Kolarctic ENPI CBC – Kolarctic salmon project (KO197) - Report XIII

# Long-term variations in the juvenile salmon (*Salmo salar*) growth and the temperature effects in the River Tana from 1990 to 2012

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*Cover picture: Juvenile wild salmon scale, caught in May age 3 + years (in the beginning of fourth growth season), source FGFRI.*

*This report has been produced with the assistance of the European Union, but the contents can in no way be taken to reflect the views of the European Union.*

# Abstract

Different age groups (0+, 1+ and 2+ -juveniles) of salmon have slightly different temperature requirements. For all age groups, in July the average water temperature was the most significant factor for growth, but the timing and optimal temperatures were different. The results are based on the best generalized additive model explaining the growth increment of juveniles. For the first growth increment of juveniles, the average temperature at the end of July was the most important factor, not only one optimal average temperature was found. The second growth increment was best explained by the average temperature at the beginning of July, which had an optimal temperature around 12-13 °C. The third growth increment was best explained by the average temperature in the middle of July having an optimal temperature around 16 °C.

# Results

The aim of this study was to find out, how the changes in water temperature in the River Tana affect the growth of the salmon juveniles of different age groups in different years. We had data on the growth increments of the first (Figure 1), second (Figure 2) and third (Figure 3) year river juveniles from 1976 to 2011 and river temperature data for the River Tana since 1976. We only analyzed the data from 1991 onwards as it seems that there has been a bias in river temperature sampling until the year 1990, since the river temperatures did not follow the pattern of the air temperature measurements made by the Finnish Meteorological Institute in the same area. From 1991 onwards the sampled river temperatures and air temperature measurements do correlate, so in the study we used river temperatures from 1991 to 2011.

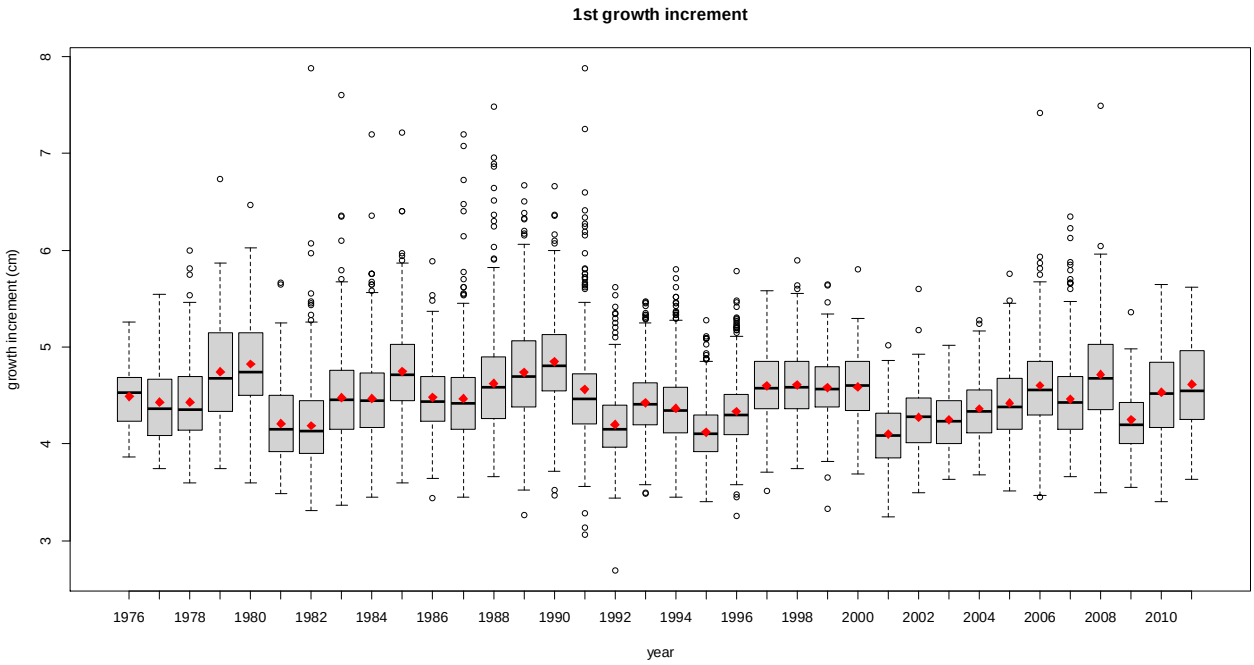


Figure 1. Boxplot of the 1st year growth increments of juvenile salmon in the River Tana. Means are shown as red dots.

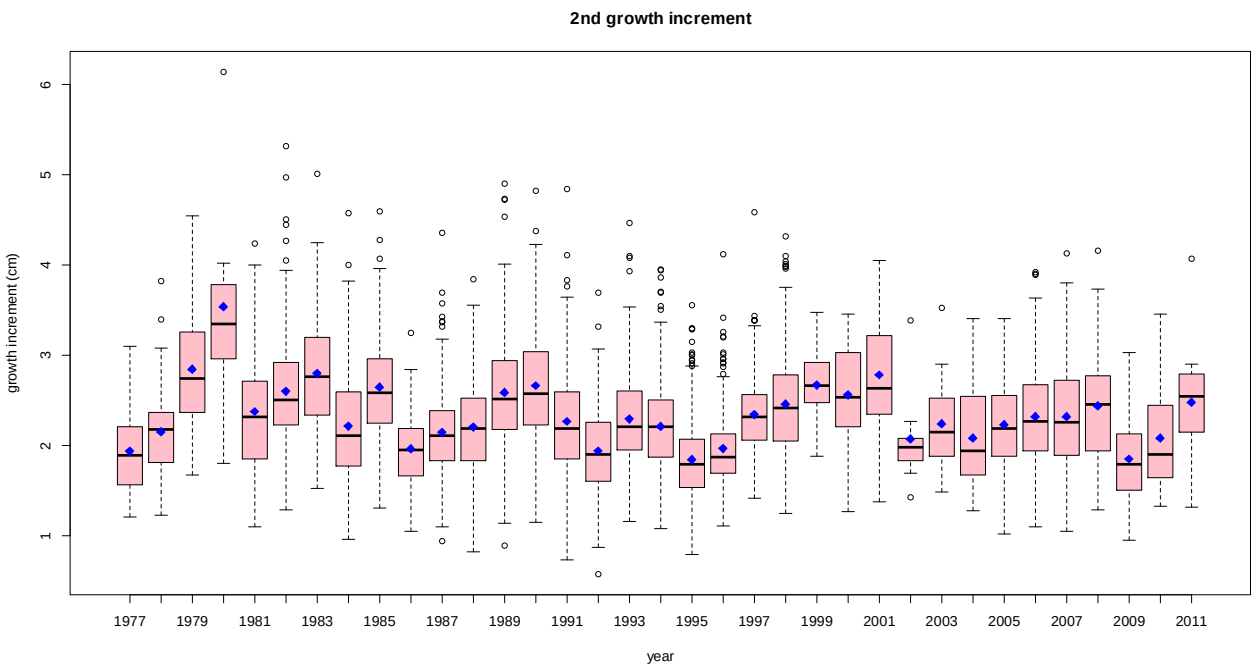


Figure 2. Boxplot of the 2nd year growth increments of juvenile salmon in the River Tana. Means are shown as blue dots.

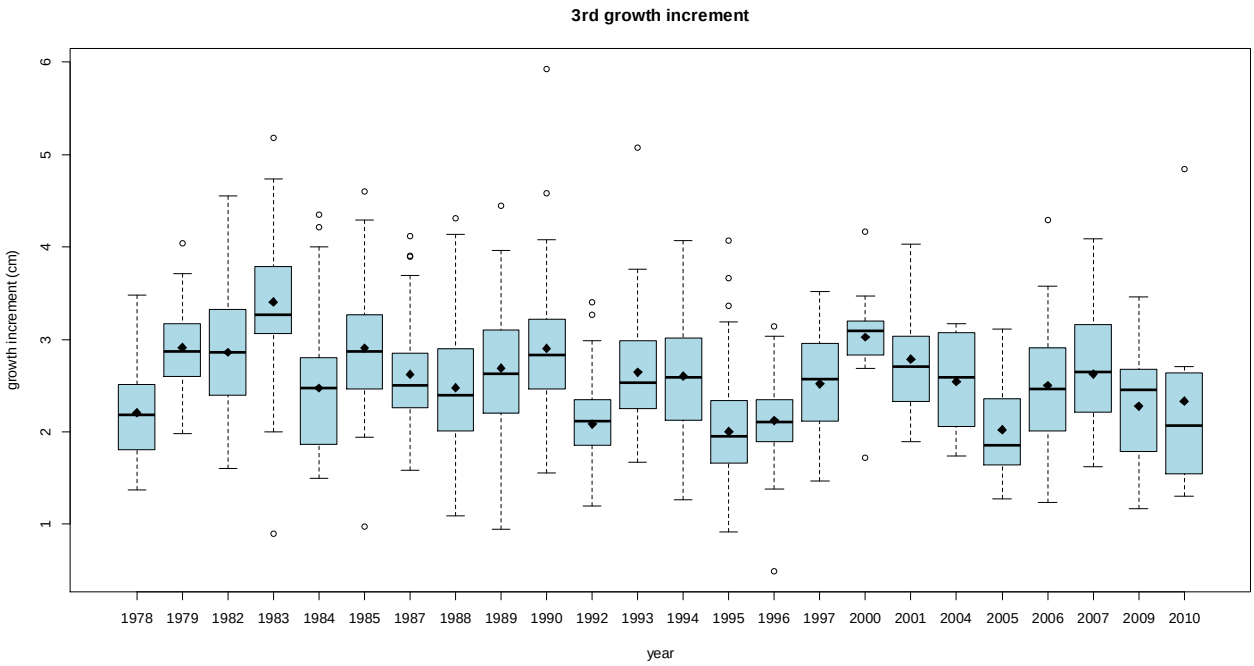


Figure 3. Boxplot of the 3rd year growth increments of juvenile salmon in the River Tana. Means are shown as black dots.

The growth increments of the individual juvenile salmon do not correlate in consecutive years (Figure 4). So the intrinsic factors alone will not explain the growth rate for juveniles in different ages. However, the median growth increments between the first year and second year growers as the second and third year growers do correlate in the certain years (Figure 5). So it seems that there is some extrinsic factor that explains the growth rate of the juveniles. However, there is no significant correlation between the median growth increments of the first and third year growers, which might be caused by the different growth requirements of the juveniles at a different age.

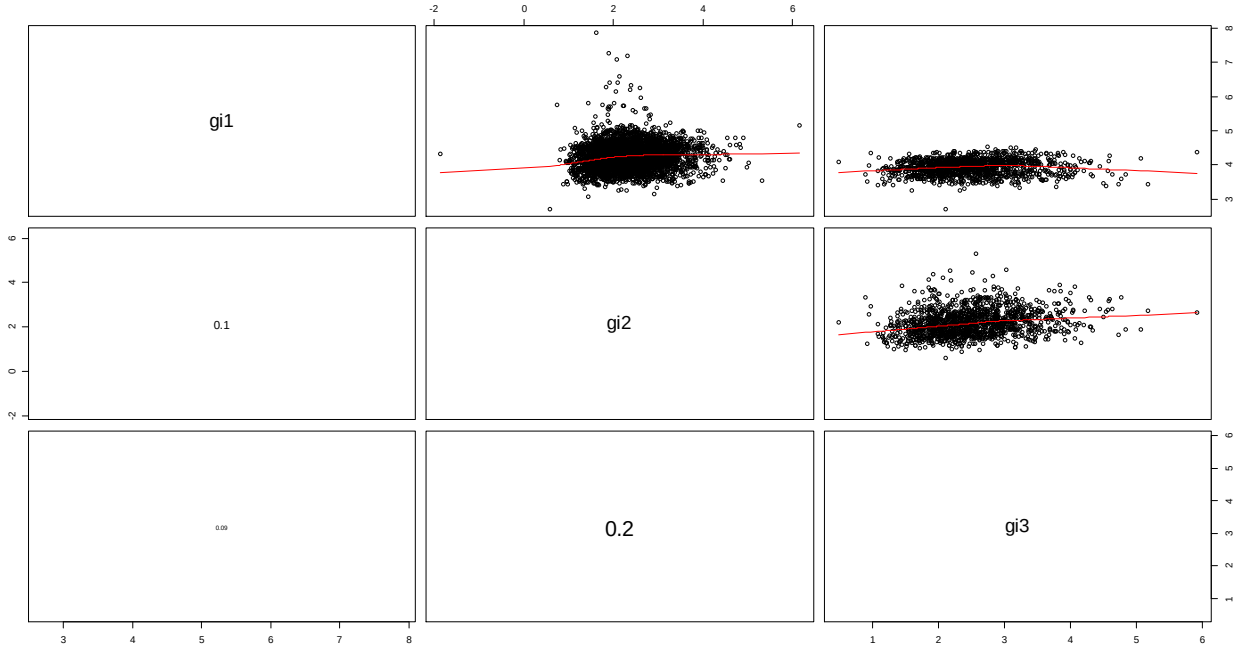


Figure 4. Correlations between the growth increments of individuals in consecutive years.

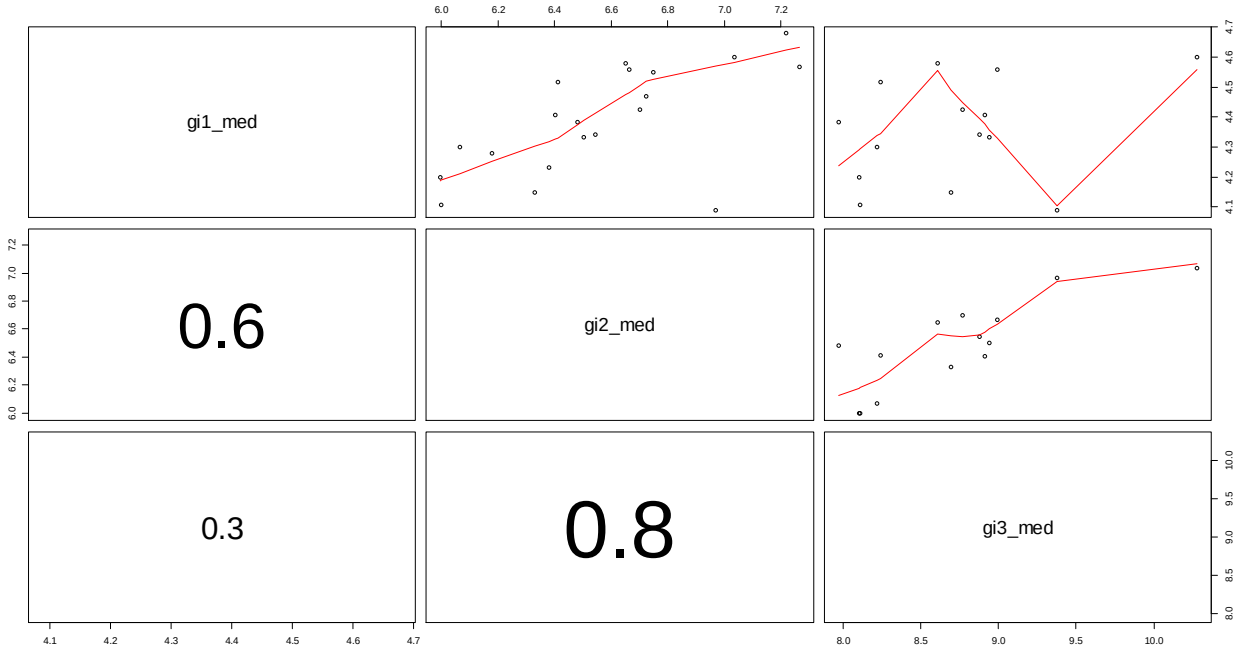


Figure 5. Correlation between the median growth increments at the given year.

Previous studies have shown that the growth of the River Tana juvenile salmon is the fastest in the beginning of July. We calculated the average over five 10-day periods from the end of June to the beginning of August to study the effect of river temperatures on juvenile growth. Explanatory variables used were average water temperature from June 21st to 30th. (variable name *aver_June3*), from July 1st to 10th (*aver_July1*), from July 11th to 20th (*aver_July2*), from July 21st to 30th (*aver_July3*) and from July 31st to August 9th (*aver_Aug1*). The average temperatures of consecutive time periods were correlated for all age groups and were not used in the same model (Figures 6, 7 and 8). We also tested the effect of the year and accumulated water temperature (*awt*) (Figure 9) over July on the juvenile salmon growth at different age. There is a difference in accumulated water temperature in cold and warm years.

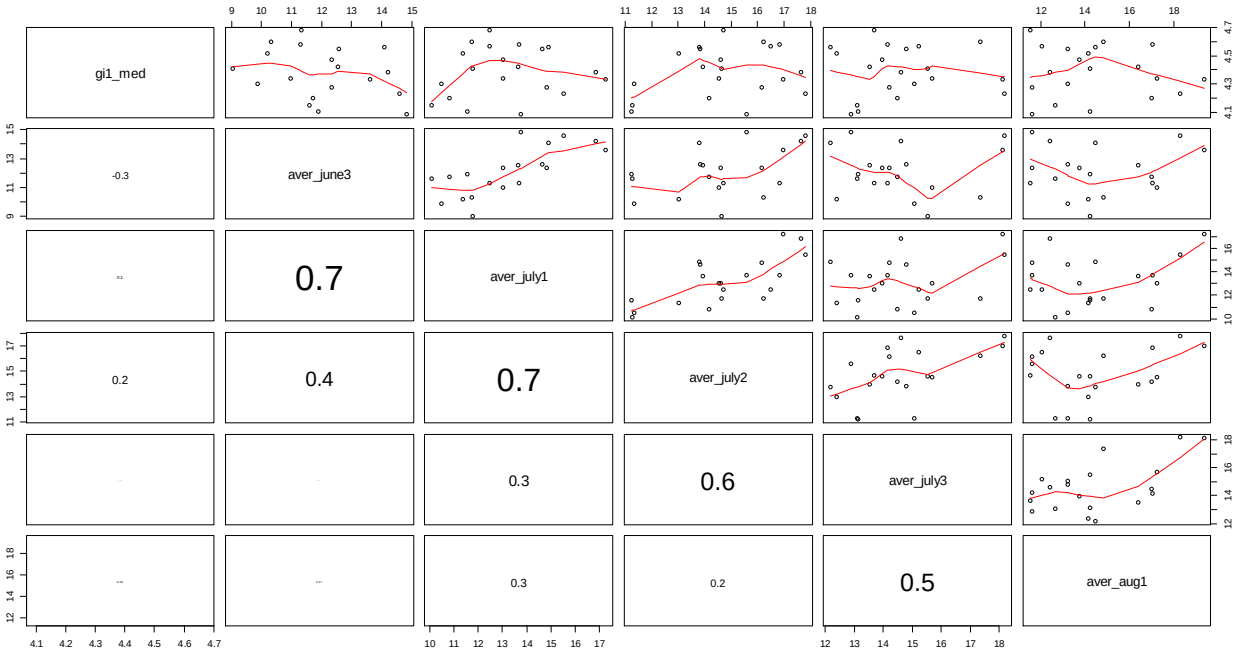


Figure 6. Correlations between the first year growth increment and averages over 10-days river temperatures from the beginning of June to the beginning of August.

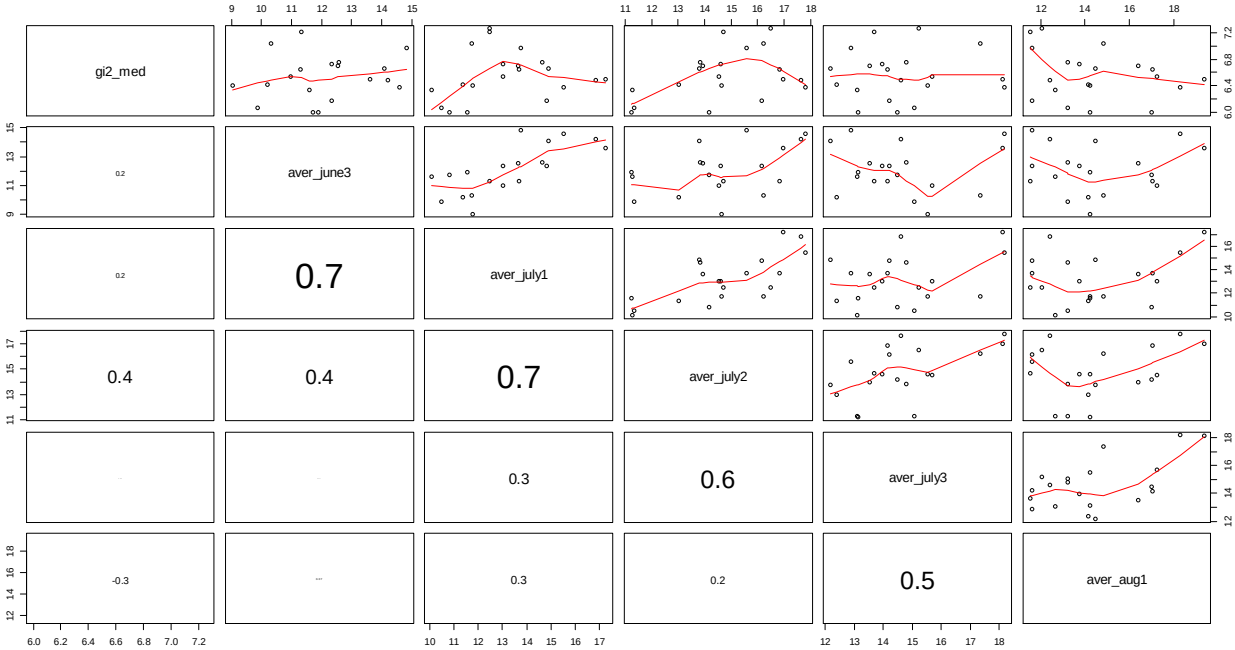


Figure 7. Correlations between the second year growth increment and averages over 10-days river temperatures from the beginning of June to the beginning of August.

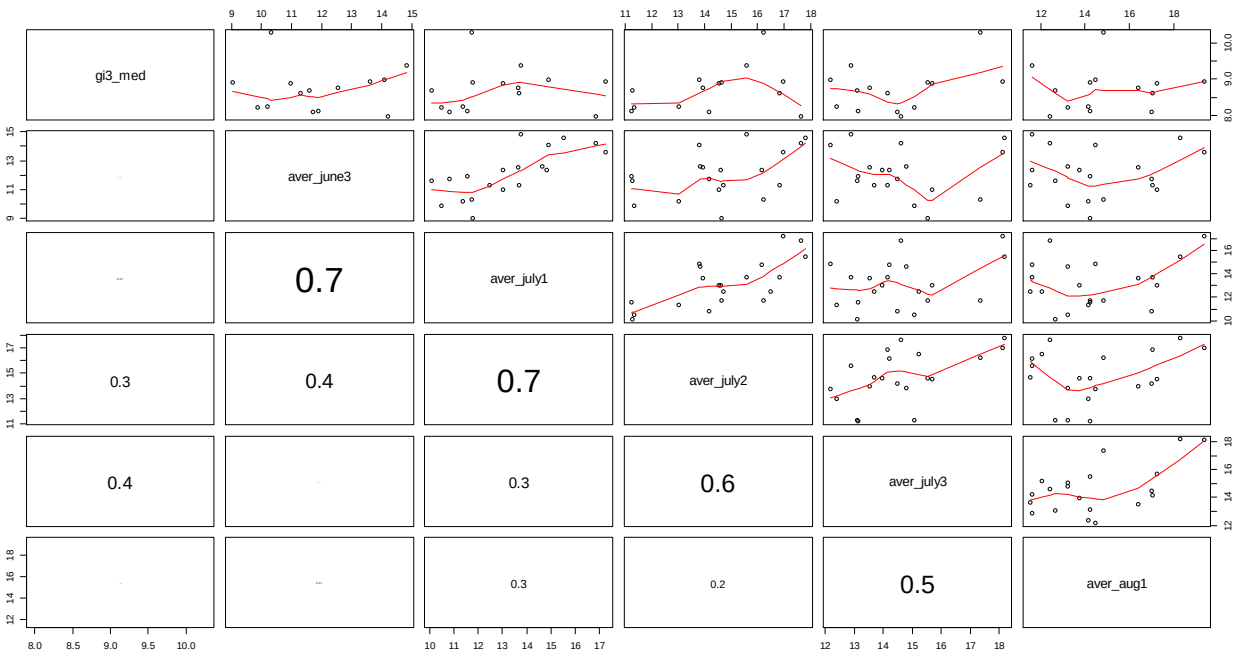


Figure 8. Correlations between the third year growth increment and averages over 10-days river temperatures from the beginning of June to the beginning of August.

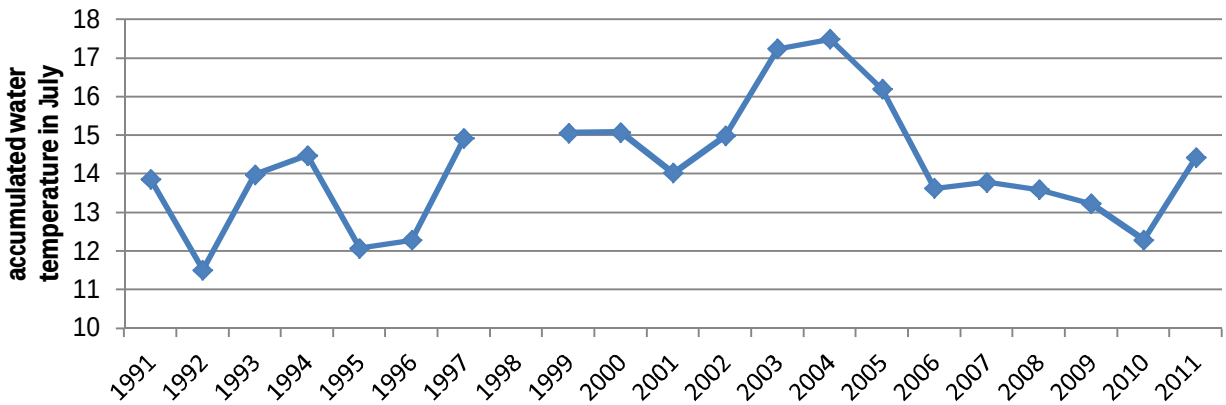


Figure 9. Accumulated water temperatures in July during the study period.

Different age groups (0+, 1+ and 2+ -juveniles) had slightly different temperature requirements. For all age groups, in July the average water temperature was the most significant factor for growth, but the timing and optimal temperatures were different. Also all the age groups most likely have other significant factors determining the growth that were not taken into account in this study.

The best generalized additive model (Figure 10) explaining the first growth increment of juveniles included a spline smoothed function of average temperature at the end of July (*aver_July3*) (Table 1). The thin plate regression spline was used for smoothing (Figure 10). Accumulated water temperature had a positive effect on the growth in the first summer (estimate=0.001, s.e. = 0.01), but adding the year and accumulated water temperature does not change the fit of the model. However since the difference between model AICs is smaller than 2, model averaged predictions might be better when these variables are included (Table I). In all the GAM based analysis we used mgcv-package (version 1.7-22.) of the R program (R Core Team 2013). There does not seem to be only one optimal temperature for the first year growth as the GAM curve peaks around 12, 14 and 17 degrees centigrade.

Table I. Comparison of generalized additive models for the first growth increments of juvenile salmon. The best models are shown in bold text.

| Explanatory variables (smoothed variables in parenthesis) | df | AIC | ΔAIC | $R^2$ | Deviance explained (%) |
|---|---|---|---|---|---|
| **s(aver_june3)** | 8.96 | -13.22 | 7.65 | 0.36 | 61.0 |
| **s(aver_july1)** | 3.98 | -9.52 | 11.35 | 0.07 | 16.8 |
| **s(aver_july2)** | 3.90 | -11.22 | 9.65 | 0.14 | 23.0 |
| **s(aver_july3)** | **9.66** | **-20.87** | **0** | **0.55** | **73.3** |
| **s(aver_aug1)** | 3.00 | -7.94 | 12.93 | -0.05 | 0.7 |
| **s(aver_july3)+year** | **10.12** | **-19.94** | **0.93** | **0.53** | **73.2** |
| **s(aver_july3)+awt** | 10.84 | -17.86 | 3.01 | 0.51 | 74.9 |
| **s(aver_july3)+year+awt** | **10.81** | **-19.86** | **1.01** | **0.51** | **74.9** |

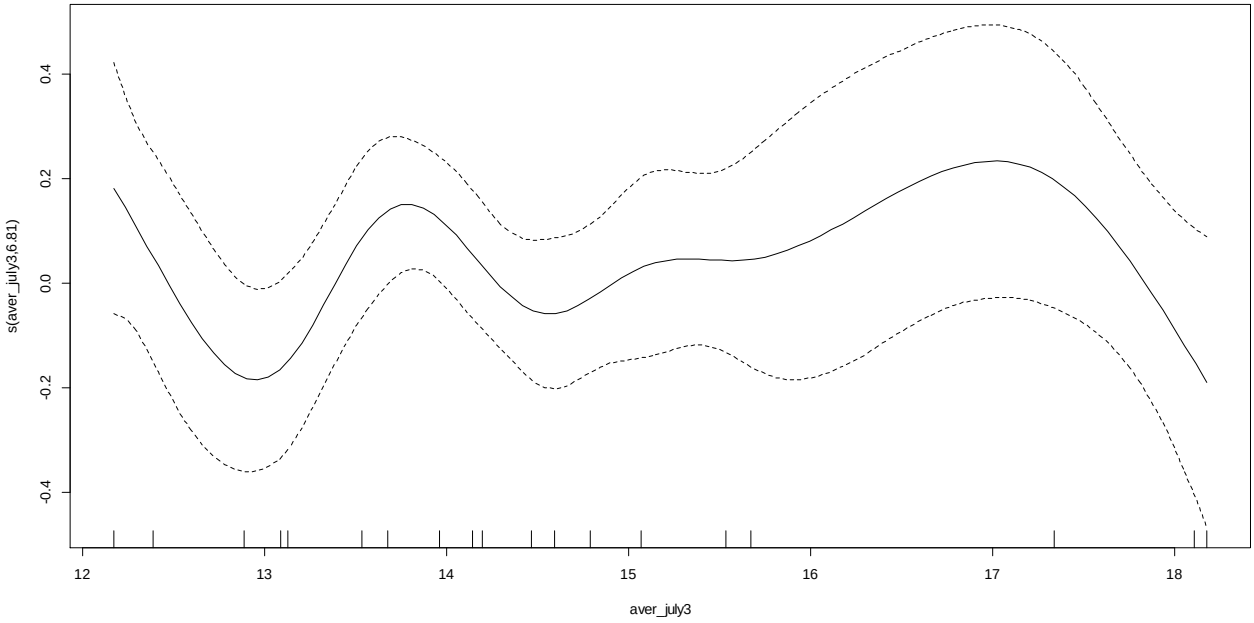


Figure 10. Graphical summary of the GAM for the first year growth increments. Estimated smoother for the additive model (solid line) and the 95% point-wise confidence bands (dotted lines) of the end of July average temperatures (*aver_July3*). Vertical bars at the base of the graph denote an observation with that value.

The second growth increment was best explained by the GAM model including a spline smoothed function of average temperature at the beginning of the July (*aver_July2*) (Table II) and year. The thin plate regression spline was used for smoothing. For second growth increment there seems to be an optimal temperature around 12-13 °C as there is a peak in the GAM curve around that temperature (Figure 11).

Table II Comparison of generalized additive models for the second growth increments of juvenile salmon. The best models are shown in bold text.

| Explanatory variables (smoothed variables in paranthesis) | df | AIC | ΔAIC | $R^2$ | Deviance explained (%) |
|---|---|---|---|---|---|
| **s(aver_june3)** | 3.00 | 17.30 | 11.00 | -0.03 | 2.51 |
| **s(aver_july1)** | 8.11 | 11.85 | 5.55 | 0.46 | 63.3 |
| **s(aver_july2)** | 3.94 | 16.08 | 9.78 | 0.24 | 31.7 |
| **s(aver_july3)** | 3.00 | 21.81 | 15.51 | -0.05 | 0.11 |
| **s(aver_aug1)** | 3.00 | 20.34 | 14.04 | 0.02 | 7.19 |
| **s(aver_july1)+year** | **9.70** | **6.30** | **0** | **0.60** | **76.5** |
| **s(aver_july1)+awt** | 5.37 | 14.06 | 7.76 | 0.21 | 35.8 |
| **s(aver_july1)+year+awt** | **10.29** | **6.71** | **0.41** | **0.52** | **74.1** |

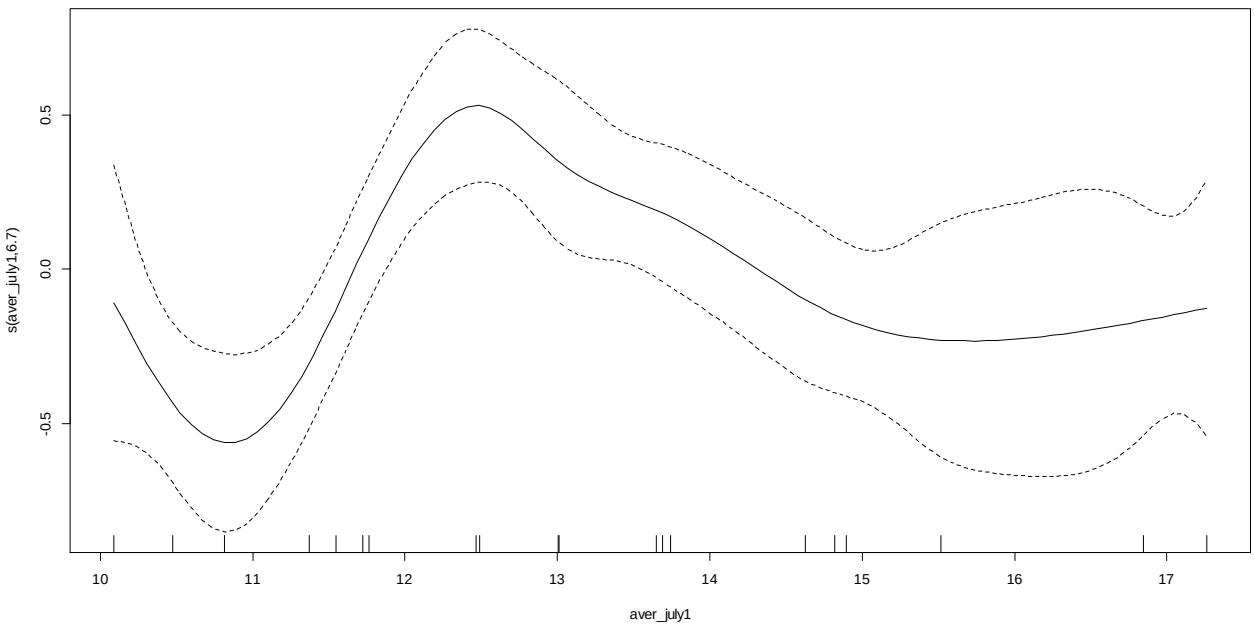


Figure 11. Graphical summary of the GAM for the second year growth increments. Estimated smoother for the additive model (solid line) and the 95% point-wise confidence bands (dotted lines) of the beginning of July average temperatures (*aver_July1*). Vertical bars at the base of the graph denote an observation with that value.

The third growth increment was best explained by the GAM model including a spline smoothed function of average temperature in the middle of the July (*aver_July2*) (Table III), year and accumulated July water temperature. The average temperature at the beginning of August also seems to be relevant to the growth of the third river year and should be added to the model if predictions are made for the growth. The thin plate regression spline was used for smoothing. For third growth increment there seems to be an optimal

temperature around 16 °C as there is a peak in the GAM curve around that temperature (Figure 12). That is higher than the optimal temperatures for younger juveniles.

Table III. Comparison of generalized additive models for the third growth increments of juvenile salmon. The best models are shown in bold text.

| Explanatory variables (smoothed variables in paranthesis) | df | AIC | ΔAIC | $R^2$ | Deviance explained (%) |
|---|---|---|---|---|---|
| **s(aver_june3)** | 3.00 | 30.88 | 16.03 | -0.08 | 0.00 |
| **s(aver_july1)** | 3.34 | 30.52 | 15.67 | -0.04 | 7.07 |
| **s(aver_july2)** | 5.90 | 20.59 | 5.74 | 0.55 | 68.3 |
| **s(aver_july3)** | 6.49 | 21.32 | 6.47 | 0.53 | 69.3 |
| **s(aver_aug1)** | 8.89 | 19.08 | 4.23 | 0.61 | 81.5 |
| **s(aver_july2)+year** | 6.61 | 21.75 | 6.90 | 0.52 | 68.9 |
| **s(aver_july2)+awt** | **9.49** | **14.85** | **0** | **0.70** | **87.4** |
| **s(aver_july2)+year+awt** | **9.49** | **14.85** | **0** | **0.70** | **87.4** |
| **s(aver_aug1)+year** | **9.49** | **15.78** | **0.93** | **0.68** | **86.5** |
| **s(aver_aug1)+awt** | 9.55 | 21.37 | 6.52 | 0.52 | 80.1 |
| **s(aver_aug1)+year+awt** | 10.13 | 18.51 | 3.66 | 0.60 | 85.1 |

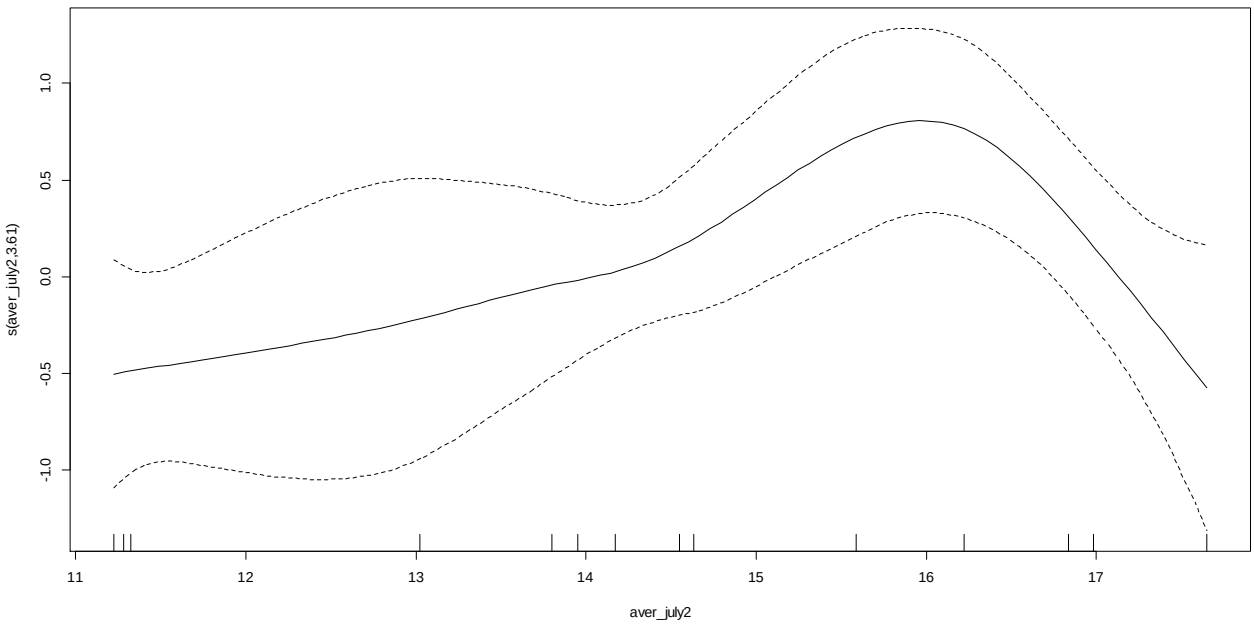


Figure 12. Graphical summary of the GAM for the third year growth increments. Estimated smoother for the additive model (solid line) and the 95% point-wise confidence bands (dotted lines) of the middle of July average temperatures (*aver_July2*). Vertical bars at the base of the graph denote an observation with that value.

# Acknowledgements

This study was funded by the European Union, Kolarctic ENPI CBC project – *Trilateral cooperation on our common resource; the Atlantic salmon in the Barents region* - "Kolarctic salmon" (KO197) and national sources in each participating country. The Lead partner of the project is the Office of the Finnmark County Governor (FMFI). Partners in Finland: Finnish Academy of Science – the University of Turku (UTU) and Finnish Game and Fisheries Research Institute (FGFRI). Partners in Norway: Institute of Marine Research (IMR) and Norwegian Institute of Nature Research (NINA). Partner in Russia: Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO).

Responsibilities in this report: FGFRI has collected during the last 35 years biological material from juvenile salmon in the River Tana and in this report we analysed the long-term growth of juveniles combining it to the river temperatures. FGFRI planned the report and produced graphs and statistical analysis.

*This report has been produced with the assistance of the European Union, but the contents can in no way be taken to reflect the views of the European Union.*

# References

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.