Not to be cited without prior reference to the authors

International Council for the
Exploration of the Sea

CM 2000/O:01
Sustainable Aquaculture
Development

WASTE PRODUCTION BY FARMED ATLANTIC SALMON (*SALMO SALAR*) IN SCOTLAND

I.M. Davies

FRS Marine Laboratory, PO Box 101, Victoria Road,
Aberdeen, AB11 9DB, Scotland, UK

ABSTRACT

The assessment of the acceptable level of fish farm development in Scottish coastal areas is strongly dependent on the predicted rate of release of nitrogenous nutrients and particulate organic waste. A simple mass balance model has been used to estimate the rate of production of dissolved and particulate nitrogenous waste by cultivated salmon. The predicted release of dissolved nitrogen is 35-45 kg N/tonne of fish produced, depending upon details of the stocking, feeding and harvesting strategies adopted. Calculations based upon records from a number of Scottish salmon farms indicate that the net waste productions during the cultivation of 'normal' S1 and PP1 (photoperiod modified) smolts are similar.

INTRODUCTION

The most important product of the marine fish cultivation industry in the North-east Atlantic is the Atlantic salmon, *Salmo salar*. Production in coastal waters now exceeds 500,000 tonnes per annum, and the industry continues to make a very significant contribution to the economy of rural areas of countries including Scotland, Norway and Ireland. The growth of the industry has been accompanied by increasingly comprehensive regulatory and monitoring procedures designed to protect the environment. For example, in Scotland, farms are required to obtain Discharge Consent under the Control of Pollution Act, 1974, which commonly limit factors such as the tonnage of fish that may be held (or produced), and the amounts of medicines (such as sea lice treatments) that may be used at each site. The quantities are determined on the basis of a system of environmental quality objectives (EQOs) and standards (EQSs) which have been established to ensure that unacceptable environmental impact does not occur.

An EQO/EQS system can provide a flexible and environmentally sensitive basis for regulation which takes into account differences (for example in hydrographic characteristics, or conservation interests) between individual sites. However, the equity and effectiveness of the system is dependent upon the quality and reliability of the scientific information used to predict the degree of environmental impact.

Fish farmers in Scotland are required to obtain leases for suitable sites from the Crown Estate Commissioners and permission to discharge wastes (Discharge Consent under the Control of Pollution Act, 1974, as amended by the Environment Act, 1995) from the Scottish Environment Protection Agency. Applications for Leases are now processed through Local Planning Authorities who can take account of a wide range of factors. However, the current Policy Guidance Note issued by the UK Government to assist Local Authorities in this task classifies coastal areas, in terms of their relative potential for further fish farming development. The criteria used to establish these categories include natural heritage conservation aspects, and also the current contributions of fish farming to nitrogenous nutrient levels in the water column, and to organic enrichment of the sea bed. Areas where fish farming is already fairly intense in relation to the characteristics of the receiving environment are unlikely to be appropriate for further development.

Similarly, the Scottish Environment Protection Agency, in its considerations of applications for Discharge Consents, takes account of predicted impacts of fish farm developments on nutrient levels and on the sea bed (SEPA, 1998). Measurement of nutrient levels is normally part of the routine environmental monitoring required by SEPA, and the predicted scale of impact on the sea bed is the dominant factor used by SEPA to determine the appropriate tonnage of fish that may be held at each farm site. Waste production rates are therefore central to estimation of the environmental carrying capacity for fish farming, and to the development and regulation of the mariculture sector.

There are relatively few recent studies of the production of waste at salmon farms. At the same time, there have been very considerable developments in feed technology, for example the movement towards high energy feeds with increased proportions of lipid and corresponding lower proportions of protein (and therefore less nitrogen). This has been accompanied by improvements in feed conversion ratios (FCR, the ratio of the weight of feed added to the weight of fish produced) from perhaps 1.6-2.0 to current values of 1.3 or less. As a consequence, the utilisation of nitrogen in feed is now much more efficient.

The most frequently cited values for the rate of excretion of dissolved nitrogen by farmed fish are in the range 75-120 kg N/tonne of fish produced (GESAMP, 1996). A typical salmon farm in Scotland would currently utilise feed containing around 42% protein, with an FCR of around 1.3. This is equivalent to feeding 87 kg N/tonne of fish produced. From this simple calculation it is clear that the higher estimates of the rate of nutrient release (GESAMP, 1996) cannot reflect current farm practice.

The purpose of this paper is to present estimates of the current rates of nitrogen release from marine salmon farms in Scotland. The paper integrates information on typical current (1997-99) feeding, harvesting etc strategies with a mass balance model to provide estimates of waste production resolved into time steps of 4 weeks throughout the marine phase of the production cycle. Comparisons are also made between ‘normal’ S1 smolts which are transferred to the sea in spring (April-May) and photo-period modified smolts which are placed in sea cages during the autumn (PP1, October-December).

METHODS

A simple mass-balance model has been developed to predict the production of dissolved and particulate waste in salmon farming. In order to undertake the modelling, values have to be selected for a number of basic forcing parameters. These values have been derived initially from a simulation of a salmon farm using values which are considered to be typical of the Scottish industry. The model was then applied to records of a major salmon producer in Scotland, averaged over a large number of their sea sites, using data referring to S1 smolts and PP1 smolts.

The basis of the model is that the dominant source of nitrogen to the fish is the diet, ie that they receive a negligible proportion of their nutrition from natural sources in the surrounding environment of the farm. The feeding rate varies with size of fish and temperature. A proportion of the feed will be lost from the system as uneaten feed pellets. Current salmon farming practice limits wastage to no more than 5% of the added feed, although reliable data on this are rare.

Of the feed which is ingested, a proportion is not digestible by the fish. Feed manufacturers typically estimate the digestibility of feed as in excess of 85%, probably close to 90%. The undigested matter is considered to be excreted as faecal material.

The nitrogen in the digested feed will be partitioned between incorporation into the tissues of the fish as they grow, and released to the environment as dissolved substances (mainly ammonia and dissolved organic compounds). Feed Conversion Ratios (FCR, weight of feed used divided by increase in wet weight of fish) are calculated monthly, from farm records of feed utilised and fish growth indicate. The bulk composition of farmed fish (Ackefors and Enell, 1990) is taken as 3.4% nitrogen (on a wet weight basis), which permits calculation of the amount of nitrogen incorporated in the fish as they grow.

Allowance is made in the model for mortalities of fish. The pattern of mortality reflects common experience, with the highest rates of mortality occurring in the three months immediately after transfer of smolts to sea. The total mortality over the full marine phase is approximately 10%. The harvesting pattern used in the initial simulation again reflects a typical Scottish farm, in which harvesting commences when the mean fish weight reaches approximately 3 kg, and continues for three to five months.

The amount of nitrogen released as dissolved substances is calculated as the difference between the amount input in the feed, and the sum of the amounts in particulate waste (excess pellets plus undigested material) and fish growth.

In the second simulation, real averaged farm records have been used to provide information on the main parameters of the model. These parameters include the staggering of smolt inputs at different sites, the patterns of mortalities, the type of feed used (and therefore its composition), and the feeding rate. The composition of the feed varies as the fish grow; post-smolt diets generally contain more protein than diets fed to larger fish. Allowance is made for harvesting to concentrate on the larger fish in the stocks, and to be spread over a longer time period.

RESULTS

The farm initially simulated by the model produced 1,000 tonnes of salmon from S1 smolts using 1,167 tonnes of feed over a period of 20 months, therefore with an overall FCR (from the transfer to cages to harvest) of 1.17, calculated on total fish weight. Some farms calculate FCR on the weight of fish in harvest condition, after a short period of starvation, and the above FCR is approximately equivalent to an FCR of 1.29 calculated on starved weight of fish. The maximum rate of feed input occurred during the second summer when the fish were in the sea, and ranged from 106-115 tonnes per four week period over 12 weeks (Fig. 1). The peak biomass on the farm occurred over the same period and was 700-800 tonnes (Fig. 2).

The nitrogen input in the feed was calculated to be partitioned as 15% in particulate waste, 40.4% retained in fish growth, 1.6% lost as mortalities and 42.3% lost as dissolved waste. The predicted total amount of dissolved nitrogen released over the full grow-out cycle was 35.6 kgN/t fish produced. The monthly amounts of solid and dissolved waste (Fig. 3) were directly proportional to the amount of feed used, because fixed values were selected for feed wastage, digestibility and FCR.

The sensitivity of the model to variations in the forcing parameters was explored. A decrease of 5% in either the proportion of waste feed pellets or indigestibility decreases the predicted amount of solid waste by 30%, and increases the dissolved nitrogen release by approximately 12%.

Changing the assumed composition of the fish to 3% nitrogen decreased the nitrogen retained by the fish by 12% and increased the dissolved nitrogen loss by 11%.

The model was then applied to real records from a group of salmon farms operated by a major company in the Scottish industry. Calculations were made for S1 smolts and also for PP1 smolts, ie smolts put to sea during the autumn. The results of the calculations are summarised in Table 1. The efficiencies of feed utilisation and the waste production are rather similar for salmon production based upon S1 and PP1 smolts. In both cases, the proportion of feed nitrogen excreted as dissolved waste is greater than that in the initial simulation. This arises from a range of factors, including the relatively poor FCR values experienced in small fish which are contemporaneous with the use of high protein feeds, and the slightly higher rate of losses as mortalities recorded in the real farm data.

The general temporal patterns of release of dissolved nitrogen by S1 and PP1 smolts are rather similar (Fig. 4). Both increase as the rate of feeding increases during the first year at sea. Maximum feed utilisation and dissolved nitrogen excretion occur after the first summer at sea, with a second maximum during the following spring. The second maximum is less marked for the PP1 generation, as by that time the harvest of the PP1 fish is more advanced than that of the S1 fish, and therefore less feed is required. The main differences between the temporal patterns is the greater excretion by the PP1 fish during their first winter and spring at sea, ie before the S1 smolts have gone to sea and during their immediate post-smolt period. Conversely, there is greater excretion by S1 fish in the latter third of their production cycle, mainly due to the earlier harvest of the PP1 fish.

DISCUSSION

The mass balance approach adopted in this model has been shown to provide a robust estimate of the waste production from modern salmon farms in Scotland using high energy feed. The precise values obtained from the model differ between the simulation and the calculations based upon real averaged farm data. Clearly the values obtained are to a degree dependent upon details of the feeding regime, stocking and harvesting patterns. However, taken over a full growing cycle, the release of dissolved nitrogen is very likely to be in the range of 35-45 kg/tonne of production, ie much less than the GESAMP (1996) estimates.

Looking to the future, improvements in husbandry and feed technology are likely to reduce the rate of waste production further. The current main areas of improvement are:

a) There may be some room for improvement in the current digestibility values of feed of around 90%, although the inevitable inclusion to a few percent of ash in the feed will provide a limit to the possible maximum digestibility, unless economic methods are found to reduce the ash content.

b) The wider introduction of automatic feeders responsive to the demands of the fish provide several benefits. For example, the fish will not be fed beyond satiation, and therefore the amount of uneaten feed pellets may be decreased below the 5% assumed in the above calculations. This will reduce the amount of particulate waste, reduce the environmental impact on the sea bed below the farms and make a higher proportion of the feed available for assimilation by the fish.

   Also, they will encourage optimum feeding rates throughout the growing cycle. Traditional feeding regimes for S1 smolts greatly reduce the rate of feeding during the second winter at sea. There is increasing evidence that feeding rates can be held at higher values at this time, resulting in continuing rapid growth and improved FCR values.

c) The almost universal use of vaccination for disease control, and the increased availability of a range of sealice treatment chemicals together with strategic approaches to sea lice control, should improve the overall health and performance of the salmon stocks.

As a result of these and other developments, it has been the experience in the Scottish industry that FCR values have improved by approximately 0.05 per growing cycle. It is anticipated that this pattern will continue. If the FCR can be reduced to 1.0, feed wastage to 1%, and indigestibility to 5%, the release rate of dissolved nitrogen would be approximately 33 kg/tonne of production. This may be close to the limit achievable using the methods currently in use in Scotland, and further marked reductions in dissolved nitrogen release may require more innovative approaches.

It is beyond the scope of this paper to discuss in any detail the fate of the nitrogen released from the farmed salmon. The models do not attempt to partition dissolved nitrogen between ammonia, urea and other soluble compounds. The nature of this partitioning will influence the subsequent utilisation of the nitrogen by the algal (micro and macro) and microbial communities.

CONCLUSION

Simple mass balance models can be used to estimate the rate of production of dissolved and particulate waste by cultivated salmon. Calculations based on a single simulated farm, and on data from a multi-site business in Scotland, indicate that the estimates are robust to changes in input parameters within reasonable ranges for the Scottish salmon industry. Comparison with established estimates indicates that current feed technology and husbandry methods result in a comparatively low rate of nitrogen release to the surrounding environment. The models do not attempt to partition dissolved nitrogen between ammonia, urea and other soluble compounds. The nature of this partitioning will influence the subsequent utilisation of the nitrogen by the algal (micro and macro) and microbial communities.

REFERENCES

Ackefors, H. and Enell, M. 1990. Discharge of nutrients from Swedish fish farming to adjacent sea areas. *Ambio*, **19**, 28-35.

GESAMP, 1996. Monitoring the ecological effects of coastal aquaculture wastes. Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. No 57, FAO, Rome.

SEPA, 1998. Regulation and monitoring of marine cage fish farming in Scotland. Scottish Environment Protection Agency, Stirling, UK.

TABLE 1

Input parameters and calculated values of waste production during the on-growing of S1 and PP1 salmon smolts.

	S1 smolts	PP1 smolts
Period of transfer to sea	March-May, year 2	Oct-Dec, year 1
Period of harvest	Dec year 2 - Feb year 4	Nov year 2 – Nov year 3
Overall FCR (starved weight)	1.35	1.37
Overall FCR (“live” weight)	1.22	1.23
% N lost as solid waste	15.0	15.0
% N in fish growth	37.9	41.1
% N as dissolved waste	47.1	43.9
Dissolved N lost	42.9 kg/tonne harvest*	44.3 kg/tonne harvest*
Particulate N lost	13.7 kg/tonne harvest*	14.0 kg/tonne harvest*

*Based on starved weight, reduce by 10% for ‘live’ weight

LIST OF FIGURES