

# Climate Change May Have Affected Growth and Life History in Atlantic Salmon Juveniles over the Past 30 Years

ETIENNE RIVOT\*, CHARLE PERRIER, CÉLINE JOUANIN, AND JEAN-MARC ROUSSEL  
*Agrocampus Rennes, INRA, UMR 985 Ecologie et Santé des Ecosystèmes  
65 rue de St Brieuc, 35042 Rennes, France*

PASCAL RIERA  
*Station Biologique de Roscoff, UMR 7127 CNRS-INSUE Université Pierre et Marie Curie  
Place Georges Tessier BP74, 29682 Roscoff, France*

JEAN-PIERRE PORCHER  
*ONEMA, Office National de l'Eau et des Milieux Aquatiques  
84 rue de Rennes, 35510 Cesson Sévigné, France*

JEAN-LUC BAGLINIÈRE  
*Agrocampus Rennes, INRA, UMR 985 Ecologie et Santé des Ecosystèmes  
65 rue de St Brieuc, 35042 Rennes, France*

Atlantic salmon stocks are declining in European and North American rivers (ICES 2006). French rivers are located at the southern edge of the species distribution in Europe, providing a good opportunity to study life history variants in a changing environment (local and global) where unfavorable conditions may occur rapidly. In these rivers, almost all juveniles smoltify at age 1 (Smolt1) or age 2 (Smolt2), and adults return to rivers to spawn after 1 or 2 sea winters (1SW or 2SW). In the present work, we focus on the age at smoltification as an integrated parameter of changes occurring during the juvenile period in rivers. More precisely, variations in the mean age at smoltification (MAS) were studied in 23 rivers of the Armorica Massif (western France) belonging to three geographical regions: northern Brittany, southern Brittany, and lower Normandy.

Archived scales of 24,500 adult salmon caught by anglers from 1972 to 2005 were read to estimate smolt age and sea age of each individual (Baglinière 1985). Logistic regressions indicated that MAS decreased significantly over the study period whatever the geographical region and sea age. Moreover, the analysis of autocorrelation in the

time series of residuals highlighted the existence of medium-term fluctuations that were synchronous across the rivers, suggesting a response to a global environmental forcing. The proportion of Smolt1 and average monthly air temperature showed significant increasing time trends over the period (Figure 1). Linear correlation between series of residuals (proportion of Smolt1 and air temperature after removing the linear trend) was positive and highly significant ( $R^2 = 0.55$ ,  $P = 0.006$ ) despite reduction of the degrees of freedom due to high autocorrelation in the series.

The hypothesis that the temporal changes in MAS results from modifications in juvenile growth conditions was investigated on the Scorff River in southern Brittany. We used archived scales of 720 adult salmon caught by anglers, juvenile salmon caught during annual electrofishing censuses, and complementary data from scientific surveys (adult and juvenile trapping), from 1972 to 2002. Back-calculations were performed to estimate length of juveniles at their first winter, according to the method proposed by Beall et al. (1992) with recommendations from Francis (1990). Back-calculated length of juveniles during their first winter showed a significant increase of 1.5 cm, on average, over the study period (Figure 2). Similarly, water tem-

\* Corresponding author: etienne.rivot@agrocampus-rennes.fr

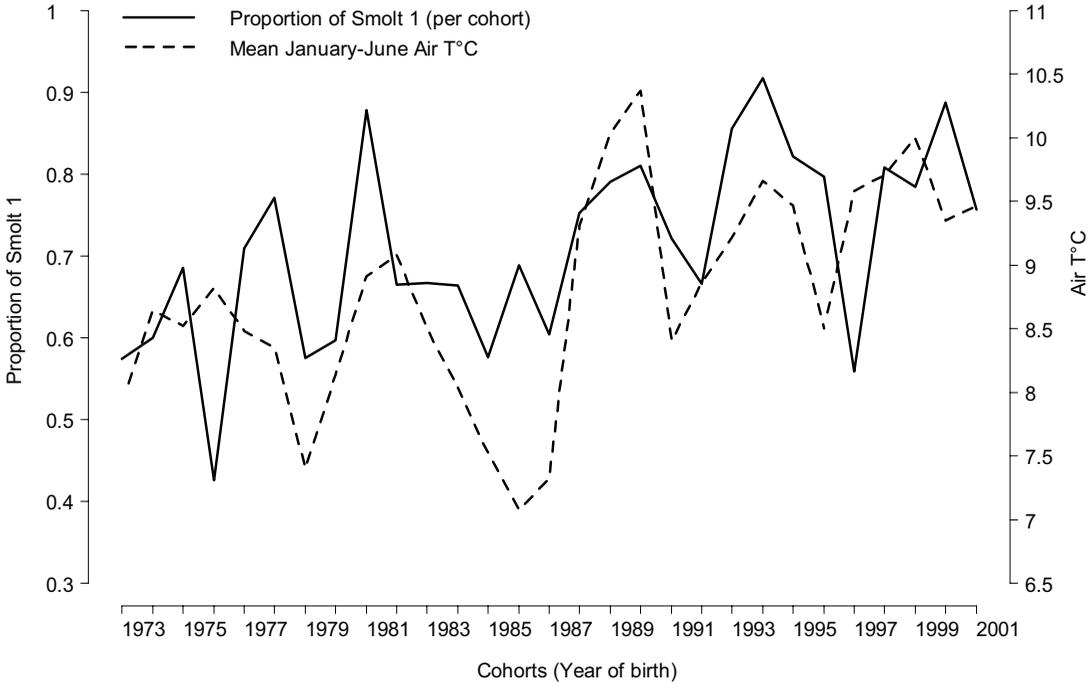


Figure 1.—Correlations between the proportions of age-1 smolt in Atlantic salmon populations in western France and mean air temperature during the spring growing period, from 1973 to 2001.

peratures during the March to June growth period correlated positively with juvenile body length.

Stable isotope analysis (C and N) were run on 162 samples of archived scales collected on juvenile Atlantic salmon caught in the Scorff River from 1977 to 2006. No specific trend was found for scale  $\delta^{15}\text{N}$ , whereas scales became increasingly  $^{13}\text{C}$ -enriched (+1.4‰ for  $\delta^{13}\text{C}$ ) over the period (Figure 2). Livestock production increased in the watershed until the mid-1990s, resulting in a remarkable enhancement of nitrate concentration ( $\text{NO}_3^-$ ; 16 mg/L) in the river. A significant positive correlation ( $R^2 = 0.67$ ,  $P = 0.004$ ) was found between  $\text{NO}_3^-$  concentration and  $\delta^{13}\text{C}$  in juvenile salmon scales, suggesting that scales became increasingly  $^{13}\text{C}$  enriched as more dissolved nutrients were available in the river. This suggests that in the context of increasing carbon demand, fixation of dissolved atmospheric  $\text{CO}_2$  (about  $-8\text{‰}$  for  $\delta^{13}\text{C}$ ) by river primary producers increased over the study period, leading to more  $^{13}\text{C}$ -enriched dissolved inorganic carbon (DIC). Under such hypothesis, the incorporation of  $^{13}\text{C}$ -enriched DIC through photosynthesis could have led to higher  $\delta^{13}\text{C}$  values from

primary producers to higher trophic levels in the entire river food web, including insectivorous Atlantic salmon *Salmo salar* juveniles.

Taken in concert, results suggest that the decrease in MAS might be due to changes in juvenile growth performance in response to climate warming, increase in stream productivity, or both. We cannot rule out the alternative hypothesis that the decrease in MAS could be a response of populations to selective fishing on late-maturing and large fish.

## References

- Baglinière, J. L. 1985. La détermination de l'âge par scalimétrie chez le saumon atlantique dans son aire de répartition méridionale: utilisation pratique et difficultés de la méthode. *Bulletin Français de la Pêche et de la Pisciculture* 298:69–105.
- Beall, E., P. Davaine, D. Bazin, and J. M. Blanc. 1992. Détermination d'un modèle de rétrocalcul pour l'estimation de la croissance de la truite de mer (*Salmo trutta*) à Kerguelen. Pages 193–198 in J. L. Baglinière, J. Castanet, F. Conand, and F. J.

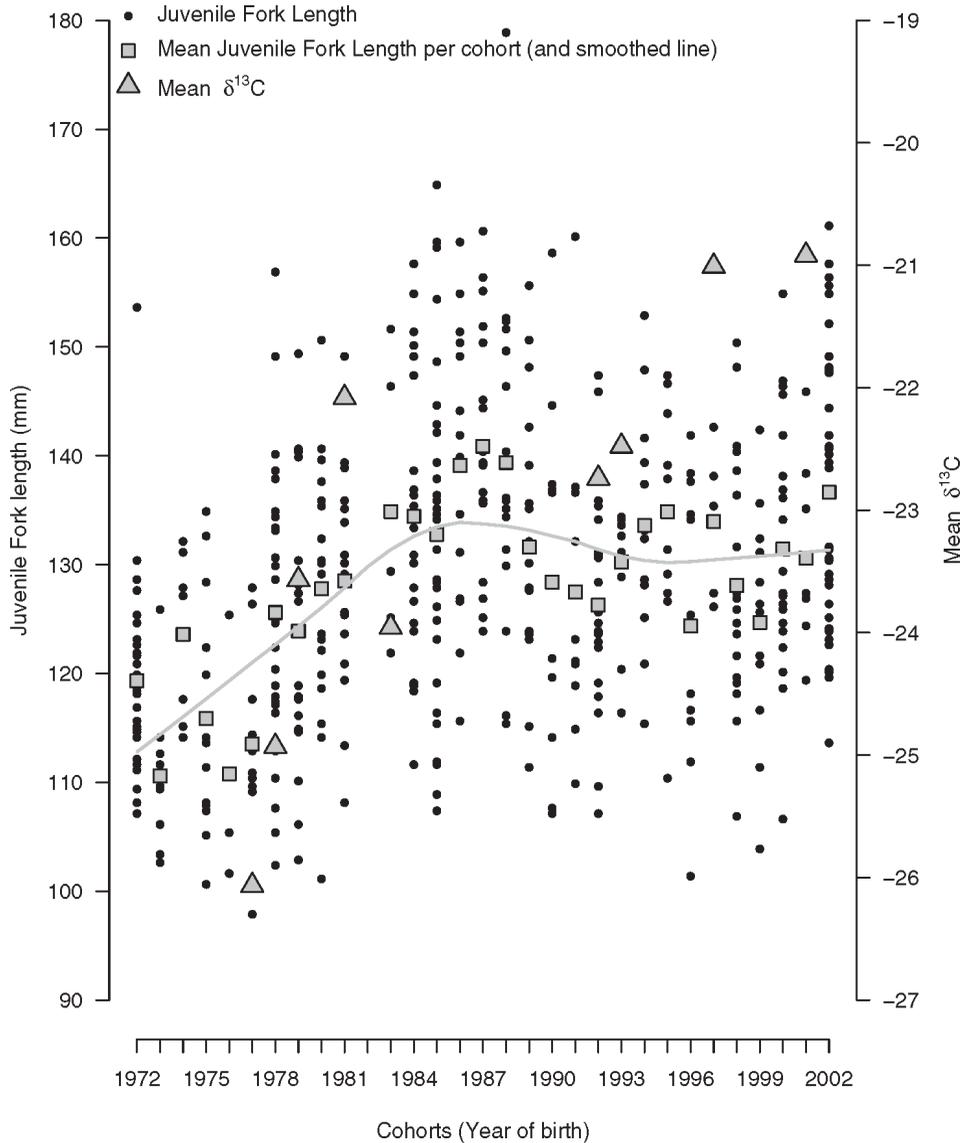


Figure 2.—Back-calculated length of juveniles during their first winter in the Scorff River (southern Brittany), and the increase in juvenile scale  $\delta^{13}\text{C}$  (‰), from 1972 to 2002.

Meunier, editors. Tissus durs et âge individuel des vertébrés, Colloque national, Bondy, France. ORSTOM-INRA Editions, Colloques et Séminaires, Paris.

Francis, R. I. C. C. 1990. Back-calculation of fish length: a

critical review. *Journal of Fish Biology* 36:883–902.  
 ICES (International Council for the Exploration of the Sea). 2006. Report of the working group on North Atlantic salmon (WGNAS). ICES CM 2006/ACFM 23.