

Supplementary material

The added value of geodiversity indices in explaining variation of stream macroinvertebrate diversity

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Table S1. Pearson correlations between the biodiversity indices, traditional environmental and geodiversity variables. Stream velocity, depth and width are based on standard deviations (SD) of measurements made at each site (see Methods). Statistically significant ($p < 0.05$) correlations are in bold.

	Species richness	Shannon diversity	Simpson diversity	Pielou evenness	Functional richness	Functional evenness	Functional dispersion	Rao's quadratic entropy
Velocity (SD)	-0.062	0.140	0.191	0.193	0.006	-0.027	0.148	0.135
Depth (SD)	-0.253	-0.176	-0.164	-0.079	-0.130	0.263	-0.058	-0.038
Width (SD)	0.101	0.079	0.071	0.062	0.152	0.031	0.138	0.098
Total N	-0.167	-0.102	-0.045	-0.032	-0.211	0.234	-0.122	-0.162
pH	0.137	-0.074	-0.040	-0.122	-0.103	0.056	-0.142	-0.213
Colour	-0.065	0.074	0.112	0.104	-0.088	0.109	-0.033	-0.003
Conductivity	0.048	0.256	0.245	0.267*	-0.003	0.034	0.066	0.042
Manganese	0.077	0.117	0.169	0.102	-0.020	-0.071	0.063	0.032
Iron	0.025	0.049	0.063	0.029	-0.044	-0.024	-0.036	-0.057
Flow type								
richness	0.407**	0.117	0.027	-0.044	0.270*	0.032	-0.043	-0.061
Geomorphological								
richness	0.091	0.024	0.057	-0.043	0.222	-0.276*	0.192	0.189
Substrate richness	0.179	0.009	-0.073	-0.106	0.219	0.037	-0.116	-0.085
Total geodiversity	0.309*	0.069	0.050	-0.092	0.355**	-0.156	0.061	0.065

P < 0.05, **P < 0.01

Table S2. Total abundances of the species found from the 55 stream sites surveyed. Also, shown are species traits based on habit trait groups (BUR = burrowers, CLIM = climbers, CLIN = clingers, SPR = sprawlers, SWIM = swimmers), functional feeding groups (FIL = filterers, GAT = gatherers, PRE = predators, SCR = scrapers, SHR = shredders) and size classes.

Taxa	Traits	Total abundance
<i>Ameletus inopinatus</i>	GAT/SWIM/1–2 cm	334
<i>Amphinemura borealis</i>	SCR/SPR/0.5–1 cm	186
<i>Amphinemura sulcicollis</i>	SCR/SPR/0.5–1 cm	193
<i>Apatania sp.</i>	SCR/CLIN/1–2 cm	17
<i>Arctopsyche ladogensis</i>	FIL/CLIN/2–4 cm	6
<i>Atherix ibis</i>	PRE/SPR/1–2 cm	3
<i>Baetis muticus</i>	SCR/SWIM/1–2 cm	918
<i>Baetis niger digitatus</i>	SCR/SWIM/1–2 cm	216
<i>Baetis rhodani</i>	SCR/SWIM/1–2 cm	11560
<i>Berdeniella sp.</i>	SCR/BUR/0.25–0.5 cm	115
<i>Bezzia</i>	PRE/BUR/0.5–1 cm	8
<i>Brachyptera risi</i>	SCR/SPR/1–2 cm	310
<i>Brillia bifida</i>	SHR/BUR/0.5–1 cm	4
<i>Cardiocladius capucinus</i>	PRE/BUR/0.5–1 cm	15
<i>Cardiocladius fuscus</i>	PRE/BUR/0.5–1 cm	36
<i>Chelifera sp.</i>	PRE/SPR/0.25–0.5 cm	160
<i>Clinocera sp.</i>	PRE/CLIN/1–2 cm	4
<i>Constempellina brevicosta</i>	FIL/BUR/≤0.25 cm	11
<i>Corynoneura lobata t.</i>	GAT/SPR/≤0.25 cm	61
<i>Cricotopus sp.</i>	SCR/CLIN/0.5–1 cm	84
<i>Diamesa bertrami</i>	SCR/SPR/1–2 cm	5
<i>Diamesa incallida</i>	SCR/SPR/1–2 cm	1
<i>Diamesa insignipes</i>	SCR/SPR/1–2 cm	3
<i>Dicranota sp.</i>	PRE/BUR/1–2 cm	285
<i>Diura nanseni</i>	PRE/CLIN/2–4 cm	13
<i>Eiseniella tetraedra</i>	GAT/BUR/4–8 cm	141
<i>Elmis aenea</i>	SCR/CLIN/0.25–0.5 cm	211
<i>Eloeophila sp.</i>	SHR/BUR/1–2 cm	4
<i>Ephemerella aurivillii</i>	SCR/CLIN/0.5–1 cm	175
<i>Ephemerella mucronata</i>	SCR/CLIN/0.5–1 cm	1
<i>Eukiefferiella boevrensis</i>	SCR/SPR/0.25–0.5 cm	56
<i>Eukiefferiella brevicar</i>	SCR/SPR/0.25–0.5 cm	313
<i>Eukiefferiella claripennis</i>	SCR/SPR/0.25–0.5 cm	9
<i>Eukiefferiella devonica agg.</i>	SCR/SPR/0.25–0.5 cm	1406
<i>Eukiefferiella minor</i>	SCR/SPR/0.25–0.5 cm	6
<i>Georthocladus luteicornis</i>	SCR/SPR/0.25–0.5 cm	2
<i>Halesus sp.</i>	SHR/CLIM/2–4 cm	1
<i>Helodon ferrugineus</i>	FIL/CLIN/0.5–1 cm	1310
<i>Heptagenia dalecarlica</i>	SCR/CLIN/1–2 cm	216
<i>Hydraena gracilis</i>	SCR/CLIN/0.25–0.5 cm	25
<i>Hydropsyche sp.</i>	FIL/CLIN/2–4 cm	27

Taxa	UTC	Total abundance
<i>Isoperla difformis</i>	PRE/CLIN/1–2 cm	331
<i>Leptophlebidae sp.</i>	GAT/SWIM/1–2 cm	1
<i>Leuctra digitatus or hippopus</i>	GAT/SPR/1–2 cm	309
<i>Leuctra nigra</i>	GAT/SPR/1–2 cm	73
<i>Limnius volcmari</i>	SCR/CLIN/0.25–0.5 cm	1
<i>Limnophyes sp.</i>	GAT/SPR/≤0.25 cm	16
<i>Metacnephia bilineata</i>	FIL/CLIN/0.5–1 cm	641
<i>Micrasema gelidum</i>	SHR/CLIN/0.5–1 cm	15
<i>Micropsectra atrofasciata agg.</i>	GAT/CLIM/0.5–1 cm	2593
<i>Micropsectra notescens</i>	GAT/CLIM/0.5–1 cm	4
<i>Molophilus sp.</i>	SHR/BUR/1–2 cm	3
<i>Nanocladius rectinervis</i>	GAT/SPR/0.5–1 cm	8
<i>Nemoura sp.</i>	SHR/SPR/0.5–1 cm	2161
<i>Nemurella pictetii</i>	GAT/SPR/0.5–1 cm	7
<i>Orthocladius olivaceus. t.</i>	FIL/SPR/0.5–1 cm	29
<i>Orthocladius rivicola</i>	SCR/SPR/0.5–1 cm	725
<i>Orthocladius rivulorum</i>	SCR/SPR/0.5–1 cm	49
<i>Orthocladius saxosus</i>	SCR/SPR/0.5–1 cm	5
<i>Orthocladius frigidus</i>	SCR/SPR/0.5–1 cm	92
<i>Orthocladius excavatus t.</i>	GAT/SPR/0.5–1 cm	22
<i>Orthocladius rhyacobius agg.</i>	GAT/SPR/0.5–1 cm	156
<i>Orthocladius wetterensis</i>	GAT/SPR/0.5–1 cm	1
<i>Orthocladius lignicola</i>	GAT/SPR/0.5–1 cm	2
<i>Oulimnius tuberculatus</i>	SCR/CLIN/0.25–0.5 cm	11
<i>Paracricotopus sp.</i>	SCR/SPR/0.25–0.5 cm	17
<i>Parametriocnemus stylatus</i>	GAT/SPR/0.25–0.5 cm	130
<i>Paratrichocladius rufiventris</i>	SCR/SPR/0.5–1 cm	4
<i>Paratrichocladius skirwithensis</i>	SCR/SPR/0.5–1 cm	96
<i>Pentaneurella katterjokki</i>	PRE/SPR/0.5–1 cm	6
<i>Philopotamus montanus</i>	FIL/CLIN/1–2 cm	59
<i>Plectrocnemia conspersa</i>	PRE/CLIN/2–4 cm	26
<i>Potamophylax cingulatus</i>	SHR/CLIM/2–4 cm	41
<i>Potthastia gaedii</i>	SCR/SPR/0.5–1 cm	9
<i>Potthastia longimanus</i>	GAT/SPR/0.5–1 cm	17
<i>Prosimulium hirtipes</i>	FIL/CLIN/0.5–1 cm	1071
<i>Prosimulium macropyga group</i>	FIL/CLIN/0.5–1 cm	226
<i>Protonemura sp.</i>	SHR/SPR/1–2 cm	4203
<i>Psectrocladius limbatellus agg.</i>	GAT/SPR/0.5–1 cm	1
<i>Pseudorthocladius sp.</i>	GAT/SPR/0.25–0.5 cm	2
<i>Pseudosmittia gracilis t.</i>	GAT/SPR/0.0–0.25 cm	56
<i>Rheocricotopus effusus</i>	GAT/SPR/0.25–0.5 cm	1
<i>Rheocricotopus fuscipes</i>	GAT/SPR/0.25–0.5 cm	8
<i>Rheopelopia sp.</i>	PRE/SPR/0.5–1 cm	243
<i>Rheotanytarsus sp.</i>	FIL/CLIN/0.25–0.5 cm	46
<i>Rhyacophila nubila.</i>	PRE/CLIN/2–4 cm	563
<i>Simulium monticola</i>	FIL/CLIN/0.5–1 cm	974
<i>Simulium murmanum</i>	FIL/CLIN/0.5–1 cm	679

Taxa	UTC	Total abundance
<i>Simulium ornatum</i> group	FIL/CLIN/0.5–1 cm	31
<i>Simulium tuberosum</i> group	FIL/CLIN/0.25–0.5 cm	328
<i>Simulium venum</i> group	FIL/CLIN/0.5–1 cm	282
<i>Siphonoperla burmeisteri</i>	PRE/CLIN/1–2 cm	43
<i>Smittia</i> sp.	GAT/BUR/≤0.25 cm	1
<i>Stegopterna trigonium</i>	FIL/CLIN/0.25–0.5 cm	143
<i>Stempellinella brevis</i>	GAT/SPR/≤0.25 cm	2
<i>Synorthocladius semivirens</i>	GAT/CLIN/≤0.25 cm	4
<i>Thienemanniella majuscula</i> t.	SCR/SPR/≤0.25 cm	20
<i>Thienemanniella vittata</i>	SCR/SPR/≤0.25 cm	1
<i>Thienemannimyia</i> sp.	PRE/SPR/0.5–1 cm	13
<i>Tokunagaia</i> sp.	GAT/SPR/0.25–0.5 cm	1140
<i>Trissopelopia longimana</i>	PRE/SPR/0.5–1 cm	55
<i>Tvetenia bavarica</i>	SCR/SPR/0.25–0.5 cm	172
<i>Tvetenia calvescens</i>	SCR/SPR/0.25–0.5 cm	567
<i>Tvetenia discoloripes</i>	SCR/SPR/0.5–1 cm	69
<i>Valvata piscinalis</i>	GAT/CLIM/0.5–1 cm	5
<i>Wiedemannia</i> sp.	PRE/CLIN/0.25–0.5 cm	114

Table S3. Number of species belonging to individual trait categories (total) and number in each of the pairwise combinations of traits, including size class (Size), habit trait group (HTG) and functional feeding group (FFG). Abbreviations: BUR = burrowers, CLIM = climbers, CLIN = clingers, SPR = sprawlers, SWIM = swimmers, FIL = filterers, GAT = gatherers, PRE = predators, SCR = scrapers, SHR = shredders.

Comparison and trait category	Trait category						Total
Size							
HTG × size	0.0–0.25	0.25–0.5	0.5–1	1–2	2–4	4–8	
BUR	2	1	4	3	0	1	11
CLIM	0	0	3	0	2	0	5
CLIN	1	8	12	6	5	0	32
SPR	6	15	24	8	0	0	53
SWIM	0	0	0	5	0	0	5
Total	9	24	43	22	7	1	106
FFG × size	Size						
FIL	1	3	9	1	2	0	16
GAT	6	5	11	4	0	1	27
PRE	0	2	7	5	3	0	17
SCR	2	14	13	9	0	0	38
SHR	0	0	3	3	2	0	8
Total	9	24	43	22	7	1	106
HTG							
FFG × HTG	BUR	CLIM	CLIN	SPR	SWIM		
FIL	1	0	14	1	0		16
GAT	2	3	1	19	2		27
PRE	4	0	7	6	0		17
SCR	1	0	9	25	3		38
SHR	3	2	1	2	0		8
Total	11	5	32	53	5		106

Table S4. Contribution of selected predictor variables and predictor variable sets to explain variation in different diversity indices. Table shows commonality coefficients (unique and common) and total contributions of all predictor variables or predictor variable sets to the regression effect. Abbreviations: Shannon = Shannon diversity; Simpson = Simpson diversity; Sp. Eve = Pielou evenness; Fric = functional richness; FEve = functional evenness; FDis = functional dispersion; Rao.Q = Rao's quadratic entropy; FlowRich = flow type richness; GeomRich = geomorphological richness; SubstrRich = substrate richness; GeoRich = total geodiversity.

	Commonality coefficients	% total
Species richness		
Unique to <i>FlowRich</i>	0.198	81.68
Unique to <i>Depth</i>	0.077	31.94
Common to <i>FlowRich</i> , and <i>Depth</i>	-0.033	-13.62
Total	0.243	100.00
Shannon		
Unique to <i>FlowRich</i>	0.083	28.59
Unique to <i>Depth</i>	0.005	1.83
Unique to <i>Width</i>	0.120	41.23
Unique to <i>pH</i>	0.047	16.36
Unique to <i>Conductivity</i>	0.098	33.49
Common to <i>FlowRich</i> , and <i>Depth</i>	-0.002	-0.91
Common to <i>FlowRich</i> , and <i>Width</i>	-0.034	-11.73
Common to <i>Depth</i> , and <i>Width</i>	0.059	20.45
Common to <i>FlowRich</i> , and <i>pH</i>	-0.032	-11.17
Common to <i>Depth</i> , and <i>pH</i>	-0.002	-0.68
Common to <i>Width</i> , and <i>pH</i>	-0.013	-4.59
Common to <i>FlowRich</i> , and <i>Conductivity</i>	-0.019	-6.54
Common to <i>Depth</i> , and <i>Conductivity</i>	0.001	0.35
Common to <i>Width</i> , and <i>Conductivity</i>	-0.016	-5.56
Common to <i>pH</i> , and <i>Conductivity</i>	-0.016	-5.7
Common to <i>FlowRich</i> , <i>Depth</i> , and <i>Width</i>	-0.015	-5.29
Common to <i>FlowRich</i> , <i>Depth</i> , and <i>pH</i>	0.001	0.49
Common to <i>FlowRich</i> , <i>Width</i> , and <i>pH</i>	0.011	3.97
Common to <i>Depth</i> , <i>Width</i> , and <i>pH</i>	-0.008	-2.97
Common to <i>FlowRich</i> , <i>Depth</i> , and <i>Conductivity</i>	-0.000	-0.02
Common to <i>FlowRich</i> , <i>Width</i> , and <i>Conductivity</i>	0.007	2.47
Common to <i>Depth</i> , <i>Width</i> , and <i>Conductivity</i>	-0.003	-1.17
Common to <i>FlowRich</i> , <i>pH</i> , and <i>Conductivity</i>	0.010	3.54
Common to <i>Depth</i> , <i>pH</i> , and <i>Conductivity</i>	0.000	0.04
Common to <i>Width</i> , <i>pH</i> , and <i>Conductivity</i>	0.004	1.49
Common to <i>FlowRich</i> , <i>Depth</i> , <i>Width</i> , and <i>pH</i>	0.006	2.1
Common to <i>FlowRich</i> , <i>Depth</i> , <i>Width</i> , and <i>Conductivity</i>	0.002	0.97
Common to <i>FlowRich</i> , <i>Depth</i> , <i>pH</i> , and <i>Conductivity</i>	-0.000	-0.03
Common to <i>FlowRich</i> , <i>Width</i> , <i>pH</i> , and <i>Conductivity</i>	-0.003	-1.22
Common to <i>Depth</i> , <i>Width</i> , <i>pH</i> , and <i>Conductivity</i>	0.002	0.8
Common to <i>FlowRich</i> , <i>Depth</i> , <i>Width</i> , <i>pH</i> , and <i>Conductivity</i>	-0.001	-0.56
Total	0.293	100.00

	Commonality coefficients	% total
Simpson		
Unique to <i>FlowRich</i>	0.013	4.08
Unique to <i>Width</i>	0.254	79.71
Unique to <i>Conductivity</i>	0.070	22.11
Unique to <i>Velocity</i>	0.027	8.72
Common to <i>FlowRich</i> , and <i>Width</i>	-0.009	-3.08
Common to <i>FlowRich</i> , and <i>Conductivity</i>	-0.004	-1.44
Common to <i>Width</i> , and <i>Conductivity</i>	-0.007	-2.43
Common to <i>FlowRich</i> , and <i>Velocity</i>	0.010	3.33
Common to <i>Width</i> , and <i>Velocity</i>	-0.024	-7.78
Common to <i>Conductivity</i> , and <i>Velocity</i>	0.005	1.7
Common to <i>FlowRich</i> , <i>Width</i> , and <i>Conductivity</i>	0.002	0.85
Common to <i>FlowRich</i> , <i>Width</i> , and <i>Velocity</i>	-0.012	-3.77
Common to <i>FlowRich</i> , <i>Conductivity</i> , and <i>Velocity</i>	-0.001	-0.39
Common to <i>Width</i> , <i>Conductivity</i> , and <i>Velocity</i>	-0.007	-2.25
Common to <i>FlowRich</i> , <i>Width</i> , <i>Conductivity</i> , and <i>Velocity</i>	0.002	0.65
Total	0.318	100.00
Sp. Eve		
Unique to <i>SubstrRich</i>	0.005	2.68
Unique to <i>Width</i>	0.114	53.09
Unique to <i>Conductivity</i>	0.085	39.84
Common to <i>SubstrRich</i> , and <i>Width</i>	0.024	11.16
Common to <i>SubstrRich</i> , and <i>Conductivity</i>	-0.005	-2.64
Common to <i>Width</i> , and <i>Conductivity</i>	0.004	1.86
Common to <i>SubstrRich</i> , <i>Width</i> , and <i>Conductivity</i>	-0.012	-5.99
Total	0.215	100
Fric		
Unique to <i>GeoRich</i>	0.084	42.38
Unique to <i>Depth</i>	0.073	36.69
Common to <i>GeoRich</i> , and <i>Depth</i>	0.041	20.93
Total	0.199	100
FEve		
Unique to <i>FlowRich</i>	0.001	1.83
Unique to <i>SubstrRich</i>	0.004	6.11
Unique to <i>Depth</i>	0.060	74.39
Unique to <i>Velocity</i>	0.041	51.35
Common to <i>FlowRich</i> , and <i>SubstrRich</i>	0.001	1.99
Common to <i>FlowRich</i> , and <i>Depth</i>	0.002	3.51
Common to <i>SubstrRich</i> , and <i>Depth</i>	-0.004	-5.64
Common to <i>FlowRich</i> , and <i>Velocity</i>	-0.001	-1.6
Common to <i>SubstrRich</i> , and <i>Velocity</i>	0.000	0.54
Common to <i>Depth</i> , and <i>Velocity</i>	-0.022	-28.2
Common to <i>FlowRich</i> , <i>SubstrRich</i> , and <i>Depth</i>	-0.000	-1.05
Common to <i>FlowRich</i> , <i>SubstrRich</i> , and <i>Velocity</i>	-0.001	-2.2
Common to <i>FlowRich</i> , <i>Depth</i> , and <i>Velocity</i>	-0.002	-2.92
Common to <i>SubstrRich</i> , <i>Depth</i> , and <i>Velocity</i>	0.000	0.17

	Commonality coefficients	% total
Common to <i>FlowRich</i> , <i>SubstrRich</i> , <i>Depth</i> , and <i>Velocity</i>	0.001	1.73
Total	0.081	100
Fdis		
Unique to <i>GeomRich</i>	0.002	0.54
Unique to <i>Width</i>	0.333	85.74
Unique to <i>pH</i>	0.028	7.44
Common to <i>GeomRich</i> , and <i>Width</i>	0.033	8.51
Common to <i>GeomRich</i> , and <i>pH</i>	0.000	0.19
Common to <i>Width</i> , and <i>pH</i>	-0.010	-2.66
Common to <i>GeomRich</i> , <i>Width</i> , and <i>pH</i>	0.000	0.23
Total	0.388	100
Rao Q		
Unique to <i>FlowRich</i>	0.031	6.88
Unique to <i>SubstrRich</i>	0.001	0.23
Unique to <i>Width</i>	0.195	43.42
Unique to <i>Depth</i>	0.022	5.04
Unique to <i>pH</i>	0.089	19.84
Common to <i>FlowRich</i> , and <i>SubstrRich</i>	0.002	0.45
Common to <i>FlowRich</i> , and <i>Width</i>	-0.016	-3.72
Common to <i>SubstrRich</i> , and <i>Width</i>	0.023	5.16
Common to <i>FlowRich</i> , and <i>Depth</i>	-0.005	-1.26
Common to <i>SubstrRich</i> , <i>Depth</i>	0.008	1.83
Common to <i>Width</i> , and <i>Depth</i>	0.183	40.69
Common to <i>FlowRich</i> , and <i>pH</i>	-0.024	-5.41
Common to <i>SubstrRich</i> , and <i>pH</i>	-0.001	-0.22
Common to <i>Width</i> , and <i>pH</i>	-0.027	-6.06
Common to <i>Depth</i> , and <i>pH</i>	-0.002	-0.65
Common to <i>FlowRich</i> , <i>SubstrRich</i> , and <i>Width</i>	-0.008	-1.81
Common to <i>FlowRich</i> , <i>SubstrRich</i> , and <i>Depth</i>	0.001	0.24
Common to <i>FlowRich</i> , <i>Width</i> , and <i>Depth</i>	-0.008	-1.83
Common to <i>SubstrRich</i> , <i>Width</i> , and <i>Depth</i>	-0.029	-6.45
Common to <i>FlowRich</i> , <i>SubstrRich</i> , and <i>pH</i>	-0.001	-0.38
Common to <i>FlowRich</i> , <i>Width</i> , and <i>pH</i>	0.011	2.63
Common to <i>SubstrRich</i> , <i>Width</i> , and <i>pH</i>	0.005	1.12
Common to <i>FlowRich</i> , <i>Depth</i> , and <i>pH</i>	0.003	0.74
Common to <i>SubstrRich</i> , <i>Depth</i> , and <i>pH</i>	-0.004	-0.93
Common to <i>Width</i> , <i>Depth</i> , and <i>pH</i>	-0.019	-4.34
Common to <i>FlowRich</i> , <i>SubstrRich</i> , <i>Width</i> , and <i>Depth</i>	0.004	1.06
Common to <i>FlowRich</i> , <i>SubstrRich</i> , <i>Width</i> , and <i>pH</i>	0.006	1.36
Common to <i>FlowRich</i> , <i>SubstrRich</i> , <i>Depth</i> , and <i>pH</i>	-0.000	-0.02
Common to <i>FlowRich</i> , <i>Width</i> , <i>Depth</i> , and <i>pH</i>	0.010	2.43
Common to <i>SubstrRich</i> , <i>Width</i> , <i>Depth</i> , and <i>pH</i>	0.002	0.49
Common to <i>FlowRich</i> , <i>SubstrRich</i> , <i>Width</i> , <i>Depth</i> , and <i>pH</i>	-0.002	-0.55
Total	0.450	100