REARING MARINE FISH FOR COMMERCIAL PURPOSES

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How do we counteract the depletion of a fishery, due to intensely competitive fishing, without unbalancing the industry? This conservation problem has pre-occupied fishery science for several decades, but internationally acceptable solutions are difficult to achieve. It is not an easy matter for nations with diverse gear, ships and market requirements, to reach agreement on hunting procedures. Ironically enough, when man's hunting instincts become in-turned upon himself, then stock depletion in our seas begins to appear less of a problem. Fishing restrictions in the North Sea during the two world wars led to striking increases in the abundance of plaice *(Pleuronectes platessa)*, without undue effects on growth rate (Borley, 1923; Margetts and Holt, 1948). We can assume, therefore, that when over-fishing prevails, the food biomass available to fish is not fully exploited. More "mouths" are needed to utilize this wastage.

THE MARINE FISH HATCHERY MOVEMENT

The idea that artificial propagation could influence the yield from inshore waters originated in the New World, and was the consequence of achievements in fresh-water fish rearing. Remarkable progress in culturing and transplanting the shad *(Alosa sapidissima)*, undoubtedly influenced the first U.S. Commissioner of Fisheries (Spencer F. Baird) in his decision to try artificial propagation as a possible means of counteracting depletion in the food-fisheries of the Atlantic seaboard.

Earll (1880) reported the successful hatching of cod, haddock, herring and pollock eggs during preliminary experiments at Gloucester, Massachusetts, in 1878. It was not until 1885 that the U.S. Fish Commission built its first commercial fish hatchery at Woods Hole. Facilities for cod propagation were extended at Gloucester Station in 1888, followed by the construction of a third east coast hatchery at Boothbay Harbor, Maine in 1905.

The Norwegians were equally interested in artificial propagation as a palliative measure. Capt. G. M. Dannevig started a cod-hatching program in 1884 at Flφdevigen, on the Skagerrak coast, financed from joint private and public funds. A second hatchery devoted to propagation of the plaice was erected at Trondhjemsfjord in 1908.

The British effort was centered around three establishments for hatching flatfish—one at Dunbar, Scotland, built in 1893 and later removed to the Bay of Nigg, Aberdeen—the other two on the Irish Sea coast, at Piel Lancashire (1897), and Port Erin, Isle of Man (1902).

Between 1890 and 1901, the Newfoundland Department of Fisheries operated a cod hatchery on Dildo Island. The movement spread as far as Gunnamatta Bay, Australia, and Dunedin, New Zealand, where hatcheries were built to propagate imported flatfish (Dannevig, 1908).

The early years of the 20th century were the 'golden' era of the marine fish hatchery movement. Commercial establishments sprang up all over the world, unhindered by the severe criticism later to be levelled at the basic concepts of hatchery practice. By 1917, the total output of newly-hatched fry from the three American hatcheries had risen to over 3 billion per annum. This greatly exceeded the aggregate annual output of the European system, in its most productive years before the first world war. When hostilities ceased, the European movement was, in fact, already declining, but the American effort continued at a high level of production until 1943, when Woods Hole was taken over by the Navy Department. The Boothbay Harbor hatchery closed down in 1950, followed by Gloucester Station in 1952. The demise of American sea-fish culture was accompanied by the following terse official statement . . . "Hatchery production of marine commercial fish species was terminated in 1952 since research had failed to disclose that worthwhile benefits were obtained from such stocking." (Duncan and Meehean, 1954).

THE TECHNIQUE AND PRACTICAL VALUE OF MARINE FISH HATCHING

The pioneers of sea-fish hatching embraced the fallacious hypothesis that the brood strength of any species entering a fishery is directly proportional to the number of eggs spawned by the adult stock. They were therefore very concerned at the loss of spawn due to the commercial fishing of spawning aggregations. Salvaged eggs could be artificially fertilized; it seemed a logical step to provide hatchery protection during the period of egg incubation.

American and European techniques differed in several respects. The Americans preferred to rely on salvaged spawn, particularly at Gloucester and Boothbay Harbor. 'Spawn-takers', operating from New England fishing vessels, selected ripe fish from the catch, and carried out artificial fertilizations using a standard technique. Fertile eggs were transported to the nearest hatchery by first train after the ship docked. At Woods Hole, hand-lined cod were also kept in floating boxes until ripe, and then stripped, at intervals of a few days, until the ovaries became completely discharged. At Flφdevigen, Capt. Dannevig exploited the uninhibited spawning of resident fish stock in hatchery ponds for his egg supply; this method was adopted by most other European hatcheries.

Incubation techniques were also different. The Americans modified the Chester jar and McDonald box (used in fresh-water hatcheries) to accommodate both pelagic and demersal marine eggs (Brice, 1898). Spawn was kept in constant motion by means of a periodic rise and fall in incubator water level. Dannevig (1910a) on the other hand, achieved a similar effect by automatically rocking his incubator boxes in a trough of running sea water. In neither case was there adequate control of the hatchery environment; high egg losses usually occurred in unfavorable weather.

Despite occasional set-backs, annual production was generally measured in 'astronomical' terms of millions of newly-hatched larvae released into local waters. Some sceptics refused to be impressed, and called for proof that marine hatcheries were substantially increasing the abundance of marketable fish. They were answered with hearsay evidence for the most part, though two attempts were made to substantiate claims by experiment—one in Norway, the other in Scotland.

1. *Hearsay evidence.* As early as 1883, only five years after the first experimental release of cod-fry, the U.S. Fish Commission reported the appearance of gray cod of a size not previously seen in coastal waters around Gloucester Station. They were generally accepted as the fruits of hatchery effort and became known locally as "Fish Commission cod." In 1898, Herdman (1889), director of the Manx hatchery, received a letter from the U.S. Fish Commissioner, which read. . . . "For about ten years the cod work has been attended with marked success, and in Massachusetts, has resulted, not only in establishing the inshore cod fishery on grounds long exhausted, but through favorable distribution of the fry, in extending the fishery to waters not originally frequented by the cod." As late as 1929, statements were being made to the effect that the winter flounder became more abundant after planting newly-hatched fry.

Dannevig (1910b), in a report on the utility of sea-fish hatching, stoutly opposed the criticism that his hatchery effort was ineffective, and in this he was supported by parish councils, commercial marine societies and private fishermen. They all agreed that an unusual number of small cod made their appearance in fiords, wherever fry were planted, and that these young fish usually had a different color to that of the local race.

Hjort and Dahl (1900) were the leading critics of the marine hatchery movement. They were convinced that the reported increases in abundance of fiord cod after the establishment of a hatchery at Flødevigen, were due to natural variations in the approach of offshore fish to the coast.

2. *Experimental evidence.* An attempt to resolve this dispute by experiment, was made in Norway between 1903 and 1905. Capt. Dannevig and Knut Dahl, representing both factions, conducted annual surveys for O-Group cod, with a large seine net in two Skagerrak fiords, before and after larval liberations from the Flødevigen hatchery. Table 1 is a summary of basic data taken from Dahl and Dannevig (1906) by Fulton (1908). Dannevig interpreted results as supporting the view that liberations were effective, while Dahl was quick to emphasize the importance of natural fluctuations, as in Hellefjord, 1903-4. The evidence is not conclusive; observations should have been continued by a strictly impartial team for many more years.

TABLE 1

BASIC DATA FROM A NORWEGIAN EXPERIMENT TO TEST THE PRACTICAL VALUE OF COD FRY LIBERATIONS (AFTER FULTON, 1908)

	SÖNDELEDFJORD			HELLEFJORD		
	Cod larvae liberated (millions)	Total catch 0-group cod	Mean number per haul	Cod larvae liberated (millions)	Total catch 0-group cod	Mean number per haul
1903	None	426	4.8	None	36	1.9
1904	20	1,523	15.1	None	133	6.5
1905	28	1,133	11.5	8-9	143	7.5

From 1896 to 1901 inclusive, plaice fry reared at the Scottish hatchery were transported overland for release into the upper reaches of Loch Fyne, on the west coast. Pushnet surveys for metamorphosed plaice were made at five specially selected stations within the loch during the summer months following each annual liberation, and these surveys were continued for six years (1903–8) following the last release. Results were published by Fulton (1908); for the purpose of this brief history, I reproduce the basic data only (Table 2). Fulton's more detailed

TABLE 2

LOCH FYNE EXPERIMENTS WITH LIBERATED PLAICE LARVAE (AFTER FULTON, 1908)

Year	No. Larvae liberated (nearest million)	Duration of fishing		No. of 0-Group plaice taken	Mean catch per hour
		hrs.	mins.		
1896	4	10	--	1,114	111.4
1897	21	2	30	60	24.0
1898	19	12	30	1,195	95.6
1899	16	17	--	488	28.7
1900	31	16	--	850	53.1
1901	51	16	--	2,784	174.0
TOTAL	143	74	--	6,491	87.7
1903	Nil	33	--	1,231	37.3
1904	"	31	45	253	8.0
1905	"	29	45	3,333	112.0
1906	"	30	25	505	16.6
1907	"	8	50	294	33.3
1908	"	31	45	961	30.3
TOTAL	Nil	165	30	6,577	39.7

analysis of statistics continued to support his main conclusion—that the mean yield of young plaice per hour during those years when larvae were liberated, was double the take during an equal period following the last release. He judged this difference to support the view that hatchery effort was worthwhile.

REARING MARINE FISH THROUGH THE LARVAL PHASE

Hjort and Dahl (1900), in their detailed criticism of hatchery methods as then practiced, stressed the fact that despite 20 years effort, no way had been found of rearing large numbers of marine fish larvae, beyond the yolk-sac phase, to a tough stage of development suitable for release into the sea. They went on to say . . . "that if the work of hatching could be perfected, so that, by its aid, the larvae of the plaice could be kept alive beyond the pelagic stage, and reared until it settled on the bottom, a way might thus be found of increasing the stock of this species on our shores". Petersen (1899) had early realized the need to improve hatchery technique, but after several attempts to rear plaice, he became convinced that . . . "at the pelagic stage, after the yolk has been absorbed, it cannot be kept alive in aquaria".

But already, Meyer (1878) had reared small numbers of Baltic winter herring through metamorphosis, in a tub of sea water partly refreshed each day. The survivors fed on plankton introduced into the tub with water renewals. Rognerud (1887) described an experiment by Capt. Dannevig at Flødevigen, in which 1-2 per cent of cod fry introduced into a marine pond, survived 8 months on plankton and triturated mackerel flesh.

At Dunbar, Harald Dannevig (1897) successfully reared a few plaice through metamorphosis in a glass carboy holding 45 liters of sea water. He introduced 1200 newly-hatched fry, fed them on plankton townettings, and attributed much importance to the fact that convection currents kept the early larvae in gentle motion. Fabre-Domergue and Bietrix (1905), at Concarneau, France, had similar success with the larvae of the sole (*Solea vulgaris*), fed on cultured flagellates and on plankton collected from neighboring rock pools. The French naturalists used a helical disc rotated on a vertical axis, to agitate occasionally renewed sea water in a 45 liter carboy. Anthony (1910) employed a similar technique to rear turbot *(Rhombus maximus)* larvae well into the feeding stage, at St. Vaast-la-Hougue, but his feeders failed to reach metamorphosis.

A few German coastal herring were reared by Schach (1939) and Kotthaus (1939) through the delicate early stages, to 40–60 mm in length, while in America, Galtsoff and Cable (1933) devised a current rotor suitable for rearing certain marine fish larvae, including the mackerel, sand-dab and tautog.

Up to the outbreak of the 1939–45 war, no determined attempt had been made to solve the outstanding hatchery problem of the time—how to produce a suitable larval food in bulk. Without this knowledge, the mass-production of sea fish was impossible, and work on the commercial value of artificial propagation could not be taken a stage further, as suggested by Hjort and Dahl (1900).

Prospects for the mass-culture of young sea fish improved substantially when Rollefsen (1939, 1940) discovered that the nauplius of *Artemia salina* (the brine shrimp) was an easily cultured and acceptable food for larval plaice. He reported being able to house many thousands of feeding larvae at Trondhjem hatchery, in an illuminated tank of 200 liters capacity, irrigated with running sea water. This promising advance was halted temporarily by the war. When hostilities ceased, experimental rearing studies continued at Flødevigen (Dannevig, 1948; Dannevig and Dannevig, 1950; Dannevig and Hansen, 1952). Their reports dealt, in a general way, with the possible causes of larval mortality in aquaria, including "gas disease", light intensity, parasitic attack and the effect of catabolic products of fish in sea water. By 1952, there were good samples of O-group herring, O and 1-group plaice and 5-year-old sole at the Flødevigen hatchery, all reared from artificially fertilized or pond-spawned eggs.

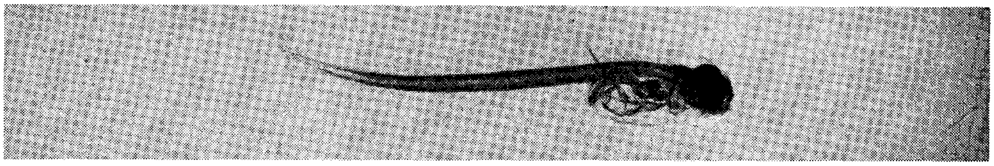
With the exception of Norwegian research, postwar attempts to rear marine fish larvae have been undertaken in the wider context of physiology, ecology and taxonomy, rather than practical fish culture. They include work by McHugh and Walker, (1948); McMynn and Hoar, (1953); Blaxter, (1955, 1956, 1957, 1962); Holliday and Blaxter, (1960); Blaxter and Hempel, (1961) and Klima *et al.,* (1962), to mention but a few.

Useful technical information on marine fish rearing has also accrued from research into factors affecting meristic characters within species. Tåning (1952) pointed out that meristic studies had been largely confined to fresh-water fish due to the unpredictable nature of marine eggs and larvae as experimental material. One exception was the work of Gabriel (1944) who reared *Fundulus heteroclitus,* to successfully relate temperature conditions and vertebral count. Dannevig (1950) studied the plaice in the same context, and confirmed Gabriel's findings. This was followed by a most interesting meristic experiment in Sweden, where Molander and Molander-Swedmark (1957) reared artificially-fertilized plaice eggs in open circulation with temperature control, achieving occasional survivals to metamorphosis exceeding 40 per cent of original egg stock.

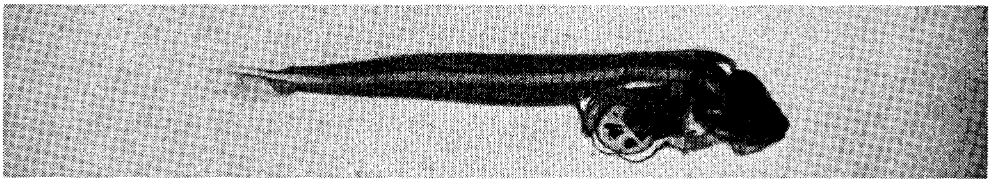
When technical studies began at the Lowestoft Fisheries Laboratory in 1957, we had every confidence that plaice could be reared in captivity. Our aim was to develop a consistent technique which could easily be expanded into a mass-production technology.

RECENT PLAICE-REARING EXPERIMENTS IN BRITAIN

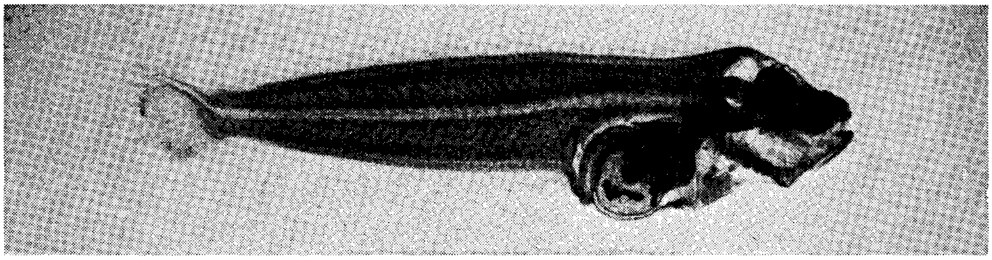
The plaice, a prime flatfish of north European waters, normally takes four or five years to reach first maturity, when the female may release 30–50,000 eggs. This figure increases with size of the fish. The fertilized egg is buoyant, transparent and about 2 mm in



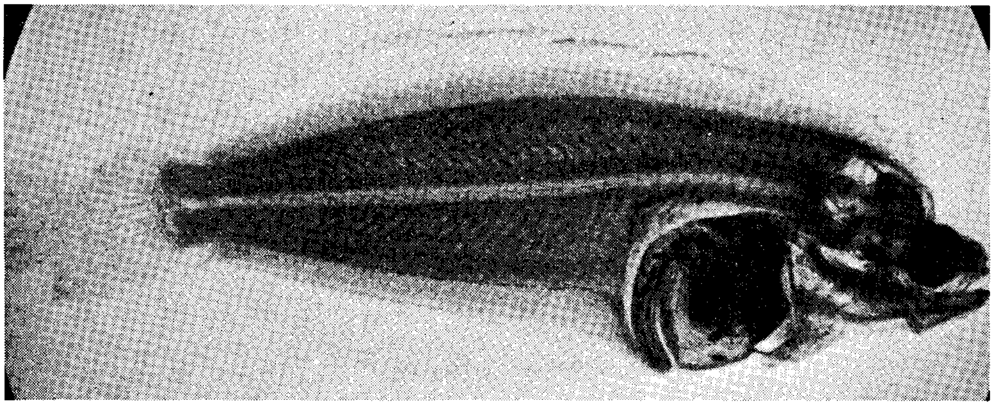
Stage 1 6.0 mm



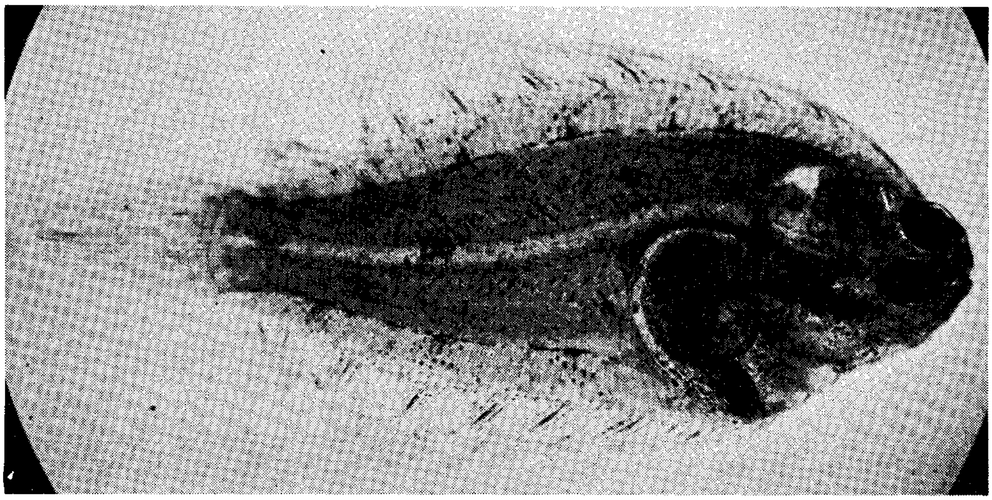
Stage 2 7.5 mm



Stage 3 9.3 mm



Stage 4 12.3 mm



Stage 5 12.4 mm

Figure 1. Development of larval plaice.

diameter. After three weeks at normal sea temperature, the egg hatches to liberate the first stage larva shown in Figure 1. It is about 6 mm long, delicate but active, and will start feeding on suitable zooplankton four or five days after hatching, before the yolk is exhausted. The eyes are precociously developed and symmetrically placed. During the next seven weeks or so, the pelagic larva passes through stages 2 and 3. At stage 4, pigment appears on the right side of the body, the left eye migrates by differential growth to the right, now dorsal side, and the metamorphosed larva adopts the demersal habit. Stage 5 is a metamorphosed plaice 10 weeks after hatching. It is tough, has 'built-in' food reserves, and would seem to have reasonable chances of further survival in the sea.

1. *Plaice-rearing in closed circulation at Lowestoft.* Between 1951 and 1956, plaice eggs, caught at sea were kept in well-lighted glass jars (capacity 2 liters sea water) standing in temperature-controlled water baths, mainly to provide material for morphological studies. Even if egg mortalities were not unduly high in these static conditions, larval survivors seldom developed beyond the early feeding stage, and structural abnormalities were common. A disturbing fall in the pH of incubator sea water often preceded egg and larval mortalities, probably due to the excretion of acid catabolites by livestock and bacteria.

By 1957, a closed circulation giving a limited degree of physico-chemical control had been designed (Fig. 2). It incorporated a basic principle of tropical aquarium technique . . . the use of photosynthesizing plants to remove CO_2 and other metabolites from the water, thus stabilizing the pH and adding oxygen at the same time. Two 2 ft × 1 ft × 1 ft molded glass incubators were partially immersed in a wooden freshwater bath cooled by a copper coil linked to a domestic refrigerator unit. Sea water ran into each incubator at a slow controlled rate, from a glass header tank containing washed fronds of the alga *Enteromorpha intestinalis* growing on pebbles collected from a local estuary. The alga received strong illumination from a battery of tungsten-filament lamps, each lamp being independently switched. A rise in pH above 8.1, which lies within the favorable range quoted by Bishai (1960), could be countered by decreasing the light intensity.

Each glass incubator contained a right-angled outlet (strictly overflow) pipe, screened at its lower end with fine-mesh bolting silk. Dim light entered the incubator through slits in the water bath cover, and a slow circulation of cooling water was maintained by an air pump. There was neither direct aeration of eggs, nor agitation of sea water. The incubator outflow drained into a lower reservoir, to be recirculated into the header by a small centrifugal pump fitted with a plastic volute. Incubators were stocked with 300–500 eggs, and the emergent larvae fed on *Artemia* nauplii.

This system gave limited, but positive results, and in 1959 the same principles were applied in a much bigger assembly (Fig. 3), comprising a large, sunken concrete reservoir, and a brick-built hatchery contain-

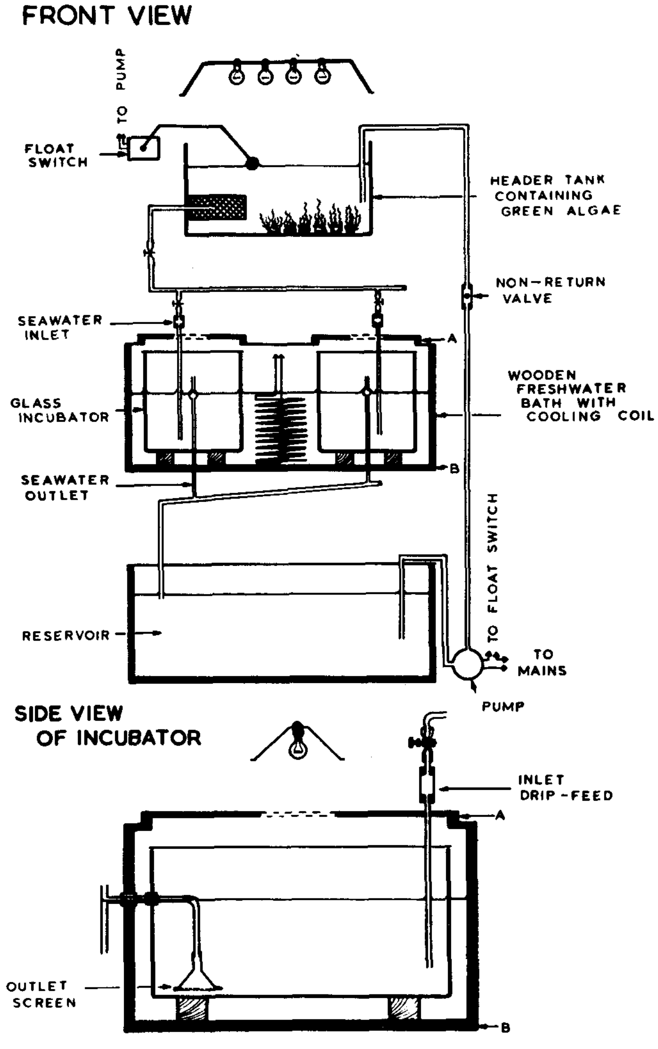


FIGURE 2. Closed sea water circulation for rearing plaice: Lowestoft, 1957.

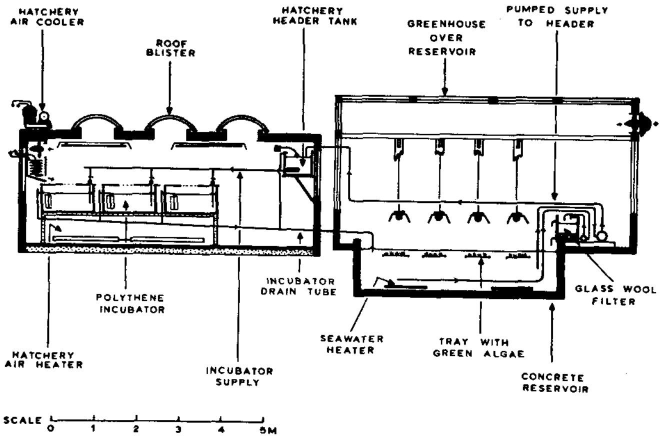


FIGURE 3. Closed sea water circulation for rearing plaice: Lowestoft, 1960.

ing a cluster of 5 ft × 2 ft × 2 ft polythene incubators. *Enteromorpha* was once again used to control pH and CO_2 concentration in the reservoir, which was covered by a greenhouse to permit algal photosynthesis during the day. The alga was illuminated by fluorescent light at night. Reservoir sea water was continuously pumped through a composite filtration, U.V. sterilization and cooling system. Additional temperature control was provided by air cooling units in the hatchery.

The total capacity of this new closed circulation was 15,000 liters, and permitted us to increase the annual production of metamorphosed plaice from a single fish in 1957, to about 3000 fish in 1961, by the simple expedient of increasing egg stocks from year to year (Fig. 4). Mean survival rates remained low however, seldom exceeding 5 per cent of original eggs. Details of lay-out, procedure and results have been published by Shelbourne *et al.* (1963) and Riley and Thacker (1963).

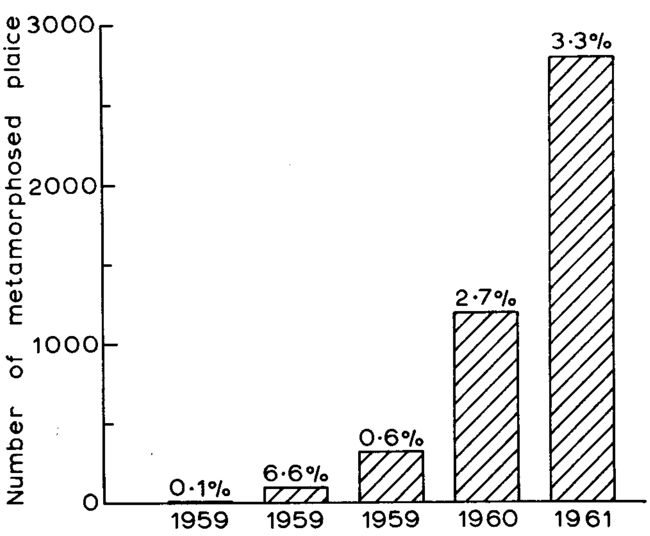


FIGURE 4. Annual production of metamorphosed plaice larvae, and percentage survival of original eggs, during rearing experiments at Lowestoft.

2. *Plaice-rearing in open circulation at Port Erin, Isle of Man.* Already in 1960, it was evident that an accessible supply of eggs and a continuous flow of good quality sea water was necessary for further progress towards large-scale plaice production. Both these conditions could be met at the Marine Biological Station, Port Erin, Isle of Man, which enjoys a hatchery tradition extending back to 1902.

Adult plaice spawn freely in large shallow ponds, but little was known about the viability of such spawn. A preliminary experiment in 1960 showed that pond-spawned eggs could give survivals to metamorphosis similar to those experienced with sea-spawned eggs, using the Lowestoft technique as it then stood. The mean 1960 survival curve (Fig. 5) was plotted by regularly removing and counting the dead in a batch of six small glass rearing tanks, each stocked with a thousand eggs. It shows the so-called 'critical period' in the tank life of a developing plaice stock, between the time when the egg yolk is used up, and the establishment of regular feeding habits.

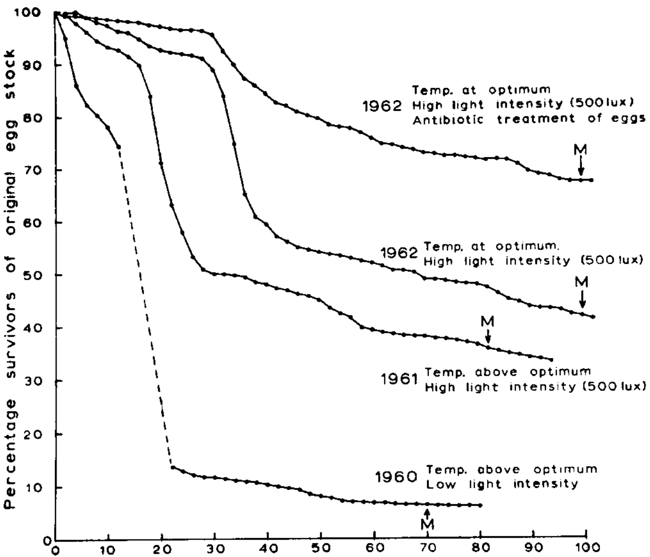


FIGURE 5. Survival curves for plaice stock in open circulation at Port Erin, 1960–62. M = metamorphosis complete.

The following year we concentrated on improving conditions during this short period—in particular, by making the food organisms (*Artemia* nauplii) more available to fish larvae. Rearing tanks were fitted with jackets of black polyethylene film to cut out side lighting. At the same time, the overhead illumination was increased from a low intensity to 400–500 lux at the water surface, as measured with a photometer corrected by filter to the wave-length response of the human eye. The results were encouraging (Fig. 5). Almost 50 per cent of newly-hatched larvae began feeding, and a final 33 per cent of the original stock passed through metamorphosis. Plaice larvae are visual feeders, but early on, their sight is not yet acute. They capture their prey more easily when it is highlighted against a contrasting background. At a later stage of pelagic development, light intensities can be cut down to a very low level indeed. By this time the eye is efficient and the larvae well practiced in the art of hunting.

Another major technical advance was made in 1962. It is a well-established fact that marine bacteria grow more readily in tanks than in the open sea. Over the plaice spawning grounds in the Irish Sea, bacterial counts may be as low as 50 per ml, whereas my tanks may contain several thousands per ml, even before eggs are put in. Bacteria proliferate on the egg shells making them sticky and opaque; eggs adhere one to another, and a variable proportion, depending on the degree of contamination, will die before hatching. Eggs which do not die may nevertheless be weakened by toxins or perhaps by direct infection.

Oppenheimer (1955) demonstrated the beneficial effect of antibiotics on the hatching rate of marine fish eggs. So, in 1962, a long-term experiment was set up to test the effect of early bacterial control on final survival to metamorphosis. Pairs of glass incubators were partially immersed in four water baths equipped with temperature control gear. Each tank could be irrigated with hatchery sea water, but only one tank of a pair was irrigated during the period of egg incubation. The other was treated with one dose of a sodium penicillin G and streptomycin sulfate mixture (50 international units and 0.05 mg per ml respectively), and then kept static until hatching began. All tanks were irrigated during the larval phase. The effect of antibiotic treatment can be seen by comparing a representative pair of 1962 curves in Figure 5. Both stocks enjoyed the same temperature conditions, illumination, tank design and feeding rate; the upper stock was treated, the lower one was not. At the end of the experiment, young fish were thick on the bottoms of the tanks, with the highest densities approaching 350 per ft.^{2}, representing survival rates exceeding 60 per cent of original eggs.

As a matter of interest, tank survivals of this order are at least several hundred times greater than the highest estimated survival in natural conditions (Gross, 1950). Low survivals in the sea are probably due mainly to food shortage and predation. These factors are absent in hatchery tanks, but other hazards take their place. I have mentioned one, namely bacteria, which we can control with antibiotics, and to some extent, with ultra-violet radiation. Another is the temperature regime in uncontrolled tanks. For plaice, a practical schedule is to incubate eggs at 6°–7°C, rising to 7°–8°C at 'first feeding', followed a gradual increase to 11°–12°C at metamorphosis. A third and very potent hazard concerns the design of tanks themselves. A plaice larva is adapted to an active life in the open sea, out of contact with surfaces until metamorphosis. Continual contact with tank walls is an unavoidable tank hazard which may put a considerable strain on the adaptive resources of a marine larva. It is therefore important to keep a tank interior as simple as possible, with no unnecessary inclusions. Two closely apposed surfaces can act as a lethal trap for roaming larvae. Crevices are a particular menace—larvae swim into them and seem unable to back out.

PECULIARITIES OF TANK-REARED PLAICE POPULATIONS

After each experiment, surviving stocks of young plaice were killed and preserved. Subsequent analysis revealed certain trends within tank populations, particularly regarding size distribution, the incidence of bitten fins and pigment abnormalities.

1. *Size distribution.* Although efforts were made to maintain a reserve of food in tanks at all times, the survivor length-range for each tank population was characteristically wide, even in those years when incubators were stocked with eggs of equal age. I have rarely found metamorphosed plaice larvae less than 13 mm long in the sea, but a fair proportion of tank survivors regularly metamorphosed before reaching this size.

It is our experience that in comparable tanks, those with smaller surviving populations contain a significantly greater proportion of larger larvae. This trend can be seen in Figure 6. To emphasize the point the same populations have been divided into large (> 20 mm) and small (< 20 mm) survivors, and then arranged in order of increasing population density (Fig. 7). The disproportionate number of small larvae among denser populations is clearly seen. Whether this was due to competition for food or the differential mortality of slow-growing forms, remains to be seen from further experiment.

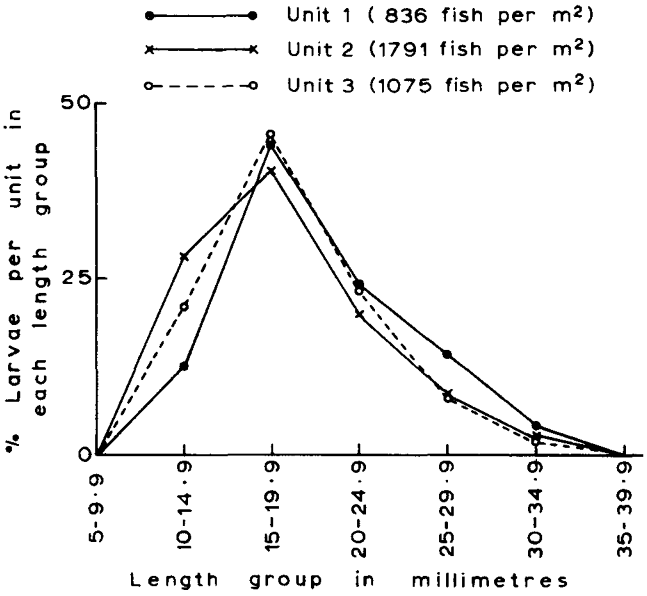


FIGURE 6. Length distribution of plaice survivors in rearing units with different survivor densities: Port Erin, 1961.

Survival or death, fast or slow growth, all reflect large differences in individual adaptability to tank

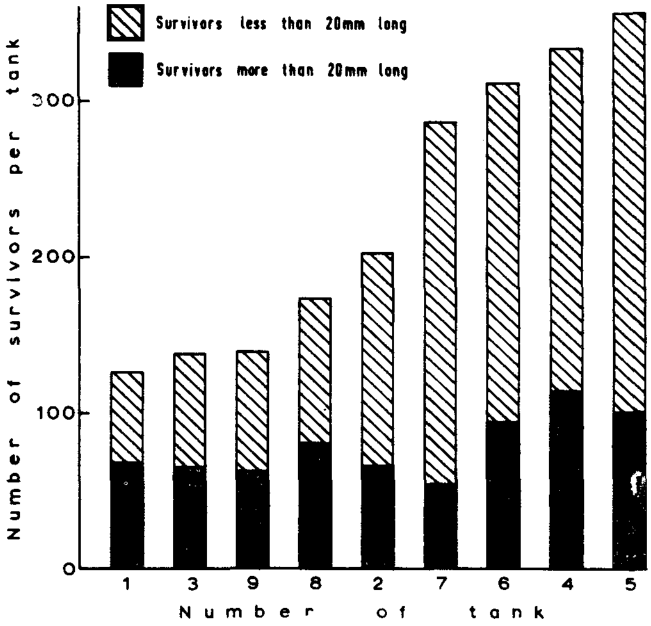


FIGURE 7. Proportions of large and small plaice in tanks with different survivor densities: Port Erin, 1961.

conditions. By this token, it is not at all certain that the larger survivors would necessarily be the best sort of fish to liberate into the sea as part of an artificial propagation program. On the other hand, if large size and 'seaworthiness' are related, then it would be efficient hatchery practice to eliminate the retarded members of a mixed tank population as early as possible—virtually skimming the cream of the stock. Target production at a low survival rate might then be met by boosting egg stocks.

2. *The incidence of bitten fins.* Metamorphosed plaice larvae bite each other when crowded together in hatchery tanks, the damage usually being sustained on the marginal or caudal fins. Damaged tissue can be regenerated, but a severe bite on a small larva could conceivably be lethal, if repairs remain incomplete before the osmoregulatory resource of the casualty is overtaxed. Bitten larvae will almost certainly be more prone to bacterial and fungal attack.

The incidence of biting varied from tank to tank in 1960 and 1961 at Port Erin, and bore little relationship to population density (Fig. 8). A more consistent correlation emerged between the incidence of biting and the size of fish (Fig. 9). Thus, within a mixed size population, with perhaps occasional food shortages, smaller fish are more likely to suffer damage from biting activity, than their larger contemporaries. Cannibalism is perhaps too strong a term to use, though adult plaice in spawning ponds have been seen to eat their newly-metamorphosed young. Biting is a manifestation of normal feeding behavior; plaice larvae instinctively snap at smaller moving organisms.

3. *Abnormal pigmentation.* At metamorphosis, the ability of a larva to merge with the background coloration will play a vital part in future survival, since defensive armament is ill-developed in the plaice. During the course of evolution, under conditions of severe selection, one might expect normal pigmentation to become a very stable characteristic indeed. Abnormally pigmented flat fish occasionally occur in the sea (Norman, 1934; Gudger, 1935, 1941; White, 1962; Eisler, 1963) but in tanks, a substantial proportion of metamorphosed survivors always show pigment deficiencies on the dorsal side, ranging from slight loss on the lower margin of the operculum to virtual absence except for traces of melanin around the eyes or on the base of the fins.

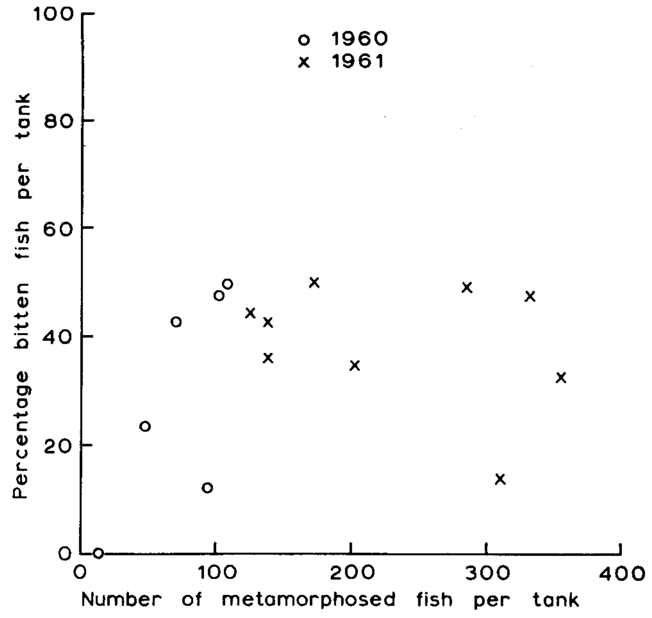


FIGURE 8. The relationship between the incidence of bitten fins among tank-reared plaice, and the population density.

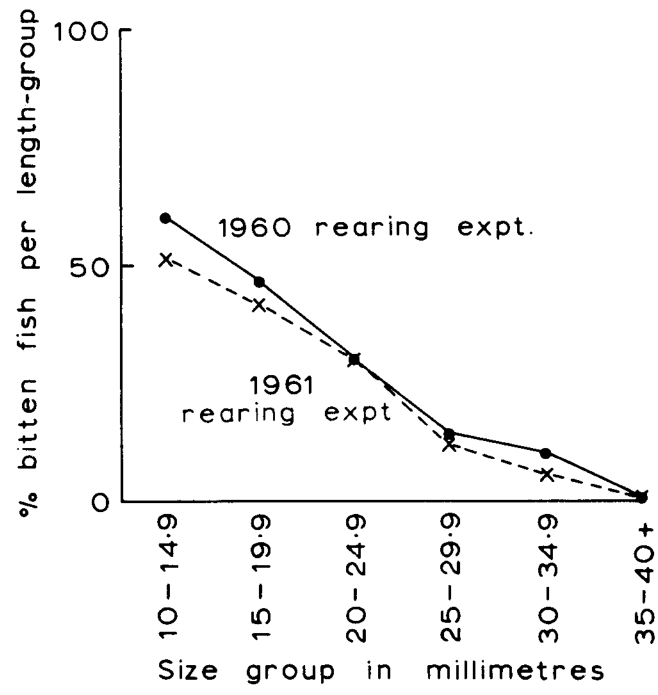


FIGURE 9. Relationship between the incidence of bitten fins among tank-reared plaice, and size of fish.

In my experience, the degree of abnormality has varied from season to season, and from place to place. For instance, at Lowestoft in 1960, 62 per cent of all survivors were normally pigmented, compared with 55 per cent at Port Erin the same year and 19 per cent in 1961. Dannevig and Hansen (1952) reported that plaice eggs hatch well in total darkness, but the larvae seem pre-disposed towards abnormal pigmentation later on. Pigment deficiency might also bear some relation to population density at metamorphosis. In Figure 10, the mean percentage of dorsal pigment for the whole of a tank stock is plotted against the survivor density. The per cent pigment cover on the dorsal side of each larva was assessed by eye. Results cover the years 1960 and 1961 at Port Erin; all tanks were of equal size, though the rearing techniques for both years are not strictly comparable. The apparent trend towards better pigmentation with decreased population density is probably linked with a second relationship given in Figure 11, showing that smaller survivors among a stock usually have less pigment cover than their larger contemporaries. It has al-

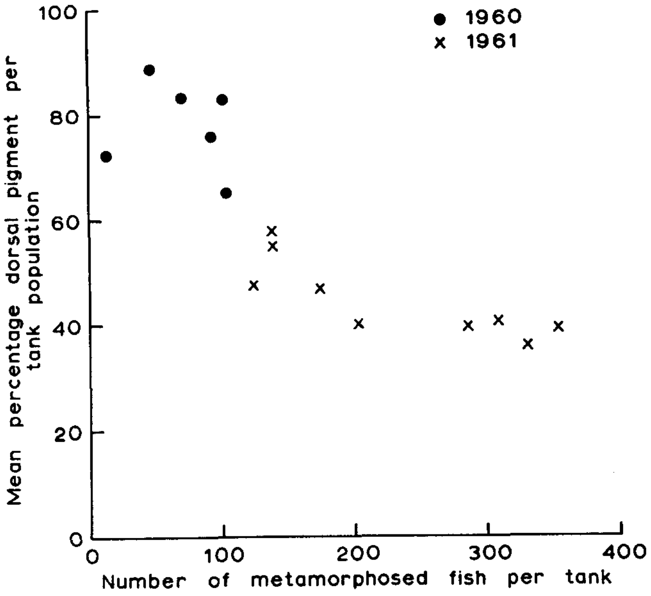


FIGURE 10. Relationship between population density and mean dorsal pigment cover among tank-reared plaice: Port Erin, 1960 and 1961.

ready been demonstrated that densely populated tanks are biased in favor of smaller larvae (Figs. 6 and 7). Experiments in 1962 also suggest a relationship between the degree of pigmentation at metamorphosis, and the temperature regime during incubation and larval development.

It looks as if chromatophore development during organogeny is a particularly sensitive and delicate process, easily disrupted by an unfavorable environment. Heuts (1953) made this point with reference to the regressive evolution of *Caecobarbus geertsii,* the blind cave fish of the Congo. Follet (1954), on the other hand, related the piebald condition in flatfish to vertebral damage, while von Ubisch (1952) considered light intensity to be important. The tank environment, involving surface contact and community conditions, is completely alien to the pelagic plaice larva, and it says a great deal for the innate adaptability of the species, that high survivals to metamorphosis can be achieved, even though abnormalities commonly occur. Since effective hatchery production for release into the wild can only be measured in terms of normally pigmented plaice larvae having a reasonable chance of survival after metamorphosis, the causes and cures of pigment deficiency are matters of great practical interest, and further experiments are planned to widen our understanding of this condition.

TOWARDS MARINE FISH FARMING

There are several different ways in which the output of a functional marine hatchery could be utilized to augment fish resources. All require a consistent technology for the annual production of young flatfish on a very large scale indeed. During the 1962 rearing experiments, a total of 25,000 metamorphosed plaice were incidentally produced; plans to push this figure up to 1 million per annum during the next five years are well advanced.

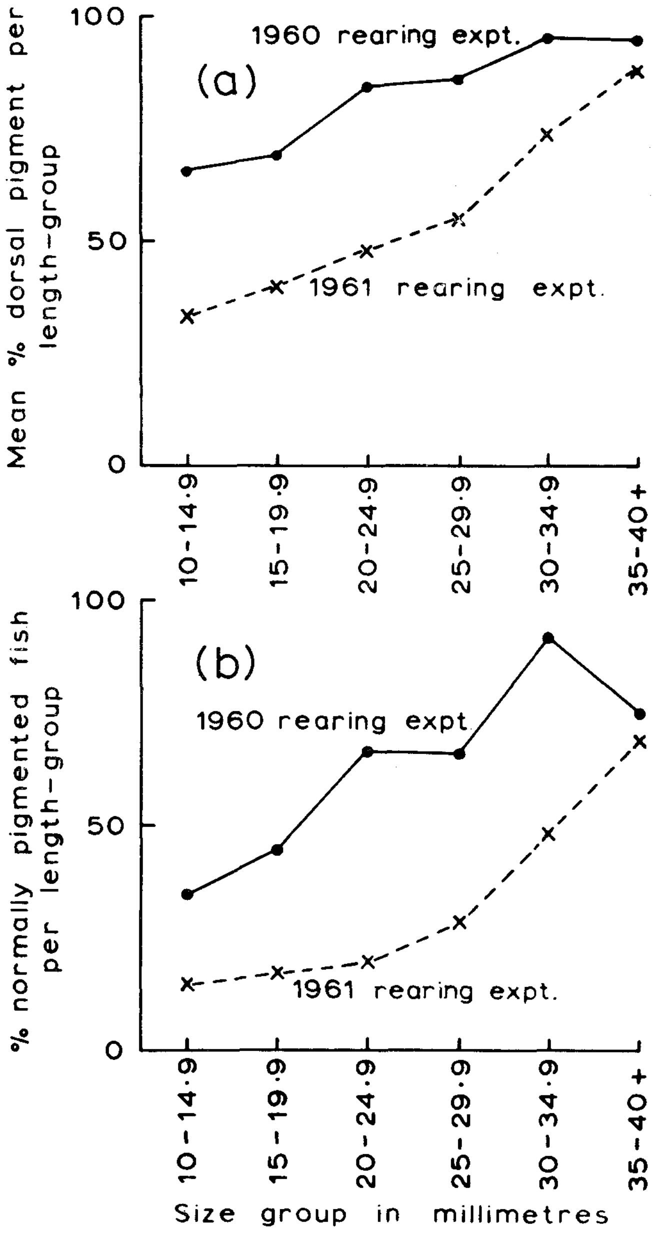


FIGURE 11. Relationship between survivor size and degree of dorsal pigmentation: Port Erin, 1960 and 1961.

A specially designed marine hatchery is now being erected on the Isle of Man, incorporating most of the relevant information gained during the past few years. It is a prefabricated, insulated structure, with air and water temperature control. About 250 black plastic incubators (4 ft x 2 ft x 1 ft deep) will be arranged in rows and layers in a space not exceeding 45 ft x 30 ft x 12 ft overall. Each incubator will be independently illuminated—the problem of heat production from light fittings has already been overcome in a test system, by situating lamps in a transparent air-duct connected to extractor fans. The building will also contain sectional fiberglass spawning ponds, pressure filtration and ultra violet sterilization systems.

A special insulated space, operating at 23°C has been allocated to the production of larval food. At peak feeding we calculate that 200 million *Artemia* nauplii per day must be made available; in round terms, about 1 cu. yd. of *Artemia* eggs will be required to raise one million fish, if nauplii alone are used as food. *Artemia* nauplii are, however, easily cultured on yeast and the alga *Phaeodactylum tricornutum;* bigger *Artemia* will be supplied to bigger fish. We are making an experimental study of other possible food sources, such as *Mytilus* trochophores and larvae, and various enchytraeid oligochaetes. The latter are readily cultured on a damp mixture of peat loam and precooked meal.

Assuming we raise our experimental technique for rearing plaice to the status of a mass production technology—and no insuperable difficulties are foreseen—then there are three main ways in which hatchery production could be utilized in the British Isles. Firstly, to augment natural recruitment in inshore waters, as suggested by Hjort and Dahl (1900). We are under no illusion about the immense numbers of hatchery fry that may be required to carry through this project. For instance, it has been estimated that between 500 million and a billion young plaice would have to be liberated in any one year to double the normal brood strength in the North Sea plaice fishery. In the smaller bay fisheries of the Irish Sea, increments of one million or so might be beneficial. Only under conditions of strict fishery control could one expect to reap the full benefits of an artificial recruitment program. Nevertheless, small scale field experiments are a necessary prelude, and surveys of suitable inshore grounds are now being made by the Lowestoft Fisheries Laboratory, in anticipation of the time when hatchery recruits will be available.

A second project, still in the planning stage, involves the release of hatchery flatfish into partly enclosed sea areas enriched with agricultural fertilizers. During the last war, a team of scientists under the late Dr. Fabius Gross of Edinburgh University, showed that inorganic fertilizers scattered into Scottish sea-lochs, could produce remarkable increases in the abundance of fish food. Resident and transplanted plaice were found to grow three or four times as fast as the stock outside. Dr. Gross (1950) was unable to exploit fully this increased food supply—transplants were difficult and expensive to obtain. Now they can be supplied from a hatchery, on site.

Our common food fishes take four or five years to reach marketable size in the sea. Winter growth is restricted by low water temperatures and perhaps seasonal food scarcity. As a third line of research, we are exploring the possibility of fattening hatchery reared fry in shore ponds irrigated by the warm outflow from coastal power stations, some of which are discharging 30 to 50 million gallons of sea water per hour at a temperature 7° C above intake level. In good conditions for continuous rapid growth, we might be able to reduce the time taken for a plaice, sole or turbot to reach marketable size, from 5 years to 18 months. It should not be too difficult to develop a cheap fish food based on agricultural by-products and fish offal, or to organize the mass-culture of the common mussel (*Mytilus edulis*) as a source of food. Controlled 'battery' production in marine ponds would enable fish processing firms to tailor their plant to deal with a continuous, predictable supply.

In a sense, we are now entering a transition period; while still relying on a hunted, natural stock for fish supplies, there is a growing international awareness of the inadequacies of such a policy, which must inevitably lead to the final farming and domestication of marine fish on a considerable scale.

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