

## Diversity and ecology of the land snails of the Palestinian Territories of the West Bank

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### ABSTRACT

The diversity of the terrestrial snails of the Palestinian Territories was presented with a total of 42 species in 26 genera representing 15 families. Families Enidae and Hygromiidae had the highest number of species, while eight families were represented by only a single species. Species association was analyzed, and the biogeographical affinities of the snail fauna were discussed. The Mediterranean zone had the highest number of land snail species (33), followed by the Irano-Turanian zone (20 species) while the Saharo-Arabian zone had the lowest number (14). Species incidence suggested that most species had restricted distributions and were recorded in relatively few sites (less than 25). Nineteen species occurred in 10 or fewer sites, 9 species in 11–25 sites, and only 10 species may be considered wide-ranging as they were recorded in 25–65 sites. The terrestrial malacofauna of central Palestine consists of several origins: endemic, regionally endemic, Levant, Circum-Mediterranean, and Western Palearctic.

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### Introduction

Terrestrial snails can act as critical indicators in response to climatic variables, including global warming, and thus are highly qualified for the use in ecosystem preservation (Capinha et al. 2014; Beltramino et al. 2015). Given the fact that they represent one of the most rapidly declining groups on a local as well as global scale, knowledge about the autecology of the species is indispensable (Lydeard et al. 2004; Cuttelod, Seddon, and Neubert 2011).

In Western Asia and the Arab World, only a few studies addressed the biodiversity and climatic association of land snails (Nevo, Bar-El, and Bar 1983; Kadmon and Heller 1998; Hausdorf 2006). Pavlíček et al. (2008) showed that the valleys near Mount Carmel have a high diversity of land snails reaching up to 26 species and that species on west- and east-facing hills differ as expected due to variation in exposure to climatic factors. Gümüş and Neubert (2009) reviewed the status and perspective of the Turkish terrestrial malacofauna. Elsewhere, the land snails of the neighbouring countries were studied, with notes on some ecological parameters (Cook 1997; Neubert 1998; Bößneck 2011; Neubert et al. 2015). A series of papers were published on the systematics and distribution of land snail species (Heller 1971, 1974, 1975, 2009). Heller (1984) presented an excellent account on

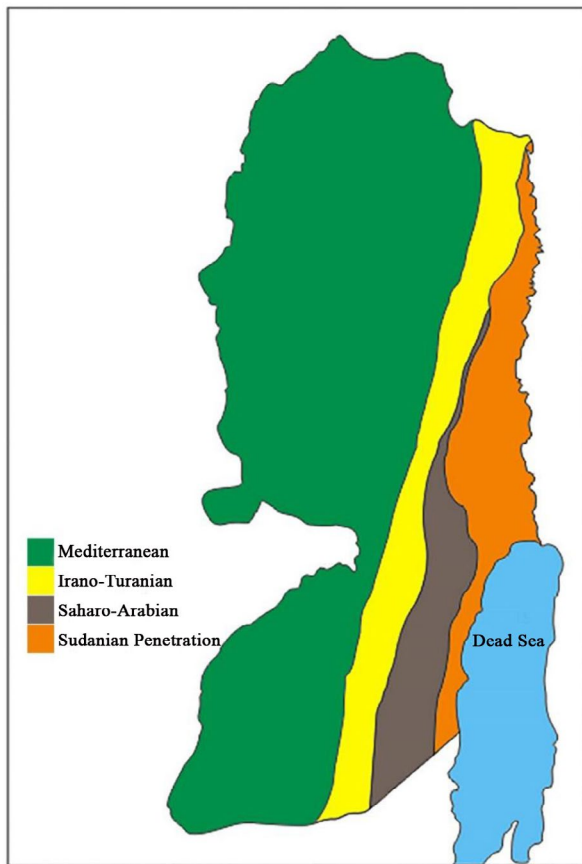
the desert land snails of southern Palestine. He discussed adaptations of some species in response to arid environments. The zoogeography of the land snails of Palestine was studied by Heller (1988) with little information on the West Bank.

The taxonomic status of many species of our region has been revised recently (Neubert et al. 2015). The present study aims to analyse the biogeographical affinities of the Palestinian land snails, their diversity and sites species richness based on up-to-date nomenclature.

### Biogeography of the Palestinian Territories

Despite its small area (5655 km<sup>2</sup>), the Palestinian Territory of the West Bank includes four main biogeographical zones (Figure 1), namely Irano-Turanian, Saharo-Arabian, Sudanian Penetration, and Mediterranean (Zohary 1947; Whyte 1950; Werner 2016). Rainfall, temperature, altitude, and soil composition vary greatly among these zones. The geographic position enabled Palestine to include faunal elements from Palaeartic, Ethiopian and Oriental regions (Por 1975; Atallah 1977).

The four biogeographical zones of the Palestinian Territories are very close to each other. With a maximum width of the West Bank not exceeding 60 km, the Irano-Turanian zone is adjacent to the eastern borders



**Figure 1.** Map of the biogeographical regions of the Palestinian Territories (modified after ARIJ, 2009).

of the Mediterranean zone, with an abrupt delineation following the common vegetation (*Sarcopoterium spinosum*) and rainfall. Similarly, the boundaries for the Irano-Turanian, Saharo-Arabian, and Sudanian zones are all close (Figure 1).

**Mediterranean zone** (Figure 2): This zone represents most of this Palestinian Territory, extending from Hebron across Jerusalem north to Jenin. Soil type is dominated by *terra rossa* and pale rendzinas with patches of grumusols, brown and pale rendzinas and solonchalks. Annual rainfall ranges from 400 to 700 mm, with occasional snowfall. Average minimum temperatures range from 8 to 12 °C during winter, and average maximum temperatures range from 22 to 28 °C in summer. Forests within this area include *Ceratonia siliqua*, *Pinus halepensis*, *Pistacia alentiscus*, *Pistacia palaestina*, *Quercus caliprinos*, *Rhamnus palaestinus*, with shrubs, including *Sarcopoterium spinosum* and *Retamaraetam* (Zohary 1947; Ghattas, Hrimat, and Isaac 2006). The core of the Mediterranean area is dominated by maquis and forests surrounded by forest of *Ceratonia siliqua* and *Pistacia alentiscus*. Semi-steppe garigue and steppe vegetation also surrounds the eastern borders of the arid regions of the Mediterranean zone (Danin 1992).

**Irano-Turanian zone** (Figure 3(b, e)): This zone represents a narrow strip stretching from Tubas region through eastern Jerusalem and southern Hebron hills. This zone is considered a transitional zone separating the

Saharo-Arabian and the Mediterranean zones. Annual rainfall ranges from 150 to 300 mm, with average minimum temperatures ranging from 10 to 30 °C during winter and average maximum temperatures reaching up to 34 °C in summer. Soil types exhibit several forms of brown lithosols and loessial arid brown soil to brown and pale rendzinas. In general, flora consists of both semi-steppe batha and steppe vegetation dominated by *Artemisia sieberi* and *Noaea mucronata* (Zohary 1947; Danin 1988).

**Saharo-Arabian zone** (Figure 3(a, f)): This zone extends from around Jericho, extending southwards in between the Sudanian Penetration and the Irano-Turanian zones, and becomes wider in the south (Bani Na'im). Annual rainfall ranges from 50 to 250 mm, with average minimum temperatures ranging from 14 to 18 °C during winter and average maximum temperatures reaching up to 32 °C in summer. Altitude ranges from –250 m b.s.l. to 370 m a.s.l. Soil is mostly brown lithosols and loessial serozems. Flora is represented by the desert and steppe vegetation cover, including *Anabasis articulata*, *Salsola inermis*, *Stipa tortilis* and *Atriplex parvifolia* (Zohary 1947; Danin 1988).

**Sudanian zone** (Figure 3(c, d)): It extends from the middle of the Jordan Valley southwards along the Jordan River and the shores of the Dead Sea. Annual rainfall ranges from 50 to 100 mm, with average minimum temperatures ranging from 10 to 14 °C during winter and average maximum temperatures reaching up to 34 °C in summer. The altitude ranges between –390 and –50 m b.s.l. Soil types are dominated by bare rocks and lithosols around the Dead Sea, to solonchalks to regosols around the Jordan River. Savannoid vegetation dominates the western borders of the Dead Sea, while wet saline vegetation is confined to the northern area around the Dead Sea (Danin 1988), with distinctive species such as *Acacia tortilis*, *Calotropis procera*, *Ziziphus spina-christi*, and *Balanites aegyptiaca* (Zohary 1947; Danin 1988).

## Materials and methods

A total of 135 sites representing various habitats within the four biogeographical regions of the Palestinian Territories were studied during 2013–2017. Each site was carefully inspected for the presence of land snails by at least 2–4 biologists from the Palestine Museum of Natural History (PMNH). Each site was photographed, and coordinates were recorded. Collected snails were kept in plastic bags or containers, then cleaned, sorted, and identified in the laboratory of PMNH.

Basic graphical and analytical statistics were used to assess species distribution (and number or specimens) among sites and coexisting species. The number of sites where a species occurred was used as a measure of its site incidence. The number of species present at a site was used as the local species richness at that site. We



**Figure 2.** Habitats within the Mediterranean zone. (a) Wadi Al Quff pine forest; (b) Seris oak forest, habitat from which *M. crispulata* was collected; (c) Wadi Qana; (d) Wadi Al Makhrou near Bethlehem; (e) Karst formation in Brukin, habitat for 14 species, including *Cristataria haasi*; (f) Dayr Baloot area dominated by lime stone rich in enclaves and crevices.

averaged the number of specimens collected over the total number of sites where each species occurred to estimate their local abundance. All species were tallied based on their site incidence and local abundance into groups to assess their distribution.

## Results

### Diversity of land snails

In total, 42 species in 26 genera representing 15 families of land snails were identified for the purpose of this study. The detailed taxonomic discussions will be published separately; here we focus on the ecological and geographical data. Families Enidae and Hygromiidae have the highest number of species, while eight families were represented by a single species only (Table 1). For

species incidence and coexistence, we did not include slugs, since they could not be sampled like shelled snails (the latter sampled year round).

The studied taxa vary greatly in their natural histories and habitat preferences. Species incidences (total number of sites in which a species occurred) ranged between 1 and 73 ( $19.76 \pm 3.42$ ). *Helix engaddensis* was the most common species and was collected from 73 sites, followed by *X. krynickii* from 65 sites. *Euchondrus saulcyi*, *P. balmei* and *T. benjamitica* were the least common species and were recovered from only one site each. Species richness (total number of species recorded within a site) ranged between 1 and 18 ( $5.6 \pm 0.35$ ). Table 1 summarizes the incidence and number of coexisting species for all species included in the analyses.



**Figure 3.** Arid habitats in the Palestinian Territories. (a) Bani Na'im area in the southern part representing the Saharo-Arabian zone; (b) Wadi Al Ta'amreh, east of Bethlehem, showing elements of the Irano-Turanian zone; (c) Wadi Al Qelt, with a mixture of both the Sudanian Penetration and the Saharo-Arabian zones; (d) Northern shores of the Dead Sea, representing the Sudanian Penetration area; (e) Al Jiftlik area, the most northern limit of the Irano-Turanian zone; (f) Zarb Khryan with rock formations suitable for *Sphincterochila zonata*.

We tallied all species in a two-dimensional table based on their site incidence (1–10, 11–25, and >25 sites) and local abundance (1, 2, and >2 specimens). This assessment categorized the snails into restricted to wide-ranging species and into locally rare to abundant ones (Table 2). Species incidence suggested that most species had restricted distributions and were recorded in relatively few sites (less than 25). 19 species occurred in 10 or fewer sites, 9 species in 11–25 sites, and only 10 species may be considered wide-ranging as they were recorded in 25–65 sites (Table 1).

Based on species incidences among sites, three groups of species are apparent: 'satellite' species which were recorded from only a few, localized sites; modal

species found at an intermediate number of sites over larger areas; and ubiquitous 'core' species recorded from a high number of sites (Table 2).

### Coexistence of species

Species coexistence ranged from 1 to 35 ( $22.68 \pm 1.46$ ) (Table 1). Six wide-ranging species (*B. labrosus*, *M. syriaca*, *E. septemdentatus*, *L. caesareana*, *X. krynickii*, and *H. engaddensis*) coexisted with 30–35 other species, whereas five of the restricted species (*B. glabratus*, *C. barbara*, *E. saulcyi*, *P. balmei*, and *S. prophetarum*) coexisted with only 3–9 other species. *Pilorcula raymondi* and *T. benjamitica* occurred at two and one site and coexisted

**Table 1.** Species incidences and coexisting species of land snails included in the study.

Family	Species	Total number of sites	Total number of coexisting species	
Pomatiidae	<i>Pomatias glaucum</i>	4	17	
Orculidae	<i>Pilorcula raymondi</i>	2	15	
Chondrinidae	<i>Granopupa granum</i>	19	30	
	<i>Rupestrella rhodia</i>	8	24	
Vertiginidae	<i>Truncatellina haasi</i>	8	24	
Enidae	<i>Buliminus glabratus</i>	2	3	
	<i>Buliminus labrosus</i>	51	30	
	<i>Buliminus marsabensis</i>	3	16	
	<i>Buliminus therinus</i>	11	22	
	<i>Euchondrus chondriformis</i>	19	31	
	<i>Euchondrus saulcyi</i>	1	9	
	<i>Euchondrus septemdentatus</i>	60	32	
	<i>Paramastus episomus</i>	25	29	
	<i>Pene bulimoides</i>	14	27	
	<i>Turanena benjamitica</i>	1	16	
	Clausiliidae	<i>Cristataria haasi</i>	9	19
		<i>Calaxis hierosolymarum</i>	9	29
	Ferussaciidae	<i>Cecilioides acicula</i>	6	27
		<i>Cecilioides genezarethensis</i>	4	15
	Subulinidae	<i>Rumina decollata</i>	1	1
Pleurodiscidae	<i>Pleurodiscus balmei</i>	1	8	
Oxychilidae	<i>Eopolita protensa jebusitica</i>	21	29	
Sphincterochilidae	<i>Sphincterochila cariosa</i>	35	29	
	<i>Sphincterochila fimbriata</i>	35	30	
	<i>Sphincterochila prophetarum</i>	2	7	
	<i>Sphincterochila zonata</i>	14	12	
Cochlicellidae	<i>Cochlicella barbara</i>	2	3	
Hygromiidae	<i>Metafruticicola berytensis</i>	6	24	
	<i>Monacha crispulata</i>	5	21	
	<i>Monacha obstructa</i>	12	25	
	<i>Monacha syriaca</i>	56	32	
	<i>Xerocrassa langloisiana</i>	34	33	
	<i>Xerocrassa seetzenii</i>	4	18	
	<i>Xerocrassa simulata</i>	24	26	
	<i>Xerocrassa tuberculosa</i>	7	18	
	<i>Xeropicta krynickii</i>	65	33	
	Helicidae	<i>Helix engaddensis</i>	73	35
		<i>Levantina caesareana</i>	62	34
		<i>Levantina lithophaga</i>	37	30
Min		1	1	
Max		73	35	
Average		19.76	22.68	
SD		3.42	1.46	

**Table 2.** Commonness and rarity of land snails within the Palestinian Territories.

		Local abundance (specimens per site)		
		1	1–2	>2
Incidence (# sites)	1–10	<i>B. glabratus</i> <i>C. acicula</i> <i>C. genezarethensis</i> <i>C. haasi</i> <i>C. hierosolymarum</i> <i>E. saulcyi</i> <i>M. crispulata</i> <i>P. balmei</i> <i>P. glaucum</i> <i>R. rhodia</i> <i>T. benjamitica</i> <i>T. haasi</i> <i>X. seetzenii</i>	<i>C. barbara</i> <i>P. raymondi</i> <i>B. marsabensis</i> <i>M. berytensis</i> <i>X. tuberculosa</i>	<i>S. prophetarum</i>
	11–25	<i>B. therinus</i> <i>G. granum</i> <i>M. obstructa</i>	<i>E. chondriformis</i> <i>E. protensa jebusitica</i> <i>P. bulimoides</i> <i>P. episomus</i> <i>S. zonata</i> <i>X. simulata</i>	
	>25		<i>B. labrosus</i> <i>E. septemdentatus</i> <i>H. engaddensis</i> <i>L. caesareana</i> <i>M. syriaca</i> <i>S. cariosa</i> <i>X. krynickii</i> <i>X. langloisiana</i>	Wide-ranging and locally abundant, 'core' species: habitat-generalists found in most assemblages <i>L. lithophaga</i> <i>S. fimbriata</i>

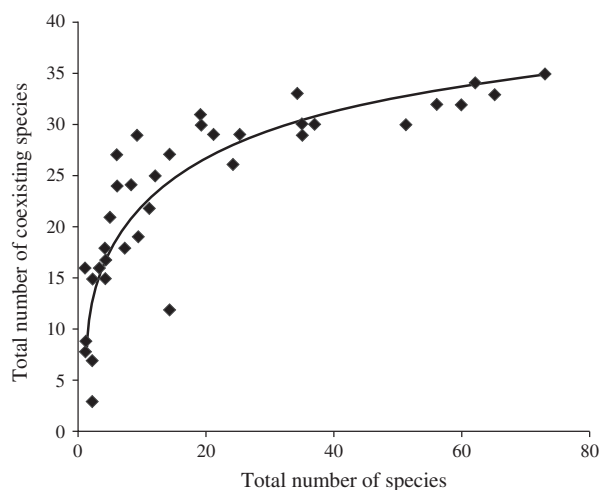
with 15 and 16 other species, respectively. The remainder of the species exhibited intermediate patterns of coexistence (Figure 4). The cumulative number of species with which a species coexisted was plotted against the number of localities at which it was recorded (Figure 4), the two attributes correlated positively (Correlation Coefficient = 0.74) and suggested greater coexistence by wide-ranging species.

Table 3 shows some examples of species association in areas with 12 or more species living together and considered as areas with high snail diversity.

### Distribution of land snails according to the biogeographical zones

#### Mediterranean zone species

Thirty-three species were found to inhabit various habitats within the Mediterranean zone (Table 4), comprising about 89% of the total of known species in the study area. Seventeen species were restricted to the Mediterranean zone, with only *C. haasi*, *M. berytensis*, *P. glaucum*, *P. raymondi*, *R. rhodia*, and *T. benjamitica* confined to areas with annual rainfall of 700 mm. Only three species were shared between the Mediterranean



**Figure 4.** The cumulative number of coexisting species and the number of localities at which it was recorded.

and the Irano-Turanian zones (*E. chondriformis*, *E. septemdentatus*, and *M. obstructa*), two with the Sudanian zone (*C. genezarethisis* and *E. protensa*), and no species shared with the Saharo-Arabian zone. Altogether, seven species were shared with all zones (*C. acicula*, *G. granum*, *H. engaddensis*, *L. caesareana*, *S. fimbriata*, *X. langloisiana*, and *X. simulata*).

The family Enidae was represented by seven species in the study area. *Buliminus labrosus* was the most common enid found in habitats with calcareous rocks. The size of specimens varied along rainfall isoheights, with large-sized individuals associated with areas with rainfall reaching 600–700 mm. *Buliminus labrosus spirectinus* was found around Nahaleen area east of Bethlehem. *Paramastus episomus* distribution reached as far as the 500 mm isoheight, and usually in rocky areas of forested regions. It could be also found around decaying oak leaves. *Penebulimoides* was found in areas between 700 and 400 mm annual rainfall, associated with calcareous rocky outcrops of various sizes. The genus *Euchondrus* included three species, whereas *E. septemdentatus* was the most widely spread species inhabiting rocky cliffs. In 14 sites, *E. chondriformis* was associated with *E. septemdentatus*. *Euchondrus saulcyi* was recovered from a single site along with *E. septemdentatus*. *Turanena benjamitica* was found from one site in Ain Yabroud, along with 16 other species. This is a very rare species with a very limited number of sites in Palestine. It was originally described from around Jerusalem by Benson (1859).

Families Clausiliidae, Cochlicellidae, Pomatiidae, Orculidae, Oxychilidae, Subulinidae, and Vertiginidae were represented by a single species for each family in our area, while families Chondrinidae and Limacidae were exemplified by two species for each family (Table 1). Rock-dwelling species were exemplified by *C. haasi*, *P. glaucum*, *R. rhodia*, *G. granum*, and *T. haasi*. *Pilorcula raymondi* and *E. protensa* were found in soft soil under large boulders and associated with oak tree litter.

The family Hygromiidae was represented by six species. *M. obstructa*, *M. syriaca*, *M. berytensis*, *X. langloisiana*, and *X. simulata* were found in various habitats, including hard rocky boulders and calcareous rocks and open rocky

**Table 3.** Areas with high land snail diversity with 12 or more species.

Locality	No. of species	Species collected
Kufr Al Deek	18	<i>B. labrosus</i> , <i>C. haasi</i> , <i>C. hierosolymarum</i> , <i>E. protensa</i> , <i>E. chondriformis</i> , <i>E. septemdentatus</i> , <i>G. granum</i> , <i>H. engaddensis</i> , <i>L. caesareana</i> , <i>M. berytensis</i> , <i>M. syriaca</i> , <i>R. rhodia</i> , <i>P. episomus</i> , <i>P. bulimoides</i> , <i>P. glaucum</i> , <i>S. cariosa</i> , <i>X. krynickii</i> , <i>X. langloisiana</i>
Ain Yabroud	18	<i>B. labrosus</i> , <i>E. protensa</i> , <i>E. chondriformis</i> , <i>E. septemdentatus</i> , <i>H. engaddensis</i> , <i>L. caesareana</i> , <i>L. lithophaga</i> , <i>M. berytensis</i> , <i>M. crispulata</i> , <i>M. syriaca</i> , <i>R. rhodia</i> , <i>P. episomus</i> , <i>P. bulimoides</i> , <i>S. cariosa</i> , <i>S. fimbriata</i> , <i>T. benjamitica</i> , <i>X. krynickii</i> , <i>X. langloisiana</i>
Brukeen	16	<i>B. labrosus</i> , <i>C. haasi</i> , <i>C. hierosolymarum</i> , <i>E. chondriformis</i> , <i>E. protensa</i> , <i>E. septemdentatus</i> , <i>G. granum</i> , <i>H. engaddensis</i> , <i>L. caesareana</i> , <i>M. berytensis</i> , <i>R. rhodia</i> , <i>P. episomus</i> , <i>P. bulimoides</i> , <i>P. glaucum</i> , <i>S. cariosa</i> , <i>X. krynickii</i>
Battir	15	<i>B. labrosus</i> , <i>H. engaddensis</i> , <i>E. protensa</i> , <i>E. septemdentatus</i> , <i>L. caesareana</i> , <i>L. lithophaga</i> , <i>M. syriaca</i> , <i>M. obstructa</i> , <i>P. episomus</i> , <i>P. raymondi</i> , <i>S. cariosa</i> , <i>S. fimbriata</i> , <i>T. haasi</i> , <i>X. krynickii</i> , <i>X. langloisiana</i>
Abood	14	<i>B. labrosus</i> , <i>C. haasi</i> , <i>E. chondriformis</i> , <i>E. protensa</i> , <i>E. septemdentatus</i> , <i>H. engaddensis</i> , <i>L. caesareana</i> , <i>M. berytensis</i> , <i>M. syriaca</i> , <i>P. bulimoides</i> , <i>P. episomus</i> , <i>P. glaucum</i> , <i>S. cariosa</i> , <i>X. krynickii</i>
Ajul	14	<i>B. labrosus</i> , <i>C. acicula</i> , <i>E. chondriformis</i> , <i>M. berytensis</i> , <i>P. episomus</i> , <i>P. bulimoides</i> , <i>P. raymondi</i> , <i>R. rhodia</i> , <i>S. cariosa</i> , <i>X. krynickii</i>
Um Al Tout	13	<i>C. hierosolymarum</i> , <i>C. genezarethisis</i> , <i>E. chondriformis</i> , <i>E. protensa</i> , <i>E. septemdentatus</i> , <i>G. granum</i> , <i>L. caesareana</i> , <i>M. syriaca</i> , <i>P. episomus</i> , <i>T. haasi</i> , <i>X. krynickii</i> , <i>X. langloisiana</i>

**Table 4.** Land snails of the Palestinian Territories according to their biogeographic zone.

Family		M	IT	SA	S
Pomatiidae	<i>Pomatias glaucum</i>	•			
Orculidae	<i>Pilorcula raymondi</i>	•			
Chondrinidae	<i>Granopupa granum</i>	•	•	•	•
	<i>Rupestrella rhodia</i>	•			
Vertiginidae	<i>Truncatellina haasi</i>	•			
Enidae	<i>Buliminus labrosus</i>	•	•		•
	<i>Buliminus marsabansis</i>		•	•	
	<i>Buliminus therinus</i>		•	•	•
	<i>Buliminus diminutus</i>		•		
	<i>Buliminus glabratus</i>			•	•
	<i>Euchondrus chondriformis</i>	•	•		
	<i>Euchondrus saulcyi</i>	•			
	<i>Euchondrus septemdentatus</i>	•	•		
	<i>Paramastus episomus</i>	•			
	<i>Pene bulimoides</i>	•			
	<i>Turanena benjamitica</i>	•			
Clausiliidae	<i>Cristataria haasi</i>	•			
Ferussaciidae	<i>Calaxis hierosolymarum</i>	•	•		•
	<i>Cecilioides acicula</i>	•	•		•
	<i>Cecilioides genezarethensis</i>	•			•
Subulinidae	<i>Rumina decollata</i>	•			
Pleurodiscidae	<i>Pleurodiscus balmei</i>				•
Limacidae	<i>Gigantomilax cecconii</i>	•			
	<i>Limacus flavus</i>	•			
Oxychilidae	<i>Eopolita protensa</i>	•			•
Sphincterochilidae	<i>Sphincterochila cariosa</i>	•			
	<i>Sphincterochila fimbriata</i>	•	•	•	•
	<i>Sphincterochila zonata</i>		•	•	•
	<i>Sphincterochila prophetarum</i>			•	•
Cochlicellidae	<i>Cochlicella barbara</i>	•			
Hygromiidae	<i>Monacha crispulata</i>	•			
	<i>Monacha obstructa</i>	•	•		
	<i>Monacha syriaca</i>	•			
	<i>Metafruticicola berytensis</i>	•			
	<i>Xerocrassa langloisiana</i>	•	•	•	•
	<i>Xerocrassa simulata</i>	•	•	•	•
	<i>Xerocrassa seetzenii</i>		•		
	<i>Xerocrassa tuberculosa</i>		•	•	
	<i>Xeropicta krynickii</i>	•	•	•	
Helicidae	<i>Helix engaddensis</i>	•	•	•	•
	<i>Levantina caesareana</i>	•	•	•	•
	<i>Levantina lithophaga</i>	•	•		•

Note: M = Mediterranean, IT = Irano-Turanian, SA = Saharo Arabian, S = Sudanian.

slaps, while *M. crispulata* was recovered along with oak tree litters. Xeric forms such as *X. langloisiana* and *X. simulata* had very few localities in the Mediterranean zone.

*Helix engaddensis*, *L. caesareana*, and *L. lithophaga* are all lithophiles inhabiting many rocky areas in Palestine. *Levantina caesareana* and *L. lithophaga* can also be found in semi-arid regions of the Mediterranean, whereas *L. caesareana* is more abundant in the north, while *L. lithophaga* is more common in the south, with areas harbouring both species around Wadi Al Quff, north of Hebron. As for family Ferussaciidae, *C. hierosolymarum*, *C. acicula*, and *C. genezarethensis* were associated with soft soil under large boulders. Slugs (*G. cecconii* and *L. flavus*) were confined to humid areas, houses, farmlands and near dense vegetation during winter. *Rumina decollata* is an introduced species found in plant nurseries.

#### Irano-Turanian zone species

The land snail fauna of the Irano-Turanian zone consisted of 20 species, with three shared with the Mediterranean (*E. chondriformis*, *E. septemdentatus*, and *M. obstructa*) and two with the Saharo-Arabian (*B. marsabansis* and *X. tuberculosa*), while the other species were shared

with the Mediterranean, Saharo-Arabian, and Sudanian Penetration zones. *Buliminus diminutus* was the only distinctive species for this zone. Indeed, Irano-Turanian is a transitional zone where land snails can move from the humid Mediterranean to the semi-arid Irano-Turanian zone, as well from the arid surrounding zones. Twelve species were shared with all other zones.

#### Saharo-Arabian zone species

Fourteen species were found to inhabit this zone (Table 1). This zone was represented by xeric species such as *S. zonata* and *S. prophetarum*. *Sphincterochila zonata* was collected from areas east of Bani Na'im, reaching as far as the Dead Sea area. Other desert dwelling species associated with this zone include *B. glabratus*, *G. granum*, *X. langloisiana*, *X. simulata*, and *X. tuberculosa*. *Sphincterochila zonata* and *X. simulata* were the most common species and were found in high densities. *Sphincterochila zonata* was distributed in deserts with 200 mm annual rainfall in the south-eastern areas of the Palestinian Territories.

Active live specimens for *S. zonata* and *X. simulata* were found mostly in January. Empty shells for *H. engaddensis* and *L. lithophaga* that represented past

**Table 5.** Zoogeographical affinities of the land snails occurring in the Palestinian Territories.

Endemic	Regionally endemic	Levantine	Circum-Mediterranean	Western Palearctic	Wider range
<i>C. haasi</i>	<i>B. diminutus</i> <i>B. glabratus</i> <i>B. marsabensis</i> <i>C. genezarethensis</i> <i>E. saulcyi</i> <i>E. chondriformis</i> <i>H. engaddensis</i> <i>L. lithophaga</i> <i>M. crispulata</i> <i>P. episomus</i> <i>P. raymondi</i> <i>S. cariosa</i> <i>S. zonata</i> <i>T. haasi</i> <i>T. benjamitica</i> <i>X. langloisiana</i> <i>X. simulata</i> <i>X. tuberculosa</i>	<i>B. labrosus</i> <i>C. hierosolymarum</i> <i>E. protensa</i> <i>E. septemdentatus</i> <i>L. caesareana</i> <i>M. berytensis</i> <i>P. bulimoides</i> <i>S. fimbriata</i>	<i>P. glaucum</i> <i>P. balmei</i> <i>R. rhodia</i>	<i>C. acicula</i> <i>G. granum</i>	<i>B. therinus</i> <i>C. barbara</i> <i>M. obstructa</i> <i>M. syriaca</i> <i>R. decollate</i> <i>S. prophetarum</i> <i>X. krynickii</i> <i>X. seetzenii</i>
2	17	8	3	2	8

populations were found in lower numbers, and no living snails were observed in our collecting (either an effect of desertification or sampling). Both *S. zonata* and *X. simulata* were found on gravelly, rocky areas and enclaves, while *B. glabratus* was mostly associated with large rocky boulders near Wadi Daraja. *Sphincterochila prophetarum* was confined to areas around Nabi Mousa, compared to the widely distributed *S. zonata*.

#### Sudanian Penetration zone species

Sixteen species were recorded from this zone. The southern part of the Sudanian zone around the Dead Sea basin harboured xeric species such as *S. prophetarum* as the dominant species, which was replaced by *S. fimbriata* in the upper part of the Sudanian zone that extends from around Jericho reaching Bardalla to the north. *Pleurodiscus balmei* was found from Dayr Qurntul. The Family Enidae was represented by three species: *B. therinus*, *B. marsabensis*, and the endemic subspecies at Jiftlik, *Buliminus labrosus jiftliki*.

#### Zoogeography of land snails of the Palestinian Territories

The terrestrial malacofauna of central Palestine consists of several origins (Table 5). Some species are strictly endemic to Palestine (*C. haasi* and *B. glabratus*), with the majority of regionally endemic species. Seven species have a distribution within the Levant, two have the Circum-Mediterranean range, two Western Palearctic, and some are with wider ranges, such as *B. therinus* (Lebanon, Iraq, and Turkey), *M. obstructa* (Egypt to Iran), *M. syriaca* (Cyprus, Egypt, Greece, Lebanon, Palestine, Syria, and Turkey), *S. prophetarum* (Jordan, Northern Egypt and Saini, Northern Arabia, and Palestine), *X. krynickii* (Eastern Europe to Arabia), *X. seetzenii* (Jordan, Iraq, North Arabia, Palestine, and Syria).

**Table 6.** Number of land snail species recorded from nearby countries.

Region	No. of species	References
Arabian Peninsula	70	Neubert (1998)
Jordan	45	Neubert et al. (2015)
Lebanon	33	Bößneck (2011)
Palestine	105	Heller (2009)
Turkey	540	Gümüş and Neubert (2009)

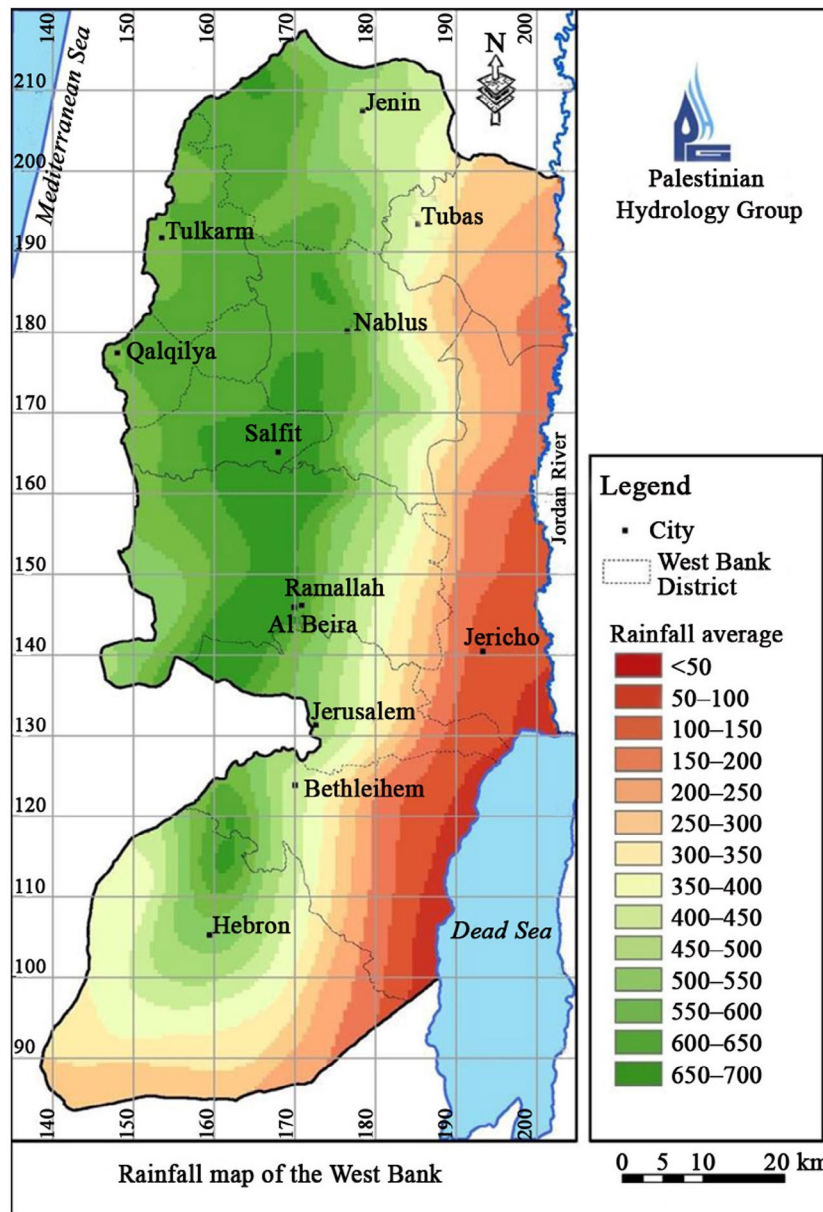
#### Discussion

The zoogeography of the Palestinian land snails was subjected to several studies (Heller 1975, 1979, 1984, 1988). The taxonomic status of some species has since been revised: *B. marsabensis alepensis* = *B. marsabensis*, *Calaxis rothi* = *C. hierosolymarum*, *L. hierosolyima* = *L. lithophaga*, *M. fourousi* = *M. berytensis*, *P. olivieri* = *P. glaucum*, *P. sidonensis* = *Penebulimoides* (Bank, Gittenberger, and Neubert 2013; Neubert et al. 2015). The present study examined over 135 sites across central Palestine representing all types of biogeographical zones and habitats and reevaluated biogeographical affinities.

This study shows that the area examined has a rich diversity of land snails considering its limited size of <6000 km<sup>2</sup> compared to Arabia, Jordan, Lebanon and Turkey and the rest of historic Palestine (Table 6) as investigated by other authors (Heller 1988, 2009; Neubert 1998; Gümüş and Neubert 2009; Neubert et al. 2015).

Heller (1988) explained that the distribution of land snails is governed by rainfall, substratum, vegetation, predation, completion and temperature. Such factors limit the distribution of many land snails, especially those of Mediterranean origin. Annual rainfall in the Palestinian Territories ranges from 700 mm around Salfit and Hebron's north-western hills to as low as 50 mm around the Dead Sea basin (Figure 5). Kadmon and Heller (1998) showed that the response of the land snails in Palestine to rainfall is correlated to faunal assemblages and variations in species composition.





**Figure 5.** Rainfall map of the Palestinian Territories (after Palestinian Hydrology Group). Source: ARIJ.

Hausdorf (2006) showed that there is no significant correlation between rainfall and the body size of shelled land snails in Palestine. Morphology and diversity is another matter. Heller (1987) related shell shape to habitat type inhabited by snails. He elaborated that high-spired shells are mostly related to rocky habitats, while low-spired and equidimensional shells are more related to bush and soil dwellers. This is in agreement with our findings, whereas most enids (e.g. *B. labrosus*, *B. glabratus*, *P. episomus*) are strictly rock dwellers, and low-spired species (e.g. *T. haasi*) were noted in other habitats.

Rare species found in the Mediterranean zone are represented by five species. Empty shells of *P. glaucum* were collected from four sites (Kuf Al Deek, Abood, Broken, and Dayr Baloot). Originally, it is known from areas close to the Mediterranean Sea. Bar (1975) showed the expansion of this species into the inland in the West Bank. *Turanena benjamitica* is another rare species

known from three sites in Palestine (Heller 2009) and in a single site in calcareous rocks in a partially wooded area in northern Lebanon (Bößneck 2011). Our samples were recovered from rocky areas. *Pilorcula raymondi* was recovered from two locations, with records from the central West Bank and around Lake Tiberias (Heller 2009). Most previous records of *E. saulcyi* came from most northern regions of historic Palestine (Heller 2009). The endemic *C. haasi* was previously recorded from the most western parts of the West Bank (Heller 2009); however, we added several localities within the northern parts of the study area.

The Mediterranean zone hosts the highest number of species given the fact that it enjoys the highest annual rainfall as well as its rocky nature and dense vegetation. In some sites (Kuf Al Deek and Ain Yabroud), a total of 18 species were recovered comparable to rich high rainfall sites such as near Mount Carmel (Pavliček et al. 2008).

The distribution of *S. prophetarum* covers the Sudanian Penetration and the Saharo-Arabian zones. Earlier, Arad, Ldenberg, and Heller (1989) claimed that the distribution of this species is confined to the southern end of the Dead Sea and extends into Al Naqab desert. However, it is noted in the northern end of the Dead Sea (Nevo, Bar-El, and Bar 1983; Heller 2009). Our study revealed that the range of this species extends to Nabi Mousa area and east of Qumran. Other species recorded here with unexpected distribution include the presence of *P. balmei* in the Jordan Valley, near Jericho. This species occurs as single or as sparsely distributed individuals in the Mediterranean zone with rainfall of 500 mm (Bar 1974).

Extreme arid regions are characterized by key species such as *B. glabratus*, *S. zonata*, and *X. tuberculosa*. All these species were reported in areas with less than 200 mm of annual rainfall (Heller 1984, 1988; Hausdorf 2006).

Both *Levantina caesareana* and *L. lithophaga* are among the most abundant species, whereas *L. caesareana* is distributed in the northern parts from Bethlehem northwards, while *L. lithophaga* is restricted to the southern part of the area. We have areas where both species coexist like, for example, in Wadi Al Quf. Heller (1979) suggested potential hybridization of the two species, and Wadi Al Quf is maybe just such hybrid zone.

This baseline survey of distribution and ecology of land snails gains significance, because we anticipate significant changes as the area suffers from decrease in annual rainfall and increase in annual temperature and desertification due to human-induced climate change (Verner 2012). Integrating species and ecosystem responses in planning for adaptation to climate change is now critical (Lavergne et al. 2010), and land snails are the best indicator species for climate change (Beltramino et al. 2015). Thus, further studies on the distribution of the land snails of our region over a longer time frame are among the highest priorities of the PMNH in focusing on habitat conservation and sustainability in the face of dramatic changes that are already having a negative impact on biodiversity in our region (e.g. Qumsiyeh, Zavala, and Amr 2014; Amr et al. 2016).

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