ONE HUNDRED AND SEVENTY-NINTH SCIENTIFIC MEETING
SEVENTY-FOURTH SCOTTISH MEETING
DEPARTMENT OF AGRICULTURE AND FISHERIES FOR SCOTLAND,
MARINE LABORATORY, VICTORIA ROAD, TORRY, ABERDEEN

29 APRIL 1966

FISH FARMING—THE INTENSIVE PRODUCTION OF FISH FOR HUMAN FOOD

Chairman: A. A. WOODHAM ESQ., BSc, PhD, FRIC, *Rowett Research Institute, Bucksburn, Aberdeen*

Fish cultivation

By C. E. LUCAS, *Marine Laboratory, Aberdeen*

First, I should explain that there is nothing original in this contribution. It is a compilation of what others and I, and mainly others, have said before. It is mainly intended to give a little background, and to lead up to the other papers which you will hear today and which I know will contain many things which are new to you. I will, therefore, begin deliberately by borrowing, appropriately enough, from another speaker, Dr Fred Hickling, in his book *Fish Culture*.

'. . . fish culture has an important part to play in supplying that animal protein which is so desirable an ingredient in human diets. This is especially so where animal husbandry is handicapped by poor pasturage, inferior stock, and disease; and in regions remote from large wild fisheries. Further, because the arts of improved pasturage and stock feeding can be applied to fishponds, together with selection of stock and selective culling, very great weights of fish can be produced in small areas. What other forms of husbandry can produce, as fish culture can, 3 to 5 tons of flesh per acre annually . . .?' As you will hear, this by no means delimits the possibilities of fish culture, but it indicates some of the most important possibilities, both in terms of scope and of world needs. One of the greatest of world problems today, as I need scarcely remind members of The Nutrition Society, is malnutrition, and especially that form of malnutrition arising from lack of animal protein. Even if one could distribute it better, the world's great production of vegetable protein alone would not solve this problem, while our production of animal protein is, reasonably enough, far smaller. Fish protein is especially suitable, and fortunately the world's catch of sea fish is already not inconsiderable. It is one of the few sources of food which is increasing faster than even the population; although, sadly, it is not all used for direct consumption by human beings. Unfortunately, it is still relatively small: most of the world's population are far from the sea, and the problems of distributing fish at an economic price are generally greater than those of distributing grain. While valuable, the natural freshwater fisheries are small by comparison, and thus it is that marine fish cultivation has at least one important role. Another is to supplement the often variable—and sometimes overfished—natural supplies, if that can be done economically.

Fish cultivation is an old art. It has been practised in the tropical East for thousands of years, and even in this country monasteries had their fish ponds during the Middle Ages; the latter were, of course, freshwater ponds and most of the present forms of fish cultivation are conducted in fresh or brackish waters. In the more temperate regions, rearing is conducted on a large scale in China, Japan, the USSR and in several European countries. In Europe, the principal forms cultivated are shellfish and, in freshwater ponds, the carp and its relatives, although cultivation of rainbow trout has also been developed in several countries.

It is in the tropics, however, as Dr Hickling will tell you, that fish cultivation has been taken the furthest—partly because it is an age-old practice there and partly because fish and their food grow so much faster at high temperatures: partly also because opportunity has been taken to rear mainly those fish which live entirely or largely on plants, unlike those we usually eat. These and other factors, can in the right circumstances provide much heavier crops than the land. So, in many parts of the East, the experience of ages, now being reinforced by scientific knowledge, is providing valuable animal crops from wasteland, swamps and deltas, and often in areas where they are most needed, although the whole is still only a small fraction of world fish production.

Returning to more temperate conditions, and Europe in particular, in brackish waters molluscan shellfish (mainly mussels and oysters) have been cultivated for many years, mainly as a luxury food in a number of countries from Portugal to Norway. Although less intensively than on the continent, oysters are cultivated in the southern half of the United Kingdom, and valuable research, from which we may expect much in the future, is being conducted by the Ministry of Agriculture, Fisheries and Food laboratories in Burnham and Conway. Formerly, there were oyster fisheries in Scotland, but all had ceased by the mid-1950s. However, a stock of oysters maintained itself in Loch Ryan and is now under experimental cultivation. In addition, imported oysters relaid in Loch Sween for growth and fattening are now being marketed and there are one or two other developments, largely the result of the enthusiasm of a small team at the Scottish Marine Biological Association Laboratory in Millport. Again, however, it is in the warmer waters that most progress has been made in the cultivation of shellfish (both molluscs and crustacea), and it may well be in the cultivation of these organisms, mostly of luxury value, I repeat, that the greatest developments will occur in the near future.

Carp are reared in several eastern European countries and in Israel, and here and there other attempts have been made. Quite the most impressive of which we hear is from the USSR, in various climates as far north as 60°N, where in the heart of a vast country there is a great need of protein of all kinds. 'Pond' production there is said to have tripled or more in the last few years and may yet come to match natural production in inland waters.

In relation to marine fish proper, around the turn of the century, considerable interest was shown in the possibility of increasing natural stocks of plaice and lobsters by hatching fry and releasing them more or less immediately into inshore waters. Such projects were initiated in different parts of the North Atlantic, but

especially in Norway, Scotland and North America. The release of such 'fry', however, has been almost completely abandoned, as it became clear that by such methods it was impossible to compete with natural production and especially natural losses.

Perhaps the only other serious activity that has deserved the name of 'cultivation' has been the transplantation of several species of fish from localities in which they are indigenous to places where they do not thrive naturally. Several attempts have been made, from the early plaice experiments in the North Sea and the transplantation of salmonid fish from this country to many others, to the recent Russian attempt to introduce Pacific salmon into the Arctic Ocean and adjacent waters. There have been both failures and successes, but this subject is perhaps not strictly relevant to this symposium, which is about fish farming.

A considerable amount of basic information is required before fish cultivation proper, particularly in the sea, can be expected to be profitable. Some of this is already known, but much more knowledge is required about the basis of production in salt water, fish nutrition at all ages, diseases and epidemics such as are met in other kinds of farming, parasites, predators, and so on, as well as the possibility of increasing natural fertility by artificial means. It must be understood, moreover, that there is a considerable difference in the rearing of herbivores (fish feeding on plants) and rearing carnivores (those feeding on animals). As scientists regard these, the former are nearer the base of the feeding system in any environment, and consequently have available to them much the greater proportion of the natural (or artificial) production of plant life. This is important because all animal life in the sea is ultimately dependent on the marine plants (unless artificial feeding is introduced), and even with a herbivorous species only a small fraction (perhaps up to 20%) of the natural plant life consumed is in fact usefully converted by that species. Some carnivorous fish feed directly on the herbivores, but again in fact make useful conversion of only 10–20% of what they consume; while others are ultimately dependent on the herbivores, there are usually one or more intermediate stages. An efficiency or conversion loss of something of the order of 80–90% must be expected at each stage, which can only be evaded, in part, by artificial feeding. It is unfortunate that, whereas in many countries herbivorous fish, for example carp and mullet, are still appreciated in the normal diet, in this country and many others the taste for such fish declined long ago, and nearly all the fish we now eat are carnivorous and often more than one stage removed from the herbivorous level.

Thus it is that, when the suggestion is casually raised of fertilizing the seas, to increase the crops of the fish we are most used to, we have to realize that it is really like suggesting wholesale fertilizing of the land in order to increase, not the cows and sheep which, at least in their natural state, depend on the grass for their increase in growth, but in fact lions and tigers: and even they are nearer to the vegetation than some of our food fish are to the basic plant life of the sea!

Despite inadequate knowledge, natural difficulties and some of the facts just mentioned, there has been intermittently in this country considerable interest in the possibilities of rearing both marine and freshwater fish. The latter has presented

no serious problems so far, except that in any temperate waters the fish inevitably grow rather slowly, so that a crop takes much longer to develop than in the tropics unless there is artificial heating (such as that at present going to waste from power stations). This slower growth necessarily means the greater costs of waiting for the crop to mature, and greater expense in providing accommodation for the different sizes of fish being reared meanwhile. But, in wholly artificial ponds valuable crops of carp (plant feeders) are produced in several European countries (up to 2 tons/acre) and also of trout (for which even larger crops are claimed). Here, artificial feeding and fertilization can have an important part to play. Even in this country, we take for granted the practice of rearing trout and salmon in fresh waters, although mainly for stocking sport waters; until recently little thought has been given to rearing these fish even for luxury foods, although the UK is the biggest importer of cultivated rainbow trout from Denmark. Now, however, interest in these possibilities is developing, and not only is there the Scandinavian example to follow, but on the whole much more of the essential information is available as regards freshwater fish than marine fish. Assuming that conditions (such as water and food supply) can be found in Scotland comparable to those in Denmark, and that the economics work out satisfactorily, there seems no reason why there should not be a useful development of trout cultivation in this country, although there may be bigger problems to face as regards salmon, if only because salmon naturally migrate over great distances and may prove less responsive to confinement; and we are still concerned with luxury foods!

The problems are much greater on the marine side, if only because as yet we have managed to rear very few fish beyond the larval stage, while marine fish generally fetch a much lower market price than salmonid fish. The marine habitat too is a much vaster and perhaps more 'natural' region than most of the so-called natural fresh waters, in which many of even the conventional food fish roam far and wide. Herring, plaice, cod, haddock and many others travel hundreds of miles in their natural life. Some, such as eels and, as we now know, even salmon in the sea phase, may migrate well over 2000 miles, so that even sea lochs, to say nothing of ponds, may prove very unnatural habitats at some stage in their lives. Doubtless there are also other reasons why so few of these fish live naturally in lochs, and we may yet need to know why this is if we are to alter the course of nature. Thus, unless a most unusual proportion of research effort is devoted to this subject, rapid progress must not be expected. Some valuable pioneer work has, however, been undertaken in this country, under two main heads.

In the first place, there were the wartime experiments conducted by Dr Gross and his colleagues in a Scottish sea loch. These were very praiseworthy efforts, at a time when almost any hopes of increasing the food available in and around these islands were vital. Initially, they worked in a small loch of 18 acres, isolated from the sea except for a narrow channel through which sea water enters at high tide. Here they showed that the addition of fertilizer increased the basic production of phytoplankton and attached algae, as might be expected. But also the production of bottom animals was increased and, beyond this, the growth rate of flounders in this pond

also increased. The main disadvantage was that in this small, sheltered, shallow loch with a muddy bottom, the imbalance produced by fertilization caused anaerobic conditions on the bottom which endangered the bottom-living population.

The experiments were repeated in a larger loch, Loch Sween, open to the sea, and the same general pattern emerged: an increased plant growth, increased plankton, and later an increase in benthos populations and in the growth rate of flounders and plaice, the latter having been specially introduced into the loch.

These results have tantalized marine ecologists because they show that apparently the effects of fertilization can be passed through the whole food chain, even though there may be time lags. They did not show, however, the causal sequence within the food chain in any detail; nor did they show the quantitative return from a given amount of enrichment. Perhaps the major problem then was that of rearing and introducing sufficient plaice into this loch, which is not their natural environment, and maintaining them long enough to test growth under normal and then much greater densities, and especially to assess the project as an economic possibility.

Following the assessment of the results of the second transplantation of half-grown plaice in the North Sea, Mr Shelbourne, of the Ministry of Agriculture, Fisheries and Food Fisheries Laboratory at Lowestoft, made a different approach to this problem by attempting to rear on shore large quantities of plaice beyond the larval and metamorphosis stages to thumbnail size. This was done in the hope that the greater part of the very heavy natural mortality would be avoided, and that the resulting young fish might be released either in natural or artificial situations for further growth. Mr Shelbourne has had remarkable success in his attempt, although certain problems remain to be solved, particularly, perhaps, whether these artificially reared plaice will prove competitive with naturally reared fish and other organisms. It is as a result of his work that the White Fish Authority, in conjunction with the Ministry of Agriculture, Fisheries and Food, was encouraged to develop at Port Erin, in the Isle of Man, a fish hatchery and rearing ponds, and to establish at Ardtoe in Ardnamurchan an enclosed section of a sea loch, for testing the growth of artificially reared fish in semi-natural conditions. As Mr Shelbourne will doubtless tell you, there are broadly speaking three main possibilities in taking advantage of his breakthrough. These are (a) to release the baby fish into the sea, where they will face not only the natural and very formidable hazards of intensive predation but many others (it may be almost like releasing week-old chicks into the wild to forage for themselves); (b) the less drastic release into the more or less natural conditions to be found in a Scottish sea loch or any other inlet, which might be open or closed, and in which feeding might be natural or improved by fertilization or even completely artificial; and (c) release into the wholly artificial life of rearing ponds, where conditions may be fully controlled if economics permit, to take account of the whole of what we know and will find out about the best way to produce the largest quantities, of the most attractive quality, of the fish in question.

Professor Frazer and Mr Shelbourne will be telling you more about the possibilities of each of these courses, but I think they will both agree with me that at this stage the emphasis must be on bringing as much research as possible to bear on the

basic problems which have to be solved, and here I will refer briefly to the work we from this laboratory are now undertaking at Loch Ewe. On the one hand, this links with research on basic productivity in the sea we have been doing for some years both at sea and in the laboratory. On the other hand, it is designed to help fill the gap in our knowledge about the complex of ecological interrelationships, existing between the basic production by marine plants, which we now understand fairly well, and the fairly detailed information we have about the population dynamics of a number of commercial fish. In other words, we are studying the flow of energy through the ecological pyramid from plants to fish, which is essential information to fish cultivation in anything approaching natural conditions; it may also provide useful information even for intensive tank-rearing, especially in so far as some of the problems (such as disease and parasitism) are likely to be faced acutely whatever method of rearing may be adopted. Already interesting information is emerging, of which you will hear in more detail from Dr Steele.

Here and elsewhere other projects are proceeding, or are being initiated, which will contribute to the understanding which is vital to the artificial increase of any marine organism, whether fish or shellfish, and whether intended as food for man or supplementary food for the fish themselves. Thus relevant biochemical, physiological and behaviour studies are proceeding here and at Lowestoft, while work on varieties of fish, with a view to the 'selection' of suitable strains is being begun, although this alone will be a large task. Nor do we need 'biological information' alone. Just for example, if fish are to be reared in natural inlets, enclosed in one way or another, it is essential to know just what kind of changes will take place after the closure, both physical and biological. Scientists at Lowestoft and Aberdeen are also studying these. In the light of the requirements of the fish in question, and of a number of economic factors, it is essential to choose the most suitable lochs for the purpose; in addition to making a general survey of most of the Scottish coastline, we at Aberdeen have made surveys of over fifty sea lochs (some very general and others more detailed) while the Department of Engineering at Strathclyde is making more detailed studies of likely ones. Obviously, special engineering problems will also arise, in loch-rearing and in tanks, and these are the special concern of Strathclyde.

Other relevant work is proceeding elsewhere, and arrangements have been made to keep all the workers in close touch. But I must repeat that progress, in economic terms, must not be expected to be so very rapid—and there are good reasons for this. We are all justly proud of our agricultural research. If its results were adopted all over the world, agricultural production could be a lot greater. But, according to how you look at it, the experimental cultivation of plants has been proceeding for over 200 years, or over 2000 years—and practically all agricultural scientists are engaged in it, to say nothing of farmers, stockbreeders and nurserymen. Research in marine fish culture has at best only been proceeding for a few years, and the much smaller number of fisheries scientists are necessarily concerned with many other fisheries problems. In this country, as against the hundreds of scientists and advisers engaged in agriculture, we can only count the marine scientists in dozens; although the seas are largely a foreign environment to us, they are twice as extensive as the land, and far

less well understood! Yet, probably well under 5% of these marine scientists are engaged in fish-rearing work, even in the widest sense!

Lastly, it will be obvious that even if scientific and technical solutions are found for any particular rearing project, and this is then approved for 'development', success at that or the production stage must in fact depend on economic factors—whether the product (either as a luxury article or as a serious contribution to the shortage of protein) can be produced economically. In any particular project this should be borne in mind from the beginning and re-assessed periodically, especially if the object is to provide cheap food to relieve malnutrition.

Ecological problems of marine fish farming

By J. H. STEELE, *Marine Laboratory, Aberdeen*

Basically, farming of any kind involves two simultaneous changes. There is, firstly, a change in the environment when an area is enclosed. Secondly, there has to be a change in the behaviour of the stock to take advantage of the enclosed area. On land much of this two-way adaptation has taken place over very long periods of time, although in recent years, with selective breeding and with battery rearing, the rate of adaptation has become very much quicker. For fish farming, a similar long-term process has taken place in the tropics and with freshwater fish where fish farms are well established. In temperate regions, however, where we are now thinking about the possibilities of marine fish farming, we are only at the beginning. Apart from fish kept in aquaria, and the tank rearing work described in this symposium by Shelbourne and Nash, we have at the moment only natural fish adapted to a natural environment.

The choice of fish for an ecological study of the problems involved in fish farming is limited to those likely to be commercially useful, and the possible success of the hatchery programmes described by Shelbourne and Nash provides a pointer. Although it would be preferable to use a herbivorous fish, the only suitable species, the grey mullet, is at the northern limit of its range in Scottish waters. Further, a major difficulty is that its breeding habits are very little known as these probably occur in deep water. Thus, one turns to carnivorous fish and in particular to the plaice which has been successfully reared from the egg by Shelbourne. Our work so far, in the 1st year of our research, has concentrated on the plaice and on its 1st year of life. It is intended to extend this and also it is hoped that this study will demonstrate the general problems facing such a change from a natural to an artificial environment.

The problems that need to be considered can be grouped under three main headings. Firstly, those concerned with food supply and therefore with the growth rate of the fish. Secondly, there is the predation on the stock of fish in its natural environment and the prevention of this within an enclosure. Thirdly, there are the problems of any parasites and diseases which may affect the fish, not only in its natural environment but especially in any artificial enclosure that may be used. In studying