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Mass Production of Atlantic Cod Juveniles *Gadus morhua* in a Norwegian Saltwater Pond

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Abstract

In March–April 1983, 2.5×10^6 yolk-sac Atlantic cod larvae were released in a dammed estuarine pond. One month later, more than half a million metamorphosed. The larvae and metamorphosed juveniles depleted the natural food supply by mid-May, but the fish accepted small pellets containing 30% krill meal dispensed from automatic feeders. From mid-June, young Atlantic cod primarily ate the pellets, supplemented with minor amounts of wild calanoid and harpacticoid copepods. The population declined during summer probably due to cannibalism and predation from birds. No outbreaks of disease were observed, and infestation with parasites (nematodes) was less than 20%. Altogether, 75,000 juvenile Atlantic cod were captured alive from late May to October. By October, about 20,000 15-cm-long juveniles were tagged and released in the Austevoll region in a first attempt to augment the fishery for Atlantic cod.

Large-scale production of juvenile salmonids for farming and stocking is a commercial activity in several countries. It has been far more difficult to commercialize production of juveniles of marine fish species for aquaculture purposes. In Great Britain, a considerable effort to rear juvenile turbots *Scophthalmus maximus* has been going on for more than 10 years with only modest success, partly due to brood-stock problems. However, the main problem is the small size of marine fish larvae. So far, it has been impossible to formulate a micropellet that has given growth and survival of the larvae. To overcome this problem, the larvae have been offered live food organisms, mainly rotifers and crustaceans. But even then there have been scaling-up problems so the production of juveniles has been at most some few hundred thousands.

A completely different strategy has been chosen in Norway. Instead of keeping the larvae in the laboratory and feeding them rotifers or crustaceans, the larvae have been transferred at the first-feeding stage to a saltwater basin in which they could feed on naturally occurring zooplankton. These studies began in 1975, lasted for 6 years, and included several commercial fish species. The conclusions drawn from these studies were: (a) marine fish larvae have a very high potential survival rate, even at marginal feeding conditions; and (b) fast-growing and healthy larvae may be very susceptible to predation (Øiestad 1985).

These initial studies were carried out in a volume of 4,400 m^3 and the principles evolved needed to be tested in larger and more natural systems. In 1980, the activity was transferred from the small basin of 4,400 m^3 to a dammed, saltwater pond of 60,000 m^3. In the pond ecosystem, Atlantic cod larvae had generally the same growth pattern as in the basin (Øiestad 1984), but the survival to metamorphosis was very low, probably due to the high density of predatory hydromedusae (Kvenseth and Øiestad 1984). In 1983, a different approach was tested, and this paper will deal with the experiences from that year's study.

We used Atlantic cod in these studies because this species is Norway's main roundfish and of great economic significance. Besides, several other studies have been undertaken on this species (Dahl et al. 1984). At the same time, the Atlantic cod in our studies is a model species, and similar studies are in progress or planned for other marine species. The restocking program for Atlantic cod has the same motivation. Independent of the actual situation of Atlantic cod populations along the Norwegian coast, the restocking program should provide general information on the value

of this type of activity, including both biological and economical implications. Also this program might be extended to include other marine fish species, like turbot and halibut *Hippoglossus hippoglossus*.

This study addresses the question of the most appropriate way to produce juveniles for farming as well as restocking. Successful rearing of juveniles based partly on the natural food production might give a more adapted (less naive) organism for restocking (Blaxter 1976). Furthermore, juvenile flatfish produced in out-door systems are fully pigmented (Øiestad et al. 1976), in contrast to those reared in the laboratory, where pseudoalbinism is common. Last but not least, the overall cost per juvenile might be below intensive production costs.

Methods

The study was carried out at the Institute of Marine Research, Marine Aquaculture Station Austevoll, south of Bergen. The "pond" is actually an arm of the sea that has been blocked off by two dams since 1980. Its volume is 60,000 m^3 and its maximum depth is 6 m. It was treated with rotenone in October 1982 and February 1983 to prevent sand lances *Ammodytes* sp. from spawning in the pond. Seawater was pumped into the pond from 40-m depths of the lower estuary at a rate of 3 m^3/min until 20 March. On that day, 1.2×10^6 5-d-old Atlantic cod larvae were transferred from a nearby hatchery to the pond (Table 1). Ten days later, another 0.7×10^6 cod larvae were transferred to the pond. Larvae were transferred every 10 days until 30 April. The total number transferred was then about 2.5 million (Table 1) in five releases.

Survival and growth of the larvae as well as zooplankton composition and densities were monitored two to three times a week, including one weekly midnight sample. Sampling was done with a two-chambered net of 350-μm mesh, which was hauled for 70 m at each of six depths; 20 m^3 of seawater were filtered in each haul. Oxygen saturation, salinity, and temperature were monitored weekly at six depths. Samples of microzooplankton were also taken weekly with an electrical pump of 36 L/min capacity and filtered with a 40-μm-mesh net. Sampling started in mid-March and was from six depths (0, 1, 2, 3, 4, and 5 m). After larvae from the first-released group metamorphosed in late April, the pumping of seawater from 40 m depth was started again.

TABLE 1.—*Number of Atlantic cod larvae released and their growth rate and survival.*

Date of release	Number of larvae released	Specific growth rate (%)		Survival (%)	
		Days 5–20	Day 20—metamorphosis	Day 20	Metamorphosis
20 Mar	1,200,000	10.4	12.0	75	50
30 Mar	700,000	13.2	10.8	65	30
9 Apr	250,000	11.1		4	0
20 Apr	150,000			0	
30 Apr	80,000			0	

By early May, the larval and juvenile Atlantic cod had depleted their natural food supply. On day 55 (measured from March 15, the date of hatching of the first larval group), we began feeding the fish, with automatic feeders, a dry pellet consisting of 30% krill meal, 60% sprat meal, and 10% binder, vitamins, etc. The krill component was reduced during the summer to 10%. On day 57, we also replaced part of the dam with a metal screen of 1,000-μm mesh to allow entry of zooplankton from the estuary.

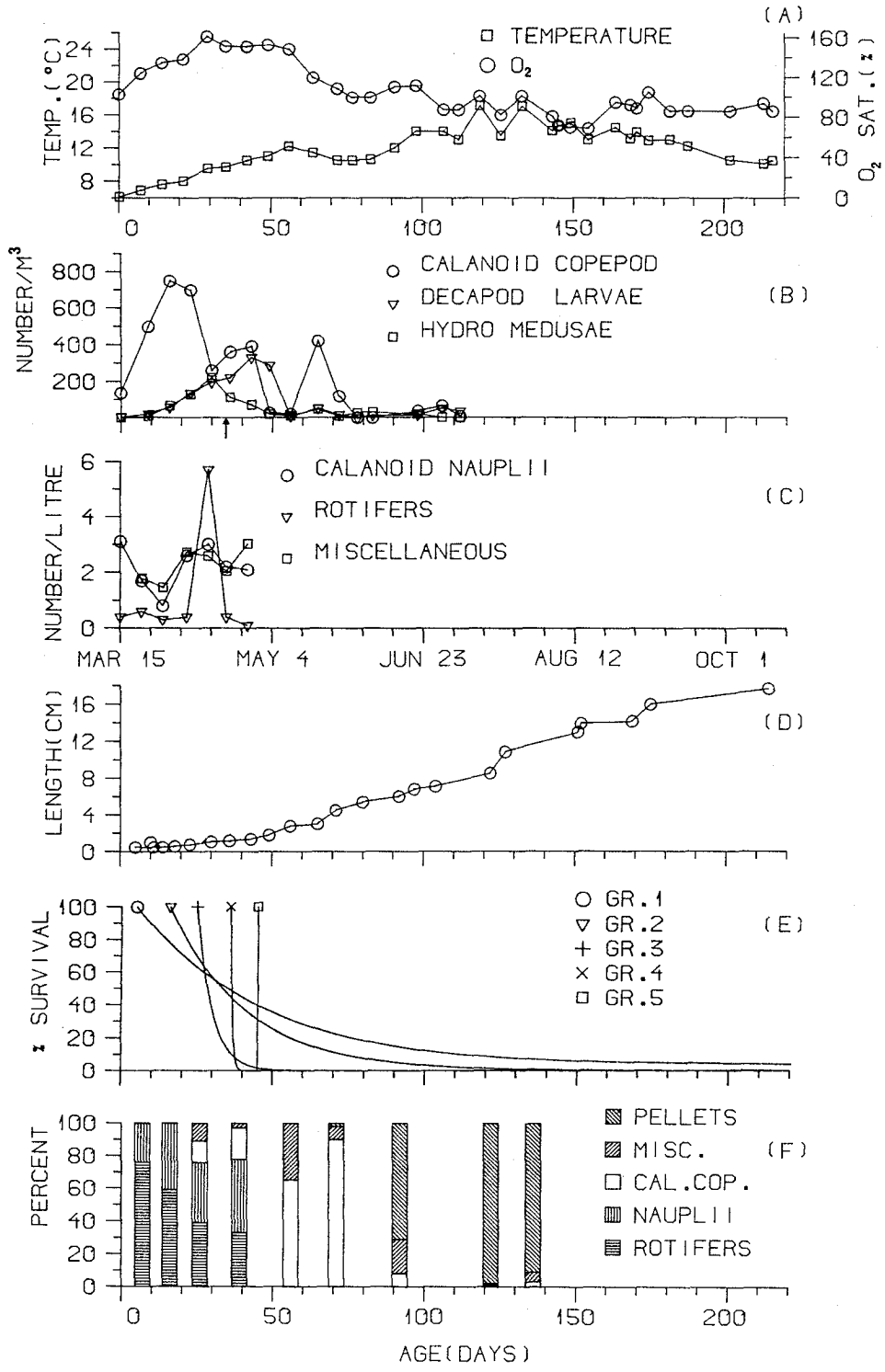
Infestation with nematodes was monitored weekly by squeezing the viscera of 10 fish between two glass plates, so that live parasites were easily observed. From late July, 200 juvenile Atlantic cod were kept in a net cage in the pond to facilitate detection of disease outbreaks in the pond.

Atlantic cod larvae were captured in the net hauls (speed approximately 0.5 m/s) until they reached a total length of 20 mm. Nets did not capture metamorphosed fish (>12 mm) in representative numbers due to net avoidance. Most fish were captured during autumn with a dip-net.

In mid-October, juveniles longer than 15 cm were tagged with Floy anchor tags, type FD 67C, and released in the Austevoll region, an archipelago with more than 300 islands south of Bergen, covering an area of 350 km^2. A recapture campaign among fishermen and visitors to those islands was started in early 1984.

Results

The temperature at 4 m depth (maximum depth 6 m) increased from 6.9°C on 22 March to 14.0°C in late June (Fig. 1A). In the summer it fluctuated in the range 14–17°C. Oxygen saturation at 4 m depth was above 100% until 30 June; values were just above 150% from mid-April to mid-May. During summer it never dropped below 70%.


(A)
TEMPERATURE
O2
TEMP.(°C)
O2 SAT.(%)
(B)
CALANOID COPEPOD
DECAPOD LARVAE
HYDRO MEDUSAE
NUMBER/M3
(C)
CALANOID NAUPLII
ROTIFERS
MISCELLANEOUS
NUMBER/LITRE
MAR 15
MAY 4
JUN 23
AUG 12
OCT 1
(D)
LENGTH(CM)
(E)
GR.1
GR.2
GR.3
GR.4
GR.5
% SURVIVAL
(F)
PELLETS
MISC.
CAL.COP.
NAUPLII
ROTIFERS
PERCENT
AGE(DAYS)

The salinity at 4 m depth was about 32‰ for the whole period.

Zooplankton

The macrozooplankton was dominated by calanoid copepods, decapod larvae, and hydromedusae (Fig. 1B). The main calanoid was *Calanus finmarchicus* in April and May and *Acartia* sp. afterward. Populations of calanoids and decapods had a sharp decline in early May, a week or two after metamorphosis of the first group of Atlantic cod larvae. Installation of the screen gave a new increase in copepod density followed by another decline in early June (about day 75). Hydromedusae, the abundance of which peaked in April, were dominated by *Rathkea octopunctata*; *Sarsia* sp. and *Tiaropsis* sp. contributed 10–20% of hydromedusa densities.

Among microzooplankton in pump samples, rotifers and nauplii of calanoid copepods occurred at densities ranging from 0.1 to 5.7/L (Fig. 1C). During first-feeding of Atlantic cod larvae, the mean density of rotifers was below 1/L. Densities of calanoid nauplii were generally 1–3/L. Other prey for the larvae (mainly copepod eggs and trocophora larvae, called miscellaneous in Fig. 1C), had about the same density as the nauplii.

The mean density of nauplii from mid-March to late April in the upper 2 m was about the same as in the three deepest samples: 2.1/L (SD = 1.0) for 0 m, 1 m, and 2 m, and 2.3/L (SD = 0.7) for 3 m, 4 m, and 5 m. The mean density of rotifers in the same period was highest in the upper 2 m, 2.1/L (SD = 3.8), and 0.1/L (SD = 0.2) in deeper water.

A few samples just above the bottom from mid-March to early April gave an overall mean density of nauplii and rotifers of 5.7/L (SD = 2.7), which was twice the mean value of the total water column (2.5/L; SD = 0.9).

Atlantic Cod Larvae

Juvenile Atlantic cod larvae reached a mean total length of about 18 cm in mid-October (Fig. 1D) and a mean wet weight of 60 g. The first and second population of Atlantic cod larvae released metamorphosed 35 d posthatch (20 April and 30 April). About 50% and 30%, respectively, reached this stage (Fig. 1E). The three next populations survived only for a fortnight (third population) or a few days after transfer to the pond (Fig. 1E). The disappearance of the third Atlantic cod cohort in late April and of the fourth and fifth as well, coincided in time with the metamorphosis of the first-released population, which at that time had a mean density of about $10/m^3$.

During the first 2–3 weeks after release, the larvae ate primarily nauplii and rotifers, then changed gradually to copepodites, copepods, and decapod larvae (the main fraction of miscellaneous; Fig. 1F). During daytime, the larvae had a lower gut fullness and feeding incidence than at dusk and dawn. Most larvae were at 3 m and 4 m depth both day and night.

Atlantic Cod Juveniles

The food supply within the pond declined in early May, when more than half a million Atlantic cod juveniles were grazing in the pond. One of the dams was then partly replaced with a screen, and for a period of about 1 month, the main food supply came with the inflowing tidal water through the screen. Most of the juveniles stemmed the current in a large school, grazing on the incoming zooplankton and paying only minor attention to the food from the automatic feeders. During June, an increasing fraction of

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FIGURE 1.—*Conditions in the culture pond and biology of stocked Atlantic cod, 1983. Days are numbered from March 15, when the first group of Atlantic cod larvae hatched; the first stocking occurred on March 20 (day 5).*

A. *Water temperature and oxygen saturation.*
B. *Mean densities of calanoid copepods, decapod larvae, and hydromedusae. The arrow at day 35 indicates metamorphosis of the first group of Atlantic cod larvae.*
C. *Mean densities of food organisms for first-feeding Atlantic cod larvae.*
D. *Mean length of Atlantic cod larvae.*
E. *Percent survival of five groups of Atlantic cod larvae; each group was stocked 5 d posthatch.*
F. *Stomach contents of Atlantic cod larvae. Through day 80, data are frequencies of occurrence. Thereafter, the volumetric fraction consisting of pellets first was estimated; then percent occurrence of organisms was calculated for the remaining fraction.*

the diet came from the feeders (Fig. 1F). In July, only a small fraction of the fish were stemming the current for food.

Cannibalism was observed among juveniles in the pond as well as among those transferred to the laboratory. Juveniles in the pond were also preyed upon by birds, mainly terns. Parasite infestation averaged 20% and did not increase during the summer. The only endoparasites observed were nematodes, with a mean of 1.5 nematodes per infested fish. No outbreak of disease was observed among the juveniles in the net cage in the pond.

We tagged 20,000 juveniles larger than 15 cm with Floy anchor tags, and released them in the Austevoll region. At the end of 1984, almost 1,000 tags had been returned (about 5%), giving information on growth (mean total length was 37 cm on 31 December), migration (87% were within 2 km of release), fraction of tagged Atlantic cod among those captured of equal size (30–50%) and type of gear used for fishing. A smaller preliminary tagging experiment with Atlantic cod in 1982 had given a 16% tag return.

Discussion

Since 1977, Atlantic cod larvae have been reared successfully in the laboratory in a few countries (Laurence 1978; Howell 1984), but there are scaling-up problems in rearing large numbers. Up to 5,000 young cod have been reared in plastic bag experiments (unpublished results). The main aim of our activity is to produce Atlantic cod to begin a restocking program. This demands a large quantity of juveniles, which preferably should be reared in a natural habitat to make them more able to survive in the open sea (Blaxter 1976). Preliminary tagging and release experiments with cod reared in a seminatural habitat at Flødevigen Biological Station in 1976 and 1977 gave about 10% tag return from fish released at a size of about 10 cm (Moksness and Øiestad 1984).

In the first 3 years of the pond study, only 10,000–15,000 Atlantic cod reached the metamorphosed stage, in contrast to about 800,000 in 1983 (Kvenseth and Øiestad 1984). The explanation for this difference might be a change in release strategy in 1983.

It seems essential to release the fish larvae some weeks before hydromedusae begin reproducing, because rapidly increasing hydromedusa populations might bring populations of larval Atlantic cod close to extinction. Furthermore, the repeated release of cod larvae every 10 d ensured a steady grazing pressure on food organisms for first-feeding larval hydromedusae. This might explain the recruitment problem for the hydromedusae in 1983, although food organisms for the adult hydromedusae were more numerous than in any year (Kvenseth and Øiestad 1984).

The sharp decline in calanoid copepods and then decapod larvae in early May (Fig. 1B) coincided with an increased grazing pressure on these species from metamorphosed Atlantic cod (Fig. 1F). The opening of the dam on day 57 gave a temporary increase in zooplankton densities (Fig. 1B), but the food demand of the fast-growing juveniles exceeded the supply of natural zooplankton in early June (day 75), and most likely the juvenile Atlantic cod were forced to feed on the dry pellets. The change from natural zooplankton to dry pellets took place rather rapidly and was most probably the result of insufficient food supply in the incoming tide water, as already indicated by the low density values (Fig. 1B). For the rest of the monitored period, the zooplankton densities remained low as zooplankton continued to be a supplementary diet for the juveniles.

The pond volume is 60,000 m^3, and the mean fish density just after metamorphosis was more than 10/m^3. Most cod were distributed in the deeper part, however, so the real local density was probably far higher.

When larvae from the three last cohorts mixed with the juvenile Atlantic cod at those high densities, it is rather likely that they were grazed down rapidly. Too few guts have been examined to verify this assumption, but juvenile Atlantic cod have been observed to ingest fish larvae in large quantities (Øiestad 1985). The reduction in number of juveniles from more than half a million to 75,000 might also be explained by cannibalism. Although juvenile Atlantic cod have been observed in the guts of larger juveniles, no systematic examination of this has been carried out on Atlantic cod captured in the pond. However, in the laboratory, cannibalism has been studied in size-graded and ungraded groups exposed to different feeding intensity (unpublished results). The highest cannibalism was observed among unsorted fish with the least intensive feeding regimen, being 22% in 2 months. However, the main cannibalism in the pond is assumed to take place before the Atlantic cod reach the size

of the juveniles in the actual study (2.5 g wet weight).

Juvenile mortality due to disease in the pond would be difficult to monitor, because dying fish would drop to the bottom and be eaten by crabs. No disease was observed among the subpopulation in the net cage and that might indicate healthy conditions also for the main population. The pellet fed to the juveniles seems to have been a proper diet, as it gave rapid growth (Fig. 1D) and kept the juveniles healthy.

The steady supply of seawater from 40 m depth from mid-May might have been important to Atlantic cod survival, as it kept the water temperature low and renewed the bottom water in the pond during summer. The bottom water is the most waste-loaded and contaminated and is seldom renewed naturally in pond systems. On the other hand, a stagnant pond from 20 March to mid-May gave no problem for the supply of oxygen (Fig. 1A). Supersaturation with oxygen is common in this type of system as a result of high phytoplankton production (Takahashi et al. 1975). The high saturation with oxygen did no harm to the fish larvae.

Pond systems are almost natural systems and it might be difficult to exploit them to produce juvenile fish. The success in 1983 might indicate that it is possible to direct the production, but most likely we do not know all the controlling factors that determine this production. In 1983, the year classes of Atlantic cod and Atlantic herring *Clupea harengus* produced along the Norwegian coast were very strong, and some of the same factors might control the success both places. Therefore, further studies are needed to determine vital factors for reliable production of juvenile fish in this type of system.

Acknowledgments

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