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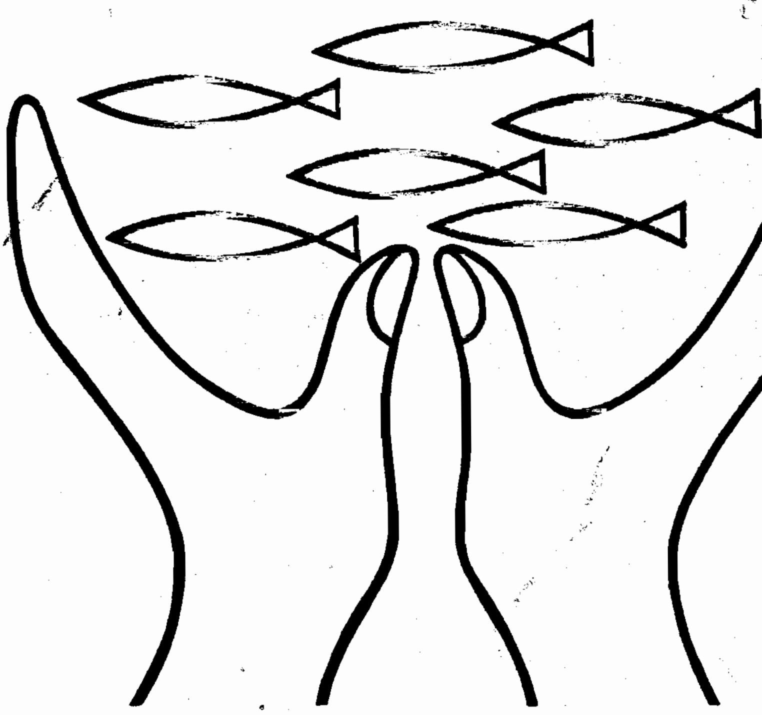
MINISTRY OF AGRICULTURE FISHERIES AND FOOD

DIRECTORATE OF FISHERIES RESEARCH



MINISTRY OF AGRICULTURE
FISHERIES AND FOOD

FISH CULTIVATION RESEARCH

LABORATORY LEAFLET No. 35

LOWESTOFT

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Laboratory Leaflet Number 35

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
FISH CULTIVATION RESEARCH

by C. E. Purdom

INTRODUCTION

What is fish farming for?

Although fish farming is not a new concept, it is currently arousing widespread interest both at home and abroad and at unprecedented levels. This intense interest arises from a variety of views as to the role that fish farming should play as a means of food production. These may be classified under three main headings:

(a) to produce cheap protein, particularly in underdeveloped countries;

(b) as a way of supplementing diminishing catches from the sea resulting from political or management decisions or from overexploitation of natural stocks;

(c) in order to meet a specific demand by the development of industry.

The first has almost no validity. A wide range of fish species is cultivated throughout the world and in almost every case the produce is high priced and in many cases of luxury status.

The second view can take either of two forms, conservational or substitutional. In the conservational form it is envisaged that juvenile fish are reared for release into the natural environment for subsequent capture. As a substitute for fishing, it is assumed that fish can be reared on farms to marketable size to offset a lack of supply from the sea. Neither view has overall validity but in each case there are specific areas where the concepts have practical value.

Releasing fish into the sea is largely ineffective simply because natural productivity is enormous and natural mortality similarly massive. Survival rates depend on size at release and, since growing fish in captivity is expensive and release into the sea relinquishes ownership, the exercise is impractical except in the case of one specific set of circumstances, namely natural return to the site of release. Salmon and sturgeon spawn in fresh water and migrate to the sea, where they spend a major part of their lives: at maturity they return, with some exactness, to their spawning sites. Sea ranching, as the release of anadromous fish into the sea is called, is undertaken for Pacific and Atlantic salmon principally in the United States and Canada, and for sturgeon in the Soviet Union. In these exercises in conservation, State authorities play a major role.

The concept that fish farming can meet deficiencies in annual catch rates from the sea has no overall validity simply because of the difference in scale of the two fields of activity. Worldwide, the annual catch of fish is about 85 million tonnes and farm production, largely in fresh water, amounts to only 7 million tonnes. In the UK the figures are even more disparate with over 800 000 tonnes landed at British ports compared to about 2 500 tonnes from farming, almost all of which is currently derived from trout farming. Political or management decisions can create fluctuations in catches measured in hundreds of thousands of tonnes; fish farming cannot make meaningful contributions on this scale. Only for specific types of fish with low annual yields, such as sole and turbot, can farming make significant contributions in terms of sea fish.

The third view, that fish farming is an independent industry to be developed in accordance with its own merits, is the only view with overall validity.

What is fish farming?

Fish farming takes many forms but there are two basic types, extensive and intensive. Extensive farming makes use of natural productivity by low-density stocking in large bodies of water in which natural conditions prevail. These may be augmented by management practice such as control of undesirable fish, fertilization to promote growth of food organisms, and supply of additional food if available. Intensive farming employs high stocking rates in small units, either ponds, tanks or cages, through which large volumes of water pass. Under these conditions natural productivity is trivial and all food has to be supplied by the farmer. Thus, extensive farming is largely natural; it is pursued mainly in the less industrialized communities of the world and production rates can be in the range of 20 to 200 kg/acre with up to a tenfold increase with supplementary feeding.

Intensive farming, by comparison, is almost wholly artificial. Fish are retained in enclosures specifically designed to hold heavy concentrations of fish and are flushed with large quantities of water, the function of which is primarily to supply oxygen and remove waste products. Production rates can be over 30 tonnes/acre and the associated need to supply all feeds means that these must be of high quality, containing high levels of animal protein. Since the protein content of the food is converted into fish protein with, at best, only a 30% efficiency, intensive fish farms are net users of protein. Intensive fish farming is therefore practical only in more affluent societies with access to cheap sources of protein and a motive for converting these into higher quality food. The UK comes into this category, with limited space for extensive farming but large resources of cheap animal protein. Research and Development (R & D) in UK fish farming, whether under government or industrial control, has been wholly orientated towards intensive systems of one kind or another.

THE HISTORY OF BRITISH FISH FARMING R & D

The early phases of marine fish farming research in Great Britain seem to stem from work started in the late 19th century to improve natural fish stocks by raising fry in hatcheries for liberation into the open sea. It was felt that by raising fry in captivity beyond the stages highly susceptible to predation, significant numbers could be released into the sea. The concept did not stand up to a quantitative study, however, since the actual productivity in the sea for common species is measured in billions of fry each year and the addition of a few more million is literally a drop in the ocean. Hatcheries were set up all around the North Atlantic seaboard, however, and it was not until the 1950s that the last ceased operations.

The two species most commonly used in this hatchery work were plaice and cod and much experience was gained in the handling of broodstock and the incubation of eggs and fry. No attempts were made to feed the fry which were released before the yolk sac was fully absorbed. With the collapse of the conservation concept, the natural next step was to consider why it was necessary to release the fish. Why not continue with husbandry towards a system of marine fish farming? This meant that suitable foods had to be found. Early experiments with plaice around the turn of the century showed that they could be fed on natural plankton, and very small numbers were raised to juvenile stages. Flatfish seemed to be favoured for this sort of work; sole, and even turbot, were amongst species examined in a fish farming context at this time. The most significant break-through on foods came many years later, however, with the discovery by a Norwegian, G. Rollefsen, around 1940, that newly-hatched nauplii from the dried eggs of the brine-shrimp, Artemia salina, were accepted by plaice larvae and represented an adequate diet for the fish during and beyond their larval stages. Systematic work was begun by MAFF in 1952 to develop plaice rearing techniques towards commercial standards. By 1966, under the direction of J. E. Shelbourne, pilot-scale projects were capable of producing hundreds of thousands of juvenile plaice at modest costs.

In the simplest terms, plaice rearing embraced three phases, the production of fertilized eggs, the incubation of eggs and yolk sac larvae and the feeding and growth of larvae up to metamorphosis. Plaice larvae, as with all flatfish, hatch as bilaterally symmetrical free-swimming 'round' fish and during early growth alter shape towards the flatfish pattern, in which the fish, with its sedentary habits, is lying on its side.

Fertilized eggs are obtained either by permitting fish to spawn naturally in a pond or tank, or by artificially stripping eggs and sperm for mixture. Plaice eggs are large by marine standards, 2 mm in diameter, and are buoyant in sea water. Incubation at 7-8°C leads to hatching within 15 days and for a further week the larvae live off their yolk reserves. At the end of this period Artemia nauplii are added and the temperature is raised to 10-11°C. This temperature rise seems to stimulate the onset of feeding and at this temperature growth to metamorphosis takes about eight weeks. Daily additions of Artemia nauplii are made during this period; the nauplii are produced by incubating eggs, available under proprietary brand names, in well aerated sea water at a temperature of about 25°C.

Production of metamorphosed plaice is performed in small shallow tanks, 60 x 30 x 30 cm being a popular size. Static water, aerated and replenished at intervals, or a slow flow-through of about one exchange per day are customary, with general hygiene the principal requirement other than the maintenance of continuous supplies of food. Under these conditions up to 3 000 juveniles can be reared per tank. Mass culture entails the use of batteries of tanks, or tanks larger in surface area but not in depth.

By 1966 the mass rearing of metamorphosed plaice was a feasible exercise and the next stage in research was to explore the on-growing problems. This work was largely undertaken by the White Fish Authority and in connection with the possible use of the warm effluents from coastal power stations. Fish growth is accelerated with increasing temperature within the range suitable for good performance, and it was found that plaice could be reared to marketable size in something less than half the four-year period normal in the natural environment. Plaice were on-grown to marketable size and to sexual maturity on diets based principally on fish meal. Unfortunately, due to the high cost of such food and the relatively low market price of plaice, it soon became apparent that the process of farming plaice was uneconomic despite its biological feasibility. This conclusion was reached in the late 1960s but it remains valid today.

In view of the economic failings of potential plaice farming, attention was turned to other flatfish species with higher market value. Sole (Solea solea) was the first given serious consideration since it was clearly the most highly priced of our marine species. Rearing systems analogous to those used for plaice were quickly found to be suitable for sole, with the main difference being that sole prefer a temperature range about 5°C above that successfully used for plaice. Mass rearing of sole soon became feasible but on-growing proved to be very difficult. The sole is a cautious feeder, basically with nocturnal habits, and its reluctance to feed when first offered food led to two related difficulties. Much food remained uneaten and deteriorated in the water so that food utilization was inefficient, an economic problem, and the water became polluted, a biological hazard.

Newly-metamorphosed sole can still be fed on Artemia nauplii but this food becomes progressively less practical as the fish grow. Live food has an advantage over prepared diets in that it remains attractive to the fish over long periods and does not deteriorate if not eaten quickly. One strategy with sole was to wean them from nauplii on to other live foods. White worm (Enchytraea spp.) and lumbricillids from seaweed heaps were both successfully employed and permitted growth of sole way beyond that practical with nauplii. Production or collection of these worms is of doubtful validity in a commercial sense, however, and their use still left a weaning problem when prepared diets were introduced into the feeding regime.

By 1970 the behavioural difficulties of sole were an obstacle to the planning of trials and the research and development effort for this species was reduced within MAFF laboratories, pending the outcome of work on some aspects of weaning which will be described under the heading of current research. Meanwhile, consideration was given to another species of flatfish, the turbot (Scophthalmus maximus), which, although not as valuable as sole, is still a prime fish and commands high market prices.

In view of the failures with on-growing both plaice and sole, attention was paid first to the performance of turbot in this context. This was achieved by growth trials using fish of the year collected from beaches. These trials demonstrated that the turbot was a good species in this respect, being voracious and easy to feed on prepared diets and trash fish, fast growing, with efficient food conversion, and docile and easy to handle for experimental purposes. On this basis a programme of hatchery work was initiated with the knowledge that the problems at that rearing stage would be formidable. Turbot eggs are very small, about 1 mm in diameter, and Artemia nauplii are too big to be used at the start of feeding. An interim food was discovered in the form of the marine rotifer Brachionus plicatilis, on which growth to a size commensurate with acceptance of nauplii became possible. Turbot were first reared to metamorphosis in 1972 with the production of about 100 juveniles from many thousands of eggs. Annual improvements in techniques since that time make feasible the production of tens of thousands of fish with much improved survival rates. This research work continues and will be described in detail under current research. In parallel with these advances, commercial interests have begun trials both in hatchery and on-growing aspects of turbot culture and there is little doubt that this species will be the first marine flatfish to be marketed commercially as farmed fish.

Apart from the pilot-scale projects with turbot, fish cultivation in Great Britain is almost entirely of salmonids, amongst which rainbow trout is the clear favourite. Up until 1975 almost all government research in fish farming was with flatfish. Research into salmonid farming became part of the MAFF fish cultivation programme when the Director of Fisheries Research's responsibilities were widened so as to include freshwater aspects. In 1976 this research into the farming of salmonids was considered in an overall review of fish cultivation activities by the Fisheries Research and Development Board. It will be described in detail under current research but it chiefly comprises studies of the genetics of salmonids and their cultivation in salt water. Fish disease studies will be described in a separate Laboratory Leaflet and will be mentioned only briefly here.

PRESENT STATUS OF R & D AND CURRENT PROGRAMME OF WORK

Turbot

On-growing

The reasons for studying this aspect of turbot cultivation first were mentioned in the previous section. Current data on growth will be reviewed here followed by an assessment of factors still requiring clarification.

The definitive trials of turbot growth were set up using wild fish collected from beaches (Purdom et al. 1972). Initially, these were held in a variety of tanks but, on evidence that the largest tank was the most effective, the fish were moved three months after the start of the trials into two fibreglass tanks measuring 8 x 6 ft with a depth of water of approximately 2 ft. Four months later the fish were transferred to two pens measuring 5 x 3 x 1 m deep in which they remained for the duration of the trials.

Fish were fed twice daily on mashed, chopped or whole trash fish. Various species of trash fish were used initially, but sandeels and sprat were the predominant species used throughout the trials. Two meals per day seemed adequate for these voracious fish, the daily intake not being significantly increased when three meals were given each day.

The growth in length of the turbot during 32 months is shown in Figure 1, together with mean monthly temperatures. For the first seven months the fish were indoors and thereafter out of doors in covered tanks. Under these conditions temperatures did not fall to ambient levels in the winter.

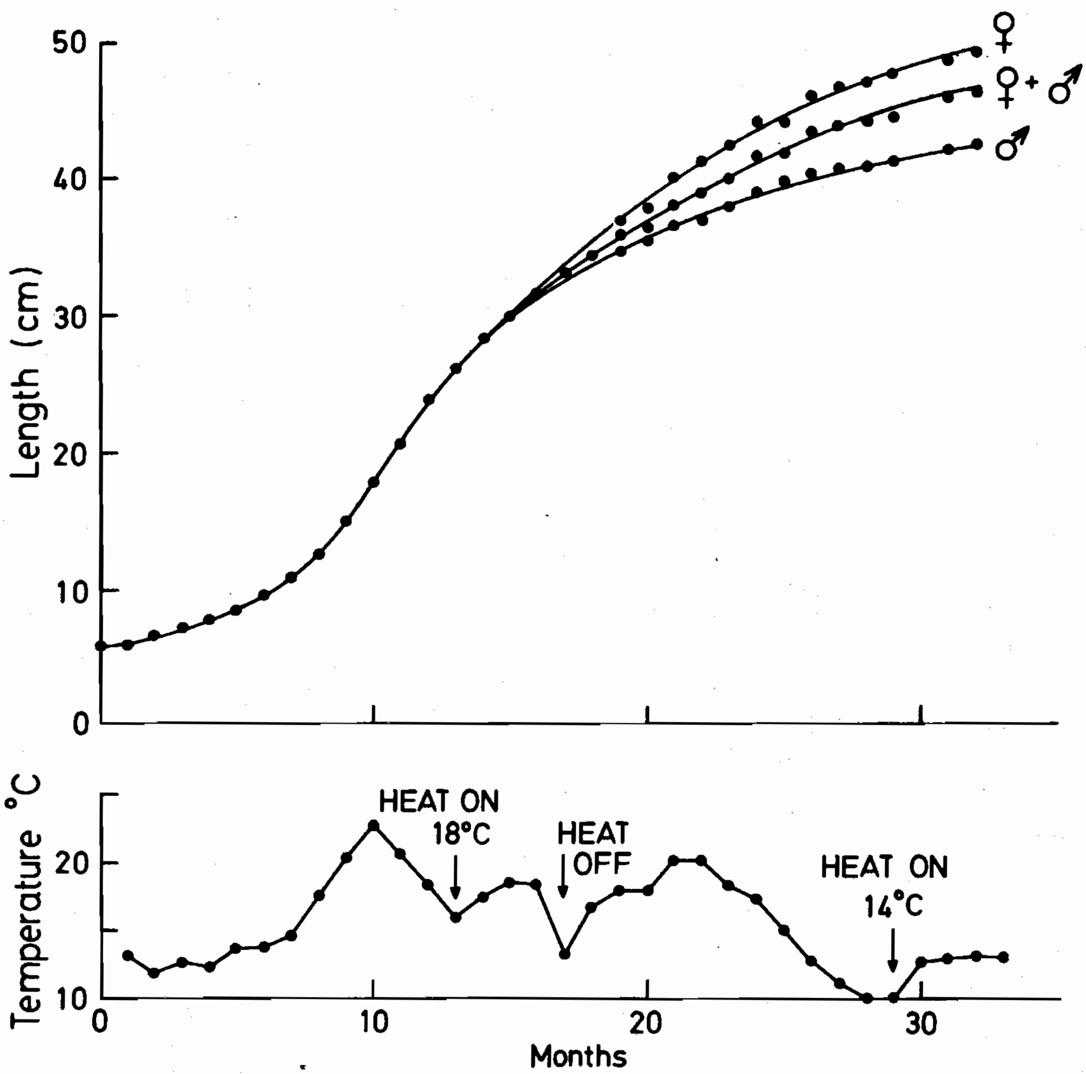

Figure 1 Growth in length of turbot.

Water heaters were used in the second winter set to operate below a nominal 18°C and in the third winter below 13°C. The overall growth curve is a composite of two basic phenomena, higher growth rate at higher temperatures and diminishing growth rate with time, particularly after the first 12 months. It may be seen that the mean length equivalent to the minimum legal size for landings (30 cm) was reached in month 15. Assuming a pre-trial life of three months, this is equivalent to marketable size within 18 months.

Fish were sexed from month 19 and it can be seen from Figure 1 that females grew more rapidly than males. By extrapolation, it seems probable that differential growth began during months 17 or 18, just over a year before the onset of sexual maturity which occurred after month 32. At the end of month 13, in a sample of fish killed for examination, females were marginally larger than males but not significantly so. The change in relative growth rate thus seems to coincide with the beginning of the first annual cycle of germ-cell development.

Apart from an accidental loss of fish due to the overnight failure of water supply on one occasion, the mortality overall was only about 10%.

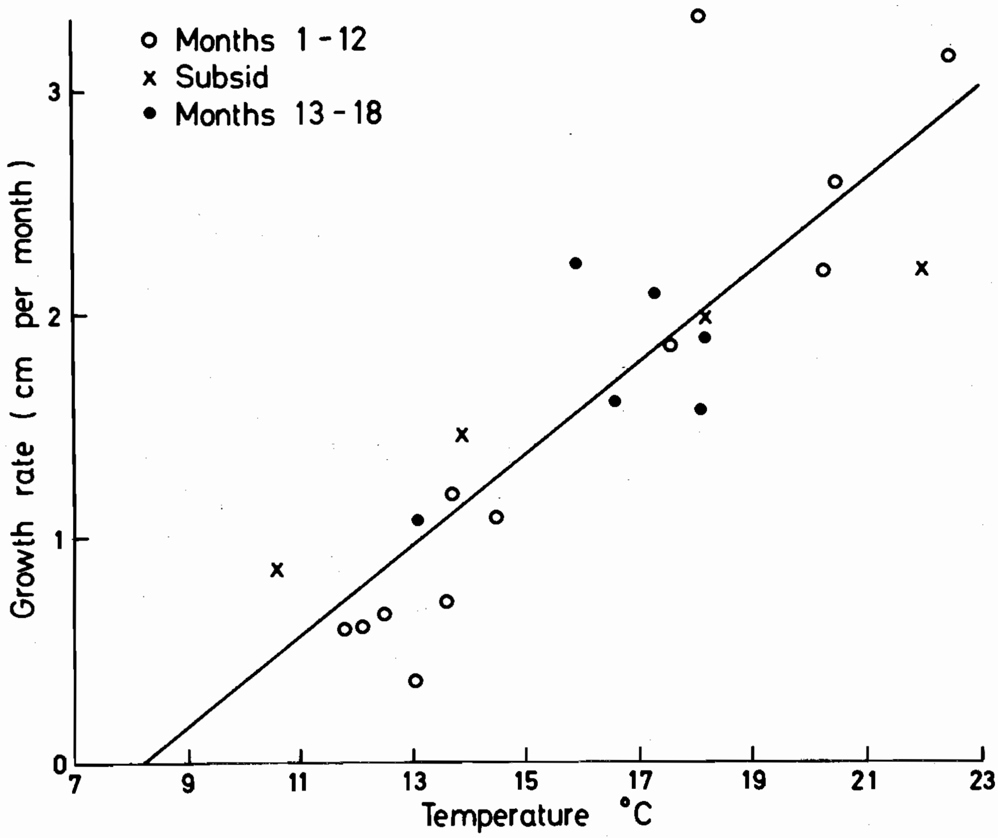

Figure 2   The relationship between temperature and growth rate in turbot.

In Figure 2 incremental growth is plotted against monthly temperatures; the data include a small subsidiary trial comparing various temperatures during the first three months of the main trial. The relationship between growth rate and temperature can be expressed by the linear regression

$$y = 0.2x - 1.7,$$

where y is growth rate in centimetres per month and x the temperature in °C. The correlation coefficient between growth rate and temperature is 0.86.

The growth parameters are almost certainly lower than the maximum possible levels because the trials themselves were exploratory and the frequent handling of fish was not conducive to maximum performance. In later trials, with recycled water maintained at 13.5°C, hatchery-reared turbot grew at 1.3 cm/month while in parallel trials wild fish grew at 0.92 cm/month.

Figure 3 shows the increase in mean weight of fish throughout the main trials. In months 28 and 29 low temperatures and reduced feeding resulted in no growth. This pause was deliberately introduced as a possible requirement for successful maturation of eggs for the forthcoming spawning season. Throughout the trial, apart from this period, growth in weight increased with time such that, although 20 months was required to produce fish with a mean weight of 1 kg, a further five months' growth doubled their weight. Careful attention to strategy is therefore important within the context of marketable size and the production cost per fish.

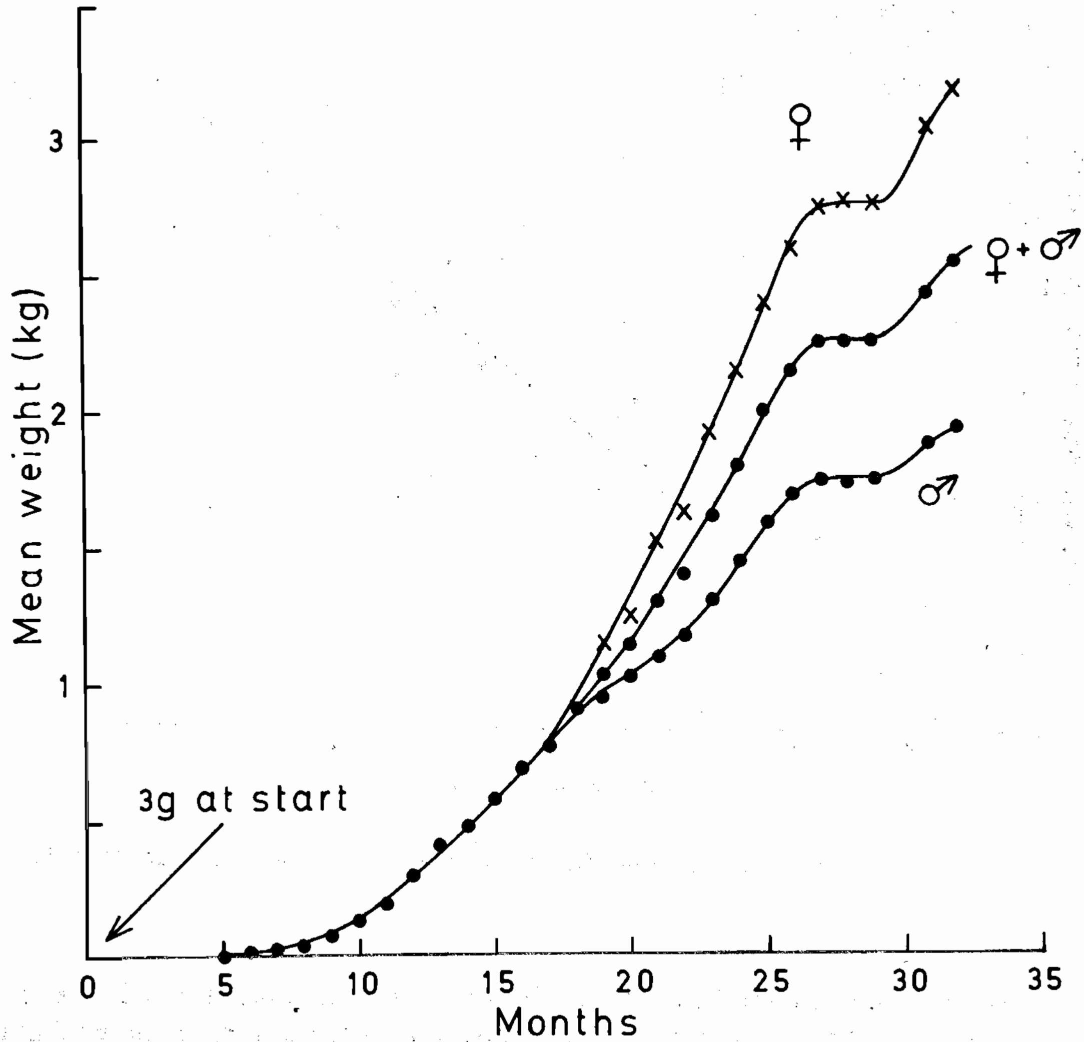

Figure 3 Growth in weight of turbot

The relationship between length and weight changed during the course of the trials. The relationships are not linear since weight in any organism increases as a function of the cube of any linear dimensions. In the first 12 months the length/weight relationship was expressed approximately by the regression

$$\log_n Y = 3.1 \log_n x - 4.2.$$

Later, the parameters were

$$\log_n Y = 3.3 \log_n x - 4.9,$$

where Y is the weight and x the length.

The superior performance of females is shown more clearly in terms of weight rather than length. From Figure 3 it is apparent that at the end of the trial females were 70% heavier than males. The control of sex composition becomes an important feature of management to produce large fish.

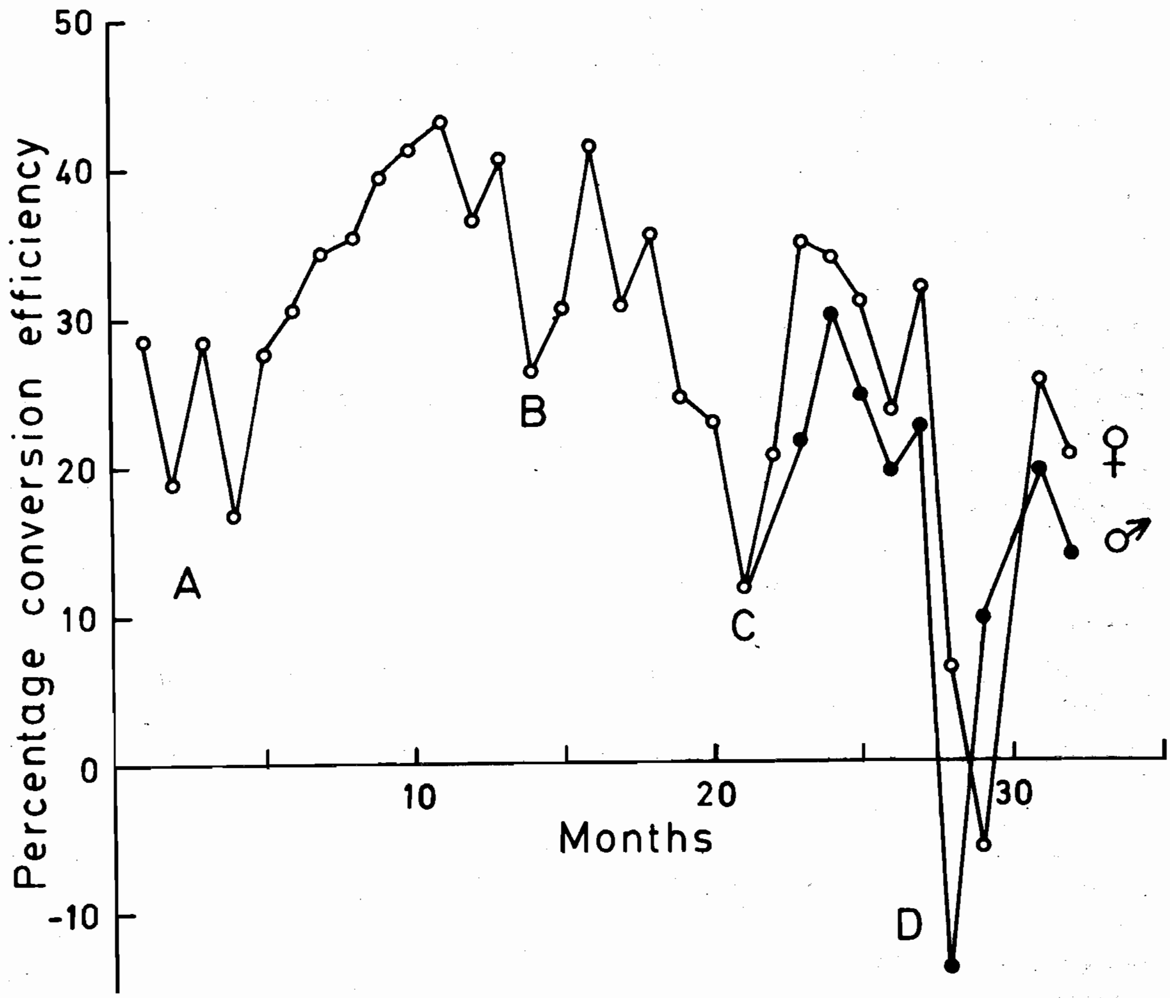

Figure 4 Monthly food conversion efficiency in turbot.

Figure 4 summarizes the monthly data on food conversion efficiency which is defined as weight gain divided by food eaten x 100. The food was trash fish of various species but predominantly comprised sprat and sandeel. Although these are relatively cheap sources of food, feed costs are an important part of production costs and require careful consideration.

Much variation in food conversion efficiency is apparent from Figure 4, with extremes from negative values, i.e. loss of weight, to levels over 40%. The four main areas of low values, marked A-D, can be identified with specific aspects of the trial management. The first, A, corresponded to early months during which appropriate tactics were being explored on a trial and error basis. During period B a variety of different foods was used but principally blue whiting and whiting, which are calorifically much poorer than sprat. In period C large numbers of fish were culled for dress-out statistics and food was withheld for the first week. Finally, period D corresponded to the aforementioned reduction in temperature and feeding rate in connection with the onset of sexual maturity. Thus it is clear that food conversion efficiency is very sensitive to management practice. Outside these marked reductions, food conversion efficiency seems to lie between 30 and 40% and the evidence, inadequate though it is, suggests a mild positive correlation with temperature and a decline with fish size after the first year. The appetite of fish, possibly the determinant of food conversion efficiency levels, showed similar correlations with temperature and with size, rising to about 6% of body weight of fish per day at month 10 and declining to about 2% by month 20. From month 23, when the sexes were kept separately, food conversion efficiency was markedly poorer for males than for females.

Sufficient information is therefore available on on-growing performance in turbot to predict the rate of growth and the food requirement in a variety of temperature conditions. Further refinement of data on temperature-dependent growth would be of value but the principal on-growing problems to be resolved are those concerned with the effectiveness of different foods and their availability and the holding capacity of fish tanks, particularly in relation to dissolved oxygen levels.

Production of juveniles

Although the data on on-growing came largely from experiments with wild juveniles collected from the beaches, it is clearly not practical to build an industry on this supply. It was necessary to develop a hatchery process to produce juveniles from the eggs.

Fecundity in turbot is very high and mature females can produce millions of eggs. Spawning can be achieved naturally by holding sexually mature fish in ponds with light and temperature regimes close to those in nature, or it can be performed artificially by stripping eggs and sperm from mature fish and mixing them in a small volume of water.

The eggs are small (1 mm diameter), transparent and buoyant. Incubation is possible over a wide range of temperature but experience shows that 11-12°C is the most useful. Eggs are best held in conditions where oxygen levels are kept high, and at 11-12°C they hatch in about eight days. At this stage the larvae float near the surface but after yolk absorption, which takes about four days at 12°C, they become free swimming. A temperature rise, as with plaice and sole, seems to be an aid to the beginning of feeding. At the end of yolk absorption, when the larvae are just under 4 mm long, they need to feed. Experience has shown that food has to be present at least two days before the completion of yolk absorption, otherwise the larvae show all the signs of starvation and die within 12 days.

The *Artemia* nauplius, the routine live food of use in most larval rearing techniques for marine fish, was unsuitable for turbot because it was too big. Smaller live foods tested included copepod nauplii, mussel veligers and the rotifer *Brachionus plicatilis*. All of these were accepted by young larvae but the latter has become the standard food for the first four days. Two strategies have proved successful. In the first, rotifers are cultured on unicellular algae in suitable vessels, then harvested and added to the tanks which contain turbot larvae. In the second, the rotifers are cultured in a fish tank, again on unicellular algae, and at the appropriate time the turbot larvae are added such that a complete food chain is provided *in situ*. The latter method is highly successful initially, but collapse of the algal bloom is often followed by heavy mortality amongst the turbot larvae. The former method is now in routine use but modified slightly by the daily addition of some unicellular algae to the fish tank. The beneficial effect of the algae is not fully understood, but some evidence suggests that it maintains the nutritional adequacy of the rotifers living in the system. Other unresolved problems include the observation that some species of algae appear better than others for rotifers vis-à-vis their suitability as food for turbot larvae.

After two or three days' active feeding on rotifers the turbot larvae can be fed with Artemia nauplii. Subsequently, partly-grown Artemia, cultured on algae, are added as the larvae increase in size. During the early phases of this stage the presence of algae in the tanks again appears to be beneficial to the well-being of the fish. This dietary regime proved feasible to take turbot to metamorphosis but survival rates were very low, often in the range of 1% survival from hatching. Undoubtedly, the provision of partly-grown Artemia was a bottleneck, and some of the larval mortality could be attributed to starvation. Weaning larvae from Artemia on to prepared diets has recently been developed and has been followed by an increase in survival rates to metamorphosis of up to 25% of hatching larvae.

Weaning has been accomplished in two ways. In the first, turbot larvae were reared in the standard way for about three weeks, finishing on partly-grown Artemia. At a length of about 12 mm they were transferred to a weaning tank comprising a black polythene inverted cone, approximately 70 cm wide at the mouth and 80 cm deep. Water turbulence was maintained by air injection at the base of the cone and by an angled jet of water at the surface. Minced fish were fed by hand during the day and a moist salmon starter diet continuously during the night. The second method used a similar inverted cone with only mild aeration and water flow and with graded salmon starter diet administered continuously. Turbot larvae from 6 to 17 mm in length were successfully weaned in this system but with improved survival from the larger specimens. Both weaning exercises greatly reduced the need for live Artemia, although in each case some Artemia was necessary during the weaning phase itself which lasted only a few days.

Thus the development of a rearing technique for turbot has been an empirical study with steady annual progress. Knowledge of the scientific nature of failures and successes is almost wholly absent, but future programmes include a biochemical analysis of the range of feeding regimes employed in order to understand more fully the nature of the feeding, growth and survival of turbot larvae. At present the methods seem adequate for the production of tens of thousands of metamorphosed fish, but require a high level of technological skill. More routine and extensive methods will need to be developed if turbot farming is to grow into an industry.

Manipulation of broodstock

With encouraging developments in larval rearing and on-growing of turbot, manipulation of broodstock to improve egg quality and supply becomes a relevant aim in research.

In turbot, as in all flatfish, ovulation occurs sequentially over a period of a few weeks. After ovulation the eggs are held within the lumen of the ovary pending release at spawning. The eggs remain viable for only a short time, possibly about a day, and in nature the fish probably ovulate and spawn on alternate days. In the hatchery turbot will spawn naturally provided they have adequate space to manoeuvre and are not disturbed. The drawbacks of natural spawning are that (i) its timing is unreliable, (ii) fertilization is not always accomplished, (iii) identification of the parentage of eggs is impossible. Artificial fertilization overcomes these difficulties and eggs may be stripped daily or on alternate days, but considerable variation in quality has always been a feature of artificially-fertilized eggs and the stress to which the fish are subjected on handling probably disturbs the normal processes of ovulation; it always prevents natural spawning from taking place. In practice it has been found that without temperature control spawning tanks become too cold in the winter and too hot in the summer, and that adjustment to a 6°C minimum in the winter and 12°C maximum during the summer spawning season improves the quality of eggs stripped artificially on a daily or alternate day regime.

The nutritional requirements for broodstock are not known, but normal practice is to feed on a variety of trash fish, but predominantly gadoids with a low lipid content.

Since the smallness of turbot eggs contributes to the problems of early feeding, it is of importance to understand the factors which control egg size. No information is available for turbot, but an analysis of egg size in plaice taken from five different spawning grounds in the North Sea revealed a 30% variation in egg weight and an analysis of variance attributed almost all of this equally to between-stock and between-individual components. Little within-egg variation occurred from each female. Similar variation has been observed with sole eggs, but for turbot such analysis is precluded by the scarcity of the fish and lack of knowledge of spawning grounds. Current practice of branding individual turbot in broodstocks will, however, permit an evaluation of egg size in future work.

Turbot spawn naturally during May and July, but commercial and research work would benefit if the spawning season could be manipulated. Individual females amongst broodstock appear to mature at specific times over the natural range with some consistency from year to year. If there is a strong genetic element to this variation there would be long-term prospects for developing early and late spawners by genetic selection. In the shorter term, however, successful manipulation of spawning time has been accomplished by control of the light regime to which the broodstock is exposed.

Experiments to investigate the use of light manipulation to control spawning were begun with the dab (Limanda limanda) simply because this small, easily reared flatfish species was suitable for the small-scale experimental facilities available. The duration of daylight hours was presumed to influence the timing of dab maturation in the sea because it was the most regular and dramatic of seasonal cycles. Temperature change is not so clearly defined and the changes are only modest over the normal period for maturation. Light was manipulated in two ways to give an accelerated light regime; first, by arranging for a full year's fluctuation to occur within six months and, second, by using a 12-hour day. Both systems were successful and dab were induced to mature and spawn three times over the period of a calendar year, comprising two normal spawning seasons, and a mid-term spawning. Slightly modified methods with turbot, to accommodate their summer spawning habit, are in operation and fish appear to be maturing in March, some two months ahead of the earliest natural spawning. Other turbot are being subjected to delaying light regimes and it is expected that future spawning seasons will extend from March to December.

Farming strategies

Three basic strategies for farming flatfish have been considered throughout the history of marine fish farming, utilizing, respectively, natural enclosures, cages in the sea and on-shore tanks supplied with pumped water.

Natural enclosures are inappropriate because of serious management difficulties. Water exchange, control of predators, parasites and disease, harvesting and general surveillance of stock are all seriously impaired under conditions found in natural enclosures.

Sea cages are practical only in relatively sheltered areas and with a moderate tidal flow to effect water exchange. The west coast of Scotland is the only area of the UK with suitable conditions for this type of farming but, for turbot, the low ambient temperature levels (6-15°C) present a problem in terms of slow growth. Figure 5 shows the predicted increase in mean weight over an annual cycle on the basis of west coast of Britain mean monthly temperatures and the temperature/growth relationships described earlier. Three starting points were envisaged, comprising 5, 15 and 20 cm fish, respectively. The first represents 0-group fish of a current spawning season, while the 15 cm fish would be one-year-olds tank-reared at ambient levels of temperature and the 20 cm fish one-year-olds reared in tanks with some supplementary heat. None of the predicted performances appear adequate for commercial exploitation. Looked at in another way, the annual predicted increment in length is 5.65 cm which is equivalent to about four months' growth at 15°C.

Tank-rearing has the advantage that it is amenable to a wide variety of management practices. Tanks can be purpose built for self-cleansing, afford protection to stock from predators, can be independent of climate or weather, allow easy handling of stock and can be sited anywhere where a suitable water supply is available.

Temperature is clearly of great importance in the management of turbot on-growing. One major concept in this connection has been the possible use of heated effluent from coastal power stations. Power station effluents, however, are not always suitable in other respects. Chlorine discharge arising from pipe cleaning operations is a continuous hazard and other water quality factors, particularly the load of suspended material in the water, present many management problems. The use of heat exchange systems can eliminate the chlorine problem but the relatively small temperature differentials make this an expensive process in capital terms. Alternative means of optimizing water temperature include the siting of farms in more southerly, warmer, localities and the use of covered tanks to make use of solar energy. Direct heating of water hardly seems appropriate over the whole production cycle for turbot because of the large volumes of water required. The use of recycled heated water during the early stages of growth, when water and space requirements are at a minimum, seems a practical approach, however, and may be necessary under UK conditions to produce an economically feasible production time-scale.

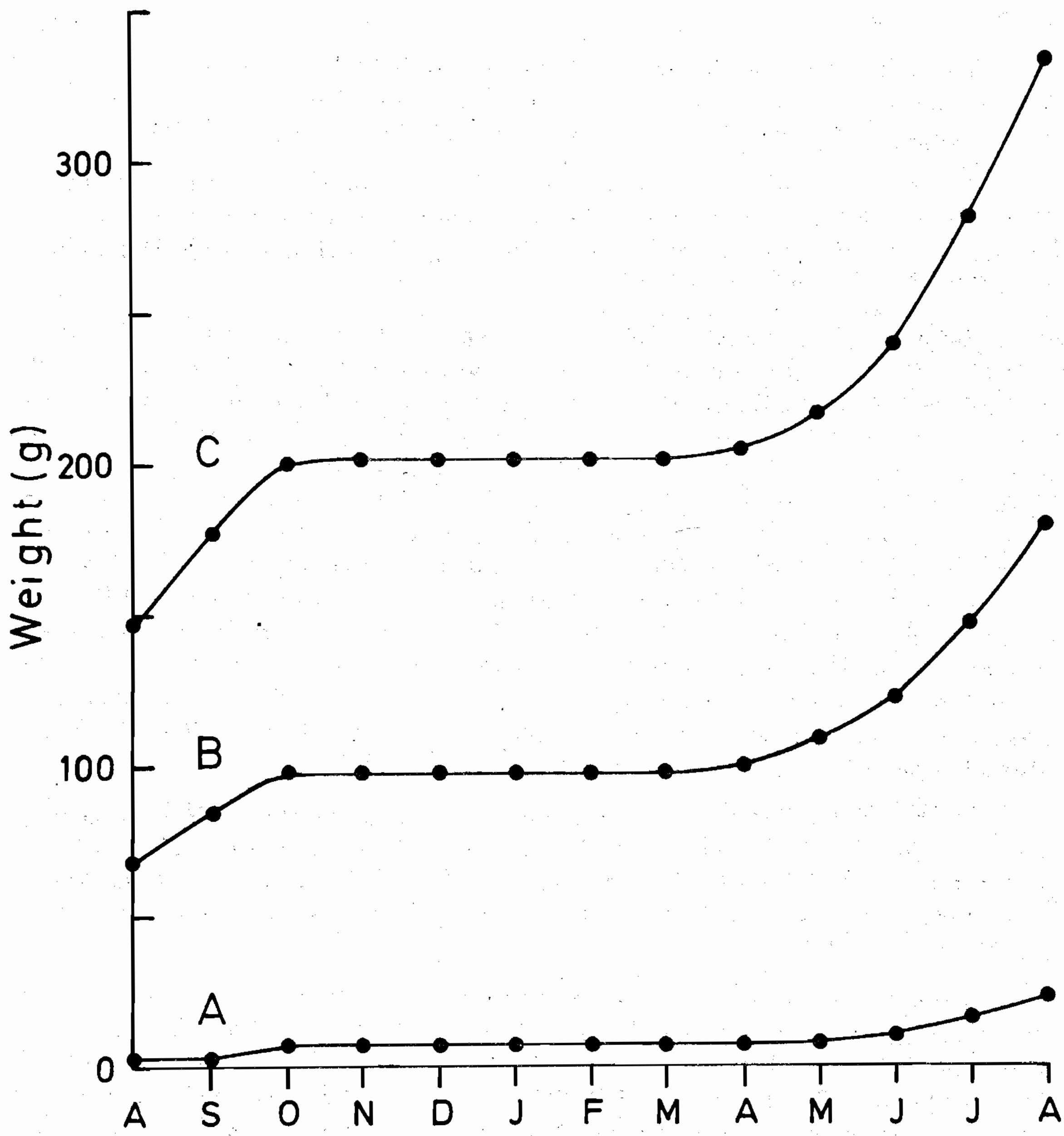

Figure 5 Predicted growth in weight of turbot under sea cage conditions.
Starting point: A 5 cm, 2.2 g
B 15 cm, 66.4 g
C 20 cm, 146.3 g

The range of possible strategies for farming turbot outside the power station or sea cage concepts has not been put to practical test but Figure 6 shows predicted growth rates for the following conditions:

1: Power station effluents (temperatures at Hunterston Power Station).

2: Tanks irrigated at Lowestoft intertidal temperatures.

3: Closed circuit rearing for six months at 18°C (December-May) followed by Lowestoft intertidal regimes.

4: Method 3 but with temperatures augmented 2°C (covered tanks).

The advantage of warm water use is obvious.

Preliminary costings

An accurate forecast of costs involved is not feasible at present in view of the lack of commercial experience with turbot. This preliminary exercise is based on research experience with turbot in relation to current practice in trout farming and on the basis of 1975 prices.

The three basic phases of farming are

1 broodstock holding and egg production;

2 larval rearing and production of juveniles;

3 growth of juveniles to marketable size.

The following costs are based on the production of 10 000 fish.

1 Egg production

This is not normally a feature of small- to medium-sized trout farms which usually obtain eggs from specialist producers in the UK or abroad. Broodstock holding is expensive for trout and likely to be more so for turbot. A small broodstock of 20-30 fish could theoretically supply all conceivable needs in the UK in view of the very high fecundity of turbot. It is therefore envisaged that would-be turbot farmers should have access to egg supplies, possibly from a central government source. It is felt that initially egg supplies might be available to farmers at little or no cost and this cost item has therefore been omitted.

2 Production of juveniles

This is a small-scale operation but with high technological needs. Live foods are required for larvae until they reach a length of about 1.2 cm after which prepared foods can be used to metamorphosis at 3 cm. Upper and lower cost estimates are given in Table 1.

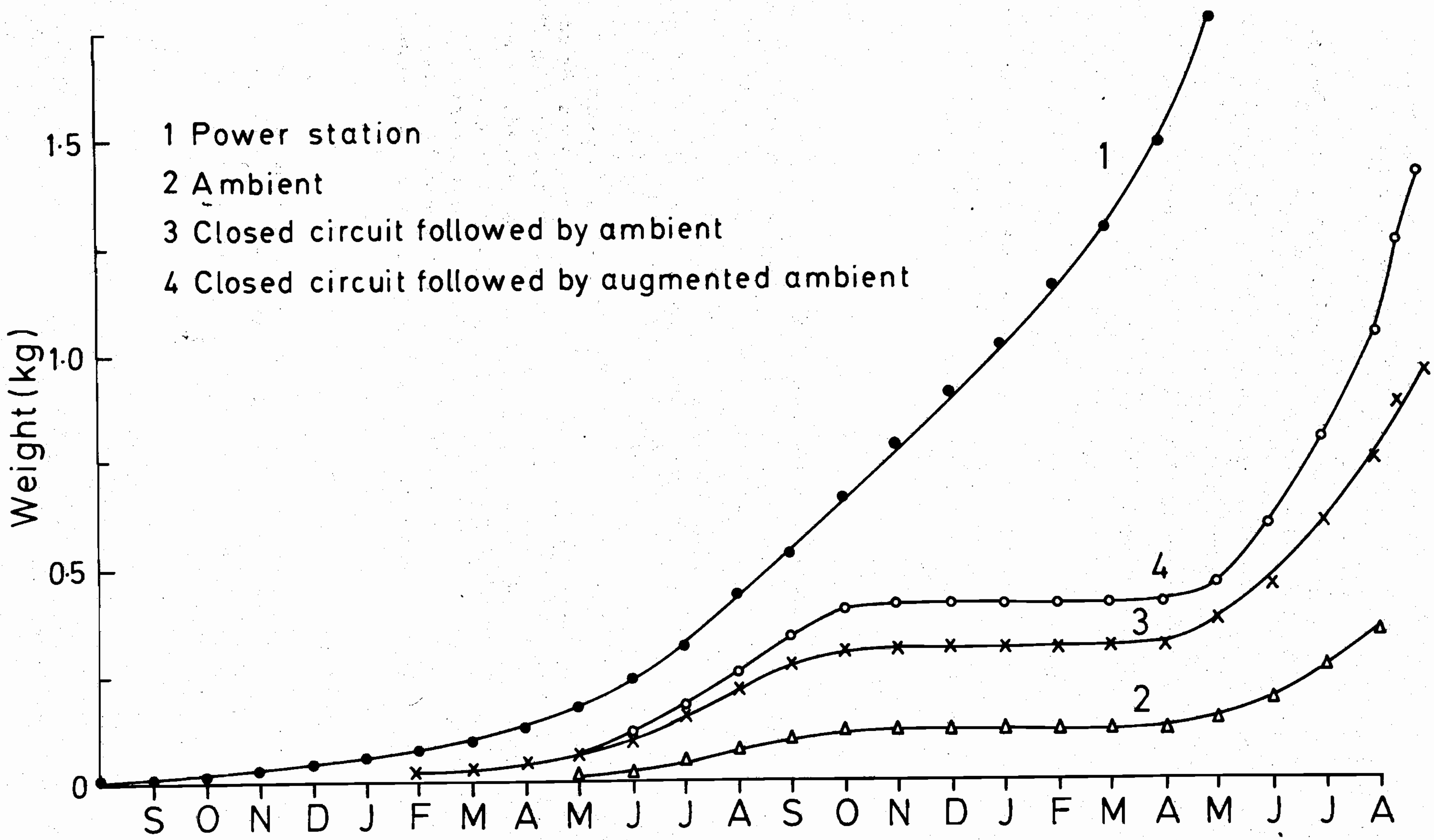

Figure 6 Predicted growth in weight of turbot in tanks under four management regimes.

Table 1 Estimated costs in producing juvenile turbot

Item	Capital, £		Depreciation, years	Annual cost, £	
	Pessimistic	Optimistic		Pessimistic	Optimistic
Accommodation	740	533	20	37	27
Tanks	680	470	10	68	47
Pumps	100	100	10	10	10
Live foods				320	105
Prepared foods				25	25
Husbandry				160	110
Maintenance at 5%				76	55
Total	1 520	1 103		696	379

3 Growth to marketable size

This is the large-scale part of the process. Strategy B of Figure 6, i.e. a combination of early culture in heated recycled water followed by tank culture at augmented ambient temperature during the first and subsequent summers after spawning, seems the most rational and the costs in Table 2 are based on this and the following plan:

> Juvenile fish raised from 1.5 to 60 g in recycled water (1 tank, 6 000 gal) replaced daily and kept at 18°C: duration six months. From 60 to 500 g in open flow at augmented ambient temperature (4 tanks): duration six months. From 500 to 1 500 g in open flow at augmented ambient temperature (10 tanks): duration 12 months. Total production over a two-year cycle, 15 tonnes.

Table 2 Estimated costs in commercial on-growing of turbot

Item	Capital, £	Depreciation, years	Annual, £
Accommodation	5 000	20	250
Cold store (-20°C), 12 tonne	12 000	20	600
Insulated covered tank, 1	1 200	10	120
Covered tanks, 15	12 000	10	1 200
Pumps	1 000	10	100
Food preparation	1 000	10	100
Pumping (equivalent costs 30 tonne/year trout farm)			2 000
Heat costs (600 gal/day, 10°C rise)			1 000
Heat loss (50% input)			500
45 tonnes (trash fish : food conversion 3 : 1)			2 700
Husbandry			2 500
Maintenance (5% capital)			1 610
TOTAL	32 200		12 680
Phase 3 production cost/ tonne			845
Total production cost/tonne, phases 2 and 3			870-890

Average monthly prices at first sale on Lowestoft market during 1976 ranged from £800 per tonne for small turbot to £2 200 per tonne for large turbot

Trout

Current practice

Trout farming is a commercially viable industry throughout most of the temperate regions of the world. The most popular species farmed for food is the rainbow trout (Salmo gairdnerii) and its popularity derives partly from the ease with which it can be reared and partly because of its fast growth. Trout farming methods vary widely, but all have in common the basic elements of artificial production of fertilized eggs, growth of fish intensively on prepared foods, and the use of water in large quantities.

Eggs hand-stripped from hen fish are fertilized with milt similarly obtained from ripe males. They are incubated in running water, hatch after about a month at 10°C, and require food about three weeks later when yolk sac reserves are used up. Trout eggs are large; at ten to the gramme they are about 100 times heavier than turbot eggs, and the fry at first feeding accept particles of prepared foods. Prepared diets in the form of dry pellets of progressively larger sizes may be used throughout growth to marketable size or to sexual maturity. These pellets have a high protein content, in the range of 40-50%, often derived from fish meal. Moist diets compounded from cheap protein sources, e.g. abattoir offal and trash fish, are used in many parts of the world but in the UK the majority of trout farmers use pellet feeds.

Freshwater production of trout for food, as opposed to production for sporting purposes, is always based on intensive methods using circular tanks or long narrow ponds (raceways) built of concrete or simply dug out of the ground. Both systems use large quantities of water. Some more or less sophisticated water-saving systems will be mentioned later, but as a general rule a supply of a million gallons per day will support an annual production of about 10 tonnes.

Apart from these basic features, trout farming embraces a wide variety of practical management approaches. Despite a long history and the existence of numerous books on methods, there is a surprising lack of standardization about the management of trout farms. Production in the UK has increased over the past five years, however, from a few hundred to over 2 500 tonnes per year. There is every prospect that development will continue and that production in the 1980s will be in excess of 10 000 tonnes/year and in line with current production levels in other parts of Europe. In response to the growing importance of trout farming as a means of food production, MAFF research is directed towards the establishment of a scientific basis for the efficient conduct of this branch of animal husbandry. Three areas of research under development are:

water management;

broodstock manipulation;

feeding strategies.

Disease studies are also an important contribution from MAFF research but these will be considered in another Leaflet.

Water management

Water is clearly a limiting factor on-site in fish farming and, in the context that supplies are already under considerable pressure from domestic and industrial use, it has been suggested that freshwater availability might be limiting in relation to the overall expansion of the trout farming industry. Three ways of minimizing such restraints are:

1. re-use of water after filtration and reconditioning;
2. slow use of water by providing additional oxygen or air;
3. use of sea water.

The first is technically feasible but, in view of the large volumes of water used in farming, the cost is likely to be prohibitive. The use of oxygenation or aeration is under development by industry, and up to a tenfold increase in the efficiency of water use can be achieved. Eliminating oxygen as a limiting factor increases the risk that excretory products may prove harmful. Assessment of the relevance of this possibility in current practice is being made and some limited trials on the toxicity of specific components of excretory products are planned. The use of sea water for farming trout is hardly exploited at all in the UK although it is a rapidly growing practice abroad. This is the area chosen for research under MAFF auspices on the grounds of its simplicity and possible broad application, and the limitless supplies which are available at temperatures less extreme than those currently experienced in surface waters on land.

Rainbow trout cannot survive as fry in sea water and an initial freshwater phase is obligatory. When a fish moves from fresh water to sea water the osmotic pressure to which it is subjected is reversed. In fresh water the fish's problem is to excrete water; in sea water to absorb water. Naturally migratory fish undergo a specific physiological change at a certain size and age, called smolting, which permits a rapid entry into sea water. Rainbow trout are not migratory in this sense but it is known that transfer to sea water becomes easier the larger the fish are on transfer.

The first problems therefore were to determine at what period to transfer fish to sea water and how quickly and to what extent seawater life changed the growth characteristics. A trial was set up using seven-month-old rainbow trout ranging in length from 8 to 19 cm and weighing from 7 to 90 g. Under standard conditions at a temperature of about 12°C the fish were grown for two months in fresh water followed by a two-week transition to sea water (32°/oo) and a further period of 2½ months in sea water. The growth in length is shown in Figure 7 and it is quite apparent that growth rate changed little during the course of the trial. Growth in weight is shown in Figure 8. At the start of the acclimatization period the fish ranged from 13 to 27 cm in length and 27 to 280 g in weight. Few deaths occurred during the months following acclimatization and a weight of about 30 g would appear satisfactory for transfer to sea water under the regime used. Details of the change in salinity are shown in Figure 9.

In two subsidiary trials fish of different sizes were compared at two rates of salinity change. The survival curves are shown in Figure 10. The smaller fish, ranging from 15 to 30 g at five months after hatching, were clearly not transferable. The larger fish, at 20 to 40 g weight and six months after hatching, were much more amenable to transfer but still suffered mortalities not commensurate with commercial practice. Much more research is required to define appropriate techniques for the early release of trout into seawater environments.

Broodstock management

Intensive systems for rearing trout are not suitable for producing broodstock. The fish are not ready for spawning until three years old and it is impractical to employ systems designed for short-term intensive production over this time-scale. Normal practice is therefore to purchase eggs from specialist producers who rear under more relaxed conditions. Eggs are easy to handle once the embryo has reached the 'eyed' stage, about one week prior to hatching, and transport presents few problems.

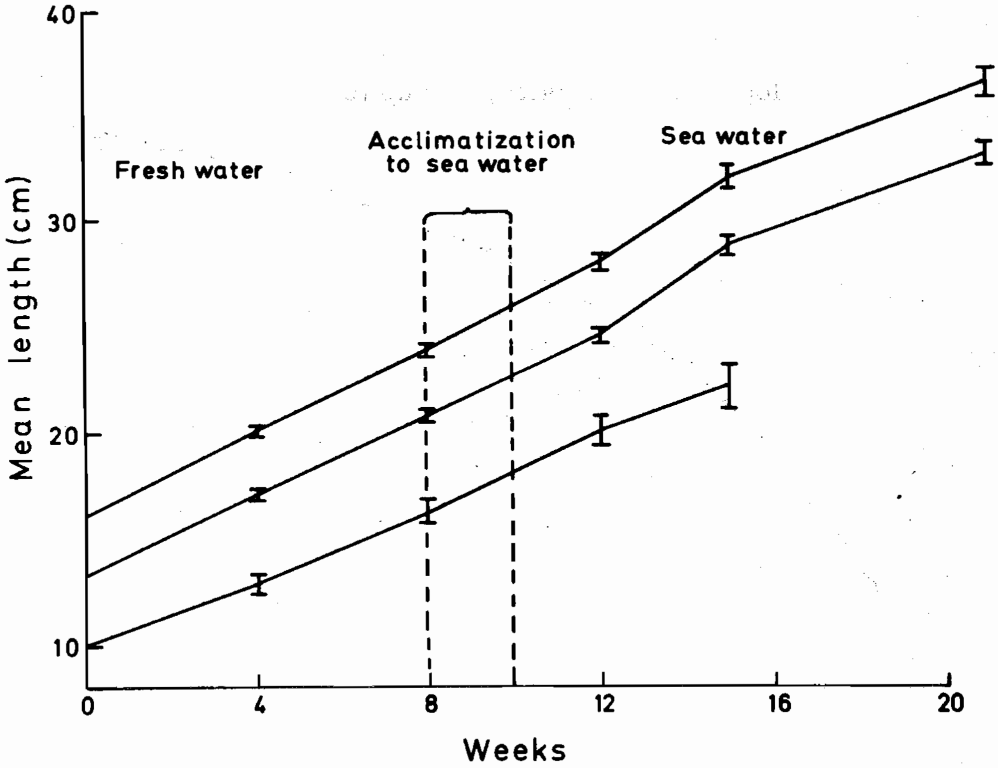

Figure 7 Growth in length of rainbow trout before, during and after acclimatization to sea water.

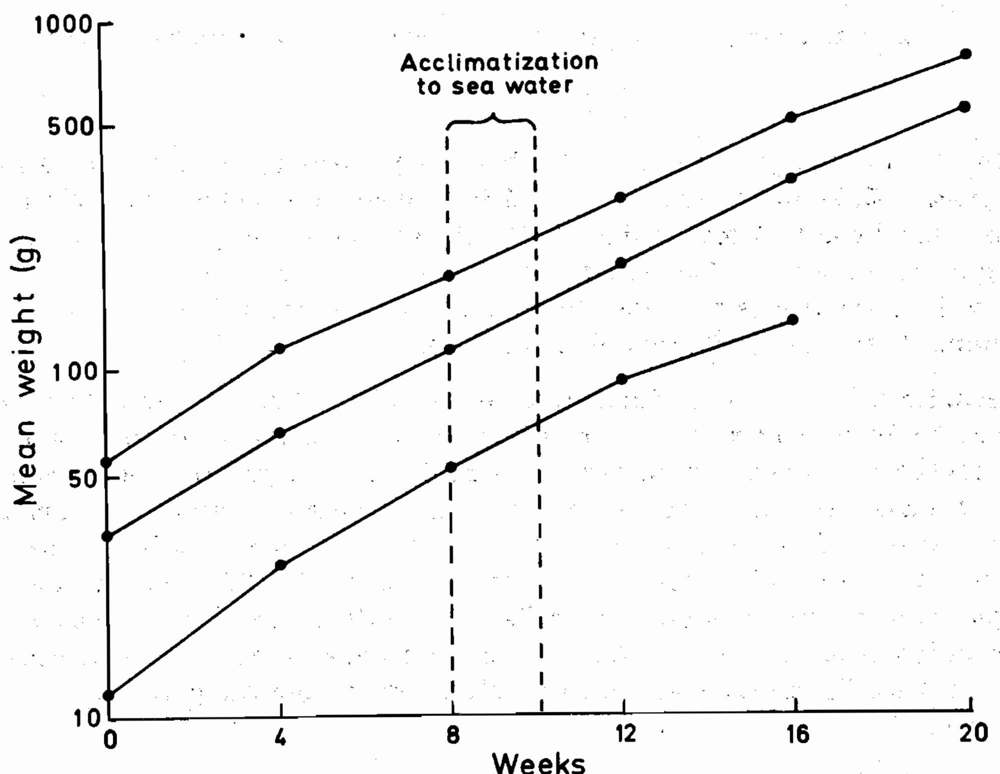

Figure 8 Growth in weight of rainbow trout before, during and after acclimatization to sea water.

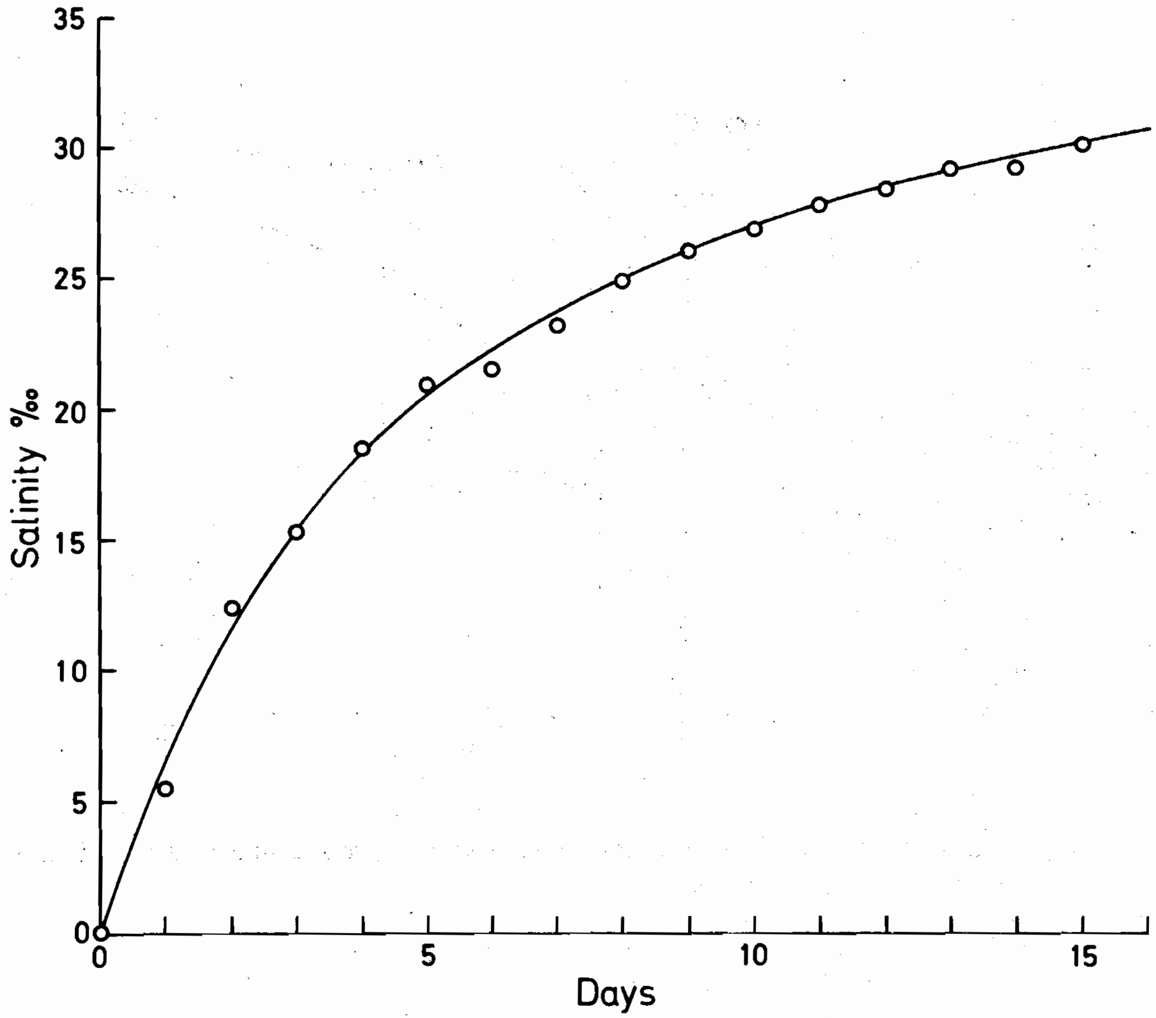

Figure 9 Salinity change during the trials described in Figures 7 and 8.

Production of eggs by specialists has many advantages other than simple convenience. Genetic and environmental improvement becomes possible and disease control can be exercised at the critical point of egg production. Current thinking on an infectious disease (Infectious Pancreatic Necrosis widespread in the UK and elsewhere) is that control by disease-free certification of egg supply systems is the most effective way forward.

Genetic modification of domesticated animals and plants has a dominant role in agriculture generally, but in fish farming no rational exploitation of genetic methods has been attempted. The scale and manpower requirements of such work makes it more suitable for government or state rather than private implementation and several countries abroad have set up research groups in this field. Genetic studies are a major part of recent MAFF plans for the development of research in support of fish cultivation. Genetics cannot be considered in isolation, however, since the performance of stock is determined by management methods (environment) as well as by the genetic potential of individuals.

The four general areas of genetics applicable to fish farming are selection, inbreeding, sex control and hybridization.

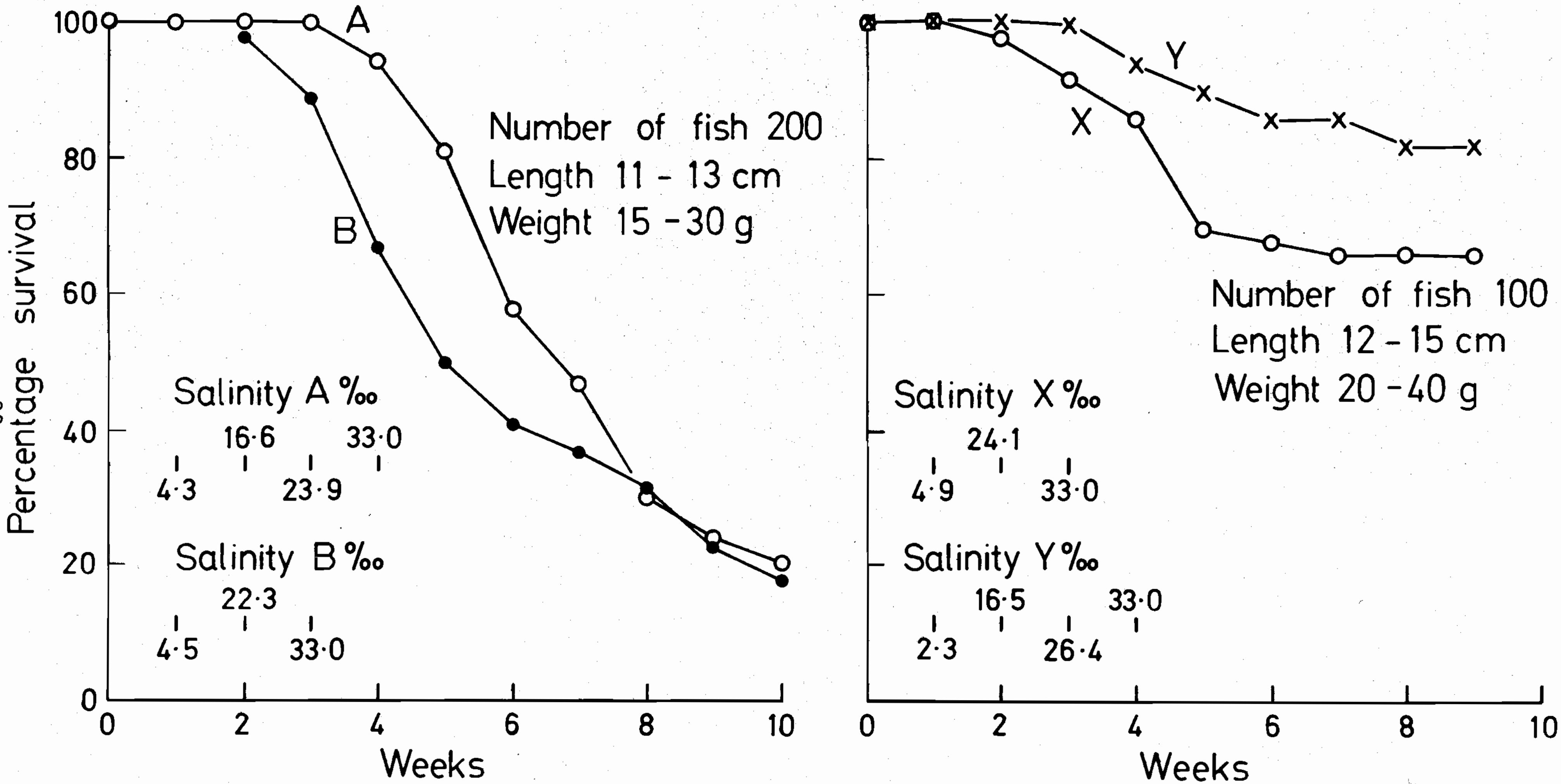

Figure 10 Mortality of young rainbow trout during acclimatization to sea water.

Selection

There is a substantial body of information on the theory and practice of selective improvement in domesticated animals and plants. Its application to fish is simply dependent upon the establishment of desired aims and the estimation of inherited variation with respect to the characteristics of value.

In general, popularly expressed aims normally centre on growth rate. This is not a highly heritable character in fish, however, and management practices are more relevant than genetics. Characteristics of more promising value are egg size, age at sexual maturity, season of spawning, tolerance of sea water, ability to utilize food and disease resistance. These and other characteristics of commercial importance require evaluation in genetic terms before costly programmes of selection are initiated.

Inbreeding

Inbreeding is both beneficial and harmful. The harm arises because inbreeding itself is normally accompanied by a loss of vigour called inbreeding depression. It is almost inevitable that inbreeding will occur in trout farming where small numbers of broodstock are used. Laboratory tests indicate that a number of commercially available strains are inbred.

The benefits of inbreeding derive from the genetic uniformity of inbred stock, together with the hybrid vigour (heterosis) observed in offspring from matings between two different inbred lines. Inbred lines are therefore developed not for their own intrinsic value but in accordance with the performance of the cross-bred offspring. This is a basic principle in plant breeding, was one of the important developments in the industrialization of poultry farming, and is becoming of increasing value in other areas of livestock management. There is good reason to believe it can become equally important in fish farming, particularly with rainbow trout for which a variety of strains, some already inbred, are available.

MAFF research in this field is based upon the collection of strains and their evaluation. This is long-term research but accommodates the requirements not only of work in inbreeding and heterosis but also of that on genetic variation in the selection content.

Sex control

Knowledge of genetic sex-determination in fish comes mainly from studies with ornamental fish and nothing is known of control systems in salmonids. The sex of a fish is of importance in salmon and trout farming chiefly because male fish may mature precociously and either die or stop growing. This is particularly relevant to sea culture of salmonids.

Various forms of genetic sex-determination exist amongst fishes and even closely related species may differ in this respect. In at least one case, different populations of a species have been shown to have different genetic sex-determination systems. Experimental procedures to evaluate systems are well known and simply need to be applied to trout and other fish of commercial value. The practical objective is to produce female-only broods of offspring and so avoid the limitation of male growth and survival.

An alternative approach is to produce sterile fish. A number of techniques are being employed for this. So far, it is not known whether or not sterile fish exhibit secondary sexual characters - the usual cause of problems in farming.

Hybridization

Fish hybridize very readily but the consequences of interspecific hybridization are not always predictable and are very rarely useful despite the popular view of hybrid vigour. In practice, hybridization is not a powerful tool in genetic manipulation of fish but could have some specific relevance. Thus it is possible that crosses between rainbow trout and steelhead trout might combine good growth rate and tolerance to sea water, although there is no evidence that this would occur. Similarly, the use of more widely separated parental species might lead to sterility, the value of which has already been mentioned.

Feeding strategies

Food costs are a major part of production costs on trout farms but feeding methods seem lacking in rigour and standards. Food materials are also highly variable and the question of what to feed and how is often raised. It is not the intention within MAFF research to explore this field comprehensively, but the maintenance of records within trials designed for other purposes will be relevant.

Two specific areas for investigation, however, are the use of novel protein sources in pelleted feeds and the exploitation of trash fish for direct feed purposes rather than indirectly through the fish meal processing system.

Costings

Trout farming is clearly cost effective now and experience within MAFF work is too limited for meaningful evaluation or prediction of future trends. The research plan, however, is based upon the concept of reducing costs by improving efficiency and cost-predictions will be a feature of the on-going programme.

A great deal depends on the nature of the site and the water supply but in general terms the capital costs of a 30 tonne/year unit are of the order of £100 000. Excluding management duties, the manpower requirement is approximately one man per 15 tonnes. Running costs otherwise relate to the provision of food at about £250 per tonne and turnover is approximately £1 000 per tonne.

<u>Sole</u>

The early work on sole was outlined in a previous section and the reason for reducing effort in this area was that sole were difficult to feed on prepared diets. Research was conducted only on the feeding performance of newly-metamorphosed fish with the objective of moving from live foods to prepared diets at the earliest opportunity.

Two series of trials were performed in small-scale experimental facilities, (a) to assess the effectiveness of different types of made-up food and (b) to explore the possibility of gradual weaning on to a commercially available salmon starter diet.

The first series of trials showed that a mussel component greater than 5% was necessary for successful feeding and that 75% fresh mussel was the basis of the most effective feed. Mussel-based diets are not commercially feasible at present, however, hence the switch to salmon food.

In the weaning trials with salmon food, graded particles were introduced into the weaning tanks continuously by automatic feeder. Newly-metamorphosed fish measuring about 1.5 cm in length were fed this way for 16 days after which small quantities of Artemia nauplii were added each day in an attempt to encourage non-feeders to start feeding. Weaning was completed within 70 days at a survival of about 50%.

These developments in the early feeding of sole are a considerable improvement over the older methods employing live foods such as white worm or lumbricillids. The commercial feasibility of sole farming is still in doubt, however, although the advances made recently justify a closer look at the possibility of trials to establish firm facts about sole. So far, little is known of (a) the growth rate dependence on temperature or (b) the food conversion efficiency under conditions which resemble those relevant in commercial production. Preliminary costings are irrelevant in view of this uncertainty and the only justification for interest in sole farming is the very high value of the product.

Other species

Well over a hundred different species of fish are employed in one form or another of fish farming throughout the world but, of these, only a few contribute significantly to food production. They include, in roughly descending order of production, carp, rainbow trout, channel catfish, yellowtail, eels, mullet, coho salmon, Atlantic salmon and various species of Tilapia.

Of the above species, eels, carp and both sorts of salmon could be farmed in Great Britain. Carp is farmed to a small extent but there is little scope for expansion due to adverse market reaction. The climate in Great Britain is also not ideal for carp farming and there are no plans for research with this species. Eels are similarly not suitable for farming in our climate and even under the warmest conditions in power station effluents growth rate is measured in only grammes per year.

Atlantic salmon are farmed in Scotland but with difficulty due partly to the slow growth and poor survival during the freshwater phase in the salmon life cycle. Limited research on the possibility of tank culture of salmonids is in progress.

Coho salmon has an advantage over salmon in that its freshwater life is much less difficult to manage. This Pacific coast species is farmed in parts of its natural range but for portion-size fish not salmon-sized individuals. Its introduction into British waters is hampered by import controls because of disease legislation and there is also opposition on environmental grounds that the species could endanger indigenous fish and, in particular, the Atlantic salmon. No research is planned for this species but the prospects are reviewed periodically.

Of fish currently supplied by the fishing industry some are worthy of comment in a fish farming context.

Cod is a highly favoured species which is subject to fluctuation in supply. Preliminary studies have indicated that larval rearing presents fewer problems for cod than for turbot and the juveniles seem easy to feed. Haddock seems a less robust species than cod but no precise information is available. Both species deserve a low level scrutiny.

Halibut is a prime quality flatfish but hatchery experience has revealed intractable problems. This species spawns at very great depths (1 000 m) and the eggs are bathypelagic, that is they exist suspended in mid-water at great depths. In the hatchery, the large but delicate-looking eggs have been hatched but no larvae have survived to complete yolk sac absorption - a phase without problems in all other fish species examined by us. The general philosophy of hatchery management of fish has been to create conditions representative of those in the natural environment. This appears to be hardly possible for halibut, requiring a cold, still, lightless environment under considerable pressure.

Several other species were considered in an economic sense but were not thought to be suitable (Jones 1972). One further species which was not considered at that time is the dab. This has excellent eating qualities but is a small fish and is probably underrated on account of this. It is a very vigorous, catholic feeder, however, and likely to perform well in the hatchery phase and in on-growing. It may deserve some consideration in a fish farming context in the future.

SUMMARY

Fish cultivation research under MAFF auspices has developed from early ill-fated attempts at natural fish stock augmentation. Its current role is to explore the creation of economically feasible farming systems and to improve existing ones within a philosophy which regards fish farming simply as an industry to produce food under normal economic constraints. Fish farming is not a means of producing cheap protein but an existing industry to produce good quality protein. It is not an alternative to, nor a competitor of, the fishing industry, by virtue of its scale.

The original concept of farming plaice failed because of economic factors. Sole and turbot do not suffer these economic failings but the former still appears unsuitable for cultivation on biological grounds. Turbot farming methodology has improved each year, particularly in the hatchery phases, and commercial trials have begun.

In the salmonid field trout farming has grown into an industry which has an importance commensurate with government funded research into those areas of investigation particularly dependent on this type of support. Marine cultivation systems, genetic manipulation and investigation of some aspects of feed management come under this heading.

Turbot and rainbow trout are the two species for which priority is given in research projects. Other fish species, such as sole and salmon, also receive attention and periodic reviews are made of the situation with regard to yet other species.

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