International Council for
the Exploration of the Sea

C.M. 1983/F:6
Mariculture Committee

APPLICATION OF LARVAL FISH POPULATION DYNAMICS IN ENCLOSURE SYSTEMS IN PRODUCTION OF MARINE FISH FRY

by

Victor Øiestad
Institute of Marine Research
N-5011 Nordnes Bergen, Norway

ABSTRACT

Since 1975 the population dynamic during the larval stage has been studied in enclosures for a large number of marin fish species. The main variables have been feeding conditions and number of predatores/competitors. All studied species are very sensitive to predation both as first-feeding larvae and as fast-growing postlarvae. It should be stressed that the predator does not need to ingest the prey, but might damage the larva severely so it will die. Predation seems to be the main reason for larval mortality in enclosed systems.

Under conditions without predatores or with low density of predatores, very high survival rates can be observed. At effluent feeding conditions survival of herring (Clupea harengus) to metamorphosis has been 70% and for cod (Gadus morhua L.) 50%. At marginal feeding condition rather high survival has been observed: plaice (Pleronecta platessa) 10%, cod 3-10% flounder (Platichtys flesus) 25% and turbot (Scophthalmus maximus) 5%.

In artificial enclosures on land predation can be controlled and by releasing the larvae during the production peak of first-feeding food organisms (rotifers and nauplii), high survival can be attained. As different species after metamorphosis exploit different food organisms, more than one fish species can be reared simultanously.

In pond systems the control with the ecosystem has to be obtained in a different way: first unwanted fish species have to be exterminated by use of rotenone and than the fish larvae have to be released in due time before the exponential increase in hydromedusae. In 1983 repeated release of cod larva populations exposed a continuous grazing pressure on first-feeding food organisms not permitting the hydromedusae to reproduce.

INTRODUCTION

Most marine fish species have an enormous fertility and reproduction potential. The realization of this potential is, however, very modest and within narrow limits as discussed by Sharp (1981). In laboratory experiments a number of species have documented very high survival rates through what has been supposed to be a critical stage: the first days or weeks or external feeding. These high survival rates have with few exceptions only been obtained at very high food levels and without predators present (Howell 1973, in press; Kuhlmann et al. 1982; Werner and Blaxter 1980).

Since 1975 enclosure experiments have been carried out and survival rates comparable to those experienced in the laboratory have been observed for a number of species, but at far lower food levels (Ellertsen et al. 1981; Haugen 1982; Øiestad 1982; Øiestad et al. 1976; Øiestad et al. 1983). The immediate question arising from these experiments was: is it possible to apply enclosures for mass-rearing of marin fish fry.

MATERIALS AND METHODS

Enclosure studies were carried out for six years at Flødevigen Biological Station (FBS) outside Arendal (1975 - 1980) and for four years at the Institute of Marine Research, Marine Aquaculture Station Austevoll (MASA), south of Bergen (1980 - 1983).

At FBS the experiments were mainly carried out in a land-sited basin with a volume of 4 400 m^3 and at MASA in a dammed pond with a volume of 60 000 m^3. For more detail, see Ellertsen et al. (1981), Øiestad et al. (1976) and Øiestad and Kvenseth (1981).

Basin experiments at FBS

In 1975 preliminary experiments were carried out with herring, cod, flounder and a flounder hybrid (Øiestad et al. 1976). In 1976 and the following years, large populations of fish larvae at the end of the yolk sac stage (EYS) were transferred from the laboratory and released in the basin (Table 1). In all years more than one species was released in the basin in order to look at possible interactions between fish species. However, the main purpose was to study the effect of the ambient feeding regime on growth and survival of the released larva populations. As large populations were released in most cases, frequent sampling could be carried out, with net hauls giving information on growth and survival rates. Both hydrography and primary and secondary production were monitored weekly.

In 1976 and 1977 cod was the main species studied; other species were of secondary interest (Table 1). In 1978 and 1979, herring was the main species. In 1980, only experiments with turbot larvae were carried out.

Pond experiments at MASA

The larger volume of the MASA pond was compensated for by releasing larger populations of larvae (Table 1).

Some weeks before larval release, the pond was treated with rotenone to kill predatory fish. No other control of potential predator was carried out. In most years the pond had an open connection to the sea, but this was closed from the day of larval release in the pond to mid-June (about 3 months). The ecosystem in the pond was somewhat more diverse than that observed in the basin at FBS.

RESULTS

Hydrography

All experiments have been initiated from March to July in water temperature increasing from about $4^{o}C$ in early spring to a summer temperature of $18-22^{o}C$ in the surface and $12-16^{o}C$ in the bottom water. The salinity has been $32-34^{o}/oo$ in the basin water and $30-32^{o}/oo$ in the pond water except in the more brackish surface layer. Oxygen saturation has been above 100% most of the time in both types of enclosures, but with values down to 70% close to the bottom in periods during summer in both basin and pond.

The first-feeding period (to day 20 posthatching)

Fish larva populations have been released during periods with affluent food, marginal feeding conditions and at periods with virtually no food organisms (Table 1). Under all conditions there have been a similar pattern with unidentificable particles in the gut during the first few days and sometimes for more than a week (cod 77-1). The colour of the gut content was ofte green or green-yellish. Gradually during this period they started to feed on rotifers and nauplii and on this mixed diet they grew and survived for the first period. The specific growth rates in this period were variable and related to the feeding conditions (Table 1). Given marginal or worser feeding conditions (cod 76 and cod 77-1), emasiated larvae were observed although the feeding incidences were close to 100%. With no predators present, the survival for the first 20 days post-hatching, has in some cases been more than 50% (Table 1).

The post-larvae period

In the next period (from day 20 to metamorphosis) another change in diet usually took place as nauplii and rotifers were replaced by older stages of calanoid copepods and adult harpacticoid copepods. This period was further characterized by a high specific growth rate and moderate mortality (Table 1).

Post-metamorphosis

The post-metamorphosed fish fry had a rapidly increasing food demand and in all experiments the holopelagic zooplankton was grazed down, first calanoid copepods, later spinoid-larvae. The main food supply onward was semi-pelagic organisms: amphipods, harpacticoids and chironomid larvae.

Table 1. Review of larval populations released in enclosure experiments and surviving to termination (Encl. = enclosure; TL = total length; DLI = daily length increment since release; -: value not monitored.

Year	Encl.	Species	Population released	Initial density (/m^3)	Initial food^x (/l)	SGR (%) 5-20	SGR (%) 20-metam.	Survival (%) →20	Survival (%) →metam.	Termination: Survival n (%)	TL mm	DLI mm	Duration (days)
						(age intervals)							
1975	Basin	Cod	5 000	1.1	1	-	-	-	-	147(3)	70	0.67	100
		Herring	40 000	9.1	1	-	-	-	-	4 300(11)	48	0.50	80
		Plaice	2 000	0.5	1	-	-	-	-	135(7)	63	0.75	77
		Flounder	2 000	0.5	1	-	-	-	-	460(23)	63	0.63	95
1976	Basin	Cod	200 000	45	2	5.0	8.8	50	12	4 000(2)	65	0.47	130
		Plaice	3 000	0.7	1	-	-	-	-	260(9)	80	0.53	140
		Hybrid	5 400	1.2	1	-	-	-	-	560(10)	76	0.58	122
1977	Basin	Cod-1	75 000	17	0.2	4.2	12.0	10	3	1 760(2)	80	0.44	180
		Cod-2	100 000	23	3	11.9	-	10	(6)$	2 150(2)	63	0.39	150
1978	Basin	Herring	10 000	2.3	20	9.5	13.4	97	90	7 000(70)	62	0.40	135
1979	Basin	Herring	25 000	5.7	3	7.5	12.7	88	56	5 500$^+$(22)	53	0.42	100
1980	Basin§	Turbot	15 000	7.5	35	33.0	13.8	6	5	600(4)	51	0.67	72
1980	Pond	Cod	500 000	10	110	11.0	16.6	7	-	200(+)	110	0.73	145
1981	Pond	Cod	610 000	12	10	8.1	15.0	8	2	3 000(0.5)	147	0.70	204
1982	Pond	Cod	60 000	1.2	1	11.3	15.0	50	15	9 000(15)	86	0.93	93
1983	Pond	Cod-1	1 200 000	24	6	10.4	13.6	70	50	} 45 000£(-)	108	0.82	127
		Cod-2	700 000	14	10	13.2	9.1	50	30				

x: mean density of appropriate food organisms in the depths with maximum densities (usually three depths)

+: corrected for sampling

(+): 0.04%

§: basin volume 2 000 m^3

$: stipulated ; £: to 3 August

In basin experiments production of fish fry was from 0.9-1.6/m^3 and due to restricted food supply the growth rate during summer was low. The overall daily length increments from release to termination of experiments have been between 0.4 - 1.0 mm (Table 1). In experiments with cod fry, outbreak of cannibalism was common in this period. In the 1980-1982 pond experiments the density of cod fry was below 0.2/m^3. In 1983 the density was above 10/m^3 at metamorphosis which was far higher than the carrying capasity of the pond. Additional feeding was started when the cod reached a size of 20 mm. It was, however, impossible to prevent cannibalism. When the fry reached a size of 10 cm, their density was still rather high being 2/m^3 and the growth was due to the feeding of the fry, higher than that observed in basin experiments at lower stocking densities (Table 1).

In addition to cannibalism among cod fry, the cod fry also attacked newly released fish larvae of other species and exterminated them within few days.

When other larvae were released at the same time as cod larvae, high survival was observed as with plaice and the hybrid plaice-flounder in the 1976 basin experiment (Table 1).

Post-metamorphosed flatfish-species had another diet than both herring and cod so they could be reared successfully in the same basin (Table 2).

Table 2. Percentage occurrence of various prey organisms in the digestive systems of cod, plaice, and flounder, captured on July 29, during daytime, in the 1975 basin experiment (From Øiestad _et_ _al_. 1976)

Species Length range of fish (mm) Number of fish examined	Cod 36-90 31	Plaice 47-76 17	Flounder 52-77 31
Polychaetes[1]	55	100	84
Harpacticoids	6	12	3
Other crustaceans[2]	42	6	3
Chironomids	3	53	6
Empty (number)	0	0	13

[1] Mainly _Terebellides_ spp.

[2] Mainly _Gammarus_ spp.

In the pond experiment, hydromedusae have been a severe predator on first-feeding cod larvae and so far this problem can only be solved by releasing cod larvae in due time before the hydromedusae start their reproduction. A repeated release as in the pond in 1983, seem to keep first-feeding food organisms for the hydromedusae at a low level, hampering the reproduction of medusae.

DISCUSSION

The enclosure experiments have demonstrated that marine fish larvae have a high survival potential even at marginal feeding conditions. However, they are very sensitive to predation, even fast-growing post-larvae (Øiestad 1983). These are the two basic recognitions.

Application of these recognitions in basin production of fish fry might be easier than in a pond as the number of predators and competitors might be controlled and food production directed into larval growth. The stocking density of fish larva in the basin might exceed the carrying capasity of the system during the larval or fry period. In the 1976 basin experiment 5 metamorphosed cod fry/m^3 did not depleat the food supply. In the 1983 pond experiment reduced growth rate was observed of the second cod population from day 25 when there was 15 metamorphosed cod fry/m^3 from the first released population. However, as most fish species are opportunistic i.e. they are able to survive periods with reduced food supply by reducing their growth rate, there is probably a minor hazard in applying stocking densities that are leading to reduced growth rate. In most cases that will take place when fish larvae are about to metamorphose and when additional feeding can start. Generally the carrying capasity in this type of systems during first feeding is 30-50 larvae/m^3 and with 30% survival beyond metamorphosis it should give 10-15 fry/m^3. Further development of the method might make it possible to increase density considerably. One of the possible improvements might be to enhance the production of first-feeding food organisms by addition of fertilizers to the basin.

The timing of larval release is a rather important question. Production of both nauplii and rotifers should have lasted for a while (1-2 weeks) before larval release. This might ensure production of copepodites and permit the rotifers to multiply to third or fourth generation before grazing from the larvae.

One further aspect with the basin is that flatfish fry production is possible as a crab population will not establish in the basin due to the annual drainage of the system. In 1984 a basin with a volume of 50 000 m^3 will be tested in a multispecies experiment with cod and flatfish. The main draw-back with a basin is the more expensive water exchange system as in contrast to a pond, the tide water can not be exploited. The feeding of fry might therefore be more restricted to prevent contamination and oxygen deficite in the bottom water.

Rearing of cod in both basins and ponds create spesial problems because of the cannibalistic behaviour, a problem not observed with any of the other fish species involved in these experiments. In addition, in numerous experiments the cod fry have eradicated newly released fish larvae within few days. To overcome these problems, cod larvae should be of about the same age when released in the pond and a proper way of feeding newly metamorphosed cod fry should be invented. In multispecies rearing involving cod, other larvae should be released before or at the same time as the cod larvae. This approach gave high survival of plaice and the plaice-flounder hybrid in the 1976 basin experiment (Table 1).

In a pond system initial stocking density should also be considered, but time of release might be of far greater importance than in a basin, due to the reproduction of predators and competitors in the pond. An early release in due time before hydromedusae reproduction, seems to be a must. Further, to keep the hydromedusae at a low level, repeated release of large populations of fish larvae might be essential. Repeated overstocking has not been tried so far, but might give a prolonged grazing pressure on first-feeding food organisms which might reduce hydromedusae reproduction even below the level in 1983.

As earlier indicated, flatfish fry production might be unsuccessful in ponds due to a large crab population, but it should be possible to invent a device that continuously remove crabs from the pond.

The collection of flatfish should be possible in the same way as for cod in the 1983 pond experiment if they are dependent on an automatic feeder for their food supply (Øiestad et al. 1983). Special for the pond production is the rotenone treatment to exterminate fish predators. The operation is easily carried out and most species are killed at a level of 0.5 ppm. However, for two years we had an eel population in the pond. In 1982, when a 1.0 ppm treatment was carried out, about 1000 eels (30-100 cm) were killed (Kvenseth and Øiestad in press). That year a high cod fry survival through the summer was obtained in contrast to 1980 and 1981 (Table 1).

Minor modifications of marine ecosystems might change fish larval survival from a few per mille to more than 50% beyond metamorphosis. These modifications can rather easily be done in enclosed systems and enable production of really large number of valuable marine fish fry. Further progress can be achieved, and the production might in the future very well reach the level of natural fry production for a number of species. In a not too far future modifications might be possible also in the open sea at the spawning and hatching grounds of marine fish. We will then realize the word in the Bible: "And thee shall have dominion over the fish of the sea".

ACKNOWLEDGEMENTS

The experiments at Flødevigen Biological Station were carried out in cooperation with Erlend Moksness and those at Aquaculture Station Austevoll with Per Gunnar Kvenseth. At both stations the experiments were to a large extend founded by Norwegian Council of Fishery Research.

REFERENCES

Ellertsen, B., Moksness, E., Solemdal, P., Tilseth, S., Westgård, T. and Øiestad, V. 1981. Growth and survival of cod larvae in an enclosure. Experiments and a mathematical model. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 178: 45-57.

Haugen, A.S. 1982. Bassengstudier av overleving, vekst og næringsopptak hos larver og yngel av piggvar (Scophthalmus maximus L.). (Enclosure studies of survival, growth and feeding of turbot beyond metamorphosis). Thesis (cand.real.), Univ. Bergen. 101 pp. [Unpublished.]

Howell, B.K. 1973. Marine fish culture in Britain. VIII. A marine rotifer, Brachionus plicatilis Muller, and the larvae of the mussel, Mytilus edulis L., as food for larval flatfish. J.Cons.int.Explor.Mer, 35: 1-6.

Howell, B.K. in press. The intensive rearing of juvenile cod, Gadus morhua. Fløddevigen rapportser., 3:

Kuhlmann, D., Quartz, G. and Witt, U. 1981. Rearing of turbot larvae (Scophthalmus maximus L.) on cultured food organisms and postmetamorphosis growth on natural and artificial food. Aquaculture, 23: 183-196.

Kvenseth, P.G. and Øiestad, V. in press. Large-scale rearing of cod fry in an enclosed pond on the natural food production. Fløddevigen rapportser., 3:

Sharp, G. 1980. Report of the workshop on effects of environmental variation on survival of larval pelagic fishes. Pp. 15-65 in Sharp, G., ed. Workshop on the effects of environmental variation on the survival of larval pelagic fishes. IOC Workshop Report no. 28.

Werner, R.G. and Blaxter, J.H.S. 1980. Growth and survival of larval herring (Clupea harengus) in relation to prey density. Can. J. Fish. Aquat. Sci., 37: 1063-1069.

Øiestad, V. 1982. Application of enclosures to studies on the early life history of fishes. Pp. 49-62 in Grice, G.D. and Reeve, M.R., eds. Marine mesocosms. Springer Verlag, Berlin.

Øiestad, V. 1983. Predation on fish larvae as a regulatory force illustrated in enclosure experiments with large groups of larvae. Coun. Meet. int. Coun. Explor. Sea, 1983 (L:39): 1-10, 3 tabs., 6 figs. [Mimeo.]

Øiestad, V. and Kvenseth, P.G. 1981. Large-scale rearing of cod fry (Gadus morhua) in an inlet. Coun. Meet. int. Coun. Explor. Sea, 1981 (F:11): 1-6, 11 figs. [Mimeo.]

Øiestad, V., Ellertsen, B., Solemdal, P., and Tilseth, S. 1976. Rearing of different species of marine fish fry in a constructed basin. Pp. 303-329 in Persoone, G. and Jaspers, E., eds. Proc. 10th Eur. mar. biol. Symp., Vol. 1. Universa Press, Wettern, Belgium.

Øiestad, V., Kvenseth, P.G. and Folkvord, A. 1983. Mass-production of cod fry in a pond in western Norway, with additional feeding post-metamorphosis. Coun. Meet. int. Coun. Explor. Sea, 1983 (F:5): 1-10, 6 figs. [Mimeo.]