Electronic supplementary material

Does global change increase the risk of maladaptation of Atlantic salmon migration through joint modifications of river temperature and discharge?

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Table S1 Percentage of significant changes in the occurrence of water temperature and discharge associations at annual and seasonal scales in the available, effective and preferential niches of spawners and smolts on the Bresle, Oir and Nivelle rivers. Total percentage of significant changes and percentages of the associations that have become more or less frequent are shown ("Total", "Gain" and "Loss", respectively).

	Bresle River			Oir River			Nivelle River		
	Total	Gain	Loss	Total	Gain	Loss	Total	Gain	Loss
Environmental trends									
Yearly	3.3	0.5	2.8	12.9	12.5	0.4	3.5	2.6	0.9
Winter (JFM)	7.9	7.9	0.0	16.1	14.5	1.6	11.0	10.6	0.4
Spring (AMJ)	0.1	0.0	0.1	10.3	8.2	2.1	6.8	2.0	4.8
Summer (JAS)	0.0	0.0	0.0	2.7	2.2	0.5	11.4	5.3	6.1
Fall (OND)	8.4	4.3	4.1	12.0	9.4	2.6	9.6	7.6	2.0
Smolt migration									
Available niche	2.4	0.0	2.4	14.4	14.4	0.0	-	-	-
Effective niche	11.1	11.1	0.0	13.5	10.2	3.3	-	-	-
Preferential niche	38.0	21.7	16.3	5.9	1.3	4.6	-	-	-
Spawner migration									
Available niche	0.0	0.0	0.0	15.0	14.2	0.8	8.1	6.6	1.5
Effective niche	0.0	0.0	0.0	15.1	11.0	4.1	4.9	0.0	4.9
Preferential niche	4.9	1.7	3.2	14.1	3.9	10.2	26.5	1.6	24.9

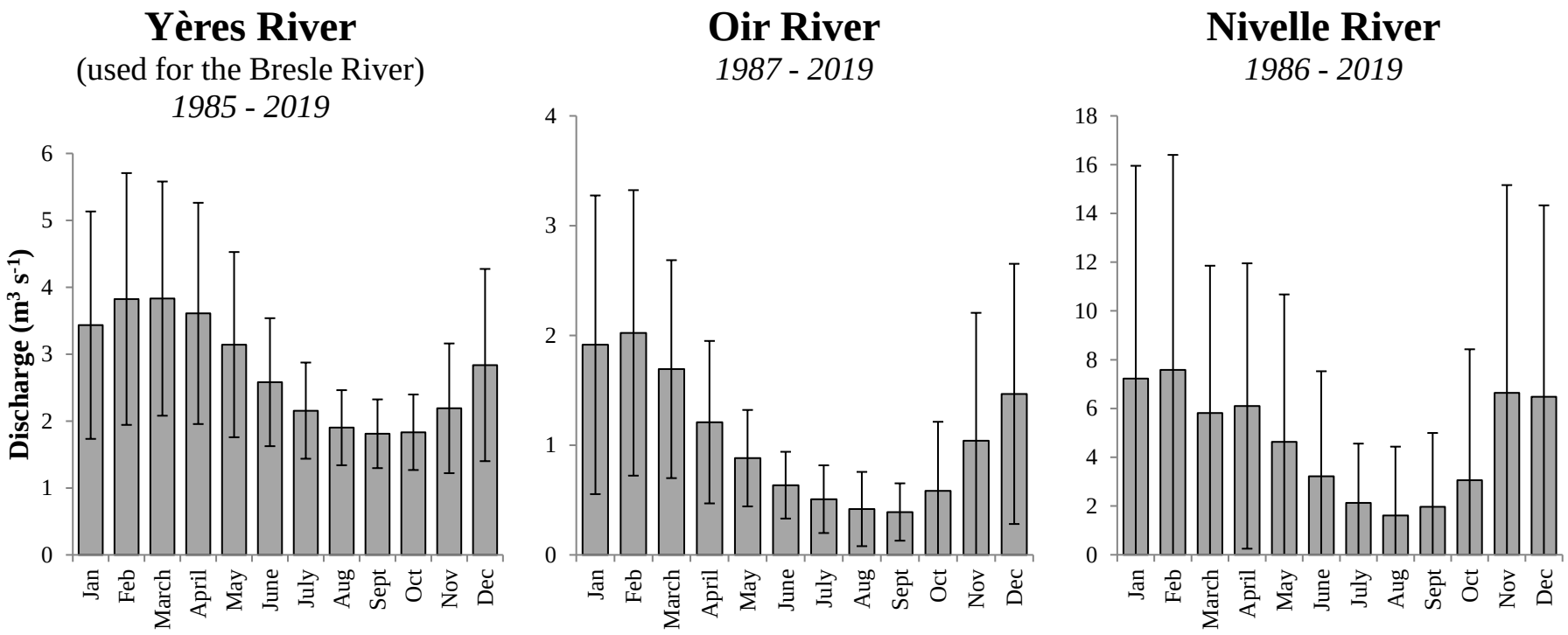

Figure S1 Monthly averages and standard deviation of discharge for each river.

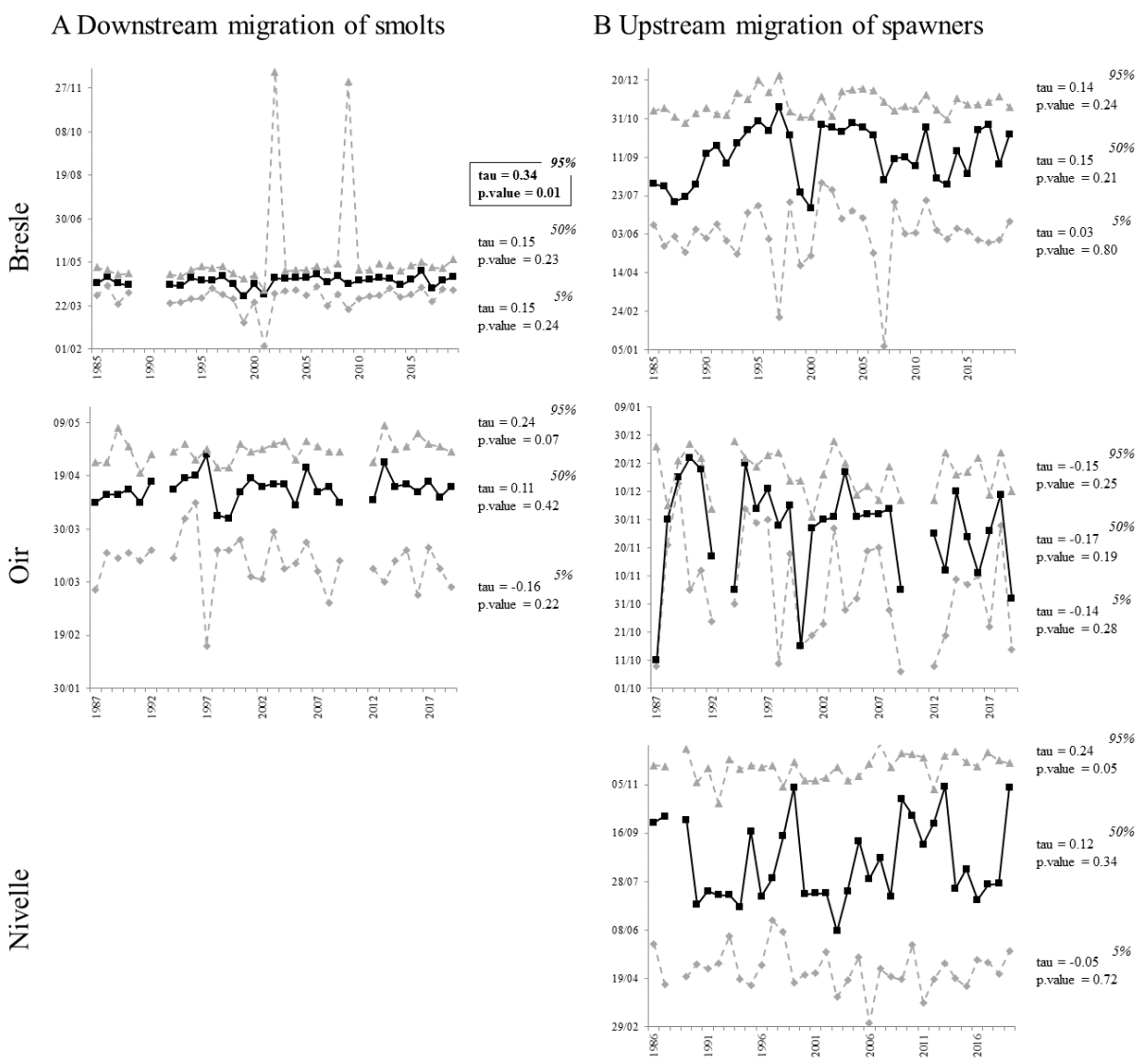

Figure S2 Dates corresponding to the passage of 5 (♦), 50 (■) and 95% (▲) of the total annual catch of (A) smolts migrating downstream and (B) spawners migrating upstream on the Bresle, Oir and Nivelle rivers. Mann-Kendall tau and p-value are indicated, with significant values in bold and framed.

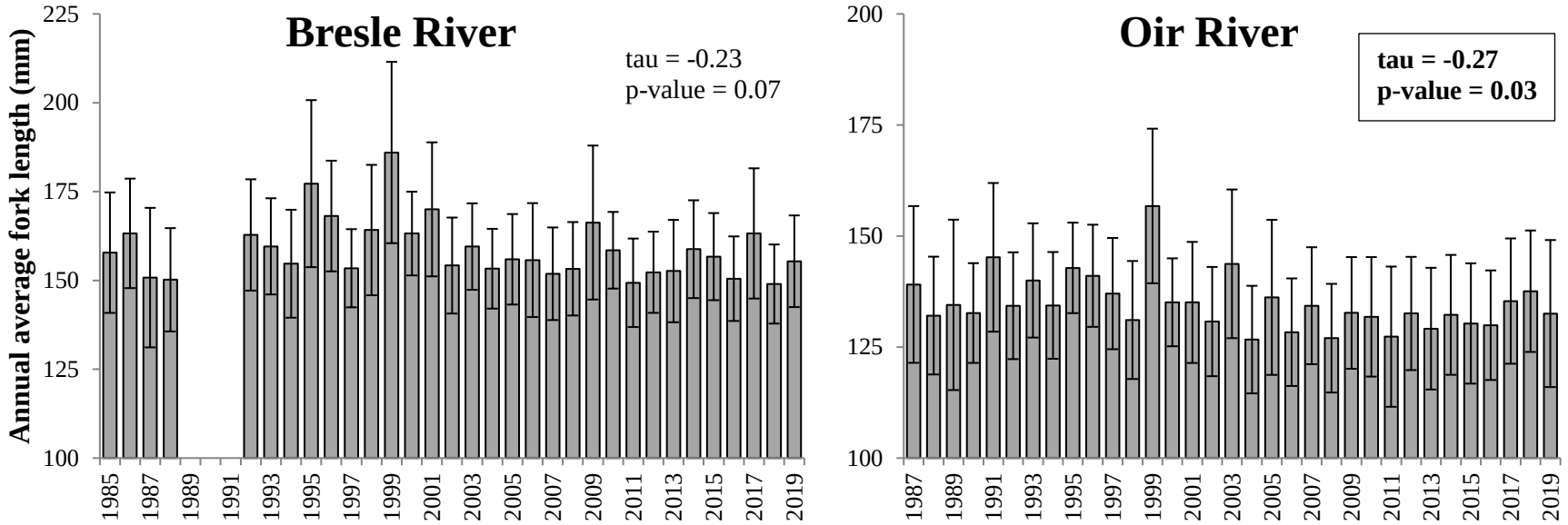

Figure S3 Annual averages and standard deviation of the fork length of smolts in mm on the Bresle and Oir rivers. Mann-Kendall tau and p-value are indicated, with significant values in bold and framed.

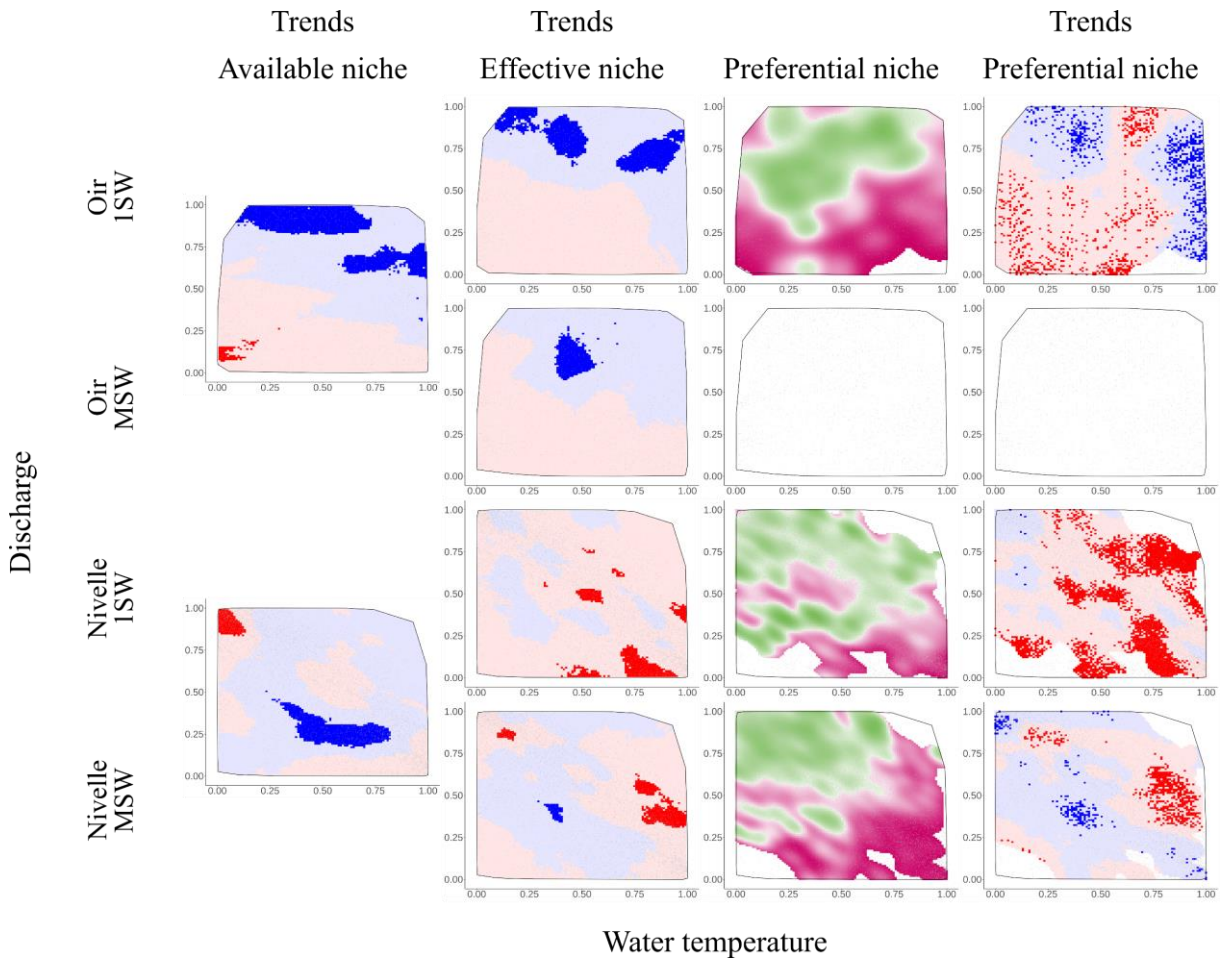

Figure S4 Conditions of spawning migration of Atlantic salmon having spent one winter at sea (1SW) and those having spent multiple winters at sea (MSW) on the Oir and Nivelle rivers. These two-dimensional heatmaps of water temperature (X-axis; quantiles) and discharge (Y-axis; quantiles) were computed for the upstream migration season and represent the trends in the available niche, the trends in the effective niche, the average preferential niche and the trends in the preferential niche. Discharge and temperature associations that have become more or less frequent over the study period are shown in blue or red, respectively. Light and dark colors correspond to non-significant and significant trends, respectively. The gray line delineates the convex hull. For the preferential niche, the 5% less frequent associations are represented in white inside the convex hull. Selected and rejected associations are shown in green or purple, respectively. Only 13% of the total number of spawners are MSW salmons on the Oir River and only 35% of the spawners caught on the Bresle River have been aged, which prevented us from computing the MSW preferential niche on the Oir River and all the ecological niches on the Bresle River.

APPENDIX A. A COMPREHENSIVE HISTORY OF THE THREE POPULATIONS STUDIED

At the beginning of the century, Atlantic salmons were only occasionally found on the Bresle River [1]. From the 1960s onwards, management measures were taken to improve the environmental quality of the Bresle River, reduce illegal fishing and introduce around 450,000 salmon eggs per year until the 1990s, initially from Scottish and Polish spawners and later from spawners caught locally in the trap [2]. The Oir River is a tributary of the Sélune River. Spawners came from other populations and smolts from the Sélune River were relocated to the Oir River [3], maintaining a sustainable population size. However, the population was impacted by the construction of two impassable dams on the Sélune River in the early 20th century [4]. On the Nivelle River, 10-30 spawners were returning per year in the 1970s [1]. Restocking operations were carried out in the 1980s with acclimatised Scottish strains [5]. However, it appears that the population size of the Nivelle River has increased primarily following the construction of fish passes at two impassable dams that have allowed spawners to access more productive areas [5]. Today the numbers of spawners remain low due to fishing pressure and the inaccessibility of the upper Nivelle River [6].

Related references:

1. Baglinière J-L, Thibault M, Dumas J. 1990 Réintroductions et soutiens de populations du saumon atlantique (*Salmo salar* L.) en France. *Rev. d'écologie* **5**, 299–323.

2. Arrignon J. 1973 Tentative de réacclimatation de *Salmo salar* dans le bassin de la Bresle (Normandie, France). *Bull. Français Piscic.*, 91–108. (doi:10.1051/kmae:1973012)

3. Nikolic N, Butler JRA, Baglènire JL, Laughton R, McMyn IAG, Chevalet C. 2009 An examination of genetic diversity and effective population size in Atlantic salmon populations. *Genet. Res. (Camb).* **91**, 395–412. (doi:10.1017/S0016672309990346)

4. Baglinière JL, Porcher JP. 1980 Principales caractéristiques des adultes de saumon atlantique (*Salmo salar* L.) capturés par pêche à la ligne dans trois fleuves côtiers du Massif Armoricain : le Scorff, la Sée et la Sélune. *Bull. Français Piscic.*, 65–75. (doi:10.1051/kmae:1980003)

5. Dumas J, Prouzet P. 2003 Variability of demographic parameters and population dynamics of Atlantic salmon (*Salmo salar* L.) in a southwest French river. *ICES J. Mar. Sci.* **60**, 356–370. (doi:10.1016/S1054-3139(03)00132-2)

6. Prévost É, Lange F. 2019 Bilan du suivi du stock de saumon de la Nivelle - Synthèse 1984-2019. 18 p.

APPENDIX B. JOINT ENVIRONMENTAL TRENDS AT THE ANNUAL SCALE

The empirical cumulative distribution functions of water temperature and discharge were used at the annual scale. To reveal significant changes in the annual occurrence of water temperature and discharge associations, the Choc method was applied.

Annually, the frequency of water temperature × discharge associations has changed little on the Bresle River (Figure A1), with a decrease in the number of days with cold water temperature associated with low discharge. For the Oir River, the highest discharges were significantly more frequent. For the Nivelle River, cold water temperatures became significantly rarer while warm water temperatures associated with low discharges were more frequent.

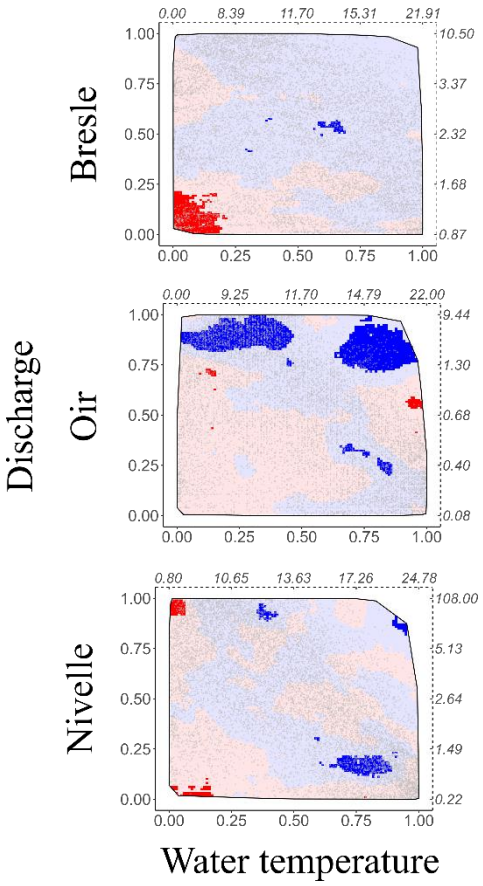

Figure A1 Two-dimensional heatmaps of trends in the associations between water temperature (X-axis; quantiles) and discharge (Y-axis; quantiles) on the Bresle, Oir and Nivelle rivers computed at the annual scale (*i.e.*, not limited to migration periods). Water temperature and discharge values in natural scale are shown in italics (in °C and m^3 s^{-1} respectively) on the dashed 3rd and 4th axes. Water temperature × discharge associations that have become more or less frequent over the study period are shown in blue or red, respectively. Light and dark colors correspond to non-significant and significant trends, respectively (e.g., dark red corresponds to significant decreasing trends, light blue to non-significant increasing trends). The gray line delineates the convex hull (*i.e.*, the smallest space encompassing all the points of the dataset).