Role of the hyporheic zone in increasing the resilience of mountain streams facing intermittency

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Supplementary Table S1. Sampling dates, surface and groundwater presence/absence, analysis factor codes; aquifer oscillation rates, average level from the ground measured over 2 and 5 days, and level measured at each sampling occasion, at int-3. Rec: recession; rew: rewetting; d: downwelling; n-d: no downwelling; LF: low flow; HF: high flow, BF: baseflow; DR: drought, Y: yes, N: no.

	Surface water			**Hydrological phase**			**Water in piezometer**			**Aquifer phase 2 days**		**Aquifer phase 5 days**		**Aquifer rate (cm day^{-1})**		**Average aquifer level (m)**		**Aquifer depth (m)**
Sampling date	**perm**	**int-1**	**int-3**	**perm**	**int-1**	**int-3**	**perm**	**int-1**	**int-3**	**int-1**	**int-3**	**int-1**	**int-3**	**2 days**	**5 days**	**2 days**	**5 days**	**(int-3)**
26 Jul 2017	Y	N	N	LF	DR	DR	Y	N	Y	rec n-d	rec n-d	rec n-d	rec n-d	-3.4	-4.07	-1.91	-1.86	-1.9
2 Aug2017	Y	N	N	LF	DR	DR	Y	N	Y	rec n-d	rec n-d	rec n-d	rec n-d	-16.73	-3.7	-2.12	-2.08	-2.5
24 Aug 2017	Y	N	N	LF	DR	DR	Y	N	Y	rec n-d	rec n-d	rec n-d	rec n-d	-9.29	-5.24	-2.66	-2.60	-2.7
19 Sep 2017	Y	N	N	LF	DR	DR	Y	N	N	rew n-d	rew n-d	rew n-d	rew n-d	0.12	0.08	-2.99	-2.99	below -3
16 Nov 2017	Y	N	N	LF	DR	DR	Y	N	Y	rew n-d	rew n-d	rew n-d	rew n-d	2.56	2.27	-2.92	-2.95	-2.9
10 Jan 2018	Y	Y	N	LF	LF	DR	Y	N	Y	rew d	rew n-d	rew d	rew n-d	24.22	52.52	-1.25	-2.30	-1.2
18 Jan2018	Y	Y	N	LF	LF	DR	Y	Y	Y	rec d	rec n-d	rec d	rec n-d	-4.1	-7.15	-1.52	-1.41	-1.54
1 Feb 2018	Y	Y	N	LF	LF	DR	Y	Y	Y	rec d	rec n-d	rec d	rec n-d	-5.47	-4.09	-1.80	-1.73	-1.7
16 Mar 2018	Y	Y	Y	HF	HF	HF	Y	Y	Y	rec d	rec d	rec d	rec d	-20.68	-1.16	-0.90	-0.89	-0.6
20 Apr 2018	Y	Y	Y	HF	HF	HF	Y	Y	Y	rec d	rec d	rew d	rew d	-5.18	3.26	-0.62	-0.66	-0.5
8 Jun2018	Y	Y	Y	HF	HF	HF	Y	Y	Y	rew d	rew d	rew d	rew d	0.92	0.52	-0.84	-0.83	-0.85
3 Jul 2018	Y	Y	N	HF	LF	DR	Y	Y	Y	rew d	rew n-d	rec d	rec n-d	0.41	-1.79	-1.25	-1.22	-1.3
1 Aug 2018	Y	N	N	HF	DR	DR	Y	N	Y	rec n-d	rec n-d	rec n-d	rec n-d	-7.66	-6.93	-1.48	-1.37	-1.7
6 Sep 2018	Y	N	N	HF	DR	DR	Y	N	Y	rec n-d	rec n-d	rew n-d	rew n-d	-2.64	0.64	-1.43	-1.44	-2.4
4 Dec 2018 (post flood)	Y	N	N	LF	DR	DR	Y	Y	Y	rec n-d	rec n-d	rew n-d	rew n-d	-0.62	0.08	-1.15	-1.15	-1.16
8 Feb 2019	Y	N	N	LF	DR	DR	Y	N	Y	rew n-d	rew n-d	rec n-d	rec n-d	0.6	-1.41	-1.78	-1.75	-1.76
4 Jun 2019	Y	N	N	LF	DR	DR	Y	N	Y	rew n-d	rew n-d	rew n-d	rew n-d	5.73	5.16	-1.15	-1.24	-1.13

Supplementary Table S2. Species traits: type of trait and selected trait state, rationale to assign the trait to the resilience/resistance categories.

RATIONALE	TRAIT type and selected trait STATE (in italics)
Resilience traits	
Common in temporary habitats or groundwater: more likely to enter the hyporheic habitat and survive there.	Transversal distribution: *groundwater, temporary waters*
1. Ability to drift: actively or passively follow the movement of the aquifer.	Dispersal, drift: *aquatic active, passive drift*
2. Flexible body: high body flexibility is a requirement to enter the interstitial space.	Body flexibility: *high*
3. Swimmer: to reach the surface water refugia and enter the hyporheic.	Swimming ability: *strong*
4. Preference to gravel-sand substrates: stronger ability to enter the hyporheic zone in gravel-bed rivers.	Substrate preferendum: *sand, gravel*
5. Ability to enter the hyporheic zone: burrowers are better able to access streambed refugia and survive fine sediment deposition [14]; interstitial taxa are preadapted to live in the hyporheic.	Locomotion and substrate relation: *burrower (epibenthic), interstitial (endobenthic)*
6. Ability to enter the hyporheic zone: small taxa have better access to refugia compared to intermediate and large body sizes [14]	Maximal potential size: *≤ 0.25 cm*
resistance traits (to desiccation)	
1. Desiccation-resistance forms: resistance forms reduce vulnerability to dessication	Dessiccation-resistance forms: *eggs, gemmula, statoblasts, cocoons, housing, diapause*
2. Aquatic respiration: only aquatic respiration is possible in the hyporheic water	Respiration: *gills, tegument*
3. Low rheophyly: According to [24]	Current velocity preferendum = *slow, null*
4. Able to feed in the hyporheic: food resources in the hyporheic zone are limited, not all feeding groups can find the required food source	Feeding Habits = *absorber, deposit feeder , predator*

Supplementary Table S3. Community composition of the three faunistic groups for each station, and as total.

Stygobites	Tot. abundance (ind L^{-1})	%	Cum %	Tot. abundance (ind L^{-1}) perm	%	Cum %	Tot. abundance (ind L^{-1}) int-3	%	Cum %	Tot. abundance (ind L^{-1}) int-1	%	Cum %
Acanthocyclops cf *magistridussarti*	8.7	45.8	46	5.5	49.2	49	0.7	20.0	20	2.4	58.0	58
Proasellus sp. aff. *intermedius*	3.6	18.9	65	3.5	31.5	81	0.0	0.4	20	0.0	0.5	58
Diacyclops antrincola	1.6	8.3	73	0.0	0.0	81	1.6	45.7	66	0.0	0.0	58
Speocyclops cf *franciscoloi*	1.3	6.9	80	0.4	3.2	84	0.2	5.7	72	0.8	17.8	76
Phreatalona protzi	0.9	4.8	85	0.9	7.8	92	0.0	0.4	72	0.0	0.5	77
Niphargus transitivus	0.6	3.1	88	0.1	0.6	92	0.5	15.0	87	0.0	0.0	77
Diacyclops cf *zschokkei*	0.6	3.0	91	0.1	1.2	94	0.0	0.0	87	0.4	10.1	87
Niphargus microcerberus	0.4	2.2	93	0.1	1.1	95	0.2	7.0	94	0.1	1.2	88
Proasellus sp.	0.4	1.9	95	0.3	3.0	98	0.0	0.0	94	0.0	0.6	89
Speocyclops sp.	0.2	1.1	96	0.0	0.4	98	0.0	0.0	94	0.2	4.0	93
Diacyclops cf *paolae*	0.2	1.0	97	0.1	1.0	99	0.0	0.0	94	0.1	1.8	94
Niphargus pescei	0.2	0.9	98	0.0	0.0	99	0.2	4.8	99	0.0	0.0	94
Diacyclops cf *maisi*	0.1	0.4	98	0.1	0.5	99	0.0	0.0	99	0.0	0.6	95
Speocyclops cf *italicus*	0.1	0.4	99	0.0	0.0	99	0.0	0.0	99	0.1	1.6	97
Tardigrada	0.1	0.3	99	0.0	0.0	99	0.0	0.4	99	0.1	1.2	98
Graeteriella unisetigera	0.1	0.3	99	0.1	0.4	100	0.0	0.0	99	0.0	0.0	98
Stammericaris sp.	0.0	0.2	100	0.0	0.0	100	0.0	0.0	99	0.0	0.9	99
Bogidiella cf *albertimagni*	0.0	0.1	100	0.0	0.0	100	0.0	0.6	100	0.0	0.0	99
Parastenocaris sp.	0.0	0.1	100	0.0	0.0	100	0.0	0.0	100	0.0	0.5	99
Stammericaris cf *orcina*	0.0	0.1	100	0.0	0.0	100	0.0	0.0	100	0.0	0.5	100
Parastenocaris gr *brevipes*	0.0	0.1	100	0.0	0.0	100	0.0	0.0	100	0.0	0.4	100
Niphargus italicus	0.0	0.1	100	0.0	0.1	100	0.0	0.0	100	0.0	0.0	100
Total	19	100.0		11.2	100.0		3.4	100.0		4.2	100.0	
Stygophiles												
Chironomidae 0-1 mm	5.0	34.9	35	1.3	26.3	26	1.5	46.2	46	2.2	36.2	36
Hydracarina	3.9	27.1	62	0.5	9.8	36	0.6	20.2	66	2.8	45.2	81
Bryocampts (Arcticocamptus) cuspidatus	2.0	13.7	76	1.9	37.9	74	0.0	0.0	66	0.0	0.4	82
Oligochaeta 0-1 mm	1.1	7.4	83	0.5	8.8	83	0.1	3.5	70	0.5	8.2	90
Ostracoda	0.6	4.4	87	0.4	8.6	91	0.1	4.5	74	0.1	0.8	91
Epactophanes richardi	0.3	2.0	89	0.0	0.2	92	0.2	5.2	80	0.1	1.8	93
Nematoda 0-1 mm	0.3	1.7	91	0.0	0.4	92	0.2	5.5	85	0.1	0.9	94
Paracyclops fimbriatus	0.2	1.5	93	0.1	2.3	94	0.1	3.1	88	0.0	0.0	94
Gastropoda Valvatidae 0-1	0.2	1.5	94	0.1	1.2	96	0.2	4.9	93	0.0	0.0	94
Naididae 0-1 mm	0.2	1.5	96	0.0	0.2	96	0.0	1.1	94	0.2	2.7	96
Ceratopogonidae 0-1 mm	0.1	0.9	97	0.0	0.0	96	0.1	2.1	96	0.1	1.1	97
Baetis 0-1 mm	0.1	0.7	97	0.0	0.4	96	0.0	1.5	98	0.0	0.5	98
Efemerottero yuv 0-1 mm	0.1	0.5	98	0.0	0.4	97	0.0	0.5	98	0.0	0.5	98
Simuliidae 0-1 mm	0.1	0.5	98	0.0	0.3	97	0.1	1.6	100	0.0	0.0	98
Leptophlebidae 0-1 mm	0.1	0.5	99	0.1	1.3	98	0.0	0.0	100	0.0	0.0	98

Limonidae 0-1 mm	0.1	0.5	99	0.0	0.0	98	0.0	0.0	100	0.1	1.1	100
Hydrophilidae 0-1 mm	0.0	0.2	99	0.0	0.5	99	0.0	0.0	100	0.0	0.0	100
Bryocamptus (Rheocamptus) pygmaeus	0.0	0.2	100	0.0	0.5	99	0.0	0.0	100	0.0	0.0	100
Macrocyclops albidus	0.0	0.2	100	0.0	0.5	100	0.0	0.0	100	0.0	0.0	100
Paracyclops imminutus	0.0	0.2	100	0.0	0.0	100	0.0	0.0	100	0.0	0.4	100
Bryocamptus (Echinocamptus) echinatus	0.0	0.1	100	0.0	0.2	100	0.0	0.0	100	0.0	0.0	100
Total	14	100		5.1	100.0		3.2	100.0		6.1	100.0	
Stygoxenes												
Eucyclops serrulatus	2.9	29.8	30	2.9	64.5	64	0.0	0.0	0	0.0	0.0	0
Chironomidae 1-2 mm	2.2	22.0	52	0.3	6.4	71	0.7	33.7	34	1.2	36.3	36
Oligochaeta 1-2 mm	1.0	10.5	62	0.2	3.6	75	0.2	11.1	45	0.6	19.7	56
Chironomidae >4 mm	0.6	5.7	68	0.4	7.7	82	0.2	7.9	53	0.1	1.5	58
Nematoda 1-2 mm	0.5	5.0	73	0.1	2.2	84	0.1	4.8	57	0.3	9.1	67
Chironomidae 2-3 mm	0.3	3.5	76	0.0	0.5	85	0.2	11.5	69	0.1	2.3	69
Nematoda >4 mm	0.3	2.7	79	0.0	0.3	85	0.2	7.9	77	0.1	2.8	72
Bryocamptus (Rheocamptus) zschokkei	0.2	2.5	82	0.2	4.4	90	0.0	2.1	79	0.0	0.0	72
Oligochaeta 2-3 mm	0.2	2.4	84	0.0	0.8	90	0.1	2.4	81	0.2	4.6	77
Oligochaeta >4 mm	0.2	1.9	86	0.1	2.5	93	0.0	1.2	83	0.1	1.5	78
Baetis >4 mm	0.2	1.8	88	0.0	0.0	93	0.1	5.9	89	0.1	1.5	80
Limonidae 1-2 mm	0.2	1.7	89	0.0	0.0	93	0.0	0.0	89	0.2	5.2	85
Oligochaet 3-4 mm	0.2	1.6	91	0.1	1.4	94	0.0	0.0	89	0.1	3.1	88
Baetis 1-2 mm	0.1	1.3	92	0.0	0.0	94	0.1	5.3	94	0.0	0.5	88
NematodaA 2-3 mm	0.1	1.3	94	0.0	0.0	94	0.0	0.0	94	0.1	3.9	92
Ceratopogonidae 1-2 mm	0.1	1.1	95	0.0	0.0	94	0.0	0.0	94	0.1	3.3	96
Limonidae 2-3 mm	0.1	0.8	95	0.0	0.0	94	0.0	0.0	94	0.1	2.6	98
Baetis 2-3 mm	0.1	0.8	96	0.0	0.0	94	0.1	3.6	97	0.0	0.0	98
Ecdyonurus >4 mm	0.1	0.6	97	0.1	1.4	96	0.0	0.0	97	0.0	0.0	98
Sericostomatidae 1-2 mm	0.1	0.5	97	0.1	1.1	97	0.0	0.0	97	0.0	0.0	98
Leptophlebidae >4 mm	0.0	0.5	98	0.0	1.0	98	0.0	0.0	97	0.0	0.0	98
Chironomidea 3-4 mm	0.0	0.4	98	0.0	0.4	98	0.0	0.0	97	0.0	0.8	99
Baetis 3-4 mm	0.0	0.3	98	0.0	0.0	98	0.0	1.2	99	0.0	0.0	99
Ecdyonurus 3-4 mm	0.0	0.2	99	0.0	0.5	99	0.0	0.0	99	0.0	0.0	99
Gyrinidae >4	0.0	0.2	99	0.0	0.5	99	0.0	0.0	99	0.0	0.0	99
Leuctra >4 mm	0.0	0.2	99	0.0	0.4	99	0.0	0.0	99	0.0	0.0	99
Naididae 1-2 mm	0.0	0.2	99	0.0	0.0	99	0.0	0.0	99	0.0	0.5	99
Caenis 1-2 mm	0.0	0.2	99	0.0	0.0	99	0.0	0.0	99	0.0	0.5	100
Leptophlebidae 3-4 mm	0.0	0.2	100	0.0	0.0	99	0.0	0.8	99	0.0	0.0	100
Epeorus >4mm	0.0	0.1	100	0.0	0.3	100	0.0	0.0	99	0.0	0.0	100
Efemerottero unid. 1-2 mm	0.0	0.1	100	0.0	0.3	100	0.0	0.0	99	0.0	0.0	100
Elminthidae 2-3 mm	0.0	0.1	100	0.0	0.0	100	0.0	0.6	100	0.0	0.0	100
Total	10	100		4.6	100.0		2.1	100.0		3.2	100.0	

Supplementary Table S4. Bray-Curtis similarity between/within samples for each factor, divided into the three faunistic groups. Aquifer phase: rec-no-dwn = recession without downwelling; rew-no-dwn = rewetting without downwelling; rec-dwn = recession with downwelling; rew-dwn = rewetting with downwelling. 2d, 5d: time intervals used for calculation of the hydrological phases (days). Station codes as in Fig. 3. Significant pairwise differences are underlined (see table 2).

Intermittent sites	Stygobites	Stygophiles	Stygoxenes
Perm vs int-1	74.69	72.12	75.99
int-3 vs int-1	77.45	72.42	79.92
perm	79.89	85.89	85.8
int-1	70.95	68.78	75.13
int-3	88.74	87.00	90.11
Rec-no-dwn vs rew-no-dwn 2d	82.02	79.88	85.26
Rec-no-dwn vs rec-dwn 2d	79.29	75.91	82.42
Rew-no-dwn vs rew-dwn-2d	83.71	84.23	88.18
Rec-dwn vs rew-dwn 2d	81.41	79.67	84.78
Rec-no-dwn 2d	88.73	82.13	86.74
Rec-dwn 2d	75.26	72.09	75.69
Rew-no-dwn 2d	76.97	75.24	81.12
Rew-dwn 2d	93.66	91.96	95.77
Rec-no-dwn vs rew-no-dwn 5d	81.96	79.99	85.57
Rec-no-dwn vs rec-dwn 5d	88.58	82.07	89.37
Rew-no-dwn vs rew-dwn-5d	69.60	76.64	76.30
Rec-dwn vs rew-dwn 5d	76.32	76.47	77.96
Rec-no-dwn 5d	89.18	81.95	86.12
Rec-dwn 5d	88.98	83.51	92.10
Rew-no-dwn 5d	74.68	75.64	82.95
Rew-dwn 5d	56.45	64.60	58.18

Supplementary table S5. Significant correlations between metrics and hydrological variables. N = total abundance; H = Shannon-Wiener Diversity Index.

	Var X	Var Y	r(X,Y)	r^2	p
Int-3	average level 2d	N stygoxenes	-0.59	0.34	0.05
Int-3	average level 2d	N stygophiles	-0.63	0.39	0.03
Int-3	average level 5d	N stygoxenes	-0.72	0.52	0.01
Int-3	average level 5d	N stygophiles	-0.73	0.53	0.01
Int-3	average level 5d	H stygobites	0.59	0.34	0.04

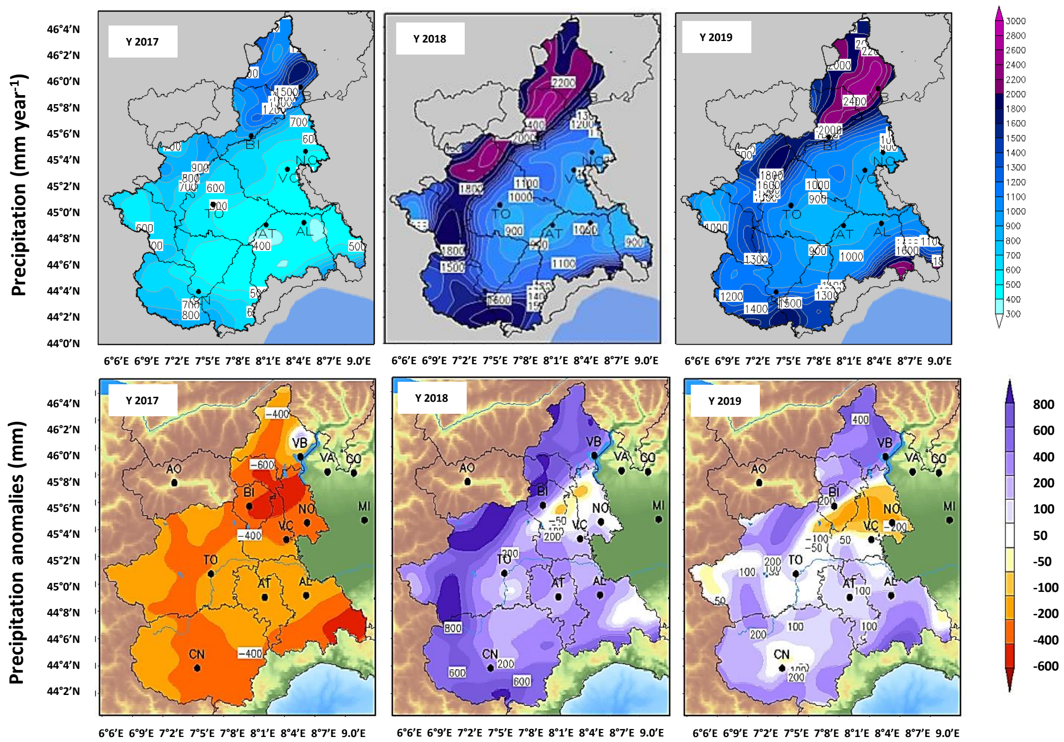

Figure 1. Top: Total annual precipitation (mm) for the three years of investigation; bottom: annual precipitation anomalies compared to the reference period (1971-2000) for the three years of investigation. Data: Piemonte Enviromental Agency (ARPA Piemonte), downloadable from: https://www.arpa.piemonte.it/rischinaturali/tematismi/clima/confronti-storici/.