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Technical Report 148

A study to define and cost
a system which might, under more
favourable market conditions, be
adopted in the commercial farming of plaice

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A study to define and cost a system which might, under more favourable market conditions, be adopted in the commercial farming of plaice

FOREWORD

Much of the Authority's early work in rearing marine fish was concentrated on plaice, however as the trials data accumulated over the late 60's and early 70's, it became apparent that, despite its suitability as a farm animal, the plaice could not under the market conditions prevailing recover its costs of production. This was demonstrated by a joint study with the Central Electricity Generating Board (ref 1) using 1971 data, which concluded that the estimated production cost of farmed plaice per ton, would be nine times the then value per ton of current trawler landings.

Since that time, W.F.A. trials have centred on two of most highly valued species, Dover sole and turbot. As the study to forecast the commercial costs of farming Dover sole and turbot, published in 1976 (ref 13), made use of considerable improvements in farming technology since the completion of the first "plaice" report, the present study has been carried out to examine how far the advances in technology and the changing market conditions may have altered the prospects of commercial viability for farming plaice.

This report provides a summary of the experimental trials conducted during the period 1968 to 1973, upon which the present study has been based. Also for ease of compilation, and comparison with the farming costs for the other species, the operative date for the price data has been taken as for the study into these species, i.e. December 1975.

Summary of the main conclusions

1. The farming of plaice on a commercial scale is technically possible but still far from being viable. Technical advances in the last five years, have however reduced the estimated cost of production from over £1,300 per tonne at 1971 prices to around £1,000 per tonne at 1975 prices, depending on method of production.

2. Sea cage and enclosure methods of fattening appear to offer production costs, lower by 20 to 25%, than the tank method of fattening.

3. The market value of wild plaice has increased from around £150 in 1971 to around £440 in 1975.

4. Thus in real terms the ratio between the value of wild plaice and the estimated cost of producing farmed fish has reduced from 9:1 to approximately 2:1 between 1971 and 1975.

5. It is considered that there is potential for further technical development, which might greatly reduce the costs of production.

6. From the foregoing, it is possible that the farming of plaice could become commercially viable in the foreseeable future.

Recommendation

1. In view of the improvement towards financial viability summarised above, it is recommended that this study should be reviewed in 2 or 3 years time.

1. Introduction

1.1 Results from the small-scale hatching and larval rearing trials with plaice, Pleuronectes platessa L., conducted by Shelbourne and his co-workers in the late 50's and early 60's (refs 2,3 and 4) demonstrated that a mass production hatchery technology was within the bounds of development feasibility. Accordingly, a joint project between the Ministry of Agriculture, Fisheries and Food (M.A.F.F.) and the White Fish Authority (W.F.A.) and financed by them, was started in 1964. A new hatchery designed and equipped with facilities based on the experience gained in the M.A.F.F. small scale trials was put into operation at Port Erin, Isle of Man, and continued to operate until 1967. After that time hatching and larval rearing was done at the W.F.A.'s Hunterston fish farm.

1.2 In developing a mass-production technology for metamorphosed plaice at the Port Erin hatchery, the first trial in 1964 demonstrated that newly metamorphosed stock of a mean size of 15mm reared on a diet of brine shrimp, Artemia salina, and transferred to large rearing facilities established by the W.F.A. at Hunterston nuclear generating station on the Clyde estuary and at Ardtoe intertidal enclosure in west Argyll (refs 5,6 and 7), could not be weaned on to inert diets at acceptable survival rates. Consequently from 1965 onwards, production of young fish in the size range 20 to 30mm was adopted, with initial weaning being completed in the hatchery.

1.3 The hatchery system initially developed at Port Erin was based on a large number (128) of tiered polythene tanks of 200 litres volume, each with its own water supply and illumination (ref 8). During 1967/68 larval rearing trials with sole at Port Erin (ref 8) and plaice at Hunterston (ref 9), both conducted in larger rearing facilities, it became apparent that for management and economic reasons the larger facilities ($6.9m^3$ and $4.3m^3$ volume), operated under relaxed environmental circumstances, were better suited to mass-production techniques compared to the small 200 litre tanks used in the earlier trials, even though survival rates from the fertilised eggs through to the 20 to 30mm size range were not so good (ref 9).

1.4 During the early Port Erin trials the incidence of abnormally pigmented fish was as high as 90%; this declined to 20% latterly and was attributed to increasing acclimatisation of resident spawning stock (ref 10).

2. Technical scope and limitations of the study

2.1 Farming methods

Three farming methods are considered in this study, they are: the 'tank method' based on larval and post-hatchery rearing carried out in tanks supplied with warm sea-water discharged by an electricity generating station such as the W.F.A. experimental farm site at Hunterston. The 'cage method' and the 'enclosure method', where larval and post-hatchery rearing is completed in ambient sea-water conditions initially in tanks on-shore to a size at which they can be transferred to either sea cages or enclosures for fattening; in the manner developed at the W.F.A. experimental farm site at Ardtoe.

Flow process charts of the three methods are shown in figure 1.

These methods differ substantially from the lagoon systems envisaged in the joint W.F.A. C.E.G.B. study of 1972 (ref 1) referred to in the foreword.

2.2 Main farming parameters on which the study is based

(i) Wherever possible proven data relating to plaice is used. Otherwise data established with sole or turbotm or where relevant with trout have been substituted.

(ii) Survivals to a size of 40mm from fertilisation proved, 9%, forecast 16%.

(iii) Well established live foods are fed in the early hatchery phase.

(iv) Established low costweaning diets are fed in the later hatchery phase (tables 3 and 4).

(v) A moist pellet diet (tables 4 and 11) costing £118 per tonne is fed throughout ongrowing.
A conversion ratio of 1.2:1 (wet:wet) has been established with turbot and is expected to be reproducable with plaice.

(vi) Maximum stocking densities are:

	in tanks	in cages	enclosures
proved,	18kg/m^3	87kg/m^3	15kg/m^3
assumed,	40kg/m^3	75kg/m^3	50kg/m^3

(vii) Minimum water flows are:

proved, plaice 0.01m^3/kgh, turbot under recirculation conditions at 3kg/m^3 density 0.001m^3/kgh (ref 11)

assumed, 0.02m^3/kgh.

(viii) Forecast growth curves are shown in figure 2.

2.3 Farm size

For simplicity a single size of farm with an annual output of 100 tonnes of plaice p.a. was considered. The main parameters are set out in table 2. The relationship between costs and farm size is discussed in the studies on Dover sole and turbot (T.R. 130) (ref 13) and is similar for plaice.

2.4 Marketing

Fish size It is assumed that the fish would be marketed at 300g as this is a size acceptable to both the wet fish and 'value added' markets.

Fish over this size in captive conditions commence maturation and the conversion ratios increase.

Value Mean monthly wholesale prices during 1975 at Lowestoft are shown in figure 4. Representative value £440 per tonne.

2.5 Labour and management

The hatchery and on-growing units are assumed to be vertically integrated, with staff transferable to suit the prevailing workload.

It is assumed that the farm will be run by a manager, a senior hand and several labourers, according to output. Productivity in the hatchery and with sea cages is deduced from W.F.A. experience, and in general on-growing in tanks from trout experience (ref 12); the latter rises from 9 to 15 tonnes/man year over the farm size range.

2.6 Equipment

Agricultural standards are adopted in specifying buildings and fittings. On-shore tanks have been specified, similar to those readily available for trout. Specialist equipment, including cages, are to commercial standards. A summary of the main capital items is given in table 5.

3. Costing procedures

3.1 All costs and sales values are 1975 figures.

3.2 Costing procedure has been similar to the studies of Dover sole and turbot. (Ref 13)

Costs of production (table 6) are calculated for each farming method/species combination against the following centres:-

(i) Hatchery
- (a) food
- (b) labour
- (c) energy consumption
- (d) depreciation
- (e) maintenance
- (f) brood stock

(ii) On-growing
- (a) food
- (b) labour
- (c) energy consumption
- (d) depreciation
- (e) maintenance

(iii) Insurance, covering both (i) and (ii) above.

(iv) Management/administration and other, covering (i) and (ii) above.

(v) Interest upon loan capital.

The "cost of production" is taken as the sum of items (i) to (iv) above and the "total farm cost" includes item (v) also. It should be noted that item (v) is given as a guide and actual charges may vary considerably, depending upon company circumstances.

3.3 The following cost centres have been omitted, as they depend so much upon the individual farm site and on company or Electricity Generating Board policy:-

(i) Land rent, lease or purchase

(ii) Distribution and marketing of the farm produce

(iii) Profit

(iv) Charge for providing warmed water in the 'tank method' (Note that all pumping costs are charged).

3.4 In this simplified study sensitivity analysis were omitted.

4. Commercial assessment

4.1 Capital

The capital costs for a 100 tonne p.a. farm unit are given in table 5. The capital cost per tonne of production for the sea cage method is about £1,300, for the enclosure method £1,800 and for the tank method £2,700. The sea cage method for farming plaice requires considerably less capital than turbot since no warm water nursery stage is required. The reduction in the cost of tanks for plaice as compared with Dover sole reflects the higher stocking density of plaice.

4.2 Breakdown of costs

The relative importance of the main cost centres as given in table 6, may be summarised as follows;

Capital items	Sea cage %	Enclosure %	Tank %
Maintenance, Depreciation and interest on fixed capital	34	42	46
Labour	22	19	13
Food	18	16	13
Energy	1	1	10
Management & administration	17	15	12
Insurance	8	7	6

The sea cage and enclosure methods seem to offer distinct advantages in lower production costs.

5. Discussion of the potential for improvement beyond the forecast performance

5.1 Area of greatest potential

This study has been based on the natural spawning period of plaice and has assumed a single production batch each year. This means that the utilisation of the farm facilities is very inefficient. Trials with out of season spawning of turbot and sole in 1976 and 1977 suggest that their spawning period can be extended considerably.* A very substantial reduction in all equipment costs could be achieved. This would be particularly

* Trials at the M.A.F.F. laboratory Port Erin in 1976 yielded turbot eggs some 3-4 months ahead of normal spawning period. Trials at W.F.A. Marine Farming Unit Hunterston in 1977 yielded sole eggs some 2 months ahead of normal spawning period.

beneficial for the tank method, where not only would the number of tanks be reduced but also the whole scale of pumping and pipework installations.

5.2 Other areas for potential improvement

The scope for technical advances with regard to Dover sole and turbot which would material reduce a number of costs is discussed in T.R. 130 (ref 13). Cost centres where similar potential might be available with plaice are;

Energy consumption,
Labour,
Hatchery.

6. Conclusions

6.1 The farming of plaice on a commercial scale is technically possible.

6.2 Plaice farming is still far from being commercially viable. The cost of producing farmed plaice by the most economic method, was at 1975 price levels, estimated to be about double the market value of trawl caught fish. However in 1972 production costs were assessed at nine times market value, so that the position has very greatly improved in five years.

6.3 There is considerable scope through technical development for further reduction in production costs.

6.4 Sea cage and enclosure methods seem to offer distinct advantages in lower production costs.

6.5 The cost centres related to capital equipment, taken together, form the most significant factor in production costs. The greatest potential for cost reduction would therefore seem to lie in the more efficient use of capital equipment.

6.6 Technical development, which allows a substantial extension of the spawning period could make a major contribution to reducing costs.

6.7 Most of the main parameters which affect the cost of marine fish farming are similar for plaice, turbot or Dover sole. The commercial potential of plaice should therefore continue to be reviewed from time to time in the light of technical progress and economic changes.

7. Detailed description of the experimental trials on which the 1968/73 system is based

The basic husbandry data based on methods and equipment in R & D trials are shown in table 1. Growth is shown in figure 2.

7.1 Spawning stock

Breeding stock have been held in ponds and tanks situated either outdoors or indoors (Ref 8). The latter situation has been preferred by the W.F.A. on the grounds of management and husbandry. Breeding stock have also been held in floating cages, although naturally spawned eggs have not been collected under these conditions.

In through flow indoor tank systems temperature regimes have followed the ambient off-shore seawater range of 6^{o} to $17^{o}C$, by direct pumping. A mean stocking density of $1.0kg/m^{3}$, with a flow rate of $0.17m^{3}/kgh$ was standard for tanks of $11.0m^{3}$ volume.

In floating cages, breeding stock have been held at a stocking density of $25kg/m^{3}$ in a cage of $5.5m^{3}$ volume with a temperature range of 6^{o} to $16^{o}C$.

The spawning period under captive conditions was on average over a period of 45 days, usually commencing in late March with stock held in tanks, and in early April with stock held in cages. An average of 50×10^{3} eggs liberated per female of a mean weight of 350g has been calculated for the purposes of this study, although double this quantity may be released by similar fish in wild conditions (Ref 16). The average egg count was 250 eggs/g. A sex ratio of one male to one female was maintained in tank and cage held stocks.

A variety of diets have been fed to breeding stocks, ranging from lugworm and fresh mussel to trash fish, the latter being more easily obtainable and prepared. An average of 2% level of the total biomass has been fed.

7.2 Egg collection and incubation

Artificially fertilised eggs obtained by manual stripping were held initially for a period of 48 hours to allow damaged and infertile eggs to drop out. Measured quantities of buoyant fertile eggs were then transferred to 200 litre tanks and stocked at a density of 20 eggs/litre for further incubation. In both instances static seawater conditions were maintained with continuous gentle aeration. A standard dosage of antiboitics, 50i.u./ml penicillin and 0.05mg/ml streptomycin were added to the seawater at both stages. Temperatures were controlled to match the spawning temperature, in the range of 6^{o} to $8^{o}C$. The last 48 hours of incubation out of a total of 15 days was completed in the larval rearing tank ($4.3m^3$). Survival from fertilisation up to hatching averaged 70%.

7.3 Larval rearing to juvenile stages prior to weaning

Eggs in the gastrula phase of development were transferred from the 200 litre incubation tanks to a $4.3m^3$ permeable cage (3 x 1.2 x 1.2m) made from a fine meshed material (chiffon) secured to a plastic pipe framework and positioned in an outdoor tank of $50m^3$ volume. Eggs were stocked at 18 eggs/l (20×10^3 eggs/m^2). Hatching was completed within 48 hours under static water conditions at a temperature of 7^{o} to $8^{o}C$. The cage was shaded to reduce light intensity and inhibit weed growth. Static water conditions were maintained for nine days (day 24 after fertilisation), when flow was commenced into the $50m^3$ tank at $0.6m^3/h$ with untreated power station discharge with a free residual chlorine content of 0.02ppm. Aeration into the larval rearing cage commenced on day 22 after fertilisation. Dissolved oxygen levels were within the range 96 to 107% saturation. Under these conditions it was not possible nor was it sought to control seawater temperatures, which fluctuated within the range 7.8° to 17.3°C (ref 9).

Feeding with Artemia nauplii commenced on day 19 after fertilisation and continued for 30 days (48 days after fertilisation).

For the purposes of this study Artemia nauplii feed rates assessed by Shelbourne (ref 8) with a temperature regime of 6° to 15°C, where a slight surplus was maintained 24 hours after feeding, have been used as a basis for estimating satiation feeding, with an approximate over allowance of 40% to compensate for increased appetite at the higher temperature regime and wastage in the more relaxed environmental conditions of a permeable cage. Daily naupliar feeding levels per larva, taking into account the factors outlined were assessed as:- 0-70 nauplii (5 days), 120-170 nauplii (5 days), 170-220 nauplii (5 days) and 220-420 nauplii (10 days). Over the last four days of Artemia nauplii feeding (days 45 to 48 after fertilisation) the daily ration was reduced proportionately by the amount by weight of live enchytraeid oligochaete worms, Lumbricillus rivalis, consumed (wet weight of 1×10^6 Artemia nauplii = 12.1g). Complete acceptance of the worms was usually accomplished by day 48 after fertilisation when the fish were released into the $50m^3$ tank (day 49). Survivalof 20-30mm fish at this time (day 48) was assessed at 26% from hatching (18% from the eggs incubated) (ref 9). This represented approximately 21×10^3 fish at an estimated biomass of 4.2kg ($0.9kg/m^3$ - mean weight fish 0.2g) at a density of 5,800 fish/m^2 (4,800 fish/m^3) with a flow rate of $0.15m^3$/kgh into the $50m^3$ tank.

7.4 Weaning the juvenile stages

The $50m^3$ tank (15 x 4 x 0.8m) lined with a fitted plastic material was stocked with approximately 21 x 10^3 juvenile fish of a mean size of 20mm at a biomass level of $0.84kg/m^3$ (420 fish/m^3 or 350 fish/m^2). A flow of untreated power station discharge at $0.7m^3/h$ was commenced and held at that rate for the 50 day period (days 48 to 98 after fertilisation). During this time weaning on to an artificial diet was completed. The free residual chlorine content remained stable at 0.02ppm. Dissolved oxygen levels were within the range 70 to 120% saturation, maintained by vigorous 24 hour aeration. The temperature range was 15^o to 21^oC. The tank was shaded to reduce light intensity and inhibit weed growth.

Lubricillus worms were fed at a satiation level for the next 22 days (days 49 to 70 after fertilisation). The daily feed of worms was based on the estimated biomass. Assuming that about 15% body weight per day was consumed, this gave a daily requirement in the range of 600 to 900g of Lumbricillus worms.

From days 71 to 98 (after fertilisation) a moist compound diet, extruded through a syringe to simulate a worm-like appearance, and injected at the aeration points to provide movement, was fed. This consisted of finely minced scallop meats with a vitamin supplement and an alginate binding agent (ref 9). An estimated 10% of the biomass was fed per day. Observed wastage was high and the estimation of conversion ratios was not possible or considered meaningful for such a short period in which the main objective was to achieve acceptance of an artificial diet.

Survival at day 98 after fertilisation was 9% (53% from days 48 to 98 the period of weaning). The population had then reached a mean size of 40mm, mean weight 0.7g, with a biomass of approximately 8kg ($0.16kg/m^3$), at a density of 190 $fish/m^2$ ($230 fish/m^3$) with a flow rate of $0.08m^3/kgh$.

7.5 Fattening in tanks

Fattening was carried out in $50m^3$ tanks until day 500 after fertilisation, and then completed to day 688 in $25m^3$ tanks. For the purposes of this study only the $50m^3$ tank is considered since the reasons for using the smaller tank were dictated by water exchange design, and the biomass levels of production have been extrapolated for a $50m^3$ tank system.

The $50m^3$ tank was stocked with 4,200 fish of a mean size of 40mm (mean weight 0.7g) at a biomass level of $0.58kg/m^3$ (day 99 after fertilisation), density was 70 $fish/m^2$ ($84 fish/m^3$). Survival to day 288 was 83% (7% from fertilisation) with a weight increase of 39.3g, giving a biomass level of 140kg ($2.8kg/m^3$).

From day 288 to 588 (days after fertilisation) mean weight increased from 40g to 200g, and the biomass level from 140kg to 660kg ($13kg/m^3$) with a survival of 95% (6% from fertilisation). Final fattening to 300g mean weight was completed in a further 100 days (588 to 688) with the biomass reaching a level of 900kg ($18kg/m^3$) and a survival of 95% (5% from fertilisation).

Water flow rates for the periods were: days 99 to 288 - 8.3m^3/h (0.06m^3/kgh), days 289 to 588 - 12.5m^3/h (0.02m^3/kgh), and days 589 to 688 - 16.6m^3/h (0.01m^3/kgh). Temperature was within the range 13° to 22°C, with residual chlorine levels at 0.02ppm except for the last 100 day period when they ranged up to 0.08ppm without any detrimental effect on the stock. Dissolved oxygen levels were in the range 80 to 120% saturation.

7.6 Food production

7.6.1 Artemia production

The standard system for all production of *Artemia* nauplii was employed (ref 17). Two tanks, each of 680 litres, for alternate daily production in the range of 70 to 175/ml at 25°C, gave an average hatch viability of 60%. At maximum egg loading (0.5g/l) the daily production of this unit was 71 x 10^6 nauplii (refs 14 &15).

7.6.2 Ongrowing diets

During the period 1968/72 various types of diets were fed to stocks being ongrown. At the start, hand shucked mussel was fed giving a mean wet to wet conversion ratio 5:1 (ref 18). This diet was abandoned on the grounds of the labour involved to produce the large quantities required.

A compounded diet was developed consisting of minced white fish with various additives and vitamins bound together with binders derived from seaweeds and later cereals. This mixture was packed into plastic troughs which were lowered into the tank for feeding. A series of trials were commenced to determine the most efficient binding agent (ref 19) which would reduce the heavy wastage rates observed with this method of food presentation. In the course of this development work a moist pelleted food was devised (ref 18), based on the 'Oregon' pellet formula (ref 20) a series of binding agents were tried with this diet (ref 21). These early formulations of the moist pellet (WFA 6) (ref 22) were fed successfully to a number of ongrowing stocks. A mean wet to wet conversion ratio of 5:1 was obtained with a feed level of 6% of the biomass. Stocks of 40mm fish were fed moist extrusions of the WFA 6 diet at various sizes to suit their mouth parts as they grew. With this diet fish attained a mean weight of 300g in 590 days from 40mm (0.7g), days 98 to 688 after fertilisation.

It should be noted that the move to pellet feeding to stocks held in tanks was largely influenced by the unhygienic bottom conditions and food particles in suspension, created by large masses of food packed into troughs.

7.7 Process for cage culture

7.7.1 Nursery phase

The following process was based upon O-group plaice collected from the beaches. On collection these fish were at an approximate age of 3 months (98 days), with a mean weight of 0.7g, length 40mm.

Before being put out into floating cages for fattening, the stock was held in onshore tanks for a period of 65 days (days 98 to 163 after fertilisation), until a mean weight of 4g, mean length 6cm, had been obtained. The 1.0m^3 tanks were situated indoors, each supplied with pumped ambient seawater at a flow rate of 0.9m^3/h. At this flow rate a final biomass of 2.5kg/m^3 was achieved with a specific flow rate of 0.03m^3/kgh. The temperature range from 14^o to 16^{o}C (July to early September). Tanks were stocked with 780 fish/m^3, a final survival of 625 fish/m^3, 80% over the 65 day period (7% from fertilisation) was achieved.

A compounded diet consisting of minced white fish with various additives and vitamins bound together with a Hydroxypropyl methylcellulose binding agent was packed into plastic troughs, and fed at satiation rates.

7.7.2 Fattening in floating cages

At day 163 fish of a mean weight of 4g (mean length 7cm) were transferred from the nursery tanks (1.0m^3) to floating cages of 3m^3 volume (ref 5). In these facilities they were stocked at 395 fish/m^3 until a mean weight of 200g was achieved (day 763). A survival of 95% over the 600 day period was obtained (6. from fertilisation), with a final density of 375 fish/m^3 at a biomass of 75kg/m^3. At this stage the stock was thinned to reduce the final stocking density to 250 fish/m^3, in order not to exceed the 75kg/m^3 biomass level which was considered the practical maximum (ref 5). For the next 120 days (days 763 to 883) 200g fish were reared to a mean weight of 300g. Survival was 95% (5% from fertilisation). Temperature ranged from 6^o to 16^{o}C during the fattening period in cages (days 163 to 883).

A compounded diet consisting of minced reclaimed cod flesh with various additives and vitamins bound together with a methycellulose binding agent, was packed into plastic troughs and fed at a daily rate of 8% of the biomass level. A wet to wet conversion ratio of 5:1 was obtained.

7.8 Process for sublittoral enclosure

7.8.1 Nursery phase

The nursery phase was identical to that of fish reared for cage culture (para 7.7.1).

7.8.2 Fattening in sublittoral enclosure

Fish of a mean weight of 4g (mean length 7cm) were transferred from the nursery tanks ($1.0m^3$) to a sublittoral enclosure of $21m^3$ (7 x 3 x 1m), positioned in the Ardtoe intertidal pond. Fish were stocked at a density of 95 fish/m^3 and reared to a mean weight of 300g in 690 days (ref 6). Survival over the period (days 163 to 853 after fertilisation) was 53% (4% from fertilisation), the final stock density was 50 fish/m^3 at a biomass level of 15kg/m^3.

A compounded diet identical to that fed to fattening stock in cages (para 7.7.2) was presented in plastic troughs at 8% of the biomass level. A wet to wet conversion ratio of 5:1 was obtained.

8. Detailed description of a forecast system for a farm having an annual production of 100 tonnes of plaice at 300g

The basic husbandry data for the forecast system are shown in table 2.

8.1 Hatchery systems

In this study three methods of fattening plaice are considered: in tanks supplied with warmed water discharged by an indsutrial process, e.g. electrical generating station, and cages or enclosures positioned in sheltered sea locations. In view of this, two hatchery systems are considered, based on either a warm or a cold sea water supply, from which each fattening system would draw on supplies of weaned juveniles reared in an environment identical to the one in the fattening stages. Although larval rearing trials to the weaned juvenile stage were completed successfully in approximately half the time scale in warmed water conditions (ref 23) compared to cold water; most production trials were conducted at much lower temperature regimes (ref 8).

The hatchery systems conducted under either cold or warm temperature regimes are based on a 16% survival from fertilisation to a weaned fish of 40mm. This forecast increase of 7% over the R & D 1968/73 trials, is approximately 50% lower than survivals obtained in laboratory trials (refs 8 and 23) and has been adopted to take into account the more relaxed environmental circumstances which would be followed in a process of mass production.

8.2 Spawning stock and egg collection

It has been established that adult plaice held in captive conditions can be manually stripped of eggs and milt during late March for stock held in tanks and early April for stock held in cages, over a period of 45 days (para 7.2).

The number of eggs required for a hatchery supplying juveniles for tank or cage culture would be 2.8×10^6. This quantity of eggs could be supplied by 56 females (50×10^3 per female). In the case of enclosure culture 68 females would be held to supply 3.4×10^6 eggs: a larger number being required as the forecast survival at the ongrowing stage (70%, i.e. 8% from fertilisation) is 25% lower than for the other ongrowing systems. The stock would be held at a sex ratio of one female to one male.

In order to stock the incubation baths and the larval rearing enclosures in as short a time scale as possible it is considered necessary to have an excess egg production capacity. Therefore, the number of adult plaice has been doubled, which gives holdings of 224 adults (tank/cage system) and 272 adults (enclosure system).

Fertilised eggs are collected by manual stripping at two day intervals over a period of 20 days, each collection giving 1,120g or 280×10^3 eggs (6 females stripped per day at an average production of 50×10^3 eggs each at 250 eggs/g). Sufficient eggs are produced in each of the ten collections to stock $14 \times 1m^3$ volume incubation baths, and eventually 3 larval rearing cages of $5m^3$ volume at the rate of 83×10^3 eggs for the completion of incubation.

8.3 Egg incubation

Egg incubation commences on day 1, the first day after fertilisation and takes 15 days at temperatures in the range 6° to 8° C (temperatures are matched to spawning temperatures). Ten egg batches each of 280 x 10^3 are required for a hatchery producing fish for either tank or sea cage rearing, whilst twelve batches of 280 x 10^3 eggs are required for enclosure rearing. In the case of the former two systems the last batch is completed on the 33rd day of the hatchery operational time scale, and for the enclosure system on the 37th day.

Incubation baths of $1m^3$ are used, stocked at 20eggs/l (20,000 eggs/tank) requiring 140 tanks to be provided. The last 48 hours of incubation are completed in $5.0m^3$ cages positioned in the $50.0m^3$ tanks, one per tank, three cages being stocked per egg batch of 280 x 10^3 (93 x 10^3 eggs/cage).

8.4 Larval rearing to juvenile stages prior to weaning

A forecast hatching rate of 90% is based on laboratory trials (refs 8 and 23). Thirty larval rearing cages are required (tank or sea cage post hatchery rearing) or forty for fish to be eventually reared in enclosures. Each cage is stocked with 93 x 10^3 eggs and, with a 30% survival to 20mm, producing approximately 25 x 10^3 juvenile fish for weaning, giving a total production of 750 x 10^3 (tank and sea cage rearing) or 930 x 10^3 (enclosure rearing).

Static water conditions are maintained until day 24 after fertilisation, when flow is commenced at a rate of $0.2m^3$/kgh ($1.0m^3$/h) into the $50m^3$ tank. This flow rate is maintained until day 48 in warmed water conditions and to day 90 in cold (estimated biomass per larval rearing cage - $1.0kg/m^3$, mean weight of fish at 20mm - 0.2g). Temperatures in the warmed water conditions where untreated power station discharge is used are in the range 7.8° to $17.3^\circ C$. In the cold water a range of 6.5° to $11.5^\circ C$ is obtained during April to mid-June (west coast Scotland ambient seawater temperature range).

Artemia nauplii are fed on day 19 after fertilisation and continued for 30 days (48 days after fertilisation) in warmed water conditions and for 75 days (90 days after fertilisation) in cold. Larval feeding rates for Artemia nauplii are based on those established under the experimental system (para 7.4). Artemia naupliar production is commenced on the 17th day of hatchery operation, to provide feeding for the first batch on the 19th day. Under warmed water conditions Artemia production continues for 63 days, and for cold water conditions 104 days (sea cages) and 108 days (enclosures). A peak requirement of 315×10^6 nauplii per day, calculated at 420 nauplii/larva, in warmed water conditions, and 262×10^6 nauplii per day, calculated at 350 nauplii/larva, in cold water conditions, requires three production units, each of 100×10^6 daily capacity, for either system.

It is assumed for the purpose of this study that an artificial diet, a moist extrusion based on WFA7(J) (refs 13 and 22) will replace the live food, Lumbricillus rivalis (para 7.4). Feeding this diet would overlap the Artemia nauplii (days 45 to 48 after fertilisation in warmed water and days 72 to 75 in cold water).

At the end of the larval rearing stages to a size of 20mm, approximately 750×10^3 juveniles are released into $50m^3$ circular tanks in warmed and cold water conditions for tank and sea cage rearing, and 930×10^3 juveniles for enclosure rearing, on days 48, 90 and 90 respectively.

8.5 Weaning the juvenile stages

Juveniles of a mean size of 20mm are released from the $5m^3$ larval rearing cage into $50m^3$ circular tanks. Water flows of $0.02m^3$/kgh are maintained throughout the weaning stages in warm and cold water conditions for 50 and 70 days respectively, in the temperature ranges 15^o to 21^oC (warm) and 11.5^o to 16^oC (cold). During this time, days 48 to 98 in warm water and days 90 to 160 in cold water, weaning on to an artificial diet WFA7(J) is completed. The diet is fed at 10% of the biomass with a predicted wet to wet conversion ratio of 2:1. Peak food requirements of 31.5kg (30 tanks total biomass 315kg - $0.21kg/m^3$, for tank and sea cage production) and 42.0kg (40 tanks total biomass 420kg - $0.21kg/m^3$, for enclosure production) are estimated.

8.6 Fattening in the 'tank method'

In this method the fish are fattened in tanks on-shore, supplied with warmed sea water pumped from the discharge line of a coastal electricity generating station.

Weaned juveniles of 40mm are stocked into $50m^3$ circular tanks at a density of 170 fish/m^3 (8,500 fish per tank). Fifty-two tanks are required for accommodating 450×10^3 juveniles. The fish are held in these tanks for 590 days (days 98 to 688 after fertilisation) until a mean weight of 300g is achieved.

A specific water flow of 0.02m^3/kgh (7.0m^3/h and 50m^3/h for stages 1, 2 and 3 respectively) is maintained throughout the 590 days period, with temperatures in the range of 13° to 18°C.

For convenience in assessing the biomass levels and pumping requirements the fattening period has been split into three growth stages. The first stage from 40mm (0.7g mean weight) to 40g mean weight lasts 190 days, with density commencing at 170 fish/m^3 and reducing to 147 fish/m^3 (85% survival). In the second stage growth to a mean weight of 200g is achieved with a survival of 95% (11% from the egg). Density commences at 147 fish/m^3 (5kg/m^3) and reduces to 139 fish/m^3 (27kg/m^3) in 300 days (588 days after fertilisation). The final stage to 300g takes 100 days (688 days after fertilisation) when a survival of 95% is obtained with a density of 132 fish/m^3 at a final biomass of 40kg/m^3. The predicted biomass level of 40kg/m^3 is based on trials carried out by industry with other flatfish species (ref 24).

The basic data are given in table 2, and the growth curve is shown in figure 2.

The diet of the post-hatchery rearing stages is shown in table 3. It consists of various sizes of a moist pellet diet (WFA7) fed at 10, 6 and 4% of the biomass in stages 1, 2 and 3 respectively at a wet to wet conversion factor of 1.2:1.

8.7 Fattening in the 'sea cage method'

In this method the fish are held in the $50m^3$ circular tanks until they reach a mean weight of 4g (mean length 7cm), this is termed the nursery phase, and lasts for 65 days (225 days after fertilisation). Fish of this size are seeded into cages by the end of October.

In the nursery stage fifteen circular tanks of $50m^3$ capacity are required to accommodate 450×10^3 juvenile fish, commencing on day 160 from the egg. A survival of 85% is forecast. This with an initial stocking density of 590 fish/m^3 (29,500 fish per tank), the density is 500 fish/m^3 (25,000 fish per tank) at the end of the stage with the biomass increasing from 0.41kg/m^3 to 2.0kg/m^3. The tanks are operated at a specific flow rate of 0.02m^3/kgh on a once through system, with a pumped ambient supply in the range 12^o to 15^oC.

The diet for this stage is WFA7(J) (refs 13 and 22) fed at 8% of the biomass at a wet to wet conversion factor of 2:1.

On day 225, juveniles of a mean weight of 4g are stocked into sea cages of $20.0m^3$ capacity. They are fattened there for a period of 650 days (day 875 from fertilisation) until a mean weight of 300g is achieved. There are two growth phases, nominally 4g to 200g, and 200g to 300g. Sixty-eight cages are required, forty-eight of them being occupied for the first phase of 550 days (days 225 to 775) and a further twenty for the final fattening phase of 100 days (days 775 to 875).

In the first phase of the sea-cage stage (4g to 200g) the terminal stocking density is 375 fish/m^3 at 75kg/m^3, and in the second stage (200 - 300g), 250 fish/m^3 again at 75kg/m^3. Each cage therefore, holds a maximum live weight of 1,500kg. Survival in each phase is 95%, with a terminal survival of 10% from the egg. There are no pumping requirements as all water movement is provided by the tide, at an average of approximately 1.5m^3/kgh, which is 75 times greater than specified for the 'tank method'. Temperature is in the range 6° to 16°C.

A moist pelleted diet (WFA7) is fed at various sizes to suit feeding stocks throughout the 650 day period at 5 and 3% of the biomass in stages 1 and 2 respectively, with a wet to wet conversion ratio of 1.2:1.

The basic data are given in table 2 and the growth curve is shown in figure 2.

8.8 <u>Fattening in the 'enclosure method'</u>

The nursery phase is identical to that of juveniles reared for cage fattening (para 7.7) except that twenty 50m^3 circular tanks are required to accommodate 560 x 10^3 fish at the start and 480 x 10^3 fish at the end of the phase (85% survival - 12% from egg). This increase in numbers of juveniles for enclosure stocking is accounted for by the lower survival (70%) forecast in the fattening stage.

At a mean weight of 4g (7.0cm mean length) juveniles are stocked into sublittoral enclosures of 20m^3 capacity. One hundred are required for 480 x 10^3 juveniles (48 x 10^3 per enclosure), with a final number of 340 x 10^3 at the end of the 630 days fattening phase (days 225 to 855 after fertilisation). A biomass level at dat 225 of 0.94kg/m^3 increases to a forecast level of 50kg/m^3 on day 855, when fish have achieved a mean weight of 300g. A forecast survival of 70% (8% from fertilisation) is made for the fattening phase. The basic data are given in table 2, and the gorwth curve is shown in figure 2.

Temperatures are in the range 6° to 16°C, with all water movements provided by the tide.

A moist pellet (WFA7) is fed at a forecast level of 5% of the biomass with a wet to wet conversion factor of 1.2:1.

APPENDIX I

Comparison of fillet yield between wild and farmed species

A comparison of fillet yield between 3 year old farmed plaice and wild caught specimens of a similar size showed that farmed fish have approximately a 6% higher meat yield (ref 24). In laboratory trials (ref 23) it was noted that cultured plaice grew faster than their wild counterparts and were heavier for their length.

Figure 1 Flow Process Chart Plaice rearing

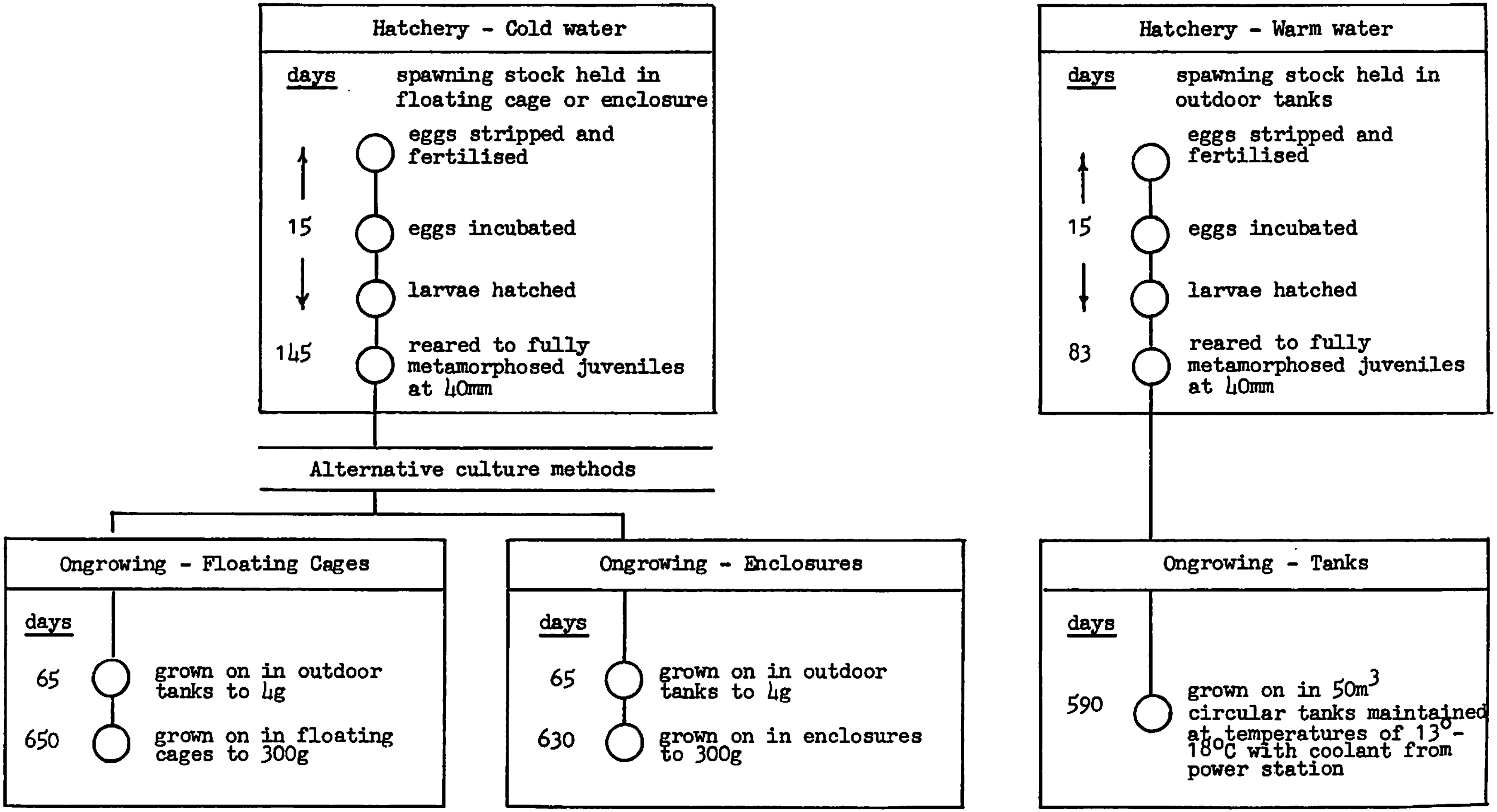

Figure 2 Forecast growth curve for Plaice

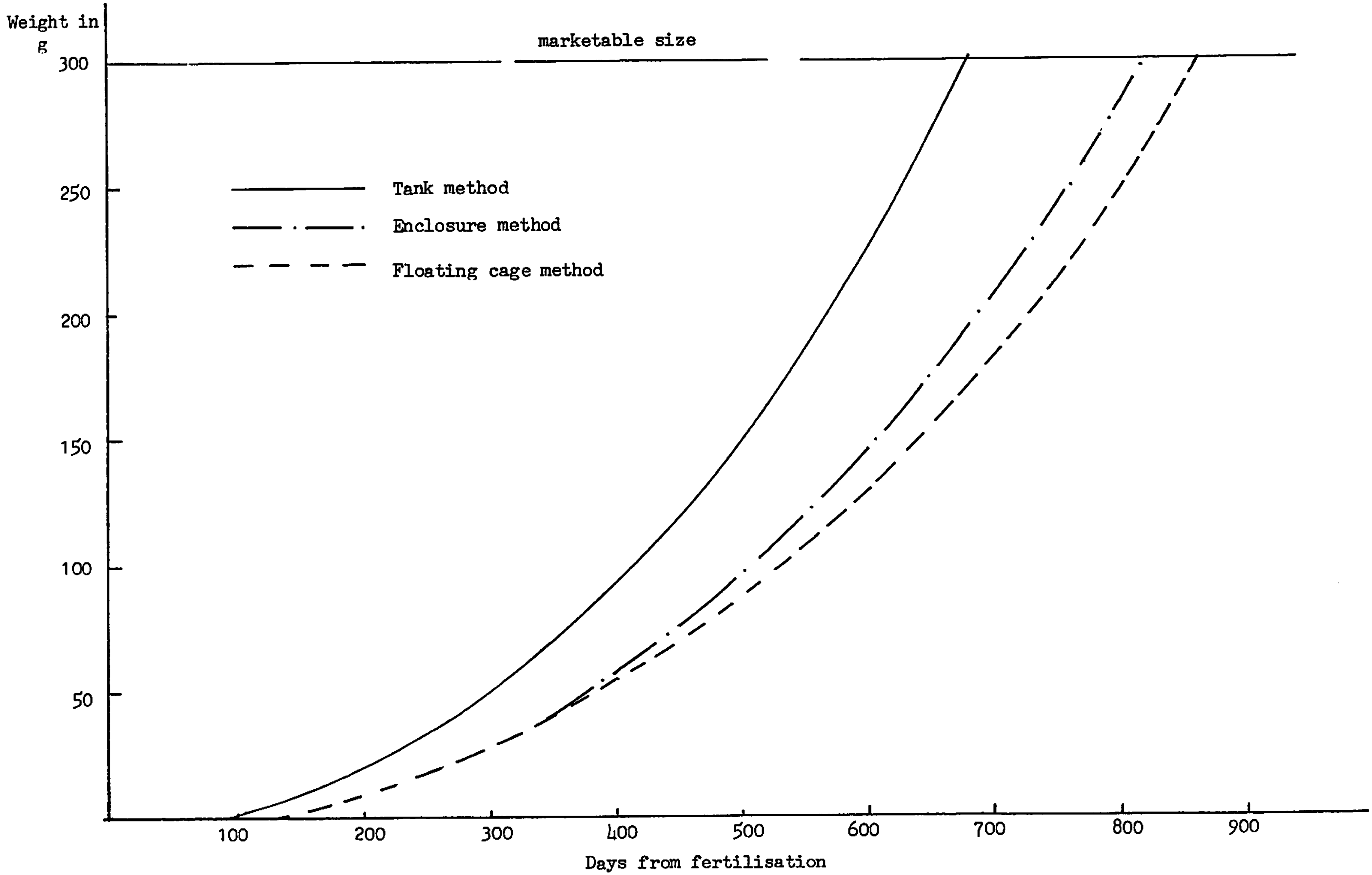

Figure 3 Plaice Approximate relationship between weight and length

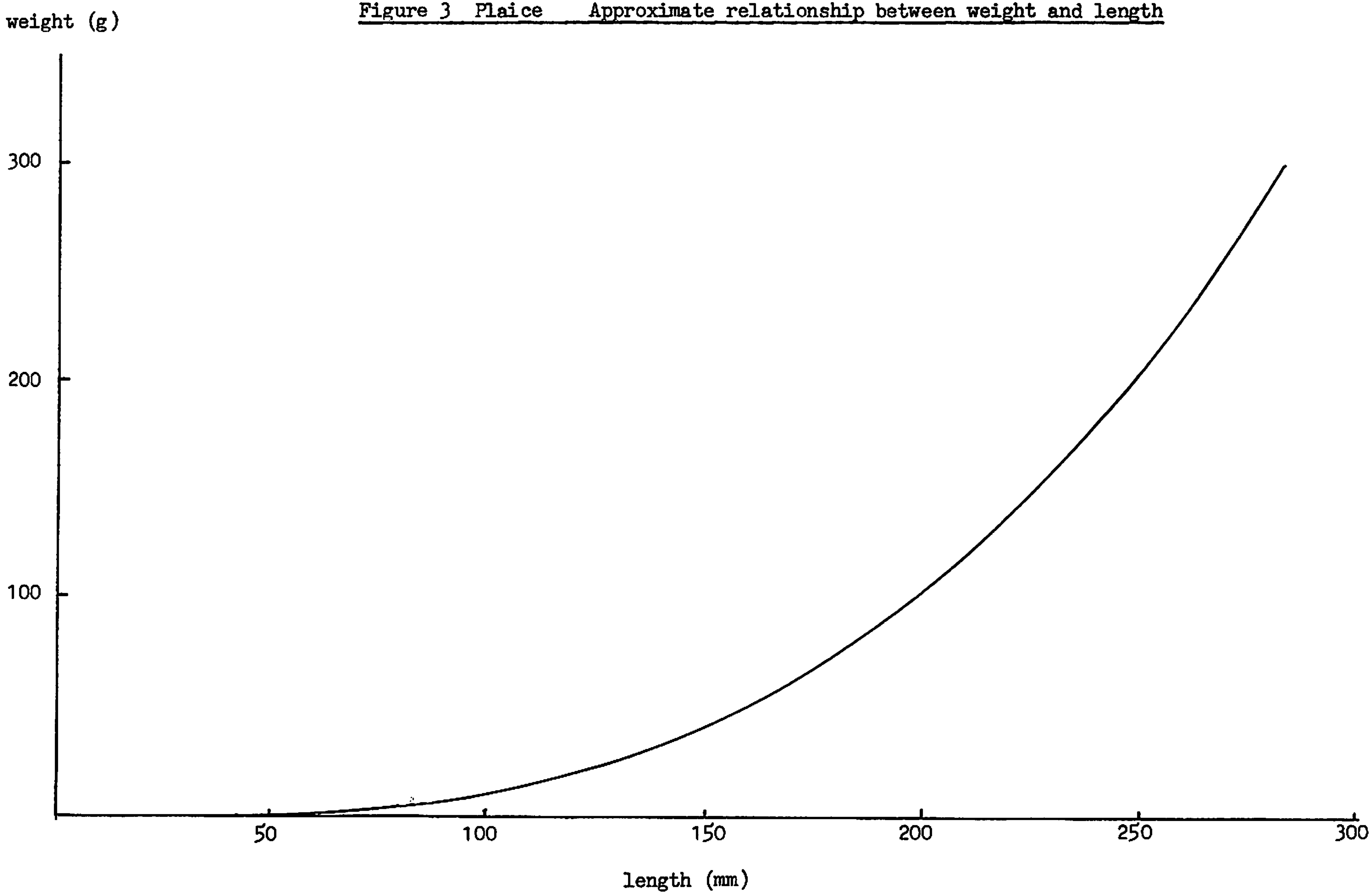

Figure 4 Monthly Port Wholesale price per tonne of Plaice in 1975 compared with estimated farm cost

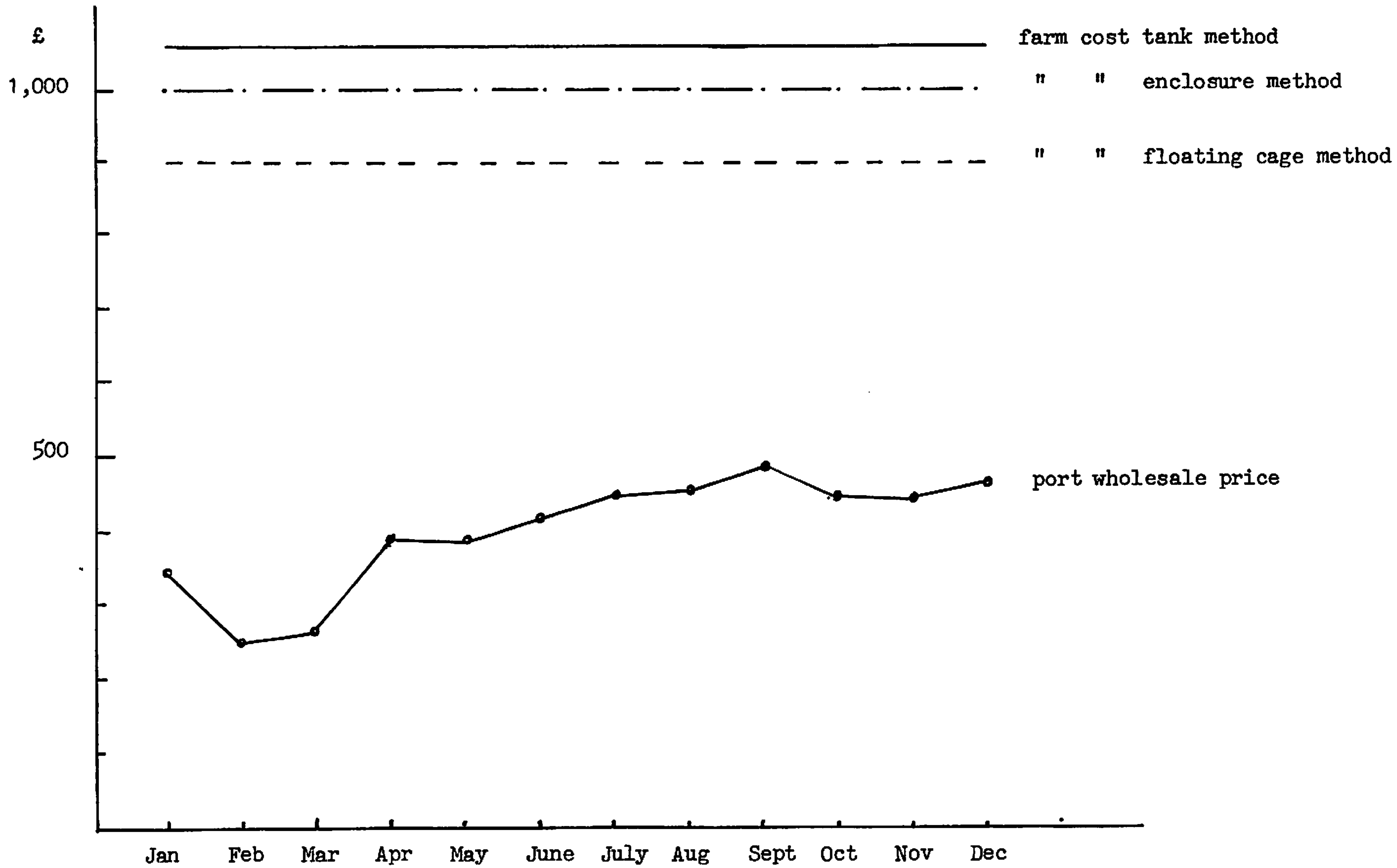

Table 1 Plaice rearing - Basic husbandry data - R & D trials 1968-1973

PRINCIPAL VARIABLES TRIAL SYSTEMS										
STAGE		MEAN SIZE/WEIGHT	STAGE DURATION	AGE AT STAGE END	SURVIVAL Stage	SURVIVAL From egg	FINAL STOCKING DENSITY	TANK OR CAGE CAPACITY	FINAL NO. PER TANK/CAGE	WATER FLOW
			days	days	%	%	kg/m^3	m^3		m^3/kgh
Spawning Stock		350g	-	-	-	-	25(cage) 1.0(tank)	5.5 11.0	400 30	Tidal 0.17
Incubation		250eggs/g	15	15	70	70	200/1	0.2	4000	-
Hatchery	1.	0 - 20mm	33	48	26	18	0.9	4.3	21000	0.6 - 0.15
(warm)	2.	20mm - 40mm	50	98	53	9	0.16	50.0	11500	0.08
Ongrowing Tanks	1.	40mm - 40g	190	288	83	7	2.8	50.0	3500	0.06
	2.	40g - 200g	300	588	95	6	13.0	50.0	3300	0.02
	3.	200 - 300g	100	688	95	5	18.0	50.0	3000	0.01
Ongrowing Sea cages	1.	40mm - 4g	65	163	80	7	2.5	1.0	625	0.36
	2.	4g - 200g	600	763	95	6	75	3.0	1125	Tidal
	3.	200 - 300g	120	883	95	5	75	3.0	750	"
Ongrowing Enclosures	1.	40mm - 4g	65	163	80	7	2.5	1.0	625	0.36
	2.	4g - 300g	690	853	53	4	15	21	1060	Tidal

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Table 2 Plaice rearing - Basic husbandry data - Forecast system

PRINCIPAL VARIABLES FORECAST SYSTEM										PRODUCTION UNIT - 100 TONNES @ 300g			
STAGE	MEAN SIZE/WEIGHT	STAGE DURATION	AGE AT STAGE END	SURVIVAL Stage	SURVIVAL From egg	FINAL STOCKING DENSITY	TANK OR CAGE CAPACITY	FINAL NO. PER TANK/CAGE	WATER FLOW	NOS. AT START OF STAGE	TOTAL BIOMASS (Live Weight)	NO. OF TANKS OR CAGES	MAX. WATER FLOW REQUIRED
		days	days	%	%	kg/m^3	m^3		m^3/kgh	$x 10^3$	Tonnes		m^3/h
Spewning Stock	350g	-	-	-	-	25(cage) 1.0(tank)	5.5 11.0	400 30	Tidal 0.17	(224) (272)	0.076 0.076	2 8	Tidal 16
Tank Method													
Incubation	250eggs/g	15	15	90	90	200/1	1.0	20000	-	2800 - 2500		140	-
Hatchery 1.	0 - 20mm	33	48	30	27	1.0	5.0	25000	0.2	2500 - 750	0.150	30	30
Hatchery 2.	20 - 40mm	50	98	60	16	0.21	50.0	15000	0.02	750 - 450	0.150 - 0.3	30	6
Ongrowing 1.	40mm - 40g	190	288	85	13	6	50.0	7350	0.02	450 - 380	0.3 - 15.2	52	260
Ongrowing 2.	40 - 200g	300	588	95	12	27	50.0	6980	0.02	380 - 360	15.2 - 72	52	[illegible]
Ongrowing 3.	200 - 300g	100	688	95	11	40	50.0	6600	0.02	360 - 340	72 - 100	52	2000
Sea Cage Method													
Incubation		15	15	90	90	200/1	1.0	20000	-	2800 - 2500		140	-
Hatchery 1.	0 - 20mm	75	90	30	27	1.0	5.0	25000	0.2	2500 - 750	0.150	30	30
Hatchery 2.	20 - 40mm	70	160	60	16	0.21	50.0	15000	0.02	750 - 450	0.150 - 0.3	30	6
Ongrowing 1.	40mm - 4g	65	225	85	12	2	50.0	25000	0.02	450 - 380	0.3 - 1.52	15	30
Ongrowing 2.	4g - 200g	550	775	95	11	75	20.0	7500	Tidal	380 - 360	1.52 - 72	48	Tidal
Ongrowing 3.	200 - 300g	100	875	95	10	75	20.0	5000	"	360 - 340	72 - 100	68	"
Enclosures													
Incubation	250eggs/g	15	15	90	90	200/1	1.0	20000	-	3400 - 3100		170	-
Hatchery 1.	0 - 20mm	75	90	30	27	1.0	5.0	25000	0.2	3100 - 930	0.186	40	40
Hatchery 2.	20 - 40mm	70	160	60	16	0.21	50.0	15000	0.02	930 - 560	0.186 - 0.4	40	12
Ongrowing 1.	40mm - 4g	65	225	85	12	2	50.0	25000	0.02	560 - 480	0.5 - 2.5	20	40
Ongrowing 2.	4g - 300g	630	855	70	8	50	20.0	3300	Tidal	480 - 340	1.9 - 100	100	Tidal

Table 3 Plaice Feeding regime - Forecast system

	DIET			
		days	% biomass	Conversion ratio
Spawning Stock		-	2	(wet:wet) -
Hatchery warm	1. Artemia nauplii 2. W.F.A. 7(J)	33 50	- 10%	2:1
cold	1. Artemia nauplii 2. W.F.A. 7 (J)	75 70	- 10%	- 2:1
Ongrowing Tanks	1. W.F.A. 7 2. W.F.A. 7 3. W.F.A. 7	190 300 100	10 6 4	1.2:1 1.2:1 1.2:1
Ongrowing Sea cages or Enclosures	1. W.F.A. 7 (J) 2. W.F.A. 7 3. W.F.A. 7	65 550 100	8% 5% 3%	1.2:1 1.2:1 1.2:1

Table 4
Plaice - feed costs

Prepared diet

Diet	Item	%	Cost/tonne	Per tonne/diet
W.F.A.7(J)	Fish meal	15	£137	20.6
	Queen offal	42	50	21.0
	Sprats	10	30	3.0
	Fresh mussel	10	250	25.0
	Blood meal	5	180	9.0
	Vitamin binder	18	140	25.2
				103.8
	Transport			10
	Power - mixing and storage			9
	Total cost as fed			122.8 say £123
W.F.A. 7	Fish meal	40	137	54.8
	Queen offal	20	50	10.0
	Sprats	20	30	6.0
	Vitamin binder	20	140	28.0
				98.8
	Transport			10
	Power - mixing and storage			9
	Total cost as fed			117.8 say £118

As a comparison with the above, current salmon and trout food costs, per tonne, ex factory are:-

Food type	Salmon	Trout
Fry	£380	£250-270
Fattening (fresh water)	£295	£175-185
Fattening (sea water)	£320	-

Table 5

Plaice farming - Forecast system

Capital cost of 100 tonne per annum farm unit

Hatchery		£
Brood stock holding tanks 8 x 11m^3 tanks	3,500	
pipework	500	4,000
Tanks 140 x 1m^3 incubation tanks	8,400	
30 x 50m^3 hatchery tanks	19,800	28,200
pipework and reservoir tanks		4,800
Pumps max demand 46m^3/hr	1,500	
compressor and pipework	2,500	4,000
Live food production Artemia units 3 x 680 litres	3,000	3,000
Building 180m^2		9,000
Miscellaneous equipment		3,000
		55,000

Ongrowing	Methods		
	Sea cage	Enclosure	Tank
	£	£	£
Floating cages 21m^3			
116 cages @ £350	41,000	-	-
Service boats 2 x 6m open boats	4,000	-	-
Fixed netting enclosures			
132 x £720	-	95,000	-
Jetty or pontoon	10,000	10,000	-
Tanks 50m^3 circular			
104 x £662	-	-	69,000
Pipework and drains	-	-	12,000
Pumps etc.	-	-	56,000
Main pipe line	-	-	55,000
Fencing and yard	-	-	2,000
Cold store 5000m^3	8,000	8,000	8,000
Food preparation machinery	2,000	2,000	2,000
Office and store	9,000	9,000	9,000
Vehicle	3,000	3,000	3,000
Ongrowing totals	77,000	127,000	216,000

Capital cost per tonne of plaice

	Sea cage	Enclosure	Tank
	£1,320	£1,820	£2,710
Assume grant @ 35%	462	637	950
	858	1,183	1,760
Interest @ 11%	94	130	194

Table 6

Plaice farming - Forecast system

Production cost per tonne for farms producing 100 tonnes p.a. of 300g fish

Hatchery	Cost per tonne of fish at 300g: Cold	% Sc.	% Enc.	Warm	%
New brood stock	1			1	
Pumping heat and light	5.7			5.6	
Food	18.8			10.7	
Husbandry (labour)	41.0			25.2	
Maintenance	7.0			7.0	
Depreciation	37.5			37.5	
	111.0	12	11	87.0	7

		Sea cage	%	Enclosure	%	Tank	%
Food		141	16	141	14	141	12
Husbandry	labour	158	18	147	15	136	11
	equipment	5		5		5	
Pumping	energy	1		1		110	9
	capital	-		-		135	11
Maintenance		40	4	74	8	70	6
Depreciation		125	14	194	20	103	9
		581		673		787	
Insurance		70	8	70	7	70	6
Management, admin.		150	17	150	15	150	13
Cost of production		801		893		978	
Interest on capital		95	11	95	10	194	16
Total farm cost		896	100	988	100	1201	100

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Table 7

Plaice hatchery - Labour cost

Warm hatchery - for tank method

4 men x 14 weeks @ £43.50	=	£2,436
preparation 2 man weeks	=	87
		£2,523

Cold hatchery - for sea cages & enclosures

preparation 2 man weeks	=	87
4 x 23 weeks @ £43.50	=	£4,002
		£4,089

Table 8 Plaice hatchery - Forecast food cost

100 tonne p.a. farm unit

Brood stock

Total biomass	=	0.078 tonnes	
Daily feed 2% biomass of industrial fish	=	0.078 x 365 x 2 / 100	
	=	0.57 tonnes	
at £55/tonne	=	£31.35	
per tonne	=	0.313	

Tank method ongrowing - warm hatchery

Artemia production unit days - 159			
Energy cost at £1.2/unit day	=	£174.9	
Cost per tonne	=		1.75
Artemia eggs 1Kg @ 60% hatch = 210 million eggs	=	£6.22	
cost/million	=	2.9p	
Annual requirement = 15,900 x 10^6 cost	=	£470	
per tonne	=		4.7
Labour 8 man weeks		£348	
			3.5
		total	9.95
		say	10.00

Sea cage & enclosures - cold hatchery

			per tonne
Artemia production/running time	297 unit days		
Energy cost @ £1.1 unit days			3.27
Artemia eggs @ 2.9p/million	29,700	=	8.61
Labour 14 man weeks		=	6.09
			17.97
Cost per tonne		say	£18.00

W.F.A. 7 (J)

Total biomass	=	0.15 tonnes
Conversion factor	=	2:1
Weight of food	=	0.3 tonnes
	=	£36.9 tonnes
per tonne of fish	=	0.37p
total cost tanks		0.31
		10.00
		0.37
		10.68
total cost sea cages		0.31
		18.00
		0.37
		18.68

Table 9 Plaice hatchery - Forecast
Energy cost

	Warm	Cold
Pumping		
Brood stock		
Water flow	$16m^3/h$	-
Cost per m^3/h per month 79p		
Annual cost 12 x 16 x 0.79	£151.7	-
Hatchery		
Warm 33 days at $30m^3/h$		
50 " at $6m^3/h$		
Annual cost = 1.1 x 30 x 0.79 = 26.0		
+ 1.7 x 6 x 0.79 = 8.1	34.1	
Cold 75 days at $30m^3/h$		
70 " at $6m^3/h$		
2.5 x 30 x 0.79 = 59.25		
2.3 x 6 x 0.79 = 10.9		70.2
Depreciation - £1500 over 7 years	214.3	214.3
Aeration 5hp compressor		
Warm energy = 5 x 0.75 x 83 x 24		
= 7,470 kWh	164.3	
Annual cost at 22p		
Cold energy = 5 x 0.75 x 145 x 24		
= 13,050 kWh		287.1
Annual cost at 22p	564.4	571.6

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Table 10

Plaice hatchery forecast maintenance & depreciation

100 tonne p.a. farm unit

	Capital Cost	%	Maintenance £	Years	Depreciation
Brood stock tanks	4,000	1	40	10	400
Tanks	29,000	1	290	15	1,933
Pipe work	4,000	1	40	15	267
Pumps	1,500	5	75		*
Compressor	2,500	3	75	10	250
Artemia units	3,000	2	60	10	300
Building	9,000	1	90	30	300
Miscellaneous	3,000	1	30	10	300
			700		3,750

Maintenance cost per tonne £ 7

Depreciation cost per tonne £37.5

* included in pumping cost

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Table 11

Plaice ongrowing - Forecast food cost

Ongrowing - tanks diet W.F.A. 7 @ £118/tonne

Conversion 1.2:1		
Growth per fish = 1g - 300g	=	299g
No. of fish per tonne @ 300g	=	3,333
Biomass increase	=	996.6kg
Weight of W.F.A. 7	=	1.196 tonnes
Cost per tonne of plaice	=	£141.11

Ongrowing - sea cages
or Enclosures

Stage 1 diet W.F.A. 7(J) @ £123/tonne

Conversion 1.2:1		
Growth per fish = 1g - 4g	=	3g
No. of fish per tonne @ 300g	=	3,333
Biomass increase	=	10kg
Weight of W.F.A. 7(J)	=	12
Cost per tonne	=	£1.48

Stages 2 & 3 diet W.F.A. 7 @ £118/tonne

Conversion 1.2:1		
Growth per fish = 4g - 300g	=	296g
Weight of W.F.A. 7	=	1.18 tonnes
Cost per tonne of plaice	=	£139.24
Total	=	£140.72

Table 12 Plaice ongrowing - Forecast labour cost

Basis - Farm labourers Scotland 1975	£40/40hr week
National Health employers contribution	£3.50
Total per 40hr week	£43.50
Cost per man year	£2,262

	Production in tonnes per annum				
Tank method	25	50	100	150	200
Estimated No. of men	3	4	6	8	10
Total labour cost	6,786	9,048	13,572	18,096	22,620
Cost per tonne	271.4	181	35.7	120.6	113.1
Tonnes/man year	8.3	12.5	16.6	18.8	20
Sea cage method					
Estimated No. of men	3.5	4.5	7	10	12
Total labour cost	7,917	10,179	15,834	22,620	27,144
Cost per tonne	316.7	203.6	158.3	150.8	135.7
Tonnes/man year	7.1	11.1	14.3	15.0	16.6
Enclosures					
Estimated No. of men	3.5	4.5	6.5	9	11
Total labour cost	7,917	10,179	14,703	20,358	24,882
Cost per tonne	316.7	203.6	147.0	135.7	124.4
Tonnes/man year	7.1	11.1	15.4	16.7	18.2

Note estimate of no. of men includes seasonal labour

Table 13
Fish farming - Tank method

Cost of pumping power station coolant and seawater 1975

Coolant head = 7.5m (6m lift and 1.5m delivering)
pipe work 150m x 25cm per 100m^3 flow

Sea water = 9m (7m lift and 2m delivering),
pipe work 500m x 25cm per 150m^3 flow

Coolant pumping

Energy required for pumping	=	$\frac{0.00273 \times 7.5}{0.5}$
	=	0.041kW
kWh per m^3/month	=	0.041 x 24 x 30
	=	29.52
Cost per m^3/month at 2.2p/kWh	=	64.94p

Sea water pumping

Energy required for pumping 1m^3/hr at 50% efficiency	=	$\frac{0.00273 \times 9}{0.5}$
	=	0.05kW
kWh per m^3/month	=	0.05 x 24 x 30
	=	36
Cost per m^3/month at 2.2p/kWh	=	79.2p

Table 14 Plaice farming - Tank method forecast

Water requirements - 100 tonne p.a. production

Mean temperature restricted to 18°C

Month	Mean/wt	No/fish 100 tonnes	Total water flow	Coolant			Sea Water	
				Mean temperature	Mixture	Flow rate	Mean temperature	Flow rate
			m^3/hr		%			
4 July	2.5	1.	22.5	21.6	50	11	14.2	11
5 August	12.5	5	100	22.2	40	40	15.1	60
6 September	20	8	160	21.2	60	96	13.8	64
7 October	27.5	10.45	209	21.3	63	132	12.4	77
8 November	35	13.3	266	19	87	231	10.3	35
9 December	40	15.2	304	below 18	100	304	-	-
10 January	50	19	380	"	100	380	-	-
11 February	60	22.8	456	"	100	456	-	-
12 March	75	28.5	570	"	100	570	-	-
13 April	87	32.2	644	"	100	644	-	-
14 May	100	37	740	18.1	100	740	9.9	-
15 June	115	42.6	852	20.6	67	571	12.7	281
16 July	130	48	960	21.6	50	480	14.2	480
17 August	148	53.3	1066	22.2	40	426	15.1	640
18 September	168	60.4	1208	21.2	60	725	13.8	483
19 October	188	67.8	1356	21.3	63	854	12.4	502
20 November	210	75.6	1412	19	87	1228	10.3	184
21 December	237	83.0	1660	below 18	100	1660	-	-
22 January	263	92.0	1840	"	100	1840	-	-
23 February	300	100	2000	"	100	2000	-	-
						13,388		2,817

133.88 x 65p = 87.02
28.17 x 79p = 22.25

109.27 take £110/tonne

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Table 15

Plaice ongrowing - forecast

Capital cost of pumping - 100 tonne p.a. farm unit

Power Station Coolant

Maximum water flow (table) 2000m^3/h x 80% (table) = 1600m^3/h

pump capacity required - 2400m^3/h at 7.5m head

		£
16 pumps x 150m^3/h	£19,200	
electrical	6,400	
		25,600
pump house		4,800

Sea Water

Maximum water flow (table) 600m^3/h

pump capacity required 750m^3/h at 9m head

5 submersible pumps x 150m^3/h		9,500
emergency generator		8,000
		47,900
	Say	48,000
Annual depreciation over 7 years		£ 6,857

Pipe work

Coolant - distance 150m
pipes 1 x 25cm per 100m^3/h
= 150m x 16 = 2400m

Sea water - distance 500m
pipes 1 x 25cm per 150m^3/h
= 500m x 4 = 2000

4400m

Total pipeline at £11/m head	£48,400
Annual depreciation over 10 years	£ 4,840
Annual capital cost of pumps and pipework	£11,697
Rounded capital cost of pumping per tonne	£ 115

Table 16 Plaice ongrowing

Estimated maintenance and depreciation

Tank method	£	Maintenance %	Maintenance £		Depreciation years	Depreciation £
Tanks and pipe work	81,000	3	2,430		10	8,100
Pumps	41,000	5	2,075			*
Pipe work	55,000	3	1,650			*
Generator	8,000	3	240			*
Food preparation	2,000	5	100		4	500
Cold store	8,000	3	240		7	1,143
Buildings etc	17,000	2	340		30	567
			7,075			10,300

Sea cage method	£	Maintenance %	Maintenance £		Depreciation years	Depreciation £
Cages	41,000	7	2,870		4	10,250
Cold store	8,000	3	240		7	1,143
Food preparation equipment	2,000	5	100		4	500
Jetty or pontoon and building	19,000	2	380		30	633
			3,590			12,526

Enclosure method	£	Maintenance %	Maintenance £		Depreciation years	Depreciation £
Netting enclosures	95,000	7	6,650	frame	10	3,960
				netting	4	13,200
Cold store	8,000	3	240		7	1,134
Food preparation equipment	2,000	5	100		4	500
Jetty or pontoon and building	19,000	2	380		30	633
			7,370			19,427

* included in pumping cost

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Table 17

Sea cage method - Service boat costs

Estimated annual cost for 100 tonne p.a. farm

Fuel	£1,100
Maintenance	300
Insurance	200
Depreciation (10 years)	400
Total	£2,000

Cost per tonne production £20

Table 18

Plaice farming - Forecast

Management & administration cost at different production levels

Production unit tonnes per annum	25	50	100	150	200
Admin costs	1,250	1,500	1,500	1,750	2,000
Rates	1,000	2,000	4,000	5,000	6,000
Motor expenses	1,500	1,500	1,500	1,750	1,750
Manager	4,500	5,000	5,000	5,500	6,000
Technician	-	-	3,000	3,250	5,250
Total	8,250	10,000	15,000	17,250	21,000
Per tonne	330	200	150	115	105

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