

Ecography

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**Supplementary material**

## Appendix 1

**Table A1.** Null model analysis of coherence and turnover at different spatial extents, where ‘Abs’ is the number of embedded absences, ‘Rep’ is the number of species replacements, and ‘Mean’ and ‘Var’ are the average and variance of null model simulations. Initial results were obtained for 999 simulations. For initially random (Coherence  $P > 0.05$  using 999 simulations) and quasi (Turnover  $P > 0.05$  using 999 simulations) cases, analysis was repeated using 2,999–4,999 simulations (bold and underlined results). We used 4,999 simulations in the watershed datasets and reduced simulations in the United States dataset (3,999 simulations to test >1 spp obs., Common species, and Lentic species; 2,999 simulations to test All data, Fish-water species, and Non-coastal species) as explained in the main text.

**Table A2.** Null model analysis of coherence and turnover at different levels of phylogeny, where ‘Abs’ is the number of embedded absences, ‘Rep’ is the number of species replacements, and ‘Mean’ and ‘Var’ are the average and variance of null model simulations. Initial results were obtained for 999 simulations. For initially random (Coherence  $P > 0.05$  using 999 simulations) and quasi (Turnover  $P > 0.05$  using 999 simulations) cases, analysis was repeated using 2,999–4,999 simulations (bold and underlined results). We used 4,999 simulations in all clades except for the *Enallagma*, which is equivalent to the United States dataset in Table A1.

**Table A1.** Null model analysis of coherence and turnover at different spatial extents, where ‘#Abs’ is the number of embedded absences, ‘#Rep’ is the number of species replacements, and ‘Mean’ and ‘Var’ are the average and variance of null model simulations. Initial results were obtained for 999 simulations. For initially random (Coherence  $P > 0.05$  using 999 simulations) and quasi (Turnover  $P > 0.05$  using 999 simulations) cases, analysis was repeated using 2,999–4,999 simulations (bold and underlined results). We used 4,999 simulations in the watershed datasets and reduced simulations in the United States dataset (3,999 simulations to test >1spp obs., Common species, and Lentic species; 2,999 simulations to test All data, Fish-water species, and Non-coastal species) as explained in the main text.

Dataset	Gradient	Scenario	Coherence			Turnover		
			#Abs	Mean (Var)	<i>P</i>	#Rep	Mean (Var)	<i>P</i>
United States	Latitude	All data	88635	107504 (5714)	0.0010	1.88E+08	<b><u>1.65E+08 (1.07E+07)</u></b>	<b><u>0.0453</u></b>
		>1spp obs.	31128	38571 (2212)	0.0008	2.60E+07	<b><u>1.89E+07 (2.42E+06)</u></b>	<b><u>0.0033</u></b>
		Common species	34542	37371 (787)	0.0003	3.47E+06	3.37E+06 (4.64E+04)	0.0376
		Lentic species	8701	13826 (1983)	0.0098	4.25E+06	<b><u>3.14E+06 (4.43E+05)</u></b>	<b><u>0.0119</u></b>
		Fish-water species	64447	77687 (4585)	0.0039	1.20E+08	<b><u>1.04E+08 (7.53E+06)</u></b>	<b><u>0.0410</u></b>
		Non-coastal species	67986	76068 (2828)	0.0043	4.01E+07	<b><u>3.55E+07 (2.31E+06)</u></b>	<b><u>0.0457</u></b>
	Longitude	All data	73763	98762 (7810)	0.0014	1.87E+08	<b><u>1.64E+08 (1.10E+07)</u></b>	<b><u>0.0427</u></b>
		>1spp obs.	25664	37587 (2978)	<0.0001	2.86E+07	2.51E+07 (1.64E+06)	0.0368
		Common species	33336	37323 (1138)	0.0005	3.58E+06	<b><u>3.03E+06 (2.66E+05)</u></b>	<b><u>0.0400</u></b>
		Lentic species	8765	13886 (1524)	0.0008	4.08E+06	3.70E+06 (1.81E+05)	0.0344

Dataset	Gradient	Scenario	Coherence			Turnover		
			#Abs	Mean (Var)	P	#Rep	Mean (Var)	P
		Fish-water species	52856	75655 (6684)	0.0006	1.22E+08	<b><u>1.07E+08 (6.87E+06)</u></b>	<b><u>0.0267</u></b>
		Non-coastal species	63518	76694 (3681)	0.0003	1.71E+06	1.64E+06 (2.72E+04)	0.0252
	Temperature	All data	91958	102933 (4380)	0.0122	1.65E+08	1.55E+08 (4.76E+06)	0.0447
		>1spp obs.	31991	39933 (2565)	0.0020	2.13E+07	1.85E+07 (1.30E+06)	0.0329
		Common species	35801	37280 (648)	0.0224	1.32E+06	<b><u>1.27E+06 (3.54E+04)</u></b>	<b><u>0.1425</u></b>
		Lentic species	9645	13868 (1527)	0.0057	4.15E+06	<b><u>2.78E+06 (5.45E+05)</u></b>	<b><u>0.0120</u></b>
		Fish-water species	67771	81581 (5024)	0.0060	1.02E+08	<b><u>8.66E+07 (7.35E+06)</u></b>	<b><u>0.0324</u></b>
		Non-coastal species	70117	75919 (1801)	0.0013	2.69E+07	<b><u>2.33E+07 (1.73E+06)</u></b>	<b><u>0.0394</u></b>
	Precipitation	All data	85883	107343 (6450)	0.0009	9.89E+07	<b><u>8.34E+07 (7.05E+06)</u></b>	<b><u>0.0287</u></b>
		>1spp obs.	28816	37881 (2378)	0.0001	1.36E+07	1.16E+07 (9.45E+05)	0.0410
		Common species	36635	37617 (386)	0.0110	9247	<b><u>9237 (10)</u></b>	<b><u>0.3340</u></b>
		Lentic species	9429	14631 (1225)	<0.0001	3.07E+06	2.61E+06 (2.00E+05)	0.0224
		Fish-water species	62904	82540 (5346)	0.0002	6.62E+07	<b><u>5.52E+07 (5.18+06)</u></b>	<b><u>0.0335</u></b>
		Non-coastal species	67936	77442 (2331)	<0.0001	3.23E+07	<b><u>2.84E+07 (1.99E+06)</u></b>	<b><u>0.0506</u></b>
Mid Atlantic	Latitude	All data	6583	8560 (506)	<0.0001	931097	771546 (61794)	0.0098
		>1spp obs.	1870	2531 (93)	<0.0001	118608	89330 (6902)	<0.0001

Dataset	Gradient	Scenario	Coherence			Turnover		
			#Abs	Mean (Var)	P	#Rep	Mean (Var)	P
		Common species	3057	3426 (111)	0.0009	62604	50131 (5813)	0.0319
		Lentic species	1019	1756 (199)	0.0002	73582	59738 (4732)	0.0034
		Fish-water species	5616	7188 (343)	<0.0001	793813	668373 (49272)	0.0109
		Non-coastal species	4919	5910 (281)	0.0004	434270	354105 (32035)	0.0123
	Longitude	All data	7966	8777 (244)	0.0009	212683	184255 (13894)	0.0408
		>1spp obs.	2321	2552 (61)	0.0002	17965	13832 (1360)	0.0024
		Common species	3320	3507 (39)	<0.0001	14370	12749 (662)	0.0143
		Lentic species	1485	1811 (95)	0.0006	16122	13236 (1132)	0.0108
		Fish-water species	6883	7497 (157)	<0.0001	185387	157794 (12174)	0.0234
		Non-coastal species	5832	6188 (134)	0.0081	53969	45686 (3881)	0.0328
	Temperature	All data	7217	8538 (311)	<0.0001	418082	350373 (27210)	0.0128
		>1spp obs.	2014	2560 (90)	<0.0001	52227	38759 (4184)	0.0013
		Common species	3461	<b>3487 (45)</b>	<b>0.5715</b>	<i>Not applicable</i>		
		Lentic species	1179	1831 (133)	<0.0001	43894	31910 (4113)	0.0036
		Fish-water species	6216	7410 (457)	0.0090	355431	291873 (25981)	0.0144
		Non-coastal species	5489	6115 (183)	0.0006	94988	<b>70756 (7121)</b>	<b>0.0007</b>
	Precipitation	All data	7650	8702 (302)	0.0005	75456	62327 (5907)	0.0262

Dataset	Gradient	Scenario	Coherence			Turnover		
			#Abs	Mean (Var)	P	#Rep	Mean (Var)	P
		>1spp obs.	2237	2547 (53)	<0.0001	20093	15957 (1360)	0.0024
		Common species	3446	<b>3484 (36)</b>	<b>0.2970</b>	<i>Not applicable</i>		
		Lentic species	1245	1781 (97)	<0.0001	3014	<b>2948 (68)</b>	<b>0.3348</b>
		Fish-water species	6627	7679 (291)	0.0003	64793	55395 (4318)	0.0295
		Non-coastal species	5921	<b>6297 (123)</b>	<b>0.0022</b>	10360	<b>7082 (1123)</b>	<b>0.0035</b>
AR-White-Red	Latitude	All data	2640	2943 (74)	<0.0001	79210	57510 (7781)	0.0053
		>1spp obs.	441	<b>458 (11)</b>	<b>0.1305</b>	<i>Not applicable</i>		
		Common species	1737	1951 (75)	0.0042	19073	10988 (2830)	0.0043
		Fish-water species	2194	2475 (131)	0.0324	67621	48703 (7338)	0.0099
	Longitude	All data	2298	2807 (144)	0.0004	5282	<b>3647 (530)</b>	<b>0.0020</b>
		>1spp obs.	410	453 (13)	0.0007	209	<b>159 (16)</b>	<b>0.0023</b>
		Common species	1681	1926 (50)	<0.0001	5059	<b>3514 (560)</b>	<b>0.0058</b>
		Fish-water species	1978	2381 (90)	<0.0001	1272	<b>1089 (47)</b>	<b>&lt;0.0001</b>
	Temperature	All data	2684	<b>2959 (53)</b>	<b>&lt;0.0001</b>	49116	<b>33048 (3418)</b>	<b>&lt;0.0001</b>
		>1spp obs.	416	446 (15)	0.0415	637	<b>500 (37)</b>	<b>0.0002</b>
		Common species	1764	1959 (75)	0.0089	14824	11049 (1317)	0.0042

Dataset	Gradient	Scenario	Coherence			Turnover			
			#Abs	Mean (Var)	P	#Rep	Mean (Var)	P	
		Fish-water species	2222	2484 (85)	0.0022	44764	35384 (3990)	0.0187	
	Precipitation	All data	2276	2826 (126)	<0.0001	101493	65700 (12941)	0.0057	
		>1spp obs.	394	456 (16)	<0.0001	434	334 (30)	0.0008	
		Common species	1592	1922 (93)	0.0004	43687	32405 (4943)	0.0225	
		Fish-water species	1931	2434 (76)	<0.0001	77997	50873 (8452)	0.0013	
California	Latitude	All data	483	525 (11)	0.0001	169	118 (25)	0.0434	
		>1spp obs.	152	<b><u>157 (4)</u></b>	<b><u>0.2584</u></b>	<i>Not applicable</i>			
		Common species	373	<b><u>377 (3)</u></b>	<b><u>0.2161</u></b>	<i>Not applicable</i>			
			Fish-water species	147	170 (5)	<0.0001	<i>Failed to compute</i>		
	Longitude	All data	516	<b><u>524 (9)</u></b>	<b><u>0.3591</u></b>	<i>Not applicable</i>			
		>1spp obs.	157	<b><u>156 (3)</u></b>	<b><u>0.6578</u></b>	<i>Not applicable</i>			
		Common species	374	<b><u>371 (6)</u></b>	<b><u>0.5823</u></b>	<i>Not applicable</i>			
		Fish-water species	165	<b><u>171 (4)</u></b>	<b><u>0.1621</u></b>	<i>Not applicable</i>			
	Temperature	All data	495	527 (7)	<0.0001	573	503 (15)	<0.0001	
		>1spp obs.	142	151 (4)	0.0376	39	<b><u>39 (2)</u></b>	<b><u>0.8270</u></b>	
		Common species	353	371 (6)	0.0018	224	<b><u>179 (13)</u></b>	<b><u>0.0005</u></b>	

Dataset	Gradient	Scenario	Coherence			Turnover		
			#Abs	Mean (Var)	P	#Rep	Mean (Var)	P
		Fish-water species	174	<b><u>174 (4)</u></b>	<b><u>0.9407</u></b>	<i>Not applicable</i>		
	Precipitation	All data	480	521 (12)	0.0005	448	384 (26)	0.0133
		>1spp obs.	135	152 (5)	0.0002	184	<b><u>141 (9)</u></b>	<b><u>&lt;0.0001</u></b>
		Common species	330	371 (7)	<0.0001	160	137 (8)	0.0025
		Fish-water species	170	<b><u>172 (3)</u></b>	<b><u>0.5236</u></b>	<i>Not applicable</i>		



**Table A2.** Null model analysis of coherence and turnover at different levels of phylogeny, where ‘#Abs’ is the number of embedded absences, ‘#Rep’ is the number of species replacements, and ‘Mean’ and ‘Var’ are the average and variance of null model simulations. Initial results were obtained for 999 simulations. For initially random (Coherence  $P > 0.05$  using 999 simulations) and quasi (Turnover  $P > 0.05$  using 999 simulations) cases, analysis was repeated using 2,999–4,999 simulations (bold and underlined results). We used 4,999 simulations in all clades except for the *Enallagma*, which is equivalent to the United States dataset in Table A1.

Clade	Scenario	Gradient	Coherence			Turnover		
			#Abs	Mean (Var)	<i>P</i>	#Rep	Mean (Var)	<i>P</i>
<i>Enallagma</i>	All data	Latitude	<i>see Table A1, United States</i>			<i>see Table A1, United States</i>		
		Longitude	<i>see Table A1, United States</i>			<i>see Table A1, United States</i>		
		Temperature	<i>see Table A1, United States</i>			<i>see Table A1, United States</i>		
		Precipitation	<i>see Table A1, United States</i>			<i>see Table A1, United States</i>		
	>1spp obs.	Latitude	<i>see Table A1, United States</i>			<i>see Table A1, United States</i>		
		Longitude	<i>see Table A1, United States</i>			<i>see Table A1, United States</i>		
		Temperature	<i>see Table A1, United States</i>			<i>see Table A1, United States</i>		
		Precipitation	<i>see Table A1, United States</i>			<i>see Table A1, United States</i>		
Northern	All data	Latitude	41811	49268 (2845)	0.0088	2.62E+07	<b><u>2.09E+07 (2.35E+06)</u></b>	<b><u>0.0237</u></b>

Clade	Scenario	Gradient	Coherence			Turnover		
			#Abs	Mean (Var)	P	#Rep	Mean (Var)	P
		Longitude	34019	47519 (3781)	0.0004	4.68E+07	<b>3.80E+07 (3.46E+06)</b>	<b>0.0110</b>
		Temperature	44003	<b>53534 (2143)</b>	<b>&lt;0.0001</b>	2.54E+07	<b>1.94E+07 (2.53E+06)</b>	<b>0.0176</b>
		Precipitation	39881	48514 (2751)	0.0017	2.61E+07	<b>2.06E+07 (2.22E+06)</b>	<b>0.0124</b>
	>1spp obs.	Latitude	11855	13696 (455)	<0.0001	1.25E+06	1.08E+06 (80975)	0.0328
		Longitude	8711	13434 (694)	<0.0001	5.13E+06	4.19E+06 (385054)	0.0140
		Temperature	11875	13727 (480)	0.0001	1.39E+06	1.24E+06 (74113)	0.0416
		Precipitation	9749	13731 (654)	<0.0001	2.16E+06	1.77E+06 (168543)	0.0197
Southern	All data	Latitude	11996	16178 (1737)	0.0160	4.37E+06	3.84E+06 (244015)	0.0315
		Longitude	11595	14828 (1286)	0.0119	2.10E+06	1.93E+06 (82192)	0.0405
		Temperature	12382	15058 (902)	0.0030	3.94E+06	3.48E+06 (219071)	0.0362
		Precipitation	12486	16170 (1431)	0.0101	981168	<b>791634 (91681)</b>	<b>0.0387</b>
	>1spp obs.	Latitude	2305	3210 (186)	<0.0001	214920	172613 (14863)	0.0044
		Longitude	2296	3130 (239)	0.0005	114648	87475 (10201)	0.0077
		Temperature	2359	3230 (176)	<0.0001	192425	152264 (13717)	0.0034
		Precipitation	2406	3212 (204)	<0.0001	75848	60627 (7078)	0.0315
Northern-B	All data	Latitude	9862	12348 (788)	0.0016	396775	<b>257173 (46015)</b>	<b>0.0024</b>

Clade	Scenario	Gradient	Coherence			Turnover		
			#Abs	Mean (Var)	P	#Rep	Mean (Var)	P
		Longitude	7554	11771 (1323)	0.0014	2.15E+06	1.85E+06 (137245)	0.0305
		Temperature	10905	12130 (390)	0.0017	421602	306344 (54279)	0.0337
		Precipitation	8580	12119 (1401)	0.0115	2.28E+06	1.98E+06 (145267)	0.0410
	>1spp obs.	Latitude	1728	2006 (97)	0.0041	5700	<b>5388 (77)</b>	<b>&lt;0.0001</b>
		Longitude	1266	2124 (101)	<0.0001	80685	62207 (6601)	0.0051
		Temperature	1731	2041 (66)	<0.0001	3570	<b>3417 (108)</b>	<b>0.1564</b>
		Precipitation	1249	2030 (132)	<0.0001	51216	40535 (3849)	0.0055
Northern-C	All data	Latitude	11586	13298 (678)	0.0115	1.23E+06	<b>1.03E+06 (71998)</b>	<b>0.0074</b>
		Longitude	8794	12878 (1143)	0.0004	4.66E+06	4.31E+06 (170683)	0.0394
		Temperature	12052	13001 (444)	0.0324	788018	767358 (9733)	0.0338
		Precipitation	10599	13154 (574)	<0.0001	1.62E+06	1.56E+06 (27829)	0.0367
	>1spp obs.	Latitude	1585	1832 (69)	0.0003	21239	18242 (1098)	0.0064
		Longitude	890	1765 (125)	<0.0001	176011	140002 (10767)	0.0008
		Temperature	1650	1865 (47)	<0.0001	13893	12557 (646)	0.0386
		Precipitation	1204	1824 (111)	<0.0001	54985	45985 (4355)	0.0388
Southern-D	All data	Latitude	5050	6458 (524)	0.0072	567584	490762 (30710)	0.0124

Clade	Scenario	Gradient	Coherence			Turnover		
			#Abs	Mean (Var)	P	#Rep	Mean (Var)	P
		Longitude	5034	6436 (401)	0.0005	200194	<b><u>179621 (8449)</u></b>	<b><u>0.0149</u></b>
		Temperature	5322	6638 (376)	0.0005	448910	403106 (22873)	0.0452
		Precipitation	5307	6618 (344)	0.0001	161473	<b><u>129542 (12001)</u></b>	<b><u>0.0078</u></b>
	>1spp obs.	Latitude	487	644 (25)	<0.0001	6908	5924 (379)	0.0095
		Longitude	551	640 (21)	<0.0001	1050	897 (49)	0.0019
		Temperature	491	649 (32)	<0.0001	6516	5439 (329)	0.0011
		Precipitation	520	645 (20)	<0.0001	1686	<b><u>1473 (82)</u></b>	<b><u>0.0089</u></b>
Southern-E	All data	Latitude	1421	2315 (302)	0.0031	165990	141335 (9842)	0.0122
		Longitude	1282	2239 (218)	<0.0001	112739	104035 (3924)	0.0266
		Temperature	1423	2385 (310)	0.0019	165487	139838 (10860)	0.0182
		Precipitation	1529	2431 (315)	0.0042	47454	45630 (885)	0.0392
	>1spp obs.	Latitude	48	64 (5)	0.0017	<i>Failed to compute</i>		
		Longitude	45	65 (5)	0.0002	<i>Failed to compute</i>		
		Temperature	49	65 (6)	0.0047	<i>Failed to compute</i>		
		Precipitation	41	66 (6)	<0.0001	<i>Failed to compute</i>		