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The Propagation of Cod *Gadus morhua* L.

THE INTENSIVE REARING OF JUVENILE COD, *Gadus morhua* L.

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ABSTRACT

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Cod were reared in the laboratory from the egg to marketable size using cultured live foods for the early stages and then artificial diets. Survival to metamorphosis was about 10%; subsequent mortalities were negligible.

The techniques developed for rearing larval turbot were broadly applicable to the cod. The larvae were fed initially on rotifers, with frequent additions of *Isochrysis* to the tanks, and then on *Artemia*. Nauplii freshly hatched from San Francisco eggs were inadequate as food but were improved when fed for 2 days on *Isochrysis* before being offered. No such treatment was necessary for nauplii hatched from Brazilian eggs.

Post-metamorphosis growth rates varied from 1.9 to 2.8 cm/month at mean temperatures ranging from 6 to 17°C. The optimum temperature for growth appeared to be around 10-12°C.

The prospects and problems of mass-producing juvenile cod in hatcheries are discussed.

INTRODUCTION

Previous attempts to discover a reliable technique for rearing larval cod have failed despite a long history of interest in the rearing of them and other marine species.

Studies of larval growth under controlled (Laurence, 1978) and semi-controlled (Ellertsen et al., 1981) conditions have been possible using collected natural plankton as food, but the variable availability and nature of plankton reduces the repeatability and reliability of such rearing methods.

The use of cultured foods has met with limited success. When first able to feed, cod larvae are about 5mm long and are too small to ingest *Artemia* nauplii. However, even when larval cod have been grown to a size at which they can take nauplii, the diet has proved to be inadequate to sustain the larvae through the remainder of the larval stages (Dannevig and Dannevig, 1950). Turbot (*Scophthalmus maximus*) larvae presented similar problems which were overcome by the adoption of a feeding regime of rotifers (*Brachionus plicatilis*) followed by *Artemia* which had first been fed for 2 days on the unicellular alga, *Isochrysis galbana*. This alga was also added to the rearing tanks throughout the period of feeding on live foods (Howell, 1979; Bromley and Howell, 1983a).

This paper describes trials which tested the suitability of such a diet sequence for larval cod as well as specific experiments on the value of *Artemia* as food. Data on the growth of hatchery-reared juveniles in the laboratory are also presented.

MATERIALS AND METHODS

Egg supply and incubation

Naturally-spawned eggs were produced by a broodstock of wild-caught fish held in a 4.8 x 2.4 x 1.2 m deep sectional tank. During the spawning season the buoyant fertilised eggs were collected using a small hand net.

The eggs were incubated in 10 l, round, mesh-bottomed containers (Fig. 1). Two rows of six of these were immersed in a reservoir tank maintained at a temperature of 8.0 ± 1.0°C. Water was continuously circulated through each incubator at a rate equivalent to 20 exchanges per day by means of an airlift which fed a small header tank. Fresh sea water flowed into the

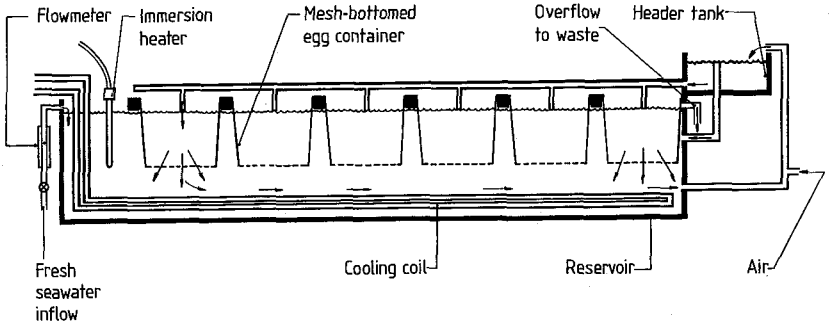

Fig. 1. Schematic representation of the egg incubation system.

reservoir at a rate equivalent to two exchanges per day, the overflow running to waste. Each incubator was stocked with up to 20,000 eggs.

Food supply

Unicellular algae and rotifers were cultured by methods similar to those described by Howell (1973). *Artemia* nauplii were hatched from eggs incubated for 24 h at 28.0 ± 1.0°C. Eggs originating from both San Francisco and Brazil were used. *Artemia* metanauplii were produced by feeding nauplii to excess on *Isochrysis galbana* for two days at about 18°C.

Juvenile fish were transferred to a semi-moist (35-40% water) compounded diet composed of trash fish (37%), trout food (60%), cod liver oil (1.5%) and a vitamin mix (1.5%).

Rearing to metamorphosis

Two rearing trials were carried out in 60 x 30 x 30 cm fibreglass tanks stocked with 1000 and 2000 yolk-sac larvae per tank respectively. The larvae were fed on rotifers for about 30 days and then on *Artemia* metanauplii. A mixture of *Isochrysis galbana* and *Pavlova lutherii* was added to the tanks each day. The tanks were gently aerated and water was

continuously exchanged at an initial rate of 12 $l \cdot h^{-1}$. This was gradually increased to 50 $l \cdot h^{-1}$. Water temperature was controlled at 10.0 ± 1.5°C.

Surviving larvae were transferred to clean tanks every 15-30 days. Mortalities could not be closely followed during the early stages and so survival data are limited to counts on the occasions when larvae were transferred. Mortalities during the later stages were recorded daily.

Small-scale feeding trials

Three experiments were carried out to explore the adequacy of *Artemia* as food for mid-stage larvae. Details of each experiment are given in Table 1.

TABLE 1

Details of the small-scale feeding experiments

	Experiment		
	A	B	C
Conditions			
No. of larvae per container	50	30	50
Mean initial length (mm)	8.9±0.9	13.2±1.4	11.9±1.8
Mean temperature (°C)	11.6±1.5	12.1±1.5	14.1±1.5
Replicates	2	2	2
Diets			
a) Rotifers with *Isochrysis*	+	-	-
b) San Francisco *Artemia* nauplii	+	+	+
c) b) with *Isochrysis*	-	-	+
d) San Francisco *Artemia* meta-nauplii	-	-	+
e) d) with *Isochrysis*	+	+	+
f) Brazilian *Artemia* nauplii	-	+	-

The experiments utilised larvae which had been reared on a diet of rotifers under the conditions described above. The larvae were stocked in 30 cm diameter black plastic containers of 12 l capacity. The food organisms were added daily in such quantity as to provide a small excess after 24 h. The containers were gently aerated and the water was refreshed daily by siphoning out 70% of the volume and replacing with fresh sea water. This procedure also served to remove most of the excess food. Each group of larvae was transferred to clean containers, every five to seven days.

Growth of juveniles

Juvenile fish (mean length 3.5 cm) produced in the rearing trials described above were roughly segregated into two groups of large and small fish and held in 80 cm diameter black polythene tanks each containing 225 l of sea water. They readily accepted and grew well on the compounded feed and reached a mean length of about 12 cm within 4 months. Both groups were then each sub-divided into two. One group of each size category was transferred to a diet of frozen chopped sandeels; the other groups continued to be fed the compounded feed. All the fish were weighed and measured every three weeks. After 15 weeks all the fish were transferred to a 240 x 120 x 60 cm deep tank and their growth on a diet of sprats and gadoids was followed for a further 27 weeks.

Throughout this period the fish were fed twice daily to satiation. All tanks were vigorously aerated and water was continuously exchanged at rates equivalent to 3-5 exchanges per day. Water temperatures were not controlled. Before being measured and weighed, the fish were starved for 24 h and then anaesthetised in 50 ppm MS 222 to facilitate handling.

RESULTS

Egg production

Fertilised eggs appeared first during January of each year

and spawning continued for a period of 8-9 weeks. Mean egg diameter ranged from 1.23 to 1.54 mm and in each year tended to decrease during the spawning season (Fig. 2).

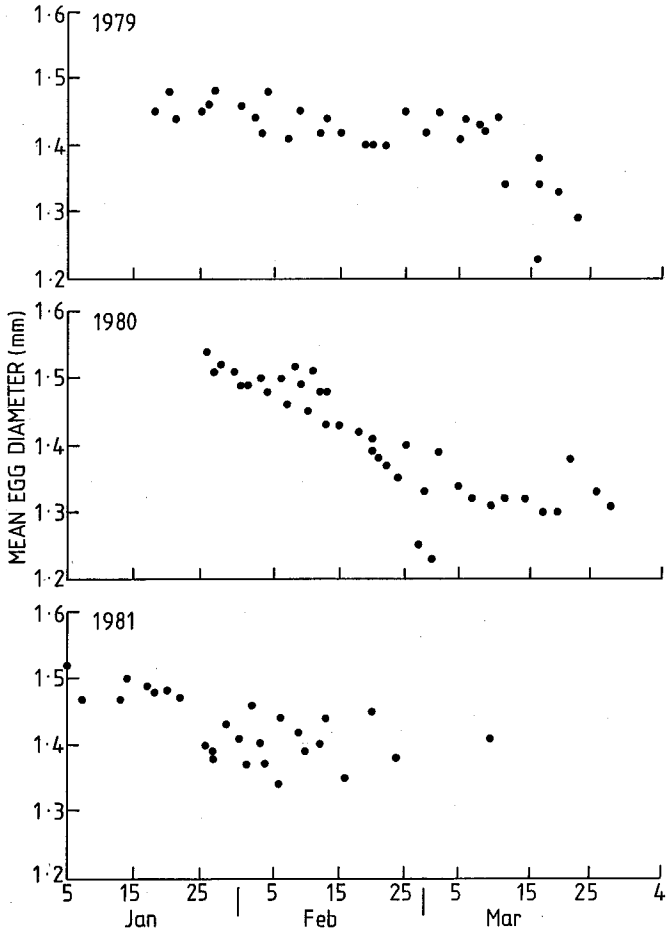

Fig. 2. Mean diameter of egg batches from the cod broodstock, 1979-1981.

Rearing through metamorphosis

Similar survival rates of larvae were observed in each of the trials, 5-7% of the initial yolk-sac larvae surviving to day 72 (Fig. 3). The mortality pattern was typical of that of other marine fish, the greatest losses occurring during the early stages, probably because many of the larvae failed to feed. The mean length of the survivors was 3.5 ± 0.2 cm.

Small-scale feeding experiments

Experiment A

After about a week the total mortality of larvae fed with nauplii was much higher than that of fish fed on either rotifers or metanauplii (Fig. 4). After 16 days the mean survivals of larvae fed on rotifers and metanauplii were 66% and 68% respectively; that of larvae fed on nauplii was only 15%. Although rotifers supported a high survival, 25% of the larvae at the end of the experiment had developed skeletal deformities indicating that prolonged feeding on this diet was detrimental.

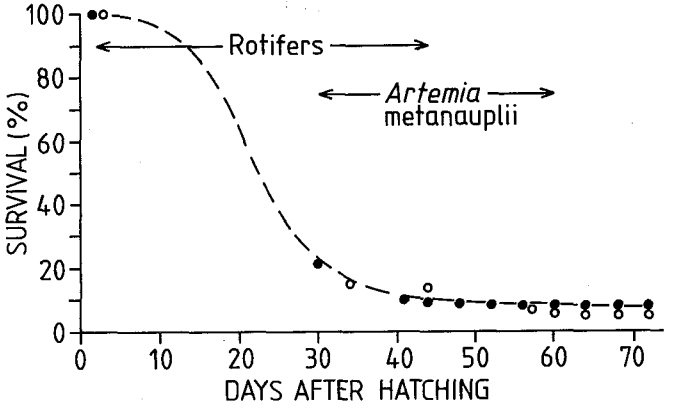

Fig. 3. The survival of cod larvae during two rearing trials.

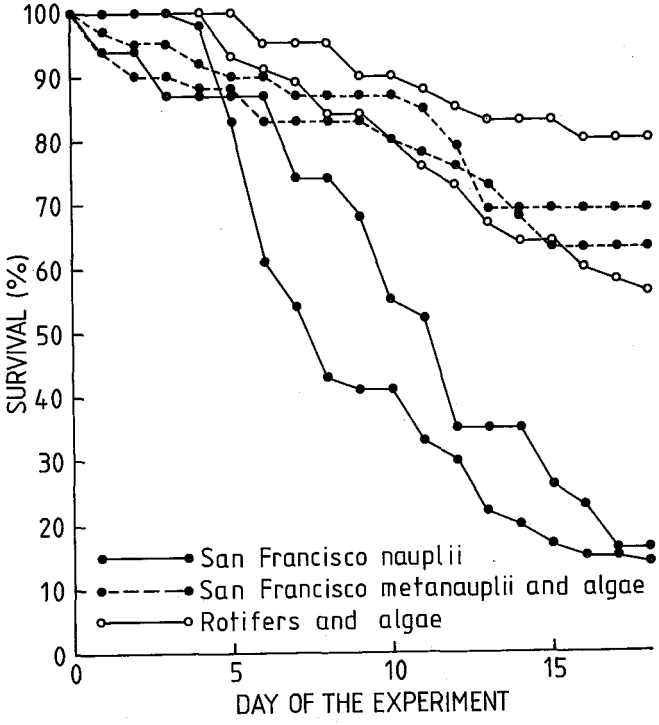

Fig. 4. The survival of cod larvae during Experiment A.

Experiment B

This experiment confirmed the inadequacy of San Francisco nauplii as food and that larval survivals are improved when the nauplii are fed for 2 days on *Isochrysis* and then offered with that alga. Freshly hatched Brazilian nauplii, however, supported survivals equivalent to those on San Francisco metanauplii (Fig. 5).

Experiment C

The addition of *Isochrysis* to tanks of larvae being fed San Francisco metanauplii proved to be unnecessary, and the

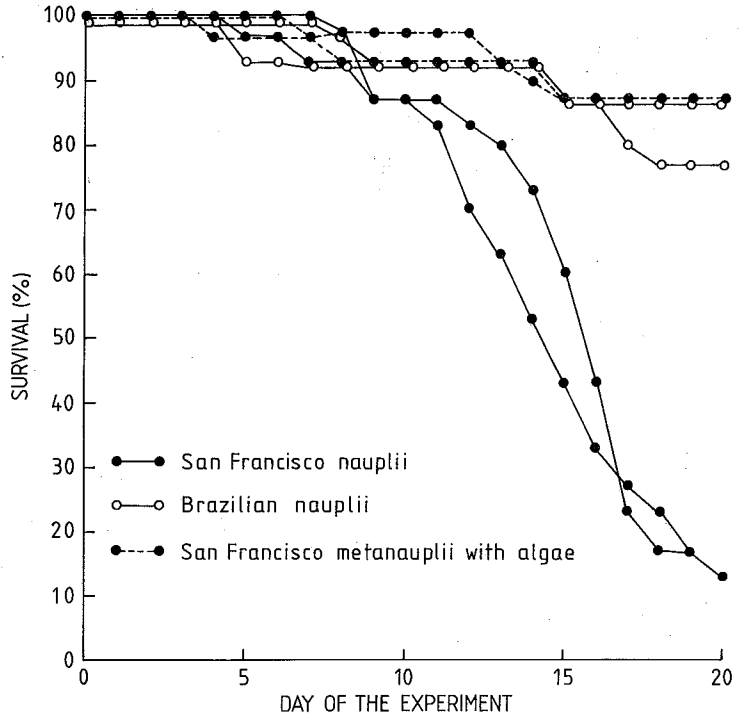

Fig. 5. The survival of cod larvae during Experiment B.

survival of larvae fed freshly hatched San Francisco nauplii was not enhanced by the addition of algae (Fig. 6).

Other problem areas during the larval stages

(a) *Cannibalism*

Cannibalism was a common occurrence, particularly during the mid- and late-larval stages. Persistent low levels of

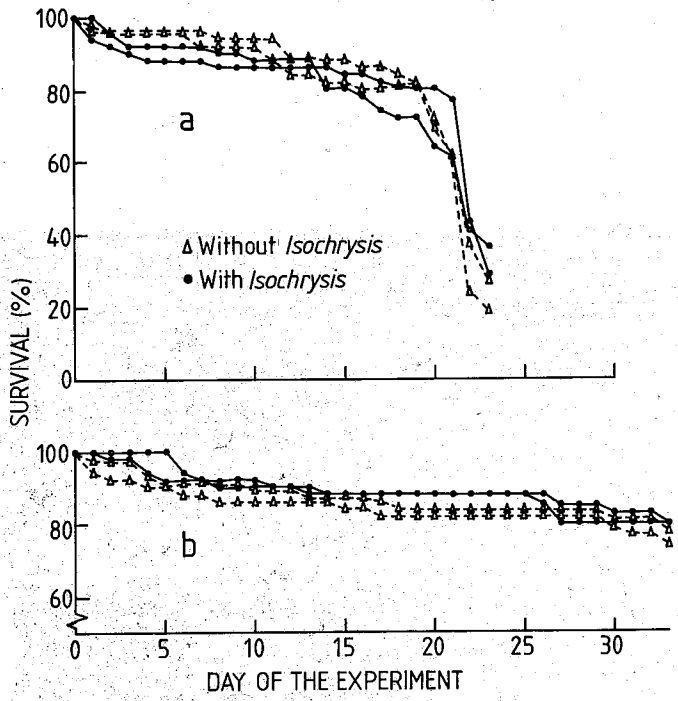

Fig. 6. The survival of cod larvae during Experiment C. (a) fed on SF nauplii, (b) fed on SF metanauplii.

mortality were frequently arrested by the removal of a small number of the larger larvae from the tanks. Cannibalism persisted even when food was present and was particularly prevalent during the transition from a live to an inert food when conditions of semi-starvation were created, but, once the feeding was established and the fish were fed to satiation twice a day, few problems were encountered.

(b) *Swimbladder deficiency*

A wide size range quickly developed amongst most groups of larvae. For example, the length distribution of one group of

larvae 30 days after hatching ranged from 5.5 to 11.5 mm (Fig. 7). The form of the distribution was markedly bimodal

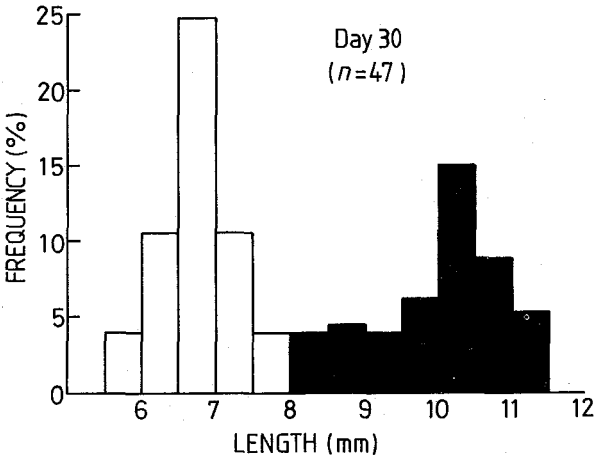

Fig. 7. The length distribution of a sample of cod larvae 30 days after hatching with (shaded) and without swimbladders.

with a clear demarkation at a length of 8 mm between those larvae with and without an inflated swimbladder. The population was roughly segregated into small and large groups and the former was re-examined 15 days later. By this time all larvae had grown to a length greater than 8 mm but there was no increase in the incidence of swimbladders (Fig. 8). This indicated that larvae which failed to fill their swimbladders initially were unable to do so subsequently. The smaller size of larvae without swimbladders no doubt reflects the extra energy expended in swimming to avoid sinking.

Growth of juveniles

Changes in mean length of the two size groups of juveniles fed on sandeels and an inert diet over a 15-week period are

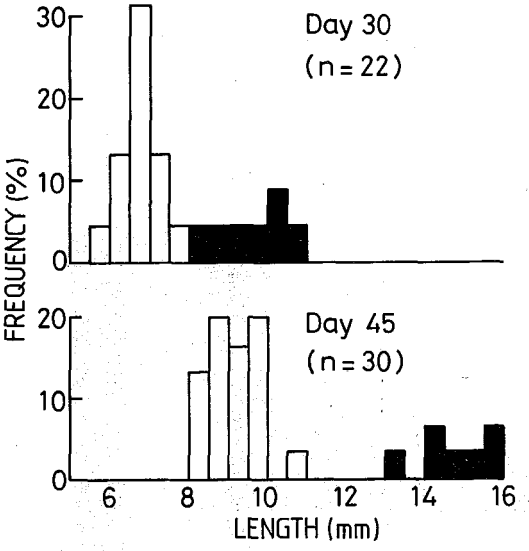

Fig. 8. The length distribution of a batch of cod larvae 30 and 45 days after hatching, with (shaded) and without swimbladders.

shown in Table 2 and Fig. 9. Both the large and small size group fish fed on sandeels grew at a faster rate than their counterparts fed on the inert diet. Mean growth rates, computed by regression analyses, were 2.60 and 2.85 (mean 2.73) cm/month on sandeels and 2.36 and 2.32 (mean 2.34) cm/month on the artificial diet.

Sandeels were converted more efficiently than the artificial diet. Food conversion ratios, expressed as dry weight of food to wet weight of fish to overcome the difference in the moisture content of the diets, were 0.51 and 0.55:1 on sandeels and 0.72 and 0.71:1 on the artificial diet.

A striking feature of the fish at the end of this trial was their difference in colour. Those fed sandeels were a rich golden colour whereas those fed the artificial diets were

TABLE 2

Increase in mean lengths (cm) and standard deviations of 'large' and 'small' cod fed sandeels and a compound feed. Numbers of fish are given in parentheses.

	Small size groups		Large size groups	
Weeks	Sandeels	Compound feed	Sandeels	Compound feed
0	11.82±0.86 (30)	11.23±0.86 (31)	13.40±1.26 (19)	13.27±1.25 (19)
3	13.40±1.25 (30)	12.57±1.13 (31)	14.75±1.61 (19)	14.62±1.55 (19)
6	15.50±1.75 (30)	14.22±1.39 (31)	16.70±1.88 (19)	16.38±1.82 (19)
9	17.85±2.02 (29)	16.18±1.47 (30)	18.70±2.16 (19)	18.18±2.14 (19)
12	20.04±2.31 (29)	18.07±1.66 (30)	20.84±2.39 (19)	20.22±2.35 (19)
15	22.36±2.41 (28)	19.78±1.90 (30)	23.02±2.69 (19)	21.95±2.56 (19)

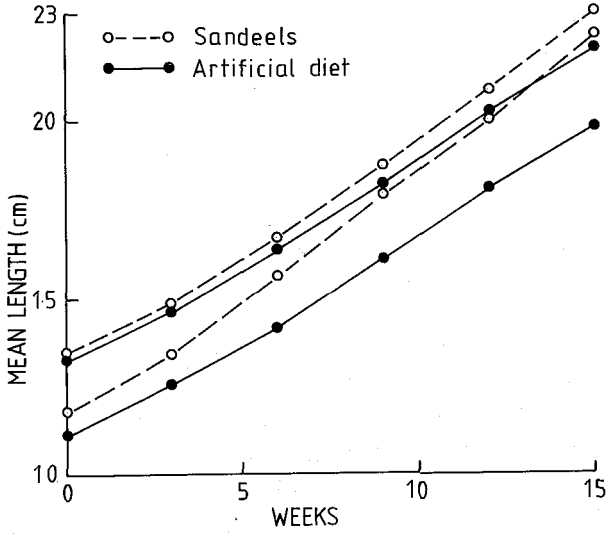

Fig. 9. The increase in mean length of juvenile cod fed on sandeels and on an artificial diet.

darker, more closely resembling the typical coloration of the species.

TABLE 3

Changes in the mean lengths and weights of cod over a 42-week period. Standard deviations are also given.

Weeks	n	Mean length (cm) ± s.d.	Mean weight (g) ± s.d.
0	99	12.21±1.37	18.07± 7.45
3	99	13.63±1.61	26.66± 10.98
6	98	15.54±1.88	40.66± 17.08
9	97	17.65±2.11	60.26± 24.94
12	97	19.62±2.38	81.33± 33.11
15	96	21.60±2.65	111.84± 44.21
19	85	24.44±2.59	175.71± 60.01
23	84	26.58±2.66	228.88± 77.04
28	80	29.15±2.69	299.45± 93.72
33	77	31.71±2.86	390.20±121.20
42	70	34.63±2.99	474.70±139.20

Changes in mean length and weight of all the fish during this period and the subsequent 27 weeks are shown in Table 3 and Fig. 10. Fish of an initial mean length of 12.2 cm (mean weight 18.1 g) attained a mean length of 34.6 cm (mean weight 474.7 g) in 42 weeks at temperatures ranging from 6.2 to 16.5°C. Despite the wide range of temperature, growth rates did not fall below 1.9 cm/month and appeared to be maximal at about 10-13°C (Fig. 11). Conclusions on the dependence of growth rate on temperature deduced from this type of data must, however, be regarded as provisional since they take no account of changes in diet, tanks or size of fish. Food conversion ratios during the last 27 weeks, during which the fish were fed

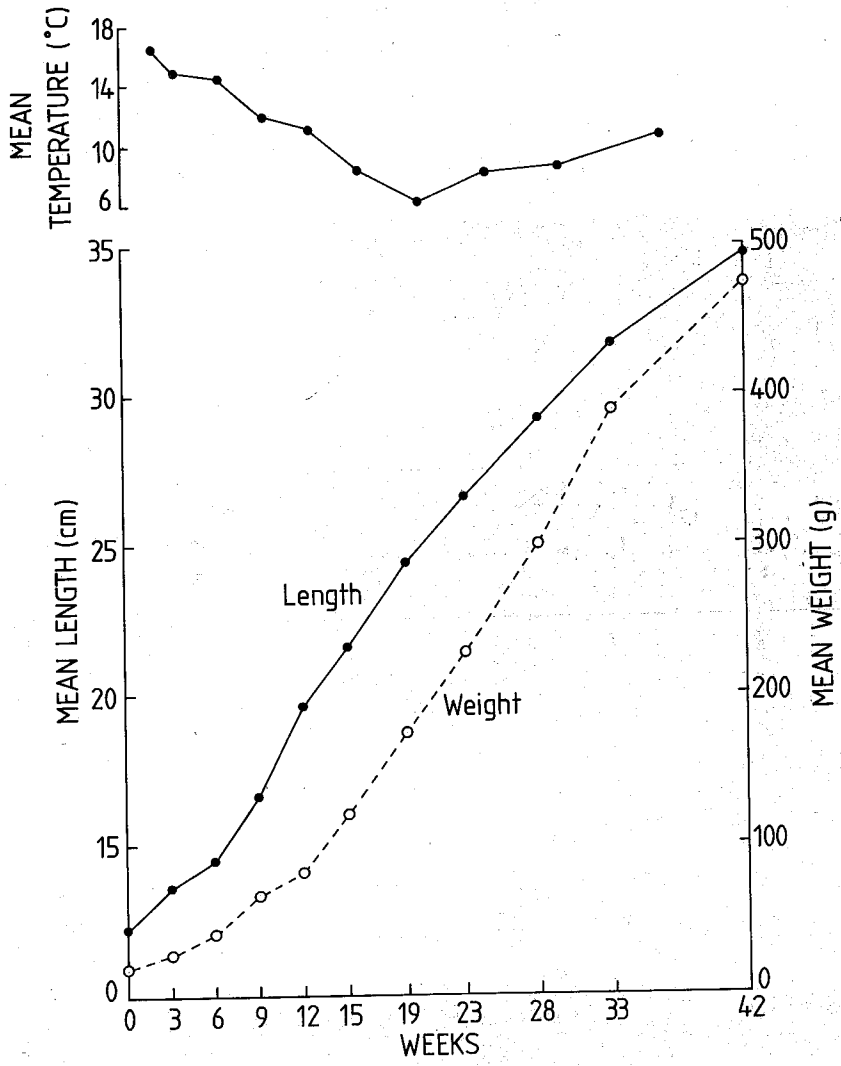

Fig.10. The increase in mean length and weight of cod at ambient temperatures.

a mixture of sprats and gadoids, ranged from 1.9:1 to 2.9:1 (mean 2.3:1).

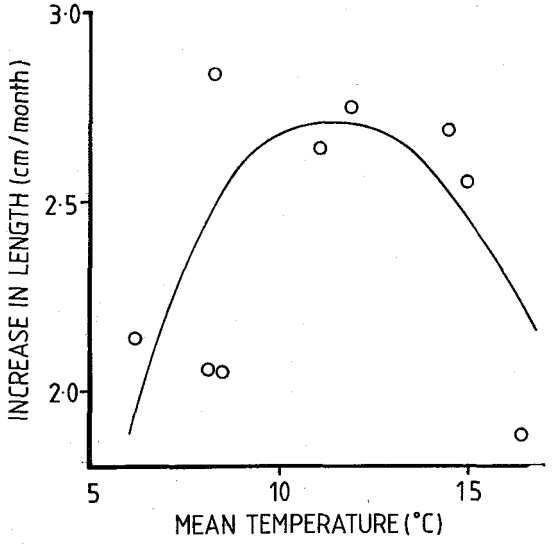

Fig.11. The increase in mean length of cod at various temperatures.

DISCUSSION

These experiments have demonstrated that cod can be reared from the eggs to, and beyond, metamorphosis using techniques similar to those devised for many other marine fish. The development of large-scale culture systems should not present major problems. This has already been accomplished for the turbot (Jones et al., 1981), a species which appears to be no more amenable to laboratory culture than the cod.

Egg supply presents few problems because the species spawns naturally in captivity. The observed decrease in egg size during the spawning season is a phenomenon previously reported for other fish both in the sea and captivity. Small eggs

produce smaller larvae with less yolk than do large eggs. Nevertheless, in the laboratory, where food of an acceptable size can be provided and predators are excluded, egg size is unlikely to be an important determinant of larval survival.

Rotifers, offered with the unicellular alga *Isochrysis galbana*, appear to be a suitable diet for early larvae, though there was some evidence that prolonged feeding on these organisms may be deleterious and should be avoided. The value of *Artemia*, however, as a subsequent live food is less predictable. Differences in the food value of *Artemia* for other marine fish larvae have been shown to occur between batches from different sources and from the same source in different years (Watanabe et al., 1978). There is evidence that the cause of these variations is the level of certain polyunsaturated fatty acids in the *Artemia*. In practice, the problem may be overcome by careful selection of the *Artemia* batch or by feeding the nauplii on a suitable food before use. Ultimately, however, the best solution is to obviate the need for *Artemia* entirely by developing suitable artificial feeds for the early larval stages. This has already been achieved for turbot larvae which, at a length of 6-7 mm, have been transferred direct from a diet of rotifers to a dry compound feed with a survival of 60-70% (Bromley and Howell, 1983b).

Cannibalism during the larval stages is likely to be a problem in intensive culture systems, particularly when conditions of semi-starvation prevail as they do, for example, during transfer from a live to a compound feed. Food availability and the size range of larvae are likely to be important in determining the degree of cannibalism, and their control should consequently minimise losses. Food size may also be of importance in this respect and, in these experiments, the failure to increase the size of food offered may have contributed to the prevalence of cannibalism during the mid- and late-larval stages when the smallest larvae may have been closer to the preferred food size of the large larvae than were the *Artemia* offered.

The failure of larvae to develop or to inflate swimbladders is common among hatchery reared fish (Doroshev et al., 1981).

It is probable that the swimbladder is initially filled by the larva swallowing a bubble of air from the water surface. The oily surface film which usually develops in hatchery tanks, and which is particularly marked in tanks to which cultures of unicellular algae are added, may deny the larvae access to the air. The regular removal of this film may, therefore, be beneficial.

No serious problems existed after metamorphosis and the high growth rate of the fish at ambient temperatures is a factor which recommends the cod as a candidate for farming in temperate waters. A consideration of the factors determining the economic feasibility of cod farming is, however, presented by Jones (1984).

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