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Systematic Structure and Ecological Distribution of the Malacological Population of the Gharb Plain (Morocco)

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ABSTRACT

The malacological inventory conducted in the Gharb Plain aims to explore the diversity and distribution of terrestrial and freshwater mollusks in the region. This study is part of a broader effort to better understand local biodiversity and the impact of human activities on ecosystems. The results reveal a rich malacological diversity, with 22 species of gastropods and 8 species of bivalves, which represent more than two-thirds of the total species in these two groups across Morocco. Additionally, the Family Planorbidae is the most abundant in the gastropod group, while the Family Sphaeridae is most represented among the bivalves. This inventory underscores the Gharb Plain's significance as a key reservoir of malacological biodiversity.

INTRODUCTION

The heterogeneity of aquatic environments in various natural and artificial water bodies, including ponds, temporary pools, rivers, dams, and irrigation canals, along with the associated hydro-agricultural developments, has created a highly favorable environment for the proliferation of aquatic malacofauna. Freshwater mollusks, in particular, play a crucial role in maintaining the balance of limnic ecosystems. Understanding the ecology, systematics, and geographical distribution of these invertebrates is vital, especially in the context of combating water-related diseases such as schistosomiasis **(Bay *et al*., 1995)**.

In this context, we aimed to examine the systematic structure, geographical distribution, species diversity, and equitability of the surveyed biotopes. Following the systematic identification of the collected species, we monitored the spatio-temporal evolution of malacological communities across more than 100 biotopes in the studied areas. The fauna were characterized using three fundamental ecological parameters that describe the organization of animal communities: species richness, species diversity, and equitability.

MATERIALS AND METHODS

1. Studied area

The Gharb plain (Fig. 1) where this study was conducted is located in the North-Western part of the Kingdom. It is bordered to the West by the Atlantic Ocean, to the North by the Tanger-Tetouan region, to the East by the two regions of Taza-Al Hoceima-Taounate and Fès-Boulemane, and to the South by the Meknès-Tafilalet and Rabat-Salé Zemmour-Zaër regions **(Sanad *et al*., 2024)**. It covers an area of approximately 801,800 ha, which is nearly 1.1% of the surface area of Morocco. The climate in the region is of the Mediterranean type **(Elkarfa *et al*., 2024)**, with a sub-humid bioclimatic zone in the west and a semi-arid zone in the east. The surface hydrological network is highly diverse.

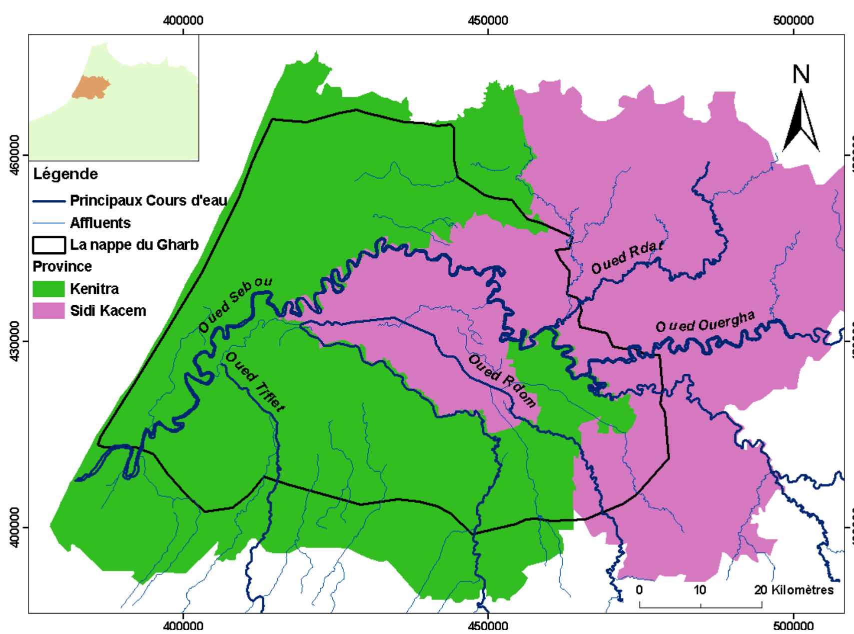

Fig. 1. Geographic situation of the Gharb plain

2. Methodology for malacological sampling and assessment of the degree of organization of the surveyed malacological communities

2.1. Malacological Sampling Methodology

At each station, samples were taken, during the year 2023/2024, from three neighboring sites. Moreover, a total of 118 stations were surveyed. The collections were conducted using three carefully designed sampling strategies, based on the typology of the biotopes.

First technique

For the sumps of irrigation canals, dredging fishing appeared to be the most suitable method for this type of biotope. The dredge used had a mesh size of 0.8 mm and a frame equipped with a metal mosquito net, allowing for scraping along the edges of the sump. This technique was also employed by **Maqboul (1996)**.

Second technique

At the level of stagnant water biotopes (merjas, dayas, drains, rice fields, etc.), a cylindrical capture chamber was used. The isolated water column was pumped and filtered through a sieve. This same technique was used by **Pont (1983)**.

Third technique

At the flowing water stations, a sieve (filter, which also serves as a screen) with a diameter of 50cm was used. The operation involves scraping the bottom over a well-defined area in front of this filter; the fauna stopped by the sieve was then brought to the laboratory and systematically identified. The systematic determination of species was based on the works of **Germain (1931)**, **Girod *et al*. (1980)**, and **Kharboua (1988, 1994)**.

The specific diversity index (H)

Specific diversity is the characteristic of an ecosystem that represents the different solutions taken by a category of components to occupy that ecosystem. It can also represent the different mesological conditions to which the aquatic ecosystem is subjected **(Vieira da Silva, 1979)**.

The Shannon and Weaver index incorporates taxonomic richness and the numerical distribution of individuals among species collected in the same environment. It also allows for the estimation of the diversity of the studied environment from the perspective of the diversity of ecological niches offered in the environment to the different species of the studied zoological group **(Vieira da Silva, 1979)**. Thus, the Shannon and Weaver index is an important index to estimate in ecology.

This index, symbolized by "H," is expressed:

$$H= -\sum \frac{ni}{N} \text{Log2} \frac{ni}{N}$$

With

ni = Number of individuals of species i

N = Total number of individuals of all collected species

S = Number of species collected in the environment.

Moreover, the low values of this index reflect a poorly diversified community characterized by numerically dominant species; conversely, high values indicate a numerically balanced community.

1.4. Equity (E)

This parameter noted "E" estimates the degree of balance between species in a given population. H is expressed:

$$E = H/\log_2 S = H'/H$$

With

H' = Maximum theoretical or hypothetical diversity index

S = Number of species collected in the environment.

Equitability values range from 0 to 1, with a value close to 1 indicating a balanced community. In contrast, values near 0 suggest numerical dominance of certain species or the presence of rare species, indicating a community with a low degree of balance. However, determining equitability can be challenging, as it assumes that the total number of species in the community is known, which is often not the case **(Vieira da Silva, 1979)**.

RESULTS

1. **Systematics and commented inventory of collected species**

1.1. Systematics of inventoried species

We were able to collect 22 species of gastropods and 8 species of bivalves. The results of this collection are mentioned as follows:

Class Gastropoda

Sub/class : Pulmonata

Order : Basommatophora

Family : Lymneidae

- *Lymnaea peregra* (Muller, 1774)
- *Lymnaea stagnalis* (Linne, 1758)
- *Lymnaea palustris* (Oller, 1774)
- *Galba truncatula* **(**Muller, 1774)

Family : planorbidae

- *Bulinus truncatus* (Audouin, 1827)
- *Planorbis planorbis* (Linne, 1758)
- *Planorbarius metidjensis* (Forbes, 1838)
- *Gyraulus crista* (Linne, 1758)
- *Gyraulus laevis* (Alder, 1838)
- *Anisus spirorbis* (Linne, 1758)

Family Physidae

- *Physa acuta* (Draparnaud, 1805)

Family Ancylidae

- *Ancylus fluviatilis* (Willer, 1774)

Family Acroloxidae

- *Acroloxus lacustris* (Linne, 1774)
- *Ferrissia wautieri* (Mirolli, 1960)

Order : Stylommatophora

Family Succinneidae

- *Succinea debilis* (Morelet, 1859)

Sub/class : Prosobranchia

Order : Nionotocardia

Family Melanoldes

- *Melanopsis praemorsa* (Linne, 1758)
- *Melanopsis costellata* (Ferussac, 1923)
- *Melanopsis scalaris* (Gassies, 1856)
- *Melanopsis tuberculate* (Willer, 1774)

Family Hydrobiidae

- *Mercuria confusa* (Frauenfeld, 1838)
- *Pseudodamnicola dupoteliana* (Forber, 1838)

Order : Diotocardia

Family Neritidae

- *Theodoxus (Neritina) fluviatilis (numidicus)* (Linne, 758)

Class Lamellibranchia

Order : Eulamel l ibranchia

Family Unionidae

- *Unio durieui* (Deshayes, 1847)
- *Anodonta cygnea* (Linne, 1758)

Family Margaritiferidae

- *Margaritana margatifera* (Linne 1758)
- *Margaritana mourebeyensis* (Linne 1758)

Family Sphaeridae

- *Pisidium casertanum* (Poll, 1791)
- *Pisidium medium* (Held, 1836)
- *Pisidium indium* (Jenuss, 1936)
- *Pisidium personatum* (Malm, 1855)

1.2. Commented inventory

A. fluviatilis

This rheophilic species mainly inhabits fast-running waters (rivers, streams, and canals) and strongly attaches to stones. It especially prefers hard substrates subjected to low flow (springs) and is uncommon on muddy substrates **(Girod *et al*., 1980; Ramdani, 1987)**. It is part of the taxa associated with running waters **(Saoud, 1995)**.

F. wautieri

Species of semi-permanent waters rich in aquatic vegetation and with a more or less high organic matter content **(Saoud, 1995)**. It is a species of stagnant water that often attaches itself to the leaves of plants **(Girod *et al*., 1980)**. It is well known in Central and Eastern Europe.

P. planorbis

This Palaearctic species colonizes calm waters or areas with low flow rates, particularly those rich in vegetation. It inhabits muddy bottoms, often found under stones or on vegetation, and can tolerate slightly brackish environments **(Ramdani, 1987)**.

B. truncatus (Found in the form of an empty shell)

Species of temporary stagnant water with a muddy substrate (pools, pits) **(Ramdani, 1987)**. This type of substrate facilitates its burrowing into the soil during the dry season **(Kharboua, 1988)**. It can also live in irrigation canals, in certain calm parts of waterways in warm regions and in slightly flowing waters **(Girod *et al*., 1980; Fahde, 1987)**.

It is a circum-Mediterranean and tropical African species that, like other planorbids, has a diet consisting of plants, algae, and hydrophytes **(Girod *et al*., 1980)**.

P. metidjensis (Found in the form of an empty shell)

This Palearctic species, often living in cohabitation with *B. truncatus*, colonizes temporary stagnant waters of low depth and sources rich in organic matter **(Ramdani, 1987: Kharboua, 1988)**. Like *B. truncatus*, its diet consists of plants, algae, and hydrophytes **(Girod *et al*., 1980)**.

G. crista

Ramdani *et al*. (1987) reported that it is a species of freshwater and slightly brackish water; the animal lives on aquatic plants or floating bodies.

G. laevis

Common holoarctic species found throughout Morocco. It develops in stagnant or low-flow waters, with a substrate that is vaso-turbid and rich in aquatic vegetation. It rarely frequents temporary waters **(Ramdani 1987; Saoud, 1995)**. According to **Saoud (1995)**, this species may have two breeding periods, one in spring and the other in autumn.

A. spirorbis

It is a holarctic species that lives in Morocco in stagnant waters with low flow velocity; it frequents muddy substrates or the vegetation of the banks **(Ramdani, 1987)**. **Saoud (1995)** reported it as a species of permanent stagnant water with rich and varied aquatic vegetation.

A. lacustris

Species from Eastern Europe that colonizes stagnant or low-flow waters in Morocco. **Ramdani (1987)** noteed that it is a limnophilic species living in semi-permanent and permanent waters rich in aquatic vegetation. It attaches to the leaves of aquatic plants and can even crawl on muddy bottoms. **Kharboua (1988)** associates it with the group of eurytopic species with a high abundance in large permanent water bodies.

G. truncatula

Holarctic species, intermediate host of Fasciola hepatica **(Moukrim, 1991; Moukrim & Rondelaud, 1992)** whose former name (*Lymnaea truncatula*) is now considered a synonym. It is characterized by an amphibious phenomenon and is classified by **Saoud (1995)** among species associated with water environments (canals, flowing waters. However, it often colonizes low-flow waters) that are very rich in organic matter and diatoms **(Ramdani, 1987)**.

The water level is a limiting factor for this species **(Ghamizi *et al*., 1997)**. Similarly, **Blaise *et al*. (2001)** indicated that this species can adapt to a wide variety of biotopes. During drying, this animal burrows into the mud, under stones, or under plant debris.

L. peregra

A fairly common Palearctic eurytopic species in the country **(Ramdani, 1987)**. It is abundant in large permanent water bodies (rivers, springs, irrigation canals, lakes, etc.), very rich in vegetation **(Kharboua, 1988)**. It can inhabit slow-flowing waters and can tolerate a salinity of 14%. **Kharboua (1988)** specifies that this species, along with *M. confusa* and *P. acuta*, can be found abundantly in the river courses of the plains, particularly on the muddy bottoms of streams and merjas. **Saoud (1995)** adds that this species thrives in biotopes rich in vegetation and in highly mineralized water with varying levels of organic matter.

L. stagnalis

A species that lives mainly in stagnant or low-flow waters, semi-permanent or permanent. It can tolerate high salinity **(Ramdani, 1987)**. **Kharboua (1988)** described it as a permanent water species.

L. palustris

Holarctic colonizing species in Morocco of marshes, ponds, and slow-flowing waterways, slightly acidic and very rich in vegetation **(Ramdani, 1987)**. **Kharboua (1988)** classified it among the eurytopic species with high abundance in large permanent bodies of water.

P. acuta

A cosmopolitan species with a wide ecological valence, very similar in shape to *B. trucatus*. It is distinguished from this species only by its pointed whorls. Its former name, *Physa acuta*, is now considered a synonym **(Gloer & Meier-brok, 1994)**. It lives in all parts of the globe but is predominantly found in Western Europe. It is collected in almost all limnic formations (rivers, streams, springs, canals, lakes, merjas, and dayas). It is also the pioneering mollusk that colonizes any new body of water **(Ghamizi *et al*., 1997)**. **Rondelaud *et al.* (2001)** added that this species is highly invasive and competitive. **Aditya and Raut (2002)** described this species as a serious pest of certain economically important plants. Furthermore, **Cheung and Lam (1989)** indicated that *P. acuta* can accumulate cadmium.

S. debilis

Species most often associated with emergent water plants **(Ramdani *et al*., 1987)**. It is therefore a species that is not strictly aquatic.

M. confusa

Eurytopic species of Mediterranean regions abundant in permanent, stagnant, or partially flowing water bodies with muddy bottoms. It can also colonize pits and marshes.

Annually, this species has several overlapping generations **(Kharboua, 1988; Ghamizi *et al*., 1997)**. Furthermore, **Saoud (1995)** reported that this species is physiologically capable of withstanding thermal and halotypic constraints.

P. dupotetiana

A species that was collected by **Kristensen (1985)** only in the waterways of the Middle Atlas. It has a tendency to colonize semi-permanent environments, with muddy substrates, rich in aquatic vegetation and highly mineralized **(Saoud, 1995)**.

M. praemorsa

It is part of the species that are associated with flowing water environments **(Saoud, 1995)** and occupies aquatic biotopes at low altitudes, with high temperatures, rich in dissolved salts and with low flow **(Tazi *et al*., 2001)**. It is a species that lives attached to stones and plants, and sometimes it crawls on the bottom. It is common in almost all the lower reaches of rivers and springs in Morocco and is abundant in the cold waters of high altitudes **(Ramdani *et al*., 1987)**. It can also live in marshes with a clay-sandy substrate **(Saoud, 1995)**.

In the Marrakech region, the reproduction of this species is continuous with a peak in the recruitment of young during the summer period (June-July) **(Ghamizi *et al*., 1997)**.

M. costellata

A species that is part of those infested in running water environments **(Kharboua, 1988)**. It inhabits the same biotopes as *M. praemorsa* and attaches to stones, plants, or crawls on the bottom. It is very common in hot springs and rivers **(Ramdani *et al.*, 1987)**.

M. scalaris

It is reported as a species associated with running waters **(Kharboua, 1988)**. It exhibits the same lifestyle as *M. praemorsa* and *A. costellata*, with which it can coexist **(Ramdani *et al.*, 1987)**.

M. mourebeyensis

Species reported as specific to the Oued Oum-er-Rabia **(Pallary, 1936)**. It often colonizes watercourses, frequently in association with *M. praemorsa*.

M. tuberculata

A highly localized species **(Kharboua, 1988)** living in colonies in waterways (rivers, Oueds, and hot springs) or in stagnant waters. It is reported as competitive with several mollusks that are vectors of schistosomiasis **(Pointier & Mccullough, 1989; Idaghour, 1991; Madsen, 1995)**.

T. fluviatile

Species from North Africa and Europe that is associated with running water environments. It is rarely collected in calm waterways and prefers hot springs (15-20 °C) and sometimes rivers **(Ramdani *et al.*, 1987)**. It is a primarily herbivorous mollusk that feeds on diatoms and periphyton.

U. durieui

A rheophilic species that is dependent on running waters **(Saoud, 1995)**. It colonizes sites with running water (Oued, streams, and canals) **(Kharboua, 1988)**.

A. cygnea

Species confined to slow-flowing freshwater and muddy bottoms, very localized and collected in the large rivers of large plains **(Kharboua, 1988)**. When the layer of water covering it becomes thin, it sinks into the mud.

M. margaritifera

Species from Europe and North Africa that inhabits turbulent waters, rivers, and large streams. It is one of the most threatened species in Europe **(Young, 1991; Geist, 2010)**.

P. casertranum

A eurytopic species, highly abundant in large permanent water bodies **(Kharboua, 1988)**. It is widely distributed and colonizes all environments, even temporary ones **(Kuiper, 1966, 1972)**. It is a species associated with the presence of soft, clayey-silty substrate, abundant in accumulation basins and downstream of irrigation canals **(Ghamizi *et al.*, 1987)**. **Saoud (1995)** noted that this species prefers environments rich in aquatic vegetation.

P. medium

It is an eurytopic species colonizing several typological levels **(Kuiper,**

1966; Mouthon, 1980; Kharboua, 1988, 1994). **Saoud (1995)** indicated that this species lives in environments with fine substrate, in clear waters rich in vegetation and organic matter. *P. midium* can also colonize temporary environments **(Kuiper, 1966, 1972)**.

P. nidium

Eurytopic species **(Kuiper, 1966; Mouthon, 1980; Kharboua, 1988, 1994)**, colonizing biotopes with fine substrate, in clear waters rich in vegetation and organic matter **(Saoud, 1995)**. Furthermore, *P. midium*, *P. nidium*, and *P. personatum* form a transitional core between the rheophilic system and the limnophilic system **(Saoud, 1995)**.

P. personatum

Like *P. midium* and *P. nidium*, this species can colonize several typological levels **(Kuiper, 1966; Mouthon, 1980; Khaboua, 1994)**. It has the same lifestyle as these species.

Specific richness, diversity, and equity

Table (1) illustrates the richness, diversity, and equity of the various surveyed biotopes. It notes that the values of these three variables are very heterogeneous and vary both within the same group, that is to say the same type of biotope, and from one type of biotope to another. Specific richness, for example, varies and seems to be relatively stable in the Oueds, less stable and relatively high in the group of dayas, relatively stable in Pc I, Sc II, and Tc III, and moderately high in Tc III. It ranges from 3 to 4 in the sumps and is greater than 4 in the gueltats.

Table. 1. Richness, diversity, and equity of the various surveyed biotopes

Stations	Type	SR	H	E
1	Oueds (O)	4	1.2	0.64
3		4	1.3	0.65
5		4	1.6	0.82
6		6	2.01	0.77
7		5	1.9	0.83
8		4	1.2	0.64
14		4	0.7	0.83
18		6	2.0	0.96
30		7	2.2	0.88
54		4	1.6	0.84
58		5	2.2	0.69
59		6	2.2	0.81
60		5	1.9	0.86
62		5	1.6	0.69
75		6	2.1	0.81

76		5	1.6	0.86
80		7	2.2	0.79
81		4	1.6	0.84
87		5	1.9	0.85
117		5	1.8	0.93
		N1= 20	N1=20	N1= 20
		$\Sigma x_{.i}$=111	$\Sigma x_{.i}$=36.08	$\Sigma x_{.i}$ =15.35
		m1=5.58	m1=1.34	m1=0.7675
21	Primary channels (Pc I)	2	0.81	0.81
22		2	0.76	0.76
28		3	0.89	0.56
35		3	0.62	0.09
36		2	0.86	0.86
37		3	1.04	0.62
69		4	1.62	0.81
70		4	1.61	0.80
77		5	1.44	0.62
88		3	1.16	0.73
109		4	1.55	0.75
		N2=11	N2=11	N2=11
		$\Sigma x_{.i}$=35	$\Sigma x_{.i}$=12.66	$\Sigma x_{.i}$=7.47
		m2=3.18	m2=1.15	m2=0.681
33	Secondary channels (Sc II)	3	0.96	0.60
50		3	0.48	0.93
51		3	1.42	0.80
95		4	1.82	0.90
98		5	1.95	0.84
99		4	1.48	0.74
		N3=6	N3=6	N3=6
		$\Sigma x_{.i}$=22	$\Sigma x_{.i}$=9.1	$\Sigma x_{.i}$=4.19
		m3=3.66	m3=1.55	m3=0.6984
9	Tertiary channels (Tc III)	2	0.17	0.83
10		2	0.83	0.83
11		3	0.72	0.45
26		4	1.63	0.81
29		4	1.24	0.62
31		4	1.86	0.93
34		4	1.41	0.84
38		5	1.65	0.82
91		4	1.75	0.77
97		4	1.39	0.69

100		4	1.69	0.84
101		4	1.48	0.94
102		4	1.64	0.82
104		3	1.47	0.93
107		3	1.58	0.99
111		3	1.38	0.87
112		4	1.41	0.70
113		3	1.22	0.77
114		5	2.28	0.98
115		4	0.93	0.46
116		3	1.51	0.95
		N4=21 $\Sigma_{X.i}$=76 m4=3.61	N4=21 $\Sigma_{X.i}$=29.24 m4=1.39	N4=21 $\Sigma_{X.i}$=15.85 m4=0.75
24	Sumps (Su)	5	1.65	0.67
25		4	1.12	0.56
27		4	1.33	0.66
32		3	1.22	0.77
89		3	1.55	0.64
90		4	1.28	0.87
92		4	1.81	0.90
103		4	1.47	0.73
105		5	1.92	0.82
106		4	1.69	0.84
108		4	1.73	0.66
110		3	1.35	0.85
118		4	1.86	0.93
		N5=13 $\Sigma_{X.i}$=51 m5=3.92	N5=13 $\Sigma_{X.i}$=19.9 m5=1.68	N5=13 $\Sigma_{X.i}$=10.2 m5=0.78
66	Sources (S)	4	1.51	0.75
78		3	1.49	0.94
79		3	1.18	0.73
82		3	1.53	0.76
84		3	1.17	0.80
86		4	1.76	0.88
		N6=6 $\Sigma_{X.i}$=20 m6=3.33	N6=6 $\Sigma_{X.i}$=8.72 m6=1.45	N6=6 $\Sigma_{X.i}$=5.06 m6=0.84
2		3	0.80	0.50
4		3	1.00	0.63
15		7	1.89	0.67

39	Dayas (D)	4	1.69	0.87
42		9	2.75	0.84
43		8	2.12	0.70
53		5	1.96	0.84
61		4	1.49	0.74
71		7	2.18	0.77
72		3	1.23	0.77
73		6	2.24	0.86
74		6	2.34	0.90
		N7=12 $\Sigma_{X.i}$=67 m7=5.58	N7=12 $\Sigma_{X.i}$=21.69 m7=1.80	N7=12 $\Sigma_{X.i}$=9.09 m7=0.75
19	Merjas (M)	4	1.07	0.53
40		3	1.39	0.87
41		5	1.87	0.80
44		6	1.99	0.77
45		6	1.97	0.76
48		5	2.16	0.93
49		4	1.82	0.91
55		6	2.42	0.93
63		5	2.27	0.97
93		6	2.41	0.93
94		7	2.22	0.79
		N8=11 $\Sigma_{X.i}$=57 m8=5.18	N8=11 $\Sigma_{X.i}$=19.72 m8=1.9	N8=11 $\Sigma_{X.i}$=9.19 m8=0.83
64	Gueltas (G)	5	2.20	0.95
65		6	2.44	0.94
67		6	2.03	0.78
16	Fosses (F)	3	0.50	0.31
17		5	1.50	0.64
23		4	1.65	0.82
20	Unpaved channels (Uc)	3	0.42	0.26
56		6	2.23	0.86
68		8	2.41	0.80
85		3	1.21	0.74
12	Drains (Dr)	9	2.80	0.88
13		4	1.49	0.74
57		4	1.38	0.69
96		5	2.27	0.97
52	Streams (St)	5	1.75	0.75
83	Seguia (Se)	3	0.99	0.63

We aimed to determine whether there is a dependency between species richness (Sr), species diversity (H), equitability (E), and the nature of the biotope. The analysis of the values for Sr, H, and E across the eight biotopes allowed us to distinguish a set of values for each biotope "i," from which we calculated the respective average values "mSri" and "mei." The calculated averages for each of the three variables showed significant differences. This leads us to question whether the observed differences between these averages reflect a real influence of the biotope type or if they can simply be attributed to sampling fluctuations. In other words, does the nature of the biotope influence Sr, H, or E, or are the differences merely a result of sampling variability?

According to the method known as "Analysis of Variance" **(Geller, 1983)**, for each of the three variables Sr, H, and E, one compares the intragroup variance (VA), which is the variance within each group, with the so-called intergroup variance (VB) that is calculated by assimilating all the values of a given group to its mean value. In other words:

$$VA = \frac{1}{N-K}\sum\sum(xi - mi)^2 \text{et} VB = \frac{1}{K-1}\sum\sum(m - M)^2$$

With

xi = Calculated value of Rs, H and E;

mi = Average value of xi of the same type of biotope;

M = Average of the average mi related to the same variable;

N = Total number of respected biotopes (i.e., 93 biotopes) in the eight groups of biotopes;

k = Number of types of biotopes, i.e., eight groups.

Furthermore, Snedecor's tables show that for a number of degrees of freedom V1 = k-1 = 7 and for V2 = N - k = 100 - 7 = 93, the critical value of F at a probability level of 0.05 is F0.05 = 2.80. The results of this study are illustrated in Table II.

Table 2. Results of the intra-group and inter-group variance analysis of the three studied variables

	SR	H	E
VA	0.07 2	0.962	0.019 5
VB	0.96	0.174	0.091 4
VA/VB ou VB/VA	13.2 78	5.528	4.687
$P_{0.05}$	2.8	2.8	2.8
Significance	*	*	*

For Sr, H, and E, the results (Table 2) show values that exceed the value of F=0.05. Therefore, the differences observed between the average divergences are highly significant and, consequently, the factor "type of biotope" has a real influence on species richness, specific diversity, and equitability of the malacofauna.

The studied biotopes are very different from each other. However, we can subdivide the 118 surveyed biotopes into several groups. In each of these groups, we can note that although the physico-chemical characteristics differ from one biotope to another, there is a certain homogeneity in the general spatio-temporal evolution of the physico-chemical characteristics of the group. The dayas, for example, are characterized by the temporality of their waters, low values for the physico-chemical characteristics (Conductivity, dry residue, organic matter, etc.) during the rainy season (dilution phenomenon), but as the dry season approaches, due to concentrations caused by evaporation of the waters, these values become high. In the Oueds, as one moves away from the source, these physico-chemical values become higher due to the mineral contributions from runoff waters and minerals from the traversed lands. At the level of the springs, a certain temporal constancy in the physico-chemical characteristics of the environment is noted. In the sumps, an intermittence in the water speed can influence the evolution of the physico-chemical characteristics of the environment, etc.

Thus, if we take into account all these divergences in the spatio-temporal revolution of the physicochemical characteristics of the environment, it seems logical to us to have a dependence between specific richness, diversity, equitability, and, in general, the degree of balance of the surveyed malacological communities and the nature of their biotopes. Indeed, a decrease in specific richness can be interpreted as a decrease in the number of potential ecological niches in the environment: A high value of the so-called Shannon and Weiner index reflects a significant diversity of ecological niches offered in the environment to different species **(Vieira Da Silva, 1979)**. It is therefore evident that the number of potential niches offered, in time and space, by a watercourse differs qualitatively and quantitatively from that offered by a pond or another type of biotope.

Similarly, by comparing the Gharb plain to other plains such as the Tadla plain and the Loukkos area, a number of similarities and differences are observed (Fig. 2).

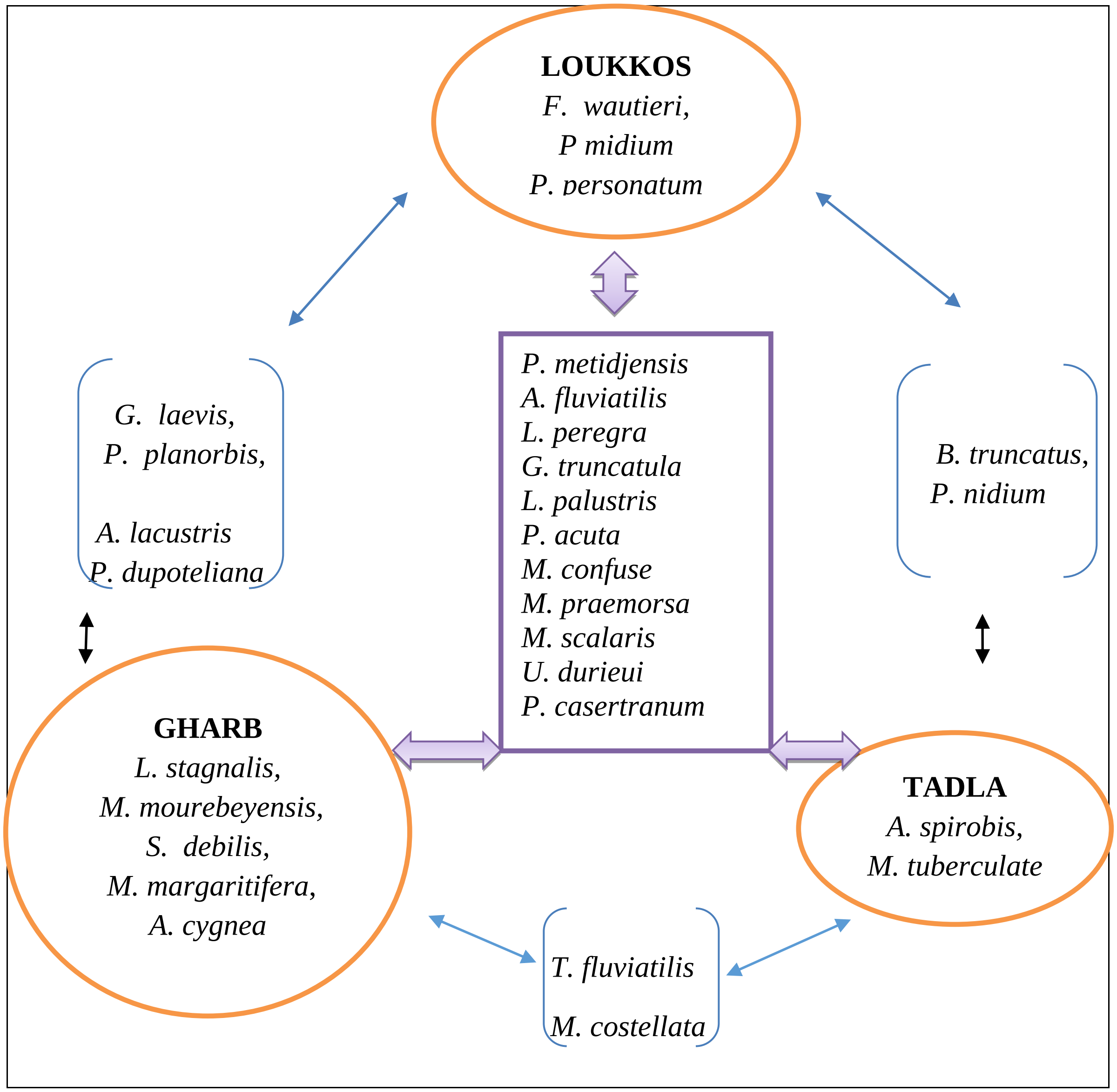

Fig. 2. Presence/absence of species collected in the studied areas

DISCUSSION

Among the 28 species of gastropods and 11 species of bivalves that make up the aquatic malacological fauna of Morocco **(Ramdani *et al*., 1987; Saoud, 1995)**, we were able to collect 22 species of gastropods and 8 species of bivalves, which is more than 2/3 of the respective total numbers for these two zoological groups.

Compared to the Tadla plain and the Loukkos area, it is the Gharb plain that has proven to be specifically the richest, a finding similar to that reported by **Elhassouni *et al*. (2024)**. Indeed, among the 39 species of aquatic mollusks inventoried across the Moroccan territory, we recorded 22 in the Gharb plain; just in the merja of Fouarates (a semi-permanent pond located near Kénitra), there are 10 species of gastropods, which is more than 1/3 of the total number of freshwater gastropods in Morocco. The representativeness and specific richness of gastropods are therefore very significant in this plain. This phenomenon can be explained by the great diversity of biotopes and the diversity of favorable hydrological and pedological conditions in this plain.

Similarly, the results show that ten species are common to the three studied areas, namely *P. metidjensis*, *A. fluviatilis*, *L. peregra*, *G. truncatula*, *L. palustris*, *P. acuta*, *M. confuse*, *M. praemorsa*, *M. scalaris*, *U. durieui*, *P. casertranum*. Only the species *L. stagnalis*, *M. mourebeyensis*, *S. debilis*, *M. margaritifera*, and *A. cygnea* are specific to the Ghrab plain; *F. wautieri*, *P. midium*, and *P. personatum* are specific to the Loukkos area; *A. spirobis* and *M. tuberculate* are specific to the Tadla plain. In addition to the other species common in the three studied areas, the Loukkos area hosts *G. laevis*, *P. planorbis*, *A. lacustris*, and *P. dupoteliana* in common with the Gharb plain, and *B. truncatus* and *P. nidium* in common with the Tadla plain and Loukkos. Finally, *M. costellata* and *T. fluviatilis* are only collected in the Gharb and Tadla plains.

Moreover, the family Sphaeridae, with four species, is the most represented among the gastropods. Following this, the families Planorbidae, Lymnaeidae (a family of significant interest in parasitology) **(Bargues *et al.*, 2001)**, and Melamoidae are also well represented, with six, four, and four species, respectively. Furthermore, *P. metidjensis* currently exists in the Gharb plain, the Tadla plain, and the Loukkos area, but at a lower frequency than what has been reported in the literature. *B. truncatus*, the main intermediate vector of schistosomiasis in Morocco, has not been collected in the Gharb plain. This absence of *B. truncatus* and the lack of concordance in the geographical distribution of the current foci of *P. metidjensis* in this plain do not allow for an explanation of the distribution of historically known foci of schistosomiasis in the Gharb plain.

Previous work that addressed the epidemiological and/or malacological study of the Gharb plain **(Gaud, 1952; Hadji, 1980; Kharboua, 1988; Makboul, 1996)** has shown the historical existence of several foci of schistosomiasis and breeding sites in the Gharb plain, such as those in Kénitra.

As for specific richness, diversity, and equity, it is noted that these three types of characteristics vary with the seasons, most often showing an enrichment and a trend towards a better balance of the malacofauna in spring **(Saoud, 1995; Maqboul, 1996)**. Similarly, for specific richness, diversity, and equity, the results show values exceeding the F=0.05 value. Therefore, the differences observed between the mean divergences are significant, indicating that the factor "type of biotope" has a real influence on the species richness, diversity, and equitability of the malacofauna.

Furthermore, the studied biotopes vary significantly from one another. However, the 118 surveyed biotopes can be grouped into several categories. Within each group, despite differences in physicochemical characteristics between biotopes, there is a certain homogeneity in the general spatiotemporal variations of these characteristics. For example, the dayas are characterized by the temporality of their waters. During the rainy season, they exhibit low values for physicochemical characteristics (such as conductivity, dry residue, and organic matter) due to the dilution effect. However, as the dry season approaches and evaporation concentrates the water, these values rise. In the oueds, physicochemical values increase with distance from the source, primarily due to mineral contributions from runoff and the minerals in the surrounding terrain. At the sources, a temporal constancy in the physicochemical characteristics is observed. In wells, intermittent water flow can influence the fluctuations in physicochemical characteristics.

Given these variations in the spatiotemporal fluctuations of physicochemical characteristics, it seems logical to expect a dependence between species richness, diversity, equitability, and the nature of the biotopes. A decrease in species richness may reflect a reduction in the number of potential ecological niches in the environment. A higher Shannon-Wiener index, for instance, indicates a more diverse range of ecological niches available to different species **(Vieira Da Silva, 1979)**. It is clear that the number of potential niches provided, in both time and space, by a watercourse differs qualitatively and quantitatively from those offered by a pond or other types of biotopes.

CONCLUSION

Overall, the number of species collected in the surveyed areas is significant. Among the bivalves, the family Sphaeridae is the most abundant. Among the gastropods, the Planorbidae and Melamidae families are the most well-represented, with the Lymnaeidae family, of particular interest in parasitology, also being well-represented. However, *Bulinus truncatus* was not collected in the Gharb plain. In the other areas, this primary vector of schistosomiasis has noticeably decreased both quantitatively and geographically. A similar, though less pronounced, trend is observed for *P. metidjensis*. The decline in the frequency of *B. truncatus* and *P. metidjensis* is so significant that the historical existence of schistosomiasis foci can no longer be explained by the current distribution of intermediate vectors in the surveyed area. Moreover, the Gharb plain is the richest in species and shares many species in common with the other two studied areas.

Most of the surveyed biotopes are characterized by populations with relatively high species richness and diversity. Nevertheless, as demonstrated, the nature of the biotope significantly influences the richness, diversity, and evenness of aquatic malacological populations.

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