Environmental determinants of mayfly assemblages in the Seybouse River, north-eastern Algeria (Insecta: Ephemeroptera)

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ORIGINAL ARTICLE

Environmental determinants of mayfly assemblages in the Seybouse River, north-eastern Algeria (Insecta: Ephemeroptera)

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Abstract

In contrast to neighbouring Maghrebian countries and despite recent progress, knowledge of the Ephemeroptera of Algeria remains fragmentary. As part of an ongoing survey of the Ephemeroptera of Algeria, we investigated the mayfly fauna of Wadi Cherf, a major tributary of the Seybouse River, northeastern Algeria, and present an updated checklist and distribution of Ephemeroptera of this major Maghrebian river. Eighteen species were identified with new records for northeastern Algeria, filling distributional gaps. In addition, two species, *Habrophlebia* sp. and *Procloeon* sp., are new to science. A multivariate analysis indicated that mayfly assemblages of the Seybouse River were driven by the physical characteristics of habitats. Species richness was positively correlated with permanent flow and coarse substrate and negatively associated with altitude and salinity. Results also showed that *Caenis luctuosa* and Baetidae, in particular *Baetis* gr. *pavidus* and *Cloeon* gr. *dipterum*, dominated the mayfly community.

Keywords Biodiversity · Ephemeroptera · Distribution · North Africa · Riverine ecosystem

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Introduction

The identification of patterns of species diversity and the basic processes driving such patterns are keys to the management and conservation of ecosystems (Chapin et al. 2000; Emmerson et al. 2001). In the context of global and local alterations, increased demography, demands and depletions, there is a real need to assess the consequences of ecosystemic changes on the sustainable use of vital ecosystem services like freshwater habitats (Pereira et al. 2012, 2013). Dam constructions, water abstraction, forest gallery destruction, channelization and pollution have for decades modified the North African and Middle East riverine landscape leading to a steep erosion of freshwater biodiversity (Hafiane et al. 2016; Al-Obaid et al. 2017; Morghad et al. 2019). These changes have impacted fluvial functioning which is characterized by high variation in hydrological regimes (Cooper et al. 2013; Elosegi and Sabater 2013). In the semi-arid North African region, climate change is expected to exacerbate such trends with adverse consequences (Jobbins and Henley 2015; Lezzaik and Milewski 2017).

Aquatic insects are key components that play an essential role on the functioning of rivers and streams (Wallace and Webster 1996; Palmer et al. 1997). The order

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Ephemeroptera includes over 3,700 species (Jacobus et al. 2019) that have aquatic egg and nymphal stages (Sartori and Brittain 2015). Mayflies exhibit specific adaptations to both lotic and lentic freshwater habitats (Bauernfeind and Soldán 2012). They are abundant and widespread across all types of freshwater habitats, and they fall prey to predatory insects, fish, and a range of other vertebrates including humans (Macadam and Stockan 2015; Jacobus et al. 2019). Mayflies' responses to changing environmental conditions make them useful bioindicators to assessing freshwater habitats (Bauernfeind and Moog 2000), especially, during the ongoing influence of global changes on biological processes (Rosenzweiget al. 2008).

Ephemeroptera research in Algeria began with pioneering investigations carried out in the nineteenth and early twentieth century (Eaton 1899; Lestage 1925). In the final decades of the past century, our understanding of the taxonomy and distribution of Algerian and Maghrebian mayflies improved further with a series of studies mainly focused on taxonomy (Thomas and Dakki 1979; Soldán and Thomas 1983a, b; Soldán and Gagneur 1985; Thomas and Vitte 1988; Gagneur and Thomas 1988; El Alami and Dakki 1998; Thomas 1998).

However, in spite of all these important efforts and recent advances addressing the taxonomy (Benhadji et al. 2018; Kechemir et al. 2020) and ecology (Mebarki et al. 2017; Benhadji et al. 2019; Bouhala et al. 2020a, b) of this order, our knowledge of mayfly biodiversity in Algeria remains incomplete.

The gradual depletion of freshwater biodiversity entails conducting extensive taxonomical and ecological surveys of the riverine fauna. This study, focused on Ephemeroptera, is part of a larger project of the Laboratoire de Conservation des Zones Humides, University of Guelma, aimed at (1) improving the knowledge of the taxonomy of Algerian freshwater macroinvertebrates, (2) mapping up their distribution and identify the driving environmental factors.

Materials and methods

The Seybouse River, the largest catchment in northeastern Algeria, flows northward from the Hauts Plateaux to the Mediterrean Sea at Annaba (Fig. 1). The upper reaches (250–900 m) of the Seybouse River, upstream of the confluence at Medjez Amar of the two main tributaries, Wadi Cherf and Wadi Bouhamdane, is dominated by scattered settlements, farming and pastoral activities (Fig. 2). The lower reach (0-100 m) of the river is occupied by intensive agriculture, industries and urban settlements and thus is the receptacle of domestic, agricultural and industrial wastes. The Seybouse watershed has a typical Mediterranean climate with a hot and dry period stretching from June to September and a rainy season from October to May (Yalles Satha and Samraoui 2017).

Ephemeroptera nymphs were collected from a set of 22 localities (S1-S22), all located along Wadi Cherf, that were sampled monthly from July 2014 to June 2017 (Bouhala et al. 2019, 2020a, b). GPS coordinates were measured using a Garmin GPS (Table 1). Mayfly nymphs were sampled using a dipnet (500 µm mesh size, 35 cm diameter) and were fixed in 5% formaldehyde. Adults were also occasionally collected and some nymphs were reared in captivity until emergence. A series of parameters (water temperatures, conductivity, water velocity, water depth, bed width, hydroperiod, vegetation cover, and substrate), measured in situ using multi-probes at mid-water depth (Bouhala et al. 2020a, b). In each locality, an area of 100 m^2 was kick-sampled by walking slowly and repeatedly across all micro-habitats for ten minutes thus providing a semi-quantitative sampling of mayflies in each locality. Both substrate and hydroperiod were classified in a dichotomic manner: coarse (cobbles and boulders)/fine (silt/clay and sand) and permanent/intermittent, respectively. Additional sampling including new localities (S23-S30) was performed in a similar way along the Seybouse River between 2016 and 2020, but specimens were preserved in ethanol. For logistics reasons, samples of the Baetidae for 2016 and 2017 (January-June) were not identified.

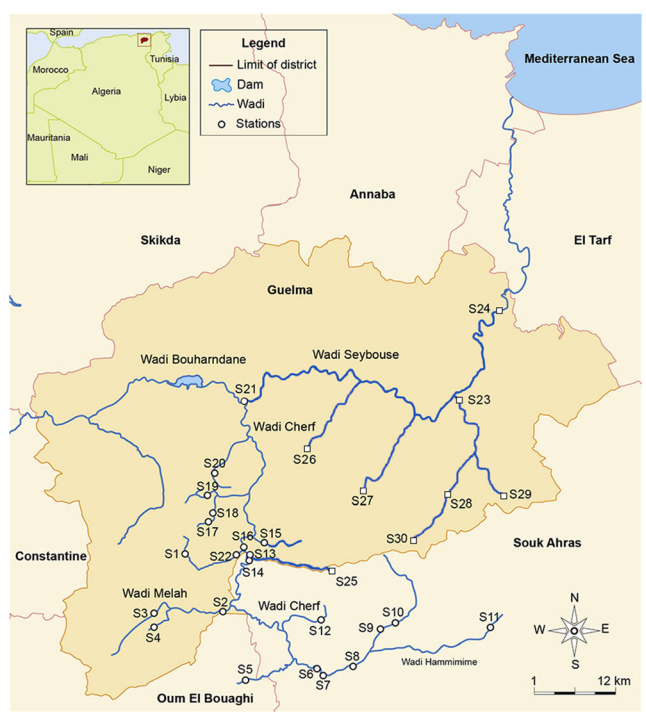

Fig. 1 Distribution map of sampling localities at the Seybouse River (open circles). Additional stations are indicated by an open square

Fig. 2 View of sampled habitats at the Seybouse River: Dbebcha with dominant vegetation made up of *Tamarix gallica* and scattered stands of *Juncus* sp. (**a**), and O. Aar dominated by *Nerium oleander*, *Juncus* sp. and *Tamarix gallica* (**b**)

Statistical analysis

We performed a Principal Component Analysis (PCA), using a matrix (site /frequency of taxa) to associate the spatial variation of mayflies with their frequency. We used the hydroperiod and the substrate as supplemental discrete variables and the altitude and species richness as supplemental continuous variables. Only regularly (monthly) sampled sites (S1-S22) were taken into account in the PCA analysis. All statistical analyses were carried out with the software R (R Development Core Team 2019).

Results

Eighteen mayfly taxa representing eight families were recorded (Table 2). *Caenis luctuosa*, *Baetis* gr. *pavidus*, and *Cloeon* gr. *dipterum* were the most widespread species with the former occupying 15/22 sites (Fig. 3a). Species richness ranged from zero (S3) to nine species (S21) (Fig. 3b). Two rare species (*Potamanthus luteus* and *Ephemera glaucops*) were additionally recorded at this site (S21) outside the sampling period.

Family Leptophlebidae

Choroterpes atlas Soldán & Thomas, 1983

Localities: Dbabcha (S13): 8.viii.2015, 25.v.2020; O. Aar (S14): 22.vi.2016; Medjez Amar (S21): 21.x.2014, 8.viii.2015, 4.vi.2016, 16.viii.2016; Hammam N'Bails (S28): 29.vii.2019.

Comments: Within the Seybouse watershed, this Maghrebian endemic seems confined to a few mid-altitude localities.

Habrophlebia sp.

Localities: O. Nil (S12): 29.iii.2016; O. Aar (S14): 24.v.2019; Boufrais (S19): 23.iv.2016, 9.v.2016; Selaoua (S20): 24.v.2018, 27.v.2020.

Comments: This genus may present a high degree of endemism within the Maghreb. Previously, only one species was known in Algeria and it was erroneously assigned to *H. fusca* (Curtis, 1834) (Gagneur and Thomas 1988). This taxon, from the Tafna River, western Algeria, turned out to be an Algerian endemic and described as *Habrophlebia hassainae* Benhadji & Sartori, 2018 (Benhadji et al. 2018). More recently, the *Habrophlebia* Eaton, 1881 populations of the central-north area of Algeria (Kabylia) were assigned to the endemic species *H. djurdjurensis* Kechemir, Sartori & Lounaci, 2020 (Kechemir et al. 2020). The Seybouse taxon is a new species which awaits formal description.

Family Potamanthidae

Potamanthus luteus (Linnaeus, 1767)

Localities: Medjez Amar (S21): 16.v.2019.

Comments: The family Potamanthidae in the Maghreb is monogeneric and monospecific; it is represented by only *P. luteus.* As was noted already in Tunisia (Boumaïza and Thomas 1986; Zrelli et al. 2015), the species seems relatively rare in the Seybouse River. However, this burrowing mayfly may evade sampling and thus be underrecorded.

Family Polymitarcyidae

Ephoron virgo (Olivier, 1791)

Localities: Dbabcha (S13): 21.v.2020, 21.vi.2020, 4.vii.2020, 14.vii.2020; Chihani (S24): 30.vi.2016, 3.viii.2016, 10.viii.2016, 23.viii.2016.

Comments: The family Polymitarcyidae in the Maghreb is monogeneric and monospecific as in all West Palaearctic regions. In Morroco, *E. virgo* is found in low-altitude rivers with relatively warm waters (El Agabani et al. 1992).

Family Ephemeridae

Ephemera glaucops Pictet, 1845

Localities: Medjez Amar (S21): 25.iii.2016; Chihani (S24): 26.v.2016.

Comments: A burrowing mayfly that may easily be overlooked.

Family Caenidae

Caenis luctuosa (Burmeister, 1839)

Table 1 Sampling sites for mayfly nymphs and adults at the Seybouse River, northeastern Algeria

Code	Name	Latitude (N)	Longitude (E)	Altitude (m a.s.l.)	Hydroperiod	Substrate
Regularly sampled:						
S1	Beldjoudi	36°13’23”	7°12’52”	822	Intermittent	Fine
S2	Ben Mheni	36°9’2”	7°16’50”	667	Intermittent	Coarse
S3	O. El Maleh	36°8’53”	7°8’38”	748	Intermittent	Fine
S4	Aïn Arko	36°7’35”	7°9’17”	750	Intermittent	Fine
S5	O. Dahmane	36°3’11”	7°19’40”	752	Permanent	Fine
S6	Sedrata Dam	36°3’34”	7°27’19”	746	Permanent	Fine
S7	Sedrata Bridge II	36°3’8”	7°27’58”	760	Intermittent	Fine
S8	Sedrata Bridge I	36°4’28”	7°29’39”	765	Permanent	Fine
S9	O. Krab	36°7’12”	7°32’46”	784	Permanent	Fine
S10	Krab Bridge	36°7’55”	7°34’16”	800	Intermittent	Fine
S11	Tiffech Bridge	36°8’28”	7°45’16”	860	Intermittent	Fine
S12	O. Nil	36°8’23”	7°26’45”	864	Intermittent	Coarse
S13	Dbabcha	36°12’50”	7°18’58”	610	Permanent	Coarse
S14	O. Aar	36°13’34”	7°19’11”	617	Intermittent	Coarse
S15	O. Cheniour	36°14’52”	7°20’36”	602	Permanent	Coarse
S16	Aïn Makhlouf Bridge	36°14’23”	7°18’41”	590	Permanent	Coarse
S17	Aazlat Hlima	36°16’11”	7°17’1”	770	Intermittent	Coarse
S18	Chaabet Bounab	36°17’5”	7°17’4”	805	Intermittent	Fine
S19	O. Boufrais	36°18’57”	7°16’20”	612	Intermittent	Coarse
S20	Selaoua	36°20’54”	7°16’2”	589	Intermittent	Coarse
S21	Medjez Amar	36°26 35”	7°18’39”	249	Permanent	Coarse
S22	Aïn Makhlouf Dam	36° 13’ 34”	7°17’48”	643	Permanent	Fine
Additional sampling:						
S23	O. Mellah	36°27 59”	7°42’8”	89	Permanent	Coarse
S24	Chihani	36°37’14”	7°47’25”	34	Permanent	Coarse
S25	Sebaa Ayoun	36°12’50”	7°27’48”	892	Permanent	Coarse
S26	Aïn Chikh	36°23’07”	7°25’10”	668	Intermittent	Coarse
S27	Hammam Laassasla	36°19’49”	7°32’13”	465	Permanent	Coarse
S28	Hammam N’Bails	36°20’31”	7 40’35”	356	Intermittent	Coarse
S29	Magroun HNB	36°20’16”	7 47’12”	473	Permanent	Coarse
S30	Guelta Zerga	36°15’49”	7°36’52”	937	Permanent	Coarse

“O.” stands for oued, meaning stream or river

Localities: Beldjoudi (S1): 11.v.2014; Ben Mhenni (S2): 7.vi.2015, 19.ii.2016; Aïn Arko (S4): 30.vii.2014, 23.viii.2014, 22.vii.2015; Sedrata Dam (S6): 23.iv.2016, 16.viii.2016; Sedrata Bridge I (S8): 23.iv.2016; O. Krab (S9): 30.vii.2014, 23.viii.2014, 29.xi.2014, 1.x.2015, 25.ix.2017; Krab Bridge (S10): 29.iii.2016, 4.vi.2016, 11.v.2017; Tiffech Bridge (S11): 16.ix.2015, 4.vi.2016; O. Nil (S12): 17.ii.2017; Dbabcha (S13): 27.i.2014, 27.x.2014, 8.viii.2015, 1.i.2016, 4.iv.2016; 28.ix.2016, 7.x.2016, 23.iv.2016, 4.vi.2016, 28.ix.2016, 27.i.2017, 25.iv.2017, 21.v.2017, 27.vi.2017, 18.x.2019, 25.v.2020, 21.vi.2020; O. Aar (S14): 21.iv.2015, 22.vii.2015, 16.ix.2015, 25.iii.2016, 17.ii.2017, 24.v.2019; 2.vii.2019, 18.ix.2019; O. Cheniour (S15): 21.iv.2015, 11.v.2015, 17.vi. 2019; Aïn Makhlouf Bridge (S16): 31.vii.2014, 16.ix.2015, 9.v.2016, 1.xi.2016, 11.iii.2017; Selaoua (S20): 27.v.2020; Medjez Amar (S21): 25.ix.2014, 22.vii.2015, 13.vii.2015, 29.iii.2016, 16.viii.2016, 28.ix.2016; Aïn Makhlouf Dam (S22): 21.v.2017; O. Mellah (S23): 19.x.2018, 5l, 22.iv.2019; Chihani (S24): 19.x.2018; Sebaa Ayoun (S25): 24.v.2018; Hammam N’Bails (S28): 29.vii.2019; Magroun HNB (S29): 29.vii.2019.

Comments: This species is the most widespread mayfly along the whole Seybouse River.

Table 2 Check-list of the Ephemeroptera recorded at the Seybouse River, northeastern Algeria

Family	Species	Maghrebian countries
Leptophlebiidae		
	Choroterpes atlas Soldán & Thomas, 1983	A, M, T
	Habrophlebia sp.	N/A
Potamanthidae		
	Potamanthus luteus (Linnaeus, 1767)	A, M, T
Polymitarcyidae		
	Ephoron virgo (Olivier, 1791)	A, M, T
Ephemeridae		
	Ephemera glaucops Pictet, 1845	A, M, T
Caenidae		
	Caenis luctuosa (Burmeister, 1839)	A, M, T
	Caenis pusilla Navás, 1913	A, M, T
Baetidae		
	Alainites sadati Thomas, 1994	A, T
	Baetis maurus Kimmins, 1938	A, M
	Baetis gr. *pavidus* Grandi, 1949	A, M, T
	Baetis gr. *alpinus*	A, M, T
	Baetis (*Rhodobaetis*) gr. *rhodani*	A, M, T
	Cloeon gr. *dipterum* (Linnaeus, 1761)	A, M, T
	Labiobaetis neglectus (Navás, 1913)	A, M, T
	Procloeon stagnicola Soldán & Thomas, 1983	A, T
	Procloeon spA	N/A
Oligoneuriidae		
	Oligoneuriopsis skhounate Dakki & Guidicelli, 1980	A, M,T
Heptageniidae		
	Ecdyonurus rothschildi Navás, 1929	A, M, T

A, M, and T stand for Algeria, Morocco, and Tunisia, respectively

Caenis pusilla Navás, 1913

Localities: Dbabcha (S13): 21.iv.2015, 11.v.2015, 7.vi.2015, 29.iii.2016, 16.vii.2016, 16.viii.2016, 12.xii.2016, 21.i.2017; 11.iii.2017, 25.iv.2017; O. Aar (S14): 19.ii.2016, 19.v.2016, 1.xi.2016; O. Cheniour (S15): 23.iv.2016; Aïn Makhlouf Bridge (S16): 29.iii.2016, 23.iv.2016, 7.x.2016, 11.iii.2017, 21.v.2017; Medjez Amar (S21): 19.ii.2016, 23.iv.2016, 4.vi.2016, 15.vii.2017.

Comments: In contrast to its common congeneric, *C. luctuosa*, this is a relatively rare species.

Family Baetidae

Alainites sadati Thomas, 1994

Localities: O. Cheniour (S15): 25.ix.2014, 27.x.2014; Magroun HNB (S29): 29.vii.2019.

Comments: This species (Fig. 4a) is not widely distributed, confined up to now to narrow streams with low conductivity and high transparency in NW Algeria (Thomas and Gagneur 1994) and Tunisia (Zrelli et al. 2012). The new record fills an important gap in the distribution of this Maghrebian endemic suggesting that it may be more widespread than previously thought.

Baetis maurus Kimmins, 1938

Localities: Guelta Zerga (S30): 29.vii.2019.

Comments: A rare species in the Seybouse watershed, only collected at the base of a series of waterfalls. The species seems more abundant in western Algeria (Benhadji et al. 2019).

Baetis gr. *pavidus* Grandi, 1949

Localities: Aïn Arko (S4): 23.viii.2014, 16.v.2015, 23.viii.2015, 27.x.2015, 14.xi.2015; O. Dahmane (S5): 11.v.2015, 27.x.2015, 14.xi.2015; Sedrata Dam (S6): 15.v.2015; Sedrata Bridge I (S7): 11.v.2015; Krab Bridge (S10): 28.ii.2015, 7.vi.2015; Dbabcha (S13): 26.ix.2014, 27.x.2014, 25.xii.2014, 21.iv.2015, 11.v.2015, 8.viii.2015, 13.xii.2015; 30.vi.2018, 18.x.2019, 30.i.2020; O. Aar (S14): 11.v.2015, 27.vii.2015, 16.ix.2015; 27.x.2015, 14.xi.2015, 13.xii.2015, 24.v.2019, 2.vii.2019, 18.ix.2019, 1l; O. Cheniour (S15): 27.x.2014, 27.ii.2015, 12.iii.2015, 1.iv.2015, 11.v.2015, 7.vi.2015, 8.viii.2015, 16.ix.2015, 27.x.2015, 14.xi.2015, 13.xii.2015, 17.vi. 2019, 2l, 18.x.2019; Aïn Makhlouf Bridge (S16): 31.vii.2014,

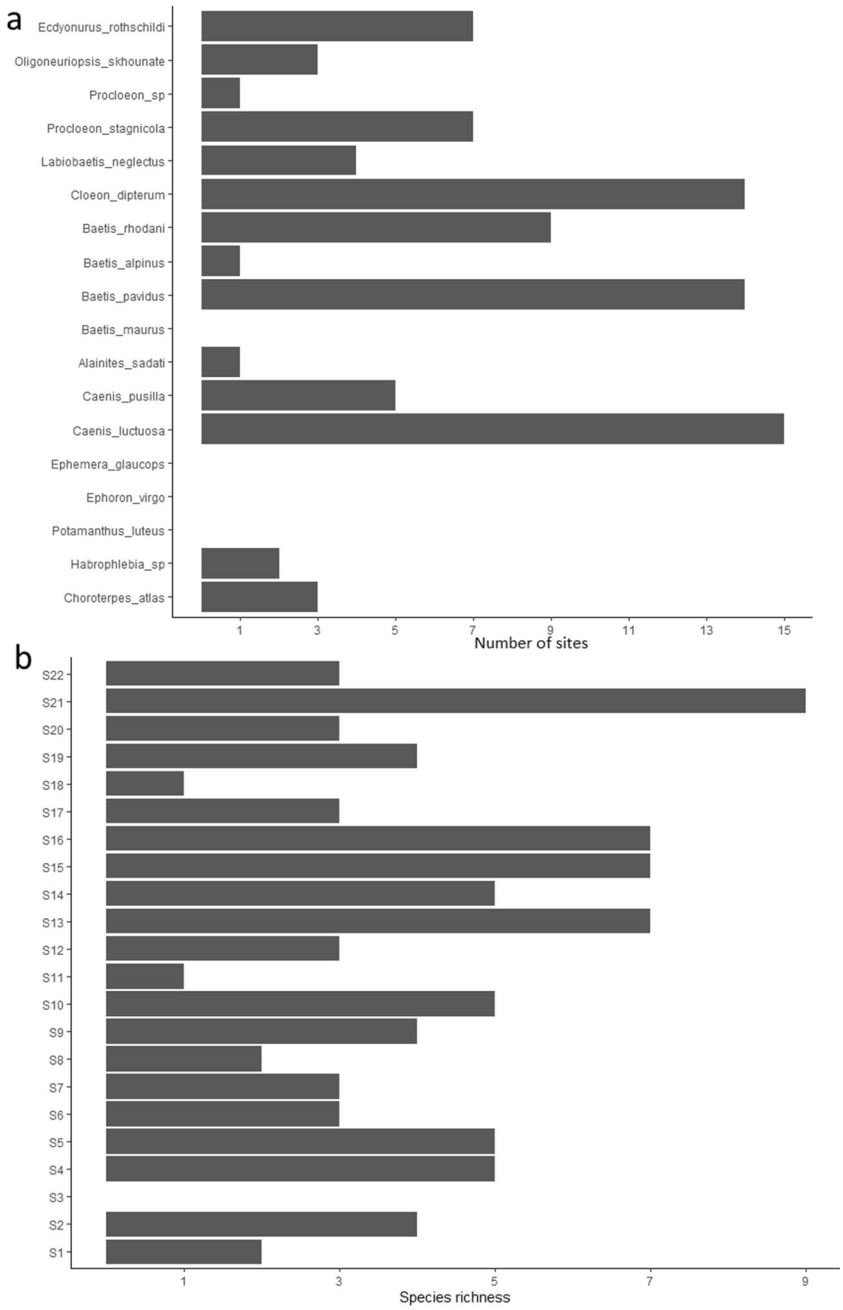

Fig. 3 Number of sites occupied by recorded taxa in 2014–2017 (**a**), and species richness of sampled sites during the same period (**b**). Some species were recorded outside the regular sampling period and are listed with zero frequency

23.viii.2014, 25.ix.2014, 27.x.2014, 29.xi.2014, 27.ii.2015, 13.iii.2015, 11.v.2015, 7.vi.2015, 12.vii.2015, 8.viii.2015, 17.ix.2015, 14.xi.2015, 13.xii.2015; Aazlet Hlima (S17): 11.vi.2015, 11.x.2015; Boufrais (S19): 11.iv.2015, 12.v.2015; Selaoua (S20): 8.viii.2015, 1l, 27.x.2015; Medjez Amar (S21): 31.vii.2014, 27.x.2014, 29.xi.2014, 25.xii.2014, 21.iv.2015, 12.v.2015, 11.vi.2015, 22.vii.2015, 8.viii.2015, 16.ix.2015, 27.x.2015, 16.xi.2015, 13.xii.2015, 25.iii.2016, 16.v.2019; Aïn Makhlouf Dam (S22): 28.xi.2014, 26.ii.2015, 13.iii.2015, 5.vi.2015, 9.viii.2015, 28.x.2015, 13.xi.2015; O. Mellah (S23): 19.x.2018, 22.iv.2019; Chihani (S24): 13.iv.2019; Sebaa Ayoun (S25): 24.v.2018, 2.vii.2019; Aïn Chikh (S26): 22.iv.2019; Hammam Laassasla (S27): 30.vi.2018; Magroun HNB (S29): 29.vii.2019.

Comments: The most frequent and widespread baetid (Fig. 4b) in the Seybouse watershed.

Baetis gr. *alpinus*

Localities: O. Nil (S12): 23.iv.2015.

Comments: Rare in the Seybouse River and confined to a single high altitude locality, this species-group, made up of cryptic species (Leys et al. 2016; Godunko et al. 2017), has larvae characterized by a reduced paracercus and numerous bristles on the distal segment of the maxillary palp (Bauernfeind and Soldán 2012). One Maghrebian endemic

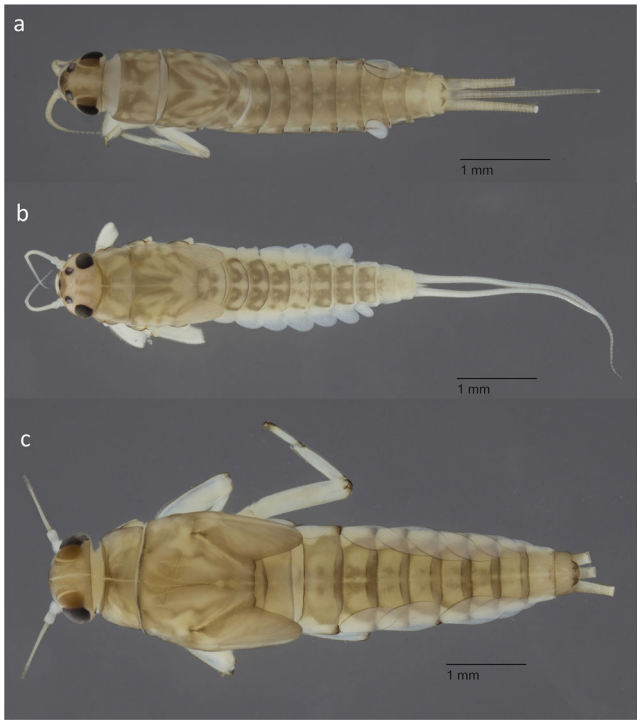

Fig. 4 Dorsal view of **a** *Alainites sadati*, **b** *Baetis pavidus*, and **c** *Baetis* gr. *rhodani*

of this species complex, *Baetis punicus* Thomas, Boumaiza & Soldán, 1983, is known from Tunisia and Algeria (Thomas et al. 1983; Thomas and Lounaci 1989).

Baetis (*Rhodobaetis*) gr. *rhodani*

Localities: Aïn Arko (S4): 16.ix.2015; O. Dahmane (S5): 23.iv.2015; O. Aar (S14): 30.vi.2018, 2.vii.2019; O. Cheniour (S15): 23.viii.2014, 25.ix.2014, 27.x.2014, 29.xi.2014, 25.xii.2014, 12.iii.2015, 11.v.2015, 7.vi.2015, 22.vii.2015, 27.x.2015, 13.xii.2015, 22.iv.2019, 17.vi.2019; Aïn Makhlouf Bridge (S16): 25.ix.2014, 29.xi.2014, 21.viii.2015; Aazlat Hlima (S17): 27.ii.2015, 13.iii.2015, 11.vi.2015, 11.x.2015; O. Boufrais (S19): 13.xii.2015; Selaoua (S20): 25.xii.2014, 21.iv.2015, 12.v.2015, 7.vi.2015, 13.xii.2015; Medjez Amar (S21): 8.viii.2015; Aïn Makhlouf Dam (S22): 30.i.2015, 21.iv.2015, 24.vii.2015; Sebaa Ayoun (S25): 24.v.2018, 30.vi.2018, 2.vii.2019; Aïn Chikh (S26): 22.iv.2019; Hammam Laassasla (S27): 30.vi.2018; Guelta Zerga (S30): 29.vii.2019.

Comments: An abundant and widespread species-group, made up of sibling species (Williams et al. 2006). Three species are reported from Algeria (Soldán et al. 2005), two of them can be separated by using DNA barcoding (Benhadji et al. 2020).

Cloeon gr. *dipterum*

Localities: Beldjoudi (S1): 25.ii.2015; Ben Mhenni (S2): 25.xii.2014, 7.vii.2015; Aïn Arko (S4): 30.vii.2014, 23.viii.2014, 12.iii.2015, 11.v.2015, 22.vii.2015, 8.viii.2015, 16.ix.2015, 27.x.2015, 5.xii.2015; O. Dahmane (S5): 23.viii.2014, 25.xii.2014, 23.iv.2015, 7.vi.2015, 22.vii.2015, 22.viii. 2015, 27.x.2015, 14.xi.2015; Sedrata Dam (S6): 23.iv.2014, 30.vii.2014, 26.ix.2014, 29.xi.2014, 25.xii.2014, 23.iv.2015, 11.v.2015, 7.vi.2015, 22.vii.2015; Sedrata Bridge II (S7): 29.ix.2014, 11.v.2015, 27.x.2015, 14.xi.2015, 13.xii.2015; Sedrata Bridge I (S8): 30.vii.2014, 22.vii.2015, 8.viii.2015, 17.x.2015, 14.xi.2015, 13.xii.2015; O. Krab (S9): 26.ix.2014, 27.x.2014, 29.i.2015; O. Krab Bridge (S10): 29.xi.2014; O. Cheniour (S15): 31.vii.2014; Azlet Hlima (S17): 11.vi.2015, 11.x.2015; Chaabet Bounab (S18): 27.i.2015; Boufrais (S19): 29.xi.2014, 25.xii.2014, 27.i.2015, 12.v.2015, 11.vi.2015, 13.xii.2015; Selaoua (S20): 25.ix.2014, 25.xii.2014.

Comments: This cosmopolitan taxon (Fig. 5b), which includes several cryptic species (Rutschmann et al. 2017; Yano et al. 2019), mainly thrives in stagnant residual pools.

Labiobaetis neglectus (Navás, 1913)

Localities: O. Krab (S9): 26.ix.2014; Dbabcha (S13): 23.viii.2014, 18.x.2019; Aïn Makhlouf Bridge (S16): 27.x.2014; Medjez Amar (S21): 23.viii.2014, 25.xii.2014.

Comments: This species (Fig. 5a) is confined to a few localities with a permanent flow.

Procloeon stagnicola Soldán & Thomas, 1983

Localities: Ben Mheni (S2): 25.xii.2014; Aïn Arko (S4): 13.xii.2015; O. Dahmane (S5): 11.v.2015; Sedrata Bridge II (S7): 29.xi.2014; O. Krab (S9): 16.ix.2015; Krab Bridge (S10): 11.v.2015; Dbabcha (S13): 30.vi.2018, 18.x.2019; Medjez Amar (S21): 23.viii.2014, 26.ix.2014.

Comments: Originally described from and long considered as endemic to Algeria, it has recently been recorded in Tunisia (Zrelli et al. 2011).

Fig. 5 Dorsal view of **a** *Labiobaetis neglectus*, and **b** *Cloeon* gr. *dipterum*

Procloeon spA

Localities: Dbabcha (S13): 18.x.2019.

Comments: An undescribed species with a fairly limited distribution.

Family Oligoneuriidae

Oligoneuriopsis skhounate Dakki & Guidicelli, 1980

Localities: Dbabcha (S13): 23.viii.2014, 25.ix.2014, 27.x.2014, 7.vi.2015, 22.viii.2015, 8.viii.2015, 14.xi.2015, 27.vi.2016, 16.vii.2016, 16.viii.2016, 28.ix.2016, 7.x.2016, 27.vi.2017, 18.x.2019, 21.vi.2020; Aïn Makhlouf Bridge (S16): 27.vi.2016, 7.x.2016, 27.vi. 2017; Medjez Amar (S21): 10.v.2015, 8.viii.2015, 16.ix.2015, 16.viii.2016, 7.x.2016.

Comments: This Ibero-Maghrebian endemic was confined to three localities (Bouhala et al. 2020a). In Morocco, this thermophilic species may ascend to altitudes above 1400 m a.s.l. when conditions (temperatures) are favorable (Dakki and Giudicelli 1980).

Family Heptageniidae

Ecdyonurus rothschildi Navás, 1929

Localities: Ben Mhenni (S2): 19.ii.2016; O. Dahmane (S5): 14.xi.2015; Dbabcha (S13): 25.ix.2014, 27.x.2014, 16.i.2015, 11.v.2015, 7.vi.2015, 22.vii.2015, 8.viii.2015, 14.xi.2015, 1.i.2016, 4.vi.2016, 16.vii.2016, 28.ix.2016, 7.x.2016, 12.xii.2016, 27.i.17, 25.iv.2017, 21.v.2017, 27.vi.2017, 18.x.2019, 30.i.2020, 25.v.2020, 21.vi.2020; O. Aar (S14): 7.vi.2015, 22.vii.2015, 16.ix.2015, 27.x.2015, 14.xi.2015, 13.xii.2015, 1.i.2016, 29.iii.2016, 23.iv.2016, 19.v.2016, 4.vi.2016, 18.ix.2019; O. Cheniour (S15): 25.xii.2014, 7.vi.2015, 22.vii.2015, 23.iv.2016, 22.iv.2019, 17.vi.2019; Aïn Makhlouf Bridge (S16):31.vii.2014, 25.ix.2014, 25.xii.2014, 7.i.2015, 22.vii.2015, 8.viii.2015, 16.ix.2015, 27.x.2015, 14.xi.2015, 1.i.2016, 29.iii.2016, 23.iv.2016, 4.vi.2016, 7.x.2016, 12.xii.2016, 17.ii.2017, 11.iii.2017, 25.iv.2017, 21.v.2017, 27.vi.2017; Selaoua (S20): 12.xii.2016; Medjez Amar (S21): 27.x.2014, 21.iv.2015, 10.v.2015, 22.vii.2015, 8.viii.2015, 16.ix.2015, 14.xi.2015, 13.xii.2015, 19.ii.2016, 23.iv.2016, 4.vi.2016, 15.vii.2016, 16.viii.2016, 28.ix.2016, 7.x.2016, 27.i.2017, 17.ii.2017, 11.iii.2017, 21.v.2017; O. Mellah (S23): 19.x.2018; Sebaa Ayoun (S25): 24.v.2018, 30.vi.2018; Hammam N'Bails (S28): 29.vii.2019; Magroun HNB (S29): 29.vii.2019; Guelta Zerga (S30): 29.vii.2019.

Comments: This thermophilous species is relatively common and can be found throughout the year (Bouhala et al. 2020b).

Statistical analysis

The PCA revealed that the first four components represented 75.8% of the total inertia. The first axis (39.7.0% of the total variance) separated permanent sites with coarse substrate from intermittent sites with fine substrate (Fig. 6a, b).The former harboured taxa like *Ecdyonurus rothschildi, Oligoneuriopsis skhounate* and *Choroterpes atlas* whereas the latter hosted *Cloeon* gr. *dipterum* (Fig. 6c). In addition, species richness was positively correlated with permanent flow and coarse substrate and negatively correlated with altitude.

The second axis (16.0% of total inertia) contrasted S15 (O. Cheniour), characterised by a high frequency of *Baetis* gr. *rhodani* and the presence of *Alainites sadati* from the rest of localities. The third axis (11.7% of total inertia) indicated an altitudinal gradient and separated localities like S12, S13, and S19 from the remaining localities. The fourth axis (8.5% of total inertia) separated the high altitude sites based on the differential presence of *Baetis* gr. *alpinus* and *Habrophlebia* sp. which are confined to a few sites (S12 and S19) (Fig. 6d).

Discussion

This study recorded 18 species of Ephemeroptera representing eight families. This total includes two new taxa, still waiting to be described. To put these results into perspective, investigations of the mayflies of Algeria in the late 20th century indicated a depauperate fauna with only 20 species reported by Soldán and Thomas (1983a, b) from the Mediterranean region of the country. This number was increased to 50 taxa by Thomas (1988), but some taxa were probably incorrectly identified by previous workers. Thus, an updated check-list of the Ephemeroptera of Algeria has yet to be produced.

Generally, the species richness of the Seybouse River compares favorably with that of other Algerian wadi: Oued Abdi in the Aures: 10 spp (Bebba et al. 2015), Tafna River, in western Algeria: 12 species (Benhadji et al. 2019), Oued Sébaou, in the Djurdjura: 22 species (Lounaci et al. 2000). Similarly, The Seybouse River includes two thirds of the impoverished Ephemeroptera fauna of Tunisia which totals 25 species (Zrelli et al. 2016). It is important to note that comparing faunas sampled at different periods is fraught with difficulties. Indeed, the Tafna River seems to have lost several species as 15 species (non-Baetidae) were previously recorded by Gagneur and Thomas (1988). It is likely that the macroinvertebrates of many other Algerian rivers may have suffered the same fate.

In contrast, the Seybouse River harbours less species than the major Moroccan rivers: 24 species in the Moulouya River (Mabrouki et al. 2017) and 30 species in Oued Laou (El Alami and Dakki 1998). The low altitudes exhibited by the Seybouse River may exclude alticolous species such as *Rhithrogena* spp or *Epeorus sylvicola* (Pictet, 1865). Other apparently missing species from the Seybouse watershed include *Oligoneuriella skoura* Dakki & Giudicelli, 1980, *Serratella ignita* (Poda, 1761), *Sparbarus kabyliensis* (Soldán, 1986), *Euthraulus lindrothi* (Peters, 1980), *Paraptophlebia cincta* (Retzius,

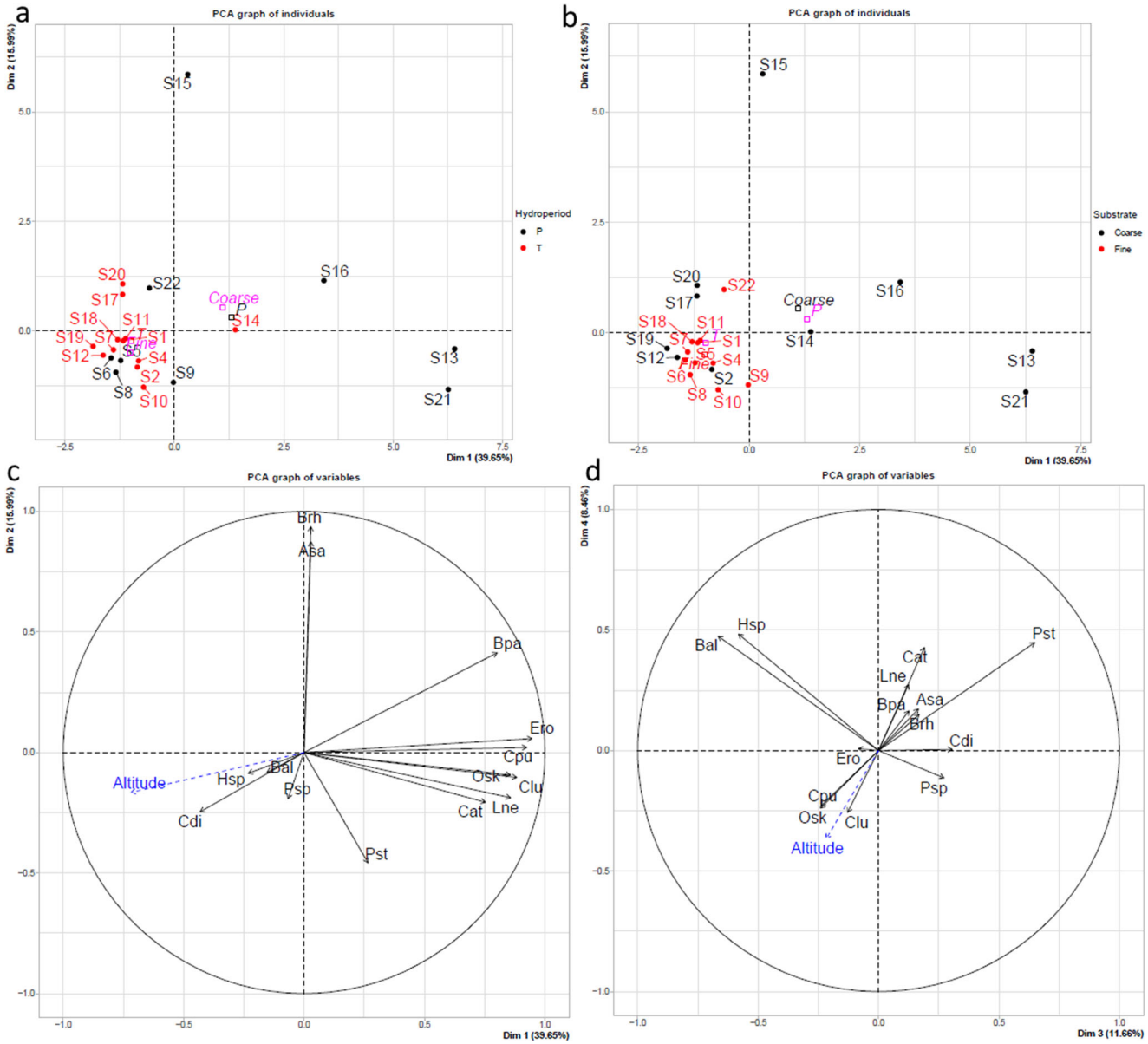

Fig. 6 First two components of the PCA displaying individual map with highlighted permanent (P)/intermittent flow (T) (**a**) and coarse/fine substrate (**b**). Variable maps of first and second components of PCA are shown in (**c**) while third and fourth components are displayed in (**d**)

1783), *Habrophlebia hassainae*, *Prosopistoma alaini* Bojková & Soldán, 2015, *Acentrella sinaica* Bogoescu, 1931, *Cloeon peregrinator* Gattolliat & Sartori, 2008, and *Nigrobaetis rhithralis* (Soldán & Thomas, 1983). A high percentage (72 %) of the recorded species is widely distributed in the Maghreb, ranging from Tunisia to Morocco. However, this value is likely to drop in the future as the taxonomic status of some species complexes will be investigated.

Species richness at the Seybouse River varied considerably between sites and was positively correlated with permanent flow and coarse substrate. The richest site (S21), located at the confluence of two major tributaries, harboured 11 species, if sampling outside the study period is included. The importance of permanent streams and rivers in arid North Africa cannot be overstated. A permanent site would accommodate univoltine summer species like *O. skhounate* (Bouhala et al. 2020a) or semivoltine species like the gomphid *Gomphus lucasii* Selys, 1849 (Samraoui et al. 2019). In addition, a perennial stream would allow multivoltine species like *Ecdyonurus rothschildi* (Fig. 4) to complete several continuous generations (Bouhala et al. 2020b).

In contrast, intermittent sites seem to favor some species like *Cloeon* gr. *dipterum* which seem to thrive in residual pools found in drying streams and rivers. Sites with a short

hydroperiod limited to winter months are occupied by species whose nymphal development is limited to winter and early spring or those with special adaptations allowing them to bridge the dry summer months. Thus, in northeastern Algeria some odonates (*Chalcolestes viridis* (Vander Linden, 1825), *Lestes barbarus* (Fabricius, 1798), *Lestes numidicus* Samraoui, Weekers & Dumont, 2003, *Aeshna mixta* Latreille, 1805, *Sympetrum meridionale* (Selys, 1841), and *Sympetrum striolatum* (Charpentier, 1840)) and the limnephilid *Mesophylax aspersus* (Rambur, 1842) are able to postpone their sexual maturation and aestivate at high altitudes or in cool shady habitats until autumn (Samraoui et al. 1998a, 2020; Samraoui 2009).

Another important environmental factor influencing mayfly assemblages in the Seybouse River was the substrate. A coarse substrate ranging from gravel to boulders would offer various microhabitats and refuges from fish which are omnipresent within the Seybouse River. A few species (*Choroterpes atlas*, *Oligoneuriopsis skhounate* and *Ecdyonurus rothschildi*) were recorded to cling to stones and their presence seems to depend closely on this microhabitat.

In contrast to the hydroperiod and the substrate, altitude was negatively associated with species richness. High altitude sites were generally intermittent streams with sandy substrate. It is important to note that the limited altitudinal gradient of the Seybouse River may constrain the presence of alticolous species like *Baetis* gr. *alpinus*. Other unmeasured factors may also be important: S3 which had a high salinity (3.6 %) (Cherairia et al. 2014) was devoid of any mayfly while S15 which hosted seven species, including the rare *Alainites sadati*, was characterized by a high frequency of *B*. gr. *rhodani*. This stream was surrounded by marly deposits and its water may possess distinct chemical properties which reflect the dominant geological nature of the stream's watershed (Leland and Porter 2000).

In contrast to stenotypic species like *Habrophlebia* sp. and *Alainites sadati*, some species exhibited a broad ecological valence. One eurytopic species, *Caenis luctuosa*, often cited as common (Gagneur and Thomas 1988), was present in 15 localities. Its congener, *Caenis pusilla*, displayed a narrower ecological valence and appeared to have declined in recent times. Both Baetids *Baetis* gr. *pavidus* and *Cloeon* gr. *dipterum* were the second most widespread species at the Seybouse River, present in 14 localities. As found in Morocco, the dominance of *B*. gr. *pavidus* may be explained by the relatively low altitudes and warm temperatures (Dakki and El Agbani 1983) characterizing the sampled localities of the Seybouse River. In one high altitude locality (S12), *B*. gr. *pavidus* was replaced by *B*. gr. *alpinus*, a typical species of high altitudes for northeastern Algeria. *C*. gr. *dipterum*, typically, was found in residual pools, frequent once intermittent streams dry out. Another species, *Ecdyonurus rothschildi*, was recorded in eight localities. The distribution of this multivoltine heptageniid was only possible because of its large ecological valence and the persistent flow in several localities of the Seybouse River.

Similarly to what was found in several freshwater groups, the Algerian mayfly fauna is believed to have a strong Palearctic affinity, with a western or circum-Mediterranean distribution (Dakki 1987; Samraoui and Menai 1999; Annani et al. 2012; Chaïb et al. 2013a, b; Cherairia et al. 2014). However, the Maghreb may also be a centre of endemicity (Yasri-Cheboubi et al. 2016) and a hotspot of biodiversity (Mittermeier et al. 2004). Only one Afrotropical element (*Oligoneuriopsis skhounate*) was recorded despite the proximity of the Seybouse River to Numidia where an Afrotropical relict freshwater fauna exists (Samraoui et al. 1993, 1998b).

Thus, the mayfly composition and distribution of the Seybouse River are markedly influenced by seasonal variations of temperature, substrate, salinity and water flow due to the semi-arid Mediterranean climate where this river originates (Bouhala et al. 2020a). Indeed, the analysis suggests that many species respond to flow duration, substrate type and an upstream-downstream gradient, but the evaluation of the autoecological preferences of most species remains to be investigated (Bouhala et al. 2020a, b). It is likely that the recorded changes in natural factors will be exacerbated in the future by anthropogenic activities like water abstraction and pollution with predictable adverse consequences for the Maghrebian freshwater biodiversity.

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Data availability Data are available on request.

Code availability Code is available on request.

Declarations

All procedures followed by this study were in accordance with international ethical standards. The research involved no human participant.

Conflicts of interest There is no conflicting interest related to this publication.

Ethics approval This study was approved by the M.E.S.R.S. and all procedures followed were in accordance with international ethical standards.

Consent for publication All the authors are in agreement with the version submitted and are in agreement with its publication in *Biologia*.

References

Al-Obaid S, Samraoui B, Thomas J, El-Serehy HA, Alfarhan AH, Schneider W, O'Connell M (2017) An overview of wetlands of Saudi Arabia: Values, threats, and perspectives. Ambio 46:98–108. https://doi.org/10.1007/s13280-016-0807-4

Annani F, Alfarhan AH, Samraoui B (2012) Aquatic Hemiptera of north-eastern Algeria: distribution, phenology and conservation. Rev Ecol –Terre Vie 67:1–13

Bauernfeind E, Moog O (2000) Mayflies (Insecta: Ephemeroptera) and the assessment of ecological integrity: a methodological approach. Hydrobiologia 422:71–83. https://doi.org/10.1023/A:1017090504518

Bauernfeind E, Soldán T (2012) The mayflies of Europe (Ephemeroptera). Apollo Books, Ollerup. https://doi.org/10.1163/9789004260887

Bebba N, El-Alami M, Arigue SF, Arab A (2015) Etude mésologique et biotypologique du peuplement des éphéméroptères de l'Oued Abdi (Algérie). JMES 6:1164–1177

Benhadji N, Abdellaoui Hassaine K, Sartori M (2018) *Habrophlebia hassainae*, a new mayfly species (Ephemeroptera: Leptophlebidae) from North Africa. Zootaxa 4403:557–569. https://doi.org/10.11646/zootaxa.4403.3.8

Benhadji N, Abdellaoui Hassaine K, Gattolliat J-L, Sartori M (2019) Thirty years after: an update to the mayflies composition in the Tafna basin (Algeria). Zoosymposia 16:22–35. https://doi.org/10.11646/zoosymposia.16.1.6

Benhadji N, Sartori M, Abdellaoui Hassaine K, Gattolliat J-L (2020) Reports of Baetidae (Ephemeroptera) species from Tafna Basin, Algeria and biogeographic affinities revealed by DNA barcoding. Biodivers Data J 8:e55596. https://doi.org/10.3897/BDJ.8.e55596

Bouhala Z, Chakri K, Márquez-Rodríguez J, Ferreras-Romero M, Samraoui F, Samraoui B (2019) Ecological correlates of odonate assemblages of a Mediterranean stream, Wadi Cherf, northeastern Algeria: implications for conservation. Int J Odonatol 22:181–197

Bouhala Z, Márquez-Rodríguez J, Chakri K, Samraoui F, El-Serehy HA, Ferreras-Romero M, Samraoui B (2020a) The life history of the Ibero-Maghrebianendemic *Oligoneuriopsis skhounate* Dakki and Guidicelli (Ephemeroptera: Oligoneuriidae). Limnologica 81:125761. https://doi.org/10.1016/j.limno.2020.125761

Bouhala Z, Márquez-Rodríguez J, Chakri K, Samraoui F, El-Serehy HA, Ferreras-Romero M, Samraoui B (2020b) The life cycle of the Maghrebian endemic *Ecdyonurus rothschildi* Navás, 1929 (Ephemeroptera: Heptageniidae) and its potential importance for environmental monitoring. Limnology. https://doi.org/10.1007//s10201-020-00625-z

Boumaiza M, Thomas AGB (1986) Répartition et écologie des éphéméroptères de Tunisie (1ère partie) (Insecta, Ephemeroptera). Arch Inst Pasteur Tunis 63:576–599

Chaïb N, Bouhala Z, Fouzari L, Marziali L, Samraoui B, Rossaro B (2013a) Environmental factors affecting the distribution of Chironomid larvae of the Seybouse wadi, North-Eastern Algeria. J Limnol 72:203–214. https://doi.org/10.4081/jlimnol.2013.e16

Chaïb N, Fouzari A, Bouhala Z, Samraoui B, Rossaro B (2013b) Chironomid (Diptera, Chironomidae) species assemblages in north-eastern Algerian hydrosystems. J Entomol Acarol Res 45:4–11. https://doi.org/10.4081/jear.2013.e2

Chapin FS III, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM et al (2000) Consequences of changing biodiversity. Nature 405:234–242. https://doi.org/10.1038/35012241

Cherairia M, Adler PH, Samraoui B (2014) Biodiversity and bionomics of the Black Flies (Diptera: Simuliidae) of Northeastern Algeria. Zootaxa 3796:166–174. https://doi.org/10.11646/zootaxa.3796.1.8

Cooper SD, Lake PS, Sabater S, Melack JM, Sabo JL (2013) The effects of land use changes on streams and rivers in Mediterranean climates. Hydrobiologia 719:383–425. https://doi.org/10.1007/s10750-012-1333-4

Dakki M (1987) Ecosystèmes d'eau courante du haut Sebou (Moyen Atlas): études typologiques et analyses écologique et biogéographique des principaux peuplements entomologiques. Trav Inst Sci Rabat Sér Zool 42:1–99

Dakki M, El Agbani MA (1983) Ephéméroptères d'Afrique du Nord. 3-Eléments pour la connaissance de la faune marocaine. Bull Inst Sci Rabat 7:115–126

Dakki M, Giudicelli J (1980) Ephéméroptères d'Afrique du Nord. 2. Description d'*Oligoneuriella skoura* n.sp. et d'*Oligoneuriopsis skhounate* n. sp., avec notes sur leur écologie (Ephem. Oligoneuriidae). Bull Inst Sci Rabat 4:13–28

Eaton AE (1899) List of Ephemeridae hitherto observed in Algeria with localities. Entomol Mon Mag 35:4–5

El Agbani MA, Dakki M, Bournaud M (1992) Etude typologique du Bou Regreg (Maroc): les milieux aquatiques et leurs peuplements en macroinvertébrés. Bull Ecol 23:103–113

El Alami M, Dakki M (1998) Peuplements d'Ephéméroptères et de Trichoptères de l'oued Laou (Rif occidental, Maroc): distribution longitudinale et biotypologie. Bull Inst Sci Rabat 21:51–70

Elosegi A, Sabater S (2013) Effects of hydromorphological impacts on river ecosystem functioning: a review and suggestions for assessing ecological impacts. Hydrobiologia 712:129–143. https://doi.org/10.1007/s10750-012-1226-6

Emmerson MC, Solan M, Emes C, Peterson DM, Raffaelli D (2001) Consistent patterns and the idio-syncratic effects of biodiversity in marine ecosystems. Nature 411:73–77. https://doi.org/10.1038/35075055

Gagneur J, Thomas AGB (1988) Contribution à la connaissance des Ephéméroptères d'Algérie. I. Répartition et écologie (1ère partie) (Insecta, Ephemeroptera). Bull Soc Hist Nat Toulouse 124:213–223

Godunko RJ, Soldán T, Staniczek AH (2017) *Baetis* (*Baetis*) *cypronyx* sp. n. a new species of the *Baetis alpinus* species-group (Insecta, Ephemeroptera, Baetidae) from Cyprus, with annotated checklist of Baetidae in the Mediterranean islands. Zookeys 644:1–32. https://doi.org/10.3897/zookeys.644.10413

Hafiane M, Hamzaoui D, Attou F, Bouchelouche D, Arab A, Alfarhan AH, Samraoui B (2016) Anthropogenic impacts and their influence on the spatial distribution of the Odonata of Wadi El Harrach (North-Central Algeria). Rev Ecol –Terre Vie 71:239–249

Jacobus LM, Macadam CR, Sartori M (2019) Mayflies (Ephemeroptera) and their contributions to ecosystem services. Insects 10:170. https://doi.org/10.3390/insects10060170

Jobbins G, Henley G (2015) Food in an uncertain future: the impacts of climate change on food security and nutrition in the Middle East and North Africa. Overseas Development Institute, London / World Food Programme, Rome. https://www.preventionweb.net/files/46974_46974odiwfpimpactofcconfnsinmena201.pdf. Accessed 15 Jan 2021

Kechemir LH, Sartori M, Lounaci A (2020) An unexpected new species of *Habrophlebia* from Algeria (Ephemeroptera, Leptophlebiidae). ZooKeys 953:31–47. https://doi.org/10.3897/zookeys.953.51244

Leland H, Porter S (2000) Distribution of benthic algae in the upper Illinois River basin in relation to geology and land use. Freshwat Biol 44:279–301. https://doi.org/10.1046/j.1365-2427.2000.00536.x

Lestage JA (1925) Éphéméroptères, Plécoptères et Trichoptères recueillis en Algérie par M.H. Gauthier et liste des espèces connues actuellement de l'Afrique du Nord. Bull Soc Hist Nat Afr N 16:8–18

Leys M, Keller I, Räsänen K et al (2016) Distribution and population genetic variation of cryptic species of the Alpine mayfly *Baetis alpinus* (Ephemeroptera: Baetidae) in the Central Alps. BMC Evol Biol 16:77. https://doi.org/10.1186/s12862-016-0643-y

Lezzaik K, Milewski A (2017) A quantitative assessment of groundwater resources in the Middle East and North Africa region. Hydrogeol J 26:251–266. https://doi.org/10.1007/s10040-017-1646-5

Lounaci A, Brosse S, Thomas A, Lek S (2000) Abundance, diversity, and community structure of macroinvertebrates in an Algerian stream: the Sébaou wadi. Ann Limnol Int J Lim 36:123–133. https://doi.org/10.1051/limn/2000008

Mabrouki Y, Taybi AF, El Alami M, Berrahou A (2017) New and interesting data on distribution and ecology of mayflies from Eastern Morocco (Ephemeroptera). JMES 8:2839–2859

Macadam CR, Stockan JA (2015) More than just fish food: ecosystem services provided by freshwater insects. Ecol Entomol 40:113–123. https://doi.org/10.1111/een.12245

Mebarki M, Taleb A, Arab A (2017) Environmental factors influencing the composition and distribution of mayfly larvae in northern Algerian wadis (regional scale). Rev Ecol –Terre Vie 72:303–313

Mittermeier RA, Robles Gil P, Hoffmann M, Pilgrim J, Brooks T, Mittermeier CG, Lamoreux J, da Fonseca GAB (2004) Hotspots revisited: Earth's biologically richest and most endangered ecoregions. CEMEX, Mexico City

Morghad F, Samraoui F, Touati L, Samraoui B (2019) The times they are a changin': impact of land-use shift and climate warming on the odonate community of a Mediterranean stream over a 25-year period. Vie Milieu 69:25–33

Palmer MA, Covich AE, Finlay BJ, Gibert J, Hyde KD, Johnson RK, Kairesaio T, Lake S, Lovell CR, Naiman RJ, Ricci C, Sabater F, Strayer D (1997) Biodiversity and ecosystem processes in freshwater sediments. Ambio 26:571–577

Pereira HM, Navarro LM, Martins IS (2012) Global biodiversity change: the bad, the good, and the unknown. Annu Rev Env Resour 37:25–50. https://doi.org/10.1146/annurev-environ-042911-093511

Pereira HM, Ferrier S, Walters M, Geller GN, Jongman RHG, Scholes RJ et al (2013) Essential biodiversity variables. Science 339:277–278. https://doi.org/10.1126/science.1229931

R Development Core Team (2019) R: a language and environment for statistical computing. Austria, Vienna

Rosenzweig C, Karoly DJ, Vicarelli M et al (2008) Attributing physical and biological impacts to anthropogenic climate change. Nature 453:353–357. https://doi.org/10.1038/nature06937

Rutschmann S, Detering H, Simon S, Funk DH, Gattolliat J-L et al (2017) Colonization and diversification of aquatic insects on three Macaronesian archipelagos using 59 nuclear loci derived from a draft genome. Mol Phylogenet Evol 107:27–38. https://doi.org/10.1016/j.ympev.2016.10.007

Samraoui B (2009) Seasonal ecology of Algerian Lestidae (Odonata). Int J Odonatol 12:383–394. https://doi.org/10.1080/13887890.2009.9748352

Samraoui B, Menai R (1999) A contribution to the study of Algerian Odonata. Int J Odonatol 2:145–165. https://doi.org/10.1080/13887890.1999.9748126

Samraoui B, Benyacoub S, Mecibah S, Dumont HJ (1993) Afrotropical libellulids in the lake district of El Kala, North-East Algeria, with a rediscovery of *Urothemis e. edwardsi* (Selys) and *Acisoma panorpoides ascalaphoides* (Rambur) (Anisoptera: Libellulidae). Odonatologica 22:365–372

Samraoui B, Bouzid S, Boulahbal R, Corbet PS (1998a) Postponed reproductive maturation in upland refuges maintains life-cycle continuity during the hot, dry season in Algerian dragonflies (Anisoptera). Int J Odonatol 1:118–135. https://doi.org/10.1080/13887890.1998.9748100

Samraoui B, Segers H, Maas S, Baribwegure D, Dumont HJ (1998b) Rotifera, Cladocera, Copepoda, and Ostracoda from coastal wetlands in northeast Algeria. Hydrobiologia 386:183–193. https://doi.org/10.1023/A:1003538730152

Samraoui B, Touati L, Samraoui F (2019) Slow and steady wins the race: Life cycle and seasonal regulation of *Gomphus lucasii* (Odonata: Gomphidae). Odonatologica 48:229–246

Samraoui B, Bouhala Z, Ruiz Garcia A, Márquez-Rodríguez J, Ferreras-Romero M, El-Serehy HA, Samraoui F (2020) Trichoptera and Plecoptera of the Seybouse River, northeast Algeria: Distribution, phenology and new records. Zootaxa 4845:552–564. https://doi.org/10.11646/zootaxa.4845.4.5

Sartori M, Brittain JE (2015) Order Ephemeroptera. In: Thorp J, Rodgers DC (eds) Thorp and Covich's freshwater invertebrates: ecology and general biology, 4th edn. Academic, New York, pp 873–891. https://doi.org/10.1016/B978-0-12-385026-3.00034-6

Soldán T, Gagneur J (1985) *Ecdyonurus rothschildi* Navás, 1929: description de la larve (Ephemeroptera, Heptageniidae). Ann Limnol – Int J Lim 21:141–144. https://doi.org/10.1051/limn/1985013

Soldán T, Thomas AGB (1983a) New and little-known species of mayflies (Ephemeroptera) from Algeria. Acta Entomol Bohemoslov 80:356–376

Soldán T, Thomas AGB (1983b) *Baetis numidicus* n. sp., Éphéméroptère nouveau d'Algérie (Baetidae). Ann Limnol – Int J Lim 19:207–211. https://doi.org/10.1051/limn/1983024

Soldán T, Godunko RJ, Thomas AGB (2005) *Baetis chelif* n. sp., a new mayfly from Algeria with notes on *B. sinespinosus* Soldán & Thomas, 1983, n. stat. (Ephemeroptera: Baetidae). Genus 16:155–165

Thomas A (1998) A provisional checklist of the mayflies of North Africa (Ephemeroptera). Bull Soc Hist Nat Toulouse 134:13–20

Thomas AGB, Dakki M (1979) Éphéméroptères d'Afrique du Nord: 1. *Ecdyonurus rothschildi* Navas, 1929. Description des imagos. Ann Limnol – Int J Lim 14:197–201. https://doi.org/10.1051/limn/1978008

Thomas A, Gagneur J (1994) Compléments et corrections à la faune des Éphéméroptères d'Afrique du Nord. 6. *Alainites sadati* n. sp. d'Algérie (Ephemeroptera, Baetidae). Bull Soc Hist Nat Toulouse 130:43–45

Thomas AGB, Lounaci A (1989) Compléments et corrections à la faune des Éphéméroptères d'Afrique du Nord. 4. Les stades ailés de *Baetis punicus* Thomas, Boumaiza et Soldán,1983 (Baetidae). Bull Soc Hist Nat Toulouse 125:27–29

Thomas AGB, Vitte B (1988) Compléments et corrections à la faune des Éphéméroptères d'Afrique du Nord. 1. Le genre *Choroterpes* Eaton, sensu stricto (Ephemeroptera). Ann Limnol – Int J Lim 24:61–65. https://doi.org/10.1051/limn/1988006

Thomas AGB, Boumaiza M, Soldán T (1983) *Baetis punicus* n.sp., Éphéméroptère nouveau de Tunisie (Baetidae). Ann Limnol – Int J Lim 19:107–111. https://doi.org/10.1051/limn/1983010

Wallace JB, Webster JR (1996) The role of macroinvertebrates in stream ecosystem function. Annu Rev Entomol 41:115–139. https://doi.org/10.1146/annurev.en.41.010196.000555

Williams HC, Ormerod SJ, Bruford MW (2006) Molecular systematics and phylogeography of the cryptic species complex *Baetis rhodani* (Ephemeroptera, Baetidae). Mol Phylogenet Evol 40:370–382. https://doi.org/10.1016/j.ympev.2006.03.004

Yalles Satha A, Samraoui B (2017) Environmental factors influencing Odonata communities of three Mediterranean rivers: Kebir-East, Seybouse, and Rhummel wadis, northeastern Algeria. Rev Ecol – Terre Vie 72:314–329

Yano K, Takenaka M, Tojo K (2019) Genealogical position of Japanese populations of the globally distributed mayfly *Cloeon dipterum* and

related species. Zool Sci 36:479–489. https://doi.org/10.2108/zs190049

Yasri-Cheboubi N, Vinçon G, Lounaci A (2016) The Nemouridae from Algeria (Insecta: Plecoptera). Zoosystema 38:295–308. https://doi.org/10.5252/z2016n3a1

Zrelli S, Boumaiza M, Béjaoui M, Gattolliat JL, Sartori M (2011) New reports of mayflies (insecta: Ephemeroptera) from Tunisia. Rev Suisse Zool 118:3–11

Zrelli S, Gattolliat J-L, Boumaiza M, Thomas A (2012) First record of *Alainites sadati* Thomas, 1994 (Ephemeroptera: Baetidae) in Tunisia, description of the larval stage and ecology. Zootaxa 3497: 60–68. https://doi.org/10.11646/zootaxa.3497.1.6

Zrelli S, Boulaaba S, Bejaoui M, Boumaïza M, Sartori M (2015) Description and répartition de *Potamanthus luteus* Linnaeus 1767 (Ephemeroptera, Potamanthidae) en Tunisie. Entomol Faun 68: 223–228

Zrelli S, Boumaiza M, Béjaoui M, Gattolliat J-L, Sartori M (2016) New data and revision of the Ephemeroptera of Tunisia. Inland Water Biol Suppl 3:99–106