

Article

Freshwater Molluscs of Morocco: An Updated Checklist, Biodiversity Hotspots, and Conservation Issues

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Abstract

This study provides the first updated checklist of Moroccan freshwater molluscs, synthesizing faunistic knowledge accumulated between 1795 and 2026. The dataset was primarily compiled from specialized literature, complemented by the authors' expertise and recent field investigations. Taxonomic classifications at the family, genus, and species levels were revised in accordance with current systematic interpretations. In total, 106 freshwater molluscan species, belonging to 55 genera and 14 families, were documented. Chorological analysis reveals a clear dominance of Palearctic elements, particularly of Mediterranean affinity, alongside a high proportion of strictly endemic Moroccan taxa. Most of these endemics are associated with springs (crenobionts) and subterranean habitats (stygobionts), emphasizing the role of these environments as key centres of micro-endemism and diversification. A comprehensive database comprising 838 occurrence records was assembled, including GPS coordinates and sampling dates. The analysis identifies biodiversity hotspots mainly concentrated in the Mediterranean part of Morocco, particularly within the Middle Atlas Mountains, followed by the northeastern regions, where the highest species richness and citation rates were recorded. Despite this progress, significant gaps remain in the knowledge of Moroccan freshwater molluscs. Several regions still require further exploration, while ongoing threats—including pollution, habitat degradation driven by anthropogenic activities, global environmental change, and biological invasions—pose significant challenges. Addressing these gaps calls for intensified research efforts, including comprehensive field surveys, integrative taxonomic and molecular approaches, and long-term ecological monitoring. Overall, this study represents a significant step toward advancing the knowledge and conservation of freshwater molluscan diversity in Morocco.



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Keywords: Gastropoda; Bivalvia; endemism; chorology; conservation; inland waters; North Africa; threats; biological invasion

1. Introduction

Situated at the crossroads of two major biogeographic realms—the Atlantic and the Mediterranean—and characterized by a diverse landscape intersected by numerous rivers and lakes, Morocco harbours a wide range of freshwater habitats that contribute to its

high faunal diversity and endemic richness [1]. The country's landscape includes major mountain systems such as the Rif, Middle Atlas, High Atlas and Anti Atlas, which capture substantial precipitation and feed numerous river systems and aquifers that drain toward both oceanic basins. These rivers, lakes, wetlands and groundwater bodies form a mosaic of aquatic habitats spanning altitudinal and climatic gradients, from montane springs to lowland rivers, thereby supporting a diverse continental fauna [2,3]. Some of the largest river basins—including the Sebou, Oum Er Rbia and Moulouya—encompass ecosystems recognized as being important for freshwater biodiversity (e.g., IUCN Key Biodiversity Areas), hosting numerous endemic and threatened taxa [4]. This complex hydrographic and ecological context, combined with Morocco's position at the interface of biogeographic regions, contributes to both a relatively high freshwater biodiversity and the occurrence of narrowly distributed endemic species across the country's inland waters [5,6].

Freshwater molluscs, including both gastropods and bivalves, are fundamental components of inland aquatic ecosystems, contributing substantially to ecological processes and biodiversity. Gastropods function as grazers and detritivores, regulating periphyton and decomposing organic matter, thereby influencing nutrient cycling and energy flow within freshwater food webs [7,8]. Similarly, bivalves, particularly unionid mussels, provide critical ecosystem services through filtration, sediment stabilization, and nutrient sequestration, which enhance water quality and affect the structure and productivity of aquatic communities [9,10].

Both groups also exhibit remarkable diversity and endemism, especially in isolated or specialized habitats such as springs, subterranean waters, lakes, and river systems. Gastropods often show high species turnover and fine-scale endemism due to their limited dispersal abilities [7,11], while many freshwater bivalves display localized distributions shaped by hydrological connectivity and historical biogeographic patterns [12].

Despite their ecological significance, freshwater molluscs are among the most threatened faunal groups worldwide. Anthropogenic pressures, including habitat destruction, pollution, flow regulation, damming, overharvesting, and invasive species, have led to severe population declines and extinctions across both gastropod and bivalve taxa [12,13]. This parallel vulnerability underlines the need to consider both groups with equal priority in conservation planning.

A crucial step toward effective management is the development of comprehensive, up-to-date inventories at national and regional scales. Such checklists provide baseline data essential for assessing biodiversity, identifying priority species and habitats, and informing conservation strategies for maintaining the structure and functioning of freshwater ecosystems [14,15].

Building on the discussion above, this study aims to provide an updated checklist of Morocco's freshwater molluscan fauna, integrating both historical records and newly collected data on the diversity of gastropods and bivalves. Furthermore, we critically assess patterns of species diversity, endemism, and biogeographic hotspots, providing a comprehensive framework for understanding the distribution and biogeography of freshwater mollusks across the country.

2. Materials and Methods

2.1. Study Area

Morocco, located in the northwestern part of Africa, exhibits marked geographic and hydroclimatic heterogeneity that strongly controls the structure and functioning of its aquatic ecosystems. The country is characterized by a complex topography dominated by the Rif Mountains in the north and the Atlas system (Middle, High, and Anti-Atlas), which

extends across the central and southern regions and constitutes the main source of surface water resources (Figure 1).

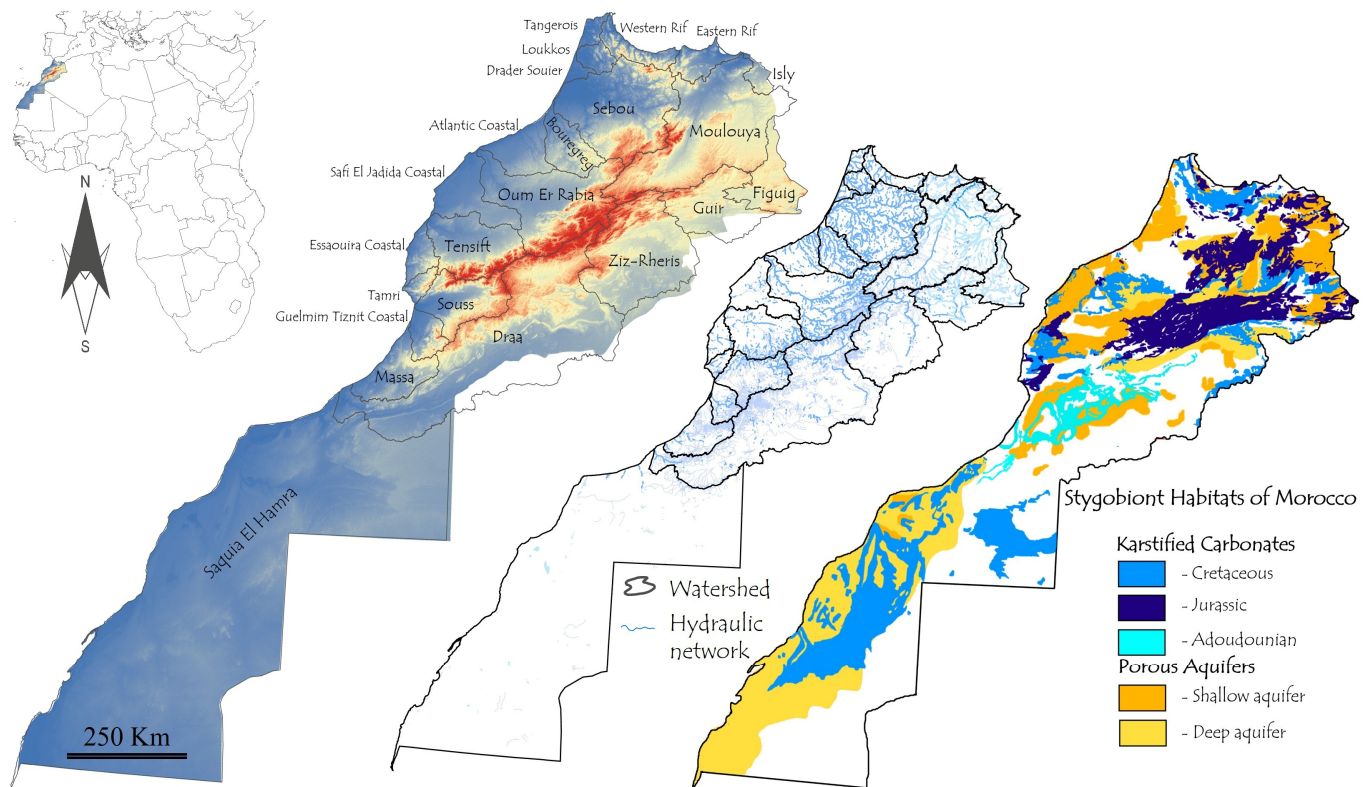


Figure 1. Topographic map of Morocco showing relief features and the main watersheds (**left**); major hydrographic networks and watersheds of Morocco (**middle**); distribution of suitable stygobiotic habitats in Morocco (**right**).

With the exception of the Moulouya River, most major river basins originate in these mountainous areas and drain toward the Atlantic Ocean, while a smaller proportion flows into the Mediterranean Sea. The hydrographic network is unevenly distributed across the country. Northern and central basins, such as the Sebou, Bouregreg, Oum Er-Rbia, and Tensift, are characterized by relatively dense river networks and more perennial flow regimes due to higher precipitation and favourable topographic conditions. In contrast, southern basins are subject to arid and semi-arid climates, resulting in intermittent or ephemeral streams and highly variable discharge patterns [16,17].

This spatial variability is primarily driven by a strong climatic gradient ranging from humid Mediterranean conditions in the north to Saharan environments in the south. Precipitation shows high spatial and temporal variability. Consequently, Moroccan hydrological regimes are typically irregular, characterized by marked seasonality, with high flows occurring during winter and spring and low-flow periods in summer [18]. Such heterogeneity in climatic and hydrological conditions leads to significant disparities in water availability and ecosystem dynamics across the country. While northwestern basins concentrate the majority of renewable water resources, southern regions face increasing water scarcity.

2.2. Data Collection and Analysis

Our updated checklist and existing records of freshwater gastropods from all over Morocco, including the sampling dates (when available), geographic coordinates and their references, was compiled from multiple sources: (i) a comprehensive review of all available malacological literature, encompassing both national and international publications [19–74];

(ii) our own research and additional personal observations [75–105]; and (iii) verified records from the Global Biodiversity Information Facility [106–121]. Fossils and taxa listed as *nomen dubium* or of uncertain status in MolluscaBase were not considered. The nomenclature and taxonomic status of gastropods follows MolluscaBase (<https://www.molluscabase.org/>). An overview of the IUCN Red List categories for freshwater molluscan taxa occurring in Morocco were compiled using the Global Red List of Non-marine Molluscs (International Union for Conservation of Nature, <https://www.iucnredlist.org/>), consulted on 13 May 2026.

The chorological categories assigned to the freshwater mollusc species presented here are based on the classifications of La Greca [122,123] and Vigna Taglianti et al. [124] for the Western Palearctic fauna. The map of stygobiont habitats in Morocco was produced by compiling data from the World Karst Aquifer Map (WOKAM) project, available through WHYMAP (<https://www.whymap.org/>), and from the British Geological Survey (BGS) (<https://www.bgs.ac.uk/>), consulted on 1 May 2026. A distribution map of biodiversity hotspots in the inland waters of Morocco was built by processing all the gathered data in ArcGIS GIS software (ArcGIS, hot spot analysis, spatial statistics, version 10.2). Occurrence data are in the Supplementary Materials (Table S1).

3. Results

3.1. Diversity of Freshwater Molluscs in Morocco

A total of 106 species of freshwater molluscs, belonging to 55 genera and 14 families, were recorded from Morocco (Table 1). Within the class Gastropoda (Figure 2A), the most diverse family is Hydrobiidae, with 52 species (56% of the total gastropod species richness), followed by Planorbidae (12 species; 13%) and Melanopsidae (9 species; 10%). The lowest diversity was observed in the families Thiaridae, Tateidae, Bulinidae, and Acroloxidae, each represented by a single species (Table 1).

Table 1. Updated checklist of freshwater molluscs of Morocco, including distribution, habitat, and IUCN conservation status (IUCN CS). Taxa with type localities in Morocco are indicated with an asterisk (*). Habitat categories are defined as: underground waters (stygobionts = hypogean waters such as caves, phreatic waters, aquifers, interstitial) (A), springs (crenobionts = spring heads, spring lakes, spring outflows) (B), rivers (lotic = rivers, creeks, rivulets, streams) (C), and standing waters (lentic = lakes, ponds, and swamps) (D). Presence of taxa in each category is indicated with a plus sign (+). The conservation status of the taxa (CS) is presented at the global level using standard IUCN abbreviations. Taxa with sequences deposited in GenBank are indicated by a hashtag (#).

Taxa List	Chorology	A	B	C	D	IUCN CS
Class Gastropoda Cuvier, 1795						
Familia Neritidae Rafinesque, 1815						
<i>Theodoxus fluviatilis</i> (Linnaeus, 1758)	Paelearctic		+	+		LC
<i>Theodoxus marteli</i> (Pallary, 1918) *	Moroccan		+			NE
<i>Theodoxus maroccanus</i> (Paladilhe, 1875) *	Moroccan			+		NE
<i>Theodoxus numidicus</i> (Récluz, 1841)	Maghrebian		+			VU
<i>Theodoxus poppei</i> Ahuir, 2020 *	Moroccan			+		NE
<i>Theodoxus sandsi</i> Mabrouki, Glöer & Taybi, 2023 *	Moroccan		+	+		NE
<i>Theodoxus vondeli</i> (Pallary, 1936) *	Moroccan		+			DD
Familia Melanopsidae H. Adams & A. Adams, 1854						
<i>Melanopsis ahui</i> Ahuir, 2014 *	Moroccan		+			NE
<i>Melanopsis cariosa</i> (Linnaeus, 1767)	Ibero-Maghrebian			+		DD
<i>Melanopsis isabelae</i> Ahuir, 2016 *	Moroccan			+		NE
<i>Melanopsis letourneuxi</i> Bourguignat, 1884 *	Moroccan			+		EN

Table 1. Cont.

Taxa List	Chorology	A	B	C	D	IUCN CS
<i>Melanopsis praemorsa</i> (Linnaeus, 1758)	Circum-Mediterranean		+	+		LC
<i>Melanopsis rifi</i> Ahuir, 2014 *	Moroccan		+			NE
<i>Melanopsis suarezi</i> Ahuir, 2016 *	Moroccan			+		NE
<i>Melanopsis torquilla</i> Pallary, 1920 *	Moroccan		+			CR
<i>Melanopsis tricarinata</i> (Bruguère, 1789)	Ibero-Maghrebian			+		LC
Familia Thiaridae T. Gill, 1871 (1823)						
<i>Melanoides tuberculata</i> (Müller, 1774)	Cosmopolitan		+	+		LC
Familia Moitessieriidae Bourguignat, 1863						
<i>Iglica seyadi</i> Backhuys & Boeters, 1974 *	Moroccan	+				NE
<i>Iglica soussensis</i> Ghamizi & Boulal, 2017 *	Moroccan	+				CR
Familia Tateidae Thiele, 1925						
<i>Potamopyrgus antipodarum</i> (J.E. Gray, 1843)	Cosmopolitan		+	+		LC
Familia Hydrobiidae W. Stimpson, 1865						
<i>Aghbalia aghbalensis</i> Glöer, Mabrouki & Taybi, 2020 *	Moroccan		+			NE
<i>Ainiella zahredini</i> Taybi, Glöer & Mabrouki, 2022 *	Moroccan		+			NE
<i>Atebbania bernasconii</i> Ghamizi, Bodon, Boulal & Giusti, 1999 *	Moroccan	+				NE
<i>Berkanelia selouensis</i> Taybi, Glöer & Mabrouki, 2024 *	Moroccan	+				NE
<i>Berkanelia tifertiensis</i> (Glöer, Mabrouki & Taybi, 2020) *	Moroccan	+	+			NE
<i>Corrosella atlasensis</i> Boulaassafer, Ghamizi & Delicado, 2021 **	Moroccan		+			CR
<i>Corrosella mahouchii</i> Boulaassafer, Ghamizi & Delicado, 2021 **	Moroccan		+			CR
<i>Corrosella marocana</i> (Pallary, 1921) **	Moroccan		+			CR
<i>Corrosella nechadae</i> Boulaassafer, Ghamizi & Delicado 2021 **	Moroccan		+			EN
<i>Corrosella pallaryi</i> (Ghamizi, Vala & Bouka, 1997) **	Moroccan		+			CR
<i>Corrosella wakrimi</i> Boulaassafer, Ghamizi & Delicado, 2021 **	Moroccan		+			CR
<i>Ecrobia vitrea</i> (Risso, 1826)	West Mediterranean				+	LC
<i>Ecrobia ventrosa</i> (Montagu, 1803)	Atlanto-Mediterranean				+	LC
<i>Fessia aouintii</i> Glöer, Mabrouki & Taybi, 2020 *	Moroccan		+			NE
<i>Heideella andreae</i> Backhuys & Boeters, 1974 *	Moroccan	+				DD
<i>Heideella makhfamanensis</i> Bodon, Ghamizi & Giusti, 1999 *	Moroccan	+				CR
<i>Hydrobia acuta</i> (Draparnaud, 1805)	Moroccan				+	LC
<i>Idrisiella bourkaizensis</i> Mabrouki, Glöer & Taybi, 2022 *	Moroccan		+			NE
<i>Ifrania bahhouensis</i> Mabrouki, Glöer & Taybi, 2022 *	Moroccan		+			NE
<i>Ifrania zerroukensis</i> Glöer, Mabrouki & Taybi, 2020 *	Moroccan		+			NE
<i>Islamia karawiyiensis</i> Mabrouki, Glöer & Taybi, 2021 *	Moroccan		+			NE
<i>Gafaita gafaitensis</i> Taybi, Glöer & Mabrouki, 2023 *	Moroccan		+			NE
<i>Gloeriella gloeri</i> Mabrouki, Taybi & Grego 2026 **	Moroccan		+			NE
<i>Mahrazia benlemlhi</i> Mabrouki, Taybi & Glöer, 2022 *	Moroccan	+				NE
<i>Maroccoarganiella touarguii</i> Ghamizi & Falniowski, 2024 **	Moroccan	+				NE
<i>Maroccohoratia bouregensis</i> Ghamizi & Falniowski, 2024 **	Moroccan	+	+	+		NE
<i>Maroccohoratia meziane</i> Mabrouki, Taybi & Grego 2026 **	Moroccan		+			NE
<i>Menzella timedrinensis</i> Mabrouki, Glöer & Taybi, 2023 *	Moroccan		+			NE
<i>Mercuria atlasica</i> Mabrouki, Glöer & Taybi, 2021 *	Moroccan		+			NE
<i>Mercuria bakeri</i> Glöer, Boeters & Walther, 2015 **	Moroccan		+			CR
<i>Mercuria halouii</i> Taybi, Glöer et Mabrouki, 2022 *	Moroccan		+			NE
<i>Mercuria gauthieri</i> Glöer, Bouzid & Boeter, 2010	Maghrebien		+	+		NE
<i>Mercuria globulina</i> (Letourneux & Bourguignat, 1887)	Maghrebien		+			NE

Table 1. Cont.

Taxa List	Chorology	A	B	C	D	IUCN CS
<i>Mercuria midarensis</i> Boulaassafer, Ghamizi & Delicado, 2018 *#	Moroccan		+	+		VU
<i>Mercuria nadorensis</i> Taybi, Glöer & Mabrouki, 2022 *	Moroccan		+			NE
<i>Mercuria targouasensis</i> Glöer, Boeters & Walther, 2015 *#	Moroccan		+	+		EN
<i>Mercuria tensiftensis</i> Boulaassafer, Ghamizi & Delicado, 2018 *#	Moroccan		+	+		EN
<i>Mercuria tingitana</i> Glöer, Boeters & Walther, 2015 *#	Moroccan		+			CR
<i>Peringia ulvae</i> (Pennant, 1777)	Atlanto-Mediterranean			+	+	LC
<i>Pikasia smenensis</i> Taybi, Glöer & Mabrouki, 2021 *	Moroccan		+			NE
<i>Pseudamnicola berrahoui</i> Taybi, Glöer & Mabrouki, 2022 *	Moroccan		+			NE
<i>Pseudamnicola bouhaddiouii</i> Taybi, Glöer & Mabrouki, 2022 *	Moroccan		+			NE
<i>Pseudamnicola dupotetiana</i> (Forbes, 1838) *#	Maghrebien		+	+		NT
<i>Pseudamnicola chavanoni</i> Mabrouki, Taybi & Grego 2026 *#	Moroccan		+			NE
<i>Pseudamnicola leprevieri</i> (Pallary, 1928) *#	Moroccan		+			CR
<i>Pseudamnicola luteola</i> (Küster, 1852)	Maghrebien		+			DD
<i>Pseudamnicola ouarzasensis</i> Boulaassafer, Ghamizi, Machordom & Delicado, 2020 *#	Moroccan		+			CR
<i>Pseudamnicola ramosae</i> Boulaassafer, Ghamizi, Machordom & Delicado, 2020 *#	Moroccan		+	+		CR
<i>Pseudamnicola skourensis</i> Taybi, Glöer & Mabrouki, 2022 *	Moroccan		+			NE
<i>Pseudamnicola tafoughaltensis</i> Taybi, Glöer & Mabrouki, 2022 *	Moroccan		+			NE
<i>Rifia yacoubii</i> Ghamizi, 2020 *	Moroccan	+				NE
<i>Znassela bninasensis</i> Taybi, Glöer & Mabrouki, 2023 *	Moroccan		+			NE
Familia Lymnaeidae Rafinesque, 1815						
<i>Galba truncatula</i> (Müller, 1774)#	Holarctic		+	+	+	LC
<i>Lymnaea stagnalis</i> (Linnaeus, 1758)	Sub-cosmopolitan			+	+	LC
<i>Peregrina peregra</i> (O. F. Müller, 1774)	Paelearctic		+	+	+	LC
<i>Stagnicola palustris</i> (Müller, 1774)	Paelearctic		+	+	+	LC
<i>Stagnicola fuscus</i> (Pfeiffer, 1821)	West Paelearctic			+	+	LC
Familia Bulinidae P. Fischer & Crosse, 1880						
<i>Bulinus truncatus</i> (Audouin, 1827)	Afrotropical			+	+	LC
Familia Physidae Fitzinger, 1833						
<i>Physa fontinalis</i> (Linnaeus, 1758)	Holarctic		+		+	LC
<i>Physella acuta</i> (Draparnaud, 1805)	Cosmopolitan		+	+	+	LC
Family Planorbidae Rafinesque, 1815						
<i>Armiger crista</i> (Linnaeus, 1758)	Holarctic			+	+	LC
<i>Ancylus fluviatilis</i> (Müller, 1774)	West Paelearctic		+	+	+	LC
<i>Ancylus striatus</i> Quoy & Gaimard, 1834	SW Paelearctic		+	+		DD
<i>Anisus spirorbis</i> (Linnaeus, 1758)	Paelearctic		+	+	+	LC
<i>Ferrissia californica</i> (Rowell, 1863)	Sub-cosmopolitan				+	LC
<i>Hippeutis complanatus</i> (Linnaeus, 1758)	West Paelearctic				+	LC
<i>Planorbis planorbis</i> (Linnaeus, 1758)	Paelearctic			+	+	LC
<i>Planorbarius metidjensis</i> (Forbes, 1838)	West Mediterranean		+	+	+	LC
<i>Planorbella duryi</i> (Wetherby, 1879)	Cosmopolitan		+	+		LC
<i>Gyraulus marocana</i> Mabrouki, Glöer & Taybi 2022 *	Moroccan			+	+	LC
<i>Gyraulus</i> cf. <i>parvus</i> (Say, 1817)	Paelearctic		+	+	+	LC
<i>Segmentina nitida</i> (O.F.Müller, 1774)	Paelearctic			+	+	LC
Familia Acroloxidae Thiele, 1931						

Table 1. Cont.

Taxa List	Chorology	A	B	C	D	IUCN CS
<i>Acroloxus lacustris</i> (Linnaeus, 1758)	Palearctic			+	+	LC
Class Bivalvia Linnaeus, 1758						
Familia Unionidae Rafinesque, 1820						
<i>Anodonta anatina</i> (Linnaeus, 1758) #	Palearctic			+		LC
<i>Potomida littoralis</i> (Cuvier, 1798) #	Atlanto-Mediterranean			+		EN
<i>Pseudunio maroccanus</i> (Pallary, 1918) *#	Moroccan			+		CR
<i>Unio foucauldianus</i> Pallary, 1936 *#	Moroccan			+	+	CR
<i>Unio gibbus</i> Spengler, 1793#	Ibero-Maghrebian			+		CR
<i>Sinanodonta woodiana</i> (I. Lea, 1834)	Sub-cosmopolitan				+	LC
Familia Cyrenidae J. E. Gray, 1840						
<i>Corbicula fluminea</i> (O.F. Müller, 1774) #	Sub-cosmopolitan			+	+	LC
Familia Sphaeriidae Deshayes, 1855 (1820)						
<i>Euglesa casertana</i> (Poli, 1791) #	Sub-cosmopolitan		+	+	+	LC
<i>Euglesa personata</i> (Malm, 1855) #	Palearctic		+	+	+	LC
<i>Euglesa moroccana</i> Bepalaya, Vinarski, Aksenova, Mabrouki, Kondakov & Palatov 2024 *#	West Palearctic		+	+		NE
<i>Euglesa subtruncata</i> (Malm, 1855)	Palearctic			+	+	LC
<i>Pisidium amnicum</i> (O. F. Müller, 1774)	Palearctic			+	+	LC
<i>Sphaerium lacustre</i> (O. F. Müller, 1774)	Holarctic				+	LC

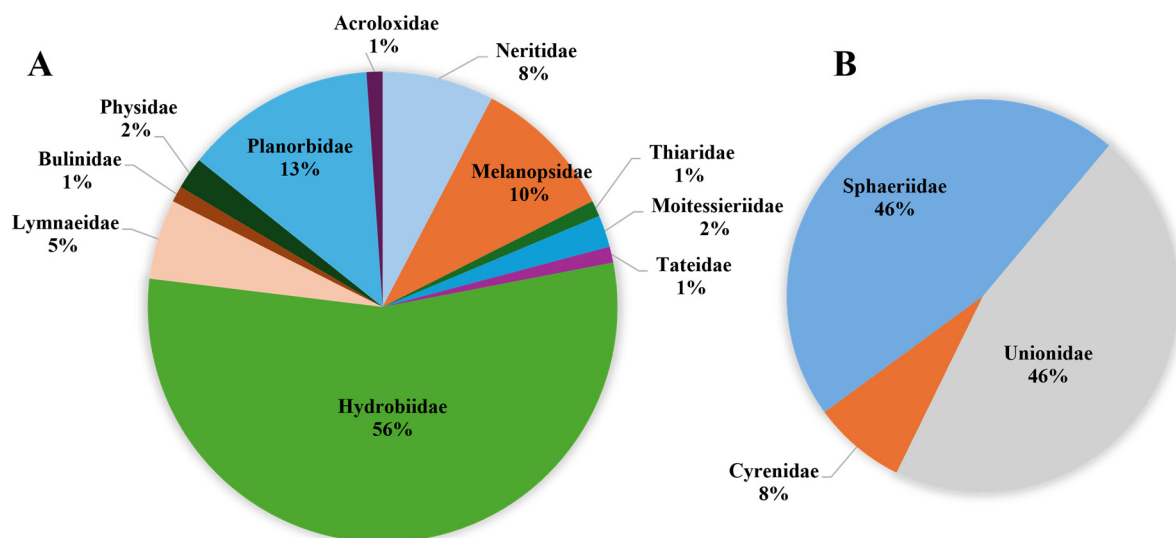


Figure 2. Composition of freshwater molluscan diversity in Morocco: Gastropoda (A) and Bivalvia (B).

Among the 106 recorded species, 16 are classified as Critically Endangered according to the IUCN Red List, five species are Endangered, two are Vulnerable, and one is Near Threatened. In addition, 37 species are classified as Least Concern, five as Data Deficient, while 40 species have not yet been evaluated (Table 1).

The most species-rich genera are *Mercuria* Boeters, 1971 and *Pseudamnicola* Paulucci, 1878, each comprising 10 species (11%), followed by *Melanopsis* A. Férussac, 1807 with 9 species (10%), *Theodoxus* Montfort, 1810 with 7 species (8%) and *Corrosella* Boeters, 1970 with 6 species (7%). All remaining genera are represented by a small number of species, each accounting for less than 2% of the total fauna (Table 1).

Within the class Bivalvia, the family Unionidae is represented by 5 genera and 6 species, followed by Sphaeriidae with 3 genera and 6 species, while Cyrenidae is represented by a

single species (Figure 2B). The most species-rich genus is *Euglesa* Jenyns, 1832, represented by 4 species (Table 1).

Taxa reported from Morocco with doubtful records, as well as species with unclear taxonomic status, were excluded from the updated checklist due to the absence of reliable evidence confirming their occurrence in the country. For instance, *Melanopsis magnifica* Bourguignat, 1884, *M. mourebeyensis* Pallary, 1901, *M. brevicula* Pallary, 1918, *M. chlorotica* Pallary, 1913, and *Limnaea maroccana* Pallary, 1889 are considered to have an uncertain taxonomic status in MolluscaBase (2026) and were therefore excluded. In addition, some unconfirmed taxa were not included because their known distributions occur outside Morocco, such as *Segmentorbis angustus* (Jickeli, 1874) and *Euglesa nitida* (Jenyns, 1832).

3.2. Biogeographic Notes

The analysis of the chorological composition of Moroccan freshwater molluscs (Figure 3), based on the distribution ranges assigned to each taxon, revealed a clear predominance of Palearctic elements, including Mediterranean taxa. Mediterranean species constitute the largest proportion of the recorded fauna (70% of all species), followed by non-Mediterranean Palearctic species (16%), while widely distributed species represent the remaining 14%.

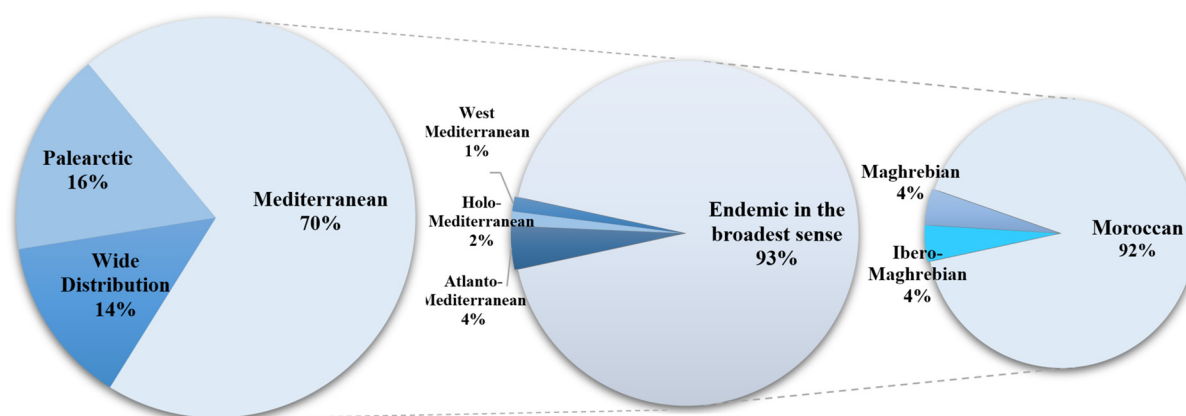


Figure 3. Overall chorological composition of Morocco's freshwater malacofauna.

Within the Mediterranean component, endemic taxa in the broad sense are overwhelmingly dominant (93%). Atlanto-Mediterranean species represent a small fraction (4%), while taxa with Holo-Mediterranean and West Mediterranean distributions are only marginally represented (2% and 1%, respectively). Freshwater molluscs exhibit one of the highest levels of endemism within the Moroccan fauna. Most of these endemic species are strictly restricted to Morocco (92%), followed by taxa displaying a Maghrebian chorotype and Ibero-Maghrebian taxa (4% each).

3.3. Endemism Patterns and Trends

In the inland waters of Morocco, the type localities of 62 species of freshwater snails and mussels have been identified (Table 1). A considerable proportion of these taxa have been described relatively recently, and the rate of discovery remains high. Approximately 47 species—predominantly belonging to the Gastropoda—were described in recent years, while many additional freshwater snail species are still likely awaiting formal description (Figure 4). With the exception of the pea clam *Euglesa moroccana*, which is also distributed in southern Europe and the Middle East, all these species are restricted to Moroccan territory. The majority of these endemic taxa inhabit springs or subterranean environments (Table 1), highlighting the importance of these habitats as centres of micro-endemism and

diversification. Species known from only one or a few localities are considered particularly vulnerable to extinction. Springs, in particular, represent highly vulnerable habitats, as they are strongly affected by anthropogenic pressures such as land-use change, groundwater abstraction, pollution and climate change.

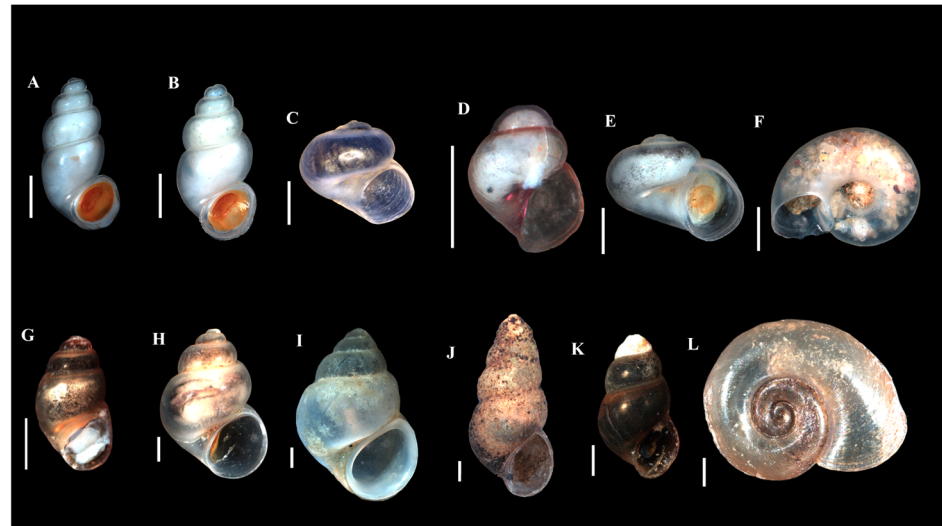


Figure 4. Examples of unidentified gastropod taxa currently under investigation: cf. *Atebbania* sp. from the Saïs Plain (A) and the Pré-Rif (B); cf. *Fessia* sp. from the Rif (C); juvenile Hydrobiidae? from the Rif (D); cf. *Berkanella* sp. from the Rif (E,F); cf. *Gafaita* sp. from the High Plateaux (G); *Mercuria* spp. from the Rif (H,I); cf. *Hydrobia* sp. from the Rif (J); *Corrosella* sp. from the Middle Atlas (K); *Planorbis* sp. from the Middle Atlas (L). Scale bar = 0.5 mm.

Despite this high diversity and endemism, only 30 species of Morocco's freshwater malacofauna have been subject to molecular studies and have sequences deposited in GenBank, whereas the remaining species remain entirely unexplored (Table 1), underscoring a substantial gap in our understanding of their genetic diversity.

3.4. Molluscan Hotspot Diversity in Morocco

After a careful review of the data, a total of 838 occurrence records of freshwater molluscan species from the inland waters of Morocco were compiled, including GPS coordinates of sampling localities, sampling dates (when available), and associated bibliographic references (Table S1 in the Supplementary Materials). Of these, 786 records were extracted from specialized published literature, including 263 from our own publications. These data were complemented by 52 additional occurrence records obtained from GBIF.

Freshwater molluscan diversity in Morocco is predominantly concentrated in the northern part of the country (Figure 5). The highest species richness is recorded in the Sebou watershed (55 species), followed by the Moulouya (35 species) and Oum Er-Rbia (29 species) basins, whereas the Guir basin appears to be the least diverse, with only a single confirmed species.

Spatially, the greatest number of records originates from the Middle Atlas, particularly in the upstream areas of the Sebou watershed. Other diversity hotspots include northeastern regions, such as the lower Moulouya and eastern Rif basins, as well as parts of the High Atlas within the Oum Er-Rbia watershed.

Regarding species distribution, the invasive gastropod *Physella acuta* is the most widespread species in Morocco, occurring in 16 watersheds. It is followed by *Melanopsis praemorsa* s.l., which is present in 13 watersheds. Among bivalves, *Euglesa casertana* is the most widely distributed species across the country.

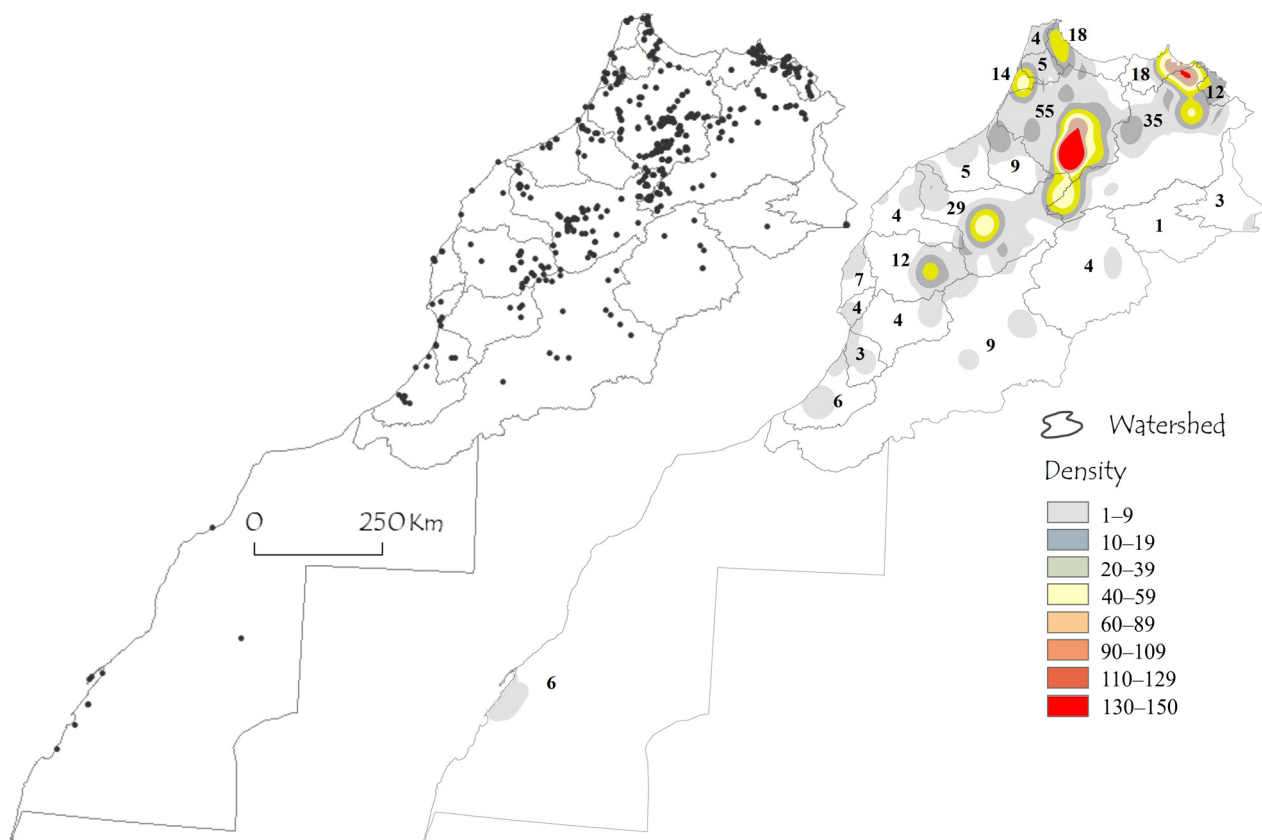


Figure 5. Spatial distribution of localities (black dots) where freshwater molluscs have been recorded in Morocco (**left**). Spatial distribution of freshwater molluscan species in Moroccan inland waters, illustrating regional species richness (**right**). Numbers (1–55) correspond to the total number of species recorded per river basin.

It should be noted that a substantial proportion of the occurrence records used in this study (263 out of 838 records) originates from the authors' own previously published field surveys. Consequently, the spatial distribution patterns presented here may partly reflect differences in sampling effort and the geographic focus of available studies, which should be considered a potential limitation of the dataset.

4. Discussion

4.1. A Rich Mediterranean-Influenced Yet Underexplored Freshwater Malacofauna

Within North Africa, Morocco's freshwater malacofauna is regarded as particularly rich and diverse [72], although the currently documented number of taxa likely underestimates the true species richness. This situation largely reflects the still incomplete state of taxonomic knowledge in the region. The earliest record of a freshwater mollusc from Morocco probably dates to 1795, when Chemnitz described "*Buccina maroccana*", later synonymized with *Melanopsis maroccana* by Morelet in 1853 [125]. Since then, the number of described and recorded species has progressively increased, and the rate of new discoveries has remained comparatively high relative to other countries of the Maghreb.

Moroccan freshwater molluscs are overwhelmingly dominated by Palearctic elements, primarily of Mediterranean affinity, and exhibiting a high level of endemism—patterns that closely parallel those reported for other freshwater faunal groups [3,126,127]. Most species inhabit regions subject to climatic influences from both the Atlantic Ocean and the adjacent European continent, resulting in pronounced biogeographical affinities with European malacofauna [32,128,129]. In contrast, Afro-tropical invertebrate elements are

comparatively rare, highlighting the strong Palearctic signature of Morocco's freshwater ecosystems. These findings underscore the importance of northern and Mediterranean-influenced regions as key reservoirs of freshwater biodiversity within the country.

Indeed, freshwater molluscan hotspots are mainly concentrated in the northern Mediterranean part of the country, where protected wetlands are particularly abundant, notably in the Middle Atlas region. This distribution pattern likely reflects the greater availability of surface water in northern Morocco when compared with the more arid southern regions. However, it may also partly result from a sampling bias, as a larger number of malacological surveys have historically been conducted in the northern part of the country. Our findings further highlight the key role of protected areas in preserving biodiversity, as they represent a fundamental component of conservation strategies aimed at mitigating biodiversity loss [130]. Nevertheless, the current network of protected areas alone may not be sufficient to ensure the long-term conservation of freshwater molluscs, particularly in the face of increasing pressures and ongoing environmental changes, highlighting the need for strengthened and timely conservation actions.

4.2. Threats and Conservation Concerns

4.2.1. Lack of Knowledge

The conservation assessment of Moroccan freshwater molluscs highlights a particularly concerning situation, with a substantial proportion of species facing different levels of extinction risk. Among the 106 recorded species, 16 are classified as Critically Endangered and five as Endangered according to the IUCN Red List, indicating the high vulnerability of freshwater ecosystems in Morocco. The presence of only two Vulnerable species and one Near Threatened species suggests that many taxa may already be experiencing severe population declines before intermediate threat categories are reached. Although 37 species are currently categorized as Least Concern, the large number of species listed as Not Evaluated (40 species) and Data Deficient (five species) underlines the important gaps that still exist in the knowledge of Moroccan freshwater malacofauna. These results emphasize the urgent need for additional taxonomic, ecological, and conservation studies, particularly for poorly known and endemic taxa, in order to improve conservation assessments and support effective freshwater biodiversity management strategies in the region.

Our study reveals a substantial gap between the number of recorded species and the number of studies addressing their phylogenetic relationships and evolutionary lineages. Of the 106 taxa documented, only 30 have been investigated using molecular approaches [30–32,44,47,55,75,76,105], highlighting a critical need for further genetic research. This is particularly relevant for widely distributed species such as *Armiger crista*, *Planorbis planorbis*, *Stagnicola palustris*, etc. These taxa may harbour regionally distinct or previously unrecognized genetic lineages [131].

In some cases, entire families require comprehensive taxonomic reassessment. This is particularly evident in the family Melanopsidae, which includes the largest number of taxa with uncertain status awaiting clarification. The family is currently the subject of an integrative taxonomic revision that combines molecular, morphological, and biogeographic data. Such approaches are expected to clarify species boundaries within the group and may lead to the recognition of additional, previously overlooked species. The Truncatelloid families such as Hydrobiidae or Moitessieriidae are characteristic of the presence of diverse microendemic species, which can only be detected by intensive field work and by sampling the particular springs, caves, wells or drills, by pumping the hyporheic water, etc.

The stygobiotic habitats of Morocco are represented by caves and karst conduits with karst springs and large aquifers based on non-karstic fissures and on young porous sediments such as alluvia and their interstitial spaces. The adaptations to the hypogean

environment are coupled with loss of the eyes and pigment, and the organisms adapt to the hypogean food sources through an entirely stygobiotic life cycle and are only incidentally washed out to the surface through springs or wells. The extent of suitable stygobiont habitats in Morocco is remarkable (Figure 1) and its diverse habitats, geology and hydrogeology, together with their fragmentation, indicate a high potential for stygofauna in Morocco, including a high potential for the presence of stygogastropoda. Most of the stygobiotic animals represent ancient climatic relicts trapped in the hypogean environment during different eons and surviving several periods of desertification while their surface relatives became extinct [132]. The relatively low number of reported species [15] rather reflects the low sampling rate dedicated to hypogean animals, together with a lack of projects supporting the systematic study of the subject. The successful sampling for stygobiotic gastropods requires a deep knowledge of hydrogeology and potential habitats or thanatocoenosis identification, together with specific sampling methods [133], resulting mostly in the detection of empty shells, while unpredictably and laboriously yielding only a few live individuals. Nevertheless, the recent fieldwork provided clear indications for the presence of this hidden biodiversity (see Figure 4). We are confident that future systematic research could reveal a stygobiotic molluscan diversity hotspot in the Atlas Mountains comparable to the other hotspots known in the Mediterranean Basin such as in the Dinaric Karst.

4.2.2. Contaminants & Liquid Pollution

In Morocco, freshwater ecosystems are increasingly exposed to multiple anthropogenic pressures that degrade water quality and threaten aquatic biodiversity, including freshwater molluscs. Agricultural intensification in major irrigated plains such as Gharb, Tadla, and Souss has led to significant inputs of fertilizers and pesticides into rivers, reservoirs, and aquifers. Runoff and leaching processes transport nitrates, phosphates, and agrochemical residues into aquatic systems, often resulting in eutrophication and deterioration of physicochemical conditions. In several Moroccan basins, including Moulouya, Sebou and Oum Er-Rbia, elevated nitrate concentrations and other pollutants have been widely reported, largely associated with agricultural drainage and untreated wastewater discharges [134–137]. Groundwater and surface water contamination by nitrates has also been documented in various areas of Morocco, where intensive agriculture and human activities have led to concentrations exceeding the recommended drinking-water limits [138,139]. Urban and industrial effluents represent an additional major source of pollution. In several Moroccan cities, untreated or partially treated domestic and industrial wastewater is still discharged into rivers, contributing organic matter, nutrients, and toxic substances, which then accumulate in sediments and subsequently degrade aquatic habitats. This situation is particularly evident in large river basins, where industrial activities and urban growth have significantly deteriorated water quality and negatively affected aquatic biodiversity [140,141]. The pollution of springs is frequently coupled with animal farming, where a large number of farm animals attracted by water can entirely destroy the natural spring habitat. Mechanical pollution by municipal waste or waste from recreational visitors is also frequently observed.

4.2.3. Habitat Destruction & Loss

In addition to chemical pollution, freshwater habitats in Morocco are increasingly impacted by hydrological modifications, land-use changes, and progressive desiccation. Large-scale water abstraction for irrigation, dam construction, river channelization, and wetland drainage has altered natural flow regimes, sediment dynamics, and habitat heterogeneity, resulting in the fragmentation of aquatic environments and reduction of suitable microhabitats containing benthic organisms such as freshwater molluscs [142]. Morocco's

semi-arid to arid climate, combined with rising temperatures, declining precipitation, and recurrent droughts, further exacerbates water scarcity, leading to seasonal or permanent drying of streams, springs, and entire wetlands [143,144]. Climate projections suggest that these trends will intensify, reducing river flows, groundwater recharge, and wetland surfaces, while increasing evapotranspiration. The resulting hydrological stress fragments populations, limits their dispersal, and heightens the risk of local extinction of freshwater molluscs. In basins such as the Tensift, Souss-Massa, and Moulouya, the combined effects of climate change, overexploitation of water resources, and groundwater depletion are driving the gradual loss of freshwater habitats and the decline of associated aquatic communities [143,145]. Destruction of spring habitats by various constructions such as reservoirs, installation of a pumping station, fountains, fishponds and swimming pools is also frequently observed during fieldwork. Groundwater changes are also detected after water exhaustion due to mining and quarrying activities. Climatic changes coupled with lower rainfall and precipitation are gradually decreasing the supply of groundwater, and as a consequence, many of the springs have lost their water during the past decade.

4.2.4. Biological Invasion

The introduction and spread of non-native species represent an additional and increasing threat to freshwater ecosystems in Morocco. In addition to the alien mollusc species reported here (e.g., *Physella acuta*, *Potamopyrgus antipodarum*, and *Sinanodonta woodiana*), overall, at least another 44 confirmed alien and invasive animal species have been recorded from Moroccan inland waters, several of which are ranked among the top 100 worst invasive species worldwide, including *Micropterus salmoides* (Lacépède, 1802), *Cyprinus carpio* (Linnaeus, 1758), *Gambusia holbrooki* (Girard, 1859), *Oncorhynchus mykiss* (Walbaum, 1792) and *Trachemys scripta elegans* (Wied, 1839) [101]. Most of these alien species are concentrated in the Mediterranean or northern part of the country, with the highest number of records coming from the Middle Atlas (upper Sebou River basin), followed by the northern part of the eastern regions (downstream Moulouya River and Marchica wetlands), which coincide closely with the freshwater mollusc hotspots reported in this study.

These alien aquatic species may compete with or displace native fauna, alter food webs, and impact ecosystem functioning. The risk of biological invasions is further amplified by environmental disturbances such as pollution, habitat degradation, and global change, which often favour opportunistic non-native species over the more specialized native taxa. In this context, the notorious invasive American blue crab *Callinectes sapidus* (Rathbun, 1896) has already exploited the salinization of Moroccan rivers to migrate upstream, potentially causing the local extinction of endemic freshwater species. For example, the last populations of *Unio foucauldianus* were completely extirpated in 2024 in certain areas of the Moulouya River [146].

5. Conclusions

Overall, the combined effects of water pollution, habitat degradation, hydrological alterations, climate-induced drying of aquatic systems, and the spread of invasive species represent major threats to freshwater ecosystems in Morocco. These pressures are likely to intensify in the coming decades as water demand increases and climatic conditions become more arid, potentially accelerating the decline of aquatic biodiversity. Freshwater molluscs are particularly vulnerable to such changes because many species have narrow ecological requirements, limited dispersal capacities, and a strong dependence on stable aquatic habitats. The microendemic species are especially sensitive to such combined environmental impacts. Despite their ecological importance as components of benthic

communities, freshwater molluscs in Morocco remain poorly studied, and information on their distribution, ecology, and conservation status is still fragmentary.

In this context, there is an urgent need to intensify research efforts on Moroccan freshwater molluscs as bio-indicators through comprehensive field surveys, taxonomic and molecular studies and long-term ecological monitoring programs. Such investigations are essential in order to improve our understanding of species' diversity, distribution patterns, and population dynamics, and to identify taxa that may already be threatened or at risk of extinction. Strengthening scientific knowledge will also support the development of effective conservation strategies and water-management policies aimed at both the preservation and conservation-management of freshwater habitats and their associated biodiversity. Without increased field research and monitoring efforts, many native mollusc species may decline or completely disappear before their ecological roles and conservation value are fully recognized.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su18115637/s1>, Supplementary Materials (Database of compiled occurrence records, including GPS coordinates, sampling dates, and references) supporting the conclusions of this article will be made available by the first author upon request.

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