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Effects of temperature and salinity on embryonic development of turbot (*Scophthalmus maximus* L.) from the North Sea, and comparisons with Baltic populations

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ABSTRACT: Optimum temperature and salinity conditions for viable hatch were studied for turbot (*Scophthalmus maximus* L.) from the North Sea. Temperatures ranging from 6 to 22 °C and salinities from 5 to 35 ‰ were used. Optimum conditions were observed to be between 12 and 18 °C at salinities between 20 and 35 ‰. This contrasted with corresponding data for turbot from the southern Baltic proper, according to which survival sharply decreased in temperatures below 14 °C and was high in salinities of 10 to 15 ‰. Thus, it is concluded that Baltic and Atlantic turbot should be considered as different races.

INTRODUCTION

Salinity within the distribution area of turbot (*Scophthalmus maximus* L.) varies from 35 ‰ in the East Atlantic Ocean to about 5 ‰ in the Baltic Sea. Similar to other flatfish, turbot has a high fecundity, i.e. about one million eggs per kg body weight (Jones, 1974). Although it is highly appreciated in the cuisine, commercial catches are smaller than those of, for example, plaice (*Pleuronectes platessa* L.), due to much lower adult stock sizes. Thus, recruitment to the adult stock, mainly determined by first year survival, is much lower for turbot than for most other flatfish. To gain a better understanding of this naturally occurring difference, it is vital to know the effects of temperature and salinity on embryonic development and larval survival. Experimental studies by Kuhlman & Quantz (1980) have shown that optimum survival of a Baltic stock occurs in the salinities prevailing on the spawning grounds (15–20 ‰). They concluded that the Baltic stock must be a brackish-water race, since salinities on the North Sea spawning grounds are much higher. However, actual data from the North Sea were insufficient to test whether the Baltic stock has different adaptations in these respects. In this paper, we present data on the effect of temperature and salinity on embryonic development and larval survival of a North Sea turbot population in order to test this hypothesis. To make proper comparisons with the data on the Baltic stock as presented by Kuhlman & Quantz (1980), similar experimental setups were used. Since sharp temperature drops may have a negative impact on larval survival (see e.g. Rutherford & Houde, 1995), effects in this respect were also studied.

MATERIAL AND METHODS

Eggs were provided by a hatchery using a North Sea breeding-stock from the south coast of Norway. During one gonad cycle the spawners were kept in tanks at ambient temperature conditions. They were stripped and fertilized – using one male for each female – in a salinity of 29 ‰ at a temperature of 13 °C. After about one hour they were transferred to 4-l jars of the different experimental setups. Starting on the second day after fertilization, 50 % of the water was changed every day. For each temperature or salinity studied, replicates were run using another pair of fish (A and B in Tables 1–4).

The percentage viable hatch was studied at temperatures of 6, 9, 12, 14, 15, 18 and 22 °C and salinities of 5, 10, 15, 20, 25, 30 and 35 ‰ at 14 °C. The temperature tolerance experiments were performed in an ambient salinity of 28 ‰. In another experiment conducted to study effects of temperature changes on mortality, newly hatched larvae were exposed to sharply falling temperatures over a period of three days, from 14 °C to 9, 6 and 4 °C respectively, each individual drop in temperature being made over 24 hours. Additional information on the experimental setups is given in Table 1. Different salinities were

Table 1. Temperature and salinity conditions in experiments I–III. The experiments were performed as two replicas, A and B. I: Effect of temperature on viable hatch; II: Effect of decreasing temperature (from 14 °C) on viable hatch; III: Effect of salinity on viable hatch

Exp. I				Exp. II				Exp. III				
A		B		A		B			A		B	
m.v. (°C)	S.D.	m.v. (°C)	S.D.	m.v. (°C)	S.D.	m.v. (°C)	S.D.	‰	m.v. (°C)	S.D.	m.v. (°C)	S.D.
6.3	0.52	6.5	0.47	4.3	0.32	3.6	0.17	5	13.7	1.29	14.0	1.30
9.1	0.41	9.1	0.49	6.4	0.47	6.9	0.38	10	14.1	1.13	14.1	1.16
12.2	1.00	12.2	1.00	9.4	0.28	9.4	0.25	15	13.9	0.95	14.0	1.07
13.7	0.28	13.8	0.20	14.2	0.34	13.0	0.48	20	14.2	0.94	14.2	1.04
15.3	0.71	15.1	0.62					25	14.1	1.03	14.2	0.97
18.1	0.60	17.8	0.72					30	14.2	1.20	14.3	1.00
21.6	0.79	22.0	0.38					35	14.0	1.35	13.9	1.19

m.v. = mean value; S.D. = standard deviation

prepared by using ordinary sea salt. In salinities of 5 to 20 ‰ the eggs were not buoyant. Thus, to prevent growth of bacteria on eggs lying on the bottom of the jars, 2 ppm of 20 % Terramycin (Pfizer) was added to all experiments.

Dead eggs were removed daily and were studied and counted under a microscope. The „viable hatch" was determined as the number of larvae that swam freely in the water. Incubation time was calculated as the period from fertilization until 50 % of the larvae were hatched.

RESULTS AND DISCUSSION

The duration of embryonic development from fertilization until 50 % hatch at different temperatures in a salinity of 28 ‰ declined from 210 h at 9 °C to 54 h at 22 °C, which is about 10 % faster than for the Baltic population studied at 15 ‰ S by Kuhlman & Quantz

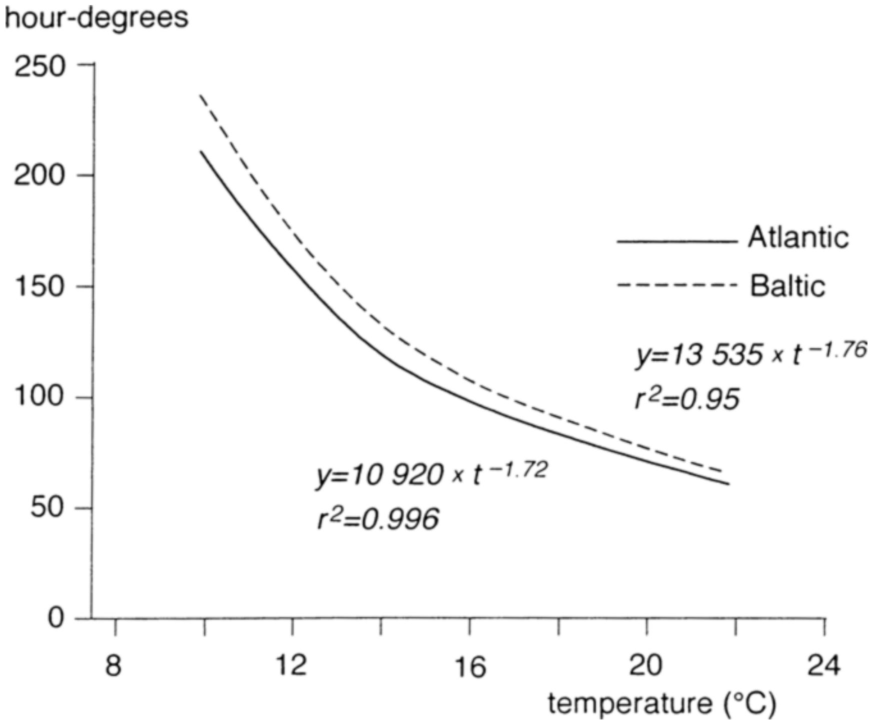

Fig. 1. Duration of embryonic development from fertilization to 50 % hatch in Baltic (from Kuhlman & Quantz, 1980) and Atlantic turbot

(1980) (Fig. 1). Increased embryonic developmental rate in higher salinity has also been demonstrated for other species of flatfish (Marx & Henschel, 1941; Alderdice & Forrester, 1968).

Survival rate of the North Sea population from fertilization up to hatch was high (40–55 %) in temperatures between 12 and 18 °C, low at 6 and 22 °C, and intermediate at 9 °C (Fig. 2 and Table 2). The level of survival at optimum temperatures is about the same as for the Baltic population studied by Kuhlman & Quantz (1980), but is much higher for the Atlantic population at temperatures between 9 and 14 °C (Fig. 2).

Investigations on the survival of Atlantic populations in different salinities during embryonic development up to hatch within the assumed optimum temperature range (14 °C) demonstrated that the highest survival rate is at salinities ranging from 20 ‰ to 35 ‰ (Fig. 3 and Table 3). Survival rate was very low at salinities of 15 ‰ and below, which was in contrast with results obtained in the Baltic population studied by Kuhlman & Quantz (1980), where the highest survival rate was at 15 ‰ and still high at 10 ‰ (Fig. 3). In the present study, there were indications that the structure of the cell wall did not develop in a normal manner when cell cleavage took place at low salinities.

Adaptations to the lower salinities in the Baltic Sea have also been demonstrated for flounder and plaice (Solemdal, 1967, 1973). This seems to be a general feature of marine species in this environment since not only flatfish but also Baltic cod show adaptations to

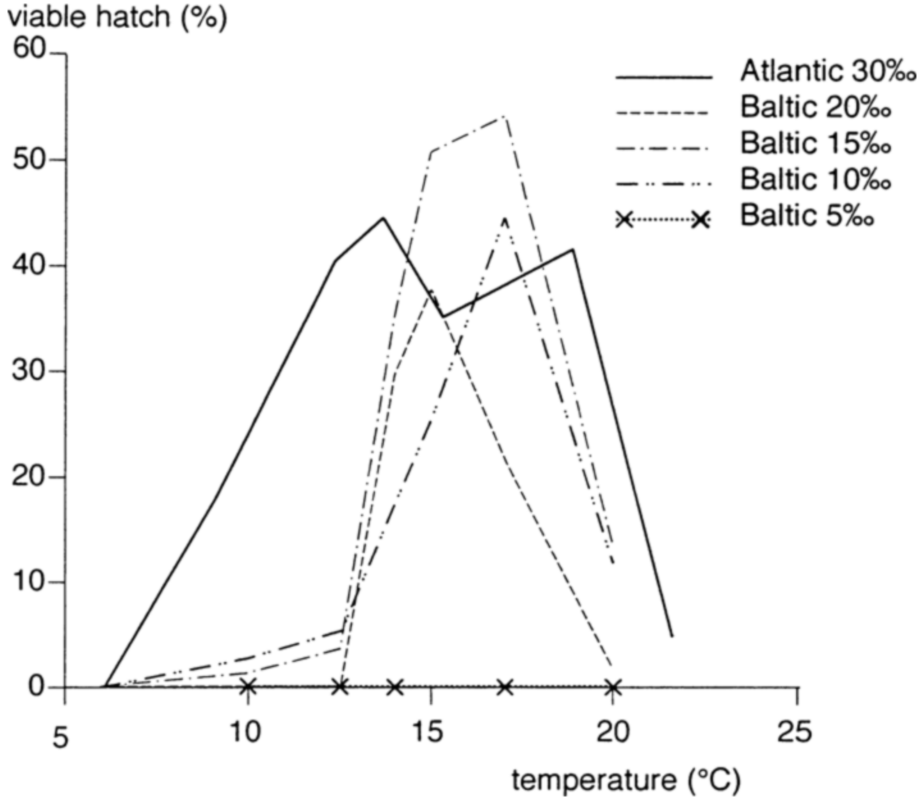

Fig. 2. Hatching frequency of turbot eggs at different temperatures and salinities in Baltic (from Kuhlman & Quantz, 1980) and Atlantic populations

Table 2. Rate of survival of turbot eggs and larvae at different temperatures

Temperature (°C)	Number of eggs A	Number of eggs B	Viable hatch (%) A	Viable hatch (%) B
6	470	460	0	0
9	533	651	22.1	13.4
12	420	410	38.1	42.7
14	450	460	37.8	51.1
15	410	410	54.4	15.8
18	430	430	29.8	53.3
22	500	480	5.6	4.2

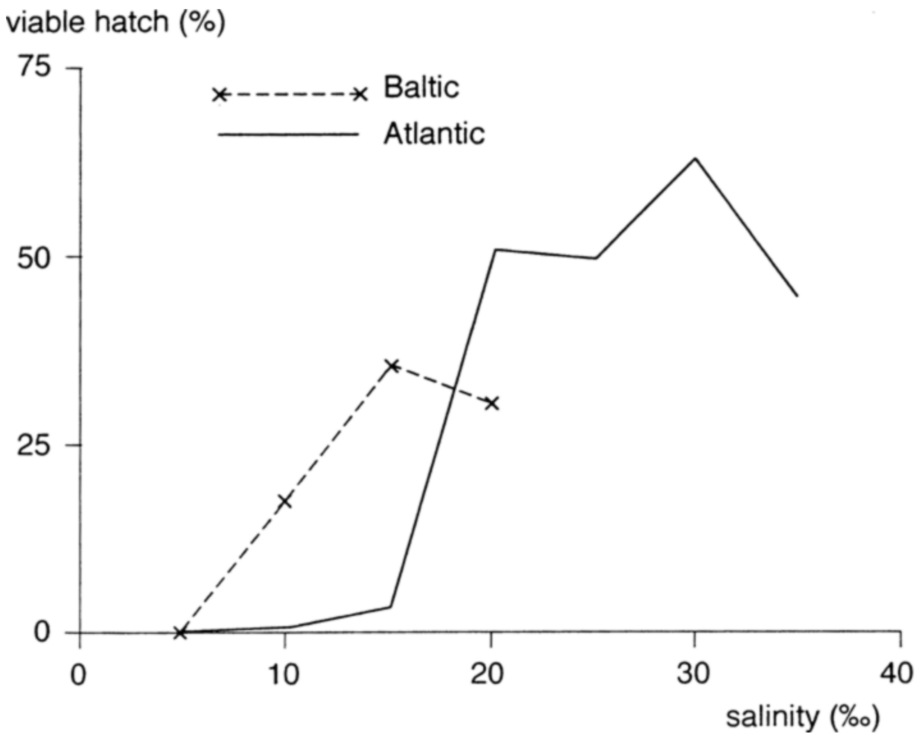

Fig. 3. Hatching frequency of turbot eggs in different salinities at 14 °C in Baltic (from Kuhlman & Quantz, 1980) and Atlantic populations

Table 3. Rate of survival of embryos in different salinities

Salinity (‰)	Number of eggs A	Number of eggs B	Viable hatch (%) A	Viable hatch (%) B
5	575	676	0	0
10	444	288	0	0
15	411	356	6.1	0
20	399	420	44.6	57.4
25	416	448	41.8	56.5
30	470	483	69.2	62.1
35	466	518	47.2	41.9

low salinity during embryonic development (Nissling & Westin, 1991a, b). The reported differences between the Atlantic and Baltic cod stocks regarding salinity tolerance (cf. Nissling & Westin, 1991a; Kjørsvik et al. 1984) are the same as those demonstrated in this paper for turbot. Thus, the Baltic populations have high survival rates in salinities of 10 and 15‰, which is an interval where there is no or only low survival among the Atlantic populations. These general results agree with the conclusion of Kuhlman & Quantz (1980) that Baltic and Atlantic turbot should be considered as different races.

When temperature dropped from the optimal temperature for hatching survival (i.e. 14 °C) down to 9, 6 and 4 °C, the larvae showed increased mortality only at the lowest temperature (about 50 % reduction, see Fig. 4 and Table 4). This low temperature is close to the lethal limit for embryo survival as presented in this paper. This implies that rapid drops in temperature caused by, for example, upwelling of cold bottom water during the early larval period, may cause severe mortality and ultimately affects year-class strength in turbot.

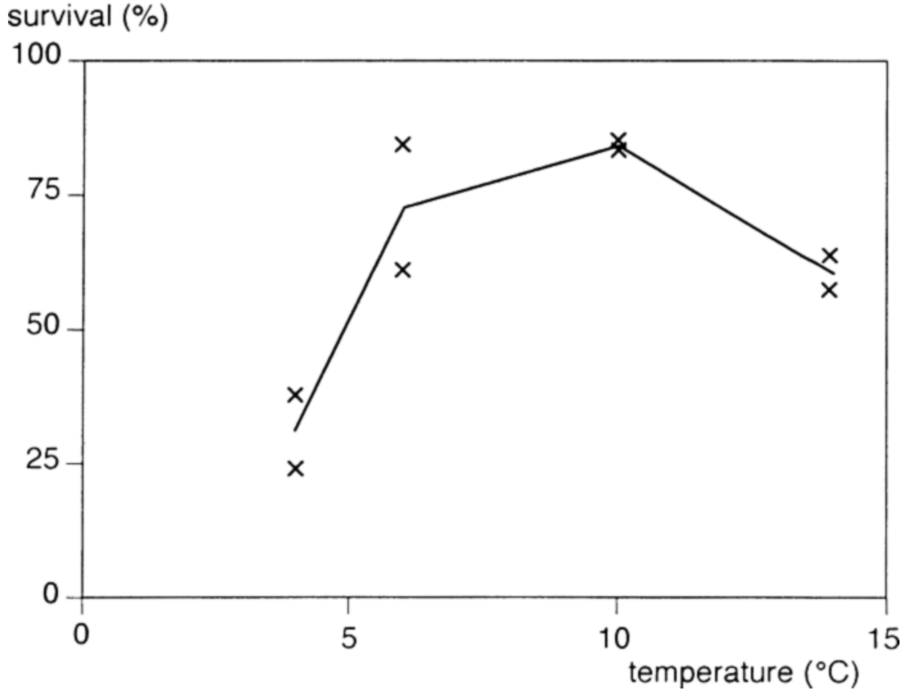

Fig. 4. Survival rate of yolk-sac turbot larvae for a three-day period at a constant temperature of 14 °C and at temperature decreases from 14° to 10, 6 and 4 °C, respectively

Table 4. Rate of survival of newly hatched larvae at decreasing temperatures

Decreases in temperature from 14 °C to	Number of larvae A	Number of larvae B	Survival (%) A	Survival (%) B
14	925	611	63.8	57.4
9	1093	1077	83.7	84.5
6	1295	1413	61.1	84.2
4	838	790	23.6	37.0

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