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Egg mortality and hatching rate of Baltic cod (*Gadus morhua*) in different salinities

A. Nissling and L. Westin

Institute of Systems Ecology, Section Gotland, University of Stockholm, S-106 91 Stockholm, Sweden

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Abstract. Egg mortality of Baltic cod (*Gadus morhua* L.), collected off northern Gotland, Sweden, in 1990, was studied in four different salinities – 10 and 15 ppt (salinity of the principal spawning areas of Baltic cod) and 5 and 7 ppt (salinity above the halocline) – in laboratory experiments. Mortality was high during the first 4 d of development, but after gastrulation mortality was low in all salinities tested, except for 5 ppt, in which mortality increased slightly before hatching. Mortality during hatching varied considerably with salinity. No hatching occurred in 5 ppt salinity, and only a few larvae survived in 7 ppt salinity; in contrast, mortality during hatching was comparatively low in salinities of 10 and 15 ppt.

Introduction

The Baltic cod stock has varied greatly over the centuries (Otterlind 1984). From the late 1970s until the middle of the 1980s high catches were reported; since then the stock has decreased considerably (Hansson and Rudstam 1990). Grauman (1973) has shown that variations in the Baltic cod stock are correlated with spawning efficiency, which depends on abiotic conditions (primarily salinity and water oxygen content) in the spawning areas, i.e. the Bornholm, Gdansk and Gotland basins.

The deep basins of the Baltic Sea are characterized by periods of stagnant deep water due to irregular inflows of saline water from the North Sea. The last major inflow occurred in winter 1976–77 (Fonselius 1988) and resulted in salinities of ca. 11 to 13 ppt in the Gdansk and Gotland basins. Today the prevailing conditions in the Gdansk and Gotland basins are unfavourable for cod reproduction because of decreased salinity (9 to 11.5 ppt) and a severe oxygen deficit.

Since cod is the most commercially valuable fish species in the Baltic Sea, it is of great interest to estimate the year-class strength in order to forecast the likely catch. Attempts to estimate the success of spawning by sampling eggs and larvae in the deep basins and to calculate cod survival rate have been made for a number of years. In calculating egg survival, knowledge about egg mortality and hatching is needed.

Salinity in the principal spawning areas of Baltic cod varies between 10 and 16 ppt, but we have previously shown (Westin and Nissling 1991) that a minimum salinity of ca. 11 ppt is necessary for successful fertilization and egg development. Fertilization in salinities of 10 ppt or less results in no egg development (development ceases before the first cleavage), but it has also been observed that eggs, fertilized in 17 ppt S, develop normally when transferred to low salinities (5 and 7 ppt) after fertilization. The aim of the present experiment is to obtain information about egg mortality from fertilization to hatching, and to investigate egg survival in low salinities.

Materials and methods

Spawning cod (*Gadus morhua* L.) were caught with gill nets at 50 to 90 m depth of northern Gotland, Sweden (58°N, 19°E), and eggs were obtained by stripping. Eggs were fertilized and held in 17-ppt-salinity water (a salinity in which fertilized eggs remain buoyant, whereas unfertilized and dead eggs sink) until the start of the experiment. Batches of 100 to 200 normally developed eggs from six different females were transferred to four salinities (5, 7, 10 and 15 ppt) at various times after fertilization, as follows: (a) 2 to 4 h (Females 1 and 2); (b) 2 d (Females 3 and 4); and (c) 3 d (Females 5 and 6). These times correspond to development stages 1–2 cells, early gastrulation, and end of gastrulation, respectively.

From each female, one egg batch was incubated in each of 10 and 15 ppt salinity, and two batches were incubated in each of 5 and 7 ppt salinity. The egg batches were incubated in 500 ml of water with the respective salinity, prepared from filtered seawater (0.2 µm) and synthethic seasalt (hw-Marinemix) or diluted with deionized water, at about 7 °C. The water was also treated with antibiotics [Mycostatin (2 500 IU/l), Streptomycin (0.05 g/l) and Doctacillin (0.2 g/l)].

The water was changed daily, and the number of both dead eggs and hatched larvae was counted. Percentage of hatched larvae and daily egg mortality were calculated relative to the number of eggs at the start of incubation (i.e., on Days 0, 2 and 3). Egg mortality at Days 13 to 15 (time of hatching) was combined and is reported as mortality during hatching.

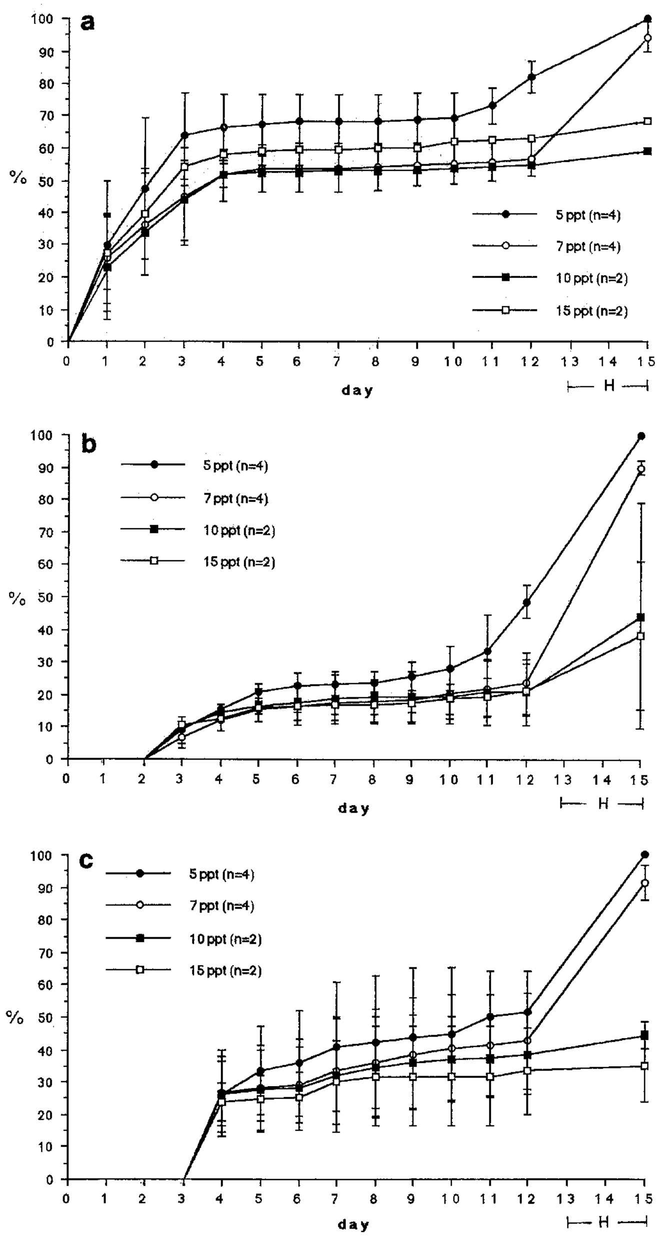

Fig. 1. *Gadus morhua.* Cumulative mortality of Baltic cod eggs in different salinities during development (Days 0 to 12) and hatching (H) (Days 13 to 15), after fertilization in 17 ppt and transference to different salinities at various time after fertilization: (a) 2 to 4 h (Females 1 and 2), (b) 2 d (Females 3 and 4), and (c) 3 d (Females 5 and 6)

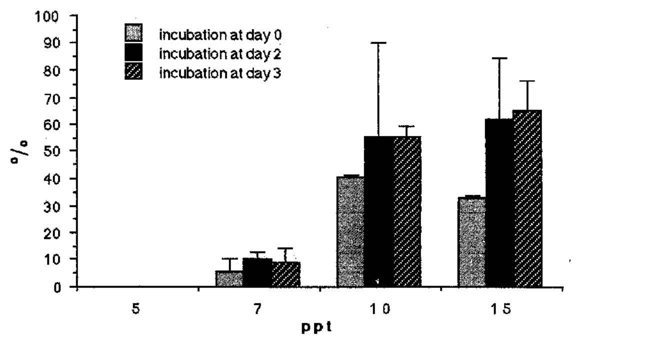

Fig. 2. *Gadus morhua.* Percentage of hatched eggs of Baltic cod in different salinities, after transfer from 17 ppt salinity at various times after fertilization: 2 to 4 h (females 1 and 2), 2 d (Females 3 and 4) and 3 d (Females 5 and 6). From each female, two egg batches were incubated in each of 5 and 7 ppt salinity, and one batch was incubated in each of 10 and 15 ppt salinity

Results

Cumulative egg mortality during development for each salinity from the different incubations is shown in Fig. 1, together with mortality during hatching. In salinities of 5, 7 and 10 ppt the eggs developed at the bottom of the beakers, while the eggs remained buoyant in 15 ppt.

Mortality of eggs incubated from Day 0 (Fig. 1 a) was high during the first 3 d of incubation; after gastrulation (from Day 4), however, mortality was low in all salinities except for 5 ppt, in which there was an increase in mortality before hatching. The pattern for eggs incubated from Day 2 (Fig. 1 b) was similar. Mortality was highest during the first 2 d of incubation and low from Day 4 until hatching, except for 5 ppt salinity, in which mortality increased towards the end of development. Eggs incubated from Day 3 (Fig. 1 c) displayed high mortality during the first day of incubation, but low mortality from Day 4 onwards; in contrast to the incubations from Days 0 and 2, there was only a slight increase in mortality immediately before hatching (Days 10 to 12) in 5 ppt salinity.

During hatching, mortality varied considerably among salinities, irrespective of development stage at the start of incubation. No larvae survived hatching in 5 ppt salinity. In 7 ppt, mortality during hatching was high, with only a few hatched larvae; mortality in 10 and 15 ppt salinity was considerably lower, although it increased during hatching. The percentage of hatched larvae from the different incubations is shown in Fig. 2.

In 5 and 7 ppt salinity an increasing number of larvae appeared in a partly emerged state from Days 9 to 12, usually with the head protruding from the egg (Fig. 3), and finally died. This was not observed in 10 or 15 ppt salinity.

Discussion

Mortality of pelagic eggs is generally high, and even small variations in mortality rate may result in large variations in year-class strength. Among the factors affecting egg survival are abiotic conditions such as temperature (Thompson and Riley 1981, Iversen and Danielssen 1984), salinity (Laurence and Rogers 1976) and water oxygen content (Grauman 1974, Wieland 1987). Biotic factors include not only predation (see Jaworski and Rijnsdorp 1989) but also egg quality, which affects fertilization rate and aberrant embryonic development (Grauman 1973, Kjørsvik et al. 1984). All of these factors must be considered when calculating survival rate and estimating year-class strength from egg abundance in the spawning areas.

Cod egg survival in the Baltic deep basins has been investigated by Grauman (1973, 1974), who sampled ichthyoplankton from 1954 to 1964 and from 1968 to

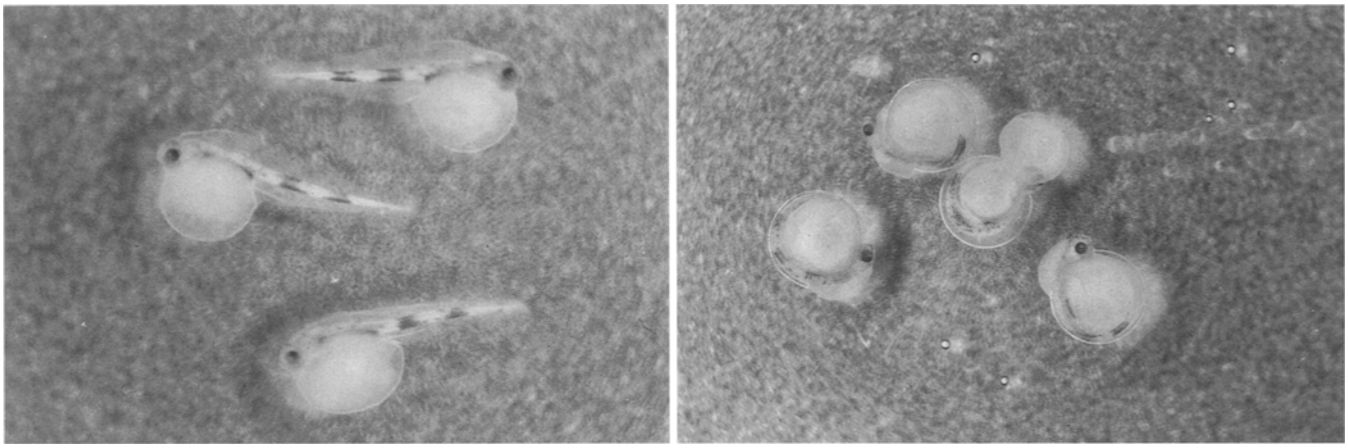

Fig. 3. *Gadus morhua.* Normally hatched Baltic cod larvae (left) and larvae appearing in a partly emerged state before hatching (right)

1970. Estimated egg survival varied between 1 and 21% and was correlated with hydrographical conditions. By comparison, Wieland (1987), who calculated egg mortality in the Bornholm basin during a cohort study, estimated daily egg mortality to be 26.9 to 27.5%, leading to an overall mortality of about 99.9%.

In our investigation egg mortality was high during early developmental stages in all salinities tested. After gastrulation, however, egg mortality remained low until hatching, except for an increase towards the end of development in 5 ppt salinity. This was true for all incubations, irrespective of development stage at the start of exposure. These results are in agreement with those of Laurence and Rogers (1976), who reported highest mortality (12 to 13%) for Atlantic cod eggs in early stages until the end of gastrulation, as well as just prior to hatching (23%). In addition, Iversen and Danielssen (1984) reported that highest egg mortality occurred during gastrulation and immediately before hatching in North Sea cod. Higher egg mortality in early developmental stages was also reported by Grauman (1973) from the Baltic deep basins; furthermore, Kjørsvik et al. (1984) reported that 20% of North Sea cod eggs, collected from plankton, were aberrant when early stages were predominant, whereas only 5% were aberrant when more advanced stages prevailed.

Experiments on tolerance of cod eggs to low salinities have been performed by Kjørsvik et al. (1984) for Atlantic cod in salinities of 14, 20, 27, 34 and 48 ppt. No cod eggs were fertilized in 14 ppt, and eggs which were fertilized in 34 ppt and then transferred to 14 and 20 ppt died before gastrulation and before closure of the blastopore, respectively. In similar experiments on Belt Sea cod in salinities of 10, 15, 20, 25, 30, 33 and 42 ppt, Westernhagen (1970) found no development in eggs fertilized at 10 ppt salinity, and eggs transferred in early stages to 7 and 10 ppt from 33 ppt died, but were able to develop and hatch if transferred in the IIb stage (i.e., after gastrulation). This contrasts with our investigation on Baltic cod, in which eggs developed normally and were able to hatch in 7 and 10 ppt, although they were transferred from a higher salinity only 2 to 4 h after fertilization; these results may indicate differences in the salinity tolerance of cod populations.

The fact that eggs transferred from higher salinities survive in salinities lower than the minimum necessary for successful fertilization might be explained by the change which occurs in permeability of the perivitelline membrane. Shortly after fertilization, permeability to water decreases to about 5% of its prefertilization value (Riis-Vestergaard 1984, Mangor-Jensen 1987). The significance of this was shown in an investigation by Kjørsvik et al. (1984), who found that fertilization in different salinities affected yolk osmolality, whereas transfer 24 h later had no effect.

From Day 8 (Riis-Vestergaard 1984) or Day 10 (Mangor-Jensen 1987) onwards, the permeability of the perivitelline membrane and the embryonic volume increase, indicating an uptake of water by the embryo (Mangor-Jensen 1987). This coincides in our investigation with the period of increased egg mortality in 5 ppt salinity and the appearance of partially emerged larvae in 5 and 7 ppt salinities. Mortality at hatching varied considerably with salinity. In 5 ppt no hatching occurred and only a few larvae survived hatching in 7 ppt, while in 10 and 15 ppt mortality at hatching was comparatively low. Thus, development of fertilized Baltic cod eggs seems to be little affected by change in salinity, but low salinities strongly affect hatching rate.

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Literature cited

Fonselius, S. (1988). Long-term trends of dissolved oxygen, pH and alkalinity in the Baltic deep basins. Int. Counc. Explor. Sea Comm. Meet. (Hydrography Comm.) C: 23: 1–6

Grauman, G. B. (1973). Investigations of factors influencing fluctuations in abundance of Baltic cod. Rapp. P.-v. Réun. Cons. int. Explor. Mer 164: 73–76

Grauman, G. B. (1974). Investigations on the spawning of Baltic cod in 1968–1970. Rapp. P.-v. Réun. Cons. int. Explor. Mer 166: 7–9

Hansson, S., Rudstam, L. G. (1990). Eutrophication and Baltic fish communities. Ambio 19: 123–125

Iversen, S. A., Danielssen, D. S. (1984). Development and mortality of cod (*Gadus morhua* L.) eggs and larvae in different temperatures. In: Dahl, E., Danielssen, D. S., Moksness, E., Solemdal, P. (eds.) The propagation of cod, *Gadus morhua* L., Part 1. Flødevigen rapportser., No. 1. Oluf Rasmussen, Skien, p. 49–65

Jaworski, A., Rijnsdorp, A. D. (1989). Size selective mortality in plaice and cod eggs: a new approach to the study of egg-mortality? Int. Counc. Explor. Sea Comm. Meet. (Biol. Oceanogr. Comm.) L: 29: 1–7

Kjørsvik, E., Stene, A., Lønning, S. (1984). Morphological, physiological and genetical studies of egg quality in cod (*Gadus morhua* L.). In: Dahl, E., Danielssen, D. S., Moksness, E., Solemdal, P. (eds.) The propagation of cod, *Gadus morhua* L., Part 1. Flødevigen rapportser., No. 1. Oluf Rasmussen, Skien, p. 67–86

Laurence, G. C., Rogers, C. A. (1976). Effects of temperature and salinity on comparative embryo development and mortality of Atlantic cod (*Gadus morhua* L.) and haddock (*Melanogrammus aeglefinus* L.). J. Cons. int. Explor. Mer. 36(3): 220–228

Mangor-Jensen, A. (1987). Water balance in developing eggs of the cod *Gadus morhua* L. Fish physiology and biochemistry, Vol. 3. Kugler Publications, Amsterdam/Berkely, p. 17–24

Otterlind, G. (1984). On fluctuations of the Baltic cod stock. Int. Counc. Explor. Sea Comm. Meet. (Baltic Fish Comm.) J: 14: 1–10

Riis-Vestergaard, J. (1984). Water balance in cod eggs. In: Dahl, E., Danielssen, D. S., Moksness, E., Solemdal, P. (eds.) The propagation of cod, *Gadus morhua* L., Part 1. Flødevigen rapportser., No. 1. Oluf Rasmussen, Skien, p. 87–103

Thompson, B. M., Riley, J. D. (1981). Egg and larval development studies in the North Sea cod (*Gadus morhua* L.). Rapp. P.-v. Réun. Cons. int. Explor. Mer 178: 553–559

Westernhagen, H. von (1970). Erbrütung der Eier von Dorsch (*Gadus morhua*), Flunder (*Pleuronectes flesus*) und Scholle (*Pleuronectes platessa*) unter kombinierter Temperatur- und Salzgehaltsbedingungen. Helgoländer wiss. Meeresunters. 21: 21–102

Westin, L., Nissling, A. (1991). Effects of salinity on spermatozoa motility, percentage of fertilized eggs and egg development of Baltic cod (*Gadus morhua*), and implications for cod stock fluctuations in the Baltic. Mar. Biol. 108: 5–9

Wieland, K. (1987). Distribution and mortality of cod eggs in the Bornholm basin (Baltic Sea). Int. Counc. Explor. Sea Comm. Meet. (Baltic Fish Comm.) G: 56: 1–14