HABITAT SUITABILITY ASSESSED BY A MODEL OF THE GROWTH OF SALMON (*SALMO SALAR*) PARR

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EXTENDED ABSTRACT ONLY – DO NOT CITE

Abstract

A model for compensatory growth of trout was adapted to model body growth of Atlantic salmon by including a behavioural response to temperatures between 0°C and 6°C. Growth responses at higher temperatures (to 22.5°C) were incorporated from a published salmon model. The new, hybrid, model was parameterised to represent growth in ideal conditions, with data from other sites and experiments. Using a detailed temperature record from the Girnock Burn, Scotland, the new model was tested against 18 years of independent data on four age-groups of salmon parr and performed better than the salmon model from which it was derived. A site-quality parameter was introduced to explain the difference between ideal growth given the temperature record and the observed, lower, growth rates. The site quality parameter varied between years in a manner that was robust to uncertainties in the model's parameters. The potential of the model for managing salmonid populations and habitats is discussed, including the need to model the smolting process and density-dependent growth.

The study site

The Girnock Burn flows for 9.4 km to join the River Dee at 57° 3' N, 3° 6' W, some 80 km from the estuary at Aberdeen. Electro-fishing surveys of parr were conducted annually between 1969 and 1986. Fished sections represented the dominant habitat types and totalled 1,260 m^2. Fork-lengths were measured, and Length to Weight relationships described from a representative sample by {a,b} in {Weight = a*Length^b}.

Water temperatures were recorded at hourly intervals near the stream's confluence with the River Dee over the period of study: the model uses daily means of the hourly values. Weight loss at low food ingestion rates over winter were estimated using data from Catamaran Brook, New Brunswick (Cunjak, pers. comm). Other parameters were estimated from data in the literature.

Applying existing models to the Girnock data

Given the Girnock temperature record the model of Elliott and Hurley (1997) (E&H) did not predict observed growth either well (Table 1), or realistically, mainly because the weight losses predicted over winter were too high (winter temperatures in the Girnock fell below the parameterisation level of the E&H model for prolonged periods).

We therefore adapted a physiological model (Broekhuizen *et al.*, 1994). This model firstly allows fish of the same weight, W, to be in different conditions, as described by both their structural weight, S (tissues that cannot be catabolised to provide energy) and a reserve weight, R (tissues can be catabolised), such that W=R+S. Further, the fish can alter their behaviour, and hence maintenance energy needs, when low temperatures constrain assimilation and growth. The new model combined the behaviour and physiology of Broekhuizen *et al.* (1994) with the temperature response functions of Elliott and Hurley (1997); new parameters were estimated from the literature and Catamaran Brook data.

Testing and development

The new ‘hybrid’ model was initially run with parameters from the literature that represented growth in ideal conditions (food not limiting) and driven by the Girnock temperatures. Its winter growth trajectories were now plausible, but weights were generally over-predicted, probably because fish in the wild were food-limited: the fit was improved, but not good (Table 1). The model was next amended to estimate the degree of reduced assimilation, ϕ, that best fitted the fish growth data (assuming wild fish fed less well than those in E&H's experiments). The best estimate of a single value of ϕ (=0.90), which was constant across all years, improved the fit only slightly (Table 1), but estimating a set of ϕ values (one for each year, having similar effects on all age classes) improved the fit appreciably, especially within age-classes (Table 1).

Boot-strap re-sampling procedures demonstrate that the annual estimates of ϕ are robust to both the variation in the fish caught and to likely uncertainties in the model's other parameter estimates (Fig 1).

The poorer fit to the data for 3+ fish can probably be improved by incorporating the smolting process into the model, such that the larger 2+ fish leave as smolts and only the smaller 2+ remain to be measured again, as 3+ parr.

Given minimal electro-fishing data (once annual) and a temperature record, the present model appears to provide a robust way whereby fisheries managers can assess if their stocks are 'growing near maximal potential' (ϕ=1.0) given the temperatures at any site. Analysis of ϕ over years would indicate the scope for 'habitat' improvement.

Acknowledgements

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References

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Elliott, J.M. and Hurley, M.A. 1997. A functional model for maximum growth of Atlantic salmon parr, *Salmo salar*, from two populations in northwest England. Funct. Ecol. **11;** 592-603.

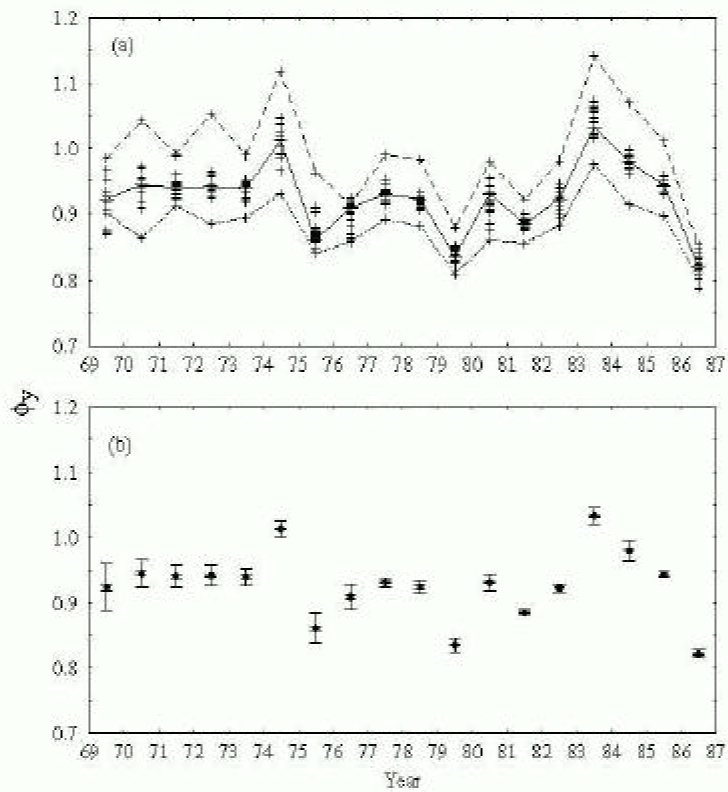
Table 1. Percent variances of the Girnock data explained by the different models, both across ages and when the fits are compared within age-classes.

	Across Ages	Within Ages				Model significance.		
Model Fitted		**0+**	**1+**	**2+**	**3+**	**d.f.**	**F**	**F sig.**
EH	42	13	10	11	0.6	0	~	~
CGME: Max	83	17	0.1	0.5	12	0	~	~
single ϕ	85	15	0.1	0.6	12	1	156.4	<<0.001
annual ϕ	92	**51**	**24**	**73**	**23**	18	1.8	0.052
Data Points	57	13	14	15	15	~	~	~

Figure 1. Sensitivity analyses of the CGME when predicting ϕ.

1.a The solid line joins predictions of ϕ using the observed temperature data, while the dotted and dashed lines join similar predictions of ϕ assuming the temperatures were consistently +1 and –1 ^{o}C different from observed, respectively. The + signs, in columns for each year, show the range of values of ϕ predicted when several model parameters, that are imprecisely known, were varied by amounts commensurate with their uncertainty (see list in Appendix 3).

1.b Variations in ϕ induced by 50 bootstrap re-samples of the fish size data. Dots show ϕ estimates with the actual data and the outer bars are one standard deviation of the bootstrap error distribution (inner bars are one standard error). Note that $0.8 < \phi < 1.0$ in 16/18 years and ϕ is never significantly greater than 1.0.



(a)
(b)
1.2
1.1
1.0
0.9
0.8
0.7
69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87
ϕ_y
Year