Ecography

ECOG-00282
Comte, L. and Grenouillet, G. 2013. Do stream fish track climate change? Assessing distribution shifts in recent decades. – Ecography 36: xxx–xxx.

Supplementary material

Appendix 1. Climatic trends from 1965 to 2008 and sites characteristics.

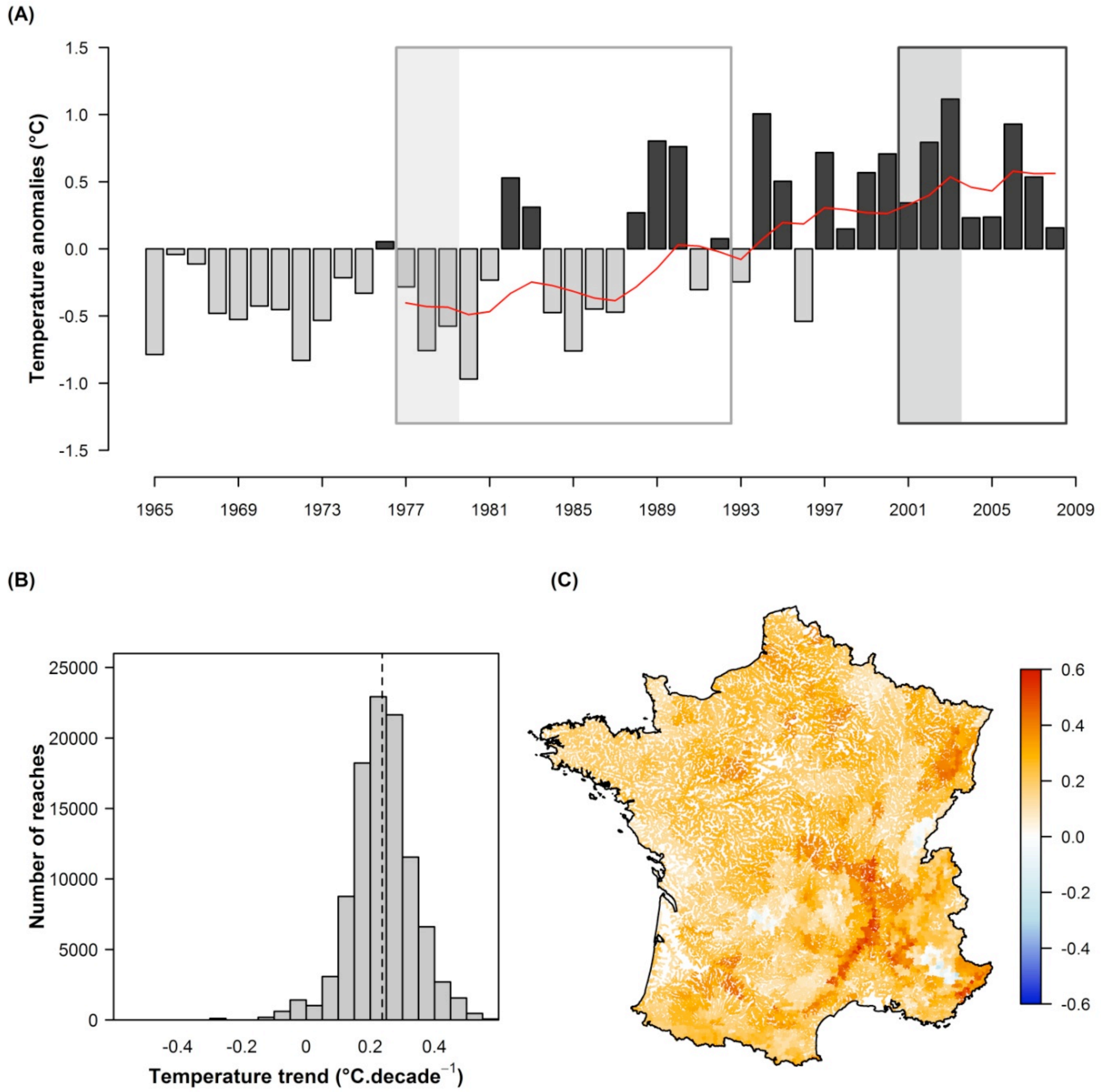

Figure A1. (A) Mean annual temperature anomalies for 1965 to 2008 (using overall air mean temperature as baseline) averaged for 8-km grid climatic data distributed over the entire study area. Grey bars refer to negative anomalies, whereas black bars refer to positive ones. The first period is mainly composed of "cold" years and the second period of only "warm" years. No temporal trend was observed within both periods. The red curve is the moving-average with use of a 10-year filter. Black rectangles show the length of the initial and the contemporary periods including the three preceding years, which are indicated by the grey shaded areas. (B) Histogram and (C) spatial distribution of the temporal trends in mean annual temperature (°C.decade^{-1}) along the reaches of the hydrographic network, calculated as the slope of the linear regression of mean annual temperature over time. The dashed line indicates the mean of the differences across all reaches. Air temperature was used as a surrogate of water temperature after applying a scaling factor of 0.8°C.

Table A1: Summary of the environmental conditions of the sampling sites.

	Units	Minimum	Maximum	Mean	SD
Elevation	m	2	2289	298	308
Slope	‰	0.001	380.902	12.301	23.805
Full area drained by the upstream area	km²	0.5	84809	1006.6	4541.1
Cumulated length of the upstream flow network	km	0.1	26732.9	370.7	1633.2
Distance from source	km	0.02	846.21	15.96	78.86

Appendix 2. Temporal variation in the sampling success between initial and contemporary surveys.

For this analysis, we initially refined the datasets to include only sites sampled at least three times during each period. In addition, to determine if the species pool was sufficiently closed during time windows of varying lengths within each period, the test of Otis et al. (1978) was used. It compares the mean observed difference between first and last detection of each species to that expected under the assumption of closure, indicating if violation of closure (i.e. gains and losses) has occurred over the period of sampling. We therefore retained for analysis only the sites for which the assumption of closure was not rejected ($p > 0.05$): 177 sites with 4.19 ± 2.39 SD surveys per site and 777 sites with 4.89 ± 1.69 SD surveys per site for the initial and contemporary periods, respectively.

To assess the completeness of the inventory (i.e. the proportion of species detected) for each sampling occasion, we calculated the ratio of observed species richness for a given sampling occasion to estimate species richness for the corresponding site. Species richness was estimated using the maximum of two different non-parametric estimators, based on the frequencies of species in the collection of sampling occasions for a given site: Chao 2 and Jackknife 1 (Colwell and Coddington 1994). We then fitted a generalized linear mixed-effects model (GLMM), designed to assess the extent of spatial and temporal variation in survey effort that might potentially have affected the proportion of species detected. After having checked for normality, we modelled the proportion of species detected for each sampling occasion according to several characteristics of the samplings using a Gaussian error distribution. To account for the relative uncertainty in species richness estimates, we included the inverse of the standard error of the estimates of species richness as weights in the GLMMs (Meyer et al. 2011). Fixed effects included in the model were season, sampling method (complete, partial or fractional), prospection method (wading, using a boat or mixed) and the number of pass removals as well as the interactions between these factors and the time period. Sampling sites nested within hydrographic basins were specified as a random effect in the model.

To obtain species-specific temporal estimates of detectability, we fitted a single GLMM with a binomial error distribution to the presence-absence data of all the species. We thus modelled the probability that the species seen during at least one survey would also be detected during subsequent surveys in each time period. Season, sampling method, prospection method and the number of pass-removals were included as fixed effects. Sampling sites nested within hydrographic basins and species were specified as random effects in the model. This partially crossed design allowed to account for the possible dependence of species detections induced by shared sites and by the identity of species (Kéry and Plattner 2007).

The significance of each effect, including interaction terms, was assessed using likelihood ratio tests, with sequential dropping of non-significant terms, starting with a full model (Gelman and Hill 2006). After model simplification, the fixed effects retained were tested using Wald tests. Models were initially fitted using maximum likelihood estimation, while the estimates of the final model parameters were obtained by re-fitting the model using the restricted maximum likelihood estimation (Pinheiro and Bates 2000).

Models were fitted using the *nlme* package (Pinheiro et al. 2011) and *lme4* package (Bates et al. 2011) using R environment software version 2.13.0 (R Development Core Team 2011).

Table A2. Results of GLMM assessing the influence of a set of predictors on the proportion of species detected.

Source of variation	L-ratio X^2	d.f.	*P*	
Random effects				
Basin	15.58479	1	< 0.001	***
Sites (Basin)	2403.733	1	< 0.001	***
Fixed effects				
Season	15.795	3	0.001	**
Sampling method	5.069	2	0.079	.
Prospection method	21.083	2	< 0.001	***
Number of passes	16.909	1	< 0.001	***
Period	0.495	1	0.482	
Season : Period	2.773	3	0.428	
Number of passes : Period	0.449	1	0.503	
Sampling method : Period	3.244	2	0.198	
Prospection method : Period	41.703	2	< 0.001	***

	Estimate (SE)	*z*	*P*	
Intercept	0.542 (0.03)	18.232	< 0.001	***
Season_Spring	< 0.001 (0.008)	-0.002	0.999	
Season_Summer	0.01 (0.006)	1.572	0.116	
Season_Winter	-0.062 (0.02)	-3.059	0.002	**
Sampling_Partial	-0.017 (0.011)	-1.461	0.144	
Sampling_Fractional	-0.026 (0.012)	-2.218	0.027	*
Prospection_Mixed	0.196 (0.055)	3.575	< 0.001	***
Prospection_Wading	0.182 (0.023)	7.788	< 0.001	***
Number of passes	0.033 (0.008)	4.088	< 0.001	***
Prospection_Mixed : Period	-0.187 (0.057)	-3.318	< 0.001	***
Prospection_Wading : Period	-0.137 (0.022)	-6.231	< 0.001	***

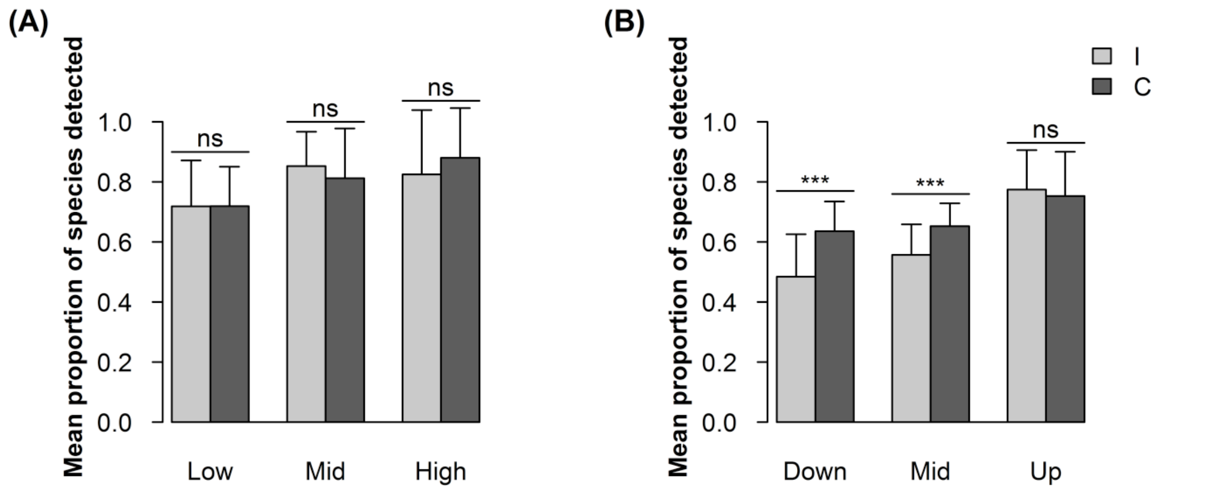

Figure A2. GLMM estimates of the mean proportion of species detected for different (A) altitudinal and (B) upstream-downstream bands and between periods (I = initial; C = contemporary). Altitudinal bands are represented by Low = 0-400 m, Mid = 400-800 m, High = > 800 m and upstream-downstream bands by Down = > 400 km, Mid = 200-400 km, Up = 0-200 km from source. ns = no significant difference, *** highly significant difference ($p < 0.001$) (Wilcoxon ranked test).

Table A3. Results of GLMM assessing the influence of a set of predictors on species-specific detection probability during successive initial surveys.

Source of variation	L-ratio X^2	d.f.	P	
Random effects				
Basin	0.735	1	0.391	
Sites (Basin)	157.820	1	< 0.001	***
Species	668.910	1	< 0.001	***
Fixed effects				
Season	5.340	3	0.149	
Sampling method	9.209	2	0.010	*
Prospection method	10.525	2	0.005	**
Number of passes	12.522	1	< 0.001	***

	Estimate (SE)	z	P	
Intercept	-0.326 (0.322)	-1.011	0.312	
Sampling_Partial	0.241 (0.181)	1.333	0.183	
Sampling_Fractional	-0.334 (0.237)	-1.409	0.159	
Prospection_Mixed	0.308 (0.235)	1.311	0.190	
Prospection_Wading	0.441 (0.157)	2.813	< 0.001	**
Number of passes	0.466 (0.131)	3.545	< 0.001	***

Table A4. Results of GLMM assessing the influence of a set of predictors on species-specific detection probability during successive contemporary surveys.

Source of variation	L-ratio X^2	d.f.	P	
Random effects				
Basin	< 0.001	1	0.9978	
Sites (Basin)	996.730	1	< 0.001	***
Species	4765.200	1	< 0.001	***
Fixed effects				
Season	4.560	3	0.207	
Sampling method	0.921	2	0.631	
Prospection method	14.113	2	< 0.001	***
Number of passes	25.166	1	< 0.001	***
	Estimate (SE)	z	P	
Intercept	0.683 (0.166)	4.112	< 0.001	
Prospection_Mixed	0.055 (0.073)	0.755	0.450	
Prospection_Wading	-0.187 (0.061)	-3.088	0.002	**
Number of passes	0.229 (0.046)	5.014	< 0.001	***

References

Bates, D. M. et al. 2011. lme4: linear mixed-effects models using S4 classes.

Colwell, R. and Coddington, J. 1994. Estimating terrestrial biodiversity through extrapolation. — Philosophical Transactions of the Royal Society B: Biological Sciences 345: 101-118.

Gelman, A. and Hill, J. 2006. Data analysis using regression and multilevel/hierarchical models. — Cambridge University Press.

Kéry, M. and Plattner, M. 2007. Species richness estimation and determinants of species detectability in butterfly monitoring programmes. — Ecological Entomology 32: 53-61.

Meyer, C. F. J. et al. 2011. Accounting for detectability improves estimates of species richness in tropical bat surveys. — Journal of Applied Ecology 48: 777-787.

Otis, D. L. et al. 1978. Statistical inference from capture data on closed animal populations. — Wildlife Monographs 62: 3-135.

Pinheiro, J. C. and Bates, D. M. 2000. Mixed-effects models in S and S-Plus. — Springer.

Pinheiro, J. C. et al. 2011. nlme: linear and nonlinear mixed effects models. R package version 3.1-100.

R Development Core Team 2011. R: a language and environment for statistical computing. R Foundation for Statistical Computing.

Appendix 3. Performance measures for the initial and the contemporary periods.

Table A5. Mean performance measures of the consensus models calibrated for each species in the initial period. Numbers in brackets indicate standard deviations.

Species	Code	Periode	Prevalence	AUC	TSS	Sensitivity	Specificity
Abramis brama	*Abb*	I	0.08	0.87 (0.01)	0.53 (0.07)	0.69 (0.15)	0.84 (0.09)
Alburnoides bipunctatus	*Alb*	I	0.04	0.89 (0.02)	0.56 (0.12)	0.71 (0.19)	0.85 (0.08)
Alburnus alburnus	*Ala*	I	0.14	0.91 (0.01)	0.64 (0.05)	0.79 (0.1)	0.86 (0.06)
Ameiurus melas	*Amm*	I	0.02	0.91 (0.02)	0.6 (0.19)	0.72 (0.25)	0.88 (0.08)
Anguilla anguilla	*Ana*	I	0.36	0.9 (0.01)	0.63 (0.02)	0.8 (0.04)	0.83 (0.04)
Barbatula barbatula	*Bba*	I	0.54	0.82 (0.01)	0.48 (0.02)	0.78 (0.06)	0.69 (0.06)
Barbus barbus	*Bab*	I	0.16	0.91 (0.01)	0.64 (0.04)	0.8 (0.09)	0.85 (0.05)
Barbus meridionalis	*Bam*	I	0.02	0.98 (0.01)	0.77 (0.17)	0.82 (0.2)	0.95 (0.03)
Blicca bjoerkna	*Blb*	I	0.03	0.91 (0.02)	0.6 (0.12)	0.73 (0.19)	0.87 (0.08)
Chondrostoma nasus	*Chn*	I	0.04	0.91 (0.01)	0.64 (0.11)	0.78 (0.16)	0.86 (0.06)
Cottus gobio	*Cog*	I	0.48	0.84 (0.01)	0.52 (0.02)	0.75 (0.04)	0.76 (0.04)
Cyprinus carpio	*Cyc*	I	0.04	0.78 (0.03)	0.39 (0.09)	0.58 (0.18)	0.81 (0.11)
Esox lucius	*Esl*	I	0.17	0.84 (0.01)	0.51 (0.05)	0.72 (0.1)	0.79 (0.07)
Gasterosteus aculeatus	*Gaa*	I	0.08	0.86 (0.02)	0.52 (0.08)	0.71 (0.16)	0.81 (0.08)
Gobio gobio	*Gog*	I	0.48	0.82 (0.01)	0.49 (0.02)	0.77 (0.05)	0.72 (0.04)
Gymnocephalus cernua	*Gyc*	I	0.03	0.9 (0.02)	0.56 (0.16)	0.69 (0.23)	0.87 (0.08)
Lepomis gibbosus	*Leg*	I	0.08	0.86 (0.02)	0.55 (0.09)	0.73 (0.15)	0.83 (0.07)
Leuciscus leuciscus	*Lel*	I	0.21	0.84 (0.01)	0.52 (0.03)	0.75 (0.09)	0.77 (0.07)
Lota lota	*Lol*	I	0.03	0.93 (0.02)	0.64 (0.14)	0.75 (0.2)	0.89 (0.08)
Parachondrostoma toxostoma	*Pat*	I	0.02	0.94 (0.02)	0.68 (0.17)	0.77 (0.21)	0.91 (0.05)
Perca fluviatilis	*Pef*	I	0.23	0.84 (0.01)	0.5 (0.04)	0.73 (0.09)	0.78 (0.07)
Phoxinus phoxinus	*Php*	I	0.49	0.8 (0.01)	0.45 (0.02)	0.74 (0.04)	0.71 (0.04)
Pungitius pungitius	*Pup*	I	0.06	0.91 (0.01)	0.61 (0.12)	0.75 (0.18)	0.86 (0.07)
Rutilus rutilus	*Rur*	I	0.40	0.87 (0.01)	0.57 (0.02)	0.78 (0.04)	0.79 (0.04)
Salmo salar	*Sas*	I	0.04	0.95 (0.01)	0.7 (0.14)	0.79 (0.18)	0.91 (0.05)
Salmo trutta	*Sat*	I	0.72	0.89 (0.01)	0.59 (0.04)	0.81 (0.06)	0.78 (0.08)
Sander lucioperca	*Sal*	I	0.02	0.91 (0.03)	0.62 (0.15)	0.72 (0.2)	0.9 (0.06)
Scardinius erythrophthalmus	*Sce*	I	0.07	0.81 (0.02)	0.42 (0.07)	0.63 (0.16)	0.79 (0.11)
Squalius cephalus	*Sqc*	I	0.41	0.86 (0.01)	0.57 (0.02)	0.78 (0.04)	0.78 (0.03)
Telestes souffia	*Tes*	I	0.04	0.98 (0.01)	0.81 (0.1)	0.87 (0.13)	0.94 (0.04)
Thymallus thymallus	*Tht*	I	0.01	0.91 (0.03)	0.59 (0.17)	0.71 (0.24)	0.88 (0.09)
Tinca tinca	*Tit*	I	0.12	0.79 (0.01)	0.42 (0.06)	0.67 (0.14)	0.75 (0.09)

Table A6. Mean performance measures of the consensus models calibrated for each species in the contemporary period. Numbers in brackets indicate standard deviations.

Species	Code	Period	Prevalence	AUC	TSS	Sensitivity	Specificity
Abramis brama	*Abb*	C	0.08	0.87 (0.01)	0.54 (0.07)	0.72 (0.14)	0.82 (0.08)
Alburnoides bipunctatus	*Alb*	C	0.14	0.89 (0.01)	0.6 (0.05)	0.77 (0.1)	0.83 (0.05)
Alburnus alburnus	*Ala*	C	0.22	0.91 (0.01)	0.65 (0.03)	0.81 (0.06)	0.84 (0.05)
Ameiurus melas	*Amm*	C	0.06	0.87 (0.02)	0.53 (0.1)	0.72 (0.18)	0.8 (0.09)
Anguilla anguilla	*Ana*	C	0.30	0.92 (0.01)	0.67 (0.02)	0.82 (0.05)	0.85 (0.04)
Barbatula barbatula	*Bba*	C	0.57	0.81 (0.01)	0.48 (0.02)	0.78 (0.04)	0.7 (0.04)
Barbus barbus	*Bab*	C	0.23	0.91 (0.01)	0.67 (0.02)	0.83 (0.05)	0.83 (0.03)
Barbus meridionalis	*Bam*	C	0.03	0.96 (0.01)	0.72 (0.15)	0.79 (0.19)	0.93 (0.05)
Blicca bjoerkna	*Blb*	C	0.09	0.89 (0.01)	0.58 (0.09)	0.74 (0.15)	0.84 (0.08)
Chondrostoma nasus	*Chn*	C	0.09	0.93 (0.01)	0.68 (0.08)	0.8 (0.12)	0.88 (0.05)
Cottus gobio	*Cog*	C	0.41	0.86 (0.01)	0.56 (0.02)	0.77 (0.04)	0.79 (0.04)
Cyprinus carpio	*Cyc*	C	0.07	0.8 (0.02)	0.41 (0.09)	0.63 (0.19)	0.78 (0.12)
Esox lucius	*Esl*	C	0.18	0.85 (0.01)	0.54 (0.04)	0.75 (0.08)	0.79 (0.05)
Gasterosteus aculeatus	*Gaa*	C	0.09	0.83 (0.02)	0.48 (0.06)	0.68 (0.13)	0.8 (0.08)
Gobio gobio	*Gog*	C	0.54	0.84 (0.01)	0.53 (0.03)	0.79 (0.04)	0.74 (0.04)
Gymnocephalus cernua	*Gyc*	C	0.08	0.89 (0.01)	0.59 (0.08)	0.76 (0.14)	0.83 (0.08)
Lepomis gibbosus	*Leg*	C	0.21	0.84 (0.01)	0.51 (0.04)	0.72 (0.1)	0.79 (0.07)
Leuciscus leuciscus	*Lel*	C	0.22	0.84 (0.01)	0.5 (0.03)	0.73 (0.08)	0.77 (0.06)
Lota lota	*Lol*	C	0.01	0.89 (0.03)	0.55 (0.19)	0.7 (0.26)	0.85 (0.1)
Parachondrostoma toxostoma	*Pat*	C	0.03	0.93 (0.01)	0.64 (0.14)	0.75 (0.19)	0.89 (0.06)
Perca fluviatilis	*Pef*	C	0.31	0.82 (0.01)	0.48 (0.03)	0.72 (0.06)	0.76 (0.06)
Phoxinus phoxinus	*Php*	C	0.55	0.8 (0.01)	0.46 (0.02)	0.75 (0.04)	0.71 (0.04)
Pungitius pungitius	*Pup*	C	0.07	0.91 (0.01)	0.61 (0.08)	0.77 (0.15)	0.84 (0.07)
Rutilus rutilus	*Rur*	C	0.43	0.87 (0.01)	0.57 (0.02)	0.77 (0.03)	0.8 (0.03)
Salmo salar	*Sas*	C	0.04	0.94 (0.02)	0.68 (0.12)	0.77 (0.16)	0.91 (0.06)
Salmo trutta	*Sat*	C	0.58	0.88 (0.01)	0.6 (0.02)	0.79 (0.03)	0.8 (0.03)
Sander lucioperca	*Sal*	C	0.03	0.87 (0.02)	0.53 (0.12)	0.69 (0.19)	0.84 (0.09)
Scardinius erythrophthalmus	*Sce*	C	0.13	0.8 (0.02)	0.43 (0.06)	0.67 (0.14)	0.77 (0.09)
Squalius cephalus	*Sqc*	C	0.54	0.88 (0.01)	0.6 (0.02)	0.81 (0.03)	0.79 (0.03)
Telestes souffia	*Tes*	C	0.06	0.94 (0.01)	0.69 (0.1)	0.79 (0.15)	0.9 (0.06)
Thymallus thymallus	*Tht*	C	0.01	0.91 (0.03)	0.55 (0.22)	0.66 (0.3)	0.89 (0.08)
Tinca tinca	*Tit*	C	0.12	0.83 (0.01)	0.49 (0.05)	0.71 (0.1)	0.79 (0.07)

Appendix 4. Range shifts.

Table A7. Changes in the spatial distribution of the species between the initial and the contemporary periods along altitudinal and upstream-downstream gradients. Positive distribution shifts indicate shifts towards higher elevation or upstream and negative shifts towards lower elevation or downstream. Bold indicates significant changes ($p < 0.05$).

		Elevation (m)			**Upstream-downstream (km)**		
Species names	Code	Range center	Lower limit	Upper limit	Range center	Lower limit	Upper limit
Abramis brama	*Abb*	-1.03	-0.1	**48.64**	**2.11**	-6.22	**-3.01**
Alburnoides bipunctatus	*Alb*	**-4.47**	**4.2**	**-34.33**	-0.94	**40.1**	**0.69**
Alburnus alburnus	*Ala*	**9.81**	**0.81**	-6.46	**12.88**	**19.97**	**1.33**
Ameiurus melas	*Amm*	**-20.34**	**-1.46**	1.9	**65.07**	**94.04**	**0.47**
Anguilla anguilla	*Ana*	**4.47**	**0.13**	**7.98**	**-3.76**	**11.28**	**-0.02**
Barbatula barbatula	*Bba*	**23.12**	**2.19**	**106.68**	**0.59**	**-20.33**	**0.29**
Barbus barbus	*Bab*	**-2.63**	**2.41**	**-90.53**	**4.74**	**-7.71**	-0.43
Barbus meridionalis	*Bam*	**102.56**	**6.97**	**204.79**	**1.68**	**40.52**	**0.07**
Blicca bjoerkna	*Blb*	**19.51**	0.04	**618.65**	**12.41**	**33.6**	-2.63
Chondrostoma nasus	*Chn*	**-7.33**	**7.43**	**-189.02**	**-16.48**	**-31.69**	**-11.44**
Cottus gobio	*Cog*	**5.92**	**1.17**	**-54.43**	**-0.75**	**-37.73**	**-0.05**
Cyprinus carpio	*Cyc*	**15.08**	**0.43**	**68.29**	**-35.51**	-10.09	**-0.29**
Esox lucius	*Esl*	**14.6**	**0.13**	**125.45**	**-3.94**	**24.26**	**-0.53**
Gasterosteus aculeatus	*Gaa*	-0.28	**-2.77**	41.27	**-2.56**	**-54.34**	**-0.01**
Gobio gobio	*Gog*	**9.43**	**0.6**	**65.09**	**2.32**	**-14.78**	0.05
Gymnocephalus cernua	*Gyc*	**43.49**	**1.02**	**392.73**	**-26.47**	**-98.88**	**-14.78**
Lepomis gibbosus	*Leg*	**12.89**	**0.49**	**30.8**	**-18.23**	-7.33	**-0.04**
Leuciscus leuciscus	*Lel*	**14.18**	**1.87**	**104.23**	-0.85	**14.92**	-0.64
Lota lota	*Lol*	**63.07**	**11.95**	**346.07**	**36.55**	**220.63**	**0.97**
Parachondrostoma toxostoma	*Pat*	**7.21**	1.01	**21.61**	**4.87**	19	0.54
Perca fluviatilis	*Pef*	-1.14	0	**65.43**	-2.44	**-27.02**	**-0.78**
Phoxinus phoxinus	*Php*	**38.82**	**7.82**	**46.64**	**0.83**	**-5**	**-0.1**
Pungitius pungitius	*Pup*	**7.49**	**-1.07**	**25.91**	**-0.68**	**-76.09**	**-0.01**
Rutilus rutilus	*Rur*	**5.58**	**0.47**	**-18.33**	**-2.6**	**-13.32**	**-0.19**
Salmo salar	*Sas*	**122.35**	**1**	**715.66**	-0.02	**19.56**	-0.07
Salmo trutta	*Sat*	**65.19**	**1.63**	**22.74**	**0.05**	**1.99**	0
Sander lucioperca	*Sal*	**8.86**	**0.2**	**72.9**	**15.16**	**31.09**	2.03
Scardinius erythrophthalmus	*Sce*	**23.29**	**0.26**	**125.41**	**8.31**	**22.71**	-0.28
Squalius cephalus	*Sqc*	**4.38**	**1.13**	**32.39**	**7.34**	**27.73**	-0.24
Telestes souffia	*Tes*	**45.36**	**23.57**	10.93	-0.82	**112.53**	0.08
Thymallus thymallus	*Tht*	**190.97**	**82.11**	**427.86**	**16.86**	**162.35**	**-1.86**
Tinca tinca	*Tit*	**16.27**	**-0.3**	**403.69**	**-35.9**	**-103.91**	**-1.3**