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The Propagation of Cod *Gadus morhua* L.

SUMMARY OF PROCEEDINGS OF A SYMPOSIUM ON THE PROPAGATION OF COD.

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We may conclude that the cod has, by marine fish standards, a conventional egg and larval development but it has rightly been pointed out that there is need for greater care in the handling of broodstock and for the use of optimum conditions for fertilization and incubation. It is, at present, quite uncertain the extent to which poor larval survival is related to the quality of eggs (using quality in a most general way) or the use of sub-optimal conditions in the hatchery. Apparent short-term success in rearing may be followed by failure in the longer term. The use of mortality as a criterion for failure or success may not be sensitive enough and sub-lethal effects may have to be evaluated over longer periods.

It is of great importance to study egg quality for three reasons: first to prevent waste-of-time rearing poor quality eggs, secondly to optimize broodstock and, thirdly, to evaluate the state of eggs in the sea. It has to be said, however, that we are not at present certain whether poor egg quality is mainly a phenomenon of the rearing tank.

There is a degree of subjectiveness in the assessment of egg quality. A weak chorion leads to infection and perhaps damage by waves but it may make it easier for the larva to hatch. Quantifiable standards should be set above which egg quality is acceptable and below which it is unacceptable. In other words threshold values of chorion strength, osmolarity, buoyancy or other factors should be established in order to decide whether to accept or reject a batch of eggs. Egg quality may also have other meanings, for example in terms of normal chromosomes or in the presence and absence of trace substances. Such criteria are more difficult to study, requiring subtle biochemical analyses and it must always be kept in mind that very specialized and time-consuming techniques should only be used if simpler tests prove inadequate.

There has been a great improvement in the ability to rear cod larvae, partly from the improved "feeling" for what makes up a suitable diet and partly from the use of larger and larger containers and enclosures for rearing, up to volumes as large as 60,000 m^3. It is not quite clear why large volumes are so effective and one must assume that at least one factor is the reduced wall effect. It is also significant that many successful experiments have been done in the open air where the sensory input, especially in terms of changing patterns of light intensity, is greater and the light regime normal. This may improve the contrast perception for detecting food, allow normal intra-specific interaction (densities are 100-1000 times lower than in small tanks) and most important, prevent excessive aggregation of the larvae and their food (not forgetting that some degree of ill-defined "patchiness" may be a good thing, at least of the food, if not of the larvae). It seems that the ideal light conditions are those where there is sufficient light to feed but not enough light to increase the activity level to a point where energy is wasted. Perhaps the large enclosures also allow a degree of vertical migration and selection of a light preferendum.

There are still some mysteries associated with feeding. Pütter's Theory (that fish larvae can utilize dissolved organic matter) has once more emerged from past history. We cannot be sure whether cod larvae take in dissolved organic matter or bacteria by osmoregulatory drinking and whether they can utilize these sources of food.

It may be worth listing some of the conclusions of the rearing and on-growing trials:

1. The light threshold for early larval feeding is 0.1 lux.

2. Feeding should start before day 5 since the larva is then consuming its own body tissues.

3. One study suggested that larvae need about 5 nauplii/l for good growth and survival, a density somewhat lower than that quoted from earliest experiments in small tanks. Other studies suggested even lower concentrations.

4. If *Artemia* is used the source may be important and secondary feeding of *Artemia* with algae such as *Isochrysis* may be desirable.

5. Very good survival rates, as high as 50% at day 35, are now possible, especially in large enclosures.

6. Mortality may be caused at an artificially high level by such pathogens as *Vibrio* and *Trichodina*. Immunization may be possible but it may be better to "live with" disease problems. Such mortalities are compensated for by reduced predation, although some predators may be introduced into rearing tanks as young stages in sieved natural plankton given as food. In successful experiments mortality rates are far below the level of around 10%/day found at sea for larvae and 22%/day for eggs. In general it can be said that none of the mortality measurements supported the idea of massive losses of larvae at first feeding as postulated by Hjort.

7. As far as growth is concerned many experiments report size-hierarchy effects. It is not certain whether this is a tank phenomenon but it may lead to cannibalism by larger cod on smaller cod larvae. It suggests that sorting for size should be an important part of cod husbandry.

8. As far as on-growing of 0-group cod is concerned optimum temperatures are around 10°C. Very remarkable growth rates have been reported in English and Norwegian experiments (500 g in 42 weeks and 2 kg in 21 months respectively). These values are 2-6 times the growth rate of wild cod.

There are serious problems with on-grown cod. There is a 5-6 month check in growth as they come into spawning condition, suggesting that some form of gonadectomy or other type of inhibition of maturation is desirable. Some of the growth occurs as excessive liver weight which is wasteful and may make marketing difficult. Nevertheless, the conversion rate is good, 2 kg of capelin as food giving about 1 kg of cod. If the economics are right the farming of cod seems a feasible proposition in the near future. At present, however, a production cost of cage-cultured cod of 25 Kr/kg wholesale is predicted, well above an economic level.

Turning now to the wild stocks of cod - extensive work has been reported on spawning, eggs and larvae, juvenile distribution and stock separation of larvae, juveniles and adults, but only a few papers dealt with the management of wild stocks. It seems, for example, that the NE Arctic and North Sea cod stocks could be increased by as much as 250,000 tonnes by increase of mesh size. Considering first, however, the sea surveys on the spawning grounds, it seems that reproductive strategy is far from clear in the cod. While at Iceland, Lofoten and Georges Bank a distinct early spring spawning season is found, this is not true of the Nova Scotian Shelf where spawning can be found in many months and especially in the winter at very low temperatures. Peak spawning may be less important than the range of spawning time which is of the order of two months in the first three groups. Following Cushing's match-mismatch hypothesis a longish spawning season may give the best chance of some larvae co-existing with an optimum food supply, but it must be accepted that this is a less tenable hypothesis on the Nova Scotian Shelf even allowing for a long incubation period at the low winter temperatures.

Egg and larval surveys have become increasingly efficient with respect to vertical distribution studies. The introduction of submersible plankton pumps and elaborate closing nets such as the Mocness net have allowed much more comprehensive data to be acquired. Evidence for diel vertical migration of larvae is good with all the implications for larval feeding strategies.

A major problem exists in quantifying the nutritional state of cod larvae in the sea, in order to decide whether starvation is occurring or how viable the larvae are. A first assessment of this may be made by comparing the quantity of food available in the sea during the larval season with the rule-of-thumb density of 50 nauplii/l quoted from rearing experiments. The sea surveys of microzooplankton show maximum values of 50 prey/l on

Georges Bank in calm conditions and 20 nauplii/l at Lofoten. Densities of 5-10 prey/l are much more common. Gut-content studies of wild larvae show 100% feeding incidence at 5-20 prey/l and the Beyer-Laurence model shows that 20 prey/l should give 50% survival for cod larvae. Hence the rearing experiments may tend to over-estimate the food density requirements for cod larvae in the sea.

There may, however, often be conditions where prey density is much lower and here the "patchiness" concept is cited to explain larval survival and growth. Little has been said about the required scale of the patches, for instance whether they are optimal when of cm, m or km dimensions? Perhaps the modellers should address themselves to this problem.

Nutritional state might also be assessed by morphological and weight measurements such as the condition factor. There are, however, serious problems in that most plankton samplers cause severe damage, especially shrinkage, to larvae, as does subsequent fixation. Any data based on W/L^3 is thus suspect, especially if related to data from controlled tank starvation experiments. Attempts have been made to avoid this problem by the use of histological criteria or by more sophisticated formulae involving dry weight and myotome height, standard length playing a minor part. Such formulae require also the age of the larvae. While this is obtained over the first 2-3 weeks (by detailed analysis of the pattern of yolk resorption) age estimates on older stages require the use of otolith ring number.

From the papers in the symposium it seems that a daily rate of otolith ring deposition is not necessarily found except in the very young larvae and in much later stages. At the most essential stages of mid-larval life there does not seem to be daily ring deposition and growth rate may be the main determining factor. Further validation seems to be required, especially in carefully designed larval surveys at sea. Such validation experiments, or others in the laboratory, should take into account the following factors:

1. Are the best counting methods being employed - should scanning electron microscopy be used and if so could it ever become a routine technique?

2. Any photoperiodicity experiments on ring formation should involve light flux measurements; sea experiments should allow for possible effects of high light flux on a 24 hour basis in the polar summer.

Some other interesting results and questions which have emerged in the sea egg and larval surveys are listed below:

1. Does the increasing depth of cod eggs during maturation demonstrate a mortality fall-out?

2. Is there evidence for poor egg quality in the sea being a widespread phenomenon?

3. Can larvae utilize phytoplankton such as *Thalassiosira* for food?

4. What are the implications for the apparent competition between cod and capelin larvae off S.W. Iceland?

5. What are the main predators of cod eggs and larvae and how can these be assessed in view of the rapid digestion of larval prey by most predators?

6. Do spawning cod eat their own eggs?

7. What is the larval escapement from the new samplers such as the plankton pumps and the Mocness net?

8. Is it possible to demonstrate microscale patchiness with any of the present plankton samplers?

The substantial body of work on juvenile cod, as described in the symposium papers, covered most of the Norwegian coast and parts of the southern North Sea. A range of sampling techniques has been used - beach seine, Danish seine, trawl and trap net and a range of techniques such as tagging, otolith analysis and electrophoresis used to demonstrate movements and stock separation. In the southern North Sea there seems to be regular offshore-inshore movements on a seasonal basis with salinity playing a role in distribution. The inshore cod stocks of S.E. Norway yield good assessments of yearclass strength. In general this work provides a sound basis for deciding potential sites for the release of reared 0-group cod.

Release of tagged reared 0-group cod near Flødevigen showed that they grew at about the same rate as wild cod and remained near the point of release, but it is not clear what the cod biomass is in the fjords and the extent to which the fjords could carry larger stocks. In other words is there excess food available to allow adequate growth with large scale release? Should the fjords have excess carrying capacity the social effects of increasing the stocks by seeding would be substantial, but the increase in employment would still not be great in country-wide terms. It is clearly of importance, however, to ensure that when planting out, the natural population is being properly managed. Although the yield from planting out will be greater during overfishing, it may be, in fact, more efficient to manage the fishing for wild stock to give the maximum sustainable yield. If fry are to be planted out to augment poor yearclasses, very large numbers might be required and early forecasts of poor yearclasses would be needed.

Several papers dealt with electrophoretic studies on polymorphic enzymes such as lactic dehydrogenase and their value for identifying the stock heterogeneity of adults or the younger stages of cod. These analyses can be carried out on single eggs and larvae. The evidence suggests that electrophoresis could become a powerful and routine tool for estimating the extent of stock mixing and so be valuable in measuring fishing effort. Genetical monitoring of this type has also a good potential in future propagation work on cod, first, as a way of characterizing the broodstock and controlling inbreeding and selection experiments, and secondly as a genetic marker for planted-out fry.

Genetical work does, however, sound a role of warning for the future. Planting out of fry in an uncontrolled way may lead to an undesirable dilution of localized gene pools. On the other hand it might have desirable effects of heterosis. In future work, genetic aspects will have to be watched as the work on cod propagation becomes increasingly successful and sophisticated.