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The Propagation of Cod *Gadus morhua* L.

LARGE-SCALE REARING OF COD FRY ON THE NATURAL FOOD PRODUCTION IN AN ENCLOSED POND

P.G. Kvenseth[1] and V. Øiestad[2]

1 Marine Aquaculture Station Austevoll, N-5392 STOREBØ, Norway
2 Institute of Marine Research, P.O.Box 1870, N-5011 NORDNES Norway

ABSTRACT

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For four years (1980-1983) populations of 5 day old cod larvae have been transferred to a dammed seawater pond (60 000 m^3). The water volume had been treated with rotenone in advance, and the larvae were released during the March - April zooplankton bloom. The hydrography, standing crops of zooplankton, fish larvae, and phytoplankton were monitored frequently. The cod larvae had a very high feeding incidence and the whole population started to grow quickly in all years, with few or no starving larvae being observed.

In 1980 and 1981, however, large populations of hydromedusae were present. These probably preyed upon the cod larvae until metamorphosis (35-40 days post-hatching). Survival to that stage was about 2%.

In 1982 a mass mortality of larvae was observed immediately after transfer to the pond. This mortality was probably due to decomposing fish and zooplankton killed by the rotenone treatment, which was carried out at 1 ppm that year compared to 0.5 ppm in other years. In 1981 and 1982 the numbers of cod at metamorphosis (12 mm length) were estimated at 15 000, about the same as estimated numbers of 0-group cod in June - July.

In 1983, two populations of cod larvae (1.2 million and 0.7 million) were transferred to the pond 10 days apart. Thirtyfive days post-hatching, about half a million larvae metamorphosed from the first group (50% survival) and another 200 000 from the second group (30% survival). This improved

survival compared with earlier years was probably due to a smaller population of predatory hydromedusae. Although cod larvae populations were considerably larger, their growth rate was comparable to that in earlier years, due to the larger food supply in the pond.

MATERIALS AND METHODS

Localization and location

The experiments were carried out in an enclosed pond (HYLTROPOLLEN) on the island of Huftarøy in western Norway, south of Bergen (at 60°4'N, 5°15'E). The pond (Fig. 1) has a surface area of 22 000 m^2, a maximum depth of 5.8 m, and a volume of 60 000 m^3.

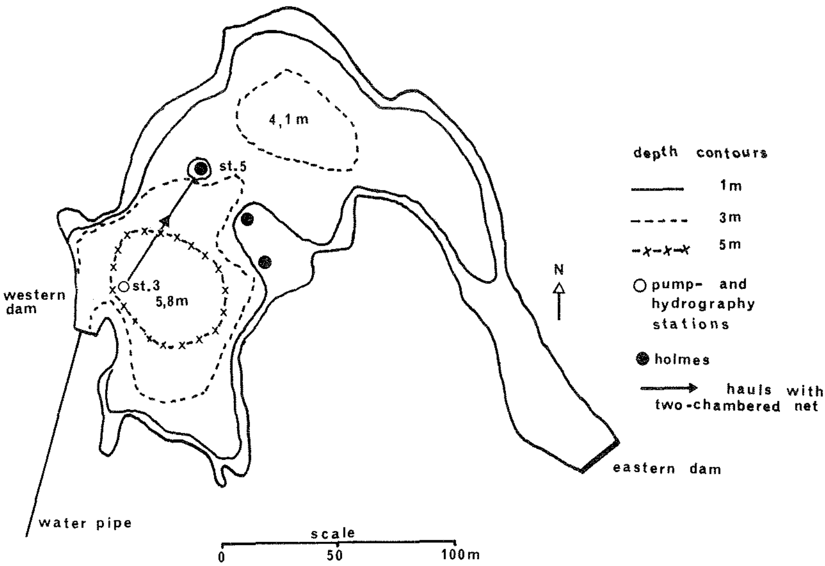


Fig. 1. A plan of the pond showing depth contours, positions of the pump and hydrography station, and directions of hauls with the twochambered net.

The pond was dammed with two dams during the winter of 1979/ 1980. Each year the water was left stagnant for 30 days after the cod larvae were released. Water was then exchanged with seawater from a depth of 40 m, through a pipe. The change in tidal height was used as a driving force for the water in 1980-1982. A submersible electrical pump was installed in early 1983 to increase the water exchange. Excess water was filtered out through a metal grating in the western dam.

Monitoring and examination procedure

Hydrographic features, including salinity, temperature, and oxygen saturation, were monitored weekly at depths of 0, 1, 2, 3, 4, and 5 m (Fig. 1).

Zooplankton was sampled weekly with a pump (capacity of 80 l/min.) at 0, 1, 2, 3, 4, 5 m depths, and at the bottom. Seawater in these samples was filtered through a 40 µm mesh net.

Large zooplankton organisms and fish larvae were sampled almost daily with a two-chambered net (350 µm mesh size). Night hauls (2300 to 0100 hr) were made weekly in 1982 and

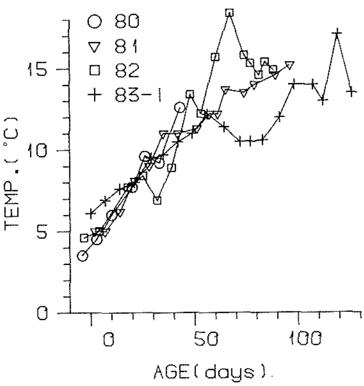


Fig. 2. Temperature in the pond at 4 m depth in 1980-1983 related to cod larval age.

1983, and fortnightly in 1980 and 1981. The net was hauled horizontally from station 3 to station 5 (67 m) with a speed of 1 m/s at 0, 1, 2, 3, 4, and 5 m depths (Fig. 1). All fish larvae and zooplankton were preserved in 4% neutral formalin.

Cod fry older than 50 days were collected with a dipnet, trawl, dragnet, and fyke net.

When calculating the standing crop of zooplankton species and fish larvae, the depths were allocated the following water volumes: 0 m, 9000 m^3; 1 m, 17 000 m^3; 2 m, 13 250 m^3; 3 m, 9 000 m^3; 4 m, 5 600 m^3; 5 m, 4 150 m^3.

Rotenone treatment

The pond had a large natural stock of small littoral fishes, mostly sticklebacks (*Gasterosteus aculeatus* L.) and gobies (*Gobius niger* L. and *Gobiusculus flavenscens* Fab.), but also sand-eels (*Ammodytes tobianus* L.) and eels (*Anguilla anguilla* L.). To get rid of these potential predators and food competitors, rotenone emulsion, at a concentration of 0.5 ppm was used each spring, at the beginning of March. In 1982, a 0.1 ppm was used to kill the more resistant eel population.

Sand-eel eggs, spawned during autumn and winter, hatched after the rotenone treatment. As fish eggs are highly tolerant of rotenone, stocks of sand-eels grew up every summer, especially in 1982. To prevent this, the pond was treated with rotenone during October 1982. No sand-eel larvae were caught by the intensive sampling in spring 1983, in contrast to all previous years.

Experimental fish

The brood stock came from the coastal cod population nearby the Aquaculture Station. The cod eggs were naturally spawned by the parent stock (80 ♀ and 20 ♂) in a 175 m^3 spawning bag made of PVC (Huse and Jensen, 1980). After incubation in the laboratory at the Aquaculture Station, Austevoll (Jensen et al., 1979), 5- day old cod larvae were transferred to the pond and released.

Control groups (starvation and transportation) were established in the laboratory to obtain information on larval viability and tolerance to transportation. Larvae in the transport groups were transported to and from the pond.

RESULTS

Hydrography

Salinity in all years was about $32^{o}/oo$, except in the brackish surface water. Oxygen saturation was above 90% except very near the bottom where it was occasionally 50 - 90% saturation. The temperature at 4 m depth increased from about 5 - $7^{o}C$ at stocking to 10 - $12^{o}C$ at metamorphosis (Fig. 2).

Phytoplankton

Every year the spring bloom was dominated by *Skeletonema costatum* . For the rest of the spring, the phytoplankton biomass was dominated by unidentified flagellates.

Zooplankton and feeding conditions

Hydromedusae were especially numerous in 1981 with *Rathkea octopunctata* and *Sarsia* spp. dominant. The density of hydro-medusae in 1983 was below $50/m^3$ during larval first feeding, compared with 100 - $600/m^3$ in other years (Fig. 3).

Rotifers were numerous (about 10-100/l) in early April, declining to 5/l in late April (Fig. 4). Calanoid copepod nauplii remained at a steady population level (about 3/l) during April, but increased in late April and May (Fig. 4). Dominant species were *Calanus finmarchicus, Centropages hamatus* and *Pseudocalanus elongatus.*

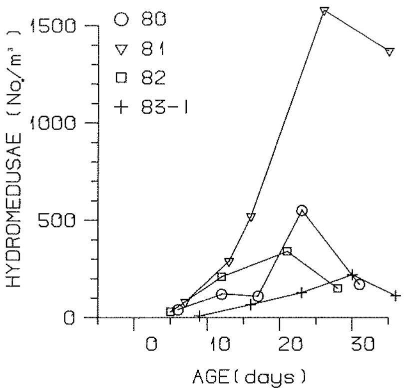


Fig. 3. Mean number of hydromedusae per m^3 during the cod larvae stage to metamorphosis in the 1980-1983 pond experiments.

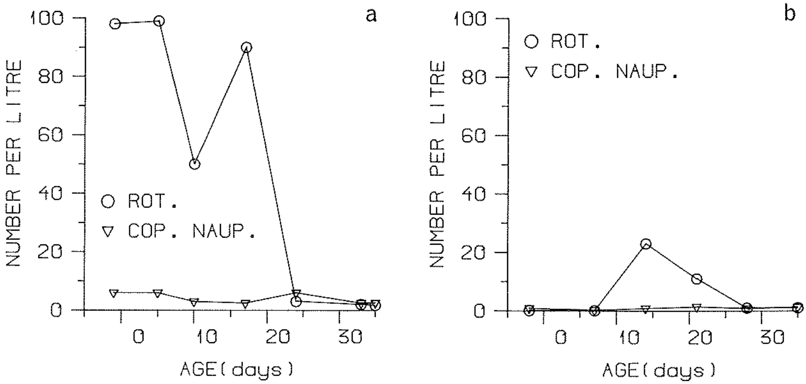


Fig. 4. Mean number of rotifers and copepod nauplii per litre in the 1980 (a) and 1981 pond experiments (b) related to cod larval age. Samples from 3, 4, 5m and the bottom have been averaged.

Cod larvae

Biological and transfer data for released groups of cod larvae are shown in Table 1. Feeding incidence rapidly increased to 100% after release (Fig. 5).

TABLE 1

Biological and transfer data of released cod populations in the 1980-1983 pond experiments.

	Biological data		Incubation		Day of transfer			
Year	Egg diam. (mm)	Larval length day 5 (mm)	Days	temp. (°C)	Date	Number+	Age (days)	Density (no/m³)
1980	1.33	4.2	14	6.5	12.4	610 000	5	11
1981	1.28	4.2	15	6.1	30.3	500 000	5	9
1982 1)	1.31	4.0	15	5.9	7.4	1 300 000 x	5	22
1982 2)	-	-	-	-	17.4	700 000 xx	5	12
1983 1)	1.37	4.6	13	7.0	20.3	1 200 000	5	21
1983 2)	1.35	4.2	14	6.5	30.3	700 000	5	12

1) first group

2) second group

+ estimated population before release

x immediate mortality reduced the population to 40 000

xx immediate mortality reduced the population to 40 000

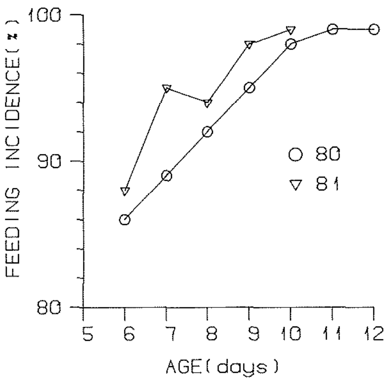
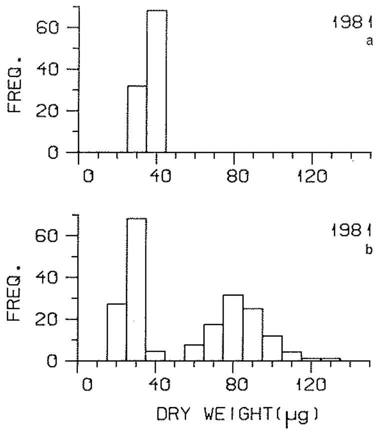


Fig. 5. Feeding incidence of cod larvae related to age in the 1980 and 1981 pond experiments.

During the first day of feeding, almost all guts were filled with a mushy green mass that could not be identified under the binocular microscope. Some guts contained eggs of invertebrates and copepod nauplii. Copepod nauplii were found



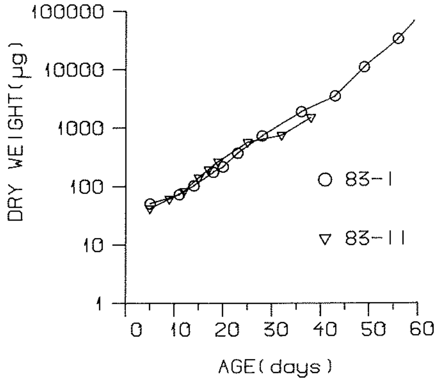


Fig. 6. Dry weight-frequency distribution of cod larvae at the day of release (a) and on day 16 post hatching (b; left histogram, starving larvae, right from the pond experiment).

Fig. 7. Dry weight-age relation for cod larvae in the 1983 pond experiment; weight in microgram.

regularly as the larvae passed the age of 9 days. Gradually the diet changed to older stages of calanoid copepods and, after metamorphosis, amphipods, harpacticoid copepods and polychaetes were included.

The cod larvae increased rapidly in dry weight from about 40 µg when 4 days old to more than 80 µg 12 days later (Fig. 6). The weight of starved larvae dropped from 37 µg when 4 days old to 28 µg 12 days later (Fig. 6). Comparison of the dry weight distribution of the pond groups and the starvation groups shows no overlap 16 days post hatching (Fig. 7).

The cod larvae passed metamorphosis 35 - 40 days post hatching, at about 12 mm standard length and 1800 µg dry weight. Weight further increased to 40 mg after 60 days post hatching (Fig. 7). The 1983 growth data shown are typical for weight increases of the pond groups.

Between 80 and 100% of the starvation and transportation groups survived for 15 days. Then they died rapidly, none surviving beyond 22 days post hatching (Fig. 8).

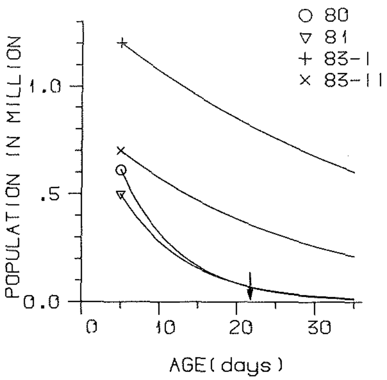


Fig. 8. Population size cod larvae from release to beyond metamorphosis in the 1980-1983 basin experiments (1982 excluded). Final mortality of starvation groups in the laboratory indicated with an arrow.

Cod larvae populations decreased rapidly in 1980 and 1981 (Fig. 8). Survival to metamorphosis in 1983 was 50% and 30% for groups 1 and 2, respectively, compared to the 2 - 3% survival in 1980 and 1981 (Fig. 8 and Table 2).

The cod fry were caught during the summer, and the catches increased from about 100 in 1980 to 9 000 in 1982 when 35 000 sand-eel fry were also caught (Table 2). In 1983 no sand-eels were present in the pond, and the potential catch of cod fry in early June was about a hundred thousand.

TABLE 2

Survival to metamorphosis of cod released in the 1980-1983 pond experiments.

Year	Age (days)	Survival (number)	Survival (%)	0-group cod recovered
1980	34	10 000	2	110
1981	35	15 000	3	2 500
1982 1)	35	11 000	1(28) +	9 000
1982 2)	35	3 000	0.5(8) +	
1983 1)	30	600 000	50	30 000 x
1983 2)	32	210 000	30	

1) first group

2) second group

x before 1 August

+ corrected value for immediate mass mortality in brackets

DISCUSSION

The purpose of the experiment was to see if it was possible, with simple modifications, to use a seawater pond to produce 0- group cod. The plankton production within the pond was intended to serve as a food supply, at least to metamorphosis.

High feeding incidence, which occurred within a day of transfer to the pond, and rapid growth, show that the cod larvae had no early feeding problems in the pond system. No detectable fraction of the population was at any time emaciated, indicating a potential survival of 100%.

The prey densities in the pond were below those stated to be necessary for growth and survival of cod larvae (Tilseth and Ellertsen, 1981), even in the deeper part of the pond where the highest densities were observed (Fig. 4). This might suggest that a natural ecosystem, such as a pond, with all trophic levels present offers the larvae better conditions than those in the laboratory where, in most cases, the phytoplankton is not included in the diet. As indicated, the cod larvae had green gut contents during first feeding. This has also been observed during a number of field studies on this species (Bainbridge and McKay, 1968; Lebour, 1919; Nordeng and Bratland 1971; Wiborg, 1948).

Although the experiments experienced some extraordinary problems like dam leakage in 1980 and immediate mass mortality of larvae in 1982, there seemed to be a connection between densities of hydromedusae and survival during the early larval stages.

When the survival values in Table 2 are compared with Fig. 3, it can be seen that 1981 and 1983 were the two extreme years when 1980 is neglected due to dam leakage. In 1981 there were high densities of hydromedusae and low larval survival, whereas in 1983 there were low densities of medusae and high larval survival. Hydromedusae are known to be potential predators of larval fish (Lebour, 1923; Fraser, 1969).

In conclusion, the pond system offered the cod larvae appropriate first feeding conditions and sufficient food to reach metamorphosis, even at a larval density of about 15/m^3 (1983). The main problem seemed to be predation by hydromedusae. An early release of cod larvae might overcome this problem. In addition, grazing of the first feeding food organisms by a large population of cod larvae might also reduce and delay hydromedusae recruitment.

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