Marine Fish Culture in Britain
IV. High Survivals of Metamorphosed Plaice during Salinity Experiments in Open Circulation at Port Erin, Isle of Man, 1961

By

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Introduction

The results of the 1960 plaice rearing experiments in open circulation at the Port Erin hatchery (SHELBOURNE, 1963), showed that an empirical technique originally developed at Lowestoft (SHELBOURNE, RILEY and THACKER, 1963; RILEY and THACKER, 1963) could give survivals to metamorphosis approaching 10%, using fertilized eggs from captive spawners in ponds. A confined tank environment probably puts a considerable strain on the adaptational resources of an organism such as a pelagic plaice larva, which in nature, has the open sea for a hunting ground. From an evolutionary standpoint, it may be expected to have a limited ability to deal with surfaces before taking to the bottom at metamorphosis. The delicate structure of the skin during early larval development (SHELBOURNE, 1956) supports the view that only the mildest degree of contact with aquarium walls or tank inclusions, would be tolerable.

Without a reasonably trustworthy tank rearing technique, long-term survival experiments to test specific physico-chemical variables are usually unrewarding, since the artificial and ill-understood hazards of tank life may have an overriding influence on mortalities. For this reason, hatchery research on marine fish larvae has been necessarily confined to the effect of short-term extremes, conditions that rarely occur in the natural habitat. Our understanding of the ways in which a tank environment can operate against survival is still imperfect, but, by a process of trial and error, a point has been reached where major technical mistakes can be consciously avoided. We are now in a better position to obtain meaningful results from long-term experiments on the effect of physico-chemical variables, than we were two or three years ago.

The declared aim of the plaice rearing project, started at Lowestoft in 1957, was to pioneer a mass-production technology, in preparation for attempts to influence the yield of selected bay fisheries by a programme of artificial recruit-

ment. Since 1957, efforts have been mainly directed towards increasing the annual production and percentage survival of plaice larvae in tanks, without too much regard to the measurement of particular environmental effects. The organization of the 1961 salinity experiment at Port Erin was influenced as much by this policy, as by an interest in the specific action of salinity variation on larval survival in a coastal hatchery, during heavy spring rainfall.

Spawning Stock and Egg Condition

Maturing plaice were trawled from offshore grounds in the Irish Sea, between 15. February and 1. March, and transferred to a spawning pond at the Port Erin hatchery. A total of 32 females and 37 males was caught, most of which were damaged in the trawl. Spawning started almost immediately, and sample shell toughness measurements gave extremely low readings. This was in marked contrast to 1960 (SHELBOURNE, 1963), when both pond and sea-wintered stock liberated eggs with tough shells, similar to those found in the sea.

The reasons for imperfect hardening of eggs liberated by captive plaice are not understood, though the observations of ZOTIN (1958), on the mechanism of hardening in the salmonid egg shell, may be relevant. He describes the process as a chain polymerization of substances within the membrane, activated by an enzyme released from the surface of the egg after fertilization. However, it is known that the normal processes of ovarian egg development and spawning in some fish species, e.g. the minnow, Chinese grass carp and herring, can be seriously affected by sub-optimal conditions in captivity. Although the plaice can produce hard eggs in ponds, frequent failure to do so reflects our ignorance of environmental optima for a captive spawning stock. In this respect, the advice of DANNEVIG (1895) is worth noting; he insisted that a period of acclimatization to pond conditions was necessary for the production of highly viable eggs by captive plaice, and regarded eggs from the older residents of his ponds as the best material for rearing experiments.

The temperature of pond water at the middle of March was 8·6°C, between 2° and 3° higher than normal for the time of year. Conditions were good for bacterial growth, and eggs became progressively contaminated during development in the pond. Mid-stage eggs selected for tank experiments were, without exception, showing signs of heavy bacterial contamination (opaque and adhesive shells) prior to hatching.

The Salinity Experiment

(1) Apparatus

Salinity experiments on marine fish eggs and larvae are usually conducted in static sea water adjusted to the desired salinity with distilled water or salt preparations (HOLLIDAY and BLAXTER, 1960). This arrangement may be satisfactory for a short time, but static water conditions are unsuitable for long-term experiments. If, as is likely, a general deterioration in the quality of the water occurs with the accumulation of metabolites, the effect of salinity may be masked. The most direct, and certainly the least laborious way to ensure a continuous flow of salinity-adjusted sea water for a long period of time, would be to operate an automatic control salinometer in an overhead mixing chamber

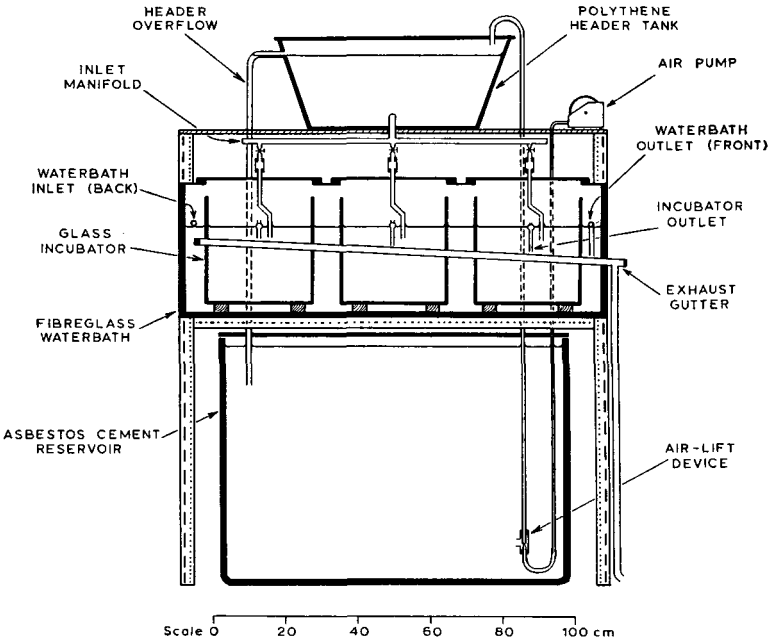

Figure 1. Open circulation system designed to test the long-term effect of salinity variation on the survival of plaice larvae (front view).

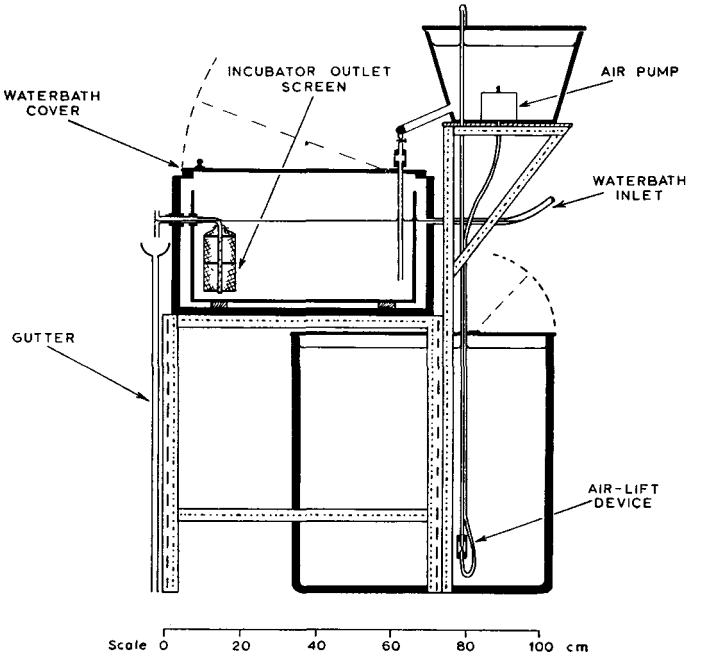

Figure 2. Open circulation system designed to test the long-term effect of salinity variation on the survival of plaice larvae (side view).

and to run the adjusted product into experimental tanks by gravity feed. A salinometer was not available in 1961, so the following method was used (Figs. 1 and 2). Each morning a measured amount of hatchery sea water of known salinity was run through a glasswool filter into a leached asbestos-cement reservoir of 450 l capacity, and a calculated volume of distilled or tap water added to lower the salinity to a pre-determined level. After thorough mixing, this water was lifted by air-pump at a rate slightly in excess of incubator requirements, into a polythene header tank above the reservoir. This header was fitted with a delivery manifold emerging from a point near the bottom on the front face, and also with an overflow pipe leading back to the reservoir. Water fell by gravity at an equal and steady rate of 4 l per hour into each of three 60 cm × 30 cm × 30 cm moulded glass incubators below the delivery manifold. This arrangement provided a constant head to facilitate delivery control. A short length of 'Perspex' tube was interposed into each tank inlet pipe, enabling the drip-feed rate to be visually counted, checked and adjusted when necessary.

The three glass incubators (40 l capacity) below the header were fitted out in a similar manner to the tanks in the 1960 experiment at Port Erin (SHELBOURNE, 1963). Their sides were shrouded with a close-fitting jacket of black polythene film. The inlets delivered their flow below the water surface, and the perforated outlet pipe had a vertical extension also below the surface, surrounded by a fine mesh nylon bag held at a distance from the pipe by three polythene discs. The three incubators sat side by side in a black fibreglass tank, through which hatchery water was slowly circulated. This waterbath buffered the incubators against the higher ambient air temperature in the hatchery, but passed on diurnal temperature variations within the hatchery sea water circulation. The outlet (strictly overflow) pipes of the incubators were extended through the front of the fibreglass waterbath to discharge into a gutter. The waterbath was fitted with a plywood cover treated on the under surface with epoxy resin, and painted on top. Access to the inner tanks was by hinged plywood flaps covering 60 cm × 30 cm holes in the cover immediately above the tanks. These flaps had central slits covered with translucent polythene film for admitting light. A 'Dexion' galvanized steel framework supported all the unit components other than the main reservoir, which stood on the floor, partly hidden under the fibreglass waterbath.

The volume of diluted sea water made up each day in the unit reservoir was considerably in excess of the day's requirements. The following morning the reservoir residue was measured with a dip-stick, and the amount of distilled water in the mixture calculated. Measured volumes of hatchery sea water and distilled water were then added to the residue, to provide the next 24 hours' supply.

In this way it was possible to maintain a continuous flow of sea water, adjusted to a pre-determined salinity below that of hatchery supply, for long periods of time. The incubators were buffered against a higher room temperature, and the air-lift pump aerated the water in addition to transferring it from reservoir to header. These triple-tank units can be modified easily, to test any long-term chemical effect on larval survival, without running the risk of secondary effects inherent in a static sea water system. Three such units, giving a total of nine experimental incubators, were constructed, placed in line, and illuminated by two 80 watt fluorescent tubes suspended above the incubators.

(2) Procedure

Plaice eggs are generally described as being buoyant in sea water. This generalization needs qualification, for a buoyancy experiment in 1952 showed that eggs naturally spawned in sea water of 35‰ salinity, sank when transferred into sea water at 32‰. The reserve buoyancy of an egg will therefore determine the range within which experimental salinities can be chosen, since, below this range, eggs will sink to the bottom. A new environmental factor — contact with the bottom — is then introduced, which might influence experimental results. Similarly, after hatching, the innate buoyancy of the yolked larva is important in determining activity and behaviour in tank conditions. At low salinities, larvae have to do more work than at higher salinities, in order to keep clear of the bottom.

Such considerations influenced the planning of this experiment. It was decided to delay the start of salinity variation until the larvae were sufficiently robust to counter easily, by swimming activity, any extra tendency to sink at lower salinities. The earliest moment in the larval life history when this situation can safely be said to prevail is at 'first-feeding', 5–8 days after the completion of hatching. The details of subsequent experimental procedure were not pre-planned, but were left until the response to initial treatment was known.

The first phase of the experiment was organized as follows:—

(a) One triple-tank unit to act as control, continually irrigated with hatchery sea water at about 34‰ salinity. (Unit 2).
(b) Another unit to operate at 31‰ salinity after 'first-feeding', the decrease from normal hatchery salinity to be gradual. (Unit 1).
(c) The final unit to operate at 28‰ after 'first-feeding', reducing to this level at the same rate as above. (Unit 3).

On 22. March each of the nine glass incubators was stocked with 1000 mid-stage gastrulae sorted from egg catches brought into the hatchery from the spawning pond. By 30. March, when hatching started, there was a noticeable bacterial scum at the surface of all tanks. Without exception, egg shells were severely contaminated and covered with sedentary and motile commensals. The hatching phase ended 5. April; from this time onwards, the fluorescent tubes above the tanks were lit for 12 hours each day, from 0900 to 2100 hrs.

The nauplii of *Balanus balanoides* L. and *Artemia salina* L. were first offered as food on 3. April, and a few older larvae started feeding. The hinged flaps above the experimental tanks were opened during the day to receive maximum illumination, and this practice was continued over the early feeding phase, until all survivors were established feeders. By 13. April the bottoms of all tanks were covered with a pink, mucilaginous carpet of partly digested and autolysed *Artemia* tissue, which was laboriously removed with an improvised polythene scraper during the period 13.–16. April. It was thought likely that this layer of decaying organic matter might prove troublesome later. On 16. April large numbers of active early feeders were present in all tanks, and the mortality rate of non-feeders was beginning to decline. The following afternoon, distilled water from a cast-iron still was used to lower the salinity in units 1 and 3. The total reduction was no more than 1·5‰ over a period of three days, as measured by the titration technique of STRICKLAND and PARSONS (1960). During this time, unexpected mortalities occurred in the treated tanks. A toxic

principle was suspected in the iron-distilled water, and the experiment was temporarily suspended. Salinities were brought back to the hatchery norm during the next seven days.

On 3. May, the survivors of this first experiment were subjected to a second gradual decrease in salinity, of greater amplitude than the first. Salinities of approximately 31‰ (unit 1) and 28‰ (unit 3) were maintained through the period of larval metamorphosis, without causing differential mortality. Ten days before the end of the experiment, salinities were gradually restored to normal hatchery level, with no undue casualties.

In contrast to procedure during past years, tank bottoms were not sanded, in order to facilitate the regular removal of dead eggs, larvae and food. Rations of *Artemia* nauplii were fed daily to all tanks in quantities usually sufficient to maintain a residual food population. The *Artemia* production technique has already been fully described by SHELBOURNE *et al.* (1963). After metamorphosis, the naupliar diet of survivors was supplemented with *Artemia* metanauplii and adults.

Results

Figure 3 gives the survival curve for each experimental unit comprising three glass incubators originally stocked with 1000 gastrulae, together with temperature and salinity records. By the time hatching was complete, 16 days after the start of the experiment, unit 2 was already ahead on survival with an egg mortality of 8·3% compared with 13·8% and 12·7% in units 1 and 3 respectively (Table 1). This lead had widened by the morning of 17. April. There seemed every chance of achieving high survivals to metamorphosis in unit 2, which was accordingly chosen as control. As previously explained, the pursuit of high tank survivals has always been a dominant feature of our annual plaice rearing programmes.

The slight lowering of salinity in units 1 and 3 during the period 17.–21. April, was accompanied by unexpected mortalities which appear as prolongations of the non-feeding mortality curves in Figure 3. Meanwhile, mortalities in the control unit gradually eased in the expected manner. Feeding larvae are easily distinguishable from thin non-feeders; records of casualties among both groups for all three units are set out in Table 2. A considerable proportion of total dead in units 1 and 3 between 19. and 23. April were, in fact, feeding larvae.

Figure 4 gives a detailed picture of mortality fluctuations throughout the experiment. It compares percentage mortality of remaining stock in each unit per 2-day interval. An interesting feature of this graph is the occurrence of a double peak in the death rate of both treated units, one before and one after first treatment. The second peak did not occur in the control unit. However, attention must be drawn to the fact that the death rate had increased somewhat in units 1 and 3 between 15. and 17. April, before the salinity was lowered. This weakens the case for supposing the second peak to be due solely to a change in the salinity regime. There were other differences between units, notably light intensity and possibly the degree of damage done to larval stocks during bottom scraping operations. The light intensity at the water surface of each tank is given in Table 1. It was measured with an 'Eel' photometer corrected by filter to the wavelength response of the human eye. Light conditions for

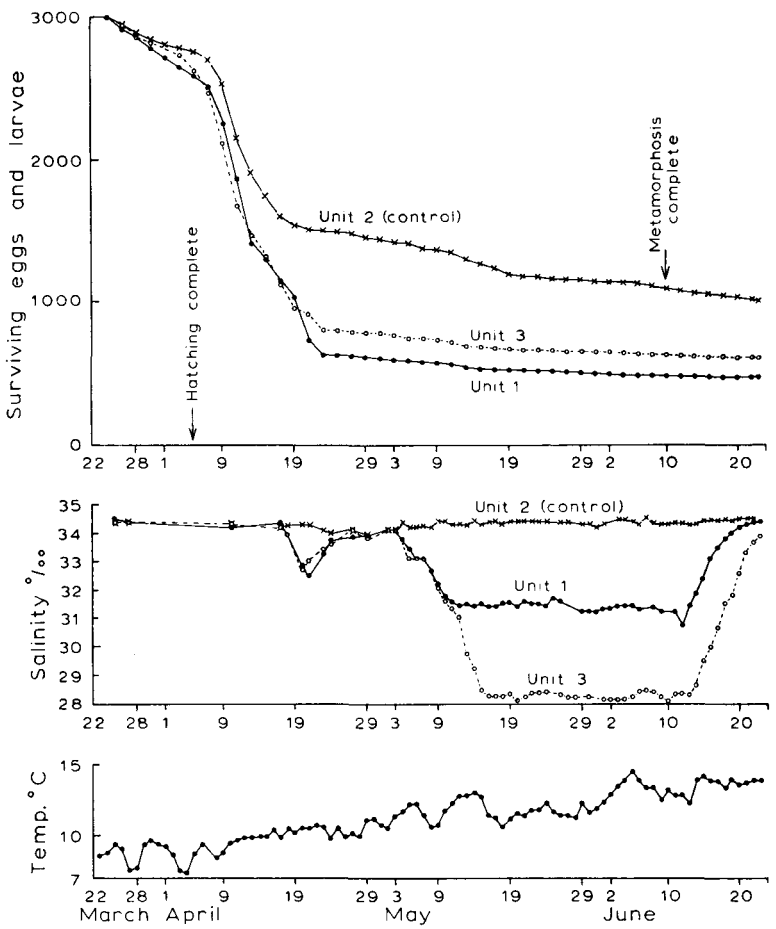

Figure 3. Stock survival curves for each experimental unit (upper), with salinity regime (middle) and mean tank temperature (lower): salinity experiment, Port Erin, 1961.

Table 1

Plaice stock data and light intensities for each tank Salinity experiment, Port Erin, 1961

Date	Developmental stage	Tank number: Unit 1			Unit 2 (control)			Unit 3		
		1	2	3	4	5	6	7	8	9
22. March	Egg stock (gastrulae).	1000	1000	1000	1000	1000	1000	1000	1000	1000
5. April	Hatched larvae.....	870	873	843	924	915	912	863	871	886
21.–23.April	Established feeders ..	165	267	185	531	545	427	358	249	207
23. June	Metamorphosed survivors.....	126	203	138	333	356	311	287	174	139
Mean length of survivors (mm).....		21·4	19·0	20·7	18·8	17·9	18·0	17·0	19·8	20·5
	S.D.....	5·6	4·4	4·9	4·8	4·8	5·1	3·8	4·4	4·6
Light intensity at water surface during early feeding: lids open (lux)		140	285	484	500	344	290	500	527	377

Table 2

Deaths of feeding and non-feeding plaice larvae during the first salinity change Salinity experiment, Port Erin, 1961

(Salinity change started p.m. 17. April, after removal of dead).

Date	Unit 1 (Treated) Feeders	Non-feeders	Unit2 (Control) Feeders	Non-feeders	Unit 3 (Treated) Feeders	Non-feeders
April 17.	9	143	13	129	7	168
– 19.	25	98	14	53	39	139
– 21.	288	15	10	15	120	23
– 23.	109	0	9	0	15	0
– 25.	3	0	6	0	3	0

feeding were worst in unit 1, which also had the lowest survival. But the discrepancy between survivals in units 2 and 3 cannot be accounted for in terms of light intensity. In any case, a considerable proportion of casualties, during the period in question, were feeding larvae. The bottoms of all tanks were scraped, including those in control unit 2. It is possible that the control stock were stronger at the time of cleaning, and may therefore have been better able to withstand disturbance and damage. The consistently better performance of the control stock, from the start of the experiment, may be significant in this context. The possible toxic principle already mentioned, was discounted in a later phase of the salinity experiment.

The evidence is provocative, but in view of background uncertainties, it would be unwise to suppose that a slight decrease in salinity, even during a delicate

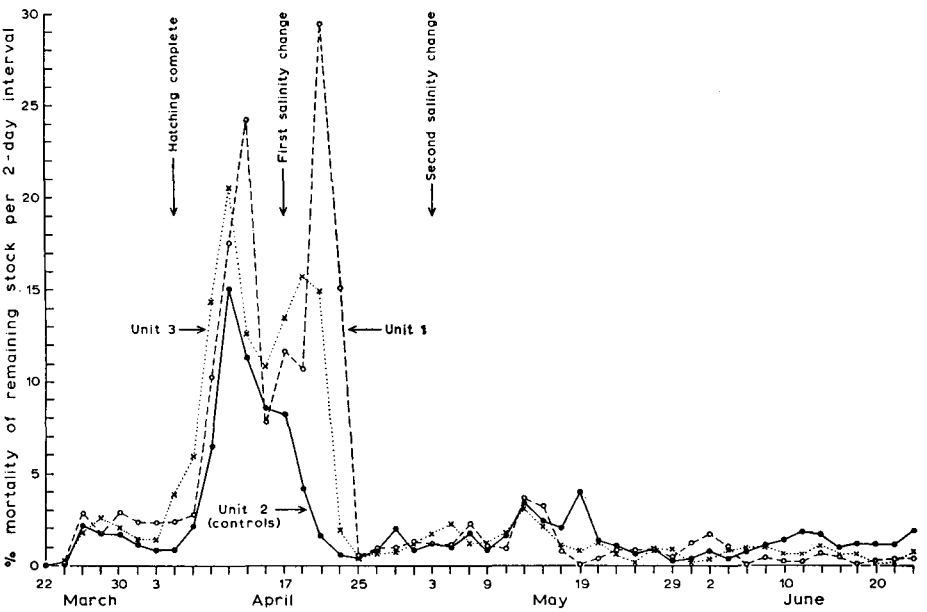

Figure 4. Percentage mortality of remaining stock in each unit per 2-day interval: salinity experiment, Port Erin, 1961.

Table 3

Mortalities of plaice larvae during successive phases of the second salinity change Salinity experiment, Port Erin, 1961

Date	Salinity changes	Unit 1 (Treated) Alive	Dead	% Dead	Unit 2 (Control) Alive	Dead	% Dead	Unit 3 (Treated) Alive	Dead	% Dead
3. May		587	–	–	1416	–	–	761	–	–
3.–15. May	Salinity changing Units 1 and 3	–	68	11·58	–	149	10·52	–	83	10·91
15. May		519	–	–	1267	–	–	678	–	–
15. May–12. June	Salinities steady	–	43	8·29	–	196	15·47	–	61	9·00
12. June		476	–	–	1071	–	–	617	–	–
12.–23. June	Salinity changing Units 1 and 3	–	9	1·89	–	71	6·63	–	17	2·76
Total % mortality over period		–	–	20·44	–	–	29·38	–	–	21·16

stage of larval development, could account completely for the subsequent increase in death rate among treated stock. The issue awaits further experimental work in more rigorously controlled conditions.

By the 25. April, mortalities in all tanks had dropped to less than 1% of remaining stock per 2-day interval, and stayed at a low level until 3. May. On that day a few precocious fish were beginning to metamorphose, though the majority were still at a truly pelagic stage. Salinities were once again varied, first of all comparing double glass-distilled water as a sea water diluent against iron-distilled water to detect possible toxic contaminants in the latter, and later on replacing double-distilled water by tap water. No differential mortalities occurred down to 32‰. The salinity was stabilized at 31–32‰ using tap water in unit 1 (heavy casualties first experiment), and at 28–29‰ using iron-distilled water in unit 3. The rate of change was similar for both units. These levels were held until 13. June when the return to normal hatchery salinity began.

Survival curves for the second phase of the salinity experiment show no marked response to differential treatment (Fig. 3). The same survival data are translated in terms of percentage mortality of remaining stock per 2-day interval in Figure 4. A common feature of each curve, including controls, is the short period of increased mortality rate after 11. May, which in the past has been related to the onset of metamorphosis. It may, however, be merely due to the fact that late pelagic larvae are strong swimmers, requiring more freedom of movement than is afforded by a small tank. A summary of proportional deaths during the various phases of the second salinity variation is given in Table 3. The mortalities in treated units 1 and 3 are similar; the higher proportional deaths in unit 2 (controls) are as likely due to high population density as to high salinity. At this point it must be emphasized that the larval stock in units 1 and 3 for the second experiment, were the survivors of the first.

Whatever the cause of post-treatment mortality in the first phase of the salinity experiment, there is little doubt that a decrease in salinity from 34‰ to 28‰, at a rate of 0·5‰ per day has no marked effect on the mortality of larval survivors at a later stage of pelagic development, and that an increase in salinity from 28‰ to 34‰, at the same rate of change, is similarly tolerated by metamorphosed fish. In practical terms, this means that salinity stabilization may not be a major consideration in the control system of a shore-based plaice hatchery, at least during the later stages of larval development.

Analysis of Surviving Stocks

The experiment ended on 23. June. All survivors were killed and preserved in 5% formaldehyde in sea water. A summary of final survival per tank is included in Table 1.

(1) Survival rates

Survival curves (Figs. 3 and 4) showed the usual trends. Firstly, an appreciable egg loss during incubation, largely due to bacterial contamination of egg shells, aggravated by crowded tank conditions. Secondly, a phase of increased mortality, the so-called 'critical period' between hatching and 'first-feeding'. Thirdly, two months of slow larval loss between first-feeding and metamorphosis, interrupted by slightly increased mortalities for a short time at the late pelagic stage.

Final survivals in the three control tanks were 36%, 33% and 31% of original eggs, at a mean density of 1790 young fish per m^2, about three times the best survival and population density at Port Erin in 1960. Results for both years are compared in Figure 5, rates being expressed in terms of percentage survival of original egg stock. The readings are means of the three best tanks in 1960 and the three salinity control unit tanks in 1961. The curve for 1961 is displaced to the right because (a) the original egg stock was somewhat younger, and (b) the mean water temperature was lower, than in 1960. An improvement in survival rate was early indicated in 1961 by the abundance of feeding larvae after the 'critical period'; 50% (1503 feeders) as opposed to 19·3% (578 feeders) in 1960. In my opinion, this improvement was mainly due to better illumination during the 'first-feeding' phase in 1961, when tanks were uncovered and larvae exposed to high light intensity (Table 1). Light readings were not taken in 1960,

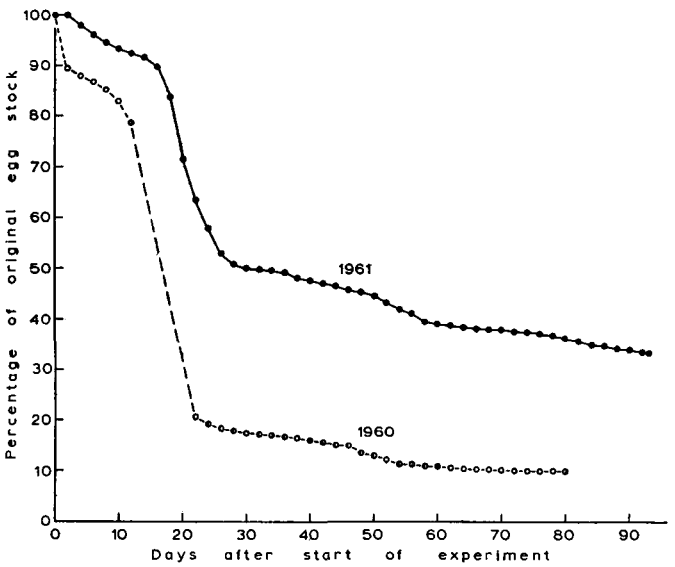

Figure 5. Survival of plaice stock at Port Erin in 1960 (three best tanks) and 1961 (salinity control unit), expressed as percentage of original eggs.

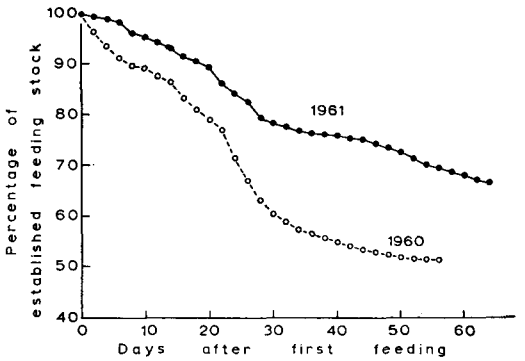

Figure 6. Survival of plaice larvae at Port Erin in 1960 (three best tanks) and 1961 (salinity control unit), expressed as percentage of established feeders.

but tank illumination must have been comparatively poor, as they were partially covered during this critical feeding phase. DANNEVIG (1897) became aware of the need for adequate lighting during his plaice rearing trials, and BLAXTER (1962) makes a similar assertion regarding the rearing of herring larvae. In the context of light intensity and early feeding, the tank background is also important. This point was discussed in the first publication of the present series (SHELBOURNE *et al.*, 1963).

The improvement in the 1961 survival rate, already apparent by 'first-feeding', was maintained during the later stages of larval development. The survival rate among *feeding* larvae during 1960 and 1961 is given in Figure 6, as a percentage of established early feeders. It can be seen that 66% of feeding larvae survived through metamorphosis, compared with 51% in 1960, even though the population density was trebled in 1961. A single environmental factor is unlikely to account for this later improvement. Mean temperatures throughout the season were lower, and perhaps nearer the optimum, in the 1961 water-bath system; tank design had been improved by modifying the tank outlets to remove a cause of mortality in earlier years; tank hygiene was also better.

The effect of technical improvements can only be assessed critically, by conducting rearing trials on egg stocks with similar viabilities. We know little about fluctuations in the viability of pond-spawned eggs from one year to another. The 1961 egg stock at Port Erin was abnormal in one respect; shells were soft and imperfectly formed giving toughness readings of 150 g or less, compared with the usual 400–600 g in the sea, or from the Port Erin spawning pond in 1960. Despite this early set-back, survivals were the highest so far, in both treated and control tanks.

(2) Length distribution of survivors

The length composition (5 mm groups) of surviving plaice populations from each unit of three tanks is given in Figure 7. All survivors were of approximately equal age; nevertheless, there was a considerable range between minimum and maximum survivor size in each unit. There was also an indication that unit 2, with the highest population density, contained greater proportions of small

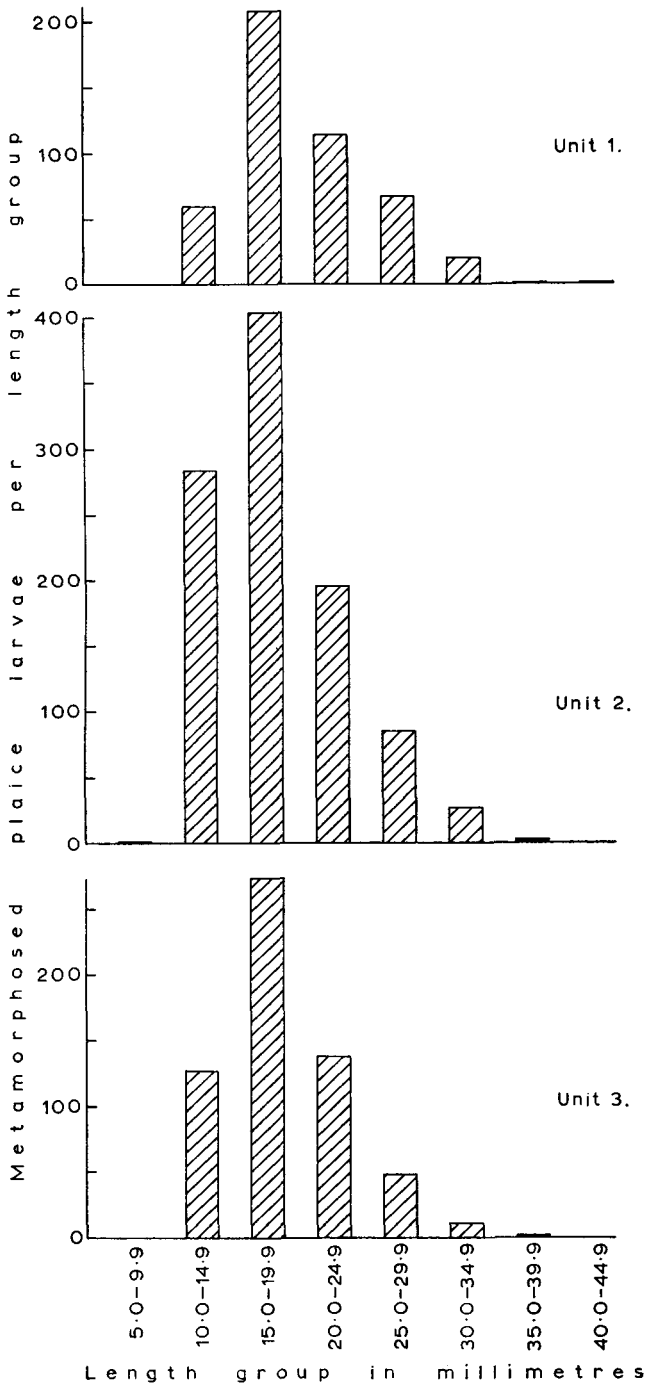

Figure 7. Length composition (5 mm groups) of surviving plaice population in each unit of three tanks: salinity experiment, Port Erin, 1961.

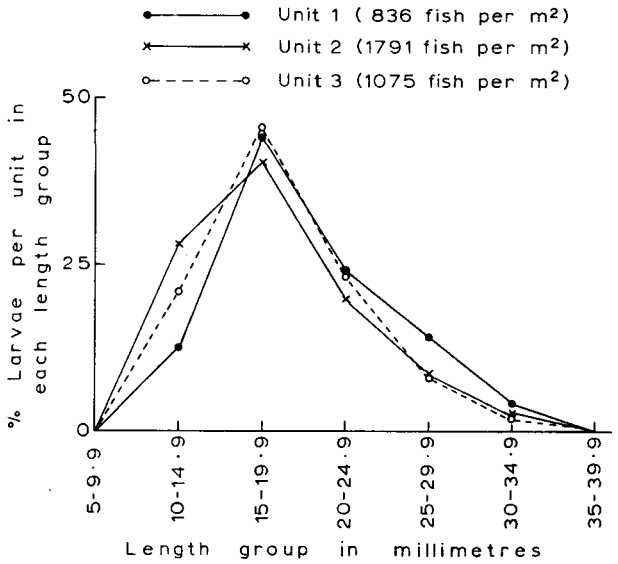

Figure 8. Proportional abundance of survivors of different length groups in each unit of three tanks: salinity experiment, Port Erin, 1961.

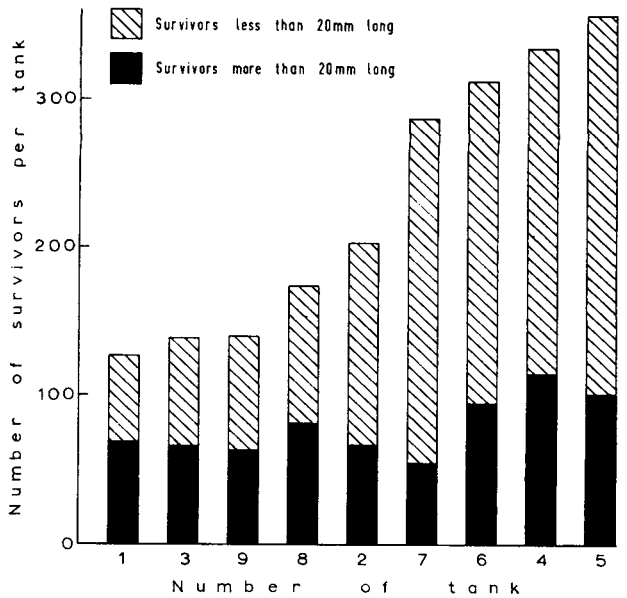

Figure 9. Proportions of large and small survivors in tanks with differing population densities: salinity experiment, Port Erin, 1961.

fish. This trend is supported by mean survivor length data in Table 1, and is explored further in Figure 8, which gives the proportions of survivors in each length group for each unit. The percentage of smaller fish increased with

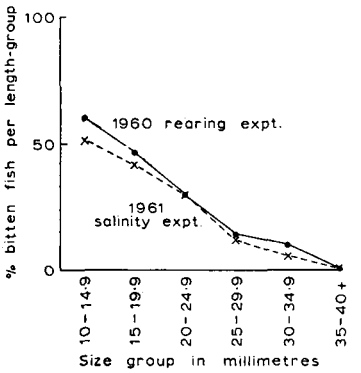

Figure 10. Proportion of bitten survivors per length group: totals for all tanks, Port Erin, 1960 and 1961.

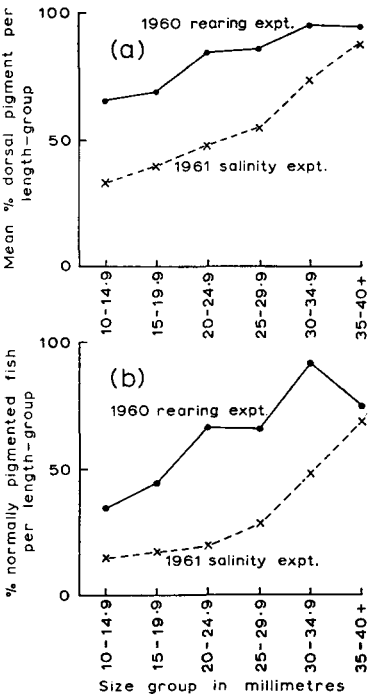

Figure 11. Relationship between dorsal pigmentation and length of surviving plaice: totals for all tanks, Port Erin, 1960 and 1961.
(a) Mean percentage pigmentation per length group.
(b) Percentage normally pigmented fish per length group.

population density; the reverse trend — a decreasing proportion of large fish with increasing density — was not so marked.

This survivor size/population density relationship is obscured to some extent by considering the populations of experimental units, rather than those of individual tanks. Figure 9 compares the numbers of small fish (less than 20 mm long) and large fish (more than 20 mm long) in each glass tank at the end of the salinity experiment. Populations are arranged in order of increasing density. The disproportionate number of small survivors among the denser populations is clearly seen. Whether this was due to competition, or to the differential mortality of weaker, slow-growing individuals during the course of the experiment, or a mixture of both factors, is not known. Although food was super-abundant before metamorphosis, competition did occur later. It was found extremely difficult to satisfy the remarkable appetite of metamorphosed stock.

Survival or death; fast or slow growth — all reflect large differences in individual adaptability to tank conditions. It is therefore by no means certain that a big survivor would be the best sort of fish to release into the sea, as part of an artificial propagation programme. If, however, there is a correlation between fast tank growth and 'sea-worthiness', it would be efficient hatchery practice to eliminate the retarded members of a mixed tank population at the earliest possible moment, by a culling technique. Target production at a low survival level would then be achieved by boosting the egg stocking rate. This practical issue has high priority in future experimental programmes.

(3) Biting and pigmentation

The way in which the incidence of bitten survivors varies with size, was fully discussed in my account of the 1960 programme at Port Erin (SHELBOURNE, 1963). The phenomenon was repeated in 1961, and may be classified as a tank hazard. The relationship between biting and survivor size shown in Figure 10, is almost identical with that for 1960. Deaths among fish of 20 mm length or more cannot be attributed directly to bitten fins, but a severe bite by a large fish on a small one of 15 mm or less, may be correspondingly serious.

Abnormal dorsal pigment was much more common at Port Erin in 1961 than in 1960 (Fig. 11). The trend towards increasing percentage dorsal pigment with size, was again paralleled by an increasing incidence of normally pigmented fish in the higher length groups. There was also a slight correlation between mean pigment and population density, but this is understandable, if, as has been previously demonstrated, the densely populated tanks were biased in favour of smaller larvae.

Gross differences in the degree of abnormality between 1960 and 1961 may be the result of variations in rearing technique, water conditions or stock. Since effective hatchery production can only be measured in terms of normally pigmented plaice, having a reasonable chance of survival after release into the sea, the causes of pigment abnormality are a matter of great practical interest to marine fish culturists. The subject was discussed in the account of work at Port Erin during 1960; there is nothing further to add, except that if a relationship exists between state of pigment and original egg condition, then some measure of environmental control will be necessary for captive spawners, before the problem can be settled.

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Summary

The plaice-rearing work at Port Erin, Isle of Man, in 1961, took the form of a long-term salinity experiment, using an apparatus designed to produce a constant flow of salinity-adjusted sea water through rearing tanks. Nine tanks were employed, grouped in three units of three, each tank being stocked with 1000 plaice eggs (gastrulae) collected from a spawning pond. Towards the end of the 'critical period' between hatching and larval 'first-feeding', the salinity was lowered in two of these units to a level 1·5‰ below the hatchery norm (34‰), at a rate of 0·5‰ per day. The sea water diluent was distilled water from a cast-iron still. Unexpected larval mortalities accompanied this treatment; it is not at all certain that the slight salinity change was directly responsible.

The experiment was repeated on surviving stock at a later stage of larval development. There was no differential mortality in tanks irrigated with sea

water of 31‰ and 28‰ salinity, using tap water and iron-distilled water as diluents. Mortalities in control tanks (34‰) were higher than in treated tanks during the second experiment, but this may have been due to higher population density. The tentative conclusion is reached that salinity stabilization may not be a major consideration in the control system of a large-scale plaice hatchery, at least during the later stages of larval development.

Final survivals to metamorphosis in the three control tanks were 36%, 33% and 31% of original eggs at a mean density of 1790 young fish per m^2 — about three times the best survivals in past seasons. This improvement probably reflected refinements in rearing technique, particularly in respect of tank illumination at 'first-feeding', tank design and tank hygiene.

Length measurements of metamorphosed survivors ranged between 10 and 45 mm, demonstrating individual variations in adaptability to tank conditions. More densely populated tanks contained higher proportions of smaller survivors. As in 1960, there was a relationship between survivor size and the incidence of bitten fins; also a strong correlation between size and dorsal pigment. As a general rule, the bigger fish among a tank population stand a better chance of being more heavily pigmented, under the present technical regime.

References

BLAXTER, J. H. S., 1962. "Herring Rearing – IV. Rearing beyond the yolk-sac stage". Mar. Res. Scot., 1962, No. 1, 18 pp.

DANNEVIG, H., 1895. "On the hatching operations at Dunbar marine hatchery during the spring season, 1895". Rep. Fish. Bd. Scot. 1894, Pt. 3: 123–32.

DANNEVIG, H., 1897. "On the rearing of the larval and post-larval stages of the plaice and other flat-fishes". Rep. Fish. Bd. Scot. 1896, Pt. 3: 175–93.

HOLLIDAY, F. G. T., & BLAXTER, J. H. S., 1960. "The effects of salinity on the developing eggs and larvae of the herring". J. mar. biol. Ass. U.K., **39**: 591–603.

RILEY, J. D., & THACKER, G. T., 1963. "Marine fish culture in Britain. III. Plaice (*Pleuronectes platessa* L.) rearing in closed circulation at Lowestoft, 1961". J. Cons. int. Explor. Mer., **28**: 80–90.

SHELBOURNE, J. E., 1956. "The effect of water conservation on the structure of marine fish embryos and larvae". J. mar. biol. Ass. U.K., **35**: 275–86.

SHELBOURNE, J. E., 1963. "Marine fish culture in Britain. II. A plaice rearing experiment at Port Erin, Isle of Man, during 1960, in open sea water circulation". J. Cons. int. Explor. Mer, **28**: 70–79.

SHELBOURNE, J. E., RILEY, J. D., & THACKER, G. T., 1963. "Marine fish culture in Britain. I. Plaice rearing in closed circulation at Lowestoft, 1957–1960". J. Cons. int. Explor. Mer, **28**: 50–69.

STRICKLAND, J. D. H., & PARSONS, T. R., 1960. "A manual of sea water analysis". Bull. Fish. Res. Bd Can., No. 125: 185 pp.

ZOTIN, A. I., 1958. "The mechanism of hardening of the salmonid egg membrane after fertilization or spontaneous activation". J. Embryol. exp. Morph., **6**: 546–68.