Economics of Potential Systems for Farmed Production of Cod

A Report Produced for the Sea Fish Industry Authority

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Executive Summary

- Experimentation with the cultivation of cod has a history going back more than a century, and the potential for developing commercial cod production has been the subject of a number of studies over the past 15 years. Most of these studies have concluded that production of cod does not appear viable in general under the most likely assumptions of performance and price in prospect at the time. However, the most recent report prepared by Nautilus (1997) draws much more favourable conclusions on the prospects for viability.
- In this report an outline model and budget of a potential commercial hatchery for producing cod juveniles is presented, based largely on the hatchery research experience gained at the Seafish Aquaculture research station at Ardtoe, Argyll. The results indicate that 25g cod juveniles ready for stocking in sea cages are likely to be able to be produced profitably at a sale price of less than 80p per fish and, if the latest favourable indications on potential performance are confirmed, possibly at a price as low as 35p per fish.
- An alternative assessment of the potential viability of cod on-growing in sea cages was made, based on the fact that cod on-growing uses essentially the same resources as salmon on-growing, and therefore will need to be broadly competitive with that alternative option for use of those resources. The margin from a business producing solely salmon was compared with the margin which could be envisaged from devoting half of its sea-cage facilities to cod production.
- The conclusions from that analysis are that :

1. On the present most likely assumptions on the main requirements, performance and sale price for cod, there is a significant gap between the margin which can be expected from growing cod and that from salmon production.
2. No single change in any of the assumptions on the requirements and performance of cod is likely to bridge that gap. There would need to be favourable changes in several of those factors before cod production could be seen as competitive.
3. The one single factor which could alter the conclusion and make cod production an economically favourable option would be the prospect of a significantly higher sale price for cultivated cod, ie a price approaching £2 per kg for ungutted cod delivered to a local processing plant.

4. Favourable performance factors which can be envisaged in the hatchery stage can make a significant difference to the view on potential viability such that, in combination with a minor improvement in the expected sale price for cultivated cod, or other improvements in expected performance in on-growing, a viable system could then be projected.

- The current upward trend in cod prices gives some encouragement, but there is a need for further research on the potential market prices which may be envisaged, in order to clarify the commercial potential for cod production.
- In addition to favourable price prospects, a clear demonstration in practical and economic terms of the viability of cod on-growing on a pilot scale will be required to encourage the large investment which is needed to establish a hatchery on a fully commercial scale.
- There are as yet great areas of uncertainty regarding both the hatchery and on-growing stages, which need to be clarified by research and pilot trials, before the potential for commercial cultivation of cod can be clearly established, but this interim analysis of the economics of the total system may help to focus on what are likely to be some of the most important issues.

Contents

1. Introduction

1.1. Terms of Reference

The Sea Fish Industry Authority commissioned this study under the following terms of reference :

Based on the best available data, prepare budgets to indicate the price for cod fry, at which the on-growing of cod in sea-cages would be competitive with salmon production in the same facilities, including sensitivity analyses of the effects of variation in key assumptions. (Whether cod on-growing develops as new fish farm sites or expansion of existing sites, or as a replacement for some existing salmon production, it will have to be broadly competitive with the alternative of using those resources for salmon production)

Based on the latest evidence and guidance from the staff carrying out the cod hatchery and early rearing work at Seafish Aquaculture's Ardtoe research station, develop an outline plan for the facilities and system for a commercial cod hatchery and prepare budgets to show the price for the fry produced which would be required for economic viability, again including sensitivity analyses for the effects of variation in key assumptions.

Complete the report with discussion of conclusions, including assessment of constraints to development of commercial cod production.

1.2. Background

The aquaculture industry in Scotland has developed into a very important element in the economy of the Highlands and Islands of Scotland over the last twenty years. It is, however, highly dependent on one species, the Atlantic salmon *Salmo salar*. Seafish Aquaculture has played a leading role in research and development work aimed at developing commercially viable systems for the cultivation of alternative species. The largest element of that work has been directed towards the cultivation of Atlantic halibut *Hippoglossus hippoglossus*, which has now reached the stage of pilot commercial production.

The Atlantic cod *Gadus morhua* is a species which has been considered by many workers at different times and places as having potential for cultivation. This is because there are major fisheries for cod in the NorthAtlantic, North Sea and Baltic Sea, with a well-established market, but falling supplies. Experimentation with cultivation of cod can be traced back to the last century, with a Norwegian, G. M. Dannevig being attributed with successfully rearing cod larvae beyond metamorphosis in 1886 (van der Meeren 1991). In the 1970s and 1980s Norwegian work developed extensive and semi-intensive systems for producing marine fish larvae, including cod, in lagoon enclosures, and van der Meeren reports production of 270,000 cod fry in 1990 by a commercial company (Sea Farm A/S), and 310,000 in 1991 by the Norwegian Institute of Marine Research. Most Norwegian cod fry production has been aimed at enhancing natural cod stocks, however, rather than cultivation through to market size (Huse 1991).

There has been some study of on-growing cod to market size in Norway, and even commercial production, reported at 235 and 320 tonnes in 1993 and 1994 (Hempel 1995), but mostly with wild caught juvenile fish. This was also the basis of commercial on-growing developed by Sea Forest Plantation Ltd in Newfoundland in the late 1980s.

Interest in the possibilities for culture of cod were raised in the UK in the early 1980s when it was demonstrated by Howell (1984) that cod juveniles could be reared in the laboratory using produced live feed. However, economic analysis by Jones (1984) concluded that " ..it is difficult to envisage....a profitable business on a large scale...". The effort in research and development of intensive hatchery production of marine fish juveniles then became directed primarily towards higher value species, such as halibut in particular. But interest in potential culture of cod was again aroused by a PhD thesis on the topic by Ahmed (1995), followed by production of a report from the Centre for the Economics and Management of Aquatic Resources, University of Portsmouth (Whitmarsh and Pickering 1996). Although Ahmed's primary analysis drew a similar conclusion to Jones, a secondary analysis looking at the cod on-growing enterprise as a marginal addition to an existing salmon farm indicated that with some fairly small improvement in the sale price of cod or the cost of feed it was possible to see a potential internal rate of return of 19 per cent, which was "..quite encouraging..". Although Ahmed viewed the costs in her model as the lowest that could be achieved, Whitmarsh and Pickering suggested otherwise, based on Norwegian costs for on-growing (Engelsen 1995) and projected costs for fry production (Tilseth 1990).

In 1996 Highlands and Islands Enterprise commissioned a study on the potential for commercial cultivation of cod in the Scottish Highlands and Islands, which concluded that "..cod farming...can form a profitable and compatible adjunct to existing salmon operations", "a viable hatchery technology has been demonstrated in Canada, and is considered viable in Scotland", and "it would be remiss of any commercial operator in fin fish cultivation not to give serious consideration to exploring this development further" (Nautilus Consultants 1997).

The degree of detail presented in that report for the hatchery model in particular was rather limited. Also Seafish Aquaculture have now a year's experience of a significant research programmme at the Ardtoe research station upon which to base an outline projection of a commercial hatchery operation. That was therefore made a primary objective of this report, with most of the technical assumptions on inputs, facilities and performance being guided by Malcolm Gillespie and Robin Shields of SeaFish, to whom sincere thanks is expressed for patience and dedication in explaining the technical issues and attempting to foresee the main elements of a commercial hatchery development, which could be operational in the near future.

Secondly it was considered that a useful alternative way of analysing the potential viability of on-growing cod would be to examine it in terms of its ability to be competitive with the established salmon production with which it would be competing for use of essentially the same resources.

2. Outline Cod Hatchery Budget and Juvenile Prices Required for Viability

2.1. *Production System and Technical Performance Assumptions*

An outline system plan for a hatchery is presented in Appendix 1, with the main technical assumptions being based on the experience at Seafish research station at Ardtoe in 1997. Some of the primary assumptions are as follows:

- There are four batches of eight broodstock, two of which are photoperiod controlled to advance spawning and one group is retarded, so as to achieve a total spread of spawning of 24 weeks starting from late October.
- The juveniles are assumed to be weaned by around nine weeks from hatching and it is assumed that they are grown on to 25g by 36 weeks from hatching, at which weight they could be transferred directly to sea-cages.
- During the period from hatching to weaning the larvae are held in fairly small tanks of 3.33 cubic metres to allow close monitoring and maximum control.
- Stocking density is low during the larval rearing stages, being at a maximum of 30 larvae per litre and a maximum of 3.47 kg per cubic metre. During the rearing to 25g the stocking rate is never more than 15 kg per cubic metre.
- Only around half the total eggs produced are utilised and fifty per cent of these are assumed to be mortalities or culls during hatching. Of the larvae retained, a survival of just 3.3 percent is assumed over the period of larval rearing and weaning onto dry diet. Further mortalities and culls assumed during the rearing to 25g bring the overall survival to 2.82 per cent.
- The larval rearing and weaning is divided into three three-week periods, with batches being combined at these points to bring stocking rates back to reasonable levels.
- The hatchery is planned as a simple flow-through unit with a maximum flow requirement of 210 litres per second, which is estimated to fully supply the oxygen requirements of the fish.

- Algal production is limited to the green water requirements for the first three weeks of feeding. Rotifers are fed for the first four weeks and artemia are fed from weeks four to nine. Proprietary emulsions are used for enrichment of both rotifers and artemia. An inert diet is introduced from week seven.

2.2. Capital Costs

The estimated capital costs are shown in Table 1 to amount to just over £400,000.

- The estimated cost of the seawater intake and pumps is based on data supplied by Filpumps Ltd (Gordon 1998).
- Because of the relatively modest algal requirement, a traditional batch production system has been assumed, with the costs based on data from a recent survey (Grubb 1996).
- Tank costs are based on prices from PPS Glassfibre Ltd and C & H Plastics Ltd.
- The building costs are based on data from the SAC Farm Building Cost Guide (1997), with allowance for 10 per cent discount in competitive tender.
- The broodstock and post-weaning tanks are assumed housed in polytunnels.
- Miscellaneous equipment costs are based on data from Dryden Aqua Ltd and Aqua Systems Ltd.

2.3. Annual Costs and Viable Sale Price for Juveniles

The estimated annual costs of operating the hatchery are set out in Table 2, together with the sales revenue at the juvenile price which is required to provide a return of 15 per cent on the total capital investment. Some of the main assumptions which may be noted here are :

- Costs of algal nutrients are based on data from the study by Grubb (1996).
- Costs of dry diets are indicative prices from Trouw UK.
- Transport and marketing costs have been assumed at 5p per juvenile, but this cost will vary significantly with the distance of the on-growing site from the hatchery.
- Material costs for vaccination against vibriosis have been included at 1.25p per juvenile.

Table 1. ESTIMATED CAPITAL COSTS FOR A HATCHERY PRODUCING 472,000 25g JUVENILES

			£
Seawater Intake, Pipeline, Pumps and Header Tank :			
providing maximum flow rate of approx. 210 litres per second			50,000
Equipment for Algal Production :			
for maximum production of approx. 700 litres per day (20-40 x 10^6cells/ml)			18,000
Live Food Culture Tanks :			
Rotifers: 10,000 litres @ £0.25 per litre		£2,500	
Artemia: 48,000 litres @ £0.25 per litre		£12,000	14,500
Incubators (incl. pipework and fittings) :			
18 (80litre) @ £80			1,440
Tanks for Fish (incl. pipework and fittings) :			
Broodstock - 4 x 30cu.m. @ £2500		£10,000	
First-Feeding Larvae - 27 x 3.33cu.m. @ £750		£20,250	
Larval Rearing - 8 x 3.33cu.m. @ £750		£6,000	
Weaning - 4 x 3.33cu.m. @ £750		£3,000	
To 5g - 19 x 11cu.m. @ £1500		£28,500	
To 20g - 12 x 30cu.m. @ £2500		£35,640	103,390
Building :			
Floor areas required -	sq. metres		
Algal culture and live food unit	50		
Egg handling, incubation and first feeding	220		
Larval rearing and weaning	100		
Store, Office, etc	140		
TOTAL	510		
eg 30m (5 x 6m. bays) x 18m. =	540		93,000
(steel portal frame, 3m. to eaves, PVC-covered steel cladding, polystyrene insulated, concrete floored, incl. drainage and internal divisions)			
Area for Broodstock and Post-Weaning Tanks :			
1000 sq. m. hardcore base and drainage			6,000
800 sq. m. polytunnel			12,000
Internal Supply and Discharge Pipework :			12,000
Cooling Equipment for Broodstock, Hatching and Larval Rearing			40,000
Access Road and Security Fencing :			15,000
Standby Generator :			10,000
Monitoring, Alarm, and Emergency Aeration Systems :			15,000
Miscellaneous Equipment (incl. vehicle):			20,000
Design and Planning			20,000
TOTAL CAPITAL COST			410,330 (excl. VAT)

- The labour bill is based on the following staffing -

Manager	£28,000
Assistant Managers (Engineering and Biological)	2 @ £18,000
General Workers	2 @ £12,000
Secretary/Book-keeper (part-time)	£4,000

Table 2 indicates that a sale price of 78p per juvenile is required in order to generate a 15 per cent return on the total capital invested. This value is actually derived by means of a cash flow budget for ten years operation, presented in Appendix 2, which shows the capital requirement peaking at around £687,000 prior to the first sales of juveniles in July/August. This occurs around 15 months from the start of operations, because of the need to establish three of the groups of broodstock on photoperiod control during the first summer, to achieve the assumed 24 week spread of spawning.

Table 2. ESTIMATED ANNUAL OPERATING COSTS FOR A HATCHERY PRODUCING 472,000 25g JUVENILES

		£	£
Broodstock Replacement :			
	16 Fish over 5 kg @ £20 each		320
Feed :	Nutrients for algal production, 120,000 litres @ 1.5p per litre	1,800	
	Rotifer enrichment emulsion, 27kg @ £22 per kg	594	
	Artemia cysts, 160 kg @ £30 per kg	4,800	
	Artemia enrichment emulsion, 90kg @ £37 per kg (50/50 Super Selco & Algamac)	3,330	
	Weaning granules, 510kg @ £1,350 per tonne	689	
	Post-weaning (& broodstk) pellets, 19 tonnes @ £950 per tonne	18,050	29,263
Transport and Marketing :			23,600
Chemicals and Consumables :	(incl. vibrio vaccine)		12,000
Labour and Management :	6 staff		92,000
Fuel and Electricity :			40,000
Repairs :	Buildings, tanks and pipelines @ 2%	5,827	
	Machinery & Other Equipment @ 5%	5,950	11,777
Insurance and Rent and Crown Estate Levy:			17,000
General Overheads :			15,000
Depreciation:	Buildings, tanks and pipelines @ 10%	29,133	
	Machinery & Other Equipment @ 15%	17,850	46,983
TOTAL COSTS (Excluding interest)			287,942
SALES REQUIRED TO GIVE 15% RETURN ON CAPITAL			
	472000 25g juveniles @ 78p		368,160
PROJECTED PROFIT BEFORE INTEREST CHARGES			80,218

3. Sensitivity Analysis and Alternative Hatchery Budget and Viable Price Estimates

3.1. Sensitivity Analysis

Examination of the production costs in Table 2 indicates that the most significant cost elements in a cod hatchery are labour, depreciation and repair costs for buildings and equipment, fuel and electricity, and feed costs. Technical assumptions likely to affect costs significantly are mortality levels, stocking rates, growth rate and feed conversion rate. An overriding economic factor affecting the costs is the scale of operation.

For most of these factors, the effects of varying the assumptions on one of them alone is very difficult to assess, because they interact with one another. In particular, a lowering of assumed mortality rates results in rapidly increasing scale of operation (unless radical reductions are made to the broodstock and hatching sections) and this greatly affects the costs of labour, buildings, equipment and other overheads per unit of production. Similarly, the effect of assuming increased stocking rates depends on whether it is also appropriate to assume larger batches of fish, because otherwise the size of tanks is reduced.

Because one is mainly concerned to see what total potential there may be to reduce production costs overall from the initial level estimated in Section 2, and because there are early indications of improvements in several aspects of performance with the 1998 cohort at the Ardtoe research station, an alternative budget has been prepared, taking more optimistic assumptions on several factors together.

3.2. Alternative Hatchery Budget

The primary change is in the assumed mortality rates. The early results for the 1998 cohort are showing a survival rate from hatching through weaning of around 25 percent, compared with the 3.3 per cent assumed in the first budget. Weaning is also being achieved at an earlier stage by some two weeks and, with the higher survival, the ability of the larvae to thrive at a higher stocking rate has also been indicated.

These more favourable performance aspects have been applied in a revised outline system plan presented in Appendix 3. The following points may be noted in this :

- The broodstock numbers have been reduced from four batches of eight to four batches of six, with around a million eggs being incubated per week instead of 1.4 million.
- With the much higher survival through weaning the total production is increased to 1.84 million juveniles.
- Somewhat higher stocking rates are assumed throughout, eg 50 fish per litre instead of 30 at first feeding, and 23 kg per cubic metre prior to sale instead of 15 kg.
- Along with the heavier stocking and higher survival, it has been assumed that larger batches of fish can be maintained after the first feeding stage, enabling use of larger tanks at an earlier stage in the rearing process.
- The larval rearing facilities required are actually reduced slightly, despite the much larger production of juveniles.
- Algal and rotifer requirements are also reduced, but artemia requirements are increased and the use of proprietary feed is increased more than proportionately to the increase in juveniles produced, because of the earlier weaning.
- Water flow requirements are more than doubled.

The capital costs of the revised hatchery plan are estimated in Table 3. Because of the reduced mortalities, the higher stocking rates and scale economies, the budgeted capital costs are only some 50 per cent higher than for the original plan.

In Table 4 the operating costs of this revised hatchery plan are estimated and it is indicated that a sale price for 25g juveniles of 35p per fish would be sufficient to provide a return of 15 per cent on the total capital invested. This is based on the cash flow presented in Appendix 4, which shows the peak capital requirement as around £950,000.

Table 3. ESTIMATED CAPITAL COSTS FOR A HATCHERY PRODUCING 1.84 million 25g JUVENILES

			£
Seawater Intake, Pipeline, Pumps and Header Tank :			
providing maximum flow rate of approx. 440 litres per second			80,000
Equipment for Algal Production :			
for maximum production of approx. 300 litres per day (20-40 x 10^6cells/ml)			12,000
Live Food Culture Tanks :			
Rotifers: 8,500 litres @ £0.25 per litre		£2,125	
Artemia: 42,500 litres @ £0.25 per litre		£10,625	12,750
Incubators (incl. pipework and fittings) :			
13 (80litre) @ £80			1,040
Tanks for Fish (incl. pipework and fittings) :			
Broodstock - 4 x 30cu.m. @ £2500		£10,000	
First-Feeding Larvae - 19 x 2cu.m. @ £550		£10,450	
Larval Rearing - 6 x 3.33cu.m. @ £750		£4,500	
Weaning - 3 x 6.5cu.m. @ £1200		£3,600	
To 1g - 12 x 15cu.m. @ £1700		£20,400	
To 5g - 11 x 30cu.m. @ £2500		£27,500	
To 25g - 22 x 42cu.m. @ £5000		£110,000	186,450
Building :			
Floor areas required -	sq. metres		
Algal culture and live food unit	50		
Egg handling, incubation and first feeding	220		
Larval rearing and weaning	100		
Store, Office, etc	140		
TOTAL	510		
eg 30m (5 x 6m. bays) x 18m. =	540		93,000
(steel portal frame, 3m. to eaves, PVC-covered steel cladding, polystyrene insulated, concrete floored, incl. drainage and internal divisions)			
Area for Broodstock and Post-Weaning Tanks :			
2500 sq. m. hardcore base and drainage			15,000
2000 sq. m. polytunnel			30,000
Internal Supply and Discharge Pipework :			20,000
Cooling Equipment for Broodstock, Hatching and Larval Rearing			40,000
Access Road and Security Fencing :			18,000
Standby Generator :			15,000
Monitoring, Alarm, and Emergency Aeration Systems :			35,000
Miscellaneous Equipment (incl. vehicle):			35,000
Design and Planning			20,000
TOTAL CAPITAL COST			593,240 (excl. VAT)

Table 4. ESTIMATED ANNUAL OPERATING COSTS FOR A HATCHERY PRODUCING 1.84 million 25g JUVENILES

		£	£
Broodstock Replacement :			
	12 Fish over 5 kg @ £20 each		240
Feed :	Nutrients for algal production, 60,000 litres @ 1.5p per litre	900	
	Rotifer enrichment emulsion, 25kg @ £22 per kg	550	
	Artemia cysts, 220 kg @ £30 per kg	6,600	
	Artemia enrichment emulsion, 120kg @ £37 per kg (50/50 Super Selco & Algamac)	4,440	
	Weaning granules, 1,350kg @ £1,350 per tonne	1,823	
	Post-weaning (& broodstk) pellets, 74 tonnes @ £950 per tonne	70,300	84,613
Transport and Marketing :			92,000
Chemicals and Consumables :	(incl. vibrio vaccine)		32,000
Labour and Management :	8 staff		119,000
Fuel and Electricity :			60,000
Repairs :	Buildings, tanks and pipelines @ 2%	8,645	
	Machinery & Other Equipment @ 5%	8,050	16,695
Insurance and Rent and Crown Estate Levy:			37,000
General Overheads :			25,000
Depreciation:	Buildings, tanks and pipelines @ 10%	43,224	
	Machinery & Other Equipment @ 15%	24,150	67,374
TOTAL COSTS (Excluding interest)			533,921
SALES REQUIRED TO GIVE 15% RETURN ON CAPITAL			
	1.84 million 25g juveniles @ 35p		644,000
PROJECTED PROFIT BEFORE INTEREST CHARGES			110,079

3.3. Scope for Achieving Lower Juvenile Production Costs

The performance assumptions in the above budget have yet to be demonstrated as feasible on a continuing basis even on a research scale, before being considered as likely on the commercial scale envisaged.

However, there is still scope for the possibility of further cost reductions from improvements in other aspects of the assumptions.

No improvement has been assumed from the growth rate budgeted in the original plan. A faster growth rate would reduce the holding tanks, water flow and labour requirements.

For simplicity in planning a simple flow-through system has been assumed. A recirculation system would involve significant additional investment in oxygenation, filtration and water treatment, but would reduce the scale and cost of the seawater intake and pumps, and by reducing the power costs for pumping and water cooling could effect some modest saving in the unit costs of production estimated.

4. Viability of Cod On-Growing as an Alternative to Salmon Production

4.1. Introduction

Cod on-growing requires essentially similar facilities to salmon production and is most likely to be started as a commercial operation by existing salmon producers. Such diversification away from reliance on a single product has advantage in reducing the dependence of the business on a single commodity market and thus the fluctuation in income arising from price trends in that particular market. There may also be possible gains in efficiency of use of labour and equipment due to differing timing of key activities between the two forms of production. However, whether cod production were introduced as a replacement for part of the salmon production using existing facilities, or was to be started in additional new facilities, it will only be launched if it is seen as offering a margin which is at least approaching that which could alternatively be generated by devoting the same facilities to salmon production.

4.2. Comparison of Margins from Salmon Production with a Combination of Salmon plus Cod

The following analysis therefore compares the margin which can be expected from a given set of facilities devoted entirely to salmon production with that which can be envisaged from devoting half the facilities to salmon production and half to cod production.

The assumptions for the salmon production enterprise are based on confidential data from a number of industry contacts, growth projections based on Trouw's Salfeed 6 model, and data in the Annual Production Survey of Scottish Fish Farms (SOAEFD 1997). An outline of the system envisaged, which produces annual sales of 1000 tonnes of salmon is presented in Appendix 5.

This is not suggested to be an entirely typical system of operation, but is designed as a system which can be used as a representative model against which to compare a system producing a combination of cod and salmon, in that it can produce at a performance level which is typical for the salmon industry and meets the following criteria :

1. There is a six to eight week fallow period between each group of fish stocked on any site.
2. There is a reasonable spread of sales around the year.

The main assumptions adopted for the planning and budgeting of the cod production enterprise are as follows:

- The projected growth of the cod is based on the following growth equation produced by Jobling (1988) and referred to in both the Nautilus (1997) and Whitmarsh and Pickering (1996) reports [although mis-quoted in both] :

  $\ln G = (0.216+0.297T-0.000538T^3)-0.441 \ln W$

  where ln = natural logarithm

  G = daily growth as % body weight

  T = temperature in °C.

  W = body weight in grams

  This indicates a growout period of 15 months from stocking at 25g to sale at 2kg.
- The plan envisages stocking of Cod juveniles at July/August, September/October and January/February. These relate with the spread of timing of juvenile production from the hatchery plan as outlined in Section 2.1 above. (NB. If stocking in January/February proves impractical due to weather constraints and/or water temperatures, the last groups in the hatchery could be retained to a heavier weight and put to sea a little further into the Spring.) Stocking with 20g fry in May, as envisaged in Nautilus' Scenario 1 (1997), may be a possibility, but would require more significant photoperiod adjustment to give spawning in August which, as the highest temperature period, would necessitate more water cooling for the hatching and larval rearing.
- Cod sales have been budgeted at £1.58 per kg for whole fish delivered to a local processing facility, based on the projected price of £1.80 per kg gutted and a conversion factor for gutting of 0.88, as set out in Tables 7.4 and 7.3 of the Nautilus report (1997).
- Pelleted rations formulated for cod production are costed at an average price £36 below those for salmon, on the basis of information provided by Trouw UK Ltd (Gallimore

1998). The saving in cost due to not requiring expensive pigmentation in the cod diet is largely balanced by the requirement of a higher content of relatively expensive fish protein.

- The feed conversion rate and mortality rate for cod have been assumed at similar levels to those for the salmon production.
- A somewhat higher maximum stocking rate of 25kg per cu.m. has been assumed for cod, compared with the 18 kg per cu.m. restriction assumed for salmon, based on the different behaviour pattern of cod which does not demand the same space as the 'cruising' behaviour of salmon, as suggested by Huse (1991 p.49).
- Veterinary costs have been assumed to be significantly lower for the joint production of cod and salmon than for salmon only, mainly reflecting an assumption that cod will not require costly treatments for disease and pest problems to the same extent as salmon, in particular for sea lice, but also that the reduction in the total biomass of salmon on the sites will reduce the level of treatments required for the salmon also.

A plan showing a potential system for devoting half of the capacity of the salmon farm to cod production is shown in Appendix 6. The following points may be noted in this plan:

- A six to eight week fallow period has been maintained between each group of fish stocked on a site, whether salmon or cod.
- It is a plan for a situation when cod juvenile production has been established on a significant scale so that large numbers of juveniles are obtainable, rather than for an initial phase of development when available numbers of cod juveniles may be restricted and therefore plans may be constrained to a smaller scale.
- Of the three sites operated by this notional business, site one is shown operating an alternating cycle of salmon and cod production, site two is shown as producing cod only and site three has been left as originally, producing only salmon. This is essentially illustrative, rather than being any recommended policy, but was adopted to show a system using cod juveniles at different points in the year at which they may be available from the hatchery, and giving a spread of salmon and cod sales around the year.
- As a result of the more intensive stocking rate assumed with the cod, the maximum biomass and total annual production of biomass is higher in the plan for production of cod plus salmon than for salmon only, but no difference is assumed in (a) the sea-site rental

(since there is little difference in the total sales receipts, as budgeted) and (b) the labour, fuel and other overhead costs (based on less frequent feeding required for cod (Huse, opp.cit.)and a more even spread of labour requirements with a dual production system than with a single species system). However, if the sites are already constrained in terms of limits on biomass stocked or annual production of biomass, the assumed expanded system will not be feasible.

The margins from the 'Salmon Only' and 'Cod plus Salmon' systems are compared in Table 5. With the assumptions which have been taken the result shows a significantly lower margin with the system including cod.

Table 5. Budget Comparing Potential Margin for Integrated On-Growing of Cod and Salmon with On-Growing of Salmon Only

Total 27,000 cu.m.cage capacity, systems detailed in Appendices 5 & 6

		Salmon Only £000	Cod plus Salmon £000
Sales:	Salmon (1000t & 500t) @ £2.20/kg	2,200	1,100
	Cod (Zero & 700t) @ £1.58/kg	___	1,106
		2,200	2,206
Variable Costs:			
	Salmon smolts (360 & 180 '000) @ £1	360	180
	Cod juveniles (0 & 378 '000) @ 78p		295
	Salmon feed (1228t & 614t) @ £736/t	904	452
	Cod feed (0 & 863t) @ £700		604
	Veterinary	70	50
	Transport to local processor	20	24
		1,354	1,605
Gross Margin		846	601

Technical Assumptions:

- Maximum stocking rates -- Salmon 18 kg /cu.m., Cod 25 kg /cu.m.
- Food Conversion Rates -- Salmon 1.25, Cod 1.25
- Average harvest weights -- Salmon 3kg, Cod 2kg
- Weight of smolt/juvenile at stocking -- Salmon 50g, Cod 25g
- Average grow-out period -- Salmon 15 months, Cod 15 months
- Single batch stocking on any one site, with 6-8 week fallow between batches
- Increased total weight of fish produced without additional labour and other operating costs
- Total biomass stocked and annual biomass produced not at the limits of the sites

4.3. Sensitivity Analysis

The sensitivity of the results of this budget to variation in some of the main assumptions is analysed in Table 6.

Table 6. Sensitivity of Margins from Salmon and Cod plus Salmon to Variation of Financial and Technical Assumptions

Change in Assumptions	**Gross Margin Salmon Only £000**	**Gross Margin Cod & Salmon £000**
1)Cod juveniles 35p instead of 78p	846	764
2)Cod sale price £1.95 per kg instead of £1.58	846	860
3)Salmon sale price £2 per kg instead of £2.20	646	501
4)FCR for cod 1.1 instead of 1.25	846	673
5)Cod reach 2.5kg after 15 months instead of 2kg (ie 303,000 juveniles bought instead of 378,000)	846	660
6)Cod diet £100/t less than salmon diet instead of £36/t less	846	656
7)Both diets £100/t cheaper than assumed	969	749
8)Maximum stocking rate 25kg /cu.m. for salmon & cod	1175	766
9)Additional labour & other operating costs assumed for increase in total weight of fish produced @ £250 /tonne	846	551
10)Cod juveniles 35p and cod sale price £1.70 per kg	846	848

This analysis suggests that for cod production to provide a margin approaching that from salmon production, there either requires to be a significantly higher sale price for cod, much nearer to that for salmon (ie approaching £2 per kg for whole ungutted fish delivered to a local processing plant), or else a number of other factors in the production of cod must prove to be more favourable than has been assumed here.

The more favourable possible price of 35p per cod juvenile, based on the latest research indications, as modelled and budgeted in section 3.2, does make a significant difference to the potential margin from the cod on-growing enterprise, but is not enough alone to make it competitive with the salmon production.

If the salmon price is budgeted at £2 per kg instead of £2.20, which is a level it has fallen to at times over the past year, the gap between the margin from the 'cod plus salmon' system and that from the 'salmon only' system is reduced somewhat, but then the viability of the salmon production is becoming very much in question at that level.

More optimistic assumptions for the food conversion rate for cod, the cod growth rate, a lower cost for the cod diet, and /or lower prices for fish feed in general all reduce somewhat the gap in the margin between the two systems, but several of these would need to be more favourable to bring the cod production to a margin approaching competitiveness with salmon production.

Sensitivity test number eight in Table 6 is a check on the result not only if the assumption of a higher stocking rate for cod is questioned, but also represents the situation which could apply in many cases, where expansion of either the maximum biomass stocked, or the annual biomass produced is not feasible. The gap in the margin is shown to widen significantly under this revision of assumptions.

It can be argued that the assumption of a higher total production of fish biomass without any additional costs of labour, fuel and other overheads, is unrealistic. At worst there could prove to be additional costs amounting to £250 per tonne of additional production. Again this widens the gap in margin, as indicated in sensitivity test nine, though not so significantly.

Sensitivity test ten shows that if the more optimistic possibility for juvenile costs of 35p is realised, then it only takes a small improvement of 12p per kilogram in the budgeted sale price for the cod production to achieve competitiveness with the salmon production.

It has to be noted that in this budget for cod production no costs have been included for artificial lighting of cages to control daylength and delay the potential onset of sexual maturation in winter with the concomitant reduction in growth rate or even weight loss. This may be necessary to achieve the planned sales of 2kg fish during the winter months and to maintain the quality of the product or, alternatively, some of the cod may be sold earlier at lighter weights.

Control of sexual maturation becomes a more important issue if one is considering extending the growout period to produce cod at heavier weights. It is indicated by Huse (1991) that, while cod may reach 2kg in 20 months, because of weight loss in spawning it may take another year to reach 3kg, though he does envisage that 3kg may be achieved by 2 years of age in future commercial production as a result of selective breeding and domestication effects. The Nautilus report (1997) indicated high returns for systems growing cod to 4kg as a result of a higher expected price, but that was based on a growout period of 18 or 19 months from 20g and "the issue of maturation has not been addressed" (p.31).

The costs of artificial illumination of cages may not be very great, depending on the type of site and the characteristics of the cages used, but environmental issues have to be considered. It is an aspect requiring further study, and if commercially practical will help towards realising a viable margin from cod production, because of the higher potential price for larger fish. However, it is not likely alone to fully close the gap between the margin from cod and that from salmon.

A minor point to be noted in relation to the analysis in Table 5 is that there will be some additional cost attaching to the cod plus salmon system in that there is an increase in the amount of working capital invested in purchases of juvenile fish and feed which could add around £15,000 in interest charges if financed from outside sources at an interest rate of 10%.

5. Discussion and Conclusions

Although there is a significant body of research publications providing information relevant to the potential for commercial cultivation of cod, and also some evidence available from pilot commercial projects, as identified in earlier reports on the subject (Whitmarsh and Pickering 1996, Nautilus 1997), there remain considerable areas of uncertainty with regard to (a) the technical requirements and likely performance of cod in commercial scale production, and (b) the price level which may be realised for regular, controlled supplies of cultivated cod.

Modelling of a potential commercial hatchery for the production of cod juveniles indicates that fish large enough for stocking in sea cages can be produced profitably at a price per fish which is at least measured in pence rather than pounds, and there are indications from the current season of the research programme by SeaFish on the hatching and rearing of cod larvae that the costs of juvenile fish could come down to a very modest level in large scale commercial production. That is an essential prerequisite for viable cod farming, but the cost of juveniles then becomes a relatively small element in an enterprise producing cod and it is other issues in farming cod which are crucial in determining the potential viability of such a venture, most importantly the sale price.

A simplifying approach to assessment of the viability of cod on-growing was adopted in this report, namely to consider it as a potential alternative use for some of the resources of an existing salmon farming business. This largely eliminates the uncertainty involved in detailed estimation of overhead costs for a cod farming business and, by examining the replacement of a salmon activity with a similar length of growout period to that for the cod on-growing, the time factor is eliminated from the analysis and discounted cash flow investment appraisal is not required to indicate the relative economic viability of the project.

The results of this analysis do not really accord with the very positive comments in the closing section of the Nautilus report (1997). Rather they tend to support the initial conclusions of Ahmed (1995) that ongrowing Atlantic cod would not be financially worthwhile under current assumptions of technical requirements, performance levels and expected prices.

Whitmarsh and Pickering (1996) saw potential for cost reductions and a price premium for cultivated cod which might potentially result in a viable enterprise as part of an existing salmon farm. However, the comparative analysis with salmon production in this report indicates that significant improvements in a number of the assumptions on performance of cod and factors determining costs would be needed to bring viability in comparison with salmon production.

The one crucial factor which will determine the prospects for the development of viable cod farming is the level of prices for farmed cod which the market will be willing to pay. Either the premium which cultivated cod may gain over wild cod will have to be significantly greater than has so far been envisaged, or the price of cod in general will need to rise significantly for cod farming to appear a favourable prospect for development on a significant scale.

It is important to note, however, that prices of cod have generally shown a significant upward trend in the past year. The average price of landings of cod in the first four months of 1998 was 11% higher than in the same period of 1997 (Worldfish 1998). A similar trend was shown in the weekly prices of fresh headless cod on the Billingsgate market[1]. Indeed it may be noted that the mean of these weekly prices over the first half of 1998, was £3.44 per kilogram which, when adjusted for 32 per cent weight loss in gutting and heading, gives a wholefish equivalent of £2.34 per kg (though the average fish weight is not known, and grading, gutting, transport, packaging costs and commission have to be allowed from that price to convert to what is likely to be obtainable for whole farmed fish delivered to a local processor). Thus further analysis of the market for cod, investigation of the potential price premium attainable for farmed cod, and assessment of the future trend in cod prices are the areas for further study which could do most to clarify the prospects for commercially viable cod production.

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1 Market report data supplied by SeaFish.

It is clear that development of farming of cod cannot follow a similar pattern to that of most of the farmed species so far developed, such as salmon, sea bream, sea bass, and probably turbot and halibut. These have been relatively high priced species with rather small existing markets. The initial production of these species was able to proceed profitably on a fairly small scale because of the high prices, though as production has expanded prices have fallen significantly in order to develop an expanded market. For cod there is a large existing market and apparently declining wild supplies, so there is large-scale market potential for cultivated cod production, but at modest price levels. Thus it will be necessary for viability, that cod cultivation be rapidly developed in large units for economies of scale. Development within the context of existing large-scale salmon units can ease the problem with regard to on-growing, but the launching of a commercial-scale hatchery could be a significant hurdle to be overcome for cod farming to develop. A clear demonstration in practical and economic terms of the potential viability of the on-growing activity will be needed on a pilot scale in order to show a potential demand for juveniles and thus encourage the investment required for a commercial-scale hatchery such as that budgeted in this report (Tables 3, 4, and Appendix 4), which is estimated at around £1million including working capital.

It must be appreciated that formal experimentation and trials in the UK aimed towards the development of potentially viable systems for the cultivation of cod are still at a very early stage, so there is considerable uncertainty surrounding many of the assumptions adopted in the analysis carried out in this report, which need to be confirmed or otherwise by that experimentation and pilot trials. It is hoped that this interim economic analysis is helpful in looking at the complete production system in economic terms and giving some idea of the issues involved and relative importance of different aspects of the production process in determining viability.

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Appendix 1. Cod Hatchery - Outline System Plan Producing 472,000 25g Juveniles

Appendix 2. Cash Flow for Hatchery Selling 472,000 25g Juveniles

Appendix 3. Cod Hatchery - Outline System Plan Producing 1.84 Million 25g Juveniles

Appendix 4. Cash Flow for Hatchery Selling 1.84 Million 25g Juveniles

Appendix 5. Plan for Salmon Production

Appendix 6. Plan for Salmon and Cod Production