ORIGINAL ARTICLE

How do substrate types affect the seasonal richness and functional feeding groups variation of benthic insects in an arid region (northeastern Algeria)?

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Abstract

The diversity of bottom substrates is a primary driver of taxonomic richness and species abundance patterns of freshwater benthic insects in space and time. Here, we examine the influence of substrate composition on the seasonal patterns of benthic insect communities in streams of arid regions. Benthic insects were sampled monthly over a year at three sampling sites distributed along the Bouilef stream within the Belezma biosphere reserve (Algeria). Different substrate types (sand, gravel, pebbles, boulders, and emergent macrophytes) were sampled in the rainy and dry seasons. During the two sampling seasons, a total of 8599 insects belonging to six orders, 26 families, and 39 genera/species were sampled and identified. Student's t-test analysis showed that season influences significantly the mean abundance of benthic insects, which increases in the rainy season. However, the season does not affect taxa richness. Substrate types influence taxa composition and variation of benthic insect communities. The results showed that pebbles and boulders are the most populated by gathering and filtering collectors in terms of taxa abundance. Emergent macrophytes are more favorable for herbivores shredders. Principal Coordinates Analysis ''PCoA'' also showed that pebbles and boulders differed significantly from other substrates, whereas sand and gravel substrates exhibited similar taxa mean abundance. Such assessments can help propose conservation measures needed to successfully safeguard these fragile ecosystems.

Keywords Benthic insects · Substrate types · Season · FFGs · Arid region stream

Introduction

Owing to their high diversity and variable tolerance to habitat variation, benthic macroinvertebrates are widely used for the biomonitoring of freshwaters across ecosystem types (e.g., lakes and rivers) and bioclimatic regions (Moisan and Pelletier 2013; Laini et al. 2022). Several physicochemical and biological factors drive the composition and variability of benthic invertebrate communities, either independently or combined (Benzina and Si Bachir 2018; Benzina et al. 2021; Buffagni 2020). Among those important physical factors, the nature and diversity of the bottom substrate are of utmost importance in shaping a benthic community. The characteristics of benthic substrates can vary across geographical and bioclimatic regions, and according to stream size and location within a drainage basin. Both local and regional settings can therefore affect the relationships between substrates and the seasonal dynamics of benthic communities. In most of the Mediterranean region, the

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substrate composition is closely related to the orography of the area crossed by streams, and to seasonal events of flooding and drying over an annual cycle (Gasith and Resh 1999). Precipitation regimes also have a major influence on aquatic ecosystems (Dodds et al. 2019; Carey et al. 2021), because they directly influence substrate size through river competence and the flow seasonality that determines the variation and composition of benthic insects (Patrick et al. 2019; Crabot et al. 2021; Carvallo et al. 2022). We know for instance that some species prefer large rocky substrates; others are typically found under pebbles or borrowed in sandy areas, while siltation tends to clog up the bottom and eliminate species (Burd et al. 2008). Some studies even provided evidence for ontogenetic habitat shifts in benthic invertebrates (Hanquet et al. 2004), thus highlighting the underlying role of substrate diversity in community seasonality. Yet, most of our current knowledge of species-substrate relationships in freshwaters has come from studies of temperate and tropical streams.

Arid-land streams of North Africa show much higher hydrological variability than their temperate and tropical counterparts (Dakki 1986, 1987; Gasith and Resh 1999; Arab et al. 2004; Benzina et al. 2019). Although the diversity of benthic macroinvertebrates communities decreases in arid regions, as they are submitted to highly selective environments. In addition, in such arid regions, stream substrate tends to be finer, and enriched of sediments such as sand, silt, and clay. Soil particles can be more compact due to aridity and low vegetation cover, which can affect permeability and water retention in the substrate (Naorem et al. 2022). This seasonal contrast is due to the fact that the seasonal patterns in these regions can vary with generally two seasons. The dry season sometimes extends up to 9 months with punctual periods of floods, which often results in increased erosion of shorelines and surrounding land. This can lead to greater sediment transport in streams, altering their substrate and morphology (Mueller and Pitlick 2013). The rainy season is generally short and characterized by low and recurrent rainfall that leads to increases in the diversity and richness of benthic macroinvertebrate communities (Tonkin et al. 2017; Patrick et al. 2019; Carvallo et al. 2022). These variations affect the structure and distribution patterns of these benthic macroinvertebrates' communities (Benzina 2019).

The study of benthic macroinvertebrates and their relationship to the substrate in arid regions can contribute to our understanding of the ecology of arid rivers and the assessment of water quality in these fragile ecosystems (Qian et al. 2021; Webster et al. 2022). It is, however, difficult to isolate substrate and seasonal effects on benthic macroinvertebrate communities from other factors such as water chemistry, temperature, or human-induced degradation of the habitats.

Here we investigate how do substrate types affect the seasonal composition and functional feeding groups variation of benthic insects in the Bouilef stream located in an arid region (northeastern Algeria).

Materials and methods

Study region and sites selection

The study sites are located in the Bouilef stream within the Belezma biosphere reserve, which ranges from 35°32′40″ and 35°37′46″ N, to 5°55′10″ and 6°10′45″ E. This protected area is part of a mountain range located in the semi-arid part of northeastern Algeria, near Batna city. The climate of the study region is influenced by its location and suffers a long period of summer drought. The climate of the reserve is globally semi-arid with cold winters and dry-hot summers at low elevations (900–1200 m a.s.l) (Boukerker and Si Bachir 2015). Over the last 10 years, mean temperatures ($\pm$ SD) were 17.46 ± 0.27 °C, with maxima of 25.86 ± 0.49 °C and minima of 8.94 ± 0.38 °C at an elevation of 1052 m a.s.l. Annual precipitations varied between 160.8 and 362.2 mm with a mean value of 310.2 ± 74.7 mm (Fig. 1). Nevertheless, in recent years, the reserve has undergone significant changes in climate and land use causing, among other adverse effects, the decline of Atlas Cedar *Cedrus atlantica*, an endemic tree species of North Africa (Cherak et al. 2021).

The Gaussen ombrothermic diagram for the study period (from September 2021 to August 2022), indicated the presence of a rainy season, spanning from February to April, and a dry season encompassing the remaining months. Precipitations and air temperature in the rainy season and dry season were 115.4 and 105.3 mm and 10.6 and.

18.2 °C, respectively. This rainy season is characterized by hydrological stability, with no occurrences of flooding before or during the insect sampling. While the dry season is marked by occasional moments of flooding.

The Bouilef stream was selected for its permanent flow compared to other streams of the protected area. It belongs to the hydrographic basin of the Constantine high plateaus (Watershed No. 07, area: 9,578 km²), and stretches over a length of 2.5 km with an average slope of 10% (ANRH, 2001). The forested stream is characterized by the presence of dense riparian vegetation on both river banks, composed mainly of trees of Atlas cedar *(Cedrus atlantica)*, Aleppo pine *(Pinus halepensis)*, Holm oak *(Quercus ilex)*, elm leaf blackberry *(Rubus ulmifolius)*, mastic *(Pistacia lentiscus)* and herbaceous vegetation. The presence of this riparian vegetation still implies higher shading and allochthonous
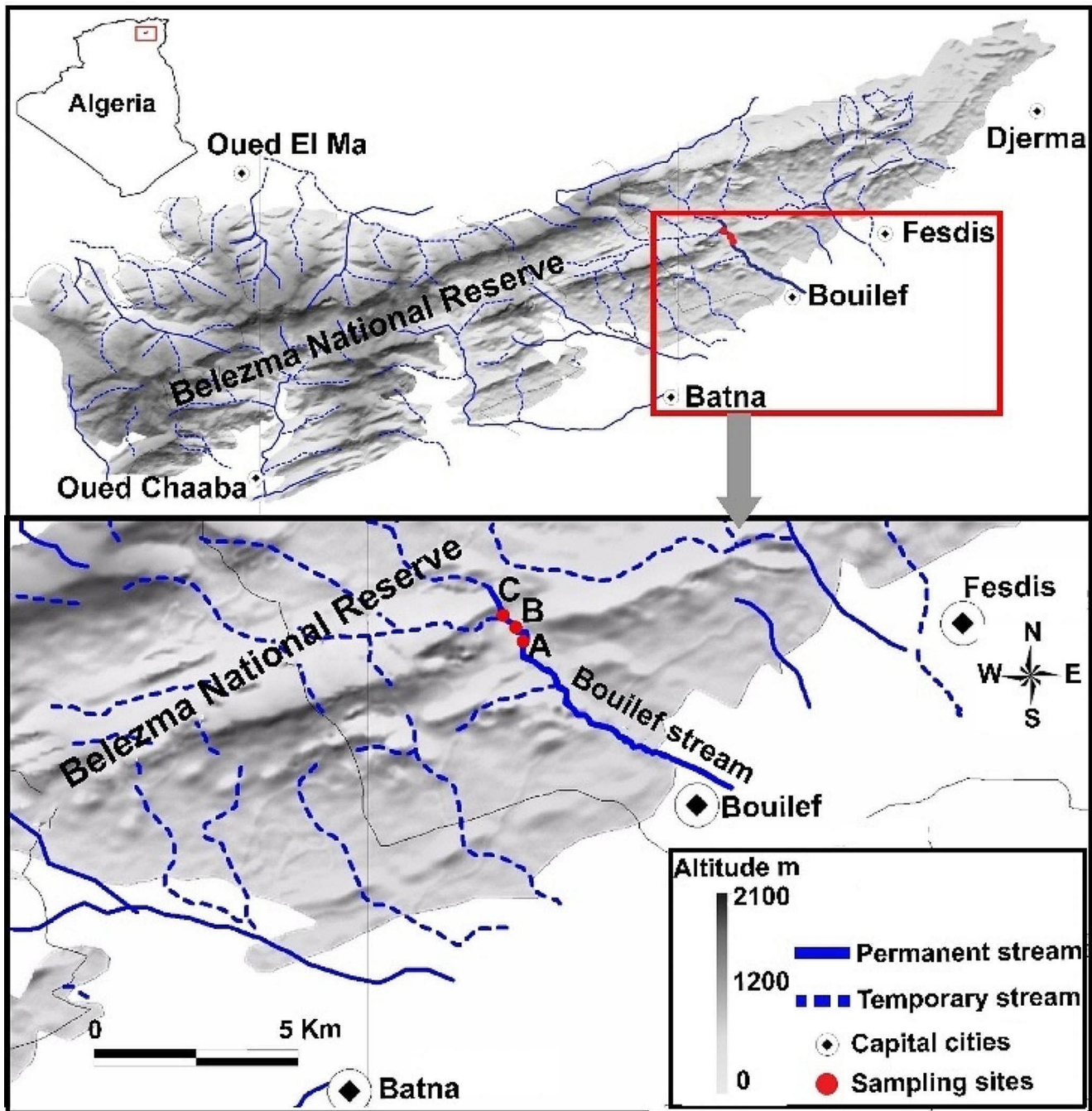
Fig. 1 Geographical location of Bouilef stream and distribution of the 3 sampling sites

material input into the stream (Boukerker and Si Bachir 2015).

Over the study period, three sites A, B, and C very close to each other (140 m between A and B and 180 m between B and C), and belonged to the same Bouilef stream (A: 35°37'03.0"N, 6°11'13.9"E, B: 35°37'01.0"N, 6°11'18.0"E, C: 35°36'55.8"N, 6°11'14.6"E) were sampled monthly. Each site (5 m² of surface area approximately) is located at elevations of 1065–1078 m (a.s.l) and was selected based

on the existence of different substrate types, including sand (< 2 mm), gravel (2–16 mm), pebbles (16–64 mm), boulders (64–256 mm), and emergent macrophytes (Tachet et al. 2010).

Physicochemical parameters of water

At the field (sites), seven parameters were measured: pH, temperature (T °C), total dissolved solids (TDS ppm), and

electrical conductivity (EC, μS cm^{-1}), were measured using a multi-parameter waterproof meter HI991300® (HANNA instruments). Turbidity (NTU: Nephrometric Turbidity Unit) was measured with a turbidimeter (HACH instruments), and water depth (cm) was measured using a graduated wooden board. Additionally, water flow velocity is measured by a flow scale: (1) very slow speed; (2) slow speed; (3) average speed, and (4) fast speed. In the laboratory, three parameters were analyzed: Salinity (mg L^{-1}), dissolved organic matter (DOM mg L^{-1}), and dissolved oxygen (DO mg L^{-1}) from 500 ml samples taken on each sampling occasion, using the standardized water quality monitoring protocols (AFNOR 2005).

Benthic insect sampling

At the field (sites), sampling of macroinvertebrates is carried out on the five types of substrates at each site using a Surber net with a 25 cm aperture and 500 μm mesh size. The percentage coverage of the different substrates was visually assessed (Touron-Poncet et al. 2014). We collected samples from the sand, gravel, and emergent macrophyte substrates by scraping them onto the Surber net surface. The same surface area was used to sample pebbles and boulders. All collected specimens were manually separated from the substrates and placed in a 4% formaldehyde solution for preservation. In the laboratory, the benthic insects were sorted, counted, and identified to the lowest possible taxonomic level (usually genus) using appropriate keys (Tachet et al. 2010; Thorp and Rogers 2016; Ochieng et al. 2019). Finally, the specimens were preserved in 70% ethanol.

Table 1 Physicochemical parameters of water in Bouilef stream according to climatic seasons

Parameters	Dry season (27 visits, 135 samples)	Rainy season (9 visits, 45 samples)	p-value
T (°C)	27.33 ± 0.63	26.33 ± 1.13	0.44
pH	8.03 ± 0.03	7.88 ± 0.11	0.20
Electrical conductivity (EC) (μS cm^{-1})	782.48 ± 6.37	766.44 ± 5.87	0.17
Turbidity (NTU)	14.82 ± 1.55	15.33 ± 2.16	0.67
TDS (mg L^{-1})	390.04 ± 3.58	382.33 ± 4.04	0.19
Salinity (%)	0.34 ± 0.01	0.35 ± 0.01	0.72
DOM (mg L^{-1})	0.59 ± 0.11	0.33 ± 0.16	0.06
Dissolved oxygen (mg L^{-1})	2.00 ± 0.16	1.93 ± 0.43	0.30
Depth (cm)	9.78 ± 0.82	10.33 ± 0.57	0.68
Flow velocity	1.97 ± 0.37	3.33 ± 0.08	**0.42**

Values are means ± SD. p-values are for t-tests

Data analysis

The benthic insects were assigned to five functional feeding groups (FFGs): gathering collectors (Gc), filtering collectors (Fc), herbivores shredders (Hs), scrapers (Sc), and predators (Pr). The FFGs assignment was at the family level according to Ramírez et al. (2014) and Cummins (2016).

The mean abundance was determined by dividing the total number of individuals by the number of surveys conducted, whether it be for seasons or substrate types. The mean taxa richness was calculated by dividing the total number of taxa by the number of surveys conducted, whether it be for seasons or substrate types.

The values of physicochemical water parameters and the abundance (Taxa and FFGs) were logx + 1 transformed. Student t-tests were performed to assess differences in the mean richness and abundance of benthic insects by season, and substrate type. T-tests were also used to assess differences in physicochemical parameters. To evaluate the seasonal variation of mean taxa richness and mean abundance of FFGs according to substrate types, a one-way non-parametric ANOVA followed by Kruskal Wallis posthoc tests were performed ($p < 0.05$). The distribution of substrates according to their abundance of FFGs was summarized using Principal Coordinates Analysis (PCoA) with Bray-Curtis distance (abundance transformed in log (x + 1)). Substrates lacking benthic insects were removed from the PCoA analysis. The analyses were performed with SPSS version 20 and PAST 4.03 software.

Results

Physicochemical parameters of water in the dry and rainy seasons

The physicochemical parameters of water showed only small variations during the rainy season and the dry seasons, and there was no significant difference between the two seasons, except flow velocity (Table 1).

Comparison between seasonal richness and abundances of benthic communities

Overall, we collected 8599 specimens belonging to six orders, 26 families, and 39 genera/species during the two studied seasons. Coleoptera was the most diversified order with 15 taxa (Table 2). Trichoptera was the most abundant taxa with 4159 individuals, followed by Ephemeroptera, Diptera, and Coleoptera with 3009, 935, and 391 individuals, respectively. Heteroptera and Odonata were only found with 95 and 10 individuals, respectively. The most abundant

Table 2 A systematic inventory of benthic insects identified in the Bouilef stream of the Belezma biosphere reserve (Algeria) and their Functional Feeding Group (FFGs). und.: undetermined taxa

Order / Family	FFGs	Genera / Species
Odonata		
Lestidae	Predators	*Lestides* sp.
		Orthetrum sp.
Ephemeroptera		
Baetidae	Gathering collectors	*Acentrella* sp.
		Baetis sp.
Caenidae	Gathering collectors	*Caenis* sp.
Leptophlebiidae	Gathering collectors	*Leptophlebia* sp.
		Choroterpes sp.
Heteroptera		
Corixidae	Scrapers	*Corixa* sp.
		Micronecta sp.
Hydrometridae	Herbivores shredders	*Hydrometra* sp.
Veliidae	Predators	*Microvelia* sp.
Mesoveliidae	Predators	*Mesovelia* sp.
Coleoptera		
Dytiscidae	Predators	*Yola* sp.
		Platambus sp.
		Ilybius sp.
		Copelatus sp.
		Nebrioporus sp.
		Dytiscidae und.
Elmidae	Scrapers	*Elmis* sp.
	Gathering collectors	*Limnius* sp.
Haliplidae	Herbivores shredders	*Haliplus* sp.
Hydrophilidae	Predators	*Hydrophilus* sp.
		Crenitis sp.
		Hemisphaera sp.
		Berosus sp.
Scirtidae	Scrabers	*Hydrocyphon* sp.
		Cyphon sp.
Staphylinidae	Predators	*Stenus* sp.
Trichoptera		
Brachycentridae	Filtering collectors	*Brachycentrus* sp.
Hydropsychidae	Filtering collectors	*Hydropsyche* sp.
		Cheumatopsyche sp.
Hydroptilidae	Herbivores shredders	*Hydroptila* sp.
Sericostomatidae	Herbivores shredders	*Sericostoma* sp.
Diptera		
Dixidae	Gathering collectors	*Dixa* sp.
Ceratopogonidae	Predators	Ceratopogonidae und.
Chaoboridae	Predators	*Chaoborus* sp.
Chironomidae	Gathering collectors	*Chironomus* sp.
Psychodidae	Gathering collectors	Psychodidae und.
Ptychopteridae	Gathering collectors	*Ptechoptera* sp.
Simuliidae	Filtering collectors	Simuliini (tribe)
		Prosimuliini (tribe)
Tipulidae	Herbivores shredders	*Tipula* sp.

families were: Sericostomatidae (2148 individuals), Hydropsychidae (2004), Baetidae (1921), and Caenidae (1053). In terms of individual numbers, the dominant FFGs were: gathering collectors with (3371 individuals), followed by filtering collectors (2943); herbivore shredders (1753); predators (102), and scrapers (150).

The student's t-test showed a significant difference in the mean abundance of benthic insects between seasons. Benthic insect abundance was higher in the rainy season ($p = 0.001$) than in the dry season. However, the mean richness did not differ significantly between seasons ($p = 0.22$) (Fig. 2).

Comparison between seasonal richness and abundances of benthic communities according to substrate types

Our analyses showed significant differences in the mean abundance of benthic insects by substrate between the dry and rainy seasons. In the rainy season, pebbles ($p = 0.001$) and boulders ($p = 0.03$) hosted significantly more benthic insects than during the dry season (Fig. 3). There were no significant differences in the mean abundance of insects between seasons for the other substrates. There were no significant differences in substrate mean taxa richness of benthic insects between seasons: sand ($p = 0.81$), gravel ($p = 0.85$), pebbles ($p = 0.41$), boulders ($p = 0.57$), and emergent macrophytes ($p = 0.06$) (Fig. 3).

## Comparison between seasonal richness and abundances of FFGs according to substrate types

During both the rainy and dry seasons, the non-parametric ANOVA revealed significant differences in the mean abundance of gathering collectors, filtering collectors, and herbivore shredders across different substrates. However, there were no differences in mean abundance for scrapers ($p = 0.08$; $p = 0.09$) and predators ($p = 0.22$; $p = 0.29$), neither in the rainy nor in the dry season.

When conducting pairwise comparisons using Kruskal-Wallis tests (Table 3)., there were no significant variations in the mean rank abundance for gathering collectors and filtering collectors between pebbles and boulders in both seasons (Group A). Similarly, no significant differences were observed between emergent macrophytes, gravel, and sand (Group B).

Nonetheless, it's important to note that gathering collectors and filtering collectors displayed greater abundance on pebbles and boulders compared to the other substrates. Additionally, in the case of emergent macrophytes (Group A), there was a higher abundance of herbivore shredders compared to other substrates, including pebbles and boulders (Group B), gravel, and sand (Group C) (Table 3).

No significant variations were observed in the mean rank of FFGs taxa richness between substrates during both seasons (Table 3). Pairwise analysis was not conducted for the
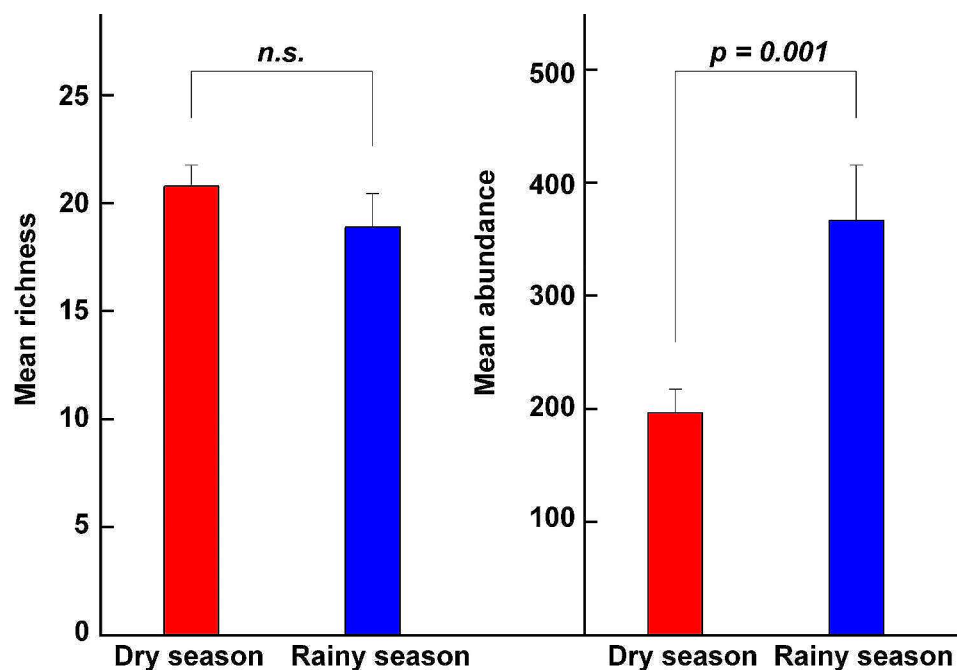
group of predators and scrapers since no significant differences were identified between substrates.

The results of the PCoA showed a distinct separation between FFG abundances according to substrate types. Substrates ranging from pebbles to boulders, which are of intermediate to large sizes, were situated on the left side of axis 1 and were characterized by a high and homogeneous abundance of benthic insects, particularly for gathering and filtering collectors. On the other hand, substrates ranging from sand to gravel, which are of smaller sizes, were grouped together on the right side of axis 1 and exhibited a low abundance of predators and scrabers. Emergent macrophytes were distributed throughout the ordination and presented intermediate abundance for herbivore shredders (Fig. 4).

Discussion

In the present study, except for the flow velocity, no measured physicochemical parameters were significantly different from each other between seasons. This low contrast may have been caused by the permanent flow of the Bouilef stream and the riparian vegetation which provides good shade for the water, meaning that we could reasonably focus on the importance of substrates to benthic communities while minimizing the potential effect of combining physicochemical factors. The mean taxa richness was not influenced by seasons or substrate types. This means either that most insects have non-seasonal life histories extending over one year or more, or that temporal turnover (multivoltine

character) occurs within the identified taxonomic units (genus). On the other hand, the mean abundance of benthic insects was higher in the rainy season, especially on pebbles and boulders. Moreover, the average flow velocity in the rainy season ensures the availability of food resources (more water, hence more fresh organic matter, algae, and detritus available) likely supports higher population densities (Theodoropoulos et al. 2018; Buffagni 2020). Also, these larger substrates (pebbles and boulders) exhibit greater stability when faced with hydrological variations (Van der Meer et al. 2021), so their distribution over river beds is less sensitive to seasonal fluctuations in water flow. Similar observations were reported by Vagenas et al. (2022) in a study carried out in the largest Moroccan river (Oum Errabia) under the same type of climate. These authors found that pebbles and boulders are the most suitable for benthic macroinvertebrates. Theodoropoulos et al. (2018) also found similar results in temperate Mediterranean areas of Greece. In tropical regions, Pereira et al. (2017) found that pebbles are the most attractive substrates for benthic macroinvertebrates compared to sand and gravel (Jones et al. 2012; Schriever et al. 2015; Theodoropoulos et al. 2018; Thomas and Thomas 2022). The low level of mean abundance observed in both seasons on sand and gravel in our study can be explained by the fact that these substrates are more vulnerable to hydrodynamic degradation and are poor in food resources (Fidelis et al. 2008; Baptista et al. 2001).

Furthermore, the water flow during the rainy season removes accumulated fine sediments from the larger substrate such as boulders and pebbles. This creates suitable habitats and opportunities for the settlement of benthic

Fig. 3 Seasonal variation of mean taxa richness and mean abundance of benthic insects according to substrate types (t-tests, *n.s.* non-significant difference)
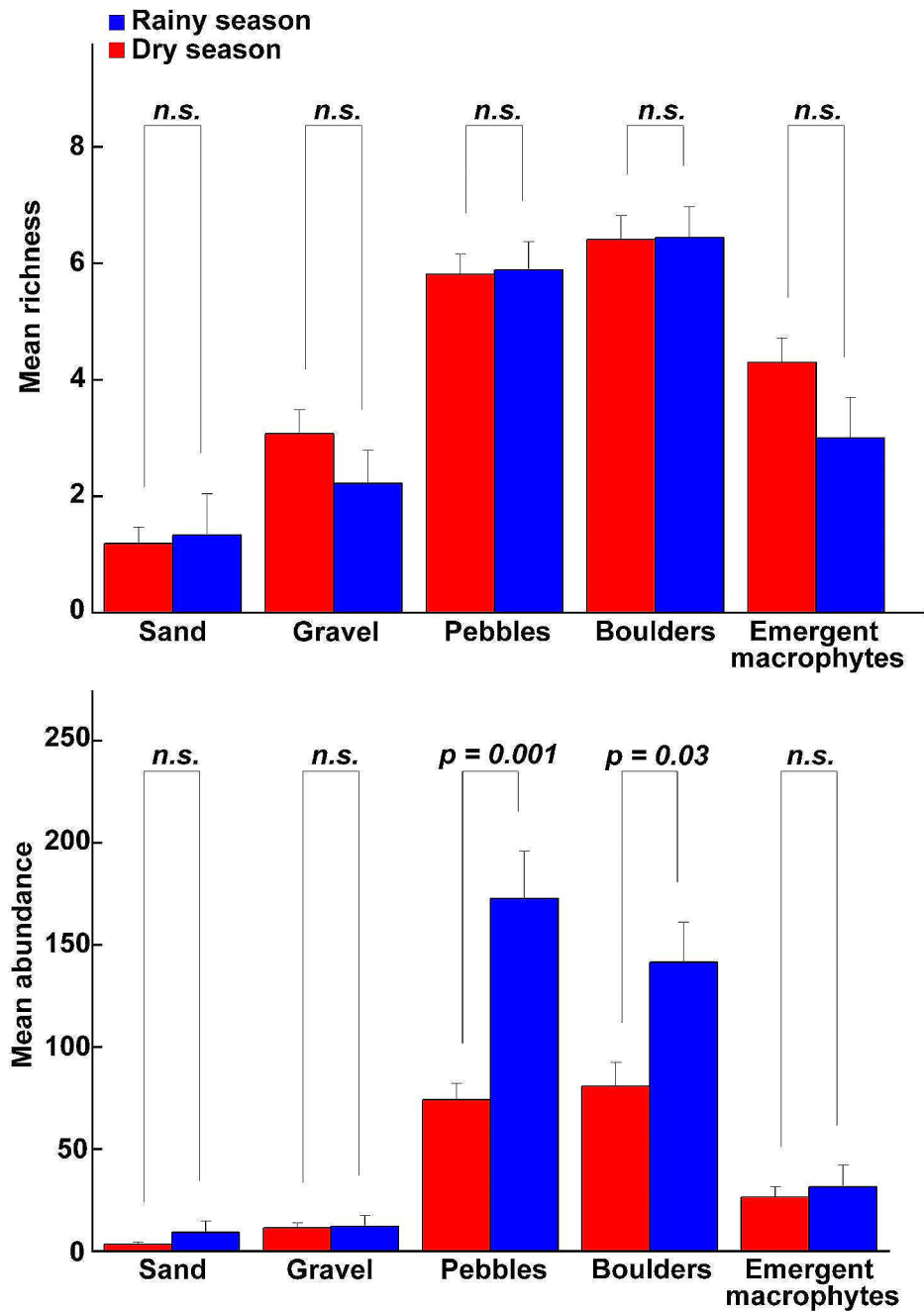
Table 3 Results of the Kruskall Wallis test comparing the mean ranks of the abundance of FFGs according to the substrate types and seasons (A, B, and C indicate the groups of identical mean ranks)

FFGs	Season	Pebbles	Boulders	Emergent macrophytes	Gravel	Sand
Gathering collectors	Rainy	94.83 (A)	95.26 (A)	59.43 (B)	57.50 (B)	32.98 (B)
	Dry	38.22 (A)	33.56 (A)	17,89 (B)	14.89 (B)	10.44 (B)
Filtering collectors	Rainy	101.04 (A)	99.30 (A)	55.25 (B)	49.81 (B)	34.33 (B)
	Dry	39.44 (A)	33.56 (A)	15.39 (B)	14.50 (B)	12.11 (B)
Herbivores shredders	Rainy	94.04 (B)	64.46 (B)	102.82 (A)	44.39 (C)	34.30 (C)
	Dry	26.28 (B)	29.78 (B)	37.78 (A)	13.67 (C)	7.50 (C)

Fig. 4 PCoA of the distribution of FFGs abundance according to substrate types/sizes
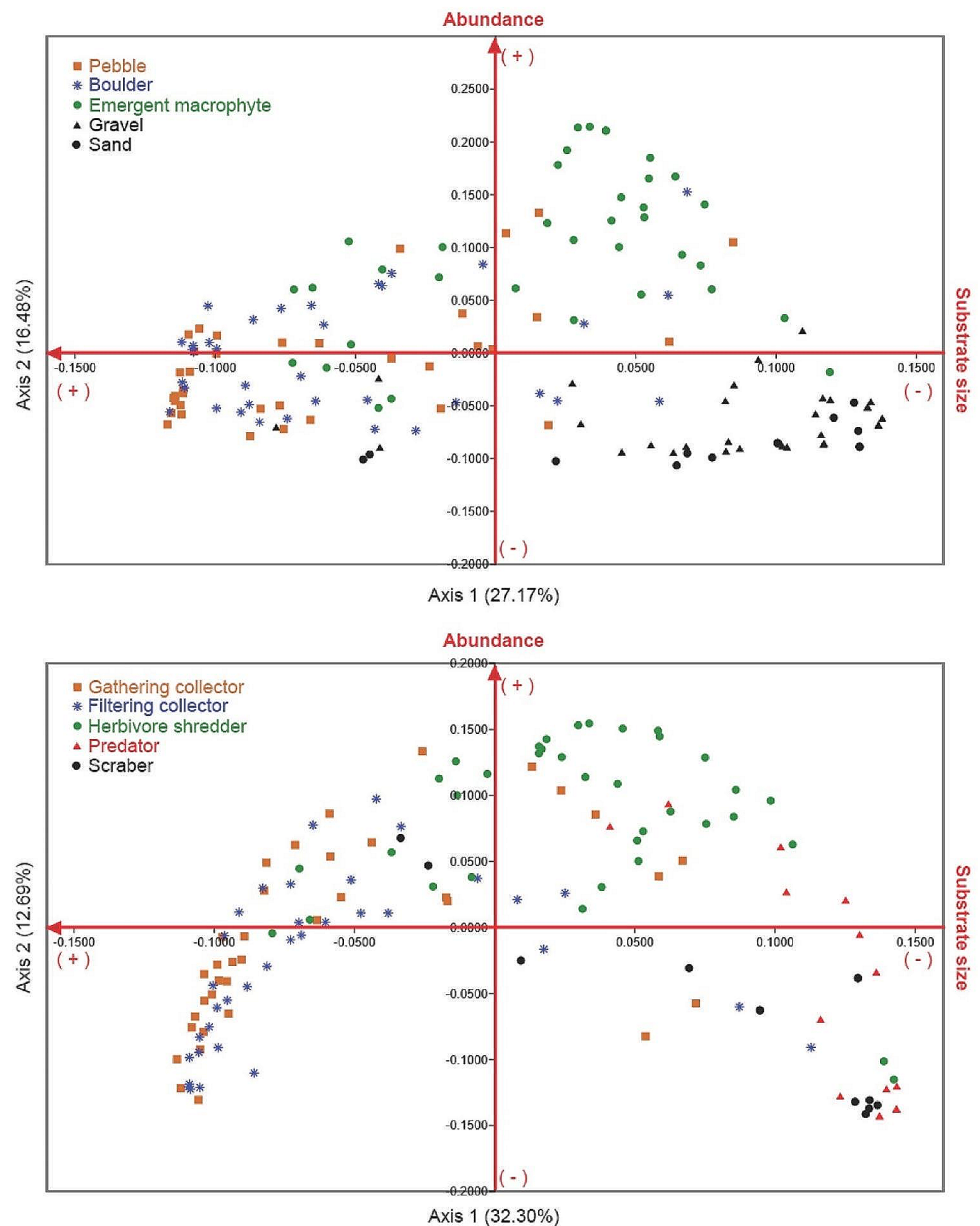
insects, especially for gathering collectors and filtering collectors. These FFG groups aggregate smaller particulate organic matter (allochthonous material input from the riparian zone) deposited on the substrate and filter organic particles directly from the water column respectively. Although autochthonous food sources may be a more important part of the diets of benthic macroinvertebrates especially for gathering collectors, filtering collectors, and shredders in forested streams (Torres-Ruiz et al. 2007; Vannote et al. 1980).

The increased water flow during this period creates also microhabitats such as riffles and pools, expanding the range of niches available for benthic insects to inhabit and exploit (Fenoglio et al. 2020; McCaffrey 2021).

During the dry season, the occurrence of floods erodes the sediments from the streambed, resulting in an increased concentration of fine particles such as sand (< 2 mm) and gravel (2–16 mm) that are easily displaced by the water flow (Holomuzki and Biggs 1999). This sand substrate, when suspended in the water column can, on one hand, affect the filtering collectors by adhering and damaging the filtration structures and decreasing the food amount to be ingested (Vasconcelos and Melo 2008), and, on the other hand, obstruct crevices and interstitial spaces of substrates for attachment and shelter that gathering organisms rely on.

In Bouilef forest stream, the abundance of herbivores-shredders on emergent macrophytes could be attributed to a higher presence of these kinds of substrates which provided

a direct food source, allowing them to consume plant tissue and utilize the resources (Waters and San Giovanni 2002; Altieri et al. 2021; Novack et al. 2021). Generally, the low numbers of shredders were partly due to less/loss of riparian vegetation resulting from human activities. Loss of riparian vegetation can cause loss of diversity and changes to structural and functional organization of macroinvertebrates in streams (Allan 2004; Jinggut et al. 2012; Ono et al. 2020).

The low abundance of scrabers and predators recorded in both seasons on sand and gravel may be attributed to the low amount of sunlight that enters the shaded stream throughout can't provide the proliferation of algae (periphyton), which serves as the primary food source for scrabers (Grubaugh et al. 1996), and probably to the low prey and ambush shelter availability for predators (Cummins 2018). Also, this low abundance for predators may be related to their univoltine or longer generation times according to Huryn et al. 2008.

Consistently, our study validates habitat preferences for benthic insect communities, which are strongly influenced by substrate types and seasons. Distinction of pebbles and boulders from the other substrates, and the strong association between sand and gravel show that substrates are not related to specific sites. This is an important factor in the composition and variation of benthic insects (Hepp et al. 2012).

Our study provides additional proof that substrate type and season play a crucial role in determining the composition and variation of benthic insect communities (Duan et al. 2009), whether the stream is located in an arid, tropical, or temperate region (Barnes et al. 2013). Although our study showed the affinity of benthic insects for substrate types in arid area, these results remain limited to a single stream and a single year of study. In addition, it does not take into account rare species. There is, therefore, a need for further research and efforts to be conducted on a larger spatial and temporal scale. This information is crucial for effective preservation and conservation measures in arid region streams.

Author contributions MK, BR, BI, MS, and Si BA designed the research; MK, BI, and MS conducted the experiments and prepared the original draft of the manuscript; Si BA: Conceptualized and supervised the work. Si BA and CR revised the final content.

Data availability Data used in the study are available upon request.

Declaration

Competing interests Authors do not have any competing interests.

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