Mesh or net screens. A visit has already been made to the Boom Defence Department of the Royal Navy to examine their anti-torpedo type of nets and to see their method of replacement. The type of anti-torpedo net used for sealing main loch entrances would appear too heavy for our type of work, but the sections used to seal the intertidal stretches look very promising and their rigidity in the centre of small channels is now under investigation. Fish stake nets are also being examined since any net system would require to be a combination of a heavy sea net against predators and a light fish retention net.

Electrical. Arrangements are now under way to visit the electrical barrier used to prevent fish entering the tailrace at Inverawe Power Station in Perthshire, Scotland.

Sonic and ultrasonic. Very little relevant information has been found to date about reaction of fish to sound and assistance of the biologists is requested.

Hydraulics and pneumatic. Both of these create vertical water currents and the reaction of fish to these requires investigation.

Power stations

A number of power stations were visited in September 1965 with Mr J. E. Shelbourne in order to appraise the merits of the various sites. The results were rather inconclusive owing to variability of power station operation and the scarcity of information on chlorination residuals. Some general observations were, however, possible.

West coast stations have a much smaller annual temperature fluctuation than east coast stations. On the east coast the stations visited were on the open coast where stormy conditions often throw a considerable amount of sediment into suspension.

It was, therefore, decided that the biologists would carry out probe experiments at Carmarthen Bay and also at Hunterston for a period of at least 3 months. At the conclusion of this period, a decision will be made as to whether, and at what station, two to three tanks 49 ft × 25 ft × 3 ft deep, would be placed in order to carry out further work. Once these tanks are in operation, tests would be carried out to determine flow patterns and heat losses within the tanks under various conditions.

Sea fish culture in Britain

By J. E. Shelbourne and C. E. Nash, *White Fish Authority, Port Erin, Isle of Man*

A study of the biological, engineering and economic implications of marine fish culture on an industrial scale is being made by the White Fish Authority, in association with the Ministry of Agriculture, Fisheries and Food, and the Civil Engineering department of the University of Strathclyde.

Fish hatching programmes

Renewed interest in sea fish farming has been stimulated by the discovery that flat-fish are not as difficult to rear as originally thought. In 1962, after several years' work on the special requirements of plaice eggs and larvae in the hatchery, 66%

survivals were achieved from pond-spawned eggs, through and beyond metamorphosis at 3 months old, representing survivor densities approaching 650 fish per ft^2 of tank bottom. Hatchery fish from wild parents show a high degree of pigment abnormality ranging from slight loss to a pseudo-albino condition.

In 1963 a prefabricated hatchery was built at Port Erin, Isle of Man, where much of the early work was done, to explore the problems of transforming a small-scale experimental technique into a mass production technology for young flat-fish. It is a comparatively small structure, insulated, with air and water temperature control. Rearing tanks are arranged in rows and tiers to make the best use of available space (Pl. 1). Each tank is independently illuminated by reflected light from fluorescent lamps, and is irrigated by a flow of filtered sea water. A small labour force is engaged on tank cleaning during the season, but a servicing system designed for automatic operation is being developed. The hatchery relies on the uninhibited spawning of captive stock in outdoor ponds for its egg supply, but there are also auxiliary indoor spawning ponds, where close control can be exercised over captive spawners throughout the year.

A heavily insulated space kept at 24°C has been allocated to the production of larval food. At peak feeding, a single metamorphosing plaice can consume 200 *Artemia nauplii* (the newly hatched form of the brine shrimp) per day. In round terms, about 100 imperial gal of *Artemia* eggs (from American sources) are required to raise one million fish, if nauplii alone are used for food. Cost of food is about $\frac{1}{8}$th of a penny per metamorphosed fish. *Artemia nauplii* are, however, easily fattened on yeast and the alga *Phaeodactylum*—bigger *Artemia* can be supplied to bigger fish. We are also interested in the value and availability of indigenous larval foods, such as mussel trochophores, oyster larvae and various easily cultured enchytrid worms. The development of a completely artificial larval food is high on our list of priorities.

During 1964, the first season of operation, our new hatchery produced 160 000 young plaice. This figure was raised to 400 000 in 1965, at a 25% survival rate, from pond-spawned eggs. In addition to plaice, 15 000 Dover sole were reared to metamorphosis from eggs spawned by freshly caught ripening adults in indoor tanks. High mortalities occurred during early egg development (a characteristic of spawn from non-acclimatized wild stock) but subsequent egg and larval mortalities were slight. Experiments indicate that 70–80% survival to metamorphosis from late eggs can be expected, using the standard plaice-rearing technique with temperature modifications. This season's production programme has shifted some of the past emphasis on plaice to the sole; preliminary rearing trials are also being run on lemon sole.

So far, our hatchery programmes have been concerned largely with housing, feeding and generally servicing large numbers of developing plaice, as a mass-production exercise. Survivors always show that great range of variation associated with the heterozygous condition. We are now proposing to improve output quality and uniformity, by short-term programmes of hybridization and longer-term selection and inbreeding, for particular farming purposes. This work is already in progress.

Now that a substantial annual supply of 'seed' fish is becoming available, we find ourselves able to press on with the development work in the field. Two projects are under way at the moment: firstly, the release and cultivation of hatchery flat-fish in enclosed coastal areas; secondly, the intensive 'battery' cultivation of flat-fish, particularly sole, in marine ponds irrigated by the warm outflow from coastal power stations.

Studies at an intertidal fish farm site

Our first farm site is at Ardtoe in north-west Argyllshire. It is a sac-shaped intertidal inlet, 5 acres in extent, very sheltered, being surrounded for the most part by steep rocky ground, and cut off from the sea by two sea walls, one either side of a rock outcrop at the mouth of the sac. These walls are furnished with a total of five screened sluice ducts at a low level, and two overflow weirs. The sluices allow the enclosure to be emptied and refilled during one or two tidal cycles when necessary; the weirs regulate pond level. The bottom is of fine and patchy coarse sand, with some silt, originally rich in intertidal worms and molluscs. Maximum depth near the walls is about 10 ft when filled at spring tides with a mean depth around 4 ft. It is virtually a large irregularly-shaped tank up on the shore, relying on tidal rise and fall during the period of spring tides, for controlled water renewal. The theoretical virtues of an intertidal fish farm site are seen as:

(1) Ease of barrier construction, in dry conditions during part of the ebb period.
(2) Gross water renewal using the tidal pulse, at no cost.
(3) A high degree of depth control which facilitates weeding, harvesting, stock sampling, culling, disease control and general cleaning.

The Ardtoe site was conceived as a means of coming to grips with the principal hydrographic, biological and management problems associated with intertidal enclosures, and not as a commercial fish farm. Three main problems are already apparent, 7 months after the first liberation of hatchery fish. They are: firstly, fresh water inflow; secondly, de-oxygenation; thirdly, predation by shore crabs.

One inch of rain in 24 h raises the pond level 15 in with the present inadequate diversionary system. Fresh water was calculated to run off the adjustable weirs in the main barrier. So it does when winds are favourable. When winds are contrary, that is blowing into the enclosure, there is considerable mixing and salinities are affected at all depths. Plaice can tolerate lowered salinities, but they cannot be considered good subjects for brackish-water farming. Fresh water inflow causes bad discoloration of pond water; bottom conditions deteriorate with an accumulating carpet of peat debris. The engineers have found a solution—the fault is being put right now.

Deoxygenation was particularly severe last autumn and was not restricted to deep water. Probable reasons were:

(1) Firstly, the decline and decay of existing intertidal forms following prolonged immersion.
(2) Secondly, the decay of terrestrial peat debris deposited by the burn, both before and after enclosure.
(3) Thirdly, the restricting effect of surface fresh water on the vertical circulation of deeper saline water.

The effective control of fresh water overspill, coupled with measures both to clear the area of rotting material and to stimulate the breakdown of residual organic debris, should eventually confine autumnal deoxygenation to the deepest parts—where aeration devices might be used effectively.

The completion of the main barriers last autumn coincided with arrangements for transporting plaice stock from the Port Erin hatchery. This left us with no time to clear the pond area of potential predators. We knew the enclosure was infested with shore crabs of all sizes, but regarded them as scavengers, according to the classical view. Our opinions have changed since finding crabs clutching half eaten small plaice, and watching their stalking activities. They occur at a population density of at least one crab per yd^2. They respond to trapping techniques, with shelled fresh cockle as bait. They can be destroyed with insecticides incorporated in bait. One way or the other we expect to bring the population under control by the summer of 1966. The crab–plaice size relationship will be of obvious importance to survival of fish stock. Our aim in the future will be to lower the vulnerability of prey by withholding release into predatory conditions until their mean size is sufficiently large, and the crab population correspondingly small, both in mean size and in numbers. Crab larvae will penetrate the sluice screens from outside, of course, but it is of some comfort to know (from observations in Port Erin bay) that O-group plaice feed on the megalopa larva of the crab.

Fully enclosed intertidal sites, where specially selected or hybrid fish stock may be intensively cultivated in predator-free conditions, on natural food or artificial food, or both, are only one type of a range of possible farming enterprises for western Scotland. Open sea lochs with narrow necks and transient summer populations of flat-fish are fairly common. They may be suitable for low-density cultivation if cheap, reliable fish screens can be devised to restrict outward winter migration, if methods of shepherding and catching stock on different substrates can be developed, and if the right sort of hybrid stock or selected stock can be bred. The postwar work of Dr F. Gross and his colleagues of Edinburgh University on the use of artificial manures in such situations produced encouraging results which need repeating and developing. An integrated programme of basic objective sea loch research cannot be started soon enough.

A second White Fish Authority farm project was started last Christmas and is expected to reach pilot-plant proportions by autumn 1966. It concerns the use of warm water effluents from coastal power stations (both conventional and nuclear) to maintain winter growth of flat-fish in captive conditions.

Fish culture in power station effluents

The base-load coastal power stations of this country discharge literally millions of gallons of sea-water each hour at temperatures some 5–9°C above ambient. This represents an enormous energy loss and there have been many ideas for utilizing this wasted potential, ranging from under-road heating, centrally heated estates and blocks of flats to marine playgrounds and aquaparks. Piping installation costs have made most of these schemes prohibitive. We are preparing to study the feasibility of using this low-grade effluent heat in a marine fish farming project based on the Dover sole (*Solea solea*), which can now be reared in the hatchery.

The sole has been categorized as a Mediterranean species but British waters are about the northern limits of distribution. Like most sea fish of temperate waters, the sole grows quickly in summer and very slowly in winter, giving a characteristic annual 'step' in the growth curve. Our aim at the power station sites is to exclude the winter period of little or no growth and provide continuous summer water temperatures in an attempt to increase the cropping rate per unit of capital expenditure.

Three basic aspects of a flat-fish farming technology occupy our attention in these preliminary stages. They are:

(1) The effect of temperature on survival and growth in captive conditions and the derivation of an optimum temperature for maximum sustained growth.

(2) The chemical suitability of power station effluent for continual survival and growth.

(3) The question of the food supply for the farm stock.

The effect of temperature on the growth rate of certain species of freshwater fish has been illustrated many times. The rates of metabolic processes are altered, leading to increased maintenance requirement and food intake. It has been shown, again with freshwater fish, that there is an optimum temperature for growth. Below this there is a gradual falling off due to decreasing activity in cooler water, and above it there is still a falling off due to wasteful overactivity and the approach of a lethal limit.

Experimental tanks have been designed for use at Port Erin to study the effect of temperature on the growth rate of hatchery-reared fish and to determine any optima. Four large tanks are maintained at the temperatures 15, 17, 19 and 23°C. These temperatures may appear high for fish but the aim is to include the likely temperatures of effluent from power stations. Each tank is divided into four compartments, each with its own water and aeration line.

In the 1st year, the large tanks at the different temperatures were stocked identically with 100 post-metamorphosis hatchery fish in each compartment. Two compartments contained plaice, and the other two sole, so that it was possible to have two feeding levels per species. The feeding levels were approximately one-tenth and one-seventh of the total weight of fish in the tank daily. The higher level made sure that there was always a surplus of food in the tank. Numerous implications have been made against the hatchery fish with poorly developed pigment concerning a higher mortality and a slower growth rate than the fully pigmented hatchery stock. To specifically test these points, the complement of a hundred young plaice in each tank was made up of fully pigmented (fifty) and poorly pigmented (fifty) hatchery fish. The high percentage of fully pigmented sole from the hatchery did not warrant the test with that species. The whole trial was conducted over a period of 220 days.

Over the first 50 days the mortality in all tanks was high. This was due almost certainly to the high stocking density and handling at the very young stage. Deaths continued to occur during the early days until there remained about thirty to forty fish per tank, and then stopped completely. This suggests that density is effective at a very early age and that young plaice and sole of 25–40 mm in length each require about $\frac{1}{2}$ ft^2 of tank bottom if there is no sand. Deaths began to occur again after about 150 days and continued at a slow and steady rate until the termination of the trial. The reasons for the second outbreak were more the inadequacies of the system than inherent properties of hatchery stock. Analysis of the water throughout the trial revealed that there was a steady build up of nitrites and nitrates in all tanks, but little is known of the lethal limits of these radicals.

Differential mortality between fully pigmented and poorly pigmented plaice in the same tank was not significant. Neither was there a differential growth rate. Apart from the inability to conceal themselves effectively, hatchery stock with pigment deficiencies have no apparent disadvantages as far as potential growth and survival in enclosed areas are concerned.

Differences in the growth rate of young fish of both species at different feeding levels were not significant, at any temperature. For O-group stock, one ration of food per day of one-tenth the weight of the tank biomass is sufficient for a mussel diet. It may be possible to induce older fish to eat more, or any fish to take more if fed twice a day, at dusk and at dawn, for at these times and through the night, the fish are most active.

After the first 50 days, when the tanks contained more appropriate numbers of fish for their size, the differential growth rates with temperature were apparent, and these were maintained until the end of the experiment. From results, it appears that for O-group hatchery-reared plaice, temperatures of 17°–15°C (or less) are more conducive to faster growth. There is still growth at higher temperatures, up to 23°C (or more) but it is below optimum, and there is the pressure of a slow but steady mortality. Compared with the growth rate in the sea over the same seasonal period, and from other experimental evidence, the growth rates in these first trials at any of the temperatures are not exceptional. But, it should be noted that all the fish were backward in their development, having come very late from an overcrowded hatchery. Young fish in the sea in August are some 50 or 60 mm in length but the hatchery stock were only 30 mm. In contrast, the hatchery stock more than doubled their mean length in the period of the trial before they became I-group fish in March, and this is more than the natural stock do in the same time from August to March.

The young sole proved more resistant to the rigours of poor tank conditions as their final mortality figures were less, but they were susceptible to handling damage and for that reason the measuring sessions were kept to a minimum. At the end of 220 days, fish in tanks at 19° and 23°C showed faster growth rates than those in tanks at 15° and 17°C, both of which were very similar. At the start of the trial the sole were just over 20 mm in mean length, and the mean range at the end varied from 85 to 100 mm according to temperature. In the later stages of the trial dead plaice and sole had swollen and slightly pink lower jaws, gills and stomach.

Before the development of pilot schemes utilizing the warm effluent of power stations, it is necessary to test the effluent for toxic elements, in particular for chlorine. In order to reduce the fouling of the intake culvert with bivalves which might fall and be carried through to the condenser tubes and cause damage, chlorine solution is either continually injected or periodically dosed into the system. Recent analysis by a chemist at a power station has shown that a small continual application or injection at 5 or 6 ppm at the intake point is still effective and most economical. The intense heat in the condenser unit drives most of the chlorine off, but some does remain and is carried in the effluent with the other waste products out to sea. The chlorine level and the waste products might be lethal instantly, or by accumulation, or they might simply retard development and suppress the growth rate.

Trials are at present being conducted at a nuclear and at a conventional power station to test the effect of chlorine. A small hut at each site contains six small polythene tanks. Four of them are filled with running effluent and the other two with running water pumped directly from the sea, to act as control. The sea water is heated to the temperature of the effluent so that it is only the chemical composition of the effluent that is under examination. The tanks, with one exception at each site, contain ten plaice taken from the sea at Port Erin.

After 84 days at the conventional station, the mean length of the plaice in the effluent has risen from 86 to 122 mm, and that of the fish in the control tanks from 86 to 116 mm. The experiment at the nuclear station has only been running for 29 days, but during that time the plaice in the effluent have increased their mean length from 88 to 110 mm, and those in the control sea water tanks from 92 to 99 mm. The slower growth rate of the fish in the control tanks at both sites is probably due to human disturbance, as these tanks are nearest to the door. O-group hatchery sole in the effluent have increased their mean length from 55 to 80 mm in 84 days.

Compared with the normal development of wild stock in the sea, the experimental fish show growth not usually achieved until late May or June in nature. Therefore, if this rate of growth could be initiated at the beginning of the winter and then maintained, the chances must be very good for significantly reducing the time for the fish to reach marketable size. The results of the trials to date to test the toxicity of chlorine in the effluent show that on present evidence the usual discharge levels of chlorine (less than 0·04 ppm) do not prevent growth. It is known that larger doses can kill and therefore the chlorine level must be monitored continuously and chances of human error in its application eliminated.

Plans for a first small-scale production unit are now being developed. Two or three sectional tanks, about the size of small swimming pools will be installed at one of the power station sites. There are still many questions to be answered on future pond design to maintain even temperatures and flow rates, but preliminary tests will be conducted in these tanks.

The initial growth-rate curves have been derived with a diet entirely composed of mussel flesh. These curves form the basis for future comparison, but it is not the intention to feed large populations of fish on fresh mussel. The whole field of economic feeding of captive fish stocks has only just been opened. Natural or artificial high-protein foods must be found and made acceptable. Fish fed on artificial pellet food have grown well and have shown that the pellet is acceptable, but it is the offal market that will probably provide the cheap soft foods which fish prefer without preliminary weaning periods.

Then there is the possibility of utilizing the effluent for growing fodder foods, either culturing bivalves or fattening *Artemia*, thus simulating the real agricultural principle of growing the animal's requirements on the site.

In the future, a power station site might consist of its own hatchery unit, nursery ponds and large lagoons, as well as food preparation units and fodder ponds. This means detailed design and planning for the best use of the available ground around a power station, and therefore it is essential that all aspects of the basic research are covered so that the first fully operational unit has all in its favour to succeed.

EXPLANATION OF PLATE

Interior view of the marine fish hatchery at Port Erin, Isle of Man, showing polythene plaice-rearing tanks arranged in rows and layers.

Socio-economic aspects of fish farming

By C. F. Hickling, 95 *Greenway*, *London*, *N* 20

Fish farming is undoubtedly a good way of growing substantial quantities of first-class animal protein in a small area; but there are practical difficulties in its further expansion, socio-economic as well as technical.

First, there is the water supply. This may be a difficulty where there is a long dry season. In such instances, fish farming can be associated with water-impoundment schemes; and though it may there compete to some extent with irrigated plant crops, fish farming can use water which has become too saline for most plant crops, since many valuable farm fish have a notable salinity tolerance. Moreover, in warm countries, worth-while fish crops can be got even where water is available for only 6 months in the year, provided there are the facilities for restocking for the next crop. Fish farms must also not be placed where they may be liable to floods.

The best results are got in slightly alkaline water, since acid water inhibits many important links in the food chain, and also makes the fish more prone to disease.

The matter of water supply may be simpler where fish farming is done in sea water or brackish water, provided the ponds are situated at the correct levels in relation to the tides; but such ponds are liable to become very saline during a dry season. Fresh water is brought, where possible, by canal to these marine fish-farm complexes to combat excessive salinity. But salinities can vary from 0·5 to 8% in the dry season. Obviously, such farms would grow only fish which have a great salinity tolerance. Such fish are the milk-fish, *Chanos chanos*, a herring-like fish, and the grey mullets, *Mugil* sp. Many species of Penaeid prawn are carried into the ponds as larvae, with the inflowing water, at times of filling, and these are a very valuable catch-crop. These fish are herbivorous, feeding on the algal felt which develops on the firm pond-mud; and in Formosa, where this form of fish farming is best developed, organic fertilizers are used to increase the production of this vegetable material. Hence the