BIODIVERSITAS
Volume 25, Number 12, December 2024
Pages: 5074-5082

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d251245

Impact of intermittent stream flow on water quality and structural composition of macroinvertebrates in a semi-arid region of South Africa

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Manuscript received: 28 October 2024. Revision accepted: 29 December 2024.

Abstract. *Matita TP, Addo-Bediako A, Luus-Powell W. 2024. Impact of intermittent stream flow on water quality and structural composition of macroinvertebrates in a semi-arid region of South Africa. Biodiversitas 25: 5074-5082.* This study investigated the impact of varying flow regimes on water quality and the structural composition of macroinvertebrates in the Moopitse River, South Africa. Samples were collected during three distinct flow conditions: high flow, low flow, and intermittent flow. Water quality parameters were measured in situ, and water samples were collected for nutrient analysis before macroinvertebrate sampling. A total of 4,094 individuals, representing seven orders and 22 families, were recorded. The assessment, based on water quality and macroinvertebrate structure, revealed that intermittent flow (cessation of flow) negatively affected both water quality and the distribution of macroinvertebrates. There was a decline in both taxa richness and abundance in response to flow intermittency. The observed low taxa richness and abundance, particularly during high flow and intermittent regimes, align with expectations for such hydrologically extreme habitats. Compared to the perennial rivers in the Olifants River Basin, the Moopitse River is less diverse, as the intermittent environment favors generalist and stress-tolerant taxa rather than sensitive taxa. Water parameters such as turbidity, conductivity, total dissolved solids (TDS), and nutrient levels were significantly higher during intermittent flow, while dissolved oxygen levels were notably lower. Overall, water quality was best during low flow, which also supported greater macroinvertebrate richness and abundance. These findings suggest that river discontinuity may lead to habitat degradation, thereby altering the structural distribution of macroinvertebrate communities. Understanding the effects of flow variation and habitat changes is crucial for environmental and biodiversity conservation. Therefore, conservation strategies should incorporate innovative approaches to mitigate the impacts of flow discontinuities and habitat degradation.

Keywords: Diversity, flow regimes, macroinvertebrates, physicochemical variables, temporary habitats

INTRODUCTION

Freshwater ecosystems are threatened by various global change stressors, including alterations to water quality and flow regimes (Milly et al. 2005; Larned et al. 2010; Di Sabatino et al. 2024), habitat fragmentation caused by dams (Bohada-Murillo et al. 2021), and increasing instances of river drying (Schinegger et al. 2012; Fuller et al. 2015; Tonkin et al. 2019). The River Continuum Concept (RCC) emphasizes the importance of river connectivity and the continuous flow of water (Vannote et al. 1980). This concept describes how interconnected river segments contribute uniquely to the movement of energy, matter, and organisms throughout the ecosystem, which is essential for supporting ecological processes and biodiversity (Doretto et al. 2020). However, many rivers in arid and semi-arid regions are intermittent or temporary, experiencing periods without flow at certain times and locations (De Girolamo et al. 2017; López 2020). The transition from perennial to non-perennial flow regimes may signify an ecological shift, resulting in significant and potentially irreversible changes to community and ecosystem dynamics (Aspin et al. 2018). Intermittent rivers undergo distinct hydrological phases: a flowing phase characterized by continuous water flow, a cessation phase where flow stops and may lead to the formation of connected or isolated pools, and a dry phase (Zimmer et al. 2020). Changes in hydrological regimes significantly influence physicochemical parameters and can affect biotic communities (Magand et al. 2020). These changes obstruct the movement of aquatic life and disrupt sediment transport, leading to alterations in water quality and fragmented habitats (Grill et al. 2019; Jones et al. 2021).

In semi-arid regions, intermittent rivers are common freshwater habitats and are an important environment for many organisms (Leigh et al. 2016). The combined effects of climate change and rising water demand are causing many perennial rivers and streams to change to an intermittent flow (Ionita et al. 2017; Straka et al. 2021). Climate change, especially alterations in the frequency and intensity of extreme events such as temperatures and rainfall, is expected to intensify these challenges (IPCC 2014). The loss of river connectivity has compromised riverine functions, such as providing diverse habitats and maintaining ecosystem integrity (Reid et al. 2019). Unfortunately, intermittent rivers often receive less attention compared to perennial streams (Ruhí et al. 2016; Acuña et al. 2017).

Macroinvertebrates are commonly used to monitor running water ecosystems (Masese and Raburu 2017; Krajenbrink et al. 2019) and water flow is an important driver of aquatic macroinvertebrate diversity (Rosser et al. 2017). Many macroinvertebrates serve as bioindicators of water quality due to their high sensitivity to changes in water conditions (Makgoalie et al. 2022). They respond to various hydrological conditions due to their ecological tolerance and requirements. Their high taxonomic diversity also allows them to offer a wide range of responses, making them effective in detecting various changes in the environment (Edegbene et al. 2021). Furthermore, their sedentary or benthic nature and their extended life cycle compared to other freshwater aquatic organisms such as algae and plankton, make them valuable indicators of freshwater ecosystems (Makgoale et al. 2022).

In the Olifants River Basin, South Africa, many rivers have become intermittent due to construction of dams and weirs, intensive mining, agriculture and urbanization, coupled with low rainfall and high evaporation rates. Recent studies in the area have assessed water and sediment quality, and their impact on aquatic biota. These studies affirm that freshwater systems in the basin are impacted by anthropogenic activities (Mmako et al. 2021; Nukeri et al. 2021). However, little is known about the impact of flow cessation on aquatic biota distribution and diversity, even though research interest in intermittent freshwater habitats is increasing globally (Magand et al. 2020), a better understanding of how flow interruption affects freshwater ecosystems is very important for river management and conservation efforts (Asmamaw et al. 2021). The Moopitse River in the Olifants River Basin experiences flow interruptions during the dry season, sometimes leading to complete flow cessation. However, no studies have assessed the aquatic biota's structural composition during flow cessation in this river. Therefore, the aims of this study were: i) to access the water quality at different streamflow regimes and ii) to determine the impact of different flow regimes on the structural composition of macroinvertebrates in the river.

MATERIALS AND METHODS

Study area

The Moopitsi River is in the Steelpoort River sub-catchment of the Olifants River Basin in South Africa (Figure 1).

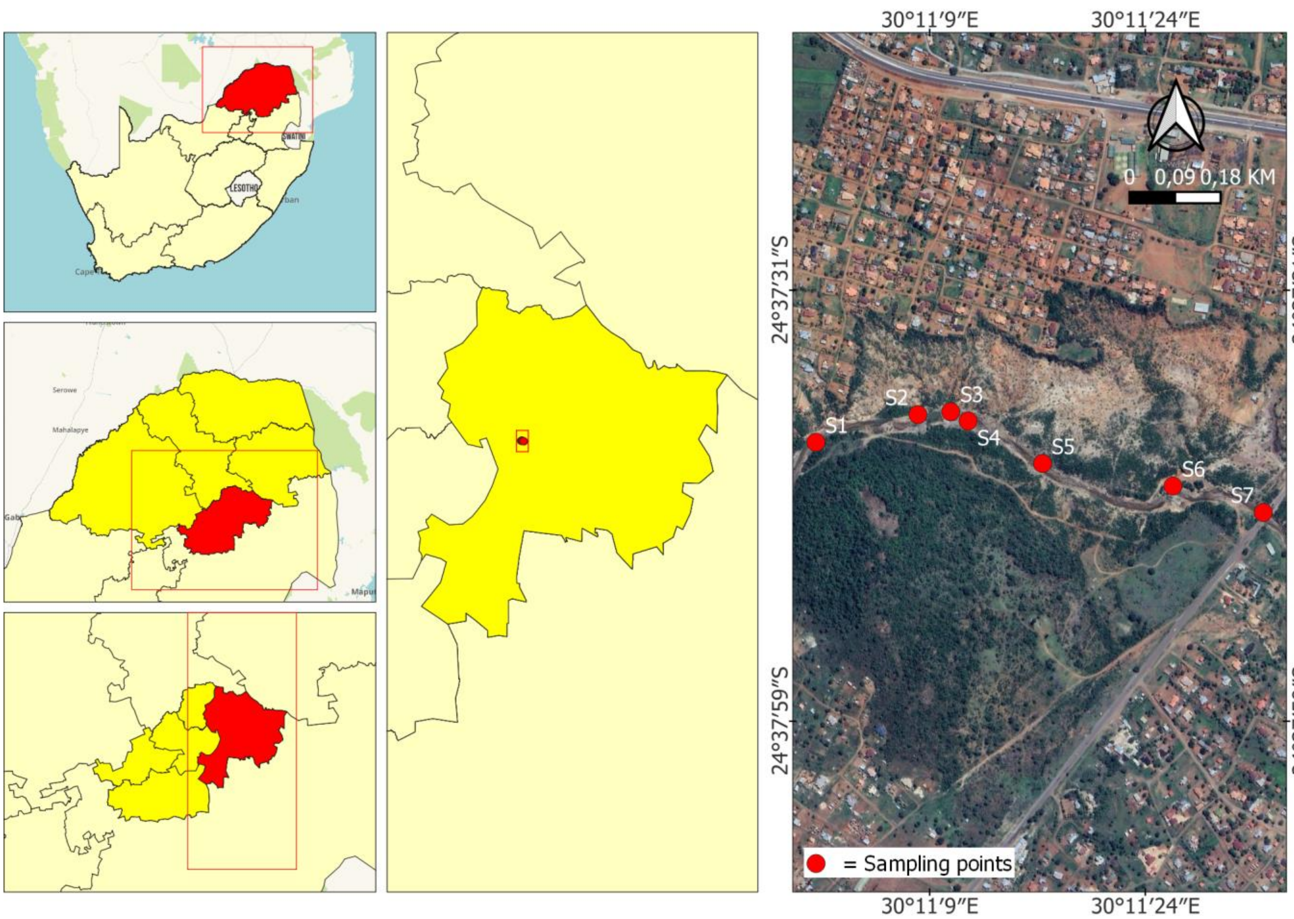

Figure 1. Map showing the seven sampling sites along the Moopitse River and the locations of different rivers in the Olifants River Basin, Sekhukhune, Limpopo, South Africa

Table 1. Description and geo-reference of the sampling sites of the Moopitse River, South Africa

Site	Description of location	Coordinates
1	Situated at the upstream of the river, the site is rocky and characterized by low density of vegetation and there are little anthropogenic activities taking place. The water is clear and fast flowing.	24°37'41.0"S, 30°11'00.5"E
2	The site is near a settlement, the riparian area alongside this site is characterized by low density. The site is mainly rocky both in the river and surrounding area. The water is clear and fast flowing during high flow and low flow.	24°37'39.2"S, 30°11'07.7"E
3	Situated midstream of the river and rocky, the riparian area consists of scattered grasses and a few shrubs. This site is used for spiritual cleansing and serves as source of drinking water for cattle. The water is slightly turbid during high flow and a lot of algae during low flow and intermittent flow.	24°37'39.0"S, 30°11'10.0"E
4	Situated under a bridge, the riparian vegetation is less dense with severe bank erosion. This site is used for car washing and serves as source of drinking water for cattle. The water is slow moving and it is usually turbid throughout the year.	24°37'39.6"S, 30°11'11.2"E
5	Situated under a bridge with dispersed vegetation and severe bank erosion. The site is adjacent to a small human settlement, with human disturbance. The water is slow moving and turbid with a lot of algae during low flow and intermittent flow.	24°37'42.3"S, 30°11'16.5"E
6	Situated in the downstream surrounded by a mountain with a few scattered grasses and shrubs. The site also experiences high soil erosion. The water is deeper than in the midstream and upstream and clearer than in the midstream of the river.	24°37'43.8"S, 30°11'25.6"E
7	Situated in the downstream and it is surrounded by a mountain, with the riparian zone consisting mainly a few grasses and shrubs. The water is deeper and clearer than in the midstream of the river.	24°37'45.5"S, 30°11'32.0"E

The size of the sub-catchment is about 7,139 km². The summer and autumn seasons are typically warm to hot, with average daytime temperatures ranging between 19°C and 22°C. Winters are mild, with average daytime temperatures ranging from 13°C to 19°C (mean daily temperature of 17.0°C in July). The area's average annual rainfall is between 600 mm and 1,000 mm, with most of the rainfall occurring during the warm seasons (December to April) (DWS 2016). The main activities in the Steelpoort River catchment are mining and agriculture. Mining activities in the upper sub-catchment include the extraction of chrome, coal, granite, magnesite, alluvial gold, platinum, and vanadium.

This study was conducted during three different seasons in 2023: autumn (April), winter (July), and spring (October), representing high flow, low flow, and intermittent flow periods, respectively. Rainfall usually occurs in summer and autumn and almost dry in winter and spring. Water and macroinvertebrate samples were collected at seven selected sites along the stream. The description and the coordinates of the sites are in Table 1. All the sites are exposed to different forms of anthropogenic activities with little or no riparian vegetation.

Water physicochemical variables

Water samples were collected in 500 mL 10% nitric acid pre-treated plastic containers. Collected water samples were kept on ice and sent to the laboratory. The samples were kept at 4°C prior to chemical analysis. Water temperature, pH, dissolved oxygen, electrical conductivity and total dissolved solids (TDS) were measured in situ using a YSI Model 554 portable multi-parameter probe (YSI Inc. Yellow Springs, OH, USA). Nutrient (ammonium, nitrite, nitrate and orthophosphate) concentrations and turbidity in the water samples were analyzed using Merck Spectroquant™ Pharo 100 spectrophotometer (Germany) with Merck cell test kits at the University of Limpopo, Biodiversity Laboratory. The nutrients and turbidity were analyzed according to the standard methods for the water assessment (APHA 2017).

Macroinvertebrate sampling

Benthic macroinvertebrates were collected using a 30 cm by 30 cm sampling net with a 500 μm mesh size. The substrate was disturbed by kicking to free macro-invertebrates from the substrate. At each site, different biotopes were sampled as outlined by Dickens and Graham (2002). Samples collected from the various heterogeneous habitats at each site were pooled to form a single composite sample. The samples were preserved in 70% ethanol in 1 L polypropylene containers and transported to the laboratory for identification. The macroinvertebrates were identified at the family level except for samples in the class Gastropoda, which were identified at the class level using the guides by Gerber and Gabriel (2002). The samples were identified with the aid of a stereomicroscope (Leica EZ4) and a magnifying glass.

Data analysis

Analysis of variance (ANOVA) was used to compare mean values of physicochemical variables among the flow regimes, after testing for homogeneity of variances (Levene's test, $p>0.05$) and normality of distribution (Shapiro-Wilk test, $p>0.05$). The same tests were used to assess for differences in macroinvertebrate abundance among sites and flow regimes. The analysis was carried out using Statistica version 10.0. The macroinvertebrate structural composition was determined for each sampling site and streamflow regime, using number of taxa (S), total number of individuals and abundance of each taxon. Macroinvertebrate community metrics such as total number of taxa, total number of families, and EPT (total number of Ephemeroptera, Trichoptera and Plecoptera) were calculated for the flow regimes. Diversity and evenness of the community were described with the Shannon-Wiener diversity index (H) and Shannon evenness (E) (also called Pielou's evenness, J) respectively (Bowman and Hacker 2020; Gauthier and Derome 2021).

$$H = -\Sigma P_i \ln P_i$$

Where:
H : Shannon Weiner species diversity index
P_i : The relative proportion (n/N) of the individual of one particular species found
$\ln P_i$: The natural logarithm (LN) of the value P_i
Σ : Summation of the outputs with the final value multiplied by negative one (-1); and

$$E (J) = H / \ln(S)$$

Where:
H : The Shannon Weiner diversity index
S : The total number of unique species

This value ranges from 0 to 1 where 1 indicates complete evenness.

RESULTS AND DISCUSSION

Physicochemical variables

The mean physicochemical variables and guideline values are shown in Table 2. All the pH values were within the guideline range of 6.5 and 9.0 (CCME 2012). The mean temperature readings across all sites during different flow conditions ranged from 18.9°C to 19.1°C, with the highest temperature recorded during high flow (autumn) and the lowest during low flow (winter). There was a significant difference in temperature between the flow regimes ($p<0.05$). The mean dissolved oxygen levels varied significantly among the flow regimes ($p<0.001$) and ranged from 98.34% during low flow to 50.14% during intermittent flow. The mean dissolved oxygen was below the guideline value (DWAF 1996). The mean electrical conductivity ranged from 963.7 µS/cm to 1114 µS/cm, with the highest mean conductivity observed during intermittent flow (1114 µS/cm) and the lowest during low flow (963.7 µS/cm) and the mean TDS ranged from 664.9 mg/L to 724.4 mg/L during low flow and intermittent flow respectively. The mean turbidity ranged from 5.99 to 6.14 NTU, with the lowest recorded during low flow and the highest during intermittent flow and the difference among the flow regimes was significant ($p<0.001$). During the intermittent flow, the highest conductivity and TDS and the lowest dissolved oxygen were recorded. The high levels of conductivity and TDS during intermittent flow were due to a decrease in water volume, which reduces dilution of dissolved substances. As water evaporates or is absorbed into the ground, the remaining water becomes more concentrated, increasing conductivity and TDS. Furthermore, during periods of no flow, the concentration of dissolved ions in the water increases as salts and minerals from the surrounding soil and rocks accumulate. Intermittent streams often have periods where the flow is sustained by groundwater inputs. Because groundwater can have prolonged contact with mineral-rich substrates, it can have a higher concentration of dissolved ions compared to surface water and can lead to increased conductivity and TDS when it feeds into streams. The increased temperature during high flow and intermittent flow could be due to autumn temperature and flow cessation respectively. On the contrary, temperature, conductivity, TDS and turbidity were lower during the low flow, but higher dissolved oxygen. The low flow condition was in winter hence the low temperature and high dissolved oxygen were not unexpected.

Table 2. Water quality parameter levels (±) recorded during the different flow regimes in the Moopitse River, South Africa (mean and standard deviation) and guidelines

Parameters	High flow	Low flow	Intermittent flow	F	p	TWQR
	Mean	Mean	Mean			
pH	8.73-8.94	8.06-9.25	8.72-9.14	46.9	0.001	6.5-9.0[2]
Temperature (°C)	19.10 ± 2.39	18.90 ± 0.41	19.07 ± 0.18	29.12	0.001	
EC (µS/cm)	1014 ± 206	963.7 ± 116	1114 ± 112	1.12	0.34	
TDS (mg/L)	714.87 ± 116	664.9 ± 106	724.4 ± 77	12.47	0.01	
DO (%)	82.0 ± 19	98.34 ± 14.8	50.14 ± 4.61	12.70	0.001	80-120[1]
Turbidity (NTU)	6.18 ± 0.58	5.99 ± 0.75	6.14 ± 0.7	73.5	0.001	
Nitrate (mg/L)	1.83 ± 1.28	1.31 ± 0.5	1.96 ± 1.35	63.50	0.0001	13[2]
Nitrite (mg/L)	0.03 ± 0.01	0.05 ± 0.02	0.103 ± 0.01	76.42	0.001	0.06[2]
Ammonium (mg/L)	0.05 ± 0.06	0.03 ± 0.01	0.27 ± 0.05	25.55	0.0001	0.007[1]
Orthophosphate (mg/L)	0.12 ± 0.01	0.12 ± 0.01	0.13 ± 0.02	1.50	0.22	0.1[3]

Note: [1] DWAF (1996)-South African Water Quality Guidelines: Volume 7: Aquatic Ecosystems; [2] CCME (2012): Canadian Council of Ministers of the Environment: Water Quality Guidelines-Aquatic Life; [3] USEPA (2012): United States Environmental Protection Agency: Water Quality Guidelines-Aquatic Life

Nutrients were found to vary significantly (ANOVA, $p<0.05$) among the three flow regimes, except orthophosphate, with intermittent flow having the highest concentrations (Table 1). The mean ammonium concentration ranged from 0.03 mg/L to 0.27 mg/L, with the highest recorded during intermittent flow and the lowest during low flow. The mean ammonium concentration exceeded the guideline value during the stream flow regimes (DWAF 1996). The mean nitrate concentration varied between 1.96 mg/L and 1.31 mg/L, with the highest level during intermittent flow and the lowest level during low flow. The mean concentration of nitrite ranged from 0.03 mg/L to 0.010 mg/L, with the highest during intermittent flow and the lowest during high flow. The mean nitrite concentration exceeded the guideline value during intermittent flow (CCME 2012). The mean orthophosphate concentrations were between 0.12 mg/L and 0.13 mg/L, with the highest values during intermittent flow and the lowest during both low flow and high flow. The mean orthophosphate concentrations during the three flow regimes exceeded the guideline value (USEPA 2012). Generally, nutrient levels were lowest during low flow, except for nitrite, and highest during intermittent flow. Agricultural fertilizers and urban sewage contribute to increased nitrogen compounds and orthophosphate in water, particularly in the absence of freshwater plants.

Macroinvertebrate structural composition

A total of 4094 individual macroinvertebrates from 6 orders, 1 class and 22 families were collected during the different flows in the Moopetsi River (Table 3). The highest number of families were recorded from Diptera (7 families), Odonata, Hemiptera and Trichoptera had 4 families each. Taxa richness among the flow regimes were 12, 17 and 15 during high flow, low flow and intermittent flow respectively. The 22 families recorded in this study represent relatively low taxa richness compared to perennial rivers in the basin, with a decrease of more than 50% of the EPT taxa. The difference observed was expected due to the extreme hydrological characteristics and significant land degradation occurring near the river. Numerous studies support the idea that macroinvertebrate communities in intermittent rivers and streams typically exhibit lower diversity compared to those in perennial lotic habitats, primarily because of variations in environmental conditions (Soria et al. 2017; White et al. 2017; Sarremejane et al. 2020; Bozóki et al. 2024). However, changes in diversity can be influenced by the timing, frequency, and periodicity of drying (Crabot et al. 2020, 2021). The communities found in such environments are typically dominated by generalist species (Armitage and Bass 2013). This assertion was observed in the current study, with Baetidae accounting for more than 34% of the total abundance in the Moopitse River.

The highest number of macroinvertebrates were recorded at S1 followed by S2, both in the upstream, then at S7 (downstream), and the lowest at S4 (midstream) of the river (Figure 2). The low numbers of macroinvertebrates in the midstream sites could be attributed to human activities such as mining and construction leading to changes in microhabitats. Such habitat changes can reduce macroinvertebrate diversity across different habitats (Do Amaral et al. 2015).

Table 3. List of benthic macroinvertebrates collected during different flows at Moopetsi River, South Africa

Order	Family	Abbreviation	HF	LF	IF	Total
Diptera	Tabanidae	TAB	20	14	8	42
	Ceratopogonidae	CER	67	145	57	269
	Chironomidae	CHI	0	158	102	260
	Muscidae	MUS	3	49	16	68
	Psychodidae	PSYC	0	14	3	17
	Culicidae	CUL	0	0	2	2
	Simulidae	SIM	0	9	0	9
Odonata	Libellulidae	LIB	116	121	18	255
	Gomphidae	GOM	80	131	12	223
	Aeshnidae	AES	0	7	3	10
	Coenagrionidae	COE	0	15	0	15
Ephemeroptera	Baetidae	BAE	130	1202	89	1421
Hemiptera	Naucoridae	NAU	3	29	42	74
	Notonectidae	NOT	0	4	4	8
	Veliidae	VEL	1	0	0	1
	Nepidae	NEP	1	0	0	1
Trichoptera	Hydropsychidae	HYDS	39	59	0	98
(Cased caddis)	Psychomyiidae	PSY	18	0	0	18
	Hydroptilidae	HYDT	0	1124	165	1289
	Leptoceridae	LEP	1	0	0	1
Coleoptera	Gyrinidae	GYR	0	4	7	11
Gastropoda	Thiaridae	THI	0	1	1	2
	Total		479	3086	529	4094

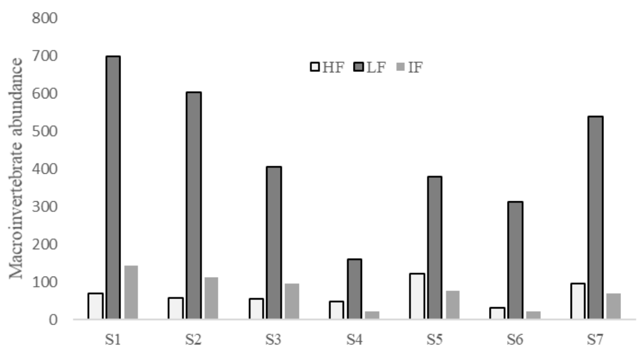

Figure 2. Abundance of macroinvertebrates recorded at the different flow regimes at each sampling site

The dominant families were Baetidae, Hydroptilidae, Ceratopogonidae and Chironomidae, accounting for 32.65%, 28.42%, 8.73% and 8.64% respectively. Approximately, 75.4% of the total abundance was collected during the low flow, 12.9% during the intermittent flow, and 11.7% during the high flow. During the high flow, Baitidae and Libellulidae were the dominant families with 130 and 116 individuals respectively, during low flow, the dominant families were Baitidae and Hydroptilidae with 1202 and 1124 individuals respectively, and during the intermittent flow, the dominant families were Hydroptilidae and Simuliidae, with 165 and 102 respectively. Only seven families were recorded during the three flow regimes: Tabanidae, Ceratopogonidae, Muscidae, Libellulidae, Gomphidae, Baetidae and Naucoridae. Figure 3 shows some of the macroinvertebrates identified during the study.

There were differences in abundance, richness, and diversity observed among the different flow regimes, suggesting a strong influence of hydrological and habitat characteristics on the flow regimes. A higher taxa richness and diversity of macroinvertebrates were recorded during low flow compared to the high and intermittent flows. This is likely due to increased habitat heterogeneity and improved water quality. The lowest abundance and richness in macroinvertebrate structural composition occurred during high flow, likely due to the comparatively harsher environmental conditions and destruction of microhabitats caused by flooding. Although, some members of Baetidae are generalist in nature and can tolerate a wide range of conditions (Vilenica et al. 2017, 2022), the low number of Baetidae during the intermittent flow supports the fact that most members of the family are sensitive to pollution (Kubendran et al. 2017). The absence of Hydropsychidae, which is an early indicator of heightened anthropogenic waste influx into aquatic environments (Akyildiz and Duran 2021), during the intermittent flow also affirmed the deteriorating water quality.

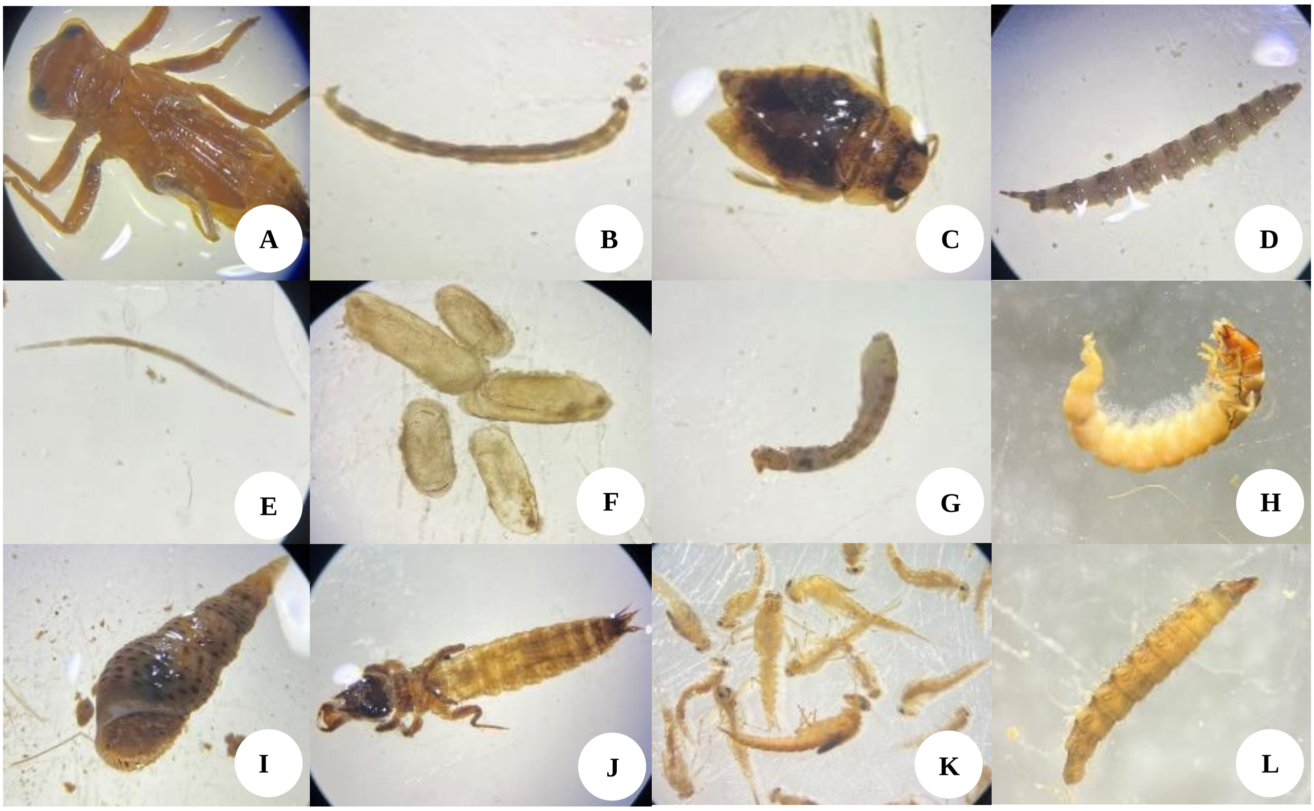

Figure 3. Photographs of some of the macroinvertebrates collected during the high flow, low flow and intermittent flow in the Moopitse River. A. Libellulidae; B. Chironomidae; C. Naucoridae; D. Tabanidae; E. Ceratopogonidae; F. Hydroptilidae; G. Simuliidae; H. Hydropsychidae; I. Thiaridae; J. Gomphidae; K. Baetidae; L. Psychodidae

The predominance of some true flies (Diptera: Ceratopogonidae, Chironomidae), mayflies (Ephemeroptera: Baetidae), Hemiptera (Naucoridae), and damselflies (Trichoptera: Hydroptilidae) during intermittent flow could be attributed to availability of habitats such as pools, stones and backwaters, their possession of resistance traits, opportunistic feeding habits, and flexible life cycles (Bogan et al. 2017). Conditions such as slow or non-flowing water and the presence of sand or mud during intermittent flow have been found to create refugia that protect some macroinvertebrates during hydrological disturbances and provide sources for post-disturbance recolonization (Rosser and Pearson 2018). Conditions such as these could have contributed to relatively higher abundance and taxa richness during the intermittent flow than high flow. Chironomidae, for example, possess traits that allow them to resist elevated temperatures, low dissolved oxygen, and desiccation, enabling them to survive the stressed environment during intermittent regime (Rosser and Pearson 2018).

During high flow, six tolerant taxa, five moderately tolerant taxa and one sensitive taxon were collected. During low flow, 11 tolerant taxa, five moderately tolerant taxa and one sensitive taxon were collected. During intermittent flow, 10 tolerant taxa, five moderately tolerant taxa and no sensitive taxa were collected (Figure 4).

The highest Shannon Weiner's diversity index (H') of 1.98 was recorded during intermittent, followed by high flow (1.83) and then low flow (1.60). Similarly, the Shannon Evenness Index was highest during intermittent flow (0.73), followed by high flow (0.69) and then low flow (0.57), however, the index values dropped below the normal metric value of 1, an indication that the proportions of all taxa in the system are similar (Figure 5). The lower diversity and evenness indices during the low flow despite higher taxa richness and abundance could be attributed to high number of two taxa, Baetidae (1202) and Hydroptilidae (1124) and low number of taxa such as Thiaridae (1), Notonectidae (4) and Gyrinidae (4), thus, individuals in the community are distributed less equitably among the taxa during low flow.

In terms of EPT taxa, the number ranged from two to four, with the lowest value during intermittent flow and the highest during high flow. Throughout the study, only a few EPT taxa were recorded in the Moopitse River, with no record of Plecoptera. This may be due to increased hydrological disturbances, which reduce stream stability and diminish the presence of flow-sensitive taxa (EPT) but promote resilient taxa such as Coleoptera, Hemiptera and Diptera (Belmar et al. 2013).

Comparing the results with other rivers in the Olifants River Basin (Table 4), a total of 36 taxa were collected from Blyde River, 33 taxa were collected from Dwars River, 42 taxa from Letaba, 40 from Selati and Spekboom, 63 from Mohlapitsi, 39 from Steelpoort and only 22 from Moopitsi River (current study). In terms of EPT taxa, the number ranged from 10 to 18 in the previous studies and only five in the current study. The variation in hydrological regimes strongly influences physicochemical parameters, including water temperature, dissolved oxygen, conductivity, total dissolved solids, and nutrient concentrations. These changes may significantly affect the biotic communities in intermittent rivers (Magand et al. 2020; Dong et al. 2024).

Variations in the physiochemical parameters across different flow regimes altered the habitat and community structure of macroinvertebrates in the river. The physicochemical variables in the river induced a substantial decrease in the abundance, taxa richness and diversity during the high flow and intermittent flow. Furthermore, the absence of most of the EPT families and the presence of only a small number of Odonata during the intermittent flow suggest that the water quality deteriorated during flow cessation. The EPT and Odonata families are generally sensitive to changes in their environment, making them among the most effective indicators of water quality (Miguel et al. 2017).

Figure 4. Distribution of tolerant, moderate tolerant and sensitive taxa during the different flow regimes

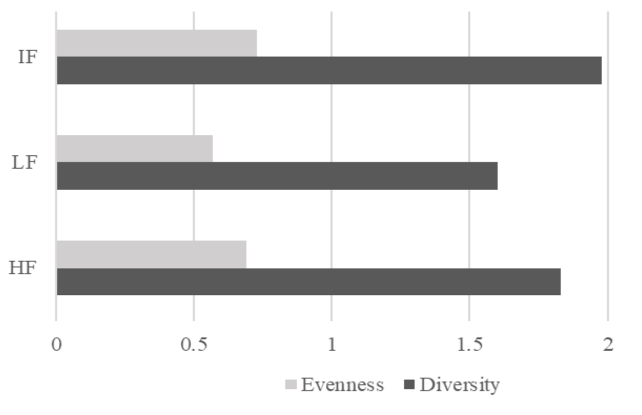

Figure 5. Shannon-Wirner diversity index and Shannon Evenness index for the three flow regimes

Table 4. Comparison of taxa richness of macroinvertebrates in different rivers in the Olifants River Basin with the current

River	Order	Family	EPT taxa	Reference
Blyde	11	36	10	Malakane et al. (2020)
Dwars	11	33	12	Addo-Bediako (2021)
Letaba	12	42	14	Kekana et al. (2022)
Spekboom	11	40	12	Nukeri et al. (2001)
Mohlapitsi	10	63	18	Raphahlelo et al. (2022)
Selati	11	40	12	Rasifudi et al. (2018)
Steelpoort	9	39	12	Makgoale et al. (2022)
Moopitse	7	22	5	This study

The study highlights the influence of hydrological regimes on the structural composition of macroinvertebrate communities in the Moopitse River, an intermittent river in a semi-arid region of South Africa. The observed low taxa richness and abundance, particularly during high flow and intermittent regimes, align with expectations for such hydrologically extreme habitats. The findings suggest that macroinvertebrate structural composition in intermittent rivers is typically less diverse compared to those in perennial rivers, as these environments favor generalist and stress-tolerant taxa. Flooding during high flow likely caused habitat destruction and the loss of taxa, while the greater diversity and richness during low flow were attributed to a better water quality. The persistent low macroinvertebrate abundance and richness across all flow regimes indicate that altered habitats and degraded environmental conditions, such as eroded banks and low vegetation cover, negatively affect the river's biota. In summary, this study reinforces the importance of understanding hydrological variability and habitat characteristics in shaping macroinvertebrate communities. Conservation efforts are essential to mitigate the impacts of hydrological disturbances and preserve the ecological integrity of intermittent rivers. The study also emphasizes the vulnerability of flow-sensitive taxa (EPT) to hydrological disturbances and the resilience of stress-tolerant species in impaired environments.

ACKNOWLEDGEMENTS

The study was supported by the National Research Foundation through the DSI-NRF SARChI Chair (Ecosystem Health; number 101054), University of Limpopo.

REFERENCES

Acuña V, Hunter M, Ruhí A. 2017. Managing temporary streams and rivers as unique rather than second-class ecosystems. Biol Conserv 211: 12-19. DOI: 10.1016/j.biocon.2016.12.025.

Akyildiz GK, Duran M. 2021. Evaluation of the impact of heterogeneous environmental pollutants on benthic macroinvertebrates and water quality by long-term monitoring of the Buyuk Menderes River basin. Environ Monit Assess 19: 280. DOI: 10.1007/s10661-021-08981-8.

APHA [American Public Health Association]. 2017. Standard Methods for the Examination of Water and Wastewater (23rd ed.). American Public Health Association, Washington DC.

Armitage PD, Bass JAB. 2013. Long-term resilience and short-term vulnerability of south winterbourne macroinvertebrates. Proc Dorset Nat Hist Archaeol Soc 134: 43-55.

Asmamaw M, Mereta ST, Ambelu A. 2021. Response of macroinvertebrates to changes in stream flow and habitat conditions in Dinki watershed, central highlands of Ethiopia. Ecol Indic 133: 108448. DOI: 10.1016/j.ecolind.2021.108448.

Aspin TWH, Khamis K, Matthews TJ, Milner AM, O'Callaghan MJ, Trimmer M, Woodward G, Ledger ME. 2019. Extreme drought pushes stream invertebrate communities over functional thresholds. Glob Chang Biol 25 (1): 230-244. DOI: 10.1111/gcb.14495.

Belmar O, Velasco J, Gutiérrez-Cánovas C, Mellado-Díaz A, Millán A Wood PJ. 2013. The influence of natural flow regimes on macroinvertebrate assemblages in a semiarid Mediterranean basin. Ecohydrology 6: 363-379. DOI: 10.1002/eco.1274.

Bogan M, Hwan JL, Cervantes-Yoshida K, Ponce J, Carlson SM. 2017. Aquatic invertebrate communities exhibit both resistance and resilience to seasonal drying in an intermittent coastal stream: Aquatic invertebrate communities exhibit both resistance and resilience to seasonal drying in an intermittent coastal stream. Hydrobiologia 799 (1): 123-133. DOI: 10.1007/s10750-017-3205-4.

Bohada-Murillo M, Castaño-Villa GJ, Fontúrbel FE. 2021. Effects of dams on vertebrate diversity: A global analysis. Diversity 13: 528. DOI: 10.3390/d13110528.

Bowman WD, Hacker SD. 2020. Ecology: Community Structure. Oxford University Press Academic, United States.

Bozóki T, Várbíró G, Csabai Z, Schmera D, Pál Boda P. 2024. Resistance not resilience trait's structure macroinvertebrate communities in newly drying stream sections. Hydrobiologia 15: 3577-3590. DOI: 10.1016/j.scitotenv.2024.176671.

CCME [Canadian Council of Ministers of the Environment]. 2012. Water Quality Guidelines-Aquatic Life. Canadian Council of Ministers of the Environment, Canada.

Crabot J, Heino J, Launay B, Datry T. 2020. Drying determines the temporal dynamics of stream invertebrate structural and functional beta diversity. Ecography 43: 620-635. DOI: 10.1111/ecog.04835.

Crabot J, Mondy C, Usseglio-Polatera P, Fritz K, Wood P, Greenwood M, Bogan M, Meyer E, Datry T. 2021. A global perspective on the functional responses of stream communities to flow intermittence. Ecography 44: 1511-1523. DOI: 10.1111/ecog.05697.

De Girolamo AM, Barca E, Pappagallo G, Lo Porto A. 2017. Simulating ecologically relevant hydrological indicators in a temporary river system. Agric Water Manag 180: 194-204. DOI: 10.1016/j.agwat.2016.05.034.

Dickens CW, Graham PM. 2002. The South African Scoring System (SASS) version 5 rapid bioassessment method for rivers, Afr J Aquat Sci **27**: 1-10.

Di Sabatino A, Rossi F, Ercolino G. 2024. Temporal changes in freshwater invertebrate communities during the drying phase of a newly intermittent river in central Italy. Environments 11: 295. DOI: 10.3390/environments11120295.

Do Amaral PHM, da Silveira LS, Rosa BFJV, de Oliveira VC, Alves RDG. 2015. Influence of habitat and land use on the assemblages of Ephemeroptera, Plecoptera, and Trichoptera in Neotropical Streams. J Insect Sci 15: 60. DOI: 10.1093/jisesa/iev042.

Dong R, Peng K, Zhang Q, Heino J, Cai Y, Gong Z. 2024. Spatial and temporal variation in lake macroinvertebrate communities is decreased by eutrophication. Environ Res 243: 117872. DOI: 10.1016/j.envres.2023.117872.

Doretto A, Piano E, Larson CE. 2020. The river continuum concept: Lessons from the past and perspectives for the future. Can J Fish Aquat Sci 77: 1853-1864. DOI: 10.1139/cjfas-2020-0039.

DWAF [Department of Water Affairs and Forestry]. 1996. South African Water Quality Guidelines: Aquatic Ecosystems: Volume 7. Department of Water Affairs and Forestry, South Africa.
DWS [Department of Water and Sanitation]. 2016. Development of an Integrated Water Quality Management Plan for the Olifants River System: Steelpoort Subcatchment Plan. Department of Water and Sanitation, South Africa.
Edegbene AO, Odume ON, Arimoro FO, et al. 2021. Identifying and classifying macroinvertebrate indicator signature traits and ecological preferences along urban pollution gradient in the Niger Delta. Environ Pollut 281:117076. doi: 10.1016/j.envpol.2021.117076.
Fuller MR, Doyle MW, Strayer DL. 2015. Causes and consequences of habitat fragmentation in river networks. Ann N Y Acad Sci 1355: 31-51. DOI: 10.1111/nyas.12853.
Gauthier J, Derome N. 2021. Evenness-richness scatter plots: A visual and insightful representation of Shannon entropy measurements for ecological community analysis. Msphere 6 (2): 10-1128. DOI: 10.1128/msphere.01019-20**.**
Gerber A, Gabriel MJM. 2002. *Aquatic Invertebrates of South African Rivers: Field guide*. Department of Water Affairs and Forestry, Pretoria. 17-78pp.
Grill G, Lehner B, Thieme M, Geenen B, Tickner D, Antonelli F, Babu S, Borrelli P, Cheng L, Crochetiere H, Ehalt Macedo H. 2019. Mapping the world's free-flowing rivers. Nature 569 (7755): 215-221. DOI: 10.1038/s41586-019-1111-9.
Ionita M, Tallaksen LM, Kingston DG, Stagge JH, Laaha G, Van Lanen HAJ, Scholz P, Chelcea SM, Haslinger K. 2017. The European 2015 drought from a climatological perspective. Hydrol Earth Syst Sci 21: 1397-1419. DOI: 10.5194/hess-21-1397-2017.
IPCC [Intergovernmental Panel on Climate Change]. 2014. Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field CB, VR Barros, DJ Dokken, KJ Mach, MD Mastrandrea, TE Bilir, M Chatterjee, KL Ebi, YO Estrada, RC Genova, B Girma, ES Kissel, AN Levy, S MacCracken, PR Mastrandrea, and LL White (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Jones PE, Tummers JS, Galib SM, Woodford DJ, Hume JB, Silva LG, Braga RR, de Leaniz GC, Vitule JR, Herder JE, Lucas MC. 2021. The use of barriers to limit the spread of aquatic invasive animal species: A global review. Front Ecol Evol 9: 611631. DOI: 10.3389/fevo.2021.611631.
Kubendran T, Selvakumar C, Sidhu AK, Nair A, Krishnan SM. 2017. Baetidae (Ephemeroptera: Insecta) as biological indicators of environmental degradation in Tamiraparani and Vaigai River Basins of Southern Western Ghats, India. Intl J Curr Microbiol Appl Sci 6 (6): 558-572. DOI: 10.20546/ijcmas.2017.606.066.
Krajenbrink HJ, Acreman M, Dunbar MJ, Hannah DM, Laizé CLR, Wood PJ. 2019. Macroinvertebrate community responses to river impoundment at multiple spatial scales. Sci Total Environ 650: 2648-2656. https://doi.org/10.1016/j.scitotenv.2018.09.264.
Larned ST, Datry T, Arscott DB, Tockner K. 2010. Emerging concepts in temporary-river ecology. Freshwater Biol 55: 717-738. DOI: 10.1111/j.1365-2427.2009.02322x.
Leigh C, Boulton AJ, Courtwright JL, Fritz K, May CL, Walker RH, Datry T. 2016. Ecological research and management of intermittent rivers: An historical review and future directions. Freshwater Biol 61: 1181-1199. DOI: 10.1111/fwb.12646.
López E, Patiño R, Vázquez-Sauceda ML, Pérez-Castañeda R, Arellano-Méndez LU, Ventura R, Heyer L. 2020. Water quality and ecological risk assessment of intermittent streamflow through mining and urban areas of San Marcos River sub-basin, Mexico. Environ Nanotechnol Monit 14: 100369. DOI: 10.1016/j.enmm.2020.100369.
Magand C, Alves MH, Calleja E, Datry T, Dörflinger G, England J, Gallart F, Gomez R, Jorda-Capdevila D, Marti E. 2020. Intermittent rivers and ephemeral streams: What water managers need to know. European Cooperation in Science and Technology, Brussels, Belgium.
Makgoale MM, Addo-Bediako A, Ayisi KK. 2022. Distribution pattern of macroinvertebrate functional feeding groups in the Steelpoort River, South Africa. Appl Ecol Environ Res 20: 189-206. DOI: 10.15666/aeer/2001_189206.
Malakane K, Addo-Bediako A, Kekana M. 2020. Benthic macroinvertebrates as bioindicators of water quality in the Blyde River of the Olifants River System, South Africa. Appl Ecol Environ Res 18 (1): 1621-1635. DOI: 10.15666/aeer/1801_16211635.
Masese FO, Raburu P. 2017. Improving the performance of the EPT Index to accommodate multiple stressors in Afrotropical streams. Afr J Aquat Sci 42: 219-233. DOI: 10.2989/16085914.2017.1392282
Miguel TB, Oliveira-Junior JMB, Ligeiro R, Juen L. 2017. Odonata (insecta) as a tool for the biomonitoring of environmental quality. Ecol Indic 81: 555-566. DOI: 10.1016/j.ecolind.2017.06.010.
Milly PCD, Dunne KA, Vecchia AV. 2005. Global pattern of trends in streamflow and water availability in a changing climate. Nature 438: 347-350. DOI: 10.1038/nature04312.
Mmako TV, Addo-Bediako A, Luus-Powell WJ, Kekana M. 2021. Assessment of river health using benthic macroinvertebrates in the Dwars River, Olifants Water Management Area, Limpopo Province, South Africa. Afr J Aquat Sci 46: 441-451. DOI: 10.2989/16085914.2021.1922348.
Nukeri S, Addo-Bediako A, Kekana MB. 2021. Macroinvertebrates assemblages in the Spekboom River of the Olifants River System, South Africa. Afr J Ecol 59: 320-325. DOI: 10.1111/aje.12811.
Raphahlelo ME, Addo-Bediako A, Luus-Powell WJ. 2022. Assessment of spatial distribution and diversity of benthic macroinvertebrates in the Mohlapitsi River of the Olifants River System, South Africa. J Freshw Ecol 37 (1): 145-160. DOI: 10.1080/02705060.2021.2023054.
Rasifudi L, Addo-Bediako A, Swemmer A, Bal K. 2018. Distribution and diversity of benthic macroinvertebrates in the Selati River of Olifants River System, South Africa. Afr Entomol 26: 398-406. DOI: 10.4001/003.026.0398.
Reid AJ, Carlson AK, Creed IF, Eliason EJ, Gell PA, Johnson PTJ, Kidd KA, MacCormack TJ, Olden JD, Ormerod SJ, Smol JP, Taylor WW, Tockner K, Vermaire JC, Dudgeon D, Cooke SJ. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol Rev 94: 849-873. DOI: 10.1111/brv.12480.
Rosser ZC, Pearson RG. 2018. Hydrology, hydraulics and scale influence macroinvertebrate responses to disturbance in tropical streams responses to disturbance in tropical streams. J Freshw Ecol 33 (1): 1-17. DOI: 10.1080/02705060.2017.1414001.
Ruhí A, Munoz I, Tornes E, Batalla RJ, Vericat D, Ponsatí L, Acuña V, Von Schiller D, Marce R, Bussi G. Frances F, Sabater S. 2016. Flow regulation increases food chain length through omnivory mechanisms in a Mediterranean River Network. Freshw Biol 61: 1536-1549. DOI: 10.1111/fwb.12794.
Sarremejane R, England J, Sefton CEM, Parry S, Eastman M, Stubbington R. 2020. Local and regional drivers influence how aquatic community diversity, resistance and resilience vary in response to drying. Oikos 129: 1877-1890. DOI: 10.1111/oik.07645.
Schinegger R, Trautwein C, Melcher A, Schmutz S. 2012. Multiple human pressures and their spatial patterns in European running waters. Water Environ J 26: 261-273. DOI: 10.1111/j.1747-6593.2011.00285x.
Soria M, Leigh C, Datry T, Bini LM, Bonada N. 2017. Biodiversity in perennial and intermittent rivers: A meta-analysis. Oikos 126: 1078-1089. DOI: 10.1111/oik.04118.
Straka M, Polášek M, Csabai Z, Zweidick O, Graf W, Meyer EI, Mišíková Elexová E, Leštáková M, Paril P. 2021. Stream drying bioindication in Central Europe: A biodrought index accuracy assessment. Ecol Indic 130: 108045. DOI: 10.1016/j.ecolind.2021.108045.
Tonkin JD, Poff NL, Bond NR, Horne A, Merritt DM, Reynolds LV, Olden JD, Ruhi A, Lytle DA. 2019. Prepare river ecosystems for an uncertain future. Nature 570 (7761): 301-303. DOI: 10.1038/d41586-019-01877-1.
USEPA [United States Environmental Protection Agency]. 2012. Water Quality Guidelines-Aquatic Life. United States Environmental Protection Agency, United States.
Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE. 1980. The river continuum concept. Can J Fish Aquat Sci 37: 130-137. DOI: 10.1139/f80-017.
Vilenica M, Stankovic VM, Sartori M, Kucinich M, Mihaljevic Z. 2017. Environmental factors affecting Mayfly structural composition in Tufa-depositing habitats of the Dinaric Karst. Knowl Manag Aquat Ecosyst 418: 14. DOI: 10.1051/kmae/2017005.
Vilenica M, Maoduš, IV, Mihaljevic Z. 2022. The impact of hydromorphological alterations on mayfly structural composition of a mid-sized lowland river in South-Eastern Europe. Insects 13: 436. DOI: 10.3390/insects13050436.
White J, House A, Punchard N, Hannah D, Wilding N, Wood P. 2018. Macroinvertebrate community responses to hydrological controls and groundwater abstraction effects across intermittent and perennial headwater streams. Sci Total Environ 610: 1514-1526. DOI: 10.1016/j.scitotenv.2017.06.081.
Zimmer MA, Kaiser KE, Blaszczak JR, Zipper SC, Hammond JC, Fritz KM. 2020. Zero or not? Causes and consequences of zero-flow stream gage readings. Wires Water 7: 27. DOI: 10.1002/wat2.1436.