

**LOCAL ADAPTATIONS OR PHENOTYPIC PLASTICITY
IN THERMAL PERFORMANCE? EVIDENCE
FROM FIELD STUDIES ON GROWTH IN 63 POPULATIONS
OF BROWN TROUT AND ATLANTIC SALMON**

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EXTENDED ABSTRACT ONLY – DO NOT CITE

New laboratory based growth models for brown trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*) fed on maximum rations (Elliott et al., 1995, Elliott and Hurley, 1997) were used as baselines to explore latitudinal variation in growth among natural populations. The models allowed us to control for differences in ambient temperatures and fish size among populations. Annual growth rates of anadromous brown trout parr from 22 Norwegian populations and Atlantic salmon parr from 19 Norwegian populations at 61 to 70 °N were compared with predictions from the growth models. Published field data for brown trout from one Spanish, 15 British and four Danish populations at 44 to 58 °N and for Atlantic salmon from two British populations at 57 and 58 °N were included in the analyses to increase the latitudinal range.

Among the Norwegian populations of brown trout, the ratio between observed and predicted growth rates were not significantly different from 1.00 in eight rivers, significantly higher in eight, and significantly lower in six. Observed growth was highest, relative to predicted growth, in the coldest rivers. In

Spanish, British and Danish rivers, observed growth did not exceed predicted growth.

The ratio between observed and predicted annual growth rate of brown trout decreased significantly with increasing annual mean temperature (Fig. 1). Observed annual growth was higher than predicted growth only in rivers with an annual mean temperature lower than 5.1 °C, and this indicates that some kind of thermal adaptation may occur in trout populations in the coldest rivers.

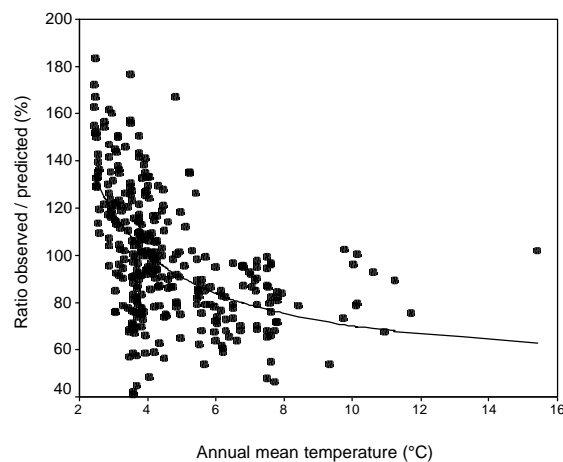


Figure 1. Relationship between the ratio of observed to predicted annual instantaneous growth rate of brown trout (RA %) in one Spanish, 15 British, four Danish and 22 Norwegian populations ($n = 365$) and the annual mean temperature (T_{ANN} °C) in the rivers in the sampling years ($RA = 186 / T_{ANN} + 55.0$, $r^2 = 0.335$, $P < 0.001$).

Regression analyses (Table 1) showed that besides the direct effects of temperature and body size predicted by the growth model, annual growth rates of brown trout were significantly related to annual mean temperature, densities of juvenile salmonids, duration of twilight (average for May-August) and latitude. Adding these variables to the original model increased the explanatory power from 73.9 to 80.6%.

Table 1. Multiple regression analysis (stepwise inclusion procedure, $P < 0.05$) of observed annual growth rate of juvenile brown trout (G_{OBS}) in relation to predicted growth rate from the model of Elliott *et al.* (1995) (G_{PRED}), latitude (L) of rivers, inverse of annual mean water temperature ($1/T_{ANN}$), annual amplitude of monthly mean temperatures (T_V), day-length at midsummer (DL), number of bright nights each year (BN), duration of the civil twilight period (TW), density of juvenile brown trout (D_{BT}) and total juvenile salmonid density (D_{TOT}).

Variables	Unstandardised Coefficients (\pm SE)	Adjusted R^2 change	t	P
G_{PRED}	0.866 ± 0.026	0.739	33.538	< 0.001
$1/T_{ANN}$	2.590 ± 0.324	0.045	7.999	< 0.001
D_{TOT}	-0.00292 ± 0.00064	0.009	-4.602	< 0.001
TW	0.00173 ± 0.00042	0.008	4.153	< 0.001
L	-0.0144 ± 0.0049	0.005	-2.954	0.003
T_V			1.948	n.s.
DL			1.253	n.s.
D_{BT}			-0.661	n.s.
BN			0.263	n.s.
(Constant)	0.253 ± 0.271		0.933	n.s.

In the two British as well as eight of the Norwegian Atlantic salmon populations, the observed growth rates were not significantly different from the predicted ones, in six rivers they were significantly higher, and in three rivers they were significantly lower than those predicted from the model. Observed growth was highest, relative to predicted growth, in the coldest rivers.

The ratio between observed and predicted annual growth rate in the 21 Atlantic salmon populations included in the analyses decreased significantly with increasing annual mean temperature. Based on multiple regression analysis, the observed annual growth rate of Atlantic salmon (G_{OBS}) was best described by the following model ($F_{3, 226} = 141.1$, $p < 0.001$):

$$G_{OBS} = 0.987 G_{PRED} + 5.114/T_{ANN} - 0.0565 L + 2.515$$

where G_{PRED} was the annual growth rate predicted from the model of Elliott and Hurley (1997), T_{ANN} was annual mean temperature and L was latitude. The new

model explained 64.7 % of the variation in annual growth, compared to 46.9 % by the original model.

In summary, the present study shows that most of the variation in growth of brown trout and Atlantic salmon in Europe can be related to environmental variables. Most of the observed variability in growth rates and body size for juvenile stages among these fish populations is phenotypic and a product of local conditions. However, even after taking into consideration the effects of temperature predicted from laboratory studies and several biological and environmental factors, a significant relationship existed between growth and temperature. This relationship (explaining ca 5 % of the variance in brown trout) occurred because the laboratory model strongly underestimated growth in some of the coldest rivers. Thus the combined modelling and field approach has successfully narrowed the geographical area and the environmental conditions in which thermal adaptation may occur. In some of the coldest rivers both species may show adaptation to life at low temperatures and/or short growth seasons. To what extent these adaptations are genetically based can be determined by performing experiments in a common environment with a selection of the populations. In contrast to several earlier studies, we found little if any support for the countergradient variation hypotheses for thermal adaptation in ectothermal animals. The general pattern appears to be phenotypic plasticity.

References

- Elliott, J.M. and M.A. Hurley. 1997. A functional model for maximum growth of Atlantic salmon parr, *Salmo salar*, from two populations in Northwest England. *Functional Ecology* 11:592-603.
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