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The Propagation of Cod *Gadus morhua* L.

CRITERIA FOR CONDITION EVOLVED FROM ENCLOSURE EXPERIMENTS WITH COD LARVA POPULATIONS

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ABSTRACT

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A number of experiments have been carried out with cod larvae in mesocosms at variable feeding conditions. Larval growth and survival has been monitored beyond metamorphosis, and in some of the experiments large subpopulations of emaciated cod larvae have been identified. A methodology for developing criteria for larval condition of general application to cod larvae is suggested based on measurements of standard length, dry weight and myotome height with age determined from the classification of yolk sac resorption.

INTRODUCTION

Since 1975, enclosure experiments have been carried out with larval fish populations to study their population dynamics in relation to food and predators (for review, see Øiestad, 1982). It was of particular interest to examine the effects of starvation on fish larvae and formulate a method that made it possible to classify the condition of fish larvae sampled in the sea. Important advantages with the enclosure method were that (1) populations of larvae of known age were released and (2) both abiotic and biotic factors could be monitored closely. Larval growth could then be strictly related to feeding conditions, and the morphometric changes of each character, such as standard length, myotome height and dry weight, could be related to larval age. Accordingly, a condition score system could be formulated. However, to apply this method to field-collected larvae, it is essential to be able to determine their ages. In this paper, only results on cod larvae have been included. For this species, age can be deduced accurately to day 20 post-hatching (±2 days) by examining the yolk sac or its remnants.

The condition factor usually has been expressed as a relation between standard length and dry weight (Le Cren, 1951). A somewhat different approach has been chosen here. Specific growth rates of three growth parameters were used to give an expression of the growth achieved (condition score) compared to the potential growth of the larva (the reference group).

MATERIALS AND METHODS

Øiestad (1982) earlier presented a preliminary condition score system for cod larvae. The present publication develops this system further.

In Øiestad (op.cit.) five categories were applied. However, it is desirable to reduce the time taken to examine each larvae and so in this study the swimbladder diameter and the gut development stage were not determined.

Reference group for growth

The condition of each cod larva within a population can be related to that of the fastest growing cod larvae in the population by a number of methods.

As larval age is known in enclosure experiments, the specific growth rate of each character examined can be calculated. To establish a reference group, the 10% with the highest dry weight (W) on each day among larvae examined were selected, and an exponential regression analysis against age was carried out to find the dry weight-growth equation. The standard lengths (SL) of the selected larvae were used to find their standard length-growth equation. A similar procedure was used for their myotome heights (MYO). The maximum growth equations for the three growth parameters were then used to find the maximum value for each character on a particular day, and the observed values for each single larva were compared to these maximum values using the equation:

$$\frac{(\ln W_O - \ln W_{EYS}) + (\ln MYO_O - \ln MYO_{EYS}) + (\ln SL_O - \ln SL_{EYS})}{(\ln W_M - \ln W_{EYS}) + (\ln MYO_M - \ln MYO_{EYS}) + (\ln SL_M - \ln SL_{EYS})} \quad (1)$$

The numerator of equation (1) gives the summation of specific growth rates for each character from the end of the yolk sac stage (EYS) for the observed larva (O). The denominator gives the summation of specific growth rates for each character from the EYS for maximum-sized larvae (M) on the same day.

The temperature conditions were different for the many cod populations released. A standardization to a 10°C regime has been carried out for age-correction by equation (2) assuming the Q_{10}-rule:

$$age_{corr.} = age_{obs} \frac{e^{0.0693 \times t}}{2} \quad (2)$$

where t is the temperature at 4 m depth.

The experiments were carried out at Flødevigen Biological Station (FBS) in 1976 and 1977 in a basin with a volume of 4 400 m^3 (for more details, see Øiestad et al., 1976) and at the Institute of Marine Research, Marine Aquaculture Station Austevoll (MASA), in 1980, 1981 and 1983 in a dammed pond with a volume of 60 000 m^3.

The cod eggs were naturally spawned in a spawning pond and hatched in the laboratory. On day five post-hatching, the larvae were released in the enclosure (Table 1). Frequent sampling of the population of cod gave information on survival, growth and diet. The food supply was studied by pump sampling at different depths. In some years the cod larvae population released was exposed to marginal feeding conditions, and in other years to good or affluent feeding conditions (Table 1).

The examination of cod larvae from the samples included measurements of standard length, myotome hight, dry weight and swim bladder diameter; and staging of the yolk sac and the gut. For more details of the basin experiments, see Ellertsen et al. (1980, 1981) and of the pond experiments, Kvenseth and Øiestad (1984).

All released groups of cod larvae had a control group in the laboratory to define the mortality curve for starved larvae. All groups had a normal mortality curve.

TABLE 1

Overview of populations of cod larvae in enclosure experiments at Flødevigen Biological Station (FBS) and at Marine Aquaculture Station Austevoll (MASA): initial size and density, feeding condition and survival to day 20 posthatching.

Year	Site	Population released	Initial density ($/m^3$)	Temp.+ day 5 (^oC)	Food++ density (/litre)	Survival to day 20 (%)	Ref. code
1976	FBS	200 000	45	4.5	4	50	76
1977	FBS	75 000	17	4.1	1	10	77 1
1977	FBS	100 000	23	7.8	8	10	77 2
1980	MASA	500 000	8	5.8	110	7	80
1981	MASA	600 000	10	4.9	10	10	81
1983	MASA	1 200 000	20	6.6	6	70	83 1
1983	MASA	700 000	12	7.7	10	50	83 2

\+ 4 m depth (basin max. depth 4.5 m, pond max. depth 5.5 m)

++ mean density per litre of potential food organisms from the maximum layer (mean of three depths day 10 post-hatching)

RESULTS

Condition score in the basin experiments

The population of cod larvae released in 1976 was exposed to rather marginal feeding conditions for a long time. About 50% survived to day 20 posthatching (Table 1). The cumulative condition score curves for days 12, 16 and 19 are shown in Fig. 1a. The first population of cod larvae released in 1977 experienced even worse feeding conditions than in 1976, and only 10% survived to day 20. Due to sparse material, the cumulative condition score curves have been given for time intervals (Fig. 1b). The curves move right with increasing

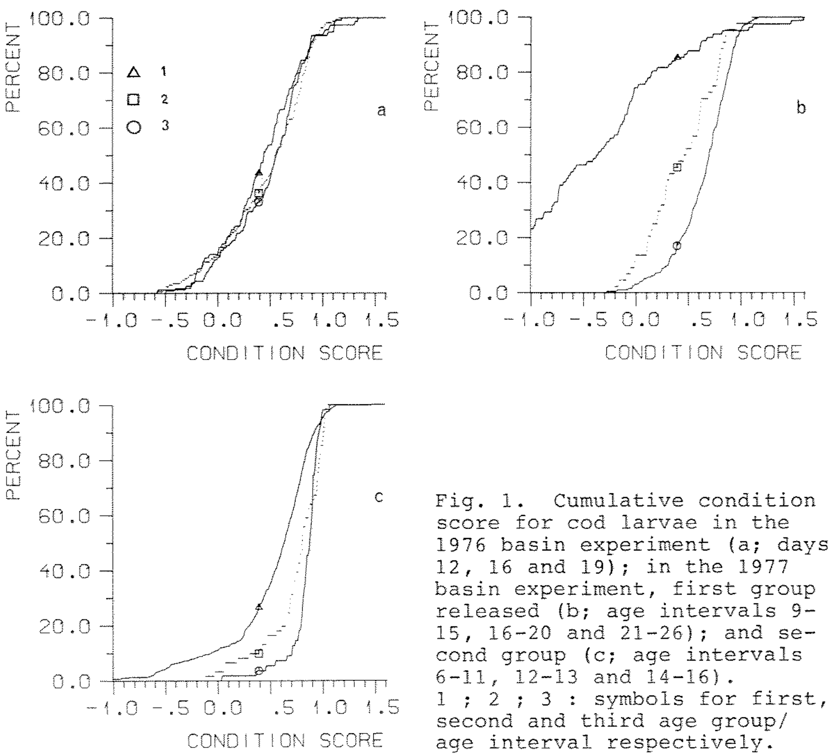

Fig. 1. Cumulative condition score for cod larvae in the 1976 basin experiment (a; days 12, 16 and 19); in the 1977 basin experiment, first group released (b; age intervals 9-15, 16-20 and 21-26); and second group (c; age intervals 6-11, 12-13 and 14-16).
1 ; 2 ; 3 : symbols for first, second and third age group/ age interval respectively.

TABLE 2.

The condition score at the 50th percentile for all groups, using an internal reference group and a general reference group after temperature correction to a 10°C regime. Age groups 1, 2 and 3 have been defined in the text for each released population.

Cod population	Score value at 50% of the population								
	Internal test without temp.corr.			77-2 as ref. group with temp. correction			83-2 as ref. group with temp. correction		
Age group	1	2	3	1	2	3	1	2	3
1976	0.43	0.56	0.56	0.25	0.35	0.30	0.30	0.32	0.33
1977-1	-0.39	0.48	0.68	-0.20	0.25	0.45	-0.25	0.23	0.41
1977-2	0.63	0.80	0.88	0.64	0.80	0.89	1.02	0.88	0.86
1980	0.52	0.69	0.78				0.63	0.73	0.74
1981	9.78	0.68	0.80				0.60	0.57	0.68
1983-1	0.70	0.80	0.87				0.78	0.78	0.78
1983-2	0.33	0.79	0.86				0.33	0.80	0.86

TABLE 3.

The condition score at the 50th percentile on day 12 in the 1976 basin experiment, using ±SD at EYS and ±2 days in eq. (1).

Cod population	Inaccuracy due to											
	Standard deviation at EYS						Age determination					
	Internal test			83-2 as ref.gr.			Internal test			83-2 as ref.gr.		
	-SD	Mean	+SD	-SD	Mean	+SD	-2 days	Mean	+2 days	-2 days	Mean	+2 days
1976	0.58	0.43	0.21	0.5	0.3	0.1	0.3	0.43	0.56	0.18	0.3	0.38

age. The second population of cod larvae released in 1977 met improved feeding conditions (Table 1), and few larvae did not show rapid growth, as illustrated by the cumulative condition score curves (also given for time intervals) in Fig. 1c. The score value at the 50th percentile of the population has been given in Table 2.

In the 1976 basin experiment, mortality reduced the larval stock from 170 000 on day 12 to 110 000 on day 19. Assuming that the larvae with the lowest condition score were those that died, the minimum score for survival to day 20 (50% survival) was 0.35 on day 12 (Fig. 2a). The minimum condition score for survival to day 50 (12% survival) was 0.84 on day 12. Similar calculations for the first cod larvae group in 1977 gave 0.20 on day 12 for survival to day 20 and 0.62 for survival to day 50 (3% survival), as indicated with arrows in Fig. 2b.

The mean contribution to the numerator in equation (1) from dry weight, myotome height and standard length with increasing age is illustrated in Fig. 3a for the 1977-2 cod larvae population. The dry weight contribution is higher

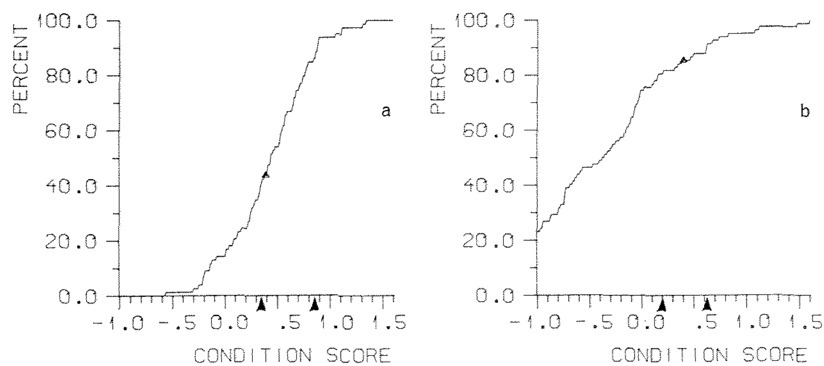

Fig. 2. Minimum condition score for survival to day 20 (left arrow) and to day 50 (right arrow) for cod larvae on day 12 in the 1976 basin experiment (a); and for cod larvae in the age interval 9-15 days from the first group released in the 1977 basin experiment (b).

than the other two together and the standard length contribution is of minor importance. In the denominator the picture is about the same, with a 4:2:1 relation from day ten onwards (Fig. 3b).

So far the mean values at EYS have been applied in the calculations. The effect of the standard deviation at EYS on the condition score for each character is illustrated in Fig.4a for the 1976 population on day 12 with lower dotted curve showing + SD and the upper - SD.

As indicated earlier, the age of larvae from sea samples cannot be given exactly. The effect of a ±2 days inaccuracy is shown in Fig. 4b for day 12 on larvae from the 1976 cod population. The lower dotted curve represents a + 2 days inaccuracy, the upper dotted curve a - 2 days inaccuracy. The score value at the 50th percentile is given in Table 3 for both ± SD and age inaccuracy.

All condition scores have been calculated in relation to the fastest growing larvae in that population. However, it is desirable to establish a general reference group. This

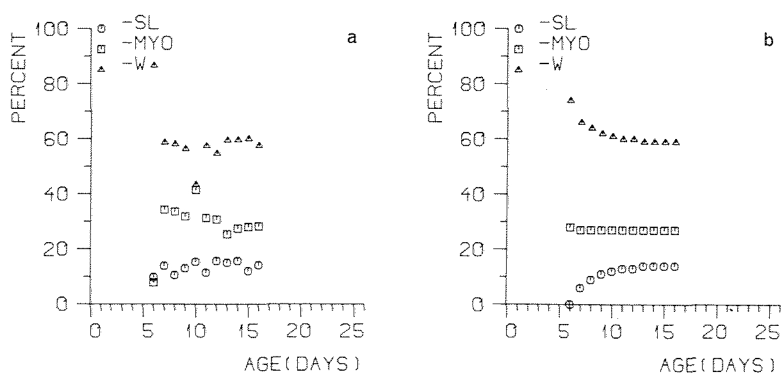

Fig. 3. The percentage contribution of specific growth rate values to the condition score from dry weight, myotome and standard length in the numerator (a) and in the denominator (b) in equation (1), illustrated with larvae from the second group in the 1977 basin experiment.

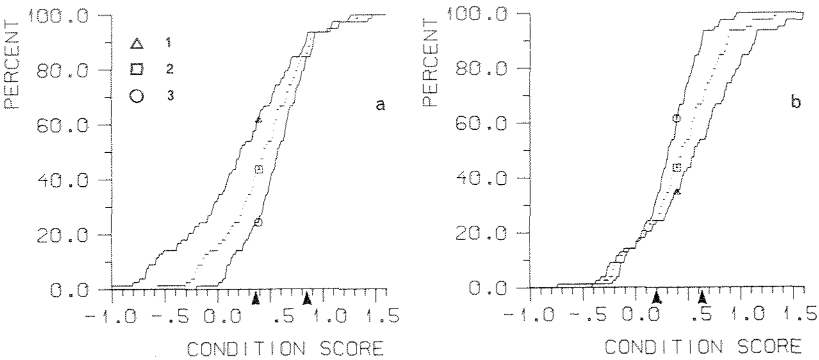

Fig. 4. The effect on the cumulative condition score curves of application of +SD (3) and -SD (1) at EYS for the three growth parameters against mean value at EYS (2) (a); and the effect of +2 days (1) and -2 days (3) deviation from the actual age against actual age (2) (b) illustrated on 12-day old larvae from the 1976 basin experiment. Arrows indicate the minimum score values for survival to day 20 and day 50 on both (a) and (b), day 20 left arrow.

group will have its specific EYS-values different from those of populations being tested.

The general reference group should be the fastest growing group after age-correction for the effect of different temperatures (equation (2)). The curves for the dry weight-growth equations for the three groups in Fig. 5

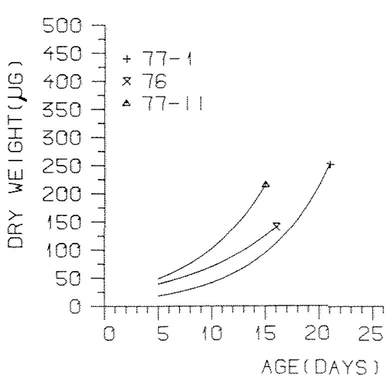

Fig. 5. The dry weight-age regression curves for the fastest growing larvae within the three cod populations from the basin experiments.

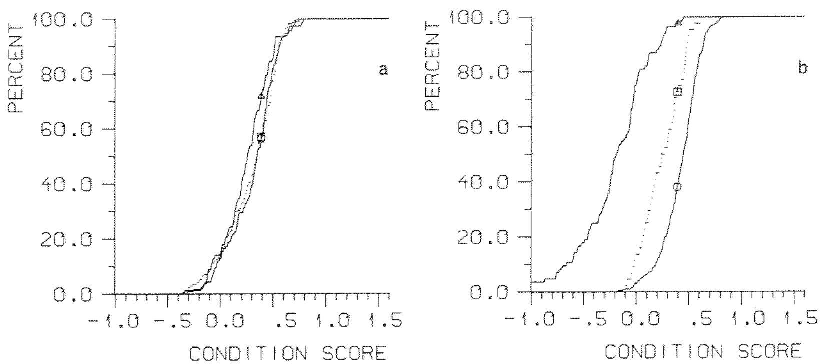

Fig. 6. Recalculation of cumulative condition score curves using the second cod-larvae group from the 1977 basin experiment as a reference group for the 1976 basin experiment (a) and for the first group in the 1977 basin experiment (b) after correction for temperature. For symbols, see Fig. 1.

indicate that the second group released in 1977 could be a reference group. The condition score for the two groups have been recalculated as shown in Figs. 6a and b.

The condition score in pond experiments

The feeding conditions for cod larvae in the pond during first feeding were rather good in all years examined, resulting in high feeding incidence and a homogeneous and rather high growth rate of the populations. The cumulative condition score curves for the groups from 1980, 1981 and the two groups from 1983 are shown in Figs. 7a-d. The condition scores were rather high in all years, particularly in 1983.

The second group from 1983 had an even steeper slope than the second group from the 1977 basin experiment (Fig. 8), and might replace that group as a general reference group. Besides, the second 1983 group has the advantage that it was monitored beyond metamorphosis for both growth and survival. The second group from 1977 was monitored closely only to day 16.

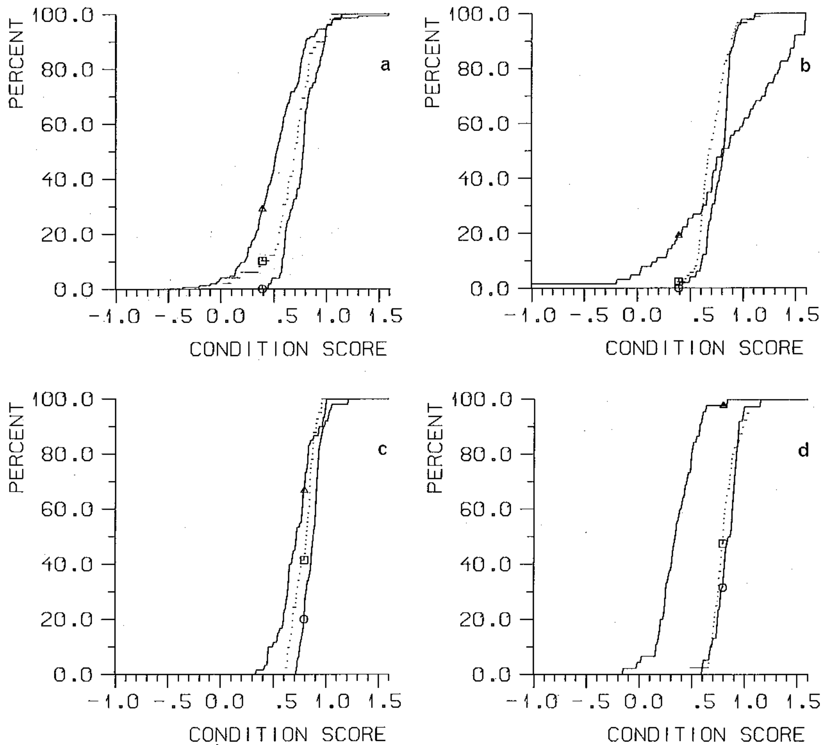

Fig. 7. Cumulative condition score for cod larvae in the 1980 pond experiment (a; days 12, 15 and 18); in the 1981 pond experiment (b; days 10, 16 and 19); for the first group released in the 1983 pond experiment (c; days 11, 14 and 18) and for the second group (d; days 12, 15 and 19). For symbols, see Fig. 1.

A recalculation of the cumulative condition score curves after age-correction is shown in Figs. 9a-f. In these figures the same age intervals have been used to facilitate comparison. The minimum score values for survival to metamorphosis (day 50) are indicated with arrows for the two populations with large cohorts of emaciated larvae, the group from 1976 and the first group in 1977 (Fig. 9a).

To demonstrate the effect of the recalculation, the score value at the 50th percentile has been given in Table 2.

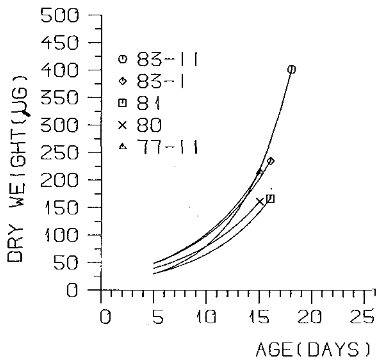

Fig. 8. The dry weight-age regression curves for the fastest growing larvae within the four cod populations from the pond experiments (1980, 1981 and 1983) and within the second group in the 1977 basin experiment, all corrected for temperature (normalized to a 10°C regime)

Generally, the application of the 1983 reference group gave a left-ward movement of the score curves.

The effect of ± SD at EYS and the ± 2 days inaccuracy was also tested using the general reference group after age-correction. The values at the 50th percentile are indicated in Table 3.

DISCUSSION

In most enclosure experiments, periods with high mortality occurred premetamorphosis (except for the two cod populations released in the pond in 1983). However, emaciated cod larvae were only detected as large cohorts in the population in the 1976 basin experiment and in the first population released in the 1977 basin experiment. In both cases, the emaciated larvae died due to starvation. That explains why their cumulative condition score curves (Figs. 9a-c) had different forms from those of populations without cohorts of emaciated larvae (Figs. 9d-f).

It is an important observation that emaciated larvae were caught together with growing and healthy larvae and that their occurrence could be linked to the feeding conditions (Ellertsen et al. 1981). On the other hand, given affluent feeding conditions, starving larvae were nearly absent. The

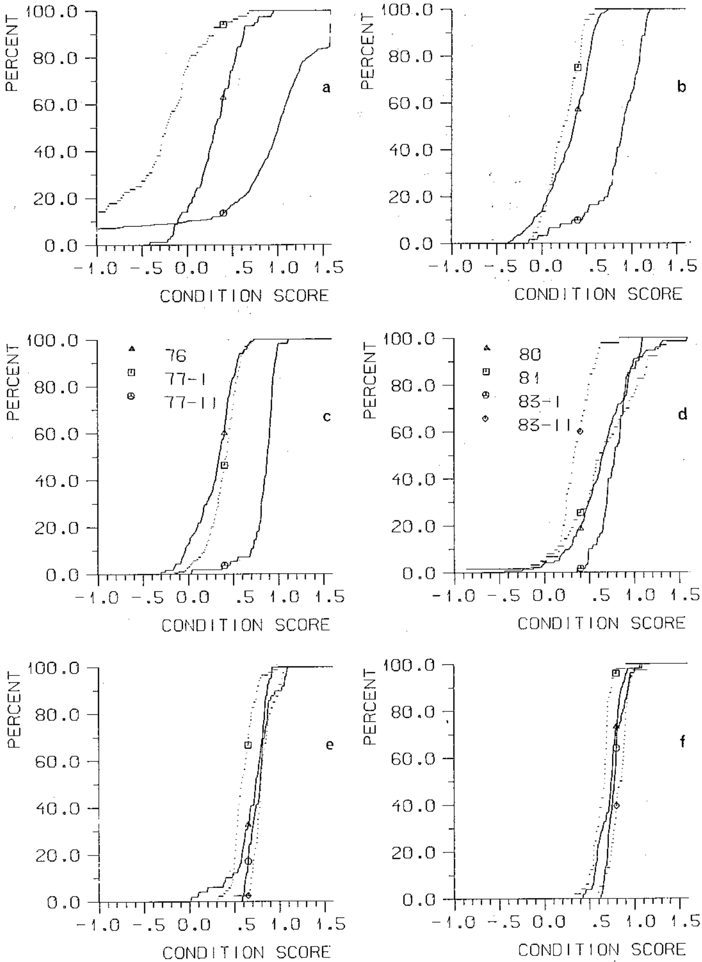

Fig. 9. Recalculated cumulative condition score curves using the second cod larvae group from the 1983 pond experiment as a reference group for all cod larvae groups: first age group from the basin experiments (a; symbols, see (c)); second age group from the basin experiment (b); and third age group (c); first group from the pond experiments (d; symbols indicated); second age group (e) and third age group from the pond experiments (f), after normalizing temperature.

reason for the observed high mortality among these larvae is probably predation from cod fry (in 1977; see Ellertsen et al., 1981) or predation from hydromedusae in the pond in 1980 and 1981; (Øiestad and Kvenseth, 1981).

Condition scores ranged mainly from 0 to 1 (Figs. 9a-f), but the frequency of values is closely related to the general feeding conditions in the enclosure. Mainly, low scores were obtained at marginal feeding conditions, while good feeding conditions gave high scores. However, the inaccuracy of methods might disturb the picture. The standard deviation of the growth parameters at EYS had only a minor effect on cumulative condition score curves. Larvae in some stage of starvation could easily be detected both when the same population was used as a reference and with a general reference group (83-2). The effect of a ±2 days inaccuracy in age determination was more pronounced. Emaciated larvae could be detected although some potential surviving larvae would be considered as starving and opposite.

When the mortality pattern in a population is known, and the reason is probably starvation, a minimum score for survival to different ages could be defined. However, in most pond experiments high mortality was combined with a lack of starving larvae and a minimum score value for survival could not be established. Generally, older larvae (beyond point of no return, suggested to be at about day 11; Ellertsen et al., 1980) with low score values should be considered to be starving. With no application of the method as yet to sea-caught cod larvae, however, no minimum score value for survival can be suggested. Another relevant question is selective predation; i.e. are mainly starving larvae predated. This implies the occurrence of predator scanning the whole actual water volume frequently. No such predator probably exsists in the area under consideration. One potential group of predators is medusae of different types, most of them searching randomly for food and accidentally encountering fish larvae. Cod larvae seem to have little avoidance behaviour toward these animals (A. Folkvord, Inst. Mar. Res., Bergen, personal communication, 1983).

An other main predator group could be euphausiids, which scan water volumes in swarms and probably leave behind a desert where no escape trials would help much. In conclusion, starving larvae should be detectable in a fairly representative number in the net haul samples if starvation caused high mortality.

The dry weight is the dominant contributor to the condition score and could be used alone to determine the condition score value. Larval examination could be reduced to ageing and weighing of the larvae. The similar condition scores calculated by the two suggested methods are shown in Table 3. *However, most investigators would hesitate to reduce their* examination to only these two characters.

TABLE 4

Comparison of condition score values using eq. (1) and eq. (3)+ on 20 larvae from the 1983 pond experiment, day 12.

Score values using eq. (1)	0.83	0.63	0.43	0.37	0.41	0.23	0.25	0.32	0.35	-0.16
Score values using eq. (3)	0.95	0.59	0.48	0.41	0.37	0.29	0.23	0.18	0.11	-0.17
Deviation	0.12	0.04	0.05	0.04	0.04	0.06	0.02	0.14	0.24	0.01
and in %	14	6	12	11	10	26	8	44	69	6

+ equation (3): $\frac{\ln W_O - \ln W_{EYS}}{\ln W_M - \ln W_{EYS}}$

The use of a general reference group established from enclosure experiments might not be considered a necessity, but it is probably impossible to establish a reference group from larvae caught in the sea, as their ages will be unknown. If a reference group from enclosure experiments is used, it might be more desirable to take one with a growth rate more equal to that observed in the sea. As indicated, cod larvae have a large degree of growth flexibility, permitting rather high survival rates even at marginal feeding conditions.

The reference group and the tested group should be compared at equal temperature conditions, as cod larvae probably have an optimum temperature for growth (Laurence, 1978). The suggested method for normalization to a $10^{\circ}C$ regime might be improved or changed by further research on the growth promoting effect of temperature.

The most important source of inaccuracy in the method is age determination of sea caught-larvae. Systematic studies of the yolk sac resorption pattern, as an effect of both temperature and age, should be initiated. Other methods for age determination, such as otolith readings, have so far given no conclusive results.

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