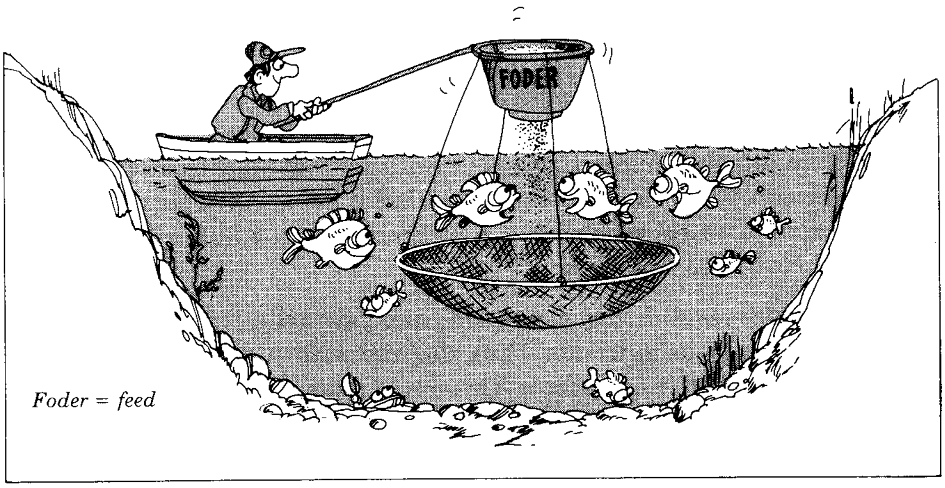


Fig. 18. Fish (or other organisms) transferred to small productive lakes may utilize the natural production (lake ranching) or may be fed to various degrees. The biggest and most aggressive fish are captured in connection with feeding.

In Sweden there are many small lakes, natural and artificial ponds which can probably be used wholly for cultivation purposes. Examples of such bodies of water are old clay pits, limestone and other quarries, marl pits, glacial pits, forest tarns, natural ponds and small lakes. Several of these types of waters are used today for purposes such as wildlife conservation and crayfish farming. In the future it will probably also be possible to carry out aquaculture operations in the lakes created by the planned large scale removal of peat. It should be possible to create favourable conditions for cultivation operations, by various means, for instance the removal of naturally occurring species which compete with the organisms to be farmed, alteration of the biotope, fertilization etc. However, such proceedings require a detailed knowledge of which organisms are suitable for cultivation in these circumstances, how feeding and harvesting are to be carried out, and so on. As knowledge in this area is poor and the environmental consequences are not understood, the prerequisites and strategies for cultivation of this kind should be studied in more detail.

It should be emphasized that, in the future, aquaculture may not necessarily be concentrated on the production of fish, but may serve other purposes.

Net pen farming in lakes should be carried out so that the wastes do not reach the deepest areas of the lake. This is because the supply of oxygen is limited in these areas during summer and winter. If oxygen-consuming matter reaches the bottom water it can result in a total lack of oxygen, which has drastic consequences for both the lake and the farm. On the other hand, farms should not be located in shallow areas with poor water turnover, as this may result in anaerobic conditions and the formation of hydrogen sulphide in the sediment which accumulates under the installation.

Development of techniques

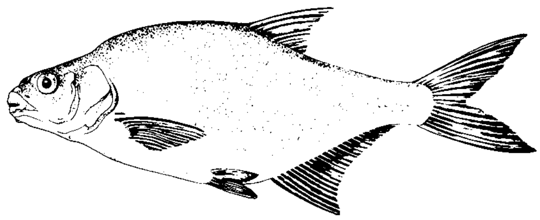
The effects of aquaculture which are at present regarded as being of the greatest long-term importance for the environment are connected with the phosphorus content of the wastes. As all of the phosphorus originates from the feeds which are used in the operations, it is important for feeding to be carried out effectively with as little waste as possible. Therefore, intensive developmental work should be carried out into the composition and phosphorus content of feeds. In addition, if the feed composition can be balanced so that it has a buffering effect on the water, farming in waters which are acid or threatened by acidification may have positive effects on the environment.

The wastes which result from farming activities have a high organic content and are also rich in various nutrients. Thus, the wastes should be regarded as a resource and be recycled in some form. This would reduce the load on the environment and make it possible to increase production. Methods should be developed for collecting and utilizing wastes, especially those from net bag farms in lakes and coastal areas. Another possible measure is the combination of various cultivation forms, for example integrating the farming of fish in net pens with the cultivation of algae.

The environmental effects may be reduced considerably by principally utilizing so-called trash fish from the water system in which farming is carried out. Problems can still arise in the immediate vicinity of the farm, but on the other hand there are no changes in the ecosystem as a whole, since there is no external input of energy and nutrients. As ensilage techniques have now been developed for the production of feeds from fish and fish offal, this method of directly linking cultivation operations with the recipient's own production may be a means of reducing the environmental effects in certain waters.

The forms of cultivation which are practised today are the result of developmental work which has been carried out for several years. This work will continue. Current farming forms should therefore be regarded as transitional, as they lead to other future forms and techniques for the production of organisms in the aquatic environment. Therefore, at an early stage it is important to adapt the development of methods to environmental demands, and not only to production results. Moreover, this is probably the only way in which continued expansion can be realized in the field of aquaculture.

Research requirements



The environmental consequences limit the extent to which lakes and waterways can be utilized by various forms of aquaculture. These consequences should therefore be analysed and evaluated in the early stages of development so that unsuitable activities can be identified and the appropriate measures taken.

The proposed research contributions are primarily aimed at a quantification of the environmental consequences, starting with already existing operations. The results can later be used to suggest and investigate various measures for reducing environmental effects, as well as to indicate forms of aquaculture that are environmentally compatible. It is important that the research contributions be combined and coordinated with the technological development within the field. It is therefore suggested that a steering committee be appointed to manage the whole area of research.

Below is a list of projects dealing with problem areas which are of importance for an evaluation of the environmental consequences of aquaculture. Most of them are concerned with net bag cultivation.

Project title — **The effects of net cage operation in freshwater and marine environments.**

Background and aims — There is a need for a total evaluation of all of the effects resulting from the cultivation of organisms in aquatic environments. The aims of the project are:

- to establish how long the environmental effects persist after cultivation has ceased.
- to determine whether any of the effects are of a permanent nature.
- to investigate how the fauna and flora are affected by the supplied feed and possible additives in the feed.
- to gain a total perspective of and evaluate the environmental effects of different cultivation operations.

Duration of project	Financial requirements	Priority
3 years	3 man-years, Ph.D. 150.000:—	1

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Project title — **The use of acid lakes for cultivation operations**

Background and aims

There are few biological methods which can be used as alternatives to lime application in the treatment of acid lakes. In this respect, cultivation operations could possibly complement other methods. The risk of conflicts with other usage interests should, moreover, be small. The aims of the project are:

- to determine how and to what extent the process of acidification in lakes and watercourses is affected by cultivation operations.
- to investigate which type of cultivation is most suitable for location in acid watercourses.
- to determine whether similar environmental effects can be expected to result from cultivation in acid waters as opposed to non-acid waters.

Project considerations

Studies into the ability of biological processes to counteract acidification have recently been started at the Swedish Water and Air Pollution Research Institute, Aneboda, by O. Westling. Before the above-mentioned project is initiated, viewpoints, experience and results will be acquired from this current project.

Duration of project	Financial requirements	Priority
3 years	3 man-years, Ph.D.	1
	1.5 man-years, lab. assistant	
	200,000:—	

Project title — **Effect of mussel cultivations on the coastal ecosystem.**

Background and aims

A likely development is the concentration of large mussel farms in certain areas off the coast. The combined environmental effects of such installations in shallow coastal areas are not known. The aims of the project are:

- to study the impact of large mussel farms on zooplankton populations in the coastal area.
- to investigate the effects of the farms on shallow nursery areas for fish.
- to estimate the size of farms that a coastal area can "tolerate" before significant environmental effects arise in the vicinity.
- to elucidate the process of recovery after cultivation has ceased.
- to investigate if any environmental effects are of a permanent nature.

Project considerations

Several institutes are involved in the project "The ecological optimization of mussel farms" under the leadership of R. Rosenberg, Institute of Marine Research, Lysekil. Evaluation of the project which ends in 1982, will determine whether further research is necessary.

Duration of project	Financial requirements	Priority
3 years	3 man-years, Ph.D. 3 man-years, lab. assistant 250,000:–	1

Project title

Methods for the collection and utilization of dissolved and particulate matter from farms in lakes and coastal areas.

Background and aims

If cultivation is managed without the use of medicines and other foreign additives, both dissolved and particulate wastes can be regarded as a resource and therefore be recycled in a suitable manner. The aims of the project are:
- to develop methods for utilizing and/or recycling dissolved nutrients and organic matter.
- to develop methods for collecting sedimenting material from net bags.
- to investigate possible uses for the sediment.

Project considerations

The combination of various cultivation forms can lead to a more efficient utilization of resources. Problems such as whether fish farming can be carried out parallel to the cultivation of algae should be studied.

Duration of the project	Financial requirements	Priority
2 years	2 man-years, Ph.D. 150,000:–	1

Project title

The choice of parameters to be included in a central program for evaluating the environmental consequences of aquaculture operations.

Background and aims

In order to make early evaluations of the environmental effects of various cultivation operations it would be useful to have access to results from simple control programs. These should also be designed so as to warn of potential damage to a farm. The aim of the project is:
- to select parameters suitable for a supervisory control program adapted to different types of cultivation operations.

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Project considerations — A register is to be set up, with explanations as to when "threshold values" are approached and the effects which can then be predicted.

Duration of project	Financial requirements	Priority
1 year	1 man-year, Ph.D. 30,000:—	2

Project title — **The effect of fish farms on natural fish populations.**

Background and aims — The release of substances by fish farms can affect natural fish populations in several ways. These include the effects of nutrients discharges as well as signals (odours, sounds) from the fish produced by the farm. In addition, secondary effects may arise due to changes in the ecological system. The aim of the project is:

- to investigate how different natural fish populations are affected by the establishment of fish farms.

Duration of the project	Financial requirements	Priority
3—5 years	5 man-years, Ph.D. 300,000:—	1

Project title — **Chemical composition and properties of sedimented material from fish farms in lakes and coastal areas.**

Background and aims — Knowledge about the release of phosphorus from fish farms is of vital importance for an evaluation of the environmental effects. The size of the fraction which is bound in the sediment for shorter or longer periods affects the total situation. As phosphorus is probably released from farms in different forms, it is important to determine these. The aims of the project are:

- to determine how much of the phosphorus originating from feeds is adsorbed to sedimented matter.
- to determine the forms in which the released phosphorus occurs.
- to investigate to what extent the phosphorus originating from a farm is biologically available.

Duration of the project	Financial requirements	Priority
3 years	3 man-years, Ph.D. 1.5 man-years, lab. assistant 150,000:—	1

Project title

Effects of sediment formation and factors affecting sediment growth beneath farming operations in lakes and coastal areas.

Background and aims

The farming of fish and other organisms has been observed to cause significant sedimentation of waste products and feed.

Depending on the hydrology of the area, various amounts of these products remain on the bottom and form a sediment layer. The thickness and the spread of this layer affect both the bottom fauna and the pelagic zone.

The aims of the project are:

- to determine the size of the area in which sedimentation occurs.
- to investigate the effect of feed type on sediment growth.
- to elucidate the effects of the newly sedimented material on the bottom fauna.

Project considerations

Projects with similar aims were started in 1981 at the Institute of Limnology, Lund (M. Enell, limnological section) and at the Institute of Ecological Zoology, Umeå (L.-O. Eriksson, marine section). Before the above project is initiated, viewpoints, experience and results will be acquired from these current projects.

Duration of the project	Financial requirements	Priority
3 years	3 man-years, Ph.D.	2
	1.5 man-years, lab. assistant	
	150,000:–	

Project title

The cultivation of organisms in waters which are "blacklisted" or otherwise classified as unsuitable.

Background and aims

There are many bodies of water which have been "blacklisted", or else found to be unsuitable as a source of food due to contamination by heavy metals or other environmental poisons. Depending on the properties of these poisons, they are absorbed and accumulated by aquatic organisms either via foodstuffs or via the water.

The aims of the project are:

- to investigate whether organisms farmed in the Baltic Sea actively take up PCB from the water.
- to determine if organisms cultivated in "blacklisted" waters, which are contaminated by mercury, accumulate the metal.

Duration of projec
2 years

Project title

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Duration of project	Financial requirements	Priority
2 years	2 man-years, Ph.D. 1 man-years, lab. assistant 150,000:–	2

Project title: **The optimization of farming operations.**

Background and aims: In order to achieve the highest possible growth rate while at the same time reducing the environmental effects of cultivation operations as much as possible, a combination of various measures is necessary.

The aim of the project is:
– to determine the measures required for optimal management.

Duration of project	Financial requirements	Priority
1 year	1 man-year, Ph.D. 30,000:–	3

Glossary of Aquaculture Terms

Algae — Unicellular or multicellular so-called cryptogams which occur mainly in water. They comprise several larger groups, e.g. red algae, brown algae, green algae and diatoms. Large algae, which are visible to the naked eye, are called macroalgae (seaweed). Small microscopic algae which drift in the water are called microalgae (phytoplankton). Both macroalgae and microalgae can be cultivated.

Anadromous fish — Fish which have their main period of growth in the sea and then migrate to fresh water to reproduce, e.g. salmon.

Aquaculture — The cultivation of aquatic organisms such as fish, shellfish, crustaceans and algae using extensive or intensive methods, in order to increase the production or yield to a level above that naturally found in the environment.

Catadromous fish — Fish which spend most of their time in fresh water and then migrate to the sea to reproduce, e.g. eel.

Compensatory stocking — The stocking of juvenile fish (e.g. smolt) to compensate for damage to natural populations by, for example, hydroelectrical development.

Crustaceans — Animals such as crayfish, lobsters, crabs, shrimps etc.

Ecology — The interactions between plants, animals and their environment.

Ethology — The study of animal behaviour.

Extensive farming — In extensive farming, *no food or other energy* is supplied by man. Only naturally produced food is utilized. In tropical and subtropical countries, fish and shrimps are farmed extensively in large areas and at low population densities. The extensive farming of mussels at high population densities in Sweden is of a completely different nature.

Fish farming — *Fish farming in its widest sense* includes the farming of fish, mussels, oysters and crustaceans. According to the first paragraph of the Swedish Fisheries Act, any references made to fish in its relevant sections also apply to lobsters, crayfish, marine crayfish, shrimps,crabs, octopuses, oysters, pearl mussels, blue mussels and lampreys. The farming of mussels is thus regarded as a form of fish farming.
Fish farming in its strictest sense is, of course solely the farming of various fish species.

Fisheries — Fishing involves the capture of fish or shellfish with fishing gear or other equipment. Commercial fishing is practised by people who depend mainly upon this activity for their income. Sport fishing consists of various forms of recreational fishing.

Fisheries management — Fisheries management means that the production of fish or shellfish is controlled so as to maintain or raise the yield of these organisms in a body of water. By adopting certain measures, such as the stocking of

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Intensive farming — Ii o si ir

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Monoculture — T

Mussel farming — T

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fish, the introduction of prey organisms, biotope maintenance (fertilization, lime treatment, the preparation of spawning grounds, etc.) and the regulation of fisheries, the objectives may be achieved.

Hatchery	A building in which fish spawn are hatched.
Intensive farming	In intensive farming, *food or other energy is supplied* by man. The organisms (fish, crustaceans, algae and so on) are concentrated in a small area. Cultivation is carried out in ponds, troughs etc. on land, or in net pens, cages etc. in lakes or coastal areas.
Macroalgae	Algae which are visible to the naked eye, often attached, e.g. the seaweed belts along Swedish coasts.
Mariculture	Cultivation in seawater.
Microalgae	Free floating phytoplankton or other microscopic phytoplankton attached to stones, shells, other algae etc.
Molluscs	Animals such as snails, mussels and octopuses.
Monoculture	The cultivation of a single species.
Mussel farming	The cultivation of mussels and oysters.
Net pen farming	The farming of fish, e.g. rainbow trout and salmon in floating net pens (cages) in lakes or coastal areas.
Polyculture	The cultivation of several species together.
Population	A group of individuals belonging to the same species.
Predator	An organism which preys on other animals.
Put and take fishing	The stocking of fish of a size suitable for fishing in recreational waters.
Recirculating system	An operation in which the water is recycled.
Reproduction	The generation of offspring.
Sea ranching	Extensive farming in the sea. The stocking of cultivated smolts (juveniles) of anadromous fish species for maturation in the sea followed by harvesting either in the sea or during migration to spawning areas.
Seaweed	Certain species of macroalgae belonging to the groups red algae, brown algae and green algae are usually called seaweed. Examples are *Fucus* (bladder-wrack), *Enteromorpha* and *Delesseria.*
Settling	The transition made by certain larvae, e.g. those of mussels, from a free swimming stage to a stationary, attached stage.
Shellfish	Crustaceans and molluscs.
Smolt	Juvenile salmon or brown trout which leave their fresh water nursery areas and migrate to the sea.
Supplementary stocking	The stocking of smolts (juveniles) with the aim of increasing the population densities of certain species in a body of water.

Glossary of environmental terms

Acidification — The combustion of fossil fuels produces sulfur oxides and nitrogen oxides. In the atmosphere, these are transformed into acids which affect soils and bodies of water in various ways, for instance by reducing the pH value.

Aerobic — In aerobic conditions, life processes occur in the presence of oxygen.

Anaerobic — In an anaerobic medium, life processes which do not require oxygen continue in its absence.

Assimilation — The building up of organic compounds in plants and lower organisms by means of photosynthesis or chemosynthesis.

Autolysis — The dissolution of cell tissues due to the action of the cells' own enzymes.

Biocide — A substance used to kill undesirable organisms (see Pesticide).

Biomass — The quantity of animals and/or plants at a given time expressed as weight per unit of volume or area, e.g. g per m^2. Note that weight may be given in various ways: dry weight, ash-free dry weight, wet weight etc.

Biotope — A term which denotes larger areas of the environment e.g. rocky shores, reed belts, coniferous forests. Whitin each of these,various plant and animal species have separate niches.

Blacklisting — Lakes and marine waters may not be utilized for commercial fishing if the levels of heavy metals or other substances in the fish exceed the permitted levels.

BOD — "Biological Oxygen Demand" — a term for the biochemical oxygen consumption. BOD_7 is a measure of the amount of oxygen used by the organic compounds in a water sample during a period of 7 days at 20°C in darkness. Stated as mg O_2/l.

Brackish water — Dilute sea water, most often with a salt content ranging from 0.5—20°/₀₀.

Chemosynthesis — The assimilation of carbon dioxide (the building up of organic substances) by utilizing chemical energy.

Chlorinated hydrocarbons — In the context of environmental protection, these are substances such as DDT, lindane, aldrin and dieldrin, which are used as pesticides, and other industrial chemicals such as PCB, all of which accumulate in organisms.

COD — "Chemical Oxygen Demand". A term for the chemical oxygen consumption. COD is a measure of the amount of organic matter which can be oxidized by a strong chemical oxidant. It is expressed as the amount of oxygen which is equivalent to the oxidant used.

DDT — Dichlorodiphenyl-trichloroethane. One of the most common pesticides. DDT breaks down to form DDD and DDE.

Ecology
Ensilage
Eutrophic
Feed
Feed coefficient
Feed utilization
Fermentation
Heavy metals
Hydrogen sulphide (H_2S)
Niche
Nutrients
Oligotrophic
Oxygen consumption
PCB
Pelagic zone
Permanganate number
Pesticide

Ecology The interactions between plants, animals and their environment.

Ensilage The preservation of fodder in an acidic environment (e.g. by the addition of acids or acid-producing bacteria).

Eutrophic Eutrophic waters are very productive, and have a high nutrient content (e.g. are nutrient-rich).

Feed The various types used in fish cultivation are dry feed (factory-made whole feed often in the form of pellets), wet feed (fish, fish offal etc. which has been chopped or ground and which is usually mixed with vitaminized binding agents) and semi-moist feed.

Feed coefficient The feed consumption per unit of weight increase ($\frac{\text{Feed consumption, kg}}{\text{Growth, kg}}$). A feed coefficient of 1.5 means that 1.5 kg of feed is used to produce 1 kg of fish. As it is difficult to determine how much feed goes to waste in fish cultivations, the feed coefficients is often based on the total use of feed.

Feed utilization The weight increase per unit of utilized feed ($\frac{\text{Feed consumption, kg}}{\text{Growth, kg}}$).

Fermentation The decomposition of feed and food products by organisms such as yeasts, into stable products.

Heavy metals Metallic elements with a high atomic weight. In the context of environmental protection, these are primarily mercury, cadmium and lead.

Hydrogen sulphide (H_2S) A poisonous, smelly gas which is formed under anaerobic conditions by the bacterial decomposition of organic compounds containing sulphur or by the reduction of sulphate.

Niche A term which refers to the nutritional intake of plants and animals (the food niche), their habitat within a biotope (the place niche) and their occurrence during the day or year (the time niche).

Nutrients Phosphorus and nitrogen compounds are the main nutrients which are important for production in water.

Oligotrophic Oligotrophic waters are less productive, and have a low nutrient content (e.g. are nutrient-poor).

Oxygen consumption The depletion of the store of oxygen in the water e.g. by the decomposition of organic matter.

PCB Polychlorinated biphenyls. PCB consists of two biphenyl molecules, in which different numbers of hydrogen atoms have been replaced by chlorine. Of 209 possible biphenyls, 40—50 have been found in the natural environment. PCB is very difficult to break down.

Pelagic zone The free water and its organisms, in contrast to the bottom and its organisms, which constitute the benthic zone.

Permanganate number A measure of the amount of organic matter in the water. The permanganate number is the amount of potassium permanganate ($KMnO_4$) which is used to oxidize the organic matter in a water sample.

Pesticide A substance used for killing parasites and other noxious organisms which cause damage, for example to crops.

pH The pH value indicates the concentration of hydrogen ions in soil and water, that is, the acidity. A pH less than 7 indicates an acid environment and a pH greater than 7 indicates a basic environment.

Photosynthesis The production by plants of organic substances by assimilating inorganic compounds such as carbon dioxide and water and using solar energy.

Plankton Animals and plants which drift in the open water and are influenced by currents. Even though they have a certain degree of movement they cannot completely control their course. Plankton range from organisms that are smaller than 1/1000 mm, such as bacterial plankton, to jellyfish which are 1—2 m in size.

Population-equivalent The phosphorus load on a recipient is about 2.5 g per day and person (= 1 population-equivalent) if this is not reduced by a treatment plant. Chemical treatment removes about 90% of this amount.

Processing Fish, shellfish and algae are converted into various products by being filletted, frozen, smoked, dried, preserved etc.

Recipient A body of water which receives waste products.

Redox potential A measure of the oxidizing or reducing power of a water or sediment. Negative values indicate reducing conditions and positive values indicate oxidizing conditions. It is measured electrically.

Sediment The organic and inorganic matter accumulated on the bottom of a body of water.

Total nitrogen The sum of the various nitrogen compounds present in a volume of water.

Total phosphorus The sum of the various phosphorus compounds present in a volume of water

UOD "Ultimate Oxygen Demand" — a term for the total oxygen consumption that results from the biochemical oxygen consumption, the oxidation of organic matter and the respiration of organisms.

List o

The list includes
mals or species w

Swedish

Alger

Blågröna alger

Gröna alger
Tarmtång m.fl.
Strutsallad

Havssallat

Bruna alger
Knöltång
Sågtång
Spiraltång
Blåstång
Fingertång
Barkig fingertång
Bladtång

Röda alger
Karragentång
Gaffeltång

Rödsallat, söl
Purpurtång

Mollusker, blötdju

Europeiskt ostron
Japanskt ostron
Amerikanskt ostr
Blåmussla

Kräftdjur

Salträka

List of species

The list includes cultivated or potentially important species of plant and animals or species which are otherwise important for Swedish aquaculture.

Swedish	**Latin**	**English**
Alger	*Algae*	*Algae*
Blågröna alger	Cyanophyceae	Bluegreen algae
	Anabaena	
	Anacystis	
	Nostoc	
	Spirulina	
Gröna alger	Chlorophyceae	Green algae
Tarmtång m.fl.	Enteromorpha spp.	
Strutsallad	Monostroma grevillei	(Green laver)
	Spirogyra spp.	
Havssallat	Ulva lactuca	Sea-lettuce, green laver
Bruna alger	Phaeophyceae	Brown algae
Knöltång	Ascophyllum nodosum	Knotted wrack
Sågtång	Fucus serratus	Toothed wrack
Spiraltång	Fucus spiralis	Flat or spiral wrack
Blåstång	Fucus vesiculosus	Bladder wrack
Fingertång	Laminaria digitata	Tangle, oarweed
Barkig fingertång	Laminaria hyperborea	Cuvie
Bladtång	Laminaria saccharina	Sea belt, sugar kelp
Röda alger	Rhodophyceae	Red algae
Karragentång	Chondrus crispus	Irish moss, carragheen
Gaffeltång	Furcellaria lumbricalis	
	Gracilaria verrucosa	
Rödsallat, söl	Palmaria palmata	Dulse
Purpurtång	Porhyra spp.	Purple laver
Mollusker, blötdjur	*Mollusca*	*Molluscs*
Europeiskt ostron	Ostrea edulis	Flat oyster
Japanskt ostron	Crassostrea gigas	Pacific oyster
Amerikanskt ostron	Crassostrea virginica	American oyster
Blåmussla	Mytilus edulis	Blue mussel
Kräftdjur	*Crustacea*	*Crustaceans*
Salträka	Artemia salina	Brine shrimp

Pungräka	Mysis relicta	Opossum shrimp
Taggmärla	Pallasea quadrispinosa	
Sjösyrsa	Gammaracanthus lacustris	
Hinnkräfta	Daphnia magna	
Nordhavsräka	Pandalus borealis	Northern shrimp
Japansk räka	Penaeus japonicus	Kuruma prawn
	Penaeus stylirostris	Blue shrimp
	Penaeus vannamei	Whiteleg shrimp
Jätteflodräka	Macrobrachium rosenbergii	Giant river prawn
Flodkräfta	Astacus astacus	European crayfish
Signalkräfta	Pacifastacus leniusculus	Signal crayfish
Smalkloig kräfta eller sumpkräfta	Astacus leptodactylus	
Stenkräfta	Austropatamobius pallipes	
Amerikansk dvärgkräfta	Orconectes limosus	
	Procambarus clarkii	Red swamp crawfish
	Procambarus acutus	White river crawfish
	Cherax destructor	Yabbie
	Cherax tenuimanus	Marron
Langust	Palinurus vulgaris	Langouste
Hummer	Homarus vulgaris (syn. H. gammarus)	European lobster
Amerikansk hummer	Homarus americanus	American lobster
Havskräfta	Nephrops norvegicus	Norwegian lobster
Krabbtaska	Cancer pagurus	Edible crab
Kungskrabba	Paralithodes camtschaticus	King crab
Japansk jättekrabba	Macrocheira kämpferi	
Fiskar	*Pisces*	*Fish*
Atlantlax, lax	Salmo salar	Atlantic salmon
Öring- (havs-, insjö-)	Salmo trutta	Brown trout
Strupsnittsöring	Salmo clarki	Cutthroat trout
Regnbåge	Salmo gairdneri	Rainbow trout
"Stillahavslax"	Oncorhynchus spp.	Pacific salmon
Kungslax	Oncorhynchus tshawytscha	Chinook or king salmon
	Oncorhyncus nerka	Sockeye or red salmon
Indianlax	Oncorhynchus nerka kennerlyi	Kokanee
Silverlax	Oncorhynchus kisutch	Coho or silver salmon
Hundlax	Oncorhynchus keta	Chum or dog salmon

Puckellax

Bäckröding
Kanadaröding
Röding
Sik
Harr
Plattfiskar
Rödspotta
Tunga
Piggvar

Hälleflundra

Europeisk ål
Braxen
Gös
Havsaborre
Gädda
Karpfiskar
Karp
Gräskarp

Sutare

Puckellax	Oncorhynchus gorbuscha	Pink or humpback salmon
Bäckröding	Salvelinus fontinalis	Brook or speckled trout
Kanadaröding	Salvelinus namaycush	Lake trout
Röding	Salvelinus alpinus	Arctic char
Sik	Coregonus spp.	Whitefish
Harr	Thymallus thymallus	Grayling
Plattfiskar	Pleuronectiformes	Flatfish
Rödspotta	Pleuronectes platessa	Plaice
Tunga	Solea solea	Dover sole
Piggvar	Scophthalmus maximus (Syn. Psetta maxima)	Turbot
Hälleflundra	Hippoglossus hippoglossus	Halibut
Europeisk ål	Anguilla anguilla	European eel
Braxen	Abramis brama	Bream
Gös	Stizostedion luciopercae	Pike-perch, sander
Havsaborre	Dicentrarchus labrax	Sea bass
Gädda	Esox lucius	Pike
Karpfiskar	Cypriniformes	Carps
Karp	Cyprinus carpio	Common carp
Gräskarp	Ctenopharyngodon idellus	Grass carp
Sutare	Tinca tinca	Tench

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THE ENVIRONMENTAL IMPACT OF AQUACULTURE

What effects do fish and mussel farms have on the environment? This report discusses the environmental implications of various forms of aquaculture. It is suggested that the cultivation of algae may be a means of reducing nutrient loads. Different methods for raising production in natural waters are also discussed.

THE SWEDISH COUNCIL FOR PLANNING AND COORDINATION OF RESEARCH (FRN)

The FRN is a new element in the organization of the Swedish research system. The back-ground to the establishment of FRN in 1977 was a need for more cooperation and closer contacts, not only between the different Research Councils but also within the research and development system in general. FRN's main tasks are:

- to initiate and support research within areas important to the society
- to further cooperation between the Research Councils and other research bodies and financiers
- to encourage the spread of information about research and its results, and to stimulate the dialouge between researchers and society in general
- to further international research cooperation in those areas not taken care of by other bodies.

THE NATIONAL MARINE RESOURCES COMMISSION (DSH)

The National Marine Resources Commission (DSH) is a governmental agency set up to coordinate Swedish marine resources activities. Its aims are to work for and support these activities by coordinating research and development in this field, to promote Swedish trade and industry in the marine sector, to suggest changes in existing law and administrative practices and to work towards international cooperation in the short- and longterm management of marine resources etc. One of its chief tasks is to develop and propose to the government a comprehensive program for the Swedish marine activities.
The first proposal was delivered to the government in 1982.

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