BIODIVERSITY ASSESSMENT OF TERRESTRIAL SNAILS (MOLLUSCA, GASTROPODA) OF ESSAOUIRA' DUNES OF MOROCCO: TESTING FACTORS AFFECTING THE DISTRIBUTION OF TERRESTRIAL MOLLUSCS

GUENNOUN, F. Z.[1,2*] – MOSTAKIM, L.[1,2] – GHAMIZI, M.[1,2]

[1]*Research Center of the Museum of Natural History, Cadi Ayyad University, Marrakesh, Morocco*
(e-mail: mostakim.lahcen@gmail.com, mohamed.ghamizi@gmail.com)

[2]*Laboratory of water, biodiversity and climate change, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakesh, B. P. 2390, 40000, Morocco*
(e-mail: mostakim.lahcen@gmail.com, mohamed.ghamizi@gmail.com)

[*]*Corresponding author*
e-mail: fatima.zahra.guennoun@gmail.com; phone: +212-684-054012

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Abstract. Essaouira dunes of Morocco is a Biological and Ecological Interest Site (BEIS) that is recently impacted and threatened by human activities and climate change. Hence, this dune ecosystem needs thorough attention to preserve its biodiversity. Our study was carried out to assess the terrestrial mollusc diversity of this BEIS, and to figure out the relationship between environmental factors and terrestrial gastropods distribution. Six stations were chosen according to the variation of ecological factors, such as: type of soil, presence of limestone rocks, type of vegetation, and wind speed. The sampling was adopted using both visual search and quadrat approach. The results revealed the existence of 23 species of terrestrial molluscs; belonging to 18 genera and 11 families. Geomitridea and Helicidae are the most dominant families (56.52%). The highest specific richness was recorded in Ounagha' station, with 17 species. The malacofaunal diversity between stations was also determined by: Constancy, Shannon, Equitability, Simpson and Jaccard indices. The relationship between the distribution of terrestrial snails and abiotic factors were involved using Canonical Correspondence Analysis (CCA). The results showed that wind speed and type of soil represent those relevant factors affecting the distribution patterns of terrestrial gastropods.
Keyword: *malacofaunal diversity, environmental factors, dunes ecosystems, Biological and Ecological Interest Site, Morocco*

Introduction

Nowadays, the anthropic exploitations have negatively affected natural environments (Parmesan and Yohe, 2003) and caused a decrease in species richness, relative abundance, and a proliferation of exotic species (Waldron et al., 2017). Hence, exploring diversity patterns and its predictors is fundamental to develop appropriate conservation scenarios (Horsák and Cernohorsky, 2008).

With approximately 35000 known species (Audibert and Bertrand, 2015), terrestrial gastropods (snails and slugs) represent the second largest group in the animal phylum after the arthropods; and the most threatened with extinction (Solem, 1984; Van Bruggen, 1995). Due to their restricted mobility, small body size and role in the food chain, as a food source and in the transfer of calcium and other nutrients, snails are considered as a good indicator of ecosystem health (Adams and Wall, 2000; Clergeau et al., 2011). Indeed, they could be used to understand the state of habitat fragmentation

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(Gotmark et al., 2008; Kappes et al., 2009; Strayer and Dudgeon, 2010; Blettler et al., 2018). Thus, the spatial distribution of terrestrial snails is closely related to the local geographic characteristics, and physiochemical biotope structure. Such ecological conditions are the primary factors governing the diversity and the distribution of terrestrial snails at small scales (Hylander et al., 2005; Juřičková et al., 2008).

Moreover, Morocco is the first exporter of terrestrial gastropods to Europe (Sebban et al., 2022), due to its physical and biogeographical characteristics. Indeed, several localities are rich in terrestrial molluscs and require a thorough study. Nevertheless, the last inventory of terrestrial molluscs in Morocco reports the presence of 28 families grouped in 90 genera and 421 species (Rour et al., 2002). Since then, the systematic position of some genera in Morocco has been verified (Holyoak et al., 2012, 2018; Torres Alba et al., 2016; Holyoak and Holyoak, 2016, 2017; Bouaziz-Yahiatene et al., 2017; Kneubühler et al., 2019). In addition, Bouchet et al. (2017) proposed a revised classification of terrestrial gastropod families and thus many species have changed their assigned genus. Hence, an update of the terrestrial inventory of Morocco is required.

Located in the South-West of Morocco, Essaouira' dunes has been classified in 1994 as a Biological and Ecological Interest Site (BEIS) (UNEP-WCMC, 2022) belonging to the coastal zone (Boulejiouch, 2003). This site is characterized by a considerable variety of fauna and flora; among the 634 species of native plants recorded, more than 58 taxa are endemic (Benabid and Fennane, 1994). Also, the BEIS site has a considerable faunal richness: 21 species of reptiles, 235 species of birds, and 15 species of mammals (Rachidi, 2015). Nevertheless, no molluscan fauna checklist currently exists. Furthemore, with the expansion of Essaouira' city and the increase of anthropogenic activities combined with the climate change, the biodiversity of the BEIS site is negatively affected, as well as the quality of terrestrial and aquatic ecosystems.

In this context, the main objectives of this study are: to establish a malacological check-list of Essaouira' dunes site, to study the similarity of the different stations surveyed using biodiversity indices (Constancy, Shannon, Equitability, Simpson and Jaccard indices), and to characterize the abiotic factors governing the distribution and abundance of terrestrial snails.

Materials and methods

Study area

The study was carried out in the Essaouira dunes located in the middle Atlantic of Morocco, between 31°30' North and 9°50' West. It is bordered to the South by the plain of Sous and to the North by Tensift watershed (Weisrock, 1982). This BEIS site covers an area of 11 000 ha (UNEP-WCMC, 2022) from Jbel Chicht to Sim Cap (*Fig. 1*) and belongs to the coastal zone (L25) with priority 1 (Boulejiouch, 2003).

The geological history of the region began with the opening of the North Atlantic. Thus, the lithological facies characterizing this area extend chronologically from the Permo-triassic to the present. The Triassic outcrops correspond to continental formations alternated by epicontinental and marine deposits. The latter testify to the existence of a paleo-rift prefiguring the opening of the Atlantic Ocean (Weistock, 1980).

With an annual rainfall pattern, the Essaouira region is part of a Mediterranean model. The annual rainfall, averaging 279 mm, constitutes a low water supply. Essaouira, a coastal city, is characterized by a maximum rainfall in Autumn – Winter,

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where it rains more, than in Winter - Spring, as in the rest of the Mediterranean. The lowest rainfall is recorded in the months of July and August characterizing a dry Summer (Simone, 2000).

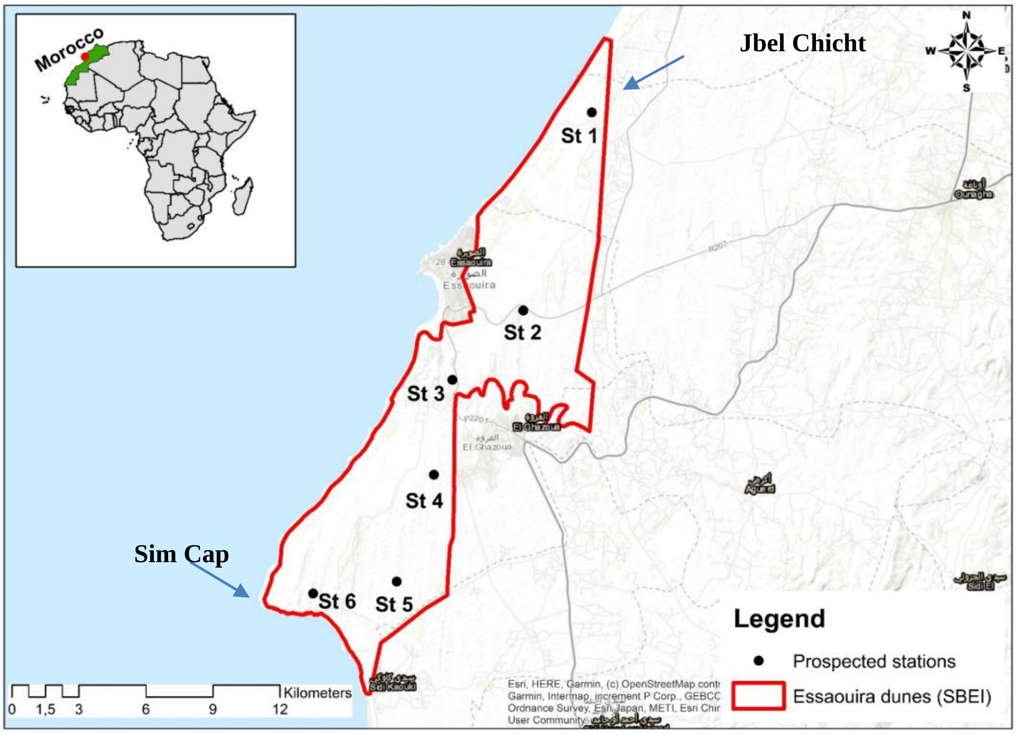

Figure 1. *Geographical location of prospected stations of Essaouira' dunes of Morocco*

Sampling and identification

Field sampling

A stratified sampling was carried out at the BEIS of Essaouira' Dunes in the spring of 2021. A total of six stations (*Figs. 1 and 2)* were covered by the survey according to the type of vegetation, and the nature of the substratum (presence of limestone, sand, clay etc.). *Fig. 1* presents the geographical distribution of the prospected stations within the BEIS site. The different characteristics of the latter are presented in *Table 1*.

During the fieldwork, both visual search and soil sampling were used, following the method of Aubry et al. (2005) with modifications. The visual search was undertaken for approximately 1 hour over 25 m² area at each station. The collect was made by hand "hand-picking" on tree trunks, under rocks and buchets, on leaf litter and soil surface. To confirm the presence of the species in the habitat, we only take into consideration living individuals and fresh empty shells that are characterised by an intact periostracum (Millar and Waite, 1999). Old empty shells with a missing or peeled periostracum are omitted from calculation. The small or very small specimens are difficult to see under the field conditions. In this context, a quadrat method was used by collecting litter and surface soil covering 25 cm² and a depth of 5 cm at different points within the same station. Bagged and brought back to the laboratory, the quadrats were examinated under a low power microscope in order to detect any molluscs present.

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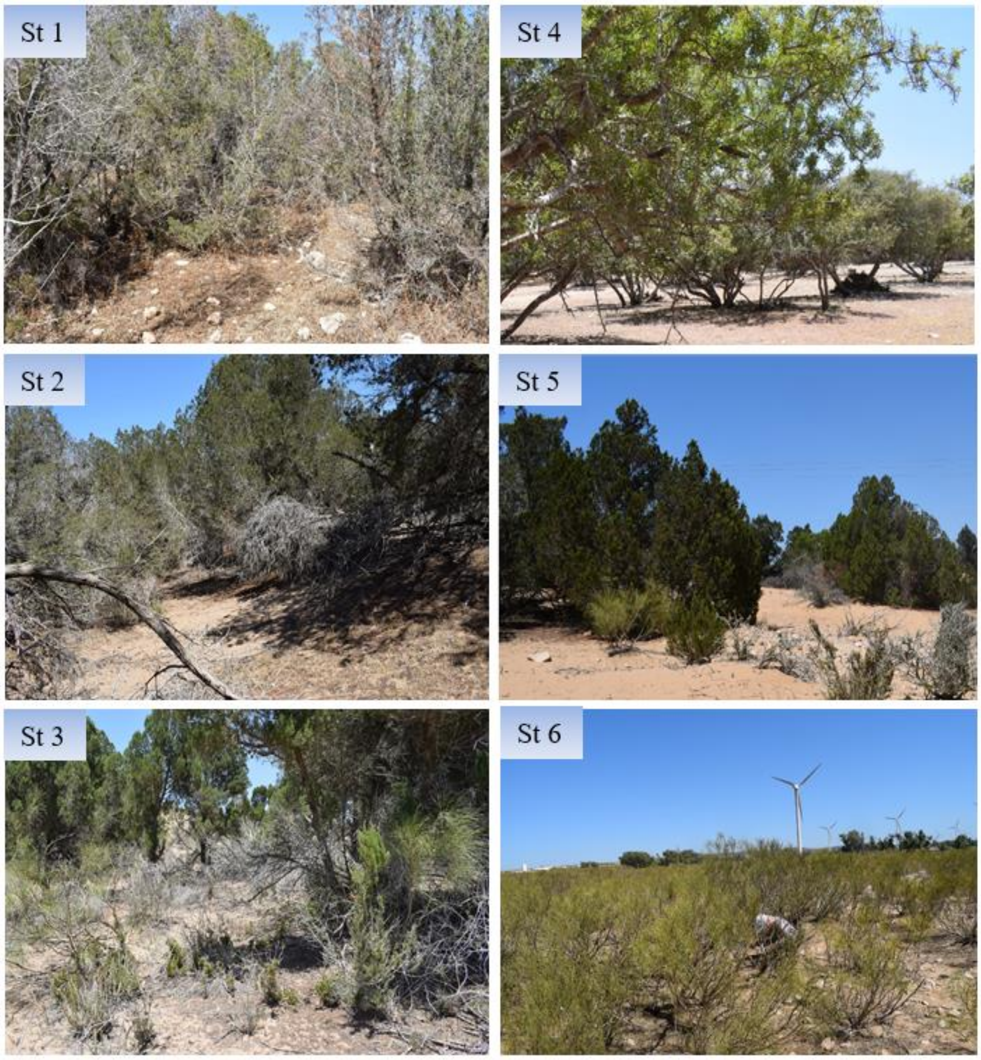

Figure 2. *Pictures of prospected stations of Essaouira' Dunes, Morocco*

Table 1. *General characteristics of the prospected stations of Essaouira Dunes, Morocco*

	Station Name	Coordinate system N / W	Altitude (m)	Air humidity (H%)	Presence of limestone rocks	Type of substrate	Dominant vegetation
S1	Ounagha	31°33,778' N 9°40,968' W	163	53,5	Yes	Clay	*J. phoenicea*
S2	Lagune site	31°29,674' N 9°43,705' W	90	51,4	Yes	Sand	*J. phoenicea*
S3	Diabate	31°28,194' N 9°45,476' W	20	56,7	No	Sand	*J. phoenicea*
S4	Oued ksob site	31°24,931' N 9°43,106' W	88	48,2	Yes	Clay	*A. spinosa*
S5	Sidi Kaouki	31°23,003' N 9°46,802' W	67	52,6	No	Sand	*J. phoenicea*
S6	Sim Cap	31°23,245' N 9°48,289' W	60	54,2	Yes	Sand	*R. monosperma*

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Identification and conservation

Transported to the laboratory, living samples were separated from empty shells. Identification then started by cleaning the shells so that the characters for identification were not masked. The empty shells were cleaned using an Ultrasonic machine and dried at room temperature while living snails were preserved in 70% ethanol for anatomical study.

Based on the morphological characters of shells and the morpho-anatomy of genitalia, identification was supported by key features cited by Germain (1930), Audibert and Bertrand (2005), Kerney and Cameron (2006), and Gargominy and Ripken (2011) according to the revised classification of Bouchet et al. (2017).

Samples were stored at the Museum of Natural History of Marrakesh, Morocco (MHNM). Small snails were photographed with a Leica D5100 digital camera connected with stereomicroscope, while large snails were photographed with a Nikon D5300.

Statistical analysis

Diversity indices provide interesting pieces of information about a community structure. They aim to describe general properties of communities that allow us to compare different regions, taxa, and trophic levels (Morris et al., 2014). Hence, several biodiversity indices were determined during the study:

Conctancy index (C): Constancy was calculated according to Dajoz (1985):

$$\mathbf{C = (p \times 100) / N} \qquad \text{(Eq.1)}$$

where C = constancy in % for each species; p = number of samples in which the species is present; N = total number of samples. Three groups can be distinguished. Species in the first group are considered constant when they are found in 50% or more of the samples. Those in the second group are accessory because they are only present in 25 to 49% of the samples. Finally, accidental species have a frequency of occurrence of less than 25%.

Shannon index (H') (Shannon and Weaver, 1949): Common biodiversity index based on the rationale that the diversity, or information, in a natural system can be measured in a similar way to the information contained in a code or message. It assumes that individuals are randomly sampled from an infinitely large community and that all species are represented in the sample. It is calculated from the following equation:

$$H' = -\sum_{i=1}^{S} pi * \log pi \qquad \text{(Eq.2)}$$

where pi is the proportion of individuals found of species i. We can estimate this proportion as pi = ni/N, where ni is the number of individuals in species i and N is the total number of individuals in the community (Magurran, 2004).

Simpson's index (D) (Simpson, 1949): This index is less sensitive to richness and more sensitive to evenness (Colwell, 2009). It computes the probability of two randomly sampled species to belong to different species (Siddique et al., 2010):

$$\mathbf{1 - D = 1 - \sum_{i=1}^{S} pi^{2}} \qquad \text{(Eq.3)}$$

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where again pi is the proportion of individuals found in species i, and pi = ni/N, where ni is the number of individuals in species i and N is the total number of individuals in the community (Magurran, 2004).

Equitability index (E): used to assess the degree of species equality in a community (Pielou, 1969, 1975):

$$\mathbf{E} = \frac{H'}{H'max} = \frac{H'}{\ln S} \quad \text{(Eq.4)}$$

where H' is Shannon's diversity index value and S is the species richness of the sample. The value between 0 and 1 with 1 being complete evenness (Mulder et al., 2004).

Jaccard Index (J): This index is a test of similarity between two habitats (stations). It allows to determine the similarity in species by crossing two different habitats.

$$\mathbf{J} = \mathbf{a} / (\mathbf{a} + \mathbf{b} - \mathbf{c}) \quad \text{(Eq.5)}$$

with a: represents the total number of unique species for station 1; b: represents the total number of unique species for station 2; c: represents the number of common species between two stations (Real and Vargas, 1996). Using "Past" software, a hierarchical clustering is used to identify the similarity between the different stations surveyed.

The Canonical Correspondence Analysis (CCA) was carried out in this study to determine the relationship between species richness and all explanatory variables such as (Sea effect, wind speed, pH of soil, temperature of soil, nature of substrat and the presence of limestone rock), using PAST software (Hammer et al., 2001). This method is suitable for analyses associated with ecological studies that assess the effect of environmental factors on the abundance and distribution of inventoried species.

Results

Malacological diversity

Twenty-three species of terrestrial molluscs were recorded in the six sampled stations; belonging to eighteen genera and eleven families. The Geomitridea is the most dominant family by the presence of eight species, followed by the Helicidea, which is characterised by five species; while the Ferussaciidae is represented by two species. The eight remaining families, notably: the Achatinidae, the Chondrinidae, the Oxychilidae, the Parmacellidae, the Pomatiidae, the Punctidae, the Trissexodontidae, and the Truncatellinidae, are represented by a single species. *Table 2* summarizes the species inventoried and their relative taxonomic families. The empty shells of all species collected throughout the study are illustrated in the *Figs. 3, 4, 5, 6,* and *7.*

Combining both sampling methods allowed us to collect species of different scales. Quadrat method provided 87% of the total specific richness while visual search yielded 73.9% of the species. The results show that the specific richness differs for the six sampled stations; ranging from 5 to 17 species (*Fig. 8*). Station 1 appeared to be the richest site with 17 species, whereas the station 6 was particularly poor with only 5 species recorded.

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Table 2. *Species of terrestrial molluscs recorded at each station of Essaouira' Dunes, Morocco and the corresponding constancy index (Both living individuals and fresh empty shells were included into calculation)*

Phylum	Class	Order	Families	Species	St 1	St 2	St 3	St 4	St 5	St 6	Total	Constancy index (%)	Categories
Mollusca	**Gastropoda**	**Stylommatophora**	**Achatinidae**	*Rumina decollata* (Linnaeus, 1758)		2					**2**	16,67	Accidental
			Chondrinidae	*Granopupa granum* (Draparnaud, 1801)		2					**2**	16,67	Accidental
			Ferussaciidae	*Cecilioides acicula* (Müller, 1774)					1		**1**	16,67	Accidental
				Ferussacia folliculum (Schröter, 1784)	3	4					**7**	33,33	Accessory
			Geomitridae	*Cochlicella acuta* (O. F. Müller, 1774)	22	64	68		67		**221**	66,67	Constant
				Cochlicella barbara (Linnaeus, 1758)			25				**25**	16,67	Accidental
				Cochlicella conoidea (Draparnaud, 1801)	19		13	1	143		**176**	66,67	Constant
				Obelus pumilio (Dillwyn, 1817)	17	28	33		34	3	**115**	83,33	Constant
				Xeroleuca turcica (Holten, 1802)	1	1		1			**3**	50,00	Constant
				Xeroplexa intersecta (Poiret, 1801)	25	25	127	97	85		**359**	83,33	Constant
				Xerotricha apicina (Lamarck, 1822)	1	3	12		43		**59**	66,67	Constant
				Xerotricha conspurcata (Draparnaud, 1801)	342	87	406	173	264	1	**1273**	100,00	Constant
			Helicidae	*Cornu aspersum* (Müller, 1774)	1						**1**	16,67	Accidental
				Otala punctata (O. F. Müller, 1774)	6		48	3	18	1	**76**	83,33	Constant
				Theba pisana (Müller, 1774)	31	62	193	149	152	103	**690**	100,00	Constant
				Theba subdentata legionaria (Sacchi, 1955)	6	1		7			**14**	50,00	Constant
				Theba subdentata helicella (Wood, 1828)		2	61		61	86	**210**	66,67	Constant
			Oxychilidae	*Oxychilus alliarius* (Miller, 1822)	1						**1**	16,67	Accidental
			Parmacellidae	*Drusia alexantoni* Martínez–Ortí & Borredà, 2013	1						**1**	16,67	Accidental
			Pomatiidae	*Leonia scrobiculata* (Mousson, 1873)	2	1					**3**	33,33	Accessory
			Punctidae	*Paralaoma servilis* (Shuttleworth, 1852)			65		88		**153**	33,33	Accessory
			Trissexodontidae	*Caracollina lenticula* (Michaud, 1831)	1				8		**9**	33,33	Accessory
			Truncatellinidae	*Truncatellina callicratis* (Scacchi, 1833)	428	17	506		1788		**2739**	66,67	Constant
				Total	**907**	**299**	**1557**	**431**	**2752**	**194**	**6140**		

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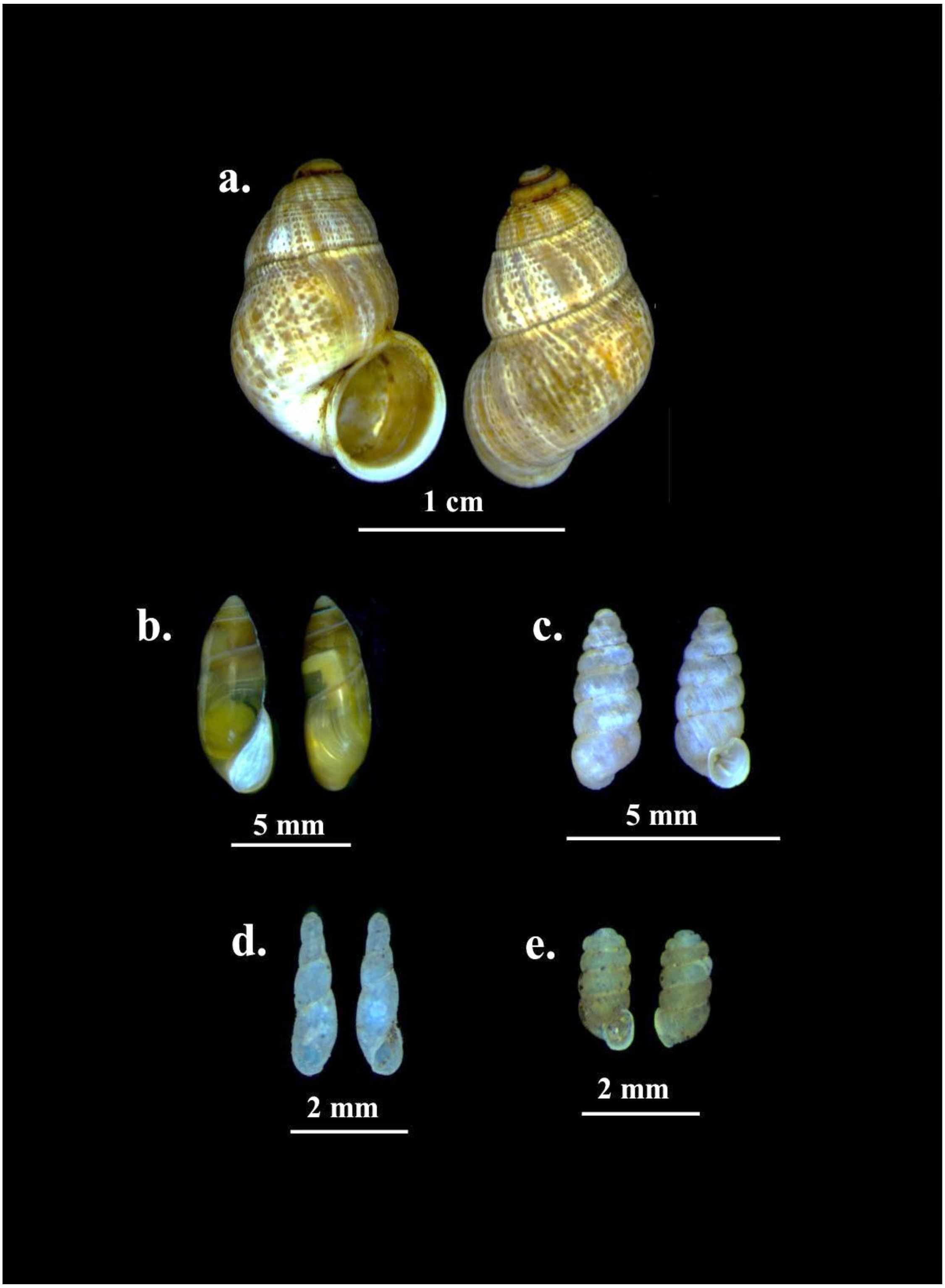

Figure 3. *Terrestrial snail species identified from Essaouira' Dunes. (a. Leonia scrobiculata (Mousson, 1873); b. Ferussacia folliculum (Schröter, 1784); c. Granopupa granum (Draparnaud, 1801); d. Cecilioides acicula (Müller, 1774); e. Truncatellina callicratis (Scacchi, 1833))*

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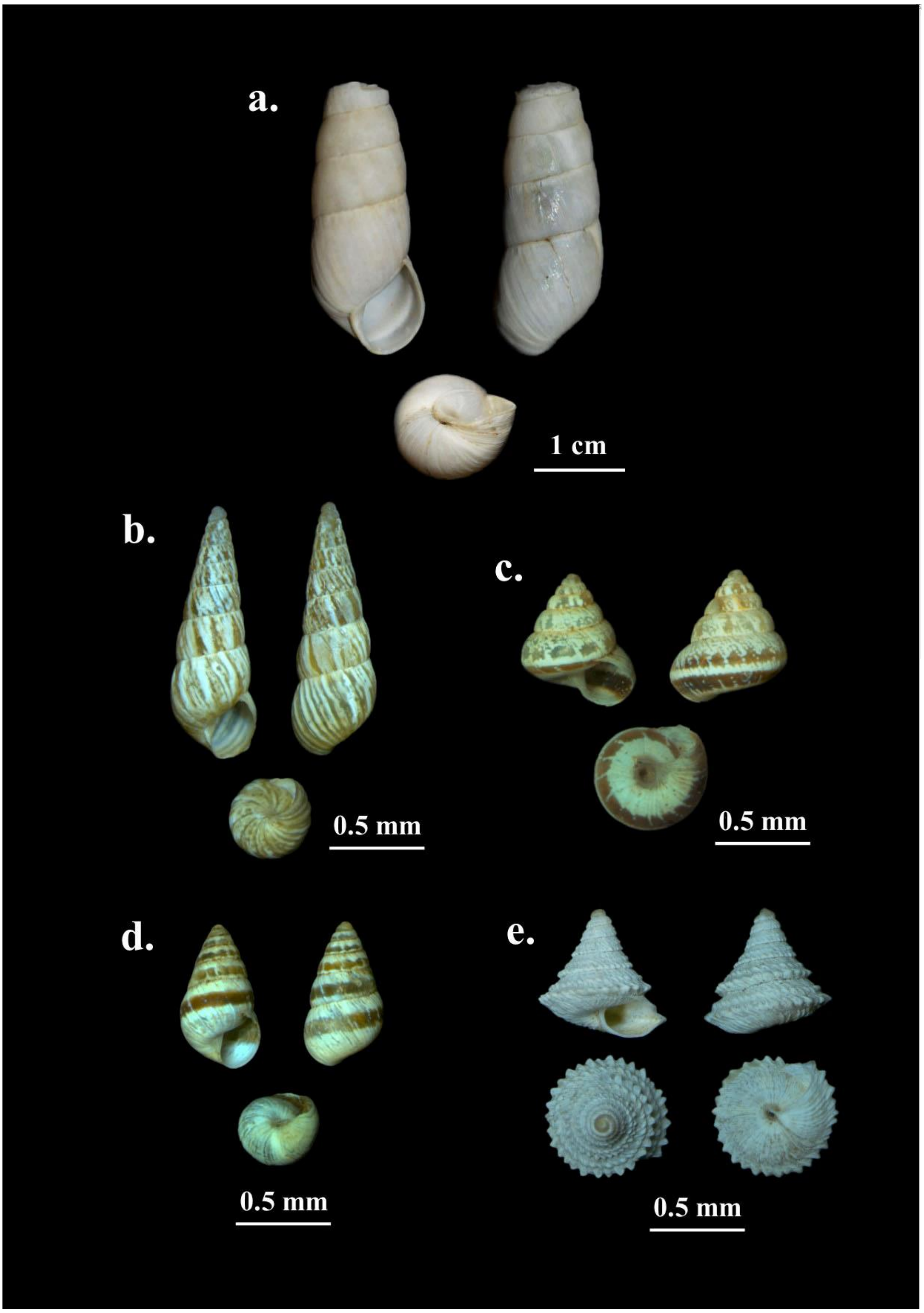

Figure 4. *Terrestrial snail species identified from Essaouira' Dunes. (a. Rumina decollata (Linnaeus, 1758); b. Cochlicella acuta (O. F. Müller, 1774); c. Cochlicella conoidea (Draparnaud, 1801); d. Cochlicella barbara (Linnaeus, 1758); e. Obelus pumilio (Dillwyn, 1817))*

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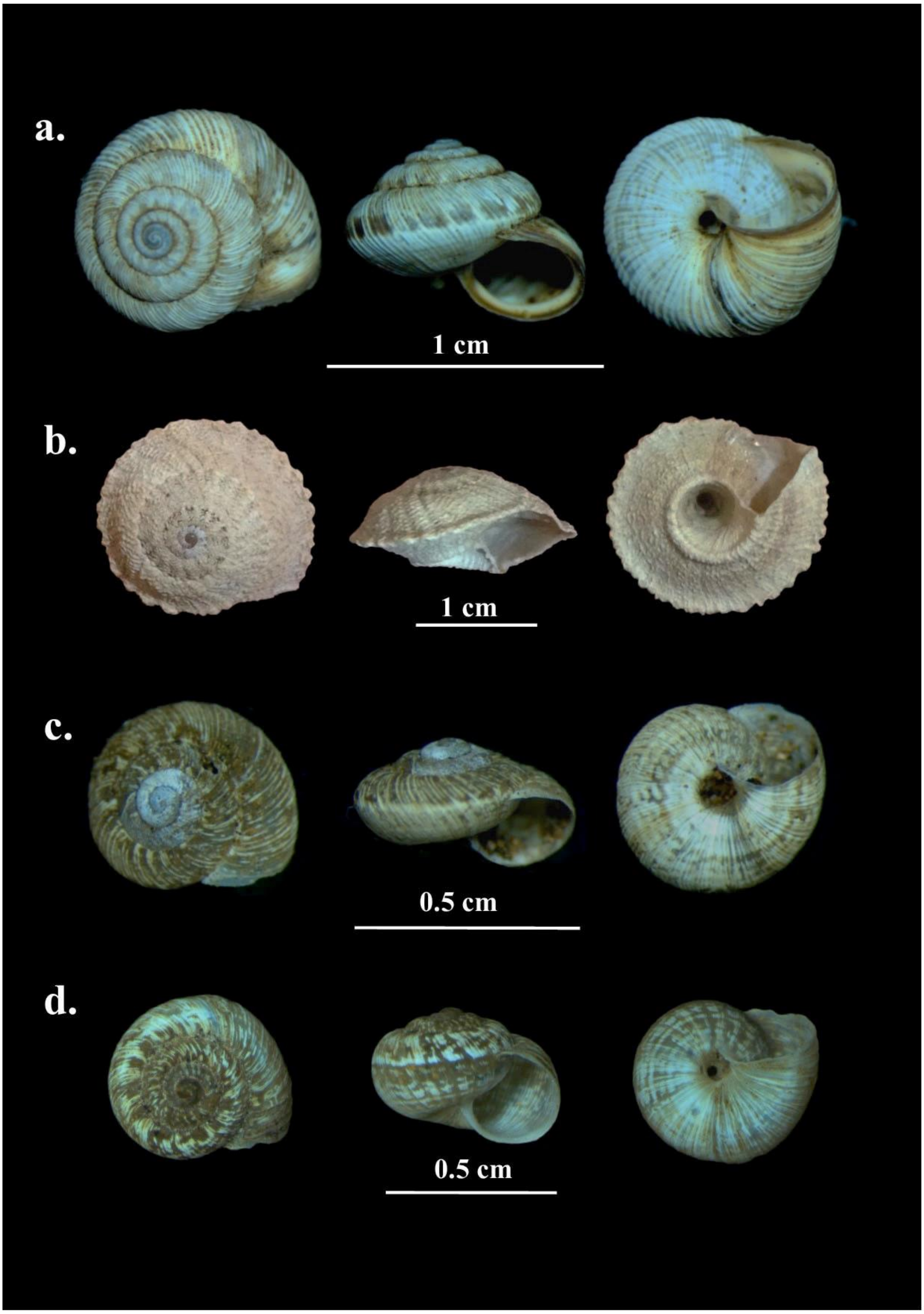

Figure 5. *Terrestrial snail species identified from Essaouira' Dunes. (a. Xeroplexa intersecta (Poiret, 1801); b. Xeroleuca turcica (Holten, 1802); c. Xerotricha conspurcata (Draparnaud, 1801); d. Xerotricha apicina (Lamarck, 1822))*

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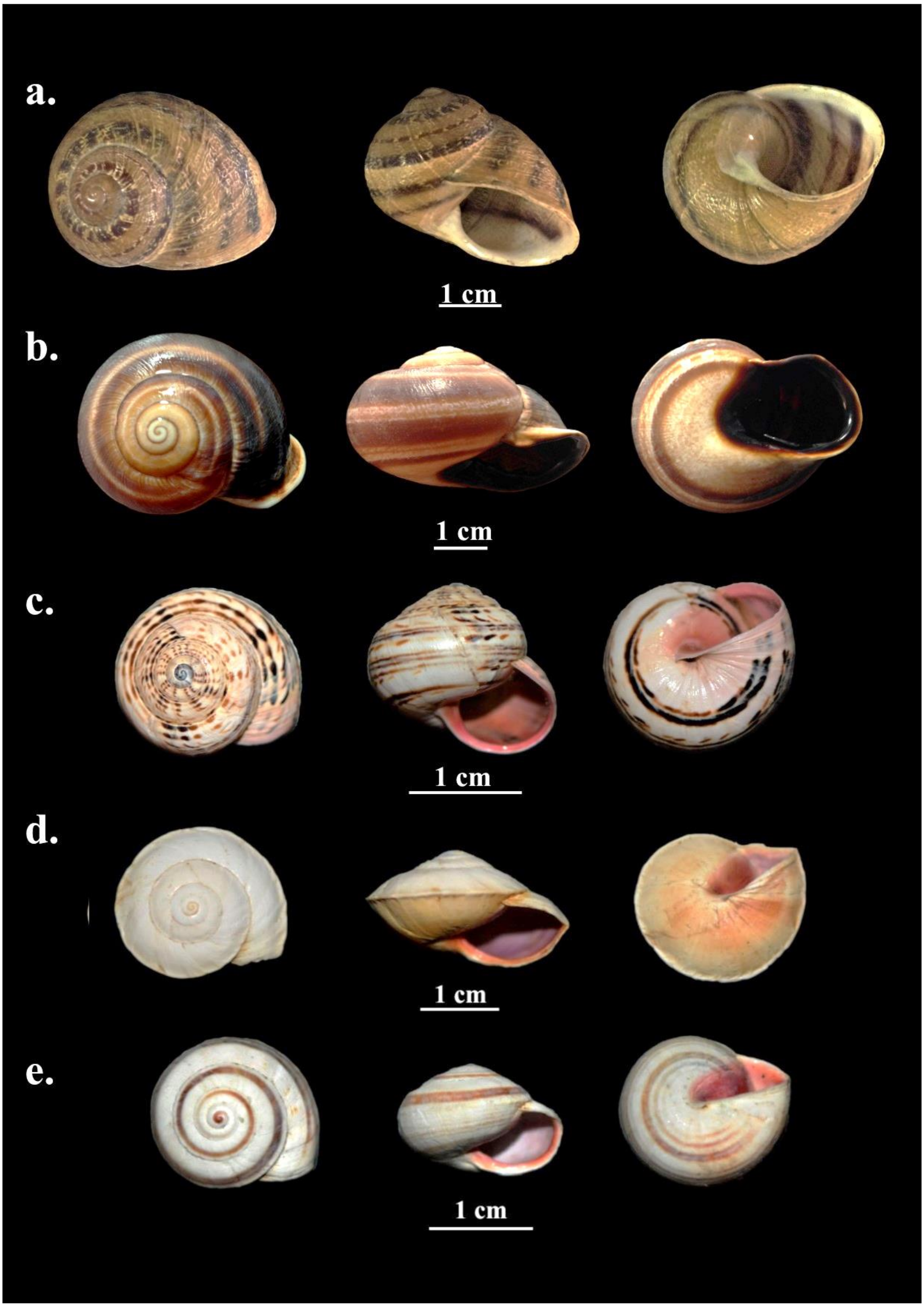

Figure 6. *Terrestrial snail species identified from Essaouira' Dunes. (a. Cornu aspersum (Müller, 1774); b. Otala punctata (O. F. Müller, 1774), c. Theba pisana (Müller, 1774); d. Theba subdentata helicella (Wood, 1828); e. Theba subdentata legionaria (Sacchi, 1955))*

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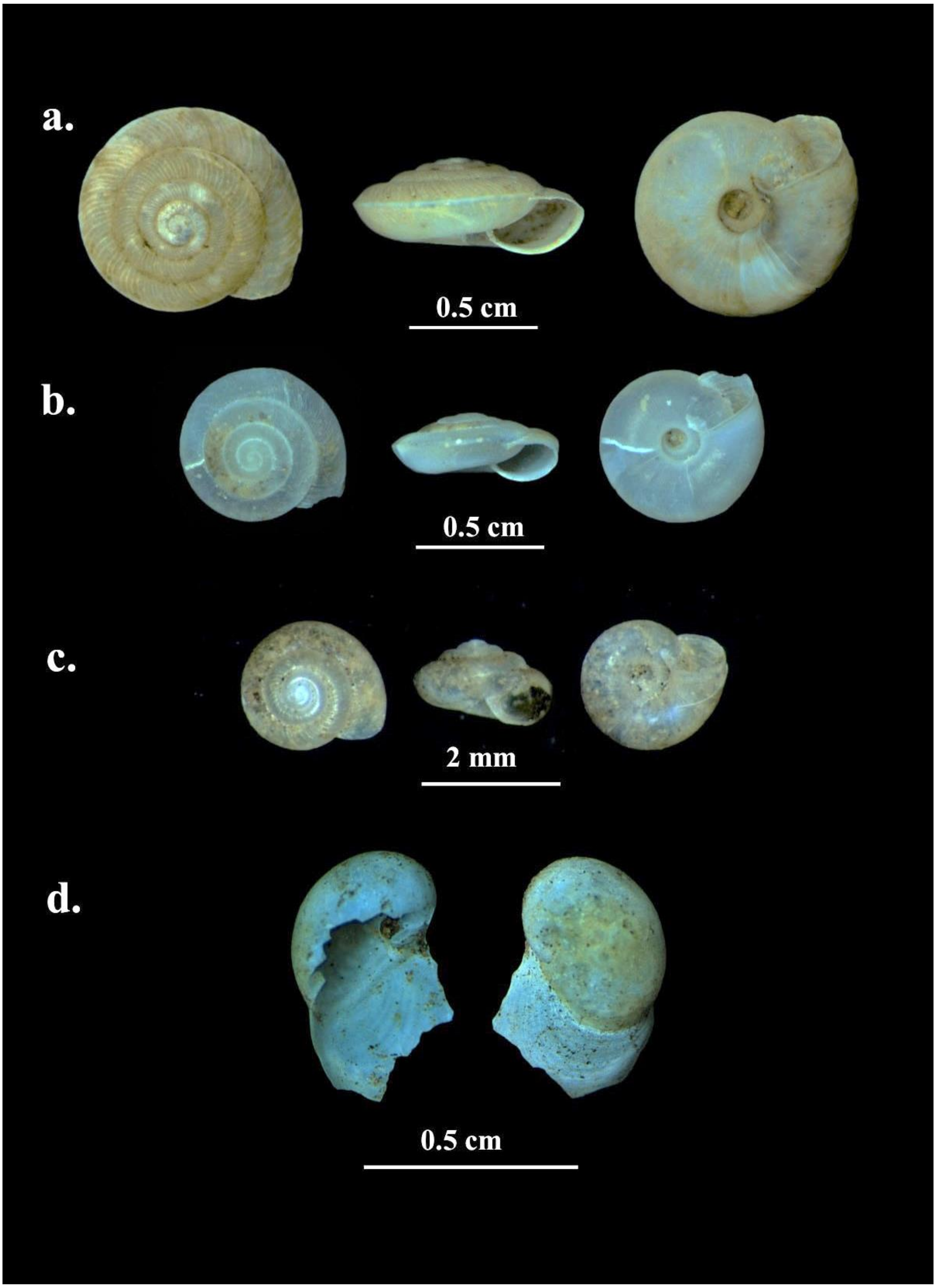

Figure 7. *Terrestrial snail species identified from Essaouira' Dunes. (a. Caracollina lenticula (Michaud, 1831); b. Oxychilus alliarius (Miller, 1822); c. Paralaoma servilis (Shuttleworth, 1852); d. Drusia (Escutiella) alexantoni Martínez–Ortí & Borredà, 2013)*

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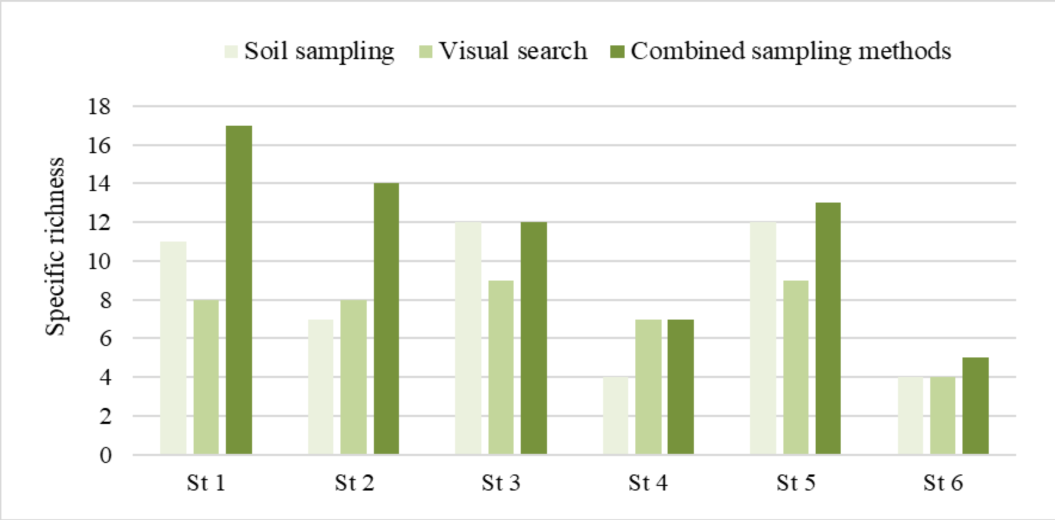

Figure 8. *Specific richness observed at each station of Essaouira' Dunes*

The Constancy index shows the presence of three categories of species at the BEIS site (Constant, accessory and accidental). The results obtained show that the species: *Cochlicella acuta* (Müller, 1774); *Cochlicella conoidea* (Draparnaud, 1801); *Obelus pumilio* (Dillwyn, 1817); *Xeroleuca turcica* (Holten, 1802); *Xeroplexa intersecta* (Poiret, 1801); *Xerotricha apicina* (Lamarck, 1822); *Xerotricha conspurcata* (Draparnaud, 1801); *Otala punctata* (Müller, 1774); *Theba pisana* (Müller, 1774); *Theba subdentata legionaria* (Sacchi, 1955); *Theba subdentata helicella* (Wood, 1828); *Truncatellina callicratis* (Scacchi, 1833) are very frequently found at the prospected stations. However, seven species are considered as accidental taxa, while the remaining four species are considered as accessory (*Table 2*).

This study allowed us to list, in total 6140 individuals of terrestrial snails (*Table 2*). The spatial distribution of the collected individuals differs from a station to another. In fact, the malacological survey shows a maximum of 2752 individuals out of 6140 at the station 5. This latter is characterised by a high density of *Truncatellina callicratis* that represent 65%. Moreover, the station 6 presents the lowest number of individuals with 194 individuals and the dominance of two species: *Theba pisana* and *Theba subdentata helicella* which represent both 87% of the total density in the station. We also noticed that the BEIS site is characterised by the dominance of four species (*Truncatellina callicratis*, *Theba pisana*, *Xerotricha conspurcata*, *Xeroplexa intersecta*) which represent 82.43% of the total density in the study area (*Fig. 9*).

Biodiversity indices

The diversity was analysed using the Shannon (H'), the Equitability (E), and the Simpson (1-D) indices, calculated separately for each prospected station (*Table 3*). The diversity index (H') shows an average diversity (H' ≥ 2) in the stations: 2, 3 and 5, while the station 6 presents a lower diversity (H' = 1.18). Equitability and Simpson's index present a higher value in the stations: 2 and 3; however, the stations: 1, 4, 5 and 6 show low values for both indices.

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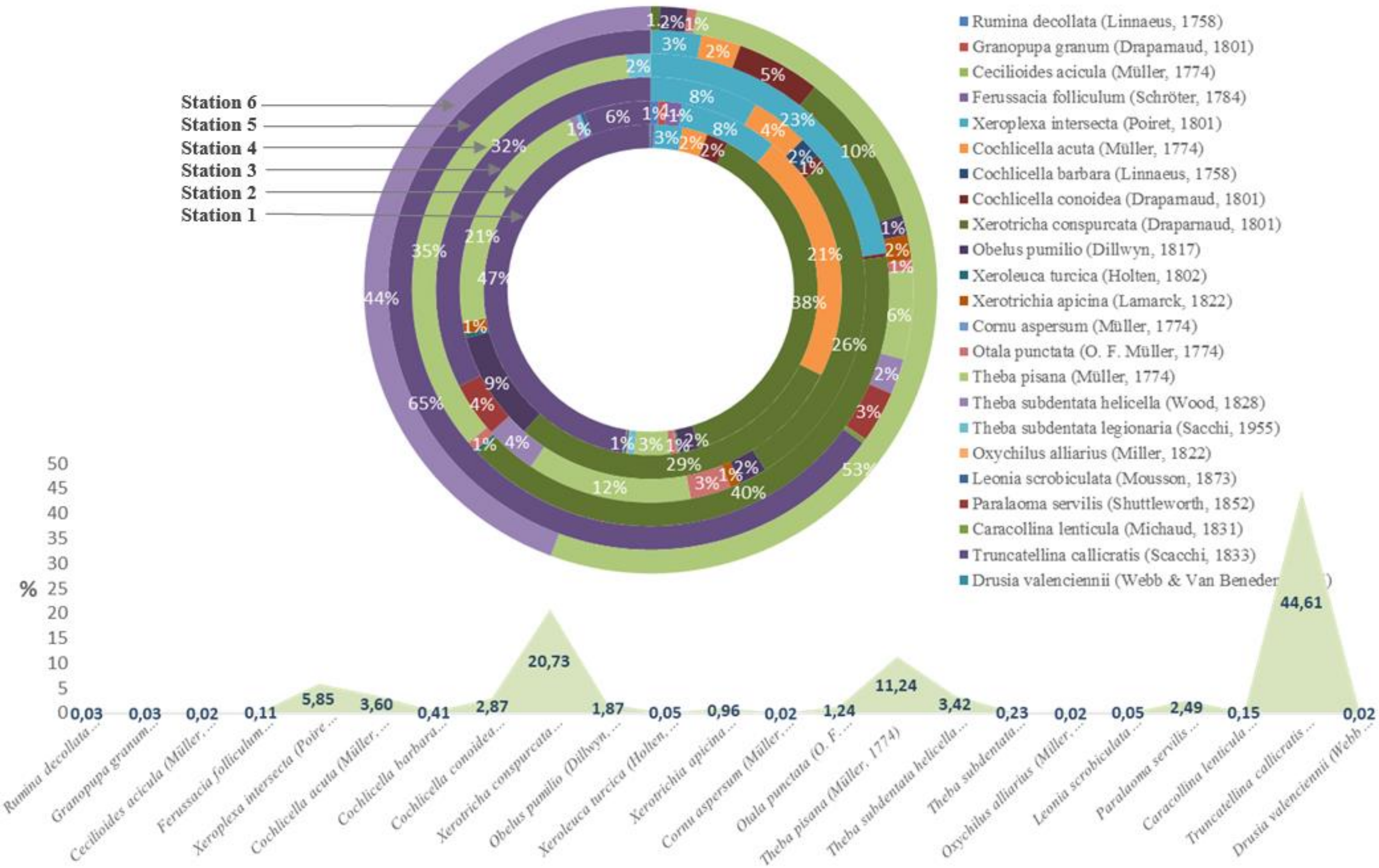

Figure 9. *Density of terrestrial mollusc species within the BEIS site of the Essaouira' Dunes*

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Table 3. *Ecological indices analysed for each station of Essaouira' Dunes*

Ecological indices	St 1	St 2	St 3	St 4	St 5	St 6
Shannon index (H')	1.91	2.73	2.75	1.73	2.00	1.18
Equitability index (E)	0.47	0.72	0.77	0.62	0.54	0.51
Simpson index (1-D)	0.63	0.81	0.80	0.67	0.56	0.52

The similarity between prospected stations was analysed using the Jaccard index which is represented in the form of a dendrogram (*Fig. 10*). The results of this hierarchical classification revealed a high similarity between stations 3 and 5 (with a value of 0.79), followed by stations: 1 and 2 with medium similarity (0.55). While the lowest similarity is observed between stations: 1 and 6 (with a value of 0.22).

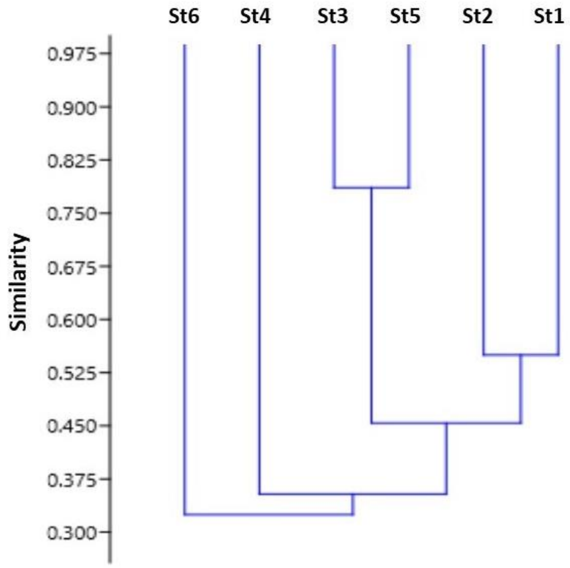

Figure 10. *Dendrogram based on the values of Jaccard index showing the similarity of the malacological communities in the sampled stations*

Relationship between malacological density and abiotic factors

The results of the Canonical Correspondence Analysis (CCA) show that the distribution and relative density of terrestrial molluscs in Essaouira' dunes are affected by two main axes representing 79.66% ($p<0.05$) of the total variability of all the data analyzed. The first CCA axis which represents 51.16% of the total data, shows a strong correlation with wind speed. On the other hand, the second axis of the CCA is mainly correlated with soil type and the presence of limestone rocks, with 28.5% of the total analyzed data.

For the positive side of axis 1 (51.16%; $p<0.05$%), the high value of wind speed is strongly related to the distribution and relative density of some species including *Theba subdentata helicella* (Wood, 1828), while, species such as*: Xerotricha apicina* (Lamarck, 1822); *Drusia (Escutiella) alexantoni* (Martínez–Ortí and Borredà, 2013); *Paralaoma; servilis* (Shuttleworth, 1852*); Truncatellina callicratis* (Scacchi, 1833), are distributed in stations that are negatively correlated with wind speed (*Fig. 11*).

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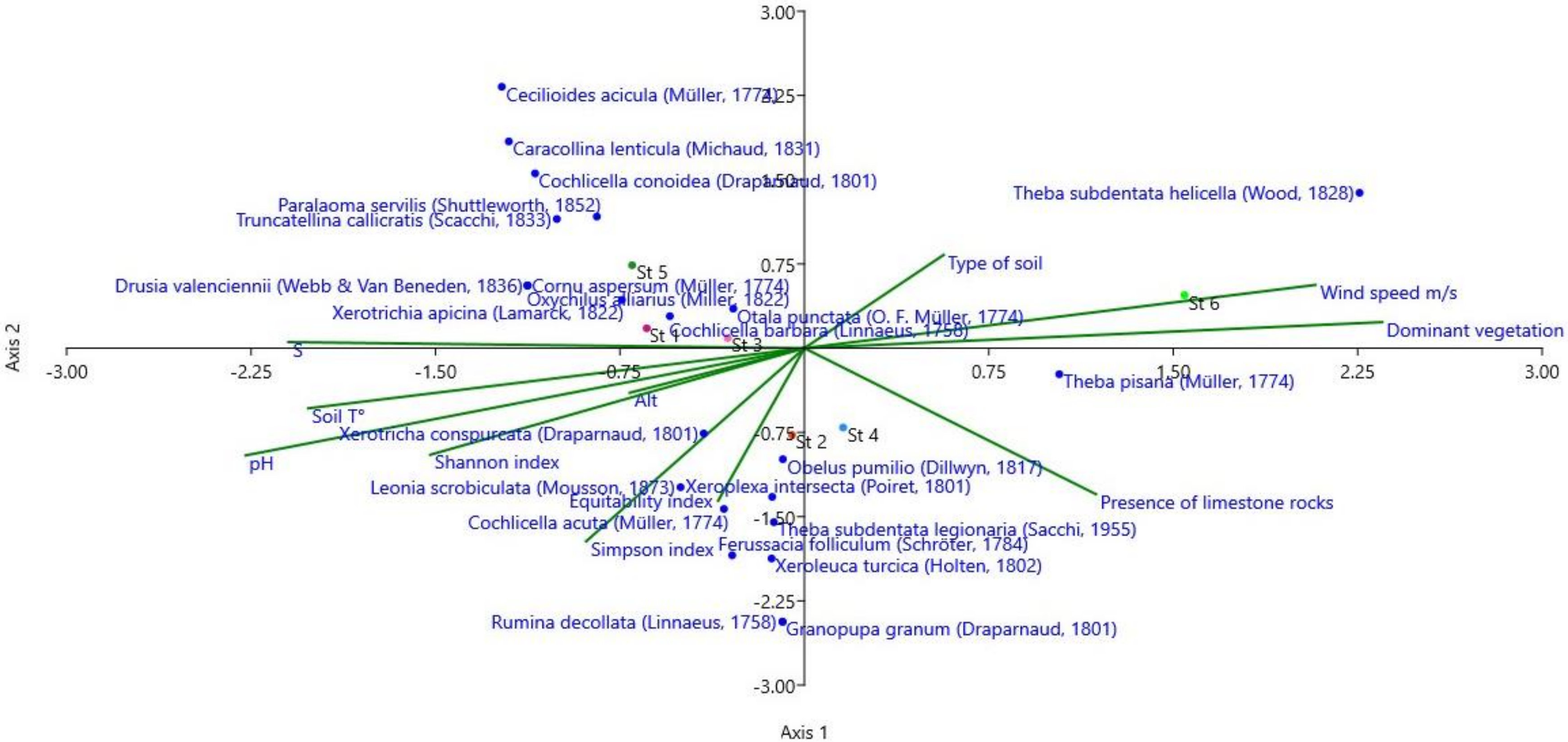

Figure 11. *Canonical correspondence analysis (CCA) ordination plots of sampling stations and environmental variables*

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In addition, the positive part of axis 2 that represents 28.5% ($p<0.05$), is strongly related with the type of soil and the presence of limestone rocks, this allows us to discriminate between two groups of specimens. A group of terrestrial molluscs related to the presence of limestone rocks often dominated by the species *Xeroleuca turcica* (Holten, 1802), and a group of species that adapts mainly to substrates with a low presence of limestone rocks such as: *Cecilioides acicula* (Müller, 1774); *Cochlicella barbara* (Linnaeus, 1758); *Truncatellina callicratis* (Scacchi, 1833) (*Fig. 11*).

Species like *Xerotricha conspurcata* (Draparnaud, 1801) and *Theba pisana* (Müller, 1774), don't require ecological factors. Hence, the distribution of the latter and its relative density is not affected by the environmental factors identified in this study.

Discussion

In this study we investigated the first assessment of the diversity of terrestrial malacological species in the Essaouira dunes (BEIS) estimated at 23 species. This richness in land snail species can be attributed to the climatic characteristics that dominates the territory of the BEIS site, qualified as a region belonging to the insular climate (M-m <15°C), which leads to low thermal contrasts and high rainfall (Beltrando, 2011). However, the total of estimated species in this BEIS represents only 5.46% of the national malacological biodiversity (Rour et al., 2002). This is in concordance with the previous studies of Pallary (1921) who noticed the remarkable poverty of the High Atlas compared to the Middle Atlas of Morocco in terms of malacological diversity.

In other hands, the Geomitridae has been identified as the most abundant family with eight species (34.78%) in all the study area, followed by Helicidae with five species (21.74%), these results are in agreement with the finding of Rour et al. (2002), and contrast with the previous results reveled by Barker and Mayhill (1999) in Northeastern of New Zealand, and Douafer and Soltani (2014) in the North-East of Algeria.

In addition, the identification of collected individuals is carried out using methods used in malacology. The morphology of the shell, and the anatomy of the genital apparatus presents a complementary and essential means for the distinction between the various species especially in case of polymorphism within the shell of the same species. Nevertheless, it is essential to mention that genetic analysis is a more complete means of identification (Kar et al., 2013; Etukudo et al., 2018).

However, this present study shows a differentiation of malacological biodiversity between prospected stations through biodiversity indices (Shannon, Simpson, Equitability and Jaccard indices). The highest specific richness in certain stations can be explained by the high rate of humidity soil and the presence of limestone substratum that favors an important richness and development of terrestrial snails (Clergeau et al., 2011). However, the lowest specific richness in other stations can be explain by the anthropogenic exploitation of dunes ecosystems of Essaouira (urban expansion, tourism projects, deforestation, and encroachment of sand), which leads to the abundance and proliferation of some invasive species such as *Theba pisana*. The latter species was reported by Gittenberger and Ripken (1987), and Holyoak and Holyoak (2016), as a species that is characterized by its dramatic expansion in Morocco and in Western and Southern Europe, to the benefit of native species.

In other hands, the constancy index indicates that 12 of terrestrial snails prospected are considered as constant species, which represents 52% of the total species, this

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confirms the stability of the dune ecosystem and the adaptation of its species to climatic and edaphic factors. These results are in harmony with the findings reported by Zaidi et al. (2021).

In addition, the results obtained using CCA reveal that the spatial organization of the terrestrial snails of Essaouira dune was influenced by several abiotic factors especially wind speed and type of soil. Many studies have proved that the biodiversity and distribution pattern of land snails depend on multiple factors, such as soil parameters (André, 1982; Ondina et al., 1998; Douafer and Soltani, 2014), climatic factors (Hermida et al., 1994; Ameur et al., 2019), vegetation type (Ondina and Mato, 2001; Damerdji, 2018; 2021), and anthropogenic disturbances (Belhiouani et al., 2019).

In this study, the results of the CAA analysis show that *Theba subdentata helicella* is strongly correlated with the wind speed effect. Many mulluscan studies have revealed that the habitat of this species is the sand dunes along the coast (Gittenberger and Ripken, 1987; Moreno and Ramos, 2007), and it is totally absent in the middle and high mountains. Moreover, this species is reported by the IUCN as a vulnerable species (D2) at the European Red List of Non-Marine Molluscs (Cuttelod et al., 2011). On the other hand, our results reveled that *Theba pisana* was mostly present in all prospected stations of Essaouira dunes, and doesn't require ecological factors. This species was reported by many researchers as an important pest in pastures and cereal crops in Southern Australian and elsewhere in the world and causes a significant damage to the vegetation cover (Baker, 1986; Baker and Vogelzang, 1988; Odendaal et al., 2008).

Conclusion

The assessment of malacological biodiversity of Essaouira dunes presents the first inventory of terrestrial gastropods. The results of this article show that this dune ecosystem is characterized by the presence of 23 species of terrestrial molluscs; belonging to 18 genera and 11 families. Geomitridea and Helicidae are the most dominant families representing 56.52%. The highest specific richness was recorded in Ounagha' station, with 17 species. While the lowest specific richness was observed at Cap Sim station, with only 5 species recorded. The malacofaunal diversity between stations was also determined by: Constancy, Shannon, Equitability, Simpson and Jaccard indices. Cap Sim was caracterised by a lower diversity and evenness compared to other stations. This station represents the lowest similarity compared with Ounagha station with a value of Jaccard index equal to 0.22. The relationship between the distribution of terrestrial snails and abiotic factors were involved using Canonical Correspondence Analysis (CCA). The results showed that the distribution and abundance of the inventoried species are influenced by the wind speed and the presence of the limestone rocks representing the relevant factors affecting the distribution patterns of terrestrial gastropods. These results open up avenues for better management and conservation of this dune ecosystem.

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