Ecography

ECOG-01092
Eme, D., Zagmajster, M., Fišer, C., Galassi, D., Marmonier, P., Stoch, F., Cornu, J.-F., Oberdorff, T. and Malard, F. 2014. Multi-causality and spatial non-stationarity in the determinants of groundwater crustacean diversity in Europe. – Ecography doi: 10.1111/ecog.01092

Supplementary material

Appendix 1

Table A1. Summary results of the simultaneous autoregressive models (SAR) and generalized linear models with negative binomial error (GLMnb) for testing separately the three broad mechanisms on the drivers of species richness of obligate groundwater crustaceans in Europe. ExVar: proportion of explained variance (%); AICc: Akaike's information criterion corrected for small sample size. For SAR, the best neighborhood distance was 300 km.

Model	Historical climate stability		Productive energy		Spatial heterogeneity	
	ExVar	AICc	ExVar	AICc	ExVar	AICc
SAR	32.0 (58.0)[a]	998.1	39.1 (59.7)[a]	970.2	32.0 (59.3)[a]	986.3
GLMnb	43.7	2995	43.8	2991	39.5	3031

[a] including the spatial component

Table A2. Parameter estimates of ordinary least squares models, simultaneous autoregressive models and generalized linear models with negative binomial error (GLMnb) for testing separately the three broad mechanisms on the drivers of species richness of obligate groundwater crustaceans in Europe. Parameter estimates and their standard error are from model averaging using a set of models whose difference in the Akaike's information criterion corrected for small sample size (AICc) with the best model was ≤ 5. AICc*w*: summed AICc weights. For SAR, the best neighborhood distance was 300 km.

			OLS				SAR			
Mechanisms	Predictors	Terms	AICc*w*	Parameters estimates (SE)	Z value	P value	AICc*w*	Parameters estimates (SE)	Z value	P value
Historical climate stability		Intercept	-	2.21 (0.05)	41.46	<0.0001	-	2.10 (0.20)	10.62	<0.0001
	Temperature anomaly	Linear	1	-0.45 (0.05)	1.96	0.0501	0.68	-0.29 (0.13)	1.69	0.0905
		Quadratic	1	-0.38 (0.04)	9.02	<0.0001	1	-0.41 (0.11)	3.78	<0.0002
	Precipitation anomaly	Linear	0.71	-0.09 (0.05)	8.60	<0.0001	0.59	-0.16 (0.09)	2.27	0.0235
		Quadratic	0.43	0.03 (0.02)	1.19	0.2324	1	0.12 (0.03)	3.80	<0.0002
Productive energy		Intercept	-	1.81 (0.05)	37.24	<0.0001	-	1.82 (0.13)	13.80	<0.0001
	Actual Evapotranspiration	Linear	1	0.61 (0.03)	17.77	<0.0001	1	0.46 (0.06)	7.894	<0.0001
		Quadratic	0.67	0.05 (0.03)	1.86	0.0634	0.32	0.02 (0.04)	0.602	0.5470
Spatial heterogeneity		Intercept	-	1.74 (0.05)	33.68	<0.0001	-	1.81 (0.16)	11.18	<0.0001
	Elevation range	Linear	1	0.41 (0.04)	10.00	<0.0001	1	0.25 (0.05)	5.03	<0.0001
		Quadratic	1	0.10 (0.03)	3.17	0.00154	0.33	0.02 (0.03)	3.24	0.0012
	Habitat diversity	Linear	1	0.33 (0.04)	8.56	<0.0001	1	0.14 (0.04)	1.35	0.1771
		Quadratic	0.26	-8.1e-5 (0.04)	0.002	0.9900	0.47	0.04 (0.03)	0.80	0.4237

Table A2 (continued):

Mechanisms	Predictors	Terms	GLMnb			
			AICc*w*	Parameters estimates (SE)	Z value	P value
Historical climate stability		Intercept	-	2.60 (0.06)	43.57	<0.0001
	Temperature anomaly	Linear	1	-0.62 (0.06)	11.09	<0.0001
		Quadratic	1	-0.67 (0.05)	12.51	<0.0001
	Precipitation anomaly	Linear	1	-0.19 (0.06)	3.25	0.0011
		Quadratic	0.34	0.02 (0.03)	0.84	0.4005
Productive energy		Intercept	-	1.97 (0.04)	44.38	<0.0001
	Actual Evapotranspiration	Linear	1	0.78 (0.04)	18.60	<0.0001
		Quadratic	0.27	-0.01 (0.04)	0.16	0.8750
Spatial heterogeneity		Intercept	-	1.97 (0.08)	24.41	<0.0001
	Elevation range	Linear	1	0.59 (0.05)	12.40	<0.0001
		Quadratic	1	0.11 (0.04)	2.64	0.0084
	Habitat diversity	Linear	1	0.35 (0.05)	6.67	<0.0001
		Quadratic	0.86	-0.10 (0.04)	2.22	0.0266

Table A3. Independent and shared contributions of historical climate stability (H), productive energy (E) and spatial heterogeneity (S) to variation in species richness of obligate groundwater crustaceans in Europe using simultaneous autoregressive models (SAR) and generalized linear models with negative binomial error (GLMnb). In abbreviations, colons denote shared variance between mechanisms. For SAR, the best neighborhood distance was 220 km.

Model	Explained variance (%)	Variance partitioning (%)						
		Historical climate stability (H)	Productive energy (E)	Spatial heterogeneity (S)	H:E	H:S	E:S	H:E:S
SAR	50.82 (62.43) [a]	0.09	9.27	5.74	9.29	2.06	5.89	18.47
GLMnb	59.19	1.55	7.97	5.74	10.19	8.13	1.83	23.78

[a] including the spatial component

Table A4. Summary results of the best simultaneous autoregressive model (SAR) and the best generalized linear model with negative binomial error (GLMnb) for testing jointly the three broad mechanisms on the drivers of species richness of obligate groundwater crustaceans in Europe. ExVar: proportion of explained variance (%); AICc: Akaike's information criterion corrected for small sample size; Ano_T: temperature anomaly; Ano_P: precipitation anomaly; AET: actual evapotranspiration; Elevr: elevation range; Hab: habitat diversity. The superscript next to the predictor's names indicates the quadratic form. For SAR, the best neighborhood distance was 220 km.

Model		ExVar	AICc	Summed AICc weights										Interactions
				Historical climate stability				Productive energy		Spatial heterogeneity				
				Ano_T	Ano_T^2	Ano_P	Ano_P^2	AET	AET^2	Elevr	Elevr^2	Hab	Hab^2	
Additive	SAR	50.82 (62.43)[a]	936	0.48	0.56	0.36	0.48	1	-	1	-	1		na
	GLMnb	59.19	2845.2	1	1	0.27	-[b]	1	-	1	0.82	1	0.40	na[c]
With interactions	SAR	54.47 (63.18)	918	0.80	0.87	0.46	0.37	1	-	1	-	1	-	Elevr × AET = 1; Elevr × Hab = 0.50
	GLMnb	61.47	2820.4	1	1	0.37	-	1	-	1	0.29	1	0.27	Elevr × AET = 1; Elevr × Hab = 1

[a] including the spatial component

[b] not included in the model selection

[c] na: not applicable

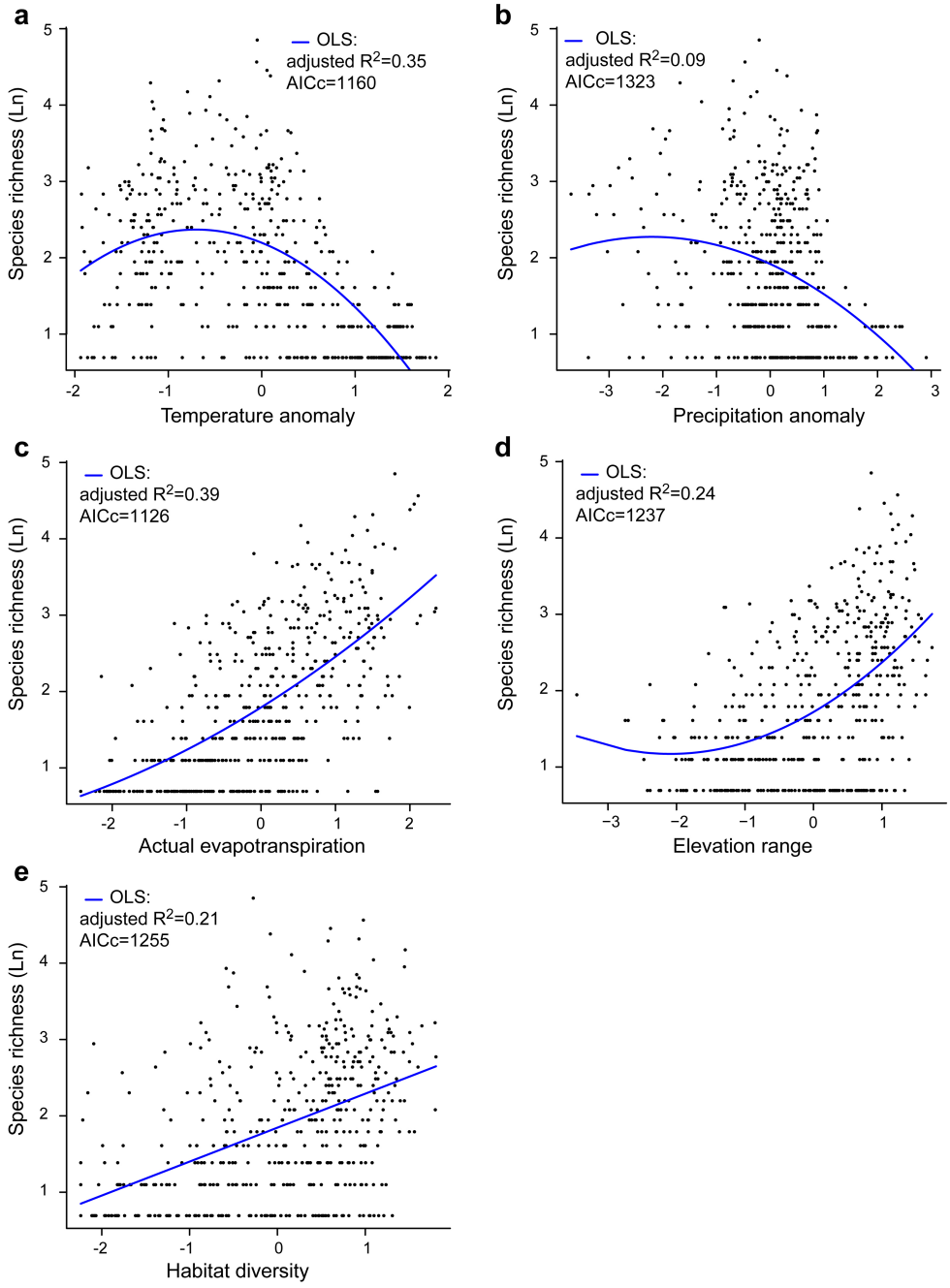
Table A5. Parameter estimates of ordinary least square (OLS) models, simultaneous autoregressive (SAR) models and generalized linear models with negative binomial error (GLMnb) for testing jointly the three broad mechanisms on the drivers of species richness of obligate groundwater crustaceans in Europe. Parameter estimates and their standard error (in parenthesis) are from model averaging using a set of models whose difference in the Akaike's information criterion corrected for small sample size (AICc) with the best model was ≤ 5. Ano_T: temperature anomaly; Ano_P: precipitation anomaly; AET: actual evapotranspiration; Elevr: elevation range; Hab: habitat diversity. The superscript next to the predictor's names indicates the quadratic form. For simultaneous autoregressive models, the best neighborhood distance was 220 km.

Model		Intercept	Historical climate stability				Productive energy		Spatial heterogeneity				Interactions
			Ano_T	Ano_T^2	Ano_P	Ano_P^2	AET	AET^2	Elevr	Elevr^2	Hab	Hab^2	
Additive	GLMnb	1.92 (0.08)	-0.23 (0.06)	-0.16 (0.05)	0.02 (0.05)	-[a]	0.50 (0.05)	-	0.28 (0.05)	0.07 (0.03)	0.25 (0.05)	0.05 (0.04)	na[b]
	OLS	1.78 (0.07)	-0.10 (0.05)	-0.07 (0.04)	0.04 (0.04)	-	0.41 (0.04)	0.06 (0.03)	0.25 (0.05)	0.07 (0.03)	0.18 (0.04)	-	na[b]
	SAR	1.90 (0.11)	-0.11 (0.08)	-0.13 (0.08)	-0.06 (0.07)	0.04 (0.03)	0.38 (0.06)	-	0.20 (0.05)	-	0.15 (0.04)	-	na
With interactions	GLMnb	1.95 (0.07)	-0.31 (0.06)	-0.23 (0.06)	-0.06 (0.05)	-	0.39 (0.06)	-	0.22 (0.05)	-0.02 (0.04)	0.24 (0.04)	0.01 (0.04)	Elevr×AET =0.22 (0.05); Elevr×Shannon = 0.13 (0.05)
	OLS	1.85 (0.06)	-0.17 (0.05)	-0.12 (0.04)	-	-	0.32 (0.04)	0.05 (0.03)	0.22 (0.04)	0.01 (0.03)	0.18 (0.04)	-	Elevr×AET =0.17 (0.04); Elevr×Shannon = 0.12 (0.04)
	SAR	1.91 (0.11)	-0.17 (0.08)	-0.17 (0.08)	-0.10 (0.08)	0.03 (0.03)	0.28 (0.06)	-	0.21 (0.05)	-	0.14 (0.04)	-	Elevr×AET= 0.18 (0.05); Elevr×Shannon_HA = 0.05 (0.04)

[a] not included in the model selection

[b] na: not applicable

Figure A1. Pairwise relationships between species richness (ln(x+1) transformed) and a) temperature anomaly, b) precipitation anomaly, c) actual evapotranspiration, d) elevation range, and e) habitat diversity. Scale for environmental variable corresponds to standardized values. OLS: ordinary least squares. AICc: Akaike's information criterion corrected for small sample size.



62 **Appendix 2**

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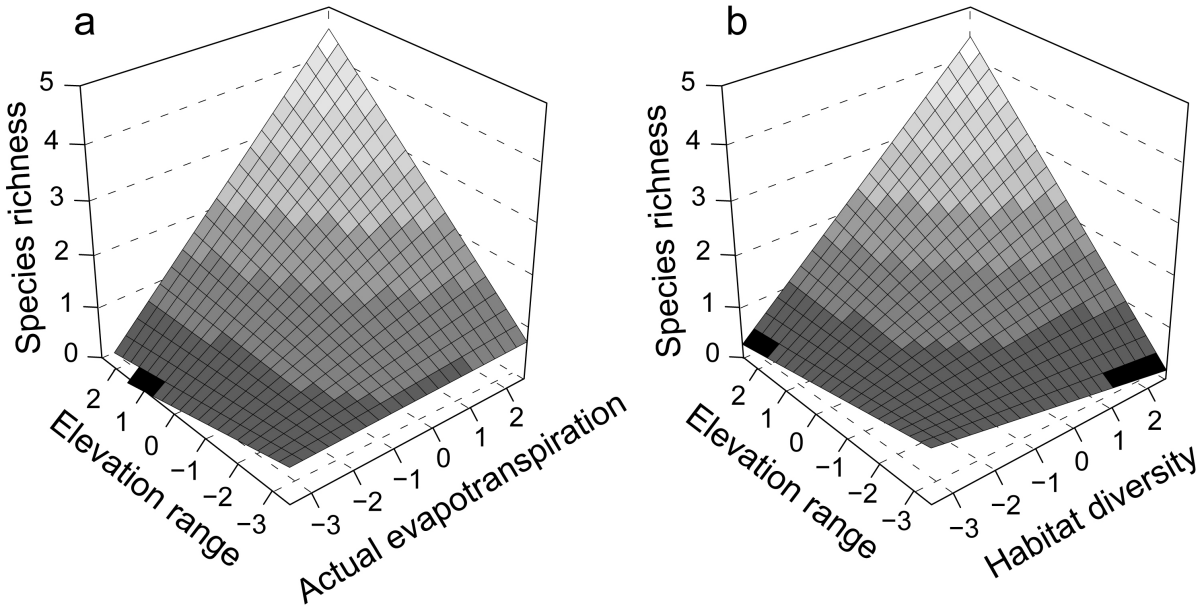
65 Figure A2. Interaction effects between elevation range (ln transformed) and (a) actual
66 evapotranspiration and (b) habitat diversity on species richness of groundwater crustaceans.
67 Species richness values are ln(x+1) transformed and correspond to fitted values from ordinary
68 least square models. Scale for environmental predictors corresponds to standardized values.



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Appendix 3

Figure A3. Top row: maps of observed (a) and estimated richness (b). Bottom row: relationships between observed and estimated species richness and latitude for western (< 15° E) (c) and eastern (>15° E) (d) Europe (see broken lines in panels a and b). Estimated richness is from geographically weighted regression. Small black and red dots are observed and estimated species richness per cell, respectively. Large black and red dots are mean observed and estimated species richness per latitudinal band, respectively. Black and red lines in panels represent the fit of a generalized additive model to the cell average per latitudinal band of observed and estimated species richness, respectively. Map projection is Lambert azimuthal equal-area (ETRS89).