

## Article

# Diversity and Distribution of Mayflies from Morocco (Ephemeroptera, Insecta)

Majida El Alami <sup>1,\*</sup>, Sara El Yaagoubi <sup>1</sup>, Jean-Luc Gattolliat <sup>2,3</sup>, Michel Sartori <sup>2,3</sup> and Mohamed Dakki <sup>4</sup>

<sup>1</sup> Laboratoire Ecologie, Systématique, Conservation de la Biodiversité (LESCB), Unité de Recherche Labellisée CNRST N°18, Département de Biologie, Faculté des Sciences, Université Abdelmalek Essaâdi, P.O. Box 2121, Tétouan 93002, Morocco; sara.elyaagoubi@etu.uae.ac.ma

<sup>2</sup> Museum of Zoology, Palais de Rumine, Place Riponne 6, CH-1014 Lausanne, Switzerland; jean-luc.gattolliat@vd.ch (J.-L.G.); michel.sartori@vd.ch (M.S.)

<sup>3</sup> Department of Ecology and Evolution, Biophore University of Lausanne, CH-1015 Lausanne, Switzerland

<sup>4</sup> Laboratory of Geo-Biodiversity and Natural Patrimony, Scientific Institute, Mohammed V University in Rabat, Av. Ibn Batouta, P.O. Box 703, Rabat 10106, Morocco; dakkiisr@gmail.com

\* Correspondence: melalami@moutaoukil@uae.ac.ma

**Abstract:** Recent research in various Moroccan areas allowed an update and a revision of the Moroccan Ephemeroptera checklist. In this case, 54 species are now listed, belonging to 10 families and 26 genera. The distribution of all studied species is discussed, as well as their biogeographical affinities. Moroccan Mayflies are characterized by a clear dominance of Mediterranean elements with a strong rate of endemism (33.4%).

**Keywords:** endemism; distribution; biogeography; Rif; Atlas; Central Plateau; Oriental Morocco



**Citation:** El Alami, M.; El Yaagoubi, S.; Gattolliat, J.-L.; Sartori, M.; Dakki, M. Diversity and Distribution of Mayflies from Morocco (Ephemeroptera, Insecta). *Diversity* **2022**, *14*, 498. <https://doi.org/10.3390/d14060498>

Academic Editor: Simon Blanchet

Received: 7 May 2022

Accepted: 8 June 2022

Published: 19 June 2022

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## 1. Introduction

The Mediterranean basin is considered as a world biodiversity hotspots; where aquatic ecosystems are highly threatened by a wide variety of anthropogenic impacts, such as pollution, habitat loss and fragmentation, alien species, and global warming [1–3]. In the southern part of this region, Morocco has the highest wetland diversity [4], due to its situation between two different seas and the Sahara desert, and to the presence of three high mountain chains, with diverse hydrogeological and climate conditions. This provides a complex river network that evolved since the late tertiary in insular conditions, this generated various exceptional ecosystems, which has a high natural heritage value. The conservation of these ecosystems requires an accurate knowledge of their fauna components and their role within these ecosystems. In this sense, aquatic macroinvertebrates constitute ideal indicators of the ecosystem diversity and health [5,6]. Ephemeroptera represent one of the major groups inhabiting lotic ecosystems [7–10] knowing that it constitutes up to 50% of the freshwater total animal biomass.

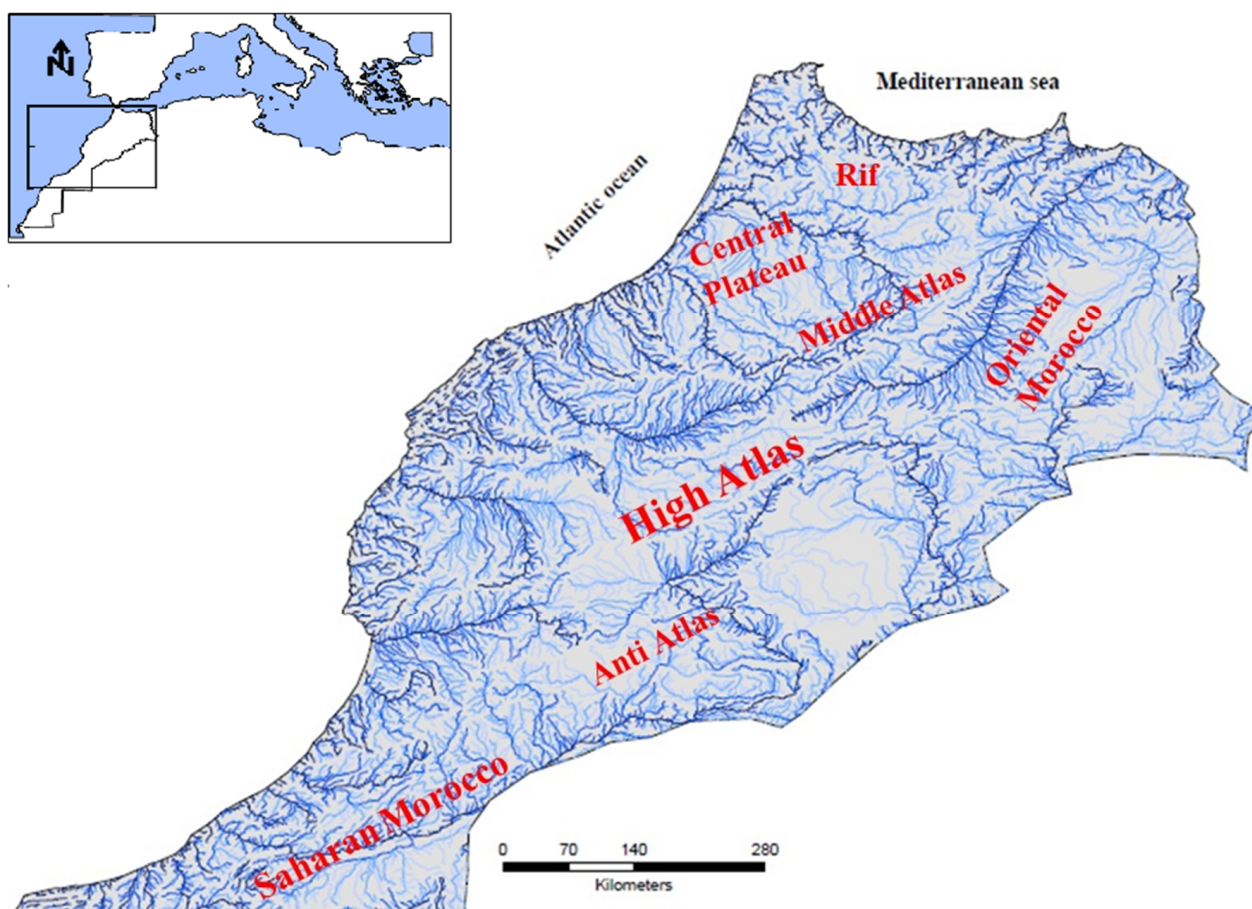
In Morocco, Ephemeroptera remained practically unknown until the 1970s. Indeed, the first work dedicated to this group was provided by Navás [11] who mentioned two species from the Rif area. Since then, thanks to the work of Lestage [12], Navás [11,13] and Kimmins [14], a first faunal list of 10 species was drawn up. The catalog produced by Dakki and El Agbani [15] was able to complete this list with 16 additional species to raise the number of Ephemeroptera to 26, distributed in the different Moroccan regions. This list has been greatly enriched through following taxonomic studies [15–25] as well as hydrobiological studies carried out on the various Moroccan hydrographic networks (listed below). Despite all these efforts, the knowledge of the Moroccan Ephemeroptera diversity and ecology remains incomplete; in particular, new approaches combining morphological, molecular, ecological and biogeographical evidence challenge the presence of some presumably widely distributed European species.

Thus, the main objective of this study is to summarize the knowledge of this Moroccan fauna with a compilation and an update of available species records of Moroccan mayflies.

## 2. Materials and Methods

This study included Ephemeroptera collected or identified by the authors in the Rif, Middle and High Atlas (1995–2019) and with material compiled from published works on the hydrographic networks of the main Moroccan domains: Rif: [23,24,26–31], Oriental Morocco: [32–37]; Central Plateau: [38,39]; Middle Atlas: [18,40–45]; High Atlas: [17,46–58].

The mayfly fauna of different Moroccan areas (Figure 1) was reviewed including all hitherto known distribution and ecology records, if some species have migrated to high altitudes to seek a milder temperature for their development, together with references and a few new records.



**Figure 1.** Different hydrographic networks and biogeographic areas of Morocco.

The sampling in the Rif area was performed by Pr. El Alami team (LESCB: Laboratory Ecology, systematics and conservation of biodiversity in the faculty of Science of Tetouan) since 1992. The identified species are conserved in alcohol at 96% or 70% in duly labeled vials and stored in the aquatic macroinvertebrates collection of the LESC. Other specimens of some species are kept in personal collection of M. Dakki. Specific species identifications sometimes required slides mounting of dissected parts of the nymphs for detailed studies.

## 3. Results

In case, 54 species of Ephemeroptera representing 26 genera and 10 families have been recorded from Morocco. Among them, 18 (33.4%) are currently considered as endemic to Morocco and 9 (16.7%) endemic to Maghreb.

### 3.1. Commented Inventory and Distribution of Moroccan Ephemeroptera

#### 3.1.1. Family Leptophlebiidae Banks, 1900

##### *Choroterpes (Choroterpes) atlas* Soldán and Thomas, 1983

This epipotamal species has a wide distribution and is found in the three Maghreb countries excepting desert areas [22]. In Morocco, this species also has a wide distribution which extends from the Rif basins area to Anti Atlas confines [22–24,26,29,33,45,52]. The streams located between the High Atlas and the Anti Atlas constitute the southern limit for this species. It presents also a wide altitudinal distribution: in the Rif, this species has a clear preference for habitats located between middle and lower courses.

In Morocco, *C. (Choroterpes) atlas* is mainly found along permanent watercourses rich in filamentous algae and occupies habitats bordering the bed in which the current is low with maximum water temperature (30 °C).

##### *Choroterpes (Choroterpes) volubilis* Thomas and Vitte, 1988

This Moroccan endemic is limited to the northern zones between Rif, Oriental Morocco and Middle Atlas and is absent in High Atlas and Central Plateau [22–24,26,27,29,41,45,59]. This thermophilic species seems to have a more restricted latitudinal distribution than the previous one. It reaches its ecological optimum in facies of rivers at medium and low altitudes where the temperature is high and the current is moderate to low (Table 1).

**Table 1.** Checklist of the Moroccan Ephemeroptera, with their geographical distribution and habitat preferences.

Species	Authorship	Distribution	Altitudes (m)					Temperature (°C)	Curent	Habitat
			Rif	M. Atlas	H. Atlas	C. Plateau	Oriental			
<i>Choroterpes (Choroterpes) atlas</i>	Soldán and Thomas, 1983	MagE	20–400	470–1300	1100–1630	55–630	245–1300	13.5–31.0	++/+	Pb, Gr
<i>Choroterpes (Choroterpes) volubilis</i>	Thomas and Vitte, 1988	MorE	20–700	210–1340			360–970	7.5–29.0	++/+	Pb, Gr
<i>Choroterpes (Euthraulus) lindrothi</i>	(Peters, 1980)	MagE	5–375	470	175–1600	60–650		13.0–24.0	++	St, Pb
<i>Habroleptoides assefae</i>	Sartori and Thomas, 1986	MorE	800–1600		1700–3000			7.5–20.5	++/+	Pb, Cb
<i>Habrophlebia fusca</i>	(Curtis, 1834)	Wpal		765–1820	765–2600	1000		8.5–29.0	++	Pb, Bld, Bed
<i>Habrophlebia vaillantorum</i>	Thomas, 1986	MorE			1700–3000			5.0–7.0	+++	Pb, Cb
<i>Habrophlebia sp1</i>		MorE	5–1600					7.5–20.5	++/+	Gr, Pb
<i>Habrophlebia sp2</i>		?	750–1550		2480–2610		565–1640	7.5–24.0	++/+	Gr, Pb
<i>Paraleptophlebia cincta</i>	(Retzius, 1783)	Wpal		1470				9.5–24.5	+	Si, Gr, Pb
<i>Thraulius sp1</i>		MagE?					280–435	16.5–20.0	++/+	Si, M
<i>Potamanthus luteus</i>	(Linné, 1767)	Tpal	20–500	210–410	950–1600			13.0–28.0	+++/>++	Cb
<i>Ephemera glaucops</i>	Pictet, 1843	Wpal	80	210–1050	450	50	930	12.0–28.0	++/+	Cb
<i>Ephoron virgo</i>	(Olivier, 1791)	Wpal	20–500	210–1425		50–660	3–625	12.0–28.0	+++/>++	Gr, Pb
<i>Serratella ignita</i>	(Poda, 1761)	Tpal	5–1600	1340–1500	650–2620	655–1120	931–1616	7.5–20.5	++	Pb
<i>Caenis luctuosa</i>	(Burmeister, 1839)	Wpal	5–1640	210–2050	650–2550	59–1235	3–1820	3.0–30.5	++/+	Gr, Pb
<i>Caenis pusilla</i>	Navás, 1913	Wpal	5–820	215–1425	650–2610		243–1425	12.0–30.5	++/+	Gr, Pb
<i>Brachycercus harrisellus</i>	Curtis, 1834	Hol					?	?	+	Si, Pb
<i>Sparbarus cf kabylensis</i>	(Soldán, 1986)	Ib-Mag		720–1600		54		10.5–29.0	++	Si, Pb
<i>Oligoneuriella skoura</i>	Dakki and Giudicelli, 1980	MorE		215–1450	850–1600		215–470	8.5–29.5	++	Cb
<i>Oligoneuriopsis skhounate</i>	Dakki and Giudicelli, 1980	Ib-Mag	20–500	215–1600	650–1200	115–660	10–1425	13.5–24.5	++	Gr, Pb, Cb
<i>Ecdyonurus ifranensis</i>	Vitte and Thomas, 1988	MorE	5–1640	530–2030	1600		1550–1820	7.5–25.5	++	Sd, Gr
<i>Ecdyonurus rothschildi</i>	Navás, 1929	MagE	20–410	215–1910	850–2610	115–1120	240–1910	14.5–30.5	++	Gr, Pb
<i>Epeorus cf torrentium</i>	Eaton, 1881	Wpal	20–1600		650–1650	356	570–1670	5.0–22.5	+++	Pb, Cb
<i>Rhithrogena sp./spp.</i>		?	100–1580	210–1500				7.5–20.5	+++/>++	Gr, Pb
<i>Rhithrogena ayadi</i>	Dakki and Thomas, 1986	MorE		1680–2200				6.5–15.0	+++	Cb
<i>Rhithrogena giudicelliorum</i>	Thomas and Bouzidi, 1986	MorE			2400–3000			5.0–13.5	+++	Pb, Cb
<i>Rhithrogena mariae</i>	Vitte, 1991	MorE	140–560					13.5–24.0	++	Pb, Cb
<i>Rhithrogena ourika</i>	Thomas and Mohati, 1985	MorE			850–2620			6.0–19.0	+++/>++	Pb, Cb
<i>Rhithrogena ryszardi</i>	Thomas, Vitte and Soldán, 1987	MorE		1260				15.0–18.0	+++	Pb, Cb
<i>Acentrella almohades</i>	Alba-Tercedor and El Alami, 1999	Ib-Mag	20–840	1870			570–930	10.0–27.0	++/+	Pb, Cb
<i>Alainites sp1</i>		MorE	5–1600	755–1820				7.5–27.0	++/+	Pb, Cb, SbV
<i>Alainites oukaïmeden</i>	(Thomas and Sartori, 1992)	MorE			950–3200			10.0–15.0	+++/>++	Si, Gr, Pb, AV
<i>Baetis berberus</i>	Thomas, 1986	MorE			2400–3000			5.0–13.5	+++	Pb, Cb
<i>Baetis gr alpinus</i>		MagE?	20–1500				987	10.0–31.5	+++	Pb, Cb
<i>Baetis maurus</i>	Kimmins, 1938	Ib-Mag	20–1500	880–1550	700–2600	659		10.0–31.5	+++	Pb, Cb
<i>Baetis punicus</i>	Thomas, Botmaïza and Soldán, 1983	Ib-Mag	40–1600					7.5–26.0	++/+	Gr, Pb
<i>Baetis gr fuscatus</i>		MorE	20–1600	530–560	730–1600	60–1120		7.5–24.0	++/+	Pb, Cb
<i>Baetis gr lutheri</i>		MorE	20–800					14.5–30.0	+++/>++	Pb, Cb
<i>Baetis pavidus</i>	Grandi, 1949	Atl-Med	5–1640	215–1915	50–2600	59–1350	2–1895	7.5–30.5	+++/>++	Pb, Cb
<i>Baetis (Rhodobaetis) gr rhodani</i>		?		470–2200	1400–2900	59–1273	10–1670	6.5–27.0	+++/>++	Pb, Cb
<i>Baetis atlanticus</i>	Soldán and Godunko, 2006	Atl-Med	5–1640					6.5–27.0	+++/>++	Pb, Cb
<i>Centropitilum cf lutoleum</i>	(Müller, 1776)	MorE	40–1283					10.5–27.0	++/+	Gr, Pb, FA, Mo
<i>Chelecoleon dimorphicum</i>	(Soldán and Thomas, 1985)	MagE	5–1400		1433	115–660	3–930	13.5–25.5	+++/>++	Gr, Pb
<i>Cloeon gr dipterum</i>		?		210–1820	850	60–1350	5–1670	8.5–30.0	++/+	Gr, Pb

Table 1. Cont.

Species	Authorship	Distribution	Altitudes (m)					Temperature (°C)	Current	Habitat
			Rif	M. Atlas	H. Atlas	C. Plateau	Oriental			
<i>Cloeon peregrinator</i>	Gattolliat and Sartori, 2008	Atl-Med	5–1400					8.0–29.5	++/+	Sd, Gr, Pb
<i>Cloeon simile</i>	Eaton, 1870	Tpal	60–1055				85–870	14.5–22.5	++	Sd, Gr, FA
<i>Labiobaetis neglectus</i>	(Navás, 1913)	Ib-Mag	20–350	210–1425	530	115–660	10–370	13.5–30.5	+++/>++	Gr, Pb
<i>Nigrobaetis numidicus</i>	(Soldán and Thomas, 1983)	MagE	20	215–245				19.5–24.0	++	Gr, Pb
<i>Nigrobaetis rithralis</i>	(Soldán and Thomas, 1983)	MagE	400–950					13.5–18.0	++/+	Gr, Pb
<i>Procloeon cf bifidum</i>	(Bengtsson, 1912)	Tpal	80–1300					14.0–20.5	++	Sd, Gr, SbV
<i>Procloeon cf concinnum</i>	(Eaton, 1885)	Ib-Mag		245–1425	1000–1550	60–1275	10–925	10.0–30.0	++/+	Sd, Gr, Pb
<i>Procloeon stagnicola</i>	(Soldán and Thomas, 1983)	MagE	20–780					12.0–27.0	++/+	Sd, Gr, Pb
<i>Procloeon pennulatum</i>	(Eaton, 1870)	Hol	60–610	210–1500	1000–1550	290–660	10,0–50	20.5–27.0	+	Sd, Gr
<i>Prosopistoma</i> sp1.		MorE		1650				8.0–26.0	++	Si, M

Table legend: Distribution patterns: Hol: Holarctic. Tpal: Transpalearctic. Wpal: Western Palearctic. Atl-Med: Atlanto-Mediterranean. Ib-Mag: Ibero-Maghrebian. MagE: Maghrebian endemic. MorE: Moroccan endemic. Unknown: ?. Current speed: +++: High. ++: Moderate. +: Low. Habitat types (substrate): Si: Silt. M: Mud. Sd: Sand. Gr: Gravels. Pb: Pebbles. Cb: Cobbles. Bld: Boulders. Bed: Bedrock. SbV: submerged vegetation. AV: Aquatic vegetation. FA: Filamentous algae. Mo: Mosses.

### *Choroterpes (Euthraulius) lindrothi* (Peters, 1980)

This Maghreb endemic is generally less abundant and less frequent than the other species of the subgenus *Choroterpes* [60]. In Morocco, this species has been collected in streams of the Rif [24,29], Middle Atlas [15,42], Central Plateau [15,39] and North High Atlas slopes [48,50,61]. The southernmost locality known for this taxon is Oued Massa located in the Anti Atlas [48,52,57,60]. This species was essentially sampled in the facies of large streams at low (5 m a.s.l) to medium (650 m a.s.l) altitudes characterized by high summer temperatures, rich in filamentous algae and with bed formed of a coarse substrate (Table 1).

### *Habroleptoides assefae* Sartori and Thomas, 1986

This Moroccan endemic presents a discontinuous distribution, and has only been detected in the Rif [24] and the High Atlas.

In the High Atlas, this species is crenobiont and found only in a few limnocrene springs [19,48,52,57]. In the Rif, it is confined in permanent streams with moderate current, stony bed and characterized by submerged macrophytes which provide excellent refuge for larvae when the current is strong.

### *Habrophlebia fusca* (Curtis, 1834)

This Palearctic species has been recorded in Middle Atlas [15,42], Central Plateau [15,38,39,61] and Oriental Morocco [33]. The presence of this species is nevertheless doubtful [24,26,31], since this genus shows a high rate of endemism in the Maghreb countries, particularly in Algeria with the recent description of two new species [62,63]. Therefore, a revision of all Moroccan *Habrophlebia* populations would be necessary as they may represent a complex of species.

### *Habrophlebia vaillantorum* Thomas, 1986

This Moroccan endemic has a restricted distribution area: it has been only located in High Atlas [48,52,53,55], and is alticolous species [64] which prefers biotopes with stony substrate and fast current [55].

### *Habrophlebia* sp1

In North of Morocco, this species is probably new for science. Its description will be carried out soon. It has a large distribution and occupies a wide range of biotopes located between 5 and 1600 m a.s.l [24,26,29]. In the Rif, its ecological optimum is reached in waters characterized by a moderate current and low mineralization.

### *Habrophlebia* sp2

The latest study in Rif rivers revealed the presence of a second species; genetic analysis revealed that it is different from *Habrophlebia* populations found in Algeria. Its identification will be carried out soon.



***Paraleptophlebia cincta* (Retzius, 1783)**

This Palearctic species has been reported in Morocco and Algeria [36,40,65], where it seems to be more alticolous than in Europe. This altitudinal shift can be attributed to the water temperature and physico-chemical parameters [42,65]. *Paraleptophlebia cincta* is apparently rheophilous and has a clear preference for permanent streams. This could explain the low number of larvae collected in these two Maghreb countries.

***Thraulius* sp1**

Specimens of this species were collected in two permanent stations of Zegzel, one of the Oriental Morocco sub-basin [37].

Its morphological study indicated similarities with its European congener *T. bellus*. However, a genetic study would be necessary to confirm this preliminary identification. This is anyway the first mention of the genus *Thraulius* in Morocco.

## 3.1.2. Family Potamanthidae Albarda, 1888

***Potamanthus luteus* (Linné, 1767)**

This is a Palearctic species found from the British Islands to Korea [66]. It has been also reported in the three Maghreb countries [67,68]. In Morocco, it is recorded from: Middle Atlas [41,42,45], High Atlas [48,49], Central Plateau [38,39] and in the Rif [24,26].

This thermophilic species has a clear preference for the facies of large rivers at low and medium altitudes, characterized by a substrate composed of cobbles and pebbles, with moderate current.

## 3.1.3. Family Ephemeridae Latreille, 1810

***Ephemera glaucops* Pictet, 1843**

This species has a West Palearctic distribution. It is present in the three Maghreb countries. In Morocco, it is found in Middle Atlas [12,13,15], Central Plateau [15], High Atlas [13,51,52], in Oriental Morocco [33]. In the Rif, a single male imago was collected by El Alami [24]. Further studies did not confirm its presence in this part of the country [26,27,29].

In Morocco, *E. glaucops* has a clear preference for running waters with low to moderate current speed, whereas in Europe, it also occupies oligotrophic lacustrine biotopes [65,69,70].

## 3.1.4. Family Polymitarciidae Banks, 1900

***Ephoron virgo* (Olivier, 1791)**

*Ephoron virgo* has a West Palearctic distribution. In North Africa, it is known in the three Maghreb countries [62]. In Morocco, the Central Plateau [38,39] and the Middle Atlas [15] seem to constitute the southern limit of its distribution since it is absent in the High Atlas. Its presence in Oriental Morocco has been recently confirmed by Mabrouki et al. [33].

As a hot water stenotherm, *E. virgo* larvae tolerates water temperatures up to 28 °C during the summer period [24]. The larvae mainly inhabit biotopes characterized by a slow to moderate current and a substrate rich in silt and sand in which they dig galleries.

## 3.1.5. Family Ephemerellidae Klapalek, 1909

***Serratella ignita* (Poda, 1761)**

This Palearctic species is distributed in Maghreb only over Algeria and Morocco. In this country, it has a wide latitudinal distribution covering all the Moroccan areas [13,15,24,26,28,29,32,33,39,42,52] reaching its southern limit at the Dr'a wadi [52].

This species essentially favors biotopes which are rich in aquatic plants and detritus. It prefers areas with a fine substrate rich in silt, sand and gravel and with moderate to null flow speed.

### 3.1.6. Family Caenidae Newman, 1853

#### ***Caenis luctuosa* (Burmeister, 1839)**

This West Palearctic species has a wide distribution and colonizes varied biotopes. In Morocco, its range extends from the northern Rif watershed to the Anti Atlas [15]. Eurytopic and eurythermous, this species abounds in running as well as in stagnant waters.

In the Moroccan hydrographic networks, *C. luctuosa* prefers the lower and middle courses with substrate dominated by a fine grain size; it is only absent in the streams with strong currents and low temperatures. This species can colonize waters with high conductivity (1600  $\mu\text{S}/\text{cm}$ ) [24] and asserts itself as the most polluo-resistant species [71,72].

#### ***Caenis pusilla* Navás, 1913**

*Caenis pusilla* is a West-Palearctic species, well known from North Africa [24,29,65]. In Morocco, this species has been found in the Rif [24,26,29]; the Oriental Morocco [33] and in the High Atlas [48,52]. In this area, *C. pusilla* seems to be more alticolous than in the Rif, where it coexists with *C. luctuosa* in some lower watercourses.

*Caenis pusilla* is less tolerant to thermal variations than *C. luctuosa*, which explains the different and complementary altitudinal distribution of these two species in the High Atlas streams. It adapts better to more rapid flows and does not tolerate low water oxygenation and high salinity values.

#### ***Brachycercus harrisellus* (Curtis 1834)**

In the last decade, this Holarctic species has been found in the Central Plateau [73]. A morphological revision and genetic analyses will be required to confirm its identification.

#### ***Sparbarus cf. kabyliensis* (Soldán, 1986)**

In Morocco, the identification of this taxon has not gone beyond the generic level. It was reported by Dakki [40,42] and Dakki and El Agbani [15] in a Middle Atlas stream and in Oriental Morocco [36]. Referring to the work of Gagneur and Thomas [65], these larvae could belong to the species *S. kabyliensis* which was described from NW Algeria [65] and whose presence has been also demonstrated in the Iberian Peninsula [74].

### 3.1.7. Family Oligoneuriidae Ulmer, 1914

#### ***Oligoneuriella skoura* Dakki and Giudicelli, 1980**

This species is a Maghreb endemic, known only from Algeria and Morocco [24] and it seems to be absent in the Rif [23,24,26,27,29] and Central Plateau [38,39]. In Morocco, it is found between 210 m and 1630 m a.s.l in the Middle and the High Atlas [25,46,52,75] and among 210–460 m a.s.l in Oriental Morocco [33]

*Oligoneuriella skoura* is rheophilic, and can be found in strong current (rarely in areas with low current) and stony bottom.

#### ***Oligoneuriopsis skhounate* Dakki and Giudicelli, 1980**

The genus *Oligoneuriopsis* is of Afrotropical origin, reaching North Africa and the Iberian Peninsula with the species *O. skhounate* on one side [75–82], and the species *O. orontensis* in the Levant and Iran [83]. In Morocco, this species shows a wide distribution. It is recorded from the Rif [24]; the Oriental Morocco [32,33]; the Middle Atlas [41,42,45] and the High Atlas [52]. This wide latitudinal distribution is associated with a wide altitudinal distribution (Table 1).

In Morocco, this thermophilic and rheophilic taxon prefers large permanent streams with high current speeds and begins its development only when it receives a relatively large thermal sum in summer. In the Rif, this sum is only reached at the beginning of summer, when the majority of rivers are drying up.

### 3.1.8. Family Heptageniidae Needham, 1901

#### ***Ecdyonurus ifranensis* Vitte and Thomas, 1988**

This Moroccan endemic has been collected in streams of the Middle Atlas [15,41,45], High Atlas [49,52], Oriental Morocco [33] and Rif [24,26–29,83].

This species colonizes the upper courses. It has a clear preference for streams with a stony bottom, strong to moderate current and is replaced downstream by its congener *E. rothschildi*.

***Ecdyonurus rothschildi* Navás, 1929**

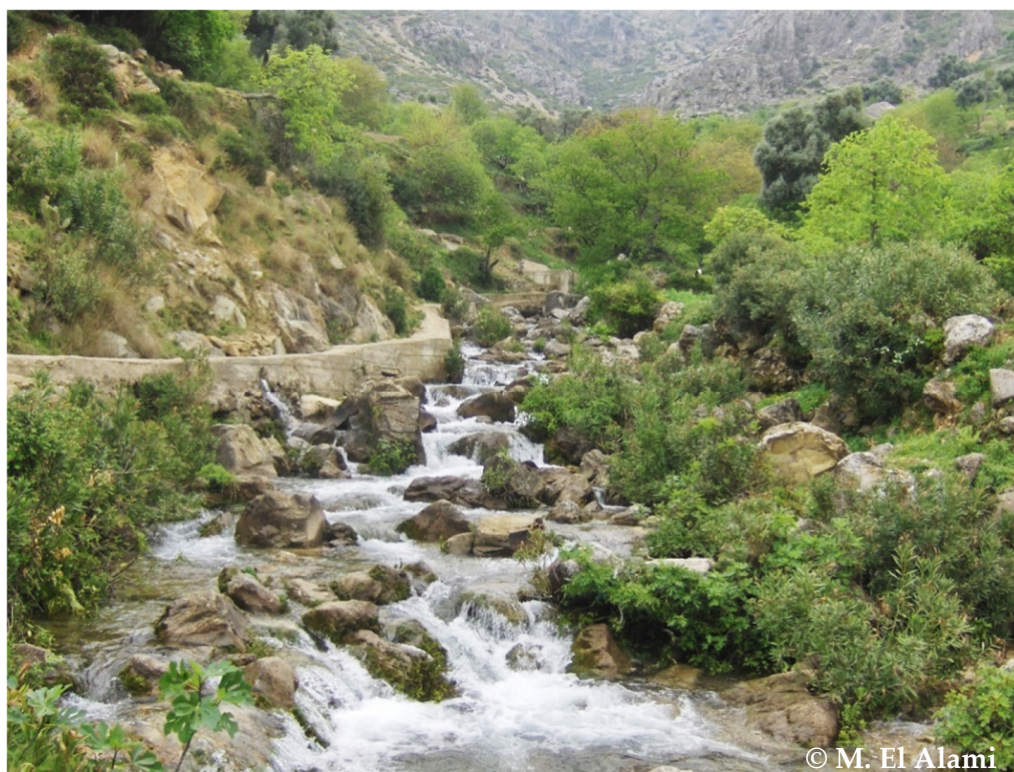
This Maghreb endemic is widely distributed in North Africa. In Morocco, its distribution extends from the Tingitane Peninsula to Oriental Morocco and from the Middle Atlas to the Anti Atlas, passing through the Central Plateau. This wide latitudinal distribution is overlaying a wide elevation [32,39,42,53,84,85].

Considered as the most eurythermal and thermophilic species among North African Heptageniidae, *E. rothschildi* colonizes the permanent and temporary streams and only avoids the most upper courses.

***Epeorus cf. torrentium* Eaton, 1881**

This taxon was reported under *E. sylvicola* in various Moroccan hydrobiological works which is probably erroneous. Indeed, the morphology of the Moroccan specimens is closer to *E. torrentium* than to *E. sylvicola*. A genetic study would be necessary to confirm the identification of this species.

In the Maghreb, this species is known only in the Moroccan hydrographic networks [61,65,78,86] where it shows a rather discontinuous distribution. It has been recorded in the High Atlas [48,49,52,55,57,58,87] and the Rif [24,26,27,29]. It seems to be absent in the Middle Atlas, the Central Plateau and Oriental Morocco. In the Rif, this rheophilic and cold water stenothermic species is confined to the upper courses (Figure 2). This important rise is probably due to the high warming of these rivers, particularly during the summer period, which becomes a limiting factor for the development of this species.



**Figure 2.** Oued Maggo a typical habitat of *Epeorus cf. torrentium*.

***Rhithrogena* spp.**

This genus presents a high degree of endemism in the Maghreb. Thus, a revision of the *Rhithrogena* collected in the different Moroccan domains must be realized, which could further increase the specific richness of Moroccan Ephemeroptera. Especially, some specimens of this genus are confined to middle and lower streams and tolerate relatively

high temperature and mineralization, while others are located in upper streams and have a preference for cold temperatures. Unfortunately, the larval taxonomy of this genus in Morocco is almost unknown, therefore larval identification remains impossible.

***Rhithrogena ayadi* Dakki and Thomas, 1986**

This Moroccan endemic species has only been found in Middle Atlas [18,42,83,88]. It was collected in streams located between 1680 and 2200 m a.s.l.

This rheophilous species has a clear preference for small torrents of high mountains whose current is fast, the substrate is coarse, and the maximum temperature of the water does not exceed 15 °C.

***Rhithrogena giudicelliorum* Thomas and Bouzidi, 1986**

This High Atlas endemic was collected in Assif n'Ouarzane in a restricted altitudinal range varying between 2400 and 3000 m.

*R. giudicelliorum* is confined to cold torrents fed by permanent snowfields and with a maximum temperature not exceeding 10 °C [48,52,54].

***Rhithrogena mariae* Vitte, 1991**

This Moroccan endemic has a wide distribution in the western Rif. Specimens were found in the middle and lower reaches of streams of this area, whose altitude varies between 140 and 560 m [21,24].

This Rifian species is less rheophilic and more thermophilic than the Atlas ones and has a clear preference for potamal waters. Its development cycle must include specific adaptations since it supports even intermittent watercourses which undergo strong seasonal variations in flow [24].

***Rhithrogena ourika* Thomas and Mohati, 1985**

This High Atlas endemic was sampled in an altitudinal range varying between 850 and 2600 m [17,57].

In a recent extensive survey of the benthic macroinvertebrates of the Ourika watershed, Abessolo et al. [57] failed to collect this species in the different prospected localities, suggesting it may be locally extinct or extremely rare.

*R. ourika* has a clear preference for the cool waters of the upper courses, but it is less alticolous than its congener *R. giudicelliorum*.

***Rhithrogena ryszardi* Thomas, Vitte and Soldán, 1987**

This is an endemic species of the Middle Atlas belonging to the so-called *germanica* group. Since its discovery in O. Tout and O. Bençmim, at 1260 m [20], this species has not been collecting again, despite numerous samplings realized in waterways of this area. Anthropogenic impacts, such as water diversion by dams and canals, irrigation and organic pollution from villages, could be the cause of its local disappearance.

### 3.1.9. Family Baetidae Leach, 1815

***Acentrella almohades* Alba-Tercedor and El Alami, 1999**

This Ibero-Moroccan endemic is replaced in the other Maghreb countries by its congener *A. sinaica* [61,89,90]. In Morocco, this species is present in the Middle Atlas, Oriental Morocco and the Rif [24,33,90].

This thermophilic species has a clear preference for the facies of rivers with a clement temperate winter and tolerates wide conductivity variations.

***Alainites* sp1**

This species is preferentially confined to northern streams of Morocco, since it appears to be absent in the High Atlas [52,53], where it is replaced by its congener *A. oukaimeden*. Its absence in Oriental Morocco [32,33] and the Central Plateau [39] is probably linked to the excessive water warming.

In the Rif and the Middle Atlas, this species has been identified as *A. muticus* by previous authors because it has seven pairs of gills [24,26,29].

In the Rif, this species has a wide distribution and a wide altitudinal range. It prefers biotopes with cobbles, pebbles and submerged vegetation (Figure 3). It also prefers the rela-



tively cool waters of the upper and middle wadis and has been found in sites characterized by high conductivities [24].



**Figure 3.** Oued Kelaa a typical habitat of *Alainites* sp1.

***Alainites oukaimeden* (Thomas and Sartori, 1992)**

This Moroccan endemic has been mainly reported in springs and their emissaries on the northern and southern watersheds of the High Atlas [48,49,52,55,56].

This species inhabits a wide range of biotopes with a certain preference for those with abundant aquatic vegetation.

***Baetis berberus* Thomas, 1986**

The distribution area of this Moroccan endemic is limited to the High Atlas. It colonizes the highest streams and torrents and has an affinity for the crenel [54,56,91]. It is a strictly stenothermal cold water.

***Baetis gr alpinus***

Located in northern Morocco, this complex presents cryptic species [91,92] whose larvae are characterized by a reduced paracercus, a single row of denticles in the tarsal claws and a paraglossus with three rows of bristles. The genetic analysis showed high distances between the Moroccan populations and Spanish ones as well as with *Baetis maurus* [93]

***Baetis maurus* Kimmins, 1938**

This Ibero-Maghrebian endemic seems to be absent only in Tunisia. In Morocco, it has been found in the Atlas and the Rif domains and is absent in the Central Plateau [39] and in the Oriental Morocco [32,33]. It has a wide altitudinal distribution [15,42,49,52,55–57,87,88,92] and preferred cold and fast waters of mountain streams.

***Baetis punicus* Thomas, Boumaiza and Soldán, 1983**

This Ibero-Maghrebian endemic [24,31,68,94] was reported only recently for the first time in Morocco [24,31] and is located in the western Rif where it was collected in fairly large altitudinal range. The first mention of this species in Europe was made by Ubero-Pascal et al. [94] who sampled it in South-East of Spain.

This species frequents permanent and temporary waters. Its ecological optimum and highest abundance are reached in the emissaries springs at high and medium altitude, but

it develops further downstream, particularly during the winter period when the flow speed is quite high [24].

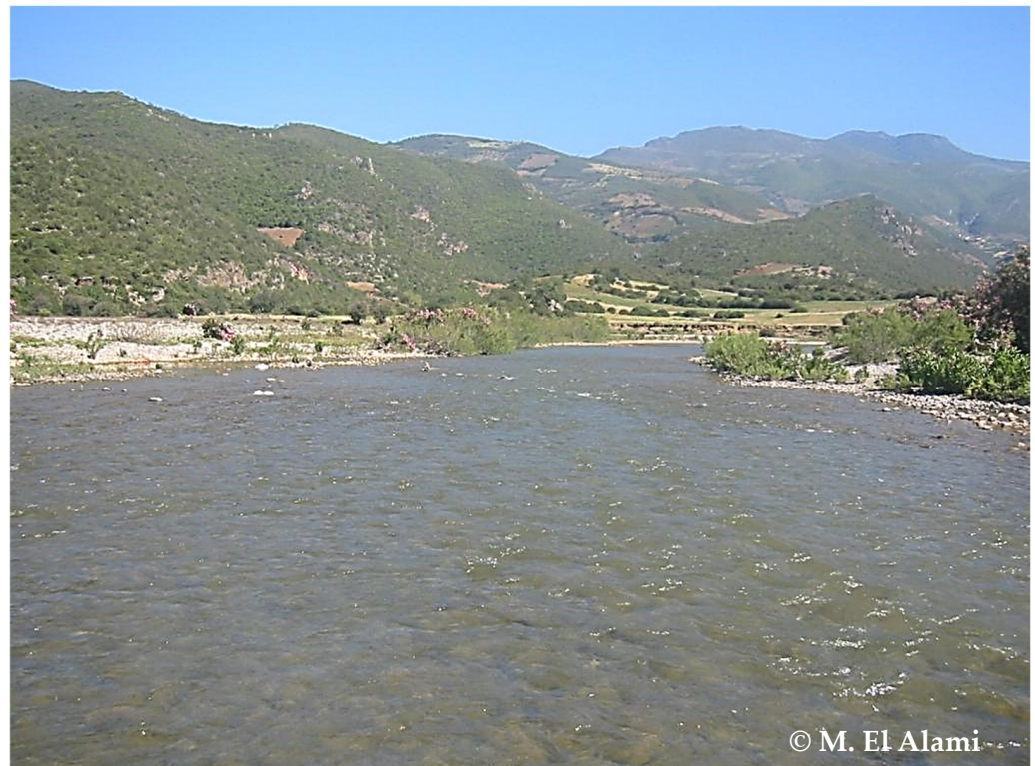
#### ***Baetis gr fuscatus***

In North Africa, this group was first found in Algeria where it was identified as *B. bioculatus* [60]. In Morocco, it seems to be absent in the Central Plateau and Oriental Morocco [33,39]. This is probably due to water warming which limits its development.

This species has a clear preference for temperate waters with moderate to low current. It favors biotopes with a stony bottom rich in gravel and pebbles which constitute a good refuge for the larvae [24].

#### ***Baetis gr lutheri***

In the Rif, specimens of *Baetis group lutheri* were preliminary identified as *B. meridionalis* [24,26,31]. They were sampled in 43 sites distributed over the lower wadis of Mediterranean and Atlantic hydrographic networks (Figure 4). Müller-Liebenau [95] mentioned the presence of *B. nigrescens* in Algeria, which also belongs to the *Baetis group lutheri*. Further studies are needed to know if the species is also present in Morocco.



**Figure 4.** Oued Laou a typical habitat of *Baetis gr lutheri*.

#### ***Baetis pavidus* Grandi 1949**

This West Mediterranean species is known from south-western Europe and the Maghreb [24,29]. It has a wide distribution and frequents the main hydrographic networks of different Moroccan areas. This broad latitudinal distribution is associated with a large altitudinal amplitude since it was collected between 5 and 2600 m a.s.l.

This species mostly colonizes temperate waters from middle and lower streams but can be also found at higher altitudes during the summer season.

#### ***Baetis (Rhodobaetis) gr rhodani***

This is an abundant and widespread species-group, made up of sibling species [96]. Three species belonging to the subgenus *Rhodobaetis* are reported by Soldán et al. from Algeria [97]. DNA barcodes are available for two of them and allow a secure identification [89]. In Morocco, *Baetis atlanticus* Soldán and Godunko 2006 has been generally reported under the name of *B. rhodani* in the Rif area where it has a wide distribution (El Yaagoubi et al.,



in preparation). *Baetis* gr *rhodani* is one of the most ubiquitous species complex and has a wide latitudinal distribution. It is also abundant in the cold waters with a fast to moderate velocity of current.

The revision of the identification of these species in different Moroccan areas will have to be carried out.

***Centroptilum* cf. *luteolum* (Müller, 1776)**

This genus is reported from the three Maghreb countries. A new species occurs in eastern Algeria [71]; the populations reported from Tunisia under *Centroptilum luteolum* [67,80] may correspond to this new species. In Morocco, the preliminary genetic and morphological studies revealed differences with populations of neighboring countries (Figure 5). Its distribution area is restricted in Morocco, as it is limited to the northern zone where it was collected in calm edge waters, loose substrate, low to moderate current, high temperatures, and sites rich in filamentous algae and mosses [24,26].



**Figure 5.** Habitus of *Centroptilum* cf. *luteolum* from the Rif.

***Cheleocloeon dimorphicum* (Soldán and Thomas, 1985)**

This Maghrebian endemic is distributed in the three Maghreb countries. In Morocco, it presents a rather discontinuous horizontal distribution since it was sampled in High Atlas [46,48,51,57], Oriental Morocco [33] and in the Rif [24,26,27,29]. It seems to be absent in the Middle Atlas and in the Central Plateau. This species deals with a wide range of habitats and occupies the permanent streams with stony bottom, moderate current and rich in plant debris.

***Cloeon* gr *dipterum* (Linné, 1761)**

*Cloeon* gr *dipterum* has a wide distribution [98]. In Morocco, it also has a large latitudinal and altitudinal distribution covering the Atlas and Rif areas, passing through the Central Plateau and Oriental Morocco. It mainly colonizes stagnant residual pools and pounds. This cosmopolitan taxon includes several cryptic species [98–101].

Recently, a morphological and genetic study made it possible to discover *Cloeon peregrinator* Gattolliat and Sartori, 2008 in Algeria [89]. In Morocco, this species has been identified under the name of *Cloeon dipterum* in the Rif area (El Yaagoubi et al., in preparation).

The revision of the identification of this species in different Moroccan areas will have to be carried out.

***Cloeon simile* Eaton, 1870**

This Palearctic species was reported by several authors from Algeria [61–63,78,84,85,102] and from north Tunisia [103]. In Morocco, this species seems more stenotopic than its congener *C. peregrinator* since it has been found in a restricted number of localities of the Rif [24] and of Oriental Morocco [33].

The larvae were found during the summer period when the temperatures are high enough. Its preferred biotopes are small streams with a moderate velocity, and with a dominant fine substrate (sand and gravel) and rich filamentous algae.

***Labiobaetis neglectus* (Navás, 1913)**

*Labiobaetis neglectus* is an Ibero-Maghrebian species, distributed in the three Maghreb countries. In Morocco, it has a fairly wide distribution area between the Rif [24,26,29], Oriental Morocco [33] and the Atlas [15,39,42,45,52]. This thermophilic species has a wide altitudinal and latitudinal distribution; it is abundant in permanent rivers at low and medium altitudes with moderate flow speeds. The larvae appear in spring, when the climate becomes temperate.

***Nigrobaetis numidicus* (Soldán and Thomas, 1983)**

This North African endemic is known only from Algeria and Morocco. It was first reported from streams in the Rif under the name *N. group gracilis* [24]. The revision of this species revealed it should be named *N. numidicus*. Less rare in Morocco than its congener *N. rhithralis*, this species has been found in streams of the Middle Atlas [45].

Found only at low altitude, this species seems to have a thermophilic tendency and present a clear preference for wide streams.

***Nigrobaetis rhithralis* (Soldán and Thomas, 1983)**

The distribution area of this Maghrebian endemic extends over the three Maghreb countries [24,89,103]. In Morocco, this species was first reported by El Alami et al. [31] under the name *Dipheter rhithralis*. It seems to present a limited ecological valence as it was only found in a restricted number of streams of the Rif.

The highest number of specimens was collected in a small stream with a quite cool water which crosses a fairly dense forest. The bed of the wadi is rich in sand; the riparian vegetation is abundant and prevents the heating of the water.

***Procloeon cf bifidum* (Bengtsson, 1912)**

In Morocco, this species has been found sporadically in some sites in the Rif area [24,26]. This species presents a great similarity with the Algerian species *Procloeon stagnicola* Soldán and Thomas, 1983. The article I of the maxillary palp is as wide as the article II with a more rounded apex; it is also characterized by lateral spines on the segments V to the XI segments. Genetic and morphological study would be necessary to confirm the identification of this species.

This species presents a discontinuous distribution. It favors the lower courses of temperate waters with low velocity, and shallow depth. The bottom is generally stony dominated by gravel and pebbles with submerged vegetation [24].

***Procloeon stagnicola* Soldán and Thomas, 1983**

In Morocco, the first mention of this North African endemic was made by Navás [11] who discovered it in the Tetouan region and who considered it as belonging to the Iberian species *Procloeon concinnum*. Similarly, studies that followed this discovery assigned the same name to this taxon [26,27,29,31]. Genetic analysis of Moroccan specimens revealed that it is indeed the species *P. stagnicola*. This species has a wide geographical distribution in Morocco since it has been found in the waterways of the different hydrographic networks.

Less altitudinal than its congener *P. bifidum*, it was collected in localities of the middle and lower reaches. It is a thermophilic species that has a clear preference for fine substrates rich in sand and gravel.

A genetic and morphologic analysis of *Procloeon* populations from Morocco; Algeria and Iberian Peninsula would be necessary to remove any ambiguity concerning the specific identification within this genus.

***Procloeon pennulatum* (Eaton, 1870)**

*Procloeon pennulatum* has a Holarctic distribution. In Maghreb, this species is only reported from Morocco where it has a wider distribution compared to that of its congeners mentioned above. It has been reported in the waterways of the Middle Atlas [42], High Atlas [46,52], Central Plateau [38,39], Oriental Morocco [32,33,36] and the Rif [23,24], in fairly large altitudinal distribution.

This species favors lentic and temperate waters and streams characterized by a sandy bottom and abundant aquatic vegetation.



### 3.1.10. Family Prosopistomatidae Latreille, 1833

#### *Prosopistoma* sp.1

This species was found for the first time in Morocco by Touabay et al. [88] who collected it in a Middle Atlas stream. So far, only one species has been mentioned in North Africa, *Prosopistoma alaini* Bojkova and Soldán 2015, described from Algeria. This Moroccan species is on the way to be described and has a fairly limited distribution.

#### 3.2. Biogeographical Affinities of Moroccan Ephemeroptera

The analysis of Ephemeroptera species composition in Morocco, based on the chorological categories assigned to each taxon, shows that they can be divided essentially in Mediterranean species (68.7%), followed by Palaearctic elements (20.4%) and lastly, the elements with wide distribution (3.7%). Four taxa have an unknown distribution (7.4%) because their identification is doubtful and requires revision. This same ratio has been found by other authors and among neighboring countries [24,29,30,33,42,68,78,89].

Likewise, within the Mediterranean elements, four distribution categories have been observed and showed a clear dominance of the Moroccan endemics, followed by the Ibero-Maghrebian ones, the Maghrebian endemics and finally the west Mediterranean elements:

- Moroccan endemics: *A. oukaimeden*, *Alainites* sp1, *B. berberus*, *C. gr luteolum*, *B. gr lutheri*, *B. gr fuscatus*, *C. (Choroterpes) volubilis*, *H. assefae*, *H. vaillantorum*, *Habrophlebia* sp.1, *O. skoura*, *E. ifranensis*, *R. ayadi*, *R. giudicellorum*, *R. mariae*, *R. ourika*, *R. ryszardi*; *Prosopistoma* sp1.
- Ibero-Maghrebian endemics: *B. maurus*, *B. punicus*, *P. concinnum*, *L. neglectus*, *A. almohades*, *O. skhounate*, *Habrophlebia* sp.2 and *S. cf. kabyliensis*.
- Maghrebian endemics: *C. dimorphicum*, *N. rhithralis*, *N. numidicus*, *P. stagnicola*, *C. (Choroterpes) atlas*, *C. (Euthraulius) lindrothi*, *Thraulius* sp1, *E. rothschildi* and *B. gr alpinus*.
- Atlanto-mediterranean species: *B. atlanticus*, *B. pavidus*, *C. peregrinator*.

This general pattern could change soon with the revision of some species whose identification is still doubtful.

## 4. Discussion

We have recorded 54 Ephemeroptera species belonging to 10 families, including some new taxa, still waiting to be described. The richness of this mayflies community is lower than that recorded in some regions of the northern Mediterranean countries neighboring Morocco [104,105]. The Mediterranean climate with strong fluctuations of temperature and rainfalls, the freshwater ecosystems with a temporary pattern [4,106], the considerable mineralization of lower courses and the wide annual thermal amplitudes [42,107–109] could explain this impoverishment.

Based on the present knowledge, the comparison of the mayflies diversity between different Moroccan biogeographical areas revealed that the Rif (37 species) has a more diversified fauna than Middle Atlas (31 species), High Atlas (30 species), Oriental Morocco (24 species) and finally Central Plateau (19 species). The coolness of the Rif climate would have favored the conservation and the colonization of some species of European origin (such as *Baetis* gr. *lutheri* and *Centroptilum* gr. *luteolum*) whose presence could not be detected in other Moroccan regions. Despite the high altitudes at which the High Atlas streams originate (2600–3000 m a.s.l.), the diversity seems lower. This is probably due to climatic constraints combined with anthropogenic impacts on macroinvertebrate populations that limit the development of orophilic and cold water stenothermal taxa [42,52,58]. In addition, the high number of temporary streams and springs in Central Plateau [39] and Oriental Morocco [32,33,35] does not represent suitable habitats for rheophilous species preferring the cool waters of upper streams. The High Atlas encompasses the highest number of endemics (10 spp) with five microendemics which are found only in this area (*A. oukaimeden*, *B. berberus*, *R. giudicellorum*, *R. ourika*, *H. vaillantorum*), followed by the Rif with nine endemics and three microendemics species (*Habrophlebia* sp.1, *Baetis* gr.

*lutheri*, *Centroptilum* cf. *luteolum*), Middle Atlas (8 spp) with three microendemics species (*R. ayadi*, *R. ryzardi*, *Prosopistoma* sp1), Oriental Morocco (5 spp) with, probably, only one microendemic species (*Thraulius* sp1) and finally Central Plateau (3 spp).

A comparison between Ephemeroptera fauna species richness from different regions of the Maghreb shows that Tunisia streams have a lower specific diversity [67,76,80,104] than Morocco and Algeria [24,42,65,71,77,89,109–111]. In addition, the analysis of the species similarity between neighboring countries shows that Morocco and Algeria have more species in common than Tunisia. They share 22 species, 13 of them are endemics to Maghreb (*B. maurus*, *B. punicus*, *C. dimorphicum*, *L. neglectus*, *N. numidicus*, *N. rhithralis*, *E. ifranensis*, *E. rothschildi*, *C. (Choroterpes) atlas*, *C. (Euthraulius) lindrothi* O. *skhounate*) and nine are found beyond the Maghreb and the Iberian Peninsula (*B. atlanticus*, *B. pavidus*, *C. peregrinator*, *C. simile*, *P. pennulatum*, *P. cincta*, *P. luteus*, *E. virgo*, *E. glaucops*, *C. luctuosa*, *C. pusilla*). Morocco and Tunisia have 13 species in common which are also present in Algeria. The Rif area appears to be the Moroccan region with the most species in common with the Iberian Peninsula (*B. punicus*, *N. rhithralis*, *L. neglectus*, *A. almohades*, *P. concinnum*). This indicates that these neighboring regions have probably the same palaeogeographical evolution.

The Moroccan palaeogeographical history most probably explains the dominance of Palearctic components in the Moroccan mayfly fauna. Afrotropical components remain very limited (*Oligoneuriopsis* and *Chelecloeon*). The Mediterranean partition into sub-regions separated by strong reliefs has favored the speciation in other taxa groups such as mammals [112]. Thus, the rate of Moroccan endemism in the mayfly populations is higher than other macroinvertebrate groups where the Ibero-Maghrebian and/or Maghrebian elements prevail over the Moroccan endemics [24,29,30,33,35,113–115]. The present situation can be explained by the Mediterranean paleogeography. The formation of the Betic-Rifian massif [116–118] and the Messinian Crisis [119,120] permitted an important fauna interchanges between northern of Morocco and Western Europe [121]; the tropical and sub-tropical macroinvertebrates, that inhabited the Moroccan hydrographic networks at that time, possibly passed into Iberic Peninsula [42]. This passage would also, testify the presence of hydrographic networks [118] which favored the intercontinental exchanges of many aquatic macroinvertebrates, including Ephemeroptera larvae whose dispersal is limited. Mayflies imagines are fragile and have a short life, so their dispersion ability is rather limited and could be mostly passive by the winds [24]. Thus, the Rif received Iberian species, which explains the species with European origin, the important diversity and endemism [122] in this part of the country. Also, the formation of barriers isolated the African continent from Europe and Asia and the quaternary climate changes has favored the taxa speciation independently of their Eurasian congeners (*B. berberus*, *H. assefae*) ensuring the increase rate of mountainous endemism in the Mediterranean regions [24,42]. Similarly, the arid Saharan climate shift 12,000 years ago [123] has divided the Maghreb into two distinct zones, separated by the Atlas Mountains. The fauna had evolved there totally isolated, which explains, also, the high rate of Moroccan endemics in mountains [42].

## 5. Conclusions

Morocco can be considered as one of the hotspots of Ephemeroptera biodiversity in North Africa. The endemism rate could even increase with the intensification of prospections in areas not/or rarely studied such as the Anti-Atlas and the Moroccan Sahara. In addition, taxonomic revision and genetic analysis could validate the hypothesis of new species and elucidate the affiliation of some others.

In order to improve our knowledge of Moroccan fauna, the production of a distribution map, a red list of Moroccan Ephemeroptera would be interesting insofar as Moroccan endemics are located in vulnerable habitats, subject to strong anthropogenic pressures combined with increasing drought events. Thus, the protection measures and the conservation of these habitats are necessary to avoid their degradation. Furthermore, it would be critical to provide tools to preserve Moroccan biodiversity, particularly endemics, sensitive to global changes.

**Author Contributions:** Conceptualization, M.E.A.; methodology, M.E.A.; software, M.E.A.; validation, M.S., J.-L.G. and M.D.; formal analysis, M.E.A.; investigation, M.E.A., S.E.Y. and M.D.; resources, M.E.A. and M.D.; data curation, M.E.A.; writing—original draft preparation, M.E.A.; writing—review and editing, all co-authors.; visualization, M.E.A., J.-L.G. and M.S.; supervision, M.E.A., J.-L.G. and M.S.; project administration, M.E.A.; funding acquisition, M.E.A. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data is available from the corresponding author upon request.

**Acknowledgments:** The first author want to thank Laurent Vuataz for his help in the genetic analysis of *Rhithrogena*. We are most grateful to Jallal Kassout for cartography support.

**Conflicts of Interest:** The authors declare no conflict of interest.

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