Biosystems Diversity

ISSN 2519-8513 (Print)
ISSN 2520-2529 (Online)
Biosyst. Divers.

Spatiotemporal dynamics of endemic macroinvertebrates in the Martil Basin (Morocco): Responses to hydroclimatic variability and anthropogenic disturbances

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Article info

Received 18.04.2025
Received in revised form 14.05.2025
Accepted 10.06.2025

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Guellaf, A., Bennas, N., El Alami, M., & Kettani, K. (2025). Spatiotemporal dynamics of endemic macroinvertebrates in the Martil Basin (Morocco): Responses to hydroclimatic variability and anthropogenic disturbances. Biosystems Diversity, 33(3), e2534. doi:10.15421/012534

This study investigates the responses of endemic macroinvertebrate species in the Martil River Basin (Morocco) to physicochemical (T, pH, Cond and DO), land use, biotic indices (IBMWP, IHF and QBR), and hydro-morphological factors. Sampling was conducted over four seasons (2017) at 19 stations, revealing 1,768 individuals belonging to 32 endemic species. *Hydropsyche iberomaroccana* was the most abundant species, while *Choroterpes volubilis* was the most widespread. Biogeographical analysis highlighted a high proportion of Ibero-Maghrebian endemics. Multivariate analyses revealed significant biotypological differences among stream types, with sensitive endemic species predominantly found in highland / midland permanent stations, positively correlated with dissolved oxygen, altitude, and biotic indices. In contrast, lentic, thermophilic, and eurytopic species were more common in downstream areas, exposed to agricultural, industrial, and urban activities, and associated with higher temperatures and pollution levels. Seasonal and spatial variability in taxonomic composition was strongly influenced by hydrological intermittency and human pressures, with endemic species diversity and abundance peaking in spring. Despite their ecological importance, with the exception of Odonata, none of the species from other orders are currently listed on the IUCN Red List or in Annex IV of Moroccan Law 29-05 concerning the protection of wild flora and fauna species and the control of their trade. The findings underscore the urgent need for targeted conservation strategies to address threats from climate change, habitat degradation, and anthropogenic activities.

Keywords: aquatic insects; endemic species; Martil Basin; Morocco; Mediterranean ecosystems.

Introduction

The Mediterranean Basin is one of the most important biodiversity hotspots (Myers et al., 2000), and hosts unique aquatic ecosystems, including rare and endemic species. Nevertheless, this region is considered one of the most sensitive areas to climate change and human activities (Sanchez-Fernández et al., 2004; Belhaj et al., 2024; Espinar-Herranz et al., 2025). Seasonal and interannual hydroclimatic changes, increasing drought severity, altering flow patterns and physicochemical characteristics, and rising temperatures are reducing habitat availability, hydrological connectivity, and increased pollutant concentration (Balzan et al, 2020; Zerrouk et al., 2021).

In general, the intensity and duration of flood and drought phases, along with hydrological conditions (substrate type and its permeability, annual precipitation regimes, and land use) in the Mediterranean biogeographical region play a key role in shaping the distribution of lotic, lentic, and terrestrial habitats (Bonada et al., 2007, 2020). These factors drive the dynamic shifts between flowing water, isolated pools, and dry phases (Datry et al., 2016; Banegas-Medina, 2021), ultimately determining the nature of stream systems, whether perennial or temporary (intermittent and ephemeral) (Bogan et al., 2013; Giam et al., 2017).

Macroinvertebrate assemblages in intermittent streams display strong seasonal turnover compared to those in perennial streams. Aquatic biota inhabiting intermittent streams must possess either drought resistance traits (desiccation-resistant eggs, long-lived or highly mobile terrestrial adult stages) (Strachan et al., 2015; Carey et al., 2023). Consequently, many endemic Mediterranean species face significant threats, including drastic range reductions, shifts in community composition, and potential extinction, and are often associated with perennial streams (Davies & Stewart, 2013; Carey et al., 2023). Changes in flow regimes and physicochemical characteristics are expected to favor the invasion of non-native species with higher tolerance to increased temperatures and pollution, leading to biotic homogenization and the loss of endemic species, further altering the ecological integrity of these hydrosystems (Clavero & Garcia-Berthou, 2006; Filipe et al., 2013).

Morocco is a region of significant biogeographic importance, recognized as one of the richest biodiverse areas in the Mediterranean basin (Laouina, 2006). This richness is particularly evident in its insect fauna, which constitutes a major component of the country's biodiversity. Among these, aquatic insects play a critical role in freshwater ecosystems, with over 2,051 species recorded in Morocco to date (Ennabili et al., 2025).

However, the combined effects of natural and human-induced stressors, caused by anthropogenic activities and increased aridity due to climate change (Faramarzi et al., 2013; Khelifa et al., 2021) have restricted endemic and ecologically specialized species to limited areas (Ribera et al., 2011; Trizzino et al., 2015). In the current situation, the only protection available to these species is the extent to which they occur in protected areas designated on the basis of other taxa or habitat features (Sánchez-Fernández et al., 2008).

However, despite numerous faunistic and taxonomic studies conducted in recent years, our understanding of freshwater macroinvertebrate patterns, functional traits, distributional data, and life history information for many endemic species in Morocco remains limited (El Haissoufi et al., 2015).

This knowledge gap arises from insufficient taxonomic expertise and a lack of data on macroinvertebrate species, particularly in southern regions of Morocco. Additionally, since the national study on aquatic fauna by Dakki (1997), inventories of aquatic species have been limited, and no comprehensive database compiling Moroccan aquatic species and their distributions exists based on existing studies (Belhaj et al., 2023a). A synthetic study on the aquatic biodiversity of Morocco, based on a recompilation of published works, was recently published (Ennabili et al., 2025). It provides valuable information on the state of knowledge regarding the aquatic biodiversity, both fauna and flora, of Morocco. However, the inventories have not been recompiled, as was the case in Dakki's national study (1997). Furthermore, this gap in the publication of updated national databases is

exacerbated by the fact that most IUCN criteria are tailored for vertebrates and vascular plants, which systematically excludes macroinvertebrates from national conservation strategies (Benamar et al., 2021c). Additionally, with the exception of Odonata and the beetle *Acilius duvergeri* Gober, 1874, none of aquatic insect species are currently listed on the IUCN Red List or under Appendix IV of Law 29-05.

In this regard, there is an urgent need to better understand hydroclimatic variability, functional traits, and adaptation strategies of sensitive and endemic macroinvertebrate species, as well as to integrate biotic approaches into aquatic ecosystem management programs. Such efforts are essential to provide a comprehensive overview of the state of aquatic biodiversity in Morocco (Fernández-Calero et al., 2024).

The Martil Basin, in this context, serves as an excellent example of a site where the combined effects of seasonal variation, envi-ronmental factors, and human pressures on endemic macroinvertebrate species are studied. Located in the Mediterranean Inter-continental Biosphere Reserve, the Martil Basin is particularly impacted by various agricultural, urban, and industrial activities, especially in the lowland part.

In this framework, the main objectives of this study are: (1) to analyze the composition, variation, and distribution of endemic macroinvertebrates in the Martil Basin, (2) to evaluate the spatial and seasonal distribution patterns of the recorded species across the basin, from upstream to downstream, and (3) to examine the responses of endemic species to the altitudinal gradient, land use, hydrological characteristics, as well as biotic and habitat indices of the sampling sites.

Materials and methods

The Martil River Basin is situated in the northwestern part of Morocco, within the Tangier-Tetouan-Al Hoceima region. It covers an area of approximately 1,259 km², extending from the Mediterranean coast to the mountainous domains of the Rif (Guellaf & Kettani, 2021a). The basin spans altitudes ranging from 0 m at the coastline to 1,782 m at its highest peaks, with an average elevation of 424 m (Karrouchi et al., 2016) (Fig. 1).

The Martil Basin is part of the Intercontinental Biosphere Reserve of the Mediterranean (IBRM), with its southern section included within the Bouhachem Natural Park. This area is recognized as a region of high biodiversity and endemicity. The climate is typically Mediterranean, characterized by two distinct seasons: a wet, cool season from October to April and a dry, hot season from May to September. Annual precipitation varies between 500 and 750 mm, with the majority of rainfall occurring during the wet season. The average annual temperature ranges from 15 to 19 °C (Karrouchi et al., 2016; Salhi et al., 2019).

The Martil River is characterized by intermittency and an irregular hydrological regime, with strong seasonal contrasts. The river is fed by three main tributaries, Oueds Mhajrat, Khemis, and Chekkoûr, which converge to supply the Oued Martil. It then flows through the Martil plain and the urban area of Tetouan before discharging into the Mediterranean Sea near the city of Martil (Karrouchi et al., 2016; Guellaf & Kettani, 2021b).

Regarding land use, the upstream areas are predominantly covered by forests, garrigue and maquis, while traditional agricultural practices characterize mid-altitude zones. In contrast, the downstream areas are dominated by intensive agriculture, industrial activities, and the urban development of Tetouan and Martil (Guellaf et al., 2021).

Sampling was conducted over an annual cycle (winter, spring, summer and autumn 2017) at 19 stations distributed among 10 watercourses: Oued Tkaraa (TK), Taida (TA), Hamma (HM), El Kebir (KB), Nakhla (NK), Zarka (ZR), Chekkoûr (CH), Mhajrat (MH), Khemis (KH), and Oued Martil (MA).

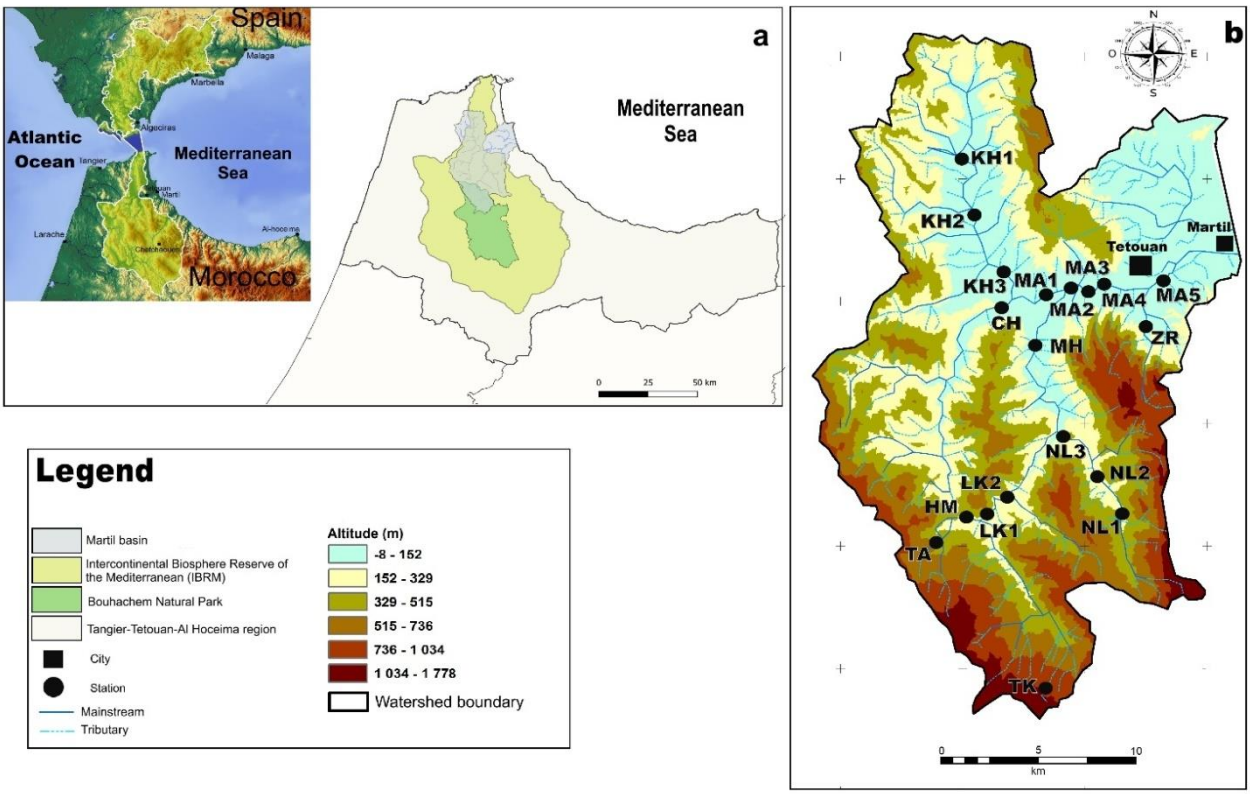

Fig. 1. Location of the Martil Basin (Morocco) (*a*) and the sampling sites (*b*)

Macroinvertebrate sampling was conducted seasonally across all surveyed sites. Two sampling techniques were employed, the Surber sampler (20 × 20 cm), opening against the current to collect organisms from riffle zones, and the kick sampling method using a standard hand net (25 × 25 cm), used by kicking and sweeping through submerged vegetation, riverbanks, pools, and sediment areas, in order to take into account all available microhabitats.

Following collection, specimens were immediately separated from debris such as stones, plant debris, and other materials to minimize damage to the specimen, then preserved in plastic jars filled with 90% alcohol, and transported for further analysis. In the laboratory, macroinvertebrates were sorted, counted, and initially identified to the family level under a binocular microscope using the taxonomic keys of Sansoni (1992) and Tachet et al. (2002). The identification of en-

demic species was carried out with the assistance of taxonomic specialists from our research team at the Laboratory of Ecology, Systematics, and Biodiversity Conservation.

Furthermore, from the list of identified species, we selected only the endemic species relevant to our study. Each species was classified into the chorological categories according to their distribution area, Ibero-Maghrebian (Ib-Mag), Maghrebian (Mag) and Moroccan (Mor), and into functional feeding groups (FFGs), including Collector-Gatherers (CG), Filterers (Fi), Omnivores (O), Shredders (Sh), Scrapers (Sc), and Predators (Pr), following the classifications proposed by Cummins (1974). The functional habits groups (FHGs) of species were also categorized into Clingers (Cg), Climbers (Cb), Crawlers (Cr), Sprawlers (Sp), Burrowers (Bu), Swimmers (Sw), and Skaters (Sk), based on the criteria of Cummins (1974) and Merritt & Cummins (1996).

To evaluate the ecological status of the studied river systems, three biotic indices were applied in accordance with the ecological status in the Mediterranean streams assessment protocols. (Jáimez-Cuéllar et al., 2002). The Iberian Biological Monitoring Working Party (IBMWP) index was applied to evaluate the biological quality of the water based on the sensitivity of macroinvertebrate families to pollution (Alba-Tercedor et al., 2002). The River Habitat Index (IHF) was used to assess the physical characteristics of the aquatic habitat, including its heterogeneity and dynamics, which influence the structure of benthic communities (Pardo et al., 2002). The Riparian Quality Index (QBR) was used to assess the condition of riparian vegetation and its ecological functionality (Munné et al., 1998, 2003). Physico-chemical and hydrological factors were also measured at each sampling site immediately before macroinvertebrate sampling. water temperature (°C), pH, electrical conductivity (µS/cm), and dissolved oxygen (mg/L) were measured in the field using a portable multiparameter probe (EUTECH CyberScan PCD 650). Hydrological characteristics were evaluated based on stream depth (m), width (m), and current velocity (m/s), measured at each station, with three replicate measurements. In addition, a 500-meter radius buffer was created around each sampling site using ArcGIS 10 to calculate the proportion of different land use variables (Natural, Agricultural, and Urban).

Descriptive statistics (mean ± SD) were used to characterize environmental variables and biotic data distributions. Spatiotemporal patterns of endemic species abundance were visualized through chord diagrams using OriginPro 2024. Factorial Component Analysis (FCA) was employed to assess species-season relationships, while Canonical Correspondence Analysis (CCA) explored the correlations between endemic species, sites, biotic and environmental factors. Multivariate analyses were conducted using XLSTAT 2024.

Results

The results of the present study revealed 10,453 occurrences of aquatic macroinvertebrates, representing 174 different aquatic taxa collected throughout four seasonal campaigns in 2017 in 19 sampling sites from the Martil Basin. Among our occurrence data, 1,768 individuals representing 32 species are broadly defined as endemic species, with distributions restricted to Morocco, the Maghreb, or the Ibero-Maghrebian region (Table 1).

Table 1
Abundances, functional traits, and chorological categories of endemic species recorded in the Martil Basin during the survey period

Species	Code	Chorotype	FFG	FHG	Winter	Spring	Summer	Autumn
Ephemeroptera								
Acentrella almohades Alba-Tercedor & El Alami, 1999	Aal	Ib–Mag	CG	Cg	28	11	53	2
Baetis maurus Kimmins, 1938	Bma	Ib–Mag	CG	Cg	37	12	1	8
Baetis punicus Thomas, Boumaiza & Soldan, 1983	Bpu	Ib–Mag	CG	Cg	86	28	–	80
Procloean concinnum Eaton, 1885	Pco	Ib–Mag	CG	Sw	–	2	5	–
Ecdyonurus rothschildi Navás, 1929	Ero	Ib–Mag	CG	Cg	6	17	9	14
Choroterpes atlas Soldan et Thomas, 1983	Chat	Mag	CG	Cg	–	1	1	–
Choroterpes volubilis Thomas et Vitte, 1988	Cvo	Mor	CG	Cg	5	185	57	–
Plecoptera								
Hemimelaena flaviventris (Pictet, 1841)	Hfl	Ib–Mag	Pr	Cg	21	9	–	–
Isoperla kir Fochetti & Vinçon, 1993	Iki	Mor	Pr	Cg	14	87	4	16
Siphonoperla lepineyi (Navás, 1935)	Sle	Mor	Pr	Cg	–	6	3	–
Brachyptera algirica Aubert, 1956	Bal	Mag	Sh	Sp	18	1	–	–
Capnopsis schilleri (Rostock, 1892)	Csc	Mor	Pr	Cg	2	–	–	31
Trichoptera								
Rhyacophila fonticola Giudicelli & Dakki, 1984	Rfo	Ib–Mag	Pr	Cg	–	–	–	1
Cheumatopsyche atlantis Navás, 1930	Cat	Mag	Fi	Cg	–	–	–	4
Hydropsyche fezana Navás, 1935	Hfe	Mag	Fi	Cg	2	12	–	4
Hydropsyche iberomaroccana González & Malicky, 1999	Hib	Ib–Mag	Fi	Cg	32	169	179	165
Hydropsyche lobata McLachlan, 1884	Hlo	Ib–Mag	Fi	Cg	1	1	23	37
Hydropsyche maroccana Navás, 1936	Hma	Ib–Mag	Fi	Cg	–	3	6	–
Odonata								
Cordulegaster boltonii algirica Morton, 1916	Cba	Ib–Mag	Pr	Bu	2	3	2	3
Coleoptera								
Helophorus algiricus Motschulsky, 1860	Hal	Mag	Sh	Sw	–	1	–	–
Helophorus atlantis Angus & Aouad, 2009	Hat	Mor	Sh	Sw	–	1	–	–
Hydrochus aljibensis Castro & Delgado, 1999	Hal	Ib–Mag	Sh	Sw	2	–	–	–
Hydraena allomorpha Fresneda & Lagar, 1991	Hall	Ib–Mag	Sc	Cg	–	1	6	2
Hydraena bisulcata Rey, 1884	Hbi	Ib–Mag	Sc	Cg	–	2	3	–
Hydraena rigua Orchymont, 1931	Hri	Mag	Sc	Cg	–	7	7	11
Elmis maugetii velutina Reiche, 1879	Ema	Mag	Sh	Cg	2	5	26	6
Oulimnius fuscipes (Reiche, 1879)	Ofu	Ib–Mag	Sh	Cg	–	8	–	–
Hemiptera								
Gerris brasili Poisson, 1941	Gbr	Ib–Mag	Pr	Sk	1	1	3	–
Velia ioannis Tamanini, 1971	Vio	Mag	Pr	Sk	7	42	2	9
Velia noualhieri Puton, 1889	Vno	Ib–Mag	Pr	Sk	1	–	–	2
Parasigara rivularis Baena, 1997	Pri	Ib–Mag	Pr	Sw	1	17	47	11
Parasigara transversa (Fieber, 1848)	Ptr	Ib–Mag	Pr	Sw	1	–	22	2

The Martil Basin alone harbors more than 17% of all the aquatic insect species endemic to Morocco. At the order level, it harbors more than 35% of the endemic Hemiptera species in Morocco, between 20% and 28% of the endemic Ephemeroptera, Trichoptera, and Plecoptera species in Morocco, and between 9% and 11% of the endemic Coleoptera and Odonata species in Morocco.

The genus *Hydropsyche* (Trichoptera) showed the highest number of endemic species and records (4 species). The most predominant groups were *Hydropsyche iberomaroccana* (31%), *Choroterpes volubilis* (14%), and *Baetis punicus* (11%). *Choroterpes volubilis* was the most widespread species, occurring in 16 sites.

The highest species richness was observed in the spring (27 species), followed by summer and winter with 21 species each, and autumn with 20 species. The greatest abundance was recorded in spring with 702 individuals. With regard to the sampling sites, Oued Tkaraa (TK) was the richest one in terms of total endemic species richness (15 species). In contrast, MA3 and MA4, located downstream of Oued Martil, registered the lowest number of species richness with only one endemic species. Oued Zarka (ZR) exhibited the greatest abundance with 1,803 individuals (Fig. 2).

The analysis of species composition, based on the chorological categories, reveals that the majority are composed of Ibero-Maghrebian elements (20 species), representing 80% of the total abundance. This is followed by Maghrebian elements (8 species), accounting for 8%, and finally, 4 species typically found in Morocco, which represent 12% of the total abundance.

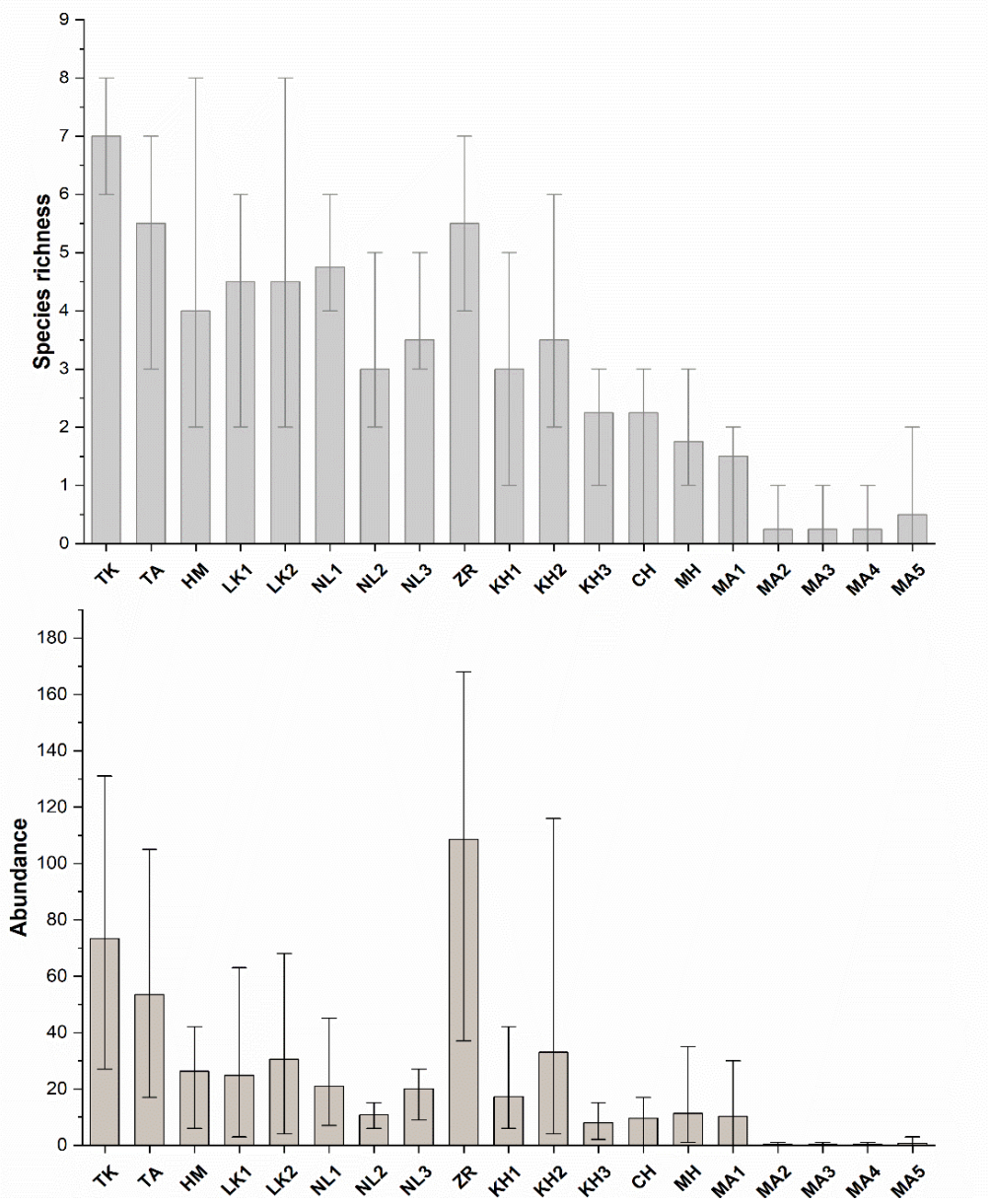

Fig. 2. Bar charts (mean, min-max) showing the seasonal variations in richness and abundance of endemic species across the sampled stations throughout the study period in the Martil Basin

Collector-gatherers were the most recorded functional feeding group with 39% of the total abundance. The proportion of Collector-Gatherers and Filterers showed contrasting patterns, Collector-Gatherers were most abundant in winter and spring, while Filterers dominated in summer and autumn. The other functional feeding groups remained relatively stable across seasons.

Regarding functional habit groups, Clingers dominated throughout the study period, representing 89% of the total individuals recorded, with a relatively stable occurrence across seasons. They were followed by swimmers, which accounted for 6% of the total abundance, while the other groups showed low percentages (Fig. 3).

The analysis of the collected samples reveals a clear dominance of Ephemeroptera and Trichoptera, which together account for more than 74% of the total abundance in the study area. endemic species of Ephemeroptera exhibit a widespread distribution across the sampling stations (Fig. 4a), with notably high proportions in permanent watercourses, especially at TK, TA, and ZR. Trichoptera are predominantly abundant in mid-streams, with ZR showing the highest proportion. In contrast, Plecoptera species are restricted to upstream stations such as TK and TA. The endemic species of Coleoptera and Hemiptera, while less abundant overall, were observed across stations from upstream to downstream. Notably, the only endemic species of the Odonata order was exclusively recorded at the TK station.

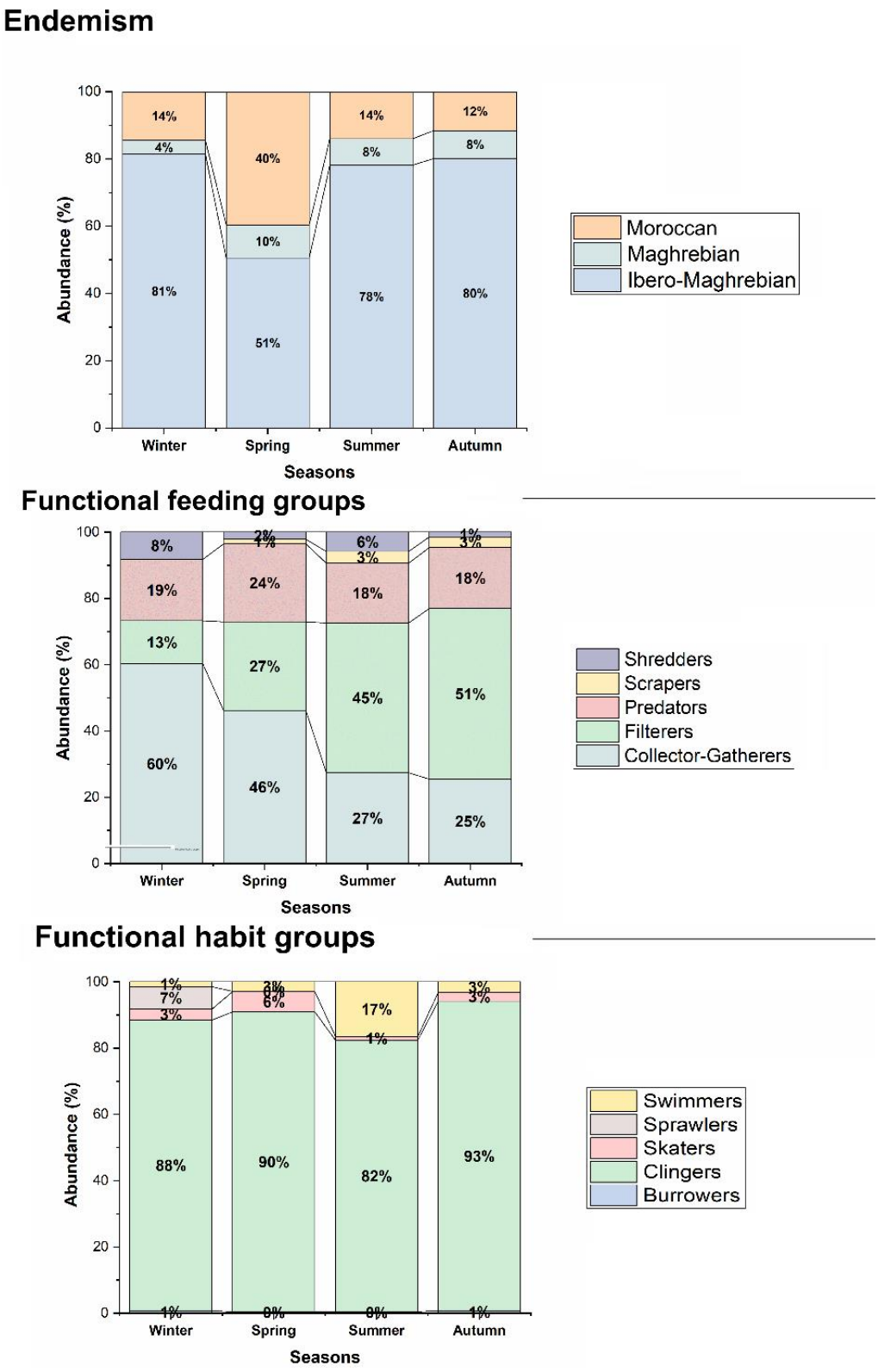

Fig. 3. Seasonal variation in the percentage abundance of endemic species based on their chorological, FFGs, and FHGs categories

Figure 4b further highlights the influence of seasonal conditions on species distribution and abundance. Spring was the most biodiverse and abundant season, with Ephemeroptera being particularly well-represented during the wet seasons (winter and spring). Plecoptera follow a similar trend, suggesting their reliance on wet conditions. Trichoptera exhibits elevated proportions during spring, summer, and autumn, indicating a preference for calmer and more stable environmental conditions. In contrast, OCH species also favor dry seasons and stable conditions. Hemiptera show a significant presence in spring and summer, while Coleoptera are most abundant during the summer.

Correspondence analysis (CA) was used to identify species groupings according to seasonal variation. The first two axes (CA1 and CA2) explained 45.59% and 33.03% of the total inertia. The CA revealed a distinct separation of species between seasons during the study period in the Martil Basin (Fig. 5).

Group A: this group is composed of *Baetis maurus*, *Brachyptera algirica*, and *Hemimelaena flaviventris*, belonging to Ephemeroptera and Plecoptera, which are plotted in the upper right side of the CA plot and mainly observed during flowing conditions in the winter season.

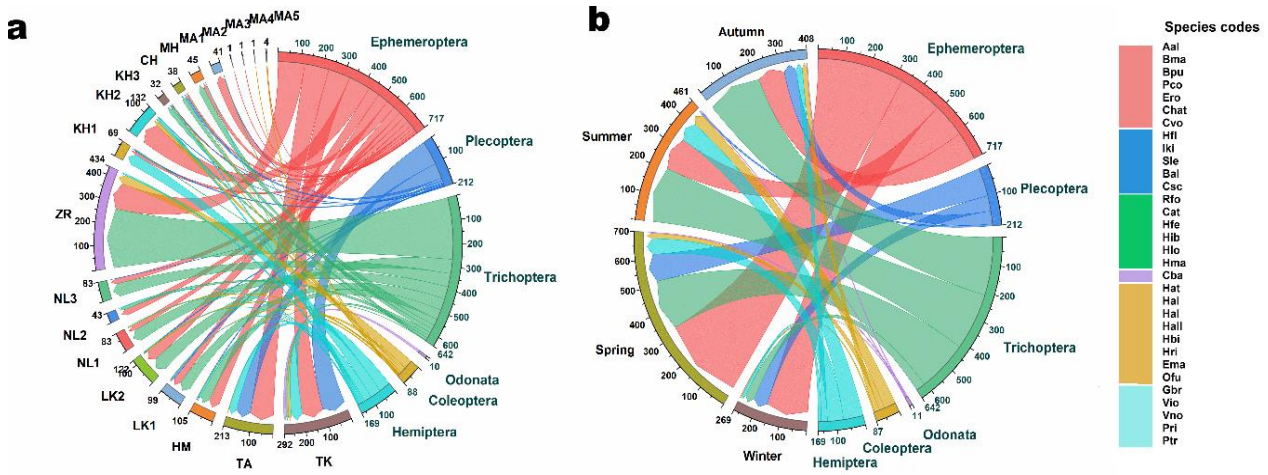

Fig. 4. Chord diagram showing the distribution of endemic species based on their abundance across the sampling sites (*a*) and the four seasons during the study period (*b*)

Group B: this group consists of eurythermic EPT taxa, including *Choroterpes volubilis*, *Choroterpes atlas*, *Isoperla kir*, *Siphoperla lepineyi*, *Hydropsyche fezana*, and OCH taxa such as *Helophorus atlantis*, *Helophorus algiricus*, and *Oulimnius fuscipes*. These species showed a preference for the spring period and stable hydrological conditions.

Group C: this group includes thermophilic EPT taxa such as *Procloeon concinnum*, *Hydropsyche iberomaroccana*, and *Hydropsyche maroccana*, as well as OCH lentic species like *Elmis maugetii velutina*, *Gerris brasiliensis*, *Hydraena allomorpha*, *Hydraena bisulcata*, *Hydraena rigua*, *Parasigara rivularis*, and *Parasigara transversa*, and exhibited a preference for the calm waters of the summer season.

Group D: this group comprises *Acentrella almohades*, *Baetis punicus*, *Ecdyonurus rothschildi*, *Capnopsis schilleri*, *Cheumatopsyche atlantis*, *Rhyacophila fonticola*, *Cordulegaster boltonii algirica*, and *Velia noualhieri*. These species were observed during the transition phase between the dry and rewetting periods in autumn.

Relationship between endemic species and environmental variables. Table 2 presents the spatio-temporal variations in physico-chemical, land use, hydrological, and ecological conditions across the four distinct river systems within the Martil Basin: natural, permanent rivers in the upstream southwest (S-W), limestone-based permanent rivers in midtream agricultural area (S-E), intermittent agricultural rivers in the northwest (N-W), and the urban-agricultural Oued Martil downstream (N-E).

Results showed increasing temperatures (16.5–20.5 °C) and conductivity (300–871 µS/cm) from upstream to downstream, alongside declining dissolved oxygen (8.21–2.59 mg/L). Land use shifted from natural cover in the upper reaches (74% in S-W) to agricul-tural and urban dominance in the lower basin. Hydrological metrics, particularly current speed, varied significantly between permanent mountainous streams, intermittent reaches, and downstream sections. Biotic indices (IBMWP, QBR, IHF) revealed higher ecological integrity in upstream natural areas (e.g., IBMWP: 80.7 vs 25.6 in N-E), demonstrating progressive degradation as we go further downstream.

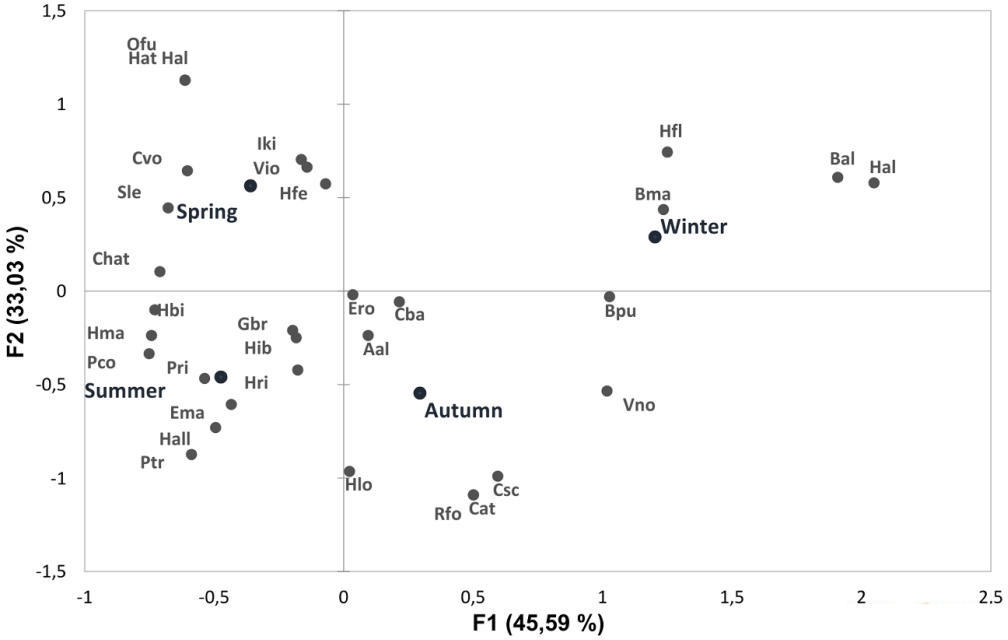

Fig. 5. Factorial component analysis (FCA) triplot illustrating the distribution of endemic species across seasons

Canonical correspondence analysis (CCA) was conducted to determine the relationships between endemic species, land use and environmental variables across sampling sites. The first two CCA axes explained 61.7% of the total variation (axis 1: 47.0% and axis 2: 14.7%).

IBMWP, IHF, QBR and DO exhibited a strong positive association with sensitive endemic species such as *Baetis punicus*, *Brachyptera algirica*, *Capnopsis schilleri*, *Siphoperla lepineyi*, *Isoperla kir*, *Hemimelaena flaviventris*, and *Rhyacophila fonticola*, which are adapted to lotic conditions, and lentic species such as *Cordulegaster boltonii algirica*, *Helophorus algiricus*, *Hydraena allomorpha*, *Velia ioannis*, *Gerris brasili*, typically inhabiting upstream stations (TK and TA), were grouped in the lower left part of the biplot.

Table 2
Environmental characteristics and biotic indices (mean ± SD) of the four distinct river systems within the Martil River during the study period

Factors	S-W	S-E	N-W	N-E
	TK-TA-HM-LK	NL-ZR	MH-CH-KH	MA
Physico-chemical				
T	16.50 ± 2.49	18.10 ± 1.25	18.90 ± 0.67	20.50 ± 0.73
pH	7.71 ± 0.20	7.71 ± 0.07	7.43 ± 0.33	7.57 ± 0.31
Cond	300 ± 146	370 ± 82	755 ± 246	871 ± 293
DO	8.21 ± 4.17	5.80 ± 3.08	4.21 ± 0.89	2.59 ± 0.53
Land use				
%Nat	74.0 ± 28.2	39.7 ± 40.5	5.3 ± 1.9	0.0 ± 0.0
%Agr	25.9 ± 28.3	59.0 ± 39.1	94.6 ± 1.9	53.5 ± 30.4
%Urb	0.0 ± 0.0	1.3 ± 2.7	0.0 ± 0.0	46.4 ± 30.4
Hydrological				
CS	2.47 ± 0.18	2.56 ± 0.07	3.51 ± 1.14	7.10 ± 2.56
WD	0.205 ± 0.032	0.213 ± 0.010	0.283 ± 0.052	0.436 ± 0.059
SW	5.40 ± 1.77	5.00 ± 0.80	5.47 ± 2.54	25.60 ± 14.81
Biotic / habitat indices				
IBMWP	80.7 ± 24.9	53.4 ± 3.9	46.8 ± 6.9	25.6 ± 9.1
QBR	100.0 ± 33.0	60.7 ± 14.9	59.4 ± 34.3	21.2 ± 28.1
IHF	88.6 ± 4.7	71.0 ± 12.5	66.2 ± 22.1	43.8 ± 8.6

Acentrella almohades, *Baetis maurus*, *Ecdyonurus rothschildi*, *Cheumatopsyche atlantis*, *Hydropsyche iberomaroccana*, and *Elmis maugetii velutina* were associated with permanent watercourses characterized by a significant percentage of limestone substratum, located in the southeastern part of the basin (NL1, NL2, NL3, and ZR).

The bottom of the upper-left part of the plot revealed an association of tolerant endemic species, including *Procloeon concinnum*, *Hemimelaena flaviventris*, and *Hydraena rigua*, which inhabit midstream agricultural localities. In contrast, *Choroterpes atlas*, *Choroterpes volubilis*, and OCH taxa such as *Parasigara rivularis*, *Parasigara transversa*, *Helophorus atlantis*, *Velia noualhieri*, and *Oulimnius fuscipes* were clustered together in the upper part of the same quadrant. These species showed a strong correlation with deep, low-current-speed sites within urban areas, characterized by high levels of temperature and pollutant concentrations (Fig. 6).

Discussion

The structure and composition of macroinvertebrate communities in Mediterranean rivers, such as the Martil Basin, are strongly influenced by seasonal hydrological fluctuations and physicochemical conditions (Gasith & Resh, 1999; Brown et al., 2009). During wet seasons, riffle habitats support EPT species, which are adapted to elevated flow permanence and dissolved oxygen levels, exhibiting functional traits like clinging / gathering, and shredding. In contrast, dry phases favor OCH taxa (Odonata, Coleoptera, Hemiptera), which are adapted to stagnant or intermittent conditions, and lend dominance to lentic predators / swimmers, as well as species with high dispersal capacity (Magoulick & Kobza, 2003; Munné et al., 2011). This seasonal turnover is consistent with Mediterranean biogeography, where groups as gatherers, filterers, and predators maintain ecosystem functions despite shifts in taxonomic composition (Feminella et al., 1996; Cid et al., 2017).

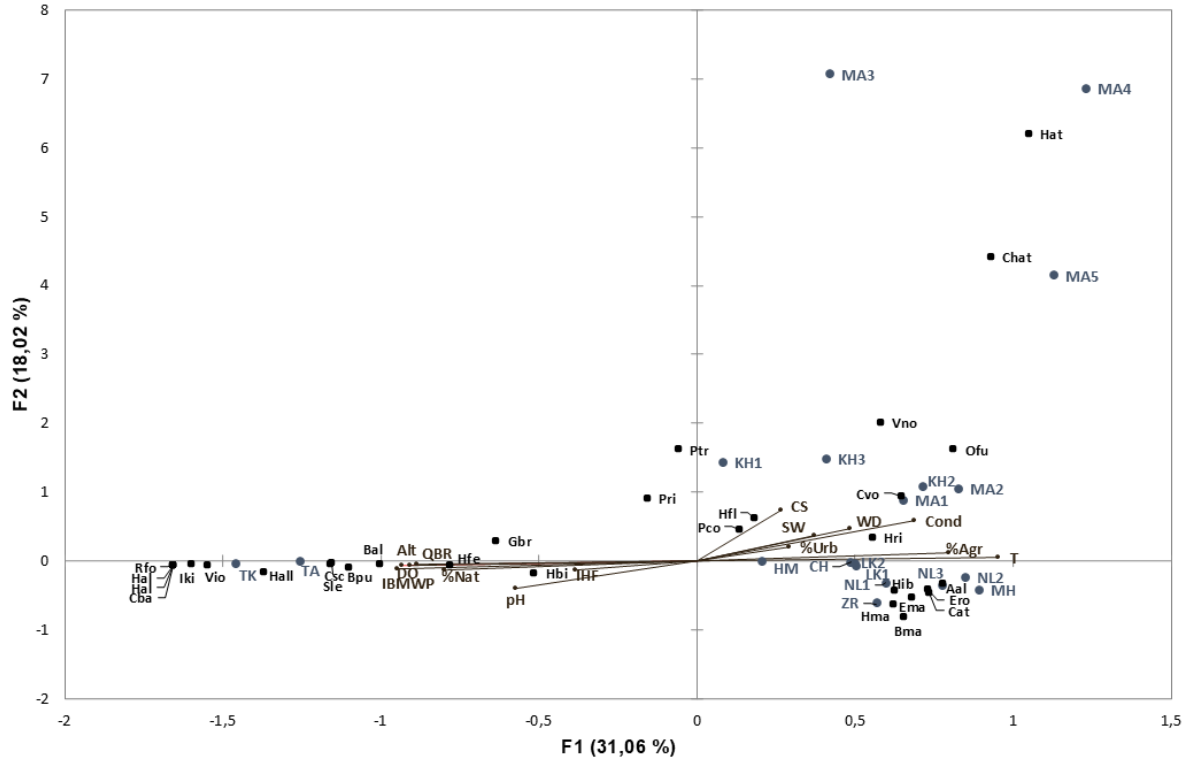

Fig. 6. Canonical correspondence analysis (CCA) biplot showing relationships between endemic species distribution and environmental variables (altitude, land use, physicochemical, and hydrological characteristics) across the 19 sampling sites

As demonstrated in Mediterranean systems (Stubbington & Datry, 2013; Carey et al., 2021, 2023), stenothermic species persist mainly in rocky, unpolluted headwaters, while impacted lowland systems without hyporheic refuges become dominated by tolerant taxa (Espinar-Herranz et al., 2025). Most endemic species are flow-specialists, becoming particularly vulnerable to climate-induced hydrological changes. As these species are sensitive to intermittency and pollution, they progressively retreat to higher altitudes, posing a threat to regional biodiversity (Domisch et al., 2013; Kroll et al., 2017).

However, certain species demonstrate resilience through physiological and life-history adaptations. In our study, several endemic EPT taxa, including *Procloeon concinnum* (Baetidae), *Choroterpes volubilis* (Leptophlebiidae), and *Hydropsyche iberomaroccana* (Hydropsychidae), exhibited low-flow adaptations. Baetidae displayed drought resistance (Banegas-Medina et al., 2021; El Yaagoubi et al., 2024a, 2024b), while Leptophlebiidae likely persist via desiccation-resistant eggs, though they remain undetected in rehydration experiments (Carey et al., 2023). Hydropsychid distribution is strongly influenced by basin geology, water mineralization, and resource availability (Leland & Porter, 2000). *H. iberomaroccana*, the most abundant EPT species in the Martil Basin and Moroccan Rif during dry seasons (Hajji, 2017), aligns with Mediterranean studies highlighting

the abundance of thermophilic Hydropsychidae (e.g., *H. lobata*, and *H. iberomaroccana*) in calcareous, mid-altitude lotic systems (Bonada et al., 2004, 2008; Bemmoussat-Dekkak et al., 2021).

Multivariate analysis revealed that Oued Tkaraa (Bouhachem Natural Park) and Oued Taida (upper natural area) maintain excellent ecological status, with high biotic/habitat indices supporting sensitive endemic lotic species in their well-oxygenated, unpolluted streams. In contrast, mid-reach agricultural zones (El Kebir, Nakhla, Zarka) hosted moderately pollution-tolerant clingers and swimmers, associated with limestone substrates and moderate-to-fast flow velocities. Generalist species (e.g., *Hydraena rigua* and *Choroterpes volubilis*) persist in intermittent conditions through adaptive traits, while resilient swimmers (e.g., *Helophorus atlantis*) tolerate anthropogenic pressures in agricultural and urban areas. These endemic species dominate the intermittent Lakhmis sub-basin and Martil River in the lowland section.

Our findings demonstrate a predominance of Ibero-Maghrebian endemics, confirming the Betic-Rif range's status as a Mediterranean biodiversity hotspot (Médail & Quézel, 1997; Bonada et al., 2008). This critical Europe-Africa biogeographic nexus emerged through complex paleogeographic dynamics, particularly via the Betic-Rifean land bridge (Bennas et al., 1992; Lavergne et al., 2012; Touaylia, 2017), establishing the Rif region as both a migration corridor and refugium. The prevalence of Ibero-Maghrebian species is well-documented across multiple macroinvertebrate groups in Morocco in general, and in northwestern Rif in particular (El Haissoufi et al., 2008; L'Mohdi et al., 2008; Benamar et al., 2011, 2021a, 2021b, 2022a, 2022b, 2024; Hajji et al., 2012; Errochdi et al., 2014; Slimani et al., 2016; El Bazi et al., 2017).

While multiple studies have examined freshwater endemic species in Morocco (Bennas et al., 2009; Errochdi et al., 2014; El Haissoufi et al., 2015; Benamar et al., 2021c; El Alami et al., 2022; Belhaj et al., 2023a), the majority have focused on individual taxonomic groups or conducted descriptive biogeographic assessments, or their degree of vulnerability. Concurrently, intensifying anthropogenic pressures, including climate change, flow intermittency, pollution, dam construction, and agricultural expansion are drastically reducing species distributions across the Ibero-Moroccan region (Taybi et al., 2018; Nogueira et al., 2021). Despite these threats, critical knowledge gaps persist regarding the survival strategies, dispersal potential, persistence of invertebrate endemic species, and their size-related functional in the Moroccan context, which constrains our understanding of species population dynamics and limits our ability to predict their responses to environmental changes.

Further ecological research on endemic species in natural areas within the mountainous ranges is essential for informing the conservation of both biological and functional diversity (Petchey & Gaston, 2002; Brown et al., 2009). Belhaj et al. (2023b) identified the Martil Basin and upper reaches of the Laou, Lokkous, Sebou, and Bouregreg basins as potential climate refugia, providing long-term habitat suitability for endemic coleopteran species, marking these basins as priority conservation areas.

Our documentation of endemics beyond Bouhachem Park underscores the need to expand protected areas to include ecologically critical sites like upper Oued Martil (Belhaj et al., 2023b). Intensive sampling remains essential for improving species inventories and conservation planning (Boys et al., 2021), with freshwater endemics as a priority for future protected area design (Sánchez-Fernández et al., 2004).

Current habitat protection decisions heavily depend on species inventories and Red List assessments, yet applying IUCN criteria to invertebrates remains problematic due to scarce population data and trends (Benamar et al., 2021c), despite known regional threats (Tierno de Figueroa et al., 2013). In Morocco, among the insects, Odonata is the only order assessed by the IUCN at global, Mediterranean, and North African scales (Riservato et al., 2009). They are also protected by Law 29-05 under national legislation. Alongside vulnerable aquatic species such as fish, crabs, mollusks, and plants, they are designated as trigger species for identifying freshwater Key Biodiversity Areas (KBAs) in the Mediterranean basin (Smith et al., 2019). However, conservation strategies must expand beyond these taxa to include aquatic invertebrates with limited dispersal capacity as trigger taxa to improve KBA coverage of freshwater biodiversity (Figueroa et al., 2013; Banegas-Medina et al., 2021; El Alami et al., 2023). Molecular approaches could also help resolve remaining taxonomic and ecological uncertainties (Arribas et al., 2013; Benamar et al., 2021a).

Conclusion

The conservation of Mediterranean endemic freshwater species requires coordinated transboundary efforts due to their ecological vulnerability and regional importance. Long-term monitoring is essential to track their dynamics and responses to natural and anthropogenic disturbances.

Our findings highlight the urgent need to protect Moroccan and Martil Basin endemic macroinvertebrates from increasing human and hydro-climatic pressures. Future conservation efforts should focus on integrating these species into protective frameworks (e.g., IUCN Red List, Moroccan Law 29-05), and identifying key freshwater biodiversity zones.

References

Alba-Tercedor, J., Jáimez-Cuéllar, P., Álvarez, M., Avilés, J., Bonada, N., Casas, J., Mellado, A., Ortega, M., Pardo, I., Prat, N., Rieradevall, M., Robles, S., Sáinz-Cantero, C. E., Sánchez-Ortega, A., Suárez, M. L., Toro, M., Vidal-Abarca, M. R., Vivas, S., & Zamora-Muñoz, C. (2002). Caracterización del estado ecológico de ríos mediterráneos ibéricos mediante el índice IBMWP (antes BMWP) [Characterization of the ecological status of Iberian Mediterranean rivers using the IBMWP index (formerly BMWP)]. Limnetica, 21, 175–185 (in Spanish).

Arribas, P., Andujar, C., Sánchez-Fernández, D., Abellán, P., & Millán, A. (2013). Integrative taxonomy and conservation of cryptic beetles in the Mediterranean region (Hydrophilidae). Zoologica Scripta, 42(2), 182–200.

Balzan, M. V., Hassoun, A. E. R., Aroua, N., Baldy, V., Dagher, M. B., Branquinho, C., Dutay, J.-C., Bour, M. E., Médail, F., Mojtahid, M., et al. (2020). First Mediterranean assessment report – Chapter 4: Ecosystems. In: Climate and environmental change in the Mediterranean basin – current situation and risks for the future. Union for the Mediterranean, Plan Bleu. Pp. 323–468.

Banegas-Medina, A., Montes, I.-Y., Tzoraki, O., Brendonck, L., Pinceel, T., Diaz, G., Arriagada, P., Arumi, J.-L., Pedreros, P., & Figueroa, R. (2021). Hydrological, environmental and taxonomical heterogeneity during the transition from drying to flowing conditions in a Mediterranean intermittent river. Biology, 10(4), 316.

Belhaj, A., Mingarro, M., Sánchez Fernández, D., Bennas, N., Chergui, B., & Pallarés, S. (2024). Conservation of freshwater biodiversity in North Africa under future climate and land-cover changes. Biodiversity and Conservation, 33, 1145–1163.

Belhaj, A., Pallarés, S., Bennas, N., Chergui, B., & Sánchez-Fernández, D. (2023b). Towards the identification of hotspots of freshwater biodiversity in North-Western Africa: A case study using species distribution models for water beetles in Morocco. Global Ecology and Conservation, 43, e02441.

Belhaj, A., Sánchez-Fernández, D., Chergui, B., & Bennas, N. (2023a). A general lack of complete inventories for aquatic beetles in Morocco. Journal of Insect Conservation, 27, 75–85.

Bemmoussat-Dekkak, S., Abdellaoui-Hassaine, K., Sartori, M., Morse, J. C., & Zamora-Muñoz, C. (2021). Larval taxonomy and distribution of genus *Hydropsyche* (Trichoptera: Hydropsychidae) in Northwestern Algeria. Zootaxa, 4915(4), 481–505.

Benamar, L., Bennas, N., & Millàn, A. (2011). Les coléoptères aquatiques du Parc National de Talassemtane (Nord-Ouest du Maroc). Biodiversité, degré de vulnérabilité et état de conservation [Aquatic beetles of Talassemtane National Park (Northwestern Morocco), biodiversity, vulnerability level, and conservation status]. Boletín Sociedad Entomológica Aragonesa, 49, 231–242 (in French).

Benamar, L., Bennas, N., Belhaj, A., Boulahfa, N., & Millán, A. (2021b). An updated checklist of Haliplidae, Gyrinidae, Noteridae, Hygrobiidae and Dytiscidae (Coleoptera: Adephaga) of Morocco, with notes on chorology. Aquatic Insects, 42(3–4), 247–371.

Benamar, L., Bennas, N., Hassoun, M., & Millán, A. (2021c). Threatened endemic water beetles from Morocco. Journal of Insect Conservation, 25, 465–477.

Benamar, L., Bennas, N., Hassoun, M., & Millán, A. (2022a). Checklist of Moroccan aquatic beetles (Coleoptera: Hydraenidae Mulsant, 1844). New records and updates. Zootaxa, 5129(4), 451–504.

Benamar, L., Bennas, N., Hassoun, M., & Millán, A. (2022b). Updating the presence, distribution and chorology of Moroccan Dryopoidea (Coleoptera: Elmidae and Dryopidae). Aquatic Insects, 43(4), 335–389.
Benamar, L., Bennas, N., Henegouwen, A. V. B., García-Meseguer, A. J., Hassoun, M., Benali, N., & Millán, A. (2024). The Hydrochidae (Coleoptera) of Morocco with a redescription of *Hydrochus* cf. *obtusicollis* Fairmaire, 1877. Zootaxa, 5458(2), 197–228.
Benamar, L., Millán, A., Sáinz-Cantero, C. E., Belhaj, A., & Bennas, N. (2021a). Annotated checklist of water scavenger beetles (Coleoptera: Polyphaga: Hydrophilidae) of Morocco. Aquatic Insects, 42(1), 87–108.
Bennas, N., Sáinz-Cantero, C. E. & Alba-Tercedor, J. (1992). Datos preliminares para un estudio biogeográfico del Macizo Bético-Rifeño basado en Coleópteros acuáticos [Preliminary data for a biogeographical study of the Betic-Rifian Massif based on aquatic beetles]. Zoologica Baetica, 3, 167–180 (in Spanish).
Bennas, N., Sanchez, D., Abellán, P., & Millán, A. (2009). Analyse de la vulnérabilité des coléoptères aquatiques dans la rive sud méditerranéenne: Cas du Rif Marocain [Vulnerability analysis of aquatic beetles in the southern Mediterranean shore: The case of the Moroccan Rif]. Annales de la Société Entomologique de France, 45(3), 309–320 (in French).
Bogan, M. T., Boersma, K. S., & Lytle, D. A. (2013). Flow intermittency alters longitudinal patterns of invertebrate diversity and assemblage composition in an arid-land stream network. Freshwater Biology, 58, 1016–1028.
Bonada, N., Cañedo-Argüelles, M., Gallart, F., von Schiller, D., Fortuño, P., Latron, J., Llorens, P., Múrria, C., Soria, M., Vinyoles, D., & Cid, N. (2020). Conservation and management of isolated pools in temporary rivers. Water, 12(10), 2870.
Bonada, N., Rieradevall, M., & Prat, N. (2007). Macroinvertebrate community structure and biological traits related to flow permanence in a Mediterranean river network. Hydrobiologia, 589(1), 91–106.
Bonada, N., Zamora-Muñoz, C., El Alami, M., Múrria, C., & Prat, N. (2008). New records of Trichoptera in reference Mediterranean-climate rivers of the Iberian Peninsula and North of Africa. Graellsia, 64(2), 189–208.
Bonada, N., Zamora-Muñoz, C., Rieradevall, M., & Prat, N. (2004). Ecological profiles of caddisfly larvae in Mediterranean streams: Implications for bioassessment methods. Environmental Pollution, 132, 509–521.
Boys, C. A., Rayner, T. S., Baumgartner, L. E., & Doyle, K. E. (2021). Native fish losses due to water extraction in Australian rivers. Ecological Management and Restoration, 22(2), 134–144.
Brown, L. E., Céréghino, R., & Compin, A. (2009). Endemic freshwater invertebrates from Southern France: Diversity, distribution and conservation implications. Biological Conservation, 142(12), 2613–2619.
Carey, N., Chester, E. T., & Robson, B. J. (2021). Flow regime change alters shredder identity but not leaf litter decomposition in headwater streams affected by severe, permanent drying. Freshwater Biology, 66(9), 1813–1830.
Carey, N., Chester, E. T., & Robson, B. J. (2023). Loss of functionally important and regionally endemic species from streams forced into intermittency by global warming. Global Change Biology, 29, 3019–3038.
Cid, N., Bonada, N., Carlson, S. M., Grantham, T. E., Gasith, A., & Resh, V. H. (2017). High variability is a defining component of Mediterranean-climate rivers and their biota. Water, 9(1), 52.
Clavero, M., & García-Berthou, E. (2006). Homogenization dynamics and introduction routes of invasive freshwater fish in the Iberian Peninsula. Ecological Applications, 16(6), 2313–2324.
Cummins, K. W. (1974). Structure and function of stream ecosystems. BioScience, 24(11), 631–641.
Dakki, M. (1997). Etude nationale sur la biodiversité. Biodiversité de la faune aquatique continentale (invertébrés et poissons) [National study on biodiversity: Biodiversity of continental aquatic fauna (invertebrates and fish)]. State Secretariat for the Environment, Morocco (in French).
Datry, T., Moya, N., Zubieta, J., & Oberdorff, T. (2016). Determinants of local and regional communities in intermittent and perennial headwaters of the Bolivian Amazon. Freshwater Biology, 61, 1335–1349.
Davies, P. M., & Stewart, B. A. (2013). Aquatic biodiversity in the Mediterranean climate rivers of Southwestern Australia. Hydrobiologia, 719, 215–235.
Domisch, S., Araújo, M. B., Bonada, N., Pauls, S. U., Jähnig, S. C., & Haase, P. (2013). Modelling distribution in European stream macroinvertebrates under future climates. Global Change Biology, 19(3), 752–762.
El Alami, M., El Yaagoubi, S., Gattolliat, J.-L., Sartori, M., & Dakki, M. (2022). Diversity and distribution of mayflies from Morocco (Ephemeroptera, Insecta). Diversity, 14(6), 498.
El Alami, M., Vuataz, L., El Yaagoubi, S., & Gattolliat, J.-L. (2023). A new species of the genus *Alainites* Waltz & McCafferty, 1994 (Ephemeroptera, Baetidae) from the north of Morocco. ZooKeys, 1176, 221–241.
El Bazi, R., El Alami, M., Khadri, O., Errochdi, S., Slimani, M., & Bennas, N. (2017). Contribution à l'étude de la biodiversité aquatique des aires protégées du Maroc [Contribution to the study of aquatic biodiversity in Morocco's protected areas]. Boletín de la Sociedad Entomológica Aragonesa, 61, 55–66 (in French).
El Haissoufi, M., Knijf, G. D., Bosch, J. V., Bennas, N., & Millán, A. (2015). Contribution to the knowledge of the Moroccan Odonata, with first records of *Orthetrum sabina*. Odonatologica, 44(3), 225–254.
El Haissoufi, M., L'Mohdi, O., Bennas, N., Mellado, A., & Millán, A. (2008). Les odonates du bassin versant Laou (Rif Occidental, Maroc) [The odonates of the Laou Watershed (Western Rif, Morocco)]. Travaux de l'Institut Scientifique Rabat, 5, 47–59 (in French).
El Yaagoubi, S., Edegbene, A. O., El Alami, M., Errochdi, S., & Harrak, R. (2024). Ephemeroptera, Plecoptera and Trichoptera (EPT) trait-based biomonitoring of rivers within the northwestern Rif of Morocco: Implications for determining riverine ecosystems ecological health in Africa. Aquatic Sciences, 86, 54.
El Yaagoubi, S., Errochdi, S., Edegbene, A. O., Kassout, J., Harrak, R., & El Alami, M. (2024a). Distribution patterns of Ephemeroptera, Plecoptera, and Trichoptera (EPT) species in the Northwestern Rif: Environmental and climate change impacts. Hydrobiologia, 852, 1575–1593.
Ennabili, A., Libiad, M., Haissoufi, M. E., Khabbach, A., & Bennas, N. (2025). Biodiversity, change, and use of Moroccan wetlands. In: Finlayson, A., Finlayson, C. M., & Milton, G. R. (Eds.). Wetlands of tropical and subtropical Asia and Africa. Springer, Cham. Pp. 265–296.
Errochdi, S., El Alami, M., Vinçon, G., Abdaoui, A., & Ghamizi, M. (2014). Contribution to the knowledge of Moroccan and Maghrebin stoneflies (Plecoptera). Zootaxa, 3838(1), 46–76.
Espinar-Herranz, S., Velázquez, J., Pérez-Andueza, G., Çiçek, K., & Rincón, V. (2025). Aquatic macroinvertebrates as indicators of climate change in the riparian environments of the Mediterranean region. Land, 14(3), 521.
Faramarzi, M., Abbaspour, K. C., Ashraf Vaghefi, S., Farzaneh, M. R., Zehnder, A. J. B., Srinivasan, R., & Yang, H. (2013). Modeling impacts of climate change on freshwater availability in Africa. Journal of Hydrology, 480, 85–101.
Feminella, J. W. (1996). Flow permanence and macroinvertebrate assemblages in small streams along a gradient of flow permanence. Journal of the North American Benthological Society, 15(4), 651–669.
Fernández-Calero, J. M., Cunillera-Montcusí, D., Hermoso, V., Quevedo-Ortiz, G., Fortuño, P., Acosta, R., Gomà, J., Cid, N., Vinyoles, D., Ruhí, A., Cañedo-Argüelles, M., & Bonada, N. (2024). Integrating spatiotemporal hydrological connectivity into conservation planning to protect temporary rivers. Freshwater Ecosystems, 34(3), e4139.
Figueroa, R., Bonada, N., Guevara, M., Pedreros, P., Correa-Araneda, F., Díaz, M. E., & Ruiz, V. H. (2013). Freshwater biodiversity and conservation in Mediterranean climate streams of Chile. Hydrobiologia, 719, 269–289.
Filipe, A. F., Lawrence, J. E., & Bonada, N. (2013). Vulnerability of stream biota to climate change in Mediterranean climate regions: A synthesis of ecological responses and conservation challenges. Hydrobiologia, 719, 331–351.
Gasith, A., & Resh, V. H. (1999). Streams in Mediterranean climate regions: Abiotic influences and biotic responses to predictable seasonal events. Annual Review of Ecology and Systematics, 30, 51–80.
Giam, X., Chen, W., Schriever, T. A., Van Driesche, R., Muneepeerakul, R., Lytle, D. A., & Olden, J. D. (2017). Hydrology drives seasonal variation in dryland stream macroinvertebrate communities. Aquatic Sciences, 79(3), 705–717.
Guellaf, A., & Kettani, K. (2021a). Assessing the ecological status using physic-chemical, bacteriological parameters and biotic indices of the Oued Martil River basin in Northwestern Morocco. Biologia, 76, 585–598.
Guellaf, A., & Kettani, K. (2021b). Performance of macroinvertebrates-based biotic indices for assessing water quality in Martil River Basin, Northern Morocco. Environmental Engineering and Management Journal, 20(1), 141–150.
Guellaf, A., El Alami, M., Kassout, J., Errochdi, S., Khadri, O., & Kettani, K. (2021). Diversity and ecology of aquatic insects (Ephemeroptera, Plecoptera, and Trichoptera) in the Martil Basin (Northwestern Morocco). Community Ecology, 22, 331–350.
Hajji, K. (2017). Les Trichoptères du Maroc: Atlas, biogéographie et degré de vulnérabilité [The caddisflies (Trichoptera) of Morocco: Atlas, biogeography, and vulnerability assessment]. Abdelmalek Essaâdi University, Tétouan (in French).
Hajji, K., Zamora-Muñoz, C., Bonada, N., & El Alami, M. (2012). Quelques notes sur l'écologie et distribution des Rhyacophilidae du Rif (Nord du Maroc) [Some notes on the ecology and distribution of Rhyacophilidae in the Rif (Northern Morocco)]. Boletín de la Sociedad Entomológica Aragonesa, 50, 559–562 (in French).
Jáimez-Cuéllar, P., Vivas, S., Bonada, N., Robles, S., Mellado, A., Álvarez, M., Avilés, J., Casas, J., Ortega, M., Pardo, I., Prat, N., Rieradevall, M., Sáinz-Cantero, C. E., Sánchez-Ortega, A., Suárez, L., Toro, M., Vidal-Abarca, M. R., Zamora-Muñoz, C., & Alba-Tercedor, J. (2002). Protocolo GUADALMED (PRECE). Limnetica, 21(3–4), 187–204.
Karrouchi, M., Touhami, M. O., Oujidi, M., & Chourak, M. (2016). Cartographie des zones à risque d'inondation dans la région Tanger-Tétouan:

Cas du bassin versant de Martil, Nord du Maroc [Mapping of flood risk areas in the Tangier-Tetouan region: Case of the Martil watershed, northern Morocco.]. International Journal of Innovation and Applied Studies, 14(4), 1019–1035 (in French).
Khelifa, R., Deacon, C., Mahdjoub, H., Suhling, F., Simaika, J. P., & Samways, M. J. (2021). Dragonfly conservation in the increasingly stressed African Mediterranean-type ecosystems. Frontiers in Environmental Science, 9, 660163.
Kroll, S. A., Ringler, N. H., Costa, M. D. L. C. C., & Ibañez, J. D. L. H. (2017). Macroinvertebrates on the front lines: Projected community response to temperature and precipitation changes in Mediterranean streams. Journal of Freshwater Ecology, 32(1), 513–528.
L'Mohdi, O., El Haissoufi, M., Bennas, N., & Millán, A. (2008). Contribution à la connaissance des Hétéroptères aquatiques du bassin versant Laou [Contribution to the knowledge of aquatic Heteroptera in the Laou Watershed]. Travaux de l'Institut Scientifique, Rabat, Série Générale, 5, 67–74 (in French).
Laouina, A. (2006). Gestion durable des ressources naturelles de la biodiversité au Maroc – prospective Maroc 2030 [Sustainable management of natural resources and biodiversity in Morocco – prospective Morocco 2030]. Report of the High Commission for Planning, Morocco (in French).
Lavergne, S., Hampe, A., & Arroyo, J. (2012). In and out of Africa: How did the Strait of Gibraltar affect plant species migration and local diversification? Journal of Biogeography, 40(1), 24–36.
Leland, H. V., & Porter, S. D. (2000). Distribution of benthic algae in the upper Illinois River basin in relation to geology and land use. Freshwater Biology, 44(2), 279–301.
Magoulick, D. D., & Kobza, R. M. (2003). The role of refugia for fishes during drought: A review and synthesis. Freshwater Biology, 48, 1186–1198.
Médail, F., & Quézel, P. (1997). Hot-spots analysis for conservation of plant biodiversity in the Mediterranean Basin. Annals of the Missouri Botanical Garden, 84, 112–127.
Merritt, R. W., & Cummins, K. W. (1996). An introduction to the aquatic insects of North America. 3rd ed. Kendall, Hunt.
Munné, A., & Prat, N. (2011). Effects of Mediterranean climate annual variability on stream biological quality assessment using macroinvertebrate communities. Ecological Indicators, 11(3), 651–662.
Munné, A., Prat, N., Solà, C., Bonada, N., & Rieradevall, M. (2003). A simple field method for assessing the ecological quality of riparian habitat in rivers and streams: QBR index. Aquatic Conservation, 13(2), 147–163.
Munné, A., Sola, C., & Prat, N. (1998). QBR: Un índice rápido para la evaluación de la calidad de los ecosistemas de ribera [QBR: A rapid index for assessing riparian ecosystem quality]. Tecnología del Agua, 175, 20–37 (in Spanish).
Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403, 853–858.
Nogueira, A. R., Gama, J., & Ferreira, C. A. (2021). Causal discovery in machine learning: Theories and applications. Journal of Dynamics and Games, 8, 203–231.
Pardo, I., Álvarez, M., Casas, J., Moreno, J. L., Vivas, S., Bonada, N., Alba-Tercedor, J., Jáimez-Cuéllar, P., Moyà, G., Prat, N., Robles, S., Suárez, M. L., Toro, M., & Vidal-Abarca, M. (2002). El hábitat de los ríos mediterráneos: Diseño de un índice de diversidad de hábitat [The habitat of Mediterranean rivers: Design of a habitat diversity index]. Limnetica, 21(3–4), 115–133 (in Spanish).
Petchey, O. L., & Gaston, K. J. (2002). Extinction and the loss of functional diversity. Proceedings of the Royal Society B: Biological Sciences, 269(1501), 1721–1727.
Ribera, I., Castro, A., Díaz, J. A., Garrido, J., Izquierdo, A., Jäch, M. A., & Valladares, L. F. (2011). The geography of speciation in narrow endemics of the ''Haenydra'' lineage (Coleoptera, Hydraenidae, Hydraena). Journal of Biogeography, 38(3), 502–516.
Riservato, E., Boudot, J. P., Ferreira, S., Jovic, M., Kalkman, V. J., Schneider, W., & Samraoui, B. (2009). The status and distribution of dragonflies of the Mediterranean Basin. IUCN, Gland.
Salhi, A., Martin-Vide, J. M., Benhamrouche, A., Benabdelouahab, S., Himi, M., Benabdelouahab, T., & Casas Ponsati, A. (2019). Rainfall distribution and trends of the daily precipitation concentration index in Northern Morocco: A need for an adaptive environmental policy. SN Applied Sciences, 1(3), 277.
Sánchez-Fernández, D., Abellán, P., Velasco, J., & Millán, A. (2004). Selecting areas to protect the biodiversity of aquatic ecosystems in a semiarid Mediterranean region using water beetles. Aquatic Conservation: Marine and Freshwater Ecosystems, 14(5), 465–479.
Sánchez-Fernández, D., Bilton, D. T., Abellán, P., Ribera, I., Velasco, J., & Millán, A. (2008). Are the endemic water beetles of the Iberian Peninsula and the Balearic Islands effectively protected? Biological Conservation, 141(7), 1612–1627.
Sansoni, G. (1992). Atlante per il riconoscimento dei macroinvertebrati dei corsi d'acqua Italiani [Atlas for the identification of macroinvertebrates in Italian watercourses]. Italian Center for Environmental Biology Studies, Trento (in Italian).
Slimani, M., Bennas, N., El Haissoufi, M., L'Mohdi, O., Khadri, O., El Bazi, R., & El Alami, M. (2016). Contribution à l'étude de la biodiversité aquatique des aires protégées du Maroc. [Contribution to the study of aquatic biodiversity in the protected areas of Morocco.] Boletín de la Sociedad Entomológica Aragonesa, 58, 168–180.
Smith, R. J., Bennun, L., Brooks, T. M., Butchart, S. H. M., Cuttelod, A., Di Marco, M., Ferrier, S., Fishpool, L. D. C., Joppa, L., Juffe-Bignoli, D., Knight, A. T., Lamoreux, J. F., Langhammer, P., Possingham, H. P., Rondinini, C., Visconti, P., Watson, J. E. M., Woodley, S., Boitani, L., … Scaramuzza, C. A. de M. (2018). Synergies between the key biodiversity area and systematic conservation planning approaches. Conservation Letters, 12(1), 12625.
Strachan, S. R., Chester, E. T., & Robson, B. J. (2015). Freshwater invertebrate life history strategies for surviving desiccation. Springer Science Reviews, 3(1), 57–75.
Stubbington, R., & Datry, T. (2013). The macroinvertebrate seedbank promotes community persistence in temporary rivers across climate zones. Freshwater Biology, 58(6), 1202–1220.
Tachet, H., Richoux, P., Bournaud, M., & Usseglio-Polatera, P. (2002). Invertébrés d'eau douce: Systématique, biologie, écologie [Freshwater invertebrates: Systematics, biology, ecology]. CNRS Éditions, Paris (in French).
Taybi, A. F., Mabrouki, Y., Chavanon, G., Berrahou, A., & Millán, A. (2018). New data on the distribution of aquatic bugs (Hemiptera) from Eastern Morocco with notes on chorology. Zootaxa, 4459(1), 139–163.
Tierno de Figueroa, J. M., López-Rodríguez, M. J., Fenoglio, S., Sánchez-Castillo, P., & Fochetti, R. (2013). Freshwater biodiversity in the rivers of the Mediterranean Basin. Hydrobiologia, 719, 137–186.
Touaylia, S. (2017). Thoughts on water beetles in a Mediterranean environment. In: Shields, V. D. C. (Ed.). Insect physiology and ecology. Intech-Open. Pp. 3–23.
Trizzino, M., Bisi, F., Maiorano, L., Martinoli, A., Petitta, M., Preatoni, D. G., & Audisio, P. (2014). Mapping biodiversity hotspots and conservation priorities for the Euro-Mediterranean headwater ecosystems, as inferred from diversity and distribution of a water beetle lineage. Biodiversity and Conservation, 24(1), 149–170.
Zerrouk, M., Dakki, M., El Agbani, M. A., El Alami, M., Bennas, N., Qninba, A., & Himmi, O. (2021). Evolution of the benthic communities in a North-African river, the upper Sebou (Middle Atlas – Morocco) between 1981 and 2017: Effects of global changes. Biologia, 76, 2683–2696.