Aquacult Int (2007) 15:403–407
DOI 10.1007/s10499-007-9099-9

BRIEF COMMUNICATION

Improving growth in juvenile turbot (*Scophthalmus maximus* Rafinesque) by rearing fish in switched temperature regimes

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Received: 12 December 2006 / Accepted: 21 February 2007 / Published online: 12 April 2007

Abstract The effect of thermal history (16 and 20°C) on growth of juvenile turbot, *Scophthalmus maximus* (initial mean weight 72.6 g, $n = 157$) was studied. Fish were divided into four groups, two groups remaining at constant temperature (C16, C20), while fish in the other groups were transferred from either 16 to 20°C (F16-20) or from 20 to 16°C (F20-16). Between 35 and 42 fish in each tank were individually tagged at the start of the experiment. The final mean weights were significantly higher in the F20-16 group (230 g) than in the C20 (213 g), F16-20 (211 g) and C16 (205 g) groups. The overall growth rate was highest in the F20-16 group (1.17% day^{-1}) but comparable in the three other groups (1.00–1.04% day^{-1}). Our findings indicate that, even at near-optimal temperature for a given size, the temperature history of the fish may influence future growth. Based on these indications, we conclude that as turbot grow larger, the temperature should be reduced to take advantage of the change in optimal temperature for growth with increasing fish size rather than rearing at constant temperatures.

Keywords Growth · Temperature regimes · Turbot (*Scophthalmus maximus*)

Introduction

A common finding in studies examining the relationship between temperature and size is that the optimum temperature for growth ($T_{opt}G$) shifts to lower temperatures as fish

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increase in size (Imsland and Jonassen 2002). The finding of different temperature optima for different size classes together with the downward trend of $T_{opt}G$ with size can be summarized in the so-called stepwise temperature hypothesis. Instead of using constant rearing temperatures one utilizes specific temperature steps where the fish are reared at optimum temperatures defined for each size class. The benefit of these temperature steps at a realistic production scale has not yet been established in turbot. This rearing model, combined with knowledge of changes in $T_{opt}G$ for different size classes of juvenile turbot was used to test the temperature step hypothesis for fish from 70 to 230 g. As earlier studies with this size range of juvenile turbot have shown that temperatures between 16 and 20°C are optimal for growth (Imsland et al. 1996) these temperatures were chosen as the experimental temperatures in the present study. The aim was to investigate the effects of different temperature backgrounds (16 and 20°C) on the subsequent growth of juvenile turbot.

Materials and methods

Juvenile turbot of mixed parental background were used in this experiment. The eggs were spawned and hatched at France Turbot, Western France, and the larvae and reared under intensive conditions. In November 2005, a batch of approximately 12,000 turbot juveniles were brought to the commercial turbot farm Zeeland Vis BV (ZLV), Yerseke, The Netherlands and reared at 17.5°C and 18 h of light:6 h of darkness (LD18:6) prior to the experiment.

The experiment was carried out from 13 December 2005 until 22 March 2006 using four 1 m^2 square, white, polyethylene experimental tanks with a rearing volume of 400 l. Each tank was stocked with 100 juvenile turbot. Commercial formulated feed (Dan-Ex 1562) was fed until satiation during at five feeding times each day (08:00, 11:00, 14:00, 17:00 and 21:00). Apparent satiation was achieved by hand feeding the fish until no feeding activity was seen. This feeding regime was used prior to the start of and during the experimental period. Seawater at a salinity of 18 ppt was supplied from a buffer tank in which seawater (34 ppt) and groundwater (7 ppt) from a depth of 180 m were thoroughly mixed. The experimental tanks were connected to one of the commercial recirculation units (system A) in the farm at an exchange rate of approximately 800 l/kg feed per day, i.e., approximately 15% of the system volume daily. Oxygen saturation, measured daily in the effluent water of all tanks, remained above 80% at all times. The fish were reared at LD18:6 during the experimental period at ZLV. On 13 December 2005 a subgroup of fish in each tank ($n_{total} = 157$) were tagged intraperitoneally with Trovan® passive transponder tags. One treatment group (two tanks) was reared at 16°C, while the other two tanks were reared at 20°C. On 16 February 2006 we divided the fish in each temperature group into two equal parts: the fish that had been held at 16°C were either moved to the 20°C tanks or kept at the 16°C tanks, while the fish at 20°C were either kept at 20°C or moved to 16°C. In this way four experimental groups (n = 35–42 tagged fish in each group) were created: constant 16°C (C16), constant 20°C (C20), from 16 to 20°C (F16-20) and from 20 to 16°C (F20-16). The growth data presented are based on the individual tagged fish only. All tagged fish were weighed individually to the nearest 0.1 g three times during the experimental period (13 December, 16 February and 22 March). The specific growth rate (G) was calculated according to the formula of Houde and Schekter (1981). One-way anasis of variations (ANOVA; Zar 1984) was applied to calculate the effect of different temperatures on mean weights, and specific growth rates. In the case of significant ANOVA

Student-Newman-Keuls multiple-comparison tests were used to locate differences among the treatments (Zar 1984). Individual growth trajectories were analyzed using a growth curve analysis model (GCM, Chambers and Miller 1995).

During the experiment, 11 tagged fish died, corresponding to an overall mortality rate of 7.3%. The mortality occurred primarily in the two 20°C tanks in the first period caused by an outbreak of the bacteria *Edwardsiella tarda* (Padros et al. 2006). At 16°C, the mortality rate was low, but the problems with *E. tarda* increased rapidly with increasing rearing temperature. During the experiment all fish were injected three times with antibiotics (marbofloxacin 15 ppm). No size-dependent mortality was found when comparing the initial size of the fish that died to that of the surviving fish (one-way ANOVA, $P > 0.35$).

Results

The mean weights of fish in the various treatments differed from day 63 onwards (one-way ANOVA, $P < 0.05$). The final size of the F20-16 group was significantly higher (230 g) compared to the three other experimental groups (213 g, 211 g and 205 g, for the C20, F20-16 and C16 groups, respectively). Specific growth rates (G) of the tagged fish in the different experimental groups differed (one-way ANOVA, $P < 0.05$, Fig. 1). In the first period the two groups at 20°C had higher growth compared to one of the groups at 16°C (one-way ANOVA, $P < 0.05$), whereas the juveniles at F20-16 had higher growth than C16 and C20 from February to March (Student-Newman-Keuls test, $P < 0.05$). The overall growth rate was highest in the F20-16 group (1.17% day^{-1}) but comparable in the three other groups (1.00–1.04% day^{-1}). Mean individual growth trajectories were different [growth curve analysis (GCM), $P < 0.001$] between the four temperature groups in the study period. Significant differences were also found in the growth over time trajectories of the experimental groups ($P < 0.01$, Fig. 1) from December onwards, as growth declined with time in all groups, but the regression coefficient differed, with the decline in growth in the two constant temperature groups being steeper than in the F20-16 group (Fig. 1).

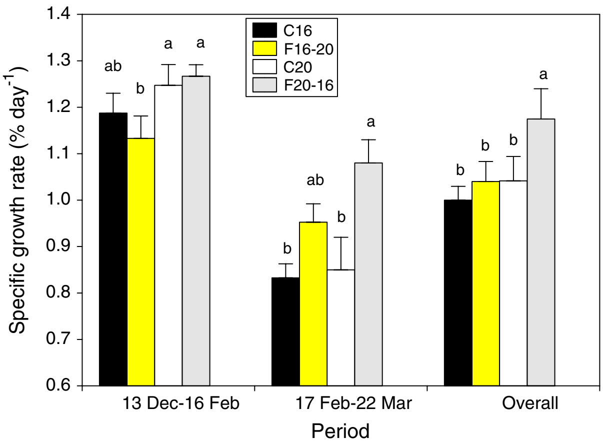

Fig. 1 Specific growth rates (G) of tagged juvenile turbot during the experimental period. Vertical lines indicate standard error of mean (SE). Different letters indicate statistical differences (Student-Newman-Keuls test) with ‘a’ being the highest value

Discussion

Growth of juvenile turbot was significantly influenced by their thermal history. THe overall growth rate was highest among the fish that had previously been reared at 20°C and then transferred to 16°C (F20-16 group, 1.12% day^{-1}) and lowest in the groups reared at constant 16°C (1.00% day^{-1}) or switched from 16 to 20°C (1.01% day^{-1}). The study indicates that, even at near-optimal temperature for a given size (Imsland et al. 1996, 2001), the thermal history of fish may influence their growth potential, so that a short rearing period at a high temperature may give a growth advantage in subsequent rearing in colder water. Such a long-term advantage of short-term heating was found for Atlantic cod *Gadus morhua* (Imsland et al. 2005), where cod reared in a declining-temperature regime were 7–12% larger than fish reared at constant temperatures. The authors concluded that environment-related growth differences in 0-group (i.e. year of birth) of fish are mirrored by size differences at harvesting. The long-term advantage of rearing at high temperatures for short periods has previously been indicated for turbot (Imsland et al. 1997). Combined with the current data, these findings are important for commercial rearing of turbot as prior growth advantages can benefit later stages of the production.

In other demersal fish species the positive effect of a T_{opt}G rearing scheme has been noted. When studying the growth of spotted wolffish (*Anarhichas minor*) larvae up to 63 days after hatching (size range 0.2–3 g), Hansen and Falk-Petersen (2002) found that growth was highest when larvae were moved from 12 to 10 and later to 8°C, compared to constant temperatures. In Atlantic halibut *Hippoglossus hippoglossus* (size range, 160–400 g) reared at constant (11°C and 14°C) or switched (14°C moved to 11°C and vice versa) temperature regimes, Aune et al. (1997) found that the growth rate was highest in fish transferred from 14°C to 11°C. This coincides with the T_{opt}G for Atlantic halibut, which has been shown to decrease from 14.9 to 12.7°C in the early juvenile stage (Jonassen et al. 1999). Our findings are in line with these results, demonstrating the possible benefits from rearing fish in stepwise regimes instead of at constant temperatures.

Conclusion

Juvenile turbot transferred from a high (20°C) to a low (16°C) temperature displayed higher growth than groups reared at constant (16°C and 20°C) or increasing (from 16 to 20°C) temperature regimes. This indicates that, even at near-optimal temperature for a given size, the temperature history of the fish may influence future growth. Based on these indications, we conclude that as turbot grow larger the temperature should be reduced to take advantage of the change in optimal temperature for growth with increasing fish size rather than rearing at constant temperatures.

Acknowledgements This study was financed by the European Commission (Contract: 508070 TURPRO).

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