Why are our grayling getting shorter?

Explaining growth patterns in European grayling near their southern range limit

Stephen D. Gregory¹, Tea Bašić², Jessica E. Marsh¹,³, Richard J. Cove⁴
Wylye grayling are getting shorter
Wylye Grayling Survey (WGS)

• Annual electrofishing surveys since 1996
  • 23 years!

• \( \approx 12K \) records from 9K individual grayling
  • fork length & weight
  • scales

• River conditions
  • daily temperature
  • sub-daily flow
Wylye Grayling Survey (WGS)

• e/f surveys with “stop nets”

• Single run survey
  • relative number
  • since 1996

• Multiple run survey
  • actual density
  • since 2009
Trout!

- 2009 – ongoing
- Multiple run e/f surveys
- Six sites
- ≈7500 individual length & weight records
Aims

Build and compare models to explore how environmental variables explain patterns in length-at-age
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1) von Bertalanffy growth function
2) Include environmental variables
3) Model building & comparison
4) Model inference
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von Bertalanffy growth

\[ E(L|t) = L_\infty \left( 1 - e^{-K(t - t_0)} + \epsilon \right) \]

where

- \( E(L|t) \) is the expected length \( L \) of fish age \( t \)
- \( L_\infty \) is the expected length of the oldest fish
- \( K \) is the Brody (growth-like) coefficient
- \( t_0 \) is the fish age when it has length 0mm
von Bertalanffy growth

\[ E(L|t) = L_{\infty} \left( 1 - e^{-K(t - t_0)} + \epsilon \right) \]

\( L_{\infty} \) enforces an upper average limit on \( L \)
von Bertalanffy growth

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\( L_\infty \) enforces an upper average limit on \( L \)
\( K \) is the slope of mean age on length
\( t - t_0 \) modifies \( K \) to give curve based on \( t \)
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Brody growth coefficient $K(t - t_0)$

Can be modified to include:

- Seasonality e.g., Pauly & Morgan 1987
- Development stage e.g., Soriano et al. 1992
- Reproduction e.g., Minte-Vera et al. 2016
- Covariates e.g., Bal et al. 2011
Brody growth coefficient $K(t - t_0)$

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- Reproduction e.g., Minte-Vera et al. 2016
- Covariates e.g., Bal et al. 2011

$$K = K^*(t - t_0)f(T)g(D)$$

* Journal of Fish Biology (2011) 78, 1002–1022
  doi:10.1111/j.1365-2469.2011.02902.x, available online at wileyonlinelibrary.com

**Effect of water temperature and density of juvenile salmonids on growth of young-of-the-year Atlantic salmon *Salmo salar***

G. Bal*, E. Rivot*, E. Prévost**, C. Piou*** and J. L. Baglinière*‡
Environmental drivers of growth

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Description</th>
<th>Influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp.</td>
<td>Mean growing temperature</td>
<td>Mean water temperature during growing period from peak emergence to autumn survey</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Growing degree days</td>
<td>Sum of mean daily water temperatures above 6oC during growing period from peak emergence to autumn survey</td>
<td>+</td>
</tr>
<tr>
<td>Flow</td>
<td>Mean growing flow</td>
<td>Mean water flow during growing period from peak emergence to autumn survey</td>
<td>-</td>
</tr>
<tr>
<td>Density</td>
<td>Conspecific abundance</td>
<td>Estimated density of all ages of European grayling during autumn survey</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Heterospecific abundance</td>
<td>Estimated density of all ages of brown trout during autumn survey</td>
<td>-</td>
</tr>
</tbody>
</table>
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Results

- Heterospecific abundance
- Conspecific abundance
- Growing degree days
- Mean growing temp.
- Mean growing flow

Pearson correlation

1.0 0.5 0.0 -0.5 -1.0
Results

The graph shows the relationship between age and fork length (mm) for different models. The models include:
- model0
- model1a
- model1b
- model1c
- model1d
- model1e
- model2a
- model2b
- model2c
- model3

The data points represent the observed fork lengths at various ages, with the curves indicating the predicted growth patterns for each model.
## Results

<table>
<thead>
<tr>
<th>Model</th>
<th>Terms</th>
<th>$elpd_{\text{loo}}$ (se)</th>
<th>$p_{\text{loo}}$ (se)</th>
<th>$\text{looic}$ (se)</th>
<th>$\delta_{\text{looic}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Mean growing temperature &amp; Conspecific &amp; heterospecific abundance</td>
<td>-7742.33 (36.65)</td>
<td>5.89 (0.49)</td>
<td>15484.65 (73.29)</td>
<td>0</td>
</tr>
<tr>
<td>1a</td>
<td>Mean growing temperature</td>
<td>-7760.03 (35.48)</td>
<td>5.41 (0.55)</td>
<td>15520.06 (70.97)</td>
<td>35.41</td>
</tr>
<tr>
<td>1d</td>
<td>Mean growing temperature &amp; flow</td>
<td>-7770.67 (35.85)</td>
<td>5.97 (0.46)</td>
<td>15541.34 (71.70)</td>
<td>56.69</td>
</tr>
<tr>
<td>1e</td>
<td>Mean growing temperature &amp; Growing degree days</td>
<td>-7775.18 (35.11)</td>
<td>5.84 (0.47)</td>
<td>15550.37 (70.22)</td>
<td>65.72</td>
</tr>
<tr>
<td>1b</td>
<td>Growing degree days</td>
<td>-7797.09 (35.07)</td>
<td>5.33 (0.54)</td>
<td>15594.18 (70.13)</td>
<td>109.53</td>
</tr>
<tr>
<td>1c</td>
<td>Mean growing flow</td>
<td>-7815.05 (35.67)</td>
<td>6.32 (0.53)</td>
<td>15630.1 (71.33)</td>
<td>145.45</td>
</tr>
<tr>
<td>2c</td>
<td>Conspecific &amp; heterospecific abundance</td>
<td>-7856.54 (36.49)</td>
<td>7.32 (0.48)</td>
<td>15713.08 (72.98)</td>
<td>228.43</td>
</tr>
<tr>
<td>2b</td>
<td>Heterospecific abundance</td>
<td>-7859.42 (36.40)</td>
<td>6.05 (0.53)</td>
<td>15718.84 (72.80)</td>
<td>234.19</td>
</tr>
<tr>
<td>2a</td>
<td>Conspecific abundance</td>
<td>-7862.65 (36.24)</td>
<td>5.81 (0.44)</td>
<td>15725.31 (72.49)</td>
<td>240.66</td>
</tr>
<tr>
<td>0</td>
<td>Null</td>
<td>-7871.41 (36.12)</td>
<td>4.06 (0.32)</td>
<td>15742.82 (72.24)</td>
<td>258.17</td>
</tr>
</tbody>
</table>
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Inference

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<thead>
<tr>
<th>Type</th>
<th>Parameter</th>
<th>Effect direction</th>
<th>Estimate</th>
<th>Lower CI</th>
<th>Upper CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural</td>
<td>$K^*$</td>
<td></td>
<td>1.489</td>
<td>1.203</td>
<td>1.833</td>
</tr>
<tr>
<td></td>
<td>$L_\infty$</td>
<td></td>
<td>391.418</td>
<td>381.637</td>
<td>401.867</td>
</tr>
<tr>
<td></td>
<td>$t_0$</td>
<td></td>
<td>0.204</td>
<td>0.176</td>
<td>0.229</td>
</tr>
<tr>
<td>Environmental</td>
<td>$\beta_{temp}$</td>
<td>++</td>
<td>0.078</td>
<td>0.066</td>
<td>0.090</td>
</tr>
<tr>
<td></td>
<td>$\beta_{flow}$</td>
<td></td>
<td>-0.006</td>
<td>-0.024</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>$\beta_{con}$</td>
<td>+</td>
<td>0.001</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>$\beta_{hetero}$</td>
<td>+</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Discussion

• Temperature +ve for grayling growth
  • Similar findings for many other fish spp, incl trout
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• Flow –ve for grayling growth
  • Higher flow -> higher energy expenditure -> lower growth?
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• Grayling and trout abundance +ve grayling growth
  • Unexpected...
  • Good conditions favour high abundance and high growth?
Perspectives

• Generalise to hierarchical model
  • Treat 6 sites as: “independent”, “related” and “pooled”

• Further explore results
  • Consider seasonal explanatory variables?

• Explore future climate change scenarios
Thanks

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Steve’s book club

Reviews:

⭐⭐⭐⭐⭐ “Fascinating!” – A. Grayling
⭐⭐⭐⭐ “Quite informative” – A. Trout
⭐⭐⭐⭐⭐ “Best book ever written” – R. Cove

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It is widely recognised that human activities have impacted abundances of wildlife populations, including fish. In some cases, the mechanism of the impact is unambiguous, such as large-scale harvesting of Atlantic salmon on their feeding grounds west of Greenland. In other cases, however, the mechanism of the impact is less clear. For example, human activities can cause unfavourable environmental conditions that impact individual fish body condition, with potential consequences to their subsequent survival. In this study, we explore the effects of environmental conditions on growth of individual European grayling in a southern English chalk stream because (1) grayling are sensitive to environmental conditions, and (2) this shrinking population is at the southern limit of their range, therefore vulnerable to climate change impacts. We describe the growth of a large sample of different age grayling marked and recaptured grayling at six sites monitored as a part of the long-term River Wylye Grayling Study (WGS). We build statistical models of varying complexity and compare them to isolate the combination of seasonal and annual temperature and flow metrics that best describes their growth. We then explore and discuss the implications of our findings for grayling and other salmonid growth under a changing climate.
Inference

\[ E(L|t) = L_\infty \left( 1 - e^{-K(t-t_0)} + e(-\beta_{\text{temp}} \times \text{temp}) + e(-\beta_{\text{con}} \times \text{con}) + e(-\beta_{\text{hetero}} \times \text{hetero}) + \epsilon \right) \]