Ecography

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Datry, T., Larned, S. T., Fritz, K. M., Bogan, M. T., Wood, P. J., Meyer, E. I. and Santos, A. N. 2013. Broad-scale patterns of invertebrate richness and community composition in temporary rivers: effects of flow intermittence. – Ecography 36: xxx–xxx.

Supplementary material

Appendix 1: Characteristics of individual studies.

Little Stour, United Kingdom

Physical setting

The Little Stour River is located in south-east England and drains a 213-km^2 catchment in permeable chalk terrain. The river flows 11.5 km from a perennial spring head to its confluence with the Great Stour River; sampling sites were located in the upper 2.5 km of the Little Stour. The chalk bedrock is overlain by alluvium in the mid-reaches of the river and there are high seepage losses into the porous alluvium during baseflow periods. The Little Stour flows along its entire length during most years; flow cessation has occurred on three occasions in the last century, in 1949, 1991-1992 and 1996-1997. Severe droughts in those years, in combination with groundwater abstraction for public water supplies, caused a 750 m reach to dry, 2 km downstream of the spring head. Flow and invertebrate data from the 1991-1992 and 1996-1997 droughts are included in this study. During both droughts, the 750 m-long temporary reach was dry for up to 15 months. Flow resumption occurred rapidly at the end of the droughts in the early winters of 1992 and 1997, although recovery of groundwater levels and surface flows to normal conditions took two years (Wood & Armitage 2004).

Invertebrate sampling

Invertebrates were collected from nine riffle-run habitats at nine sites (three temporary, six perennial) on the upper 2.5 km of the river during baseflow periods between 27 August and 3 September in each of nine years (1992-1999). Samples could not be collected from two dry sites in 1992 and 1997. Samples were collected using two-minute kick-samples with a hand-net (250-µm mesh net). Samples were preserved in the field with 4% formaldehyde. Most aquatic insects were identified to species except dipterans, which were identified to family, and baetid mayflies, which were identified to genus. Molluscs were identified to species except sphaeriid bivalves, which were identified to family. Oligochaetes and mites were identified to order. For more details on invertebrate sampling and processing, see Wood & Armitage (2004).

Albarine, France

Physical setting

The Albarine River is located in temperate eastern France and drains a 313-km^2 catchment. The river flows for 45 km through the Jura Mountains, then 15 km across an alluvial plain to its confluence with the Ain River. On the alluvial plain the river is perched 1-14 m above the regional water table, and the river loses flow to the underlying vadose zone and aquifer at an average rate of 0.4 m^3 s^{-1} km^{-1}. The entire alluvial plain reach is temporary due to the rapid seepage loss. Descriptions of the climate, geology and geomorphology of the Albarine River catchment are given in Datry (2012). Flow cessation begins in spring of most years at the confluence with the Ain River, and the drying front moves upstream over the summer. Flow resumption along the entire temporary reach generally occurs in late autumn/early winter. Flow intermittence and average annual dry event duration and frequency all increase with distance downstream. At the downstream end of the temporary reach, annual flow intermittence ranges from 50 to 90%.

Invertebrate sampling

Invertebrates were collected from riffles at 18 sites (seven perennial, 11 temporary) prior to flow cessation in spring (30 March 2009 and 27 May 2010) and autumn, ≥3 weeks after flow resumption (15 October 2008, 1 December 2010 and 12 October 2010). In October 2008, the five sites furthest downstream were not sampled because they dried two weeks after flow resumption. At each site and each sampling date, two invertebrate samples were collected at each of two riffles and composited. Invertebrates were collected with a Hess sampler (0.125-m^2 area, 200-µm mesh), and preserved with 96% ethanol. Most aquatic insects and all molluscs were identified to genus or species, and crustaceans, annelids and mites to genus, family or order. For more details on invertebrate sampling and processing, see Datry (2012).

Asse, France

Physical setting

The Asse River is located in the Provence region of southeastern France, and drains a 657-km^2 catchment in the southwestern French Alps. The main tributaries of the Asse River rise in the Préalpes de Digne, then converge 45 km downstream to form the Asse River mainstem, which flows for 30 km across an alluvial plain to its confluence with the Durance River. On the alluvial plain, the upper 15 km-long reach is perennial and the lower 15 km-long reach is temporary. Flow intermittence is caused by the combined effects of seepage into the underlying aquifer, high groundwater abstraction in the floodplain for agriculture, and bed aggradation. Along the temporary section, drying events occurred at two 4 km-long reaches spaced 7 km apart. Descriptions of the climate, geology and geomorphology of the Asse River catchment are given in Mano *et al.* (2009).

Invertebrate sampling

Invertebrates were collected from riffles at 13 sites (eight temporary, five perennial). Samples were collected in spring, just before the beginning of summer dry events (15 April March 2009 and 8 June 2010), and in autumn, at least 3 weeks after flow resumption (2 October 2008, 10 November 2010 and 19 October 2010). On each sampling date, two invertebrate samples were collected at each of two riffles per site, and the duplicate samples were composited. Invertebrates were collected using a Hess sampler (0.125-m^2 area, 200-µm mesh), and preserved with 96% ethanol. Most aquatic insects and all molluscs were identified to genus or species, and crustaceans, annelids and mites to family, order or genus.

Sycamore Branch, USA

Physical setting

Sycamore Branch drains a forested 3.1-km^2 catchment in the Charles C. Deam Wilderness Area of the Hoosier National Forest, south-central Indiana, USA. The stream flows for 3.4 km from its headwaters to the South Fork Arm of the Monroe Lake reservoir. The upper 2 km of Sycamore Branch have alternating perennial and temporary reaches, and the lower 1.4 km is perennial. Flow is primarily derived from overland flow, and secondarily from soil water and hillslope groundwater seepage. Drying occurs when soil water is depleted and the groundwater table falls below the streambed elevation. Flow intermittence generally decreases in the downstream direction. The uppermost study reach had the greatest flow intermittence (65%). Descriptions of the climate, geology, and vegetation of the area given in Homoya *et al.* (1984) and Thompson (2004).

Invertebrate sampling

Four 30-m long sampling reaches (two perennial, two temporary) were established along the upper 1.9 km of Sycamore Branch. Invertebrates were collected from riffles and pools in each reach. Samples were collected during wet (25 June 2003 and 7 April 2004) and dry periods (22 September 2003 and 11 August 2004) when surface water was present in each sampling reach. At each reach, four replicate samples from each habitat type were collected with a modified Hess sampler (0.053-m^2 area, 250-µm mesh) and preserved in 70% ethanol. Invertebrates were identified to genus or species. For more details on invertebrate sampling and processing, see Fritz *et al.* (2006).

Little Lusk, USA

Physical setting

Little Lusk Creek drains a 43.2-km^2 catchment in Shawnee National Forest, southern Illinois, USA. The creek flows 15 km from its headwaters to its confluence with Lusk Creek. The upper 3 km are temporary and the lower 12 km are perennial. Flow is primarily derived from overland flow, and channel drying occurs in the late summer when saturated soil water is depleted and the groundwater table falls below the streambed elevation Flow intermittence generally decreases in the downstream direction. The uppermost study reach had the greatest flow intermittence (82%). Descriptions of the climate, geology, and vegetation of the area are given in Schwegman (1973) and Thompson (2004).

Invertebrate sampling

Four 30-m long sampling reaches (one perennial, three temporary) were established along the upper 2.8 km of Little Lusk Creek. Invertebrates were collected from riffles and pools in each reach. Samples were collected during consecutive dry (30 August 2004) and wet (4 April 2005) seasons when surface was present in each sampling reach. Samples were collected and processed as described above for Sycamore Branch.

Orari, New Zealand

Physical setting

The Orari River drains an 850-km^2 catchment in the eastern foothills of New Zealand's Southern Alps and a portion of the alluvial Canterbury Plains to the east of the foothills. The river flows 45 km through the foothills to a gorge at the foothills-plains boundary, then 76 km across the Canterbury Plains to the Pacific Ocean. The section of the river used in the present study extended across the plains from the gorge to a point 3.5 km upstream from the river mouth. The Canterbury Plains are composed of two hydrogeological regions, the inland and coastal plains. The inland plains are underlain by glacial and periglacial gravels. Aquifers in this area are separated from land surface by a deep vadose zone. The coastal plains are underlain by alternating layers of post-glacial gravels and marine clays deposited during high sea stands. Aquifers in this area form a vertical series with the uppermost aquifer at or near ground surface. Flow patterns in the Orari River reflect the contrasting hydrogeological structures. The inland-plains section of the Orari is perched, and the river progressively loses flow to the vadose zone; all flow is lost within 20 km of the gorge for part of most years. On the coastal plain, upwelling groundwater discharges into the Orari River, starting at a point ~ 49 km from the gorge and continuing to river mouth. The river gains groundwater with distance downstream in this section, and becomes perennial ~ 69 km downstream from the gorge. At the most temporary point of the river, annual average flow permanence is ~ 60%. When a dry section is present, in expands and contracts in length in response to groundwater level fluctuations and changes in run-off from upstream; the dry section varies from 0 - 50 km in length. Flow cessation occurs in late spring or early summer of most years. Descriptions of the climate, geology and geomorphology of the Orari River catchment are given in Larned *et al.* (2011).

Invertebrate sampling

Invertebrates were collected from riffles at 11 sites (five perennial, six temporary) on 24 October 2007 and 19 February 2008. The river was flowing over its entire length on both sampling dates. At each riffle, four replicate samples were collected with a Surber sampler (0.09-m^2, 250-μm mesh), then two samples were combined into each of two composite samples and preserved in 70% isopropyl alcohol. Most aquatic insects and all molluscs were identified to genus or species (some midges were identified to tribe). Crustaceans, annelids, and mites were identified to family or order.

Selwyn, New Zealand

Physical setting

The Selwyn River drains a 975-km^2 catchment located 90 km north of the Orari River. Like the Orari River, the Selwyn River rises in the foothills of the eastern Southern Alps and flows across the Canterbury Plains. The river mainstem flows 35 km through the foothills, then 54 km across inland and coastal plains to coastal Lake Ellesmere. The Selwyn River is perched over a deep vadose zone beneath the inland plains, and loses water with distance downstream. The first 3 km of the losing reach are perennial, and the next 43 km are temporary. In the coastal plains, upwelling groundwater causes progressive flow gains, and the river becomes perennial approximately 8 km from its terminus. The severity of intermittence is greater in the Selwyn River than the Orari River, as indicated by higher flow intermittence for most of its length. At the most temporary point of the river, annual average flow intermittence is approximately 70%. During extended droughts, the river dries for most of its length on the Canterbury Plains, and portions of the central reach may remain dry for more than 1 year. Descriptions of the climate, geology and geomorphology of the Selwyn River catchment are given in Larned *et al.* (2008).

Invertebrate sampling

Invertebrates were collected from riffles at 16 sites (three perennial, 13 temporary) on 11 dates between November 2003 and October 2004. At least one site was dry on each sampling date, so the total number of sampling dates at each cross-section varied from 2-11. At each site, four replicate samples were collected with a Surber sampler (0.09-m^2 area, 250-μm mesh), then two samples were combined into each of two composite samples and preserved in 70% isopropyl alcohol. Most insects and all molluscs were identified to genus or species (some midges were identified to tribe). Crustaceans, annelids, and mites were identified to family or order.

Garden and Huachuca, USA

Physical settings

Huachuca and Garden Canyons are arid-land streams that drain catchments in the Huachuca Mountains in southeast Arizona, USA. Huachuca Canyon drains a 25-km^2 catchment before joining the Babocomari River, a tributary of the San Pedro River. Garden Canyon drains a 34-km^2 catchment before joining the San Pedro River. In the he uppermost 7 km of both streams, there is interrupted perennial flow through rugged canyons. Downstream of the canyons, the streams flow across alluvial fans where seepage losses are high; both streams become temporary at the canyon-alluvial fan boundaries. The temporary section of Huachuca Canyon extends 12.2 km to the confluence with the Babocomari River. The temporary section of Garden Canyon extends 22.1 km to the confluence with the San Pedro River. Flow intermittence in the temporary reaches of both streams increases with distance downstream. Flow intermittence ranges from 40% at the top of alluvial fans to 99% several kilometers down the fans. Descriptions of the climate, geology and geomorphology of Garden and Huachuca Canyons are given in Bogan *et al.* (2013).

Invertebrate Sampling

Invertebrates were collected from riffles at nine sites (three perennial, six temporary) from both Huachuca and Garden Canyons on 27-31 March 2010. Sampling sites were spaced 0.25 to 4 km apart. Perennial reaches were also sampled in November 2009 and 2010 and March

2011, but the temporary reaches were dry during these periods. During the March 2010 sampling period, the perennial and temporary reaches were connected by flow at both streams. At each sampling site, three replicate samples were collected with a D-net (0.09-m^2 area, 500-μm mesh) by disturbing substrate to a depth of 5 cm to dislodge invertebrates. The three replicates samples at each site were composited and preserved in 95% ethanol. All aquatic insects, mites and amphipods were identified to genus or species. All other invertebrates were identified to family or order.

Fish Creek, USA.

Physical settings

Fish Brook drains a 47-km^2 catchment on the Atlantic Coastal Plain of north-eastern Massachusetts, USA. The Fish Brook mainstem flows 31.25 km from headwater wetlands to its confluence with the Ipswich River. Descriptions of the climate and geomorphology of the Ipswich River region are given in Zarriello & Ries (2000). The sampling sites used for this study were located on perennial Fish Brook and two of its temporary headwater tributaries. All sites were within a 1-km^2 area of deciduous forested swamp, 5 km upstream of the Ipswich River confluence.

Invertebrate Sampling

Invertebrates were collected from riffles and pools at eight sites (three perennial, five temporary) on eight days in July 2004, six days in September 2004, and six days in April 2005. At each sampling site, three replicate samples were collected with a D-net (0.1 m^2 area, 500-μm mesh) and preserved in 80% ethanol. All invertebrates were identified to genus.

Alme and tributaries, Germany.

Physical setting

The Alme River drains a 763-km² catchment in East Westphalia, Germany. The river flows north for 60 km from its headwaters in the northeastern Sauerland region to its confluence with the Lippe River. The Alme River mainstem and three of its tributaries were sampled, the 28-km long Ellerbach River (catchment area 91 km²), the 8-km long Menne River (catchment area 8 km²), and the 30- km long Sauer River (catchment area 109 km²).

Seepage losses into limestone fissures and sinkholes cause flow intermittence in Alme and its tributaries. The Alme, Ellerbach and Sauer Rivers have perennial reaches extending from the headwaters downstream for 18–31 km, and temporary middle and lower reaches. The Menne River is in a completely karstified catchment and has alternating temporary and perennial reaches for its entire length. The 5-250 m-long perennial reaches in the Menne River are each downstream of a spring. The temporary reaches of the Ellerbach, Menne, and Sauer Rivers extend to their confluences with the Altenau River, which flows into the Alme. The temporary reach of the Alme River ends at the confluence with the Altenau, and the Alme is perennial from this point to its confluence with the Lippe River. Descriptions of the hydrology and geology of the Alme River and its catchment are given in Meyer & Meyer (2000), and Meyer *et al.* (2004).

Invertebrate sampling

In the Alme River, invertebrates were collected at seven sites (four perennial, three temporary) on three dates between 2005 and 2008. At each site, two or three replicate samples were taken with a Surber sampler (0.09-m², 250-µm mesh). In the Ellerbach River, invertebrates were collected at three sites (one perennial, two temporary) on four dates in

2001. At each site, three replicate samples were taken with a Surber sampler (0.09-m², 250-µm mesh). In the Menne River, invertebrates were collected at four sites (one perennial, three temporary) on three dates in 2000. At each site, two replicate samples were taken with a Surber sampler (0.09-m², 250-µm mesh). In the Sauer River, invertebrates were collected at 14 sites (four perennial, 10 temporary) on three dates between 2000 and 2007. At each site, two replicate samples were taken with a Surber sampler (0.09-m², 250-µm mesh). Invertebrate samples were preserved in 90% ethanol. All aquatic insects, mites, annelids, molluscs and amphipods were identified to genus or species. All other invertebrates were identified to family or order.

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Appendix 2. Presence of resistance and resilience trait states (+) used to assign each taxon to the following trait classes: 0 : neither *resistant* nor *resilient;* 1 : *resilient;* 2 : *resistant;* and 3 : *resilient* and *resistant* *.

Taxa	Trait class	Resilience traits: Long adult lifespan	Resilience traits: High female dispersal	Resilience traits: Strong adult flying capacity	Resilience traits: Common occurence in drift	Resilience traits: Strong swimming ability	Resistance traits: Desiccation-resistance forms	Resistance traits: Body armouring	Resistance traits: Plastron /spiracle respiration	Resistance traits: Low rheophily
Plecoptera										
Capniidae	3				+		+			
Chloroperlidae	1				+					
Eustheniidae	0									
Gripopterygidae	0									
Leuctridae	1				+					
Nemouridae	3				+		+			
Perlidae	1		+	+						
Perlodidae	0									
Taeniopterygidae	2						+			
Trichoptera										
Brachycentridae	2							+		
Calamoceratidae	2							+		
Conoesucidae	2						+	+		
Glossosomatidae	2							+		
Goeridae	2							+		
Helicopsychidae	2		+				+	+		
Hydrobiosidae	0									
Hydropsychidae	1		+	+	+					
Hydroptilidae	1		+		+					
Lepidostomatidae	0									
Leptoceridae	1		+							
Limnephilidae	2						+	+		
Molannidae	0									
Odontoceridae	2							+		
Philopotamidae	0									
Phryganeidae	2						+			
Polycentropodidae	1		+							
Psychomyiidae	1		+							
Rhyacophilidae	0									
Sericostomatidae	0									
Uenoidae	2							+		
Ephemeroptera										
Baetidae	1				+	+				
Ameletidae	1					+				
Caenidae	2									+
Ephemerellidae	1				+					
Ephemeridae	2									+
Heptageniidae	1				+					
Leptohyphidae	3				+					+
Leptophlebiidae	1				+					
Oligoneuriidae	3					+				+
Siphlonuridae	1				+	+				+
Coleoptera										
Brachypteridae	2						+		+	
Chrysomelidae	2						+		+	+
Dryopidae	2	+						+	+	
Dytiscidae	1	+	+	+		+		+	+	+
Elmidae	1	+			+		+			
Gyrinidae	1	+	+	+		+		+	+	+
Haliplidae	1	+		+				+		
Hydraenidae	1	+		+					+	
Hydrophilidae	3	+		+					+	+
Psephenidae	0									
Ptilodactylidae	1	+	+	+						
Scarabaeidae	3	+	+	+				+	+	+
Scirtidae	2		+	+			+		+	+
Staphylinidae	1	+	+	+					+	+
Diptera										
Athericidae	0									
Ceratopogonidae	2						+			
Chironomini	3		+		+		+			+
Culicidae	2	+	+				+		+	+
Cylindrotomidae	2						+			+
Diamesinae	1		+		+					
Dixidae	2				+		+		+	
Dolichopodidae	1	+	+	+					+	+
Empididae	0									
Ephydridae	3	+	+	+			+		+	+
Limonidae	2						+			
Muscidae	1	+	+	+			+		+	
Orthocladiinae	1		+		+		+			
Pediciidae	2						+			
Podonominae	1		+		+					
Psychodidae	2								+	+
Ptychopteridae	2						+		+	+
Rhagionidae	0									
Sciaridae	2						+			
Simuliidae	1			+	+					
Tabanidae	3		+	+			+		+	
Tanypodinae	1		+		+					
Tanytarsini	1		+		+					
Tipulidae	2						+			
Odonata										
Aeshnidae	1	+	+	+		+				
Calopterygidae	1			+						
Coenagrionidae	0									
Cordulegastridae	1	+		+						+
Gomphidae	1	+		+						+
Lestidae	2									+
Libellulidae	1	+	+	+						+
Protoneuridae	0									
Megaloptera										
Corydalidae	0									
Sialidae	0									
Hemiptera										
Belostomatidae	3	+	+	+		+	+	+	+	+
Corixidae	3	+	+	+		+	+	+	+	+
Nepidae	2	+					+		+	+
Notonectidae	3	+	+	+		+	+	+	+	+
Heteroptera										
Mesoveliidae	2	+				+	+		+	+
Veliidae	3	+				+	+		+	
Gerridae	2	+				+	+		+	+
Amphipoda										
Crangonyctidae	1	+	+		+		+			
Eusiridae	0									
Gammaridae	1	+			+	+				
Niphargidae	0									
Paraleptamphopidae	0									
Decapoda										
Cambaridae	1	+	+							
Isopoda										
Asellidae	3	+					+			
Janiridae	0									
Copepoda	2					+	+			+
Ostracoda	2						+			+
Cladocera	2						+			+
Mollusca										
Ancylidae	3	+						+		
Bithyniidae	0									
Hydrobiidae	3	+						+		
Lymnaeidae	2	+					+	+	+	+
Physidae	2	+					+	+	+	+
Planorbidae	2	+					+	+	+	+
Sphaeridae	2	+					+	+		+
Valvatidae	0									
Zonitidae	0									
Oligochaeta	2	+					+			+
Achaeta										
Hirudinae	0									
Plathyhelminth										
Dendrocoelidae	0									
Dugesiidae	1	+								
Planariidae	1	+								
Prorhynchidae	2						+			
Nemata	3				+		+			
Nematomopha										
Gordiidae	1		+		+					+
Hydracarina	1	+	+		+					+
Hydrozoa	2									+

* Given the coarse taxonomic resolution used (TR 3), we assigned to each taxon the traits which were dominant across the constituent families, genera or species that were collected among the study sites. Presence of trait states was weighted equally when assigning taxa to trait classes. When a dominance of resistance trait states was found in a taxon, it was classified as *resistant*. Similarly, when a dominance of resilience trait states was found in a taxon, it was classified as *resilient*. If an equal number of resistance and resilience trait states were assigned to a taxon, it was classified as *resistant* and *resilient*. When no trait states were assigned to a taxon, it was classified as neither *resistant* nor *resilient*.