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Distribution of arid-dwelling land snails according to dryness

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ABSTRACT

Although land snails are hydrophilic animals, several species inhabit arid or semi-arid environments. Here, I hypothesize that, for arid-dwelling land snails, both relatively moist environments and extreme arid zones, within their distribution ranges, should be disadvantageous. Therefore, arid-dwelling land snails should show maximal probability of presence and maximal abundances at intermediate levels of aridity. I tested this hypothesis with two land-snails from Sierra Elvira mountain range (SE Spain), *Sphincterochila candidissima* and *Iberus gualterianus*. Given that environmental variables as well as snail distribution showed spatial autocorrelation, I performed spatially explicit models, specifically simultaneous auto-regressions (SAR). The results supported the hypothesis, with the distribution of *S. candidissima* and the abundance of *I. gualterianus* following a concave-down relationship with aridity. Moreover, both species were less abundant as elevation increased, and *I. gualterianus* showed a positive association with rocky surface. Therefore, this study highlights that, in arid environments, arid-dwelling land snails show maximal abundance and probability of presence at intermediate aridity levels. Although the reasons explaining why extreme aridity values limit the abundance and distribution of land snails are well detailed, it remains intriguing why these snails decrease in abundance when moisture increases.

1. Introduction

Arid environments present characteristically low moisture and scarce vegetation (Cox and Moore, 2005). Consequently, primary productivity is very low in arid environments (Hawkins et al., 2003), and this imposes restrictive living conditions on animals (Pianka, 2000). Arid environments are especially restrictive for hydrophilic animals, despite that several hydrophilic taxa inhabit arid environments. For example, terrestrial gastropods are very hydrophilic animals, since they have a permeable skin and undergo high rates of dehydration (Luchtel and Deyrup-Olsen, 2001; Prior, 1985). In fact, in temperate realms, their distribution is strongly affected by moisture, and a greater number of individuals are typically found in moist environments than in dry environments (Martin and Sommer, 2004). Nevertheless, several snail species inhabit arid zones, where they use behavioural, physiological, and/or morphological adaptations to minimise the risk of dehydration (Arad et al., 1989; Giokas et al., 2005; Moreno-Rueda, 2007).

As mentioned above, in relatively moist zones, land snails are typically more abundant in wetter zones. Therefore, it might be concluded that in arid or semi-arid zones, such as the Mediterranean region, arid-dwelling land snail distributions increase with moisture, even more markedly than in wet realms. However, the semi-arid Sierra Elvira mountain (SE Spain), in contrast to moist sites, shows higher abundances and diversity of land snails on its drier, southern slope (Moreno-Rueda, 2002). Although dry zones offer a clearly restrictive environment for land snails (also see Tryjanowski and Koralewska-Batura, 2000), wet zones may also be restrictive in some aspects, especially for animals not adapted to moist environments. Therefore, the dispersion of arid-dwelling land snails to moister zones may be limited by a number of factors. For example, parasites are more abundant in wet zones (Moyer et al., 2002). Given that species richness is higher in more productive zones (e.g. Moreno-Rueda and Pizarro, 2009), then more productive zones (i.e. moister zones) should harbour more predators and competitors. Competition with other species or subspecies may limit the distribution of land snails (Moreno-Rueda, 2006b). In fact, climatic selection strongly influences land snail distribution (Cowie, 1990; Cowie and Jones, 1985; Johnson, 2011).

In accordance with this reasoning, I predict that in an arid or semi-arid zone, such as Sierra Elvira mountain range, the abundance and probability of detecting arid-dwelling land snails should show a concave-down relationship with aridity. In a cline of aridity, both extremes should impose restrictive situations for land snails by the aforementioned conditions, with their abundances maximized at intermediate aridity values. I test this prediction with the two main species of land snails in Sierra Elvira: *Sphincterochila candidissima* and *Iberus gualterianus* (Moreno-Rueda, 2002). In the present study, I measured in detail a number of environmental

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variables, and statistically tested whether the abundance values and probabilities of detection of the two snails show a concave-down relationship with plant cover, as an inverse indicator of micro-geographic aridity.

2. Methods

2.1. Study species

S. candidissima (Gastropoda; Sphincterochilidae) is widespread in the west side of the Mediterranean basin (Fechter and Falkner, 1993). All the species in Sphincterochilidae are well adapted to desert and subdesert environments (Arad et al., 1989; Shachak, 1981; Yom-Tov, 1971). On the other hand, the genus *Iberus* (Gastropoda; Helicidae) is endemic to Spain (García San Nicolás, 1957) and typically inhabits zones with Mediterranean climate (Ruiz Ruiz et al., 2006). *I. gualterianus* inhabits mainly arid and semi-arid zones such as the mountain range sampled in the present study (Moreno-Rueda, 2011).

2.2. Study area

Sierra Elvira (SE Spain; 37° 15′ N, 3° 40′ W), is a small karstic sierra within an elevational range of 600–1100 m a.s.l. It is characterized as having a Mediterranean climate with up five months of drought (Moreno-Rueda et al., 2009). The study area shows a mosaic of habitats composed mainly of scrubland of *Quercus coccifera*, *Juniperus oxycedrus*, *Stipa tenacissima*, *Cistus* ssp. and *Rosmarinus officinalis*, alternating with small patches of grasslands and bare soil.

2.3. Sampling

The sampling was performed between 2002 and 2004, during October and November, when detectability of snails is at its peak (Moreno-Rueda and Collantes-Martín, 2007; Moreno-Rueda and Pizarro, 2007). For the measurement of snail distribution and environmental variables, I studied 70 quadrats of 9 m^2 (3 × 3 m) randomly distributed on the mountain (Fig. 1). Quadrats were cordoned off, and I carefully searched for snails by the complete quadrat, especially scrutinizing rock crevices as well as searching inside and under scrubby vegetation, where these snails are frequently sheltered (Moreno-Rueda, 2007). Live specimens as well as empty shells were recorded. Since snails inhabit a low-productive environment, they are found at very low densities (Moreno-Rueda and Collantes-Martín, 2007; Moreno-Rueda and Pizarro, 2007). Therefore, I estimated relative abundance according to total live plus dead snails found. Previously, I tested whether this is a good estimation of relative abundance of live snails. For both species, density of live animals was significantly correlated with that of dead snails (for *I. gualterianus*: $r_s = 0.578$, $P < 0.001$; for *S. candidissima*: $r_s = 0.549$, $P < 0.001$; $n = 70$ quadrats). Slopes might encourage the accumulation of empty shells in lower flat areas (Baur et al., 1997). For this reason, I measured the slope angle of the quadrat with an inclinometer at 16 points homogeneously distributed, and estimated the average. The density of empty shells was uncorrelated with average inclination of the quadrat for both species (*I. gualterianus*: $r_s = 0.189$, $P = 0.117$; *S. candidissima*: $r_s = 0.143$, $P = 0.239$). Therefore, I considered a species to be present in a quadrat when I found at least one shell in the quadrat. The relative abundance was estimated as the total of empty shells plus live individuals found in the quadrat.

Regarding the environmental variables, I measured: (1) Plant cover, which was measured by subdividing the quadrat in 225 squares of 20 × 20 cm. For each square, I recorded whether it was mainly (>50%) covered by vegetation or not. The percentage of cover was calculated as number of squares covered by vegetation divided by 2.25. Aridity of the quadrats was approached as the absence of vegetation, estimated as 100 minus plant cover, that is, the percentage of the quadrat not covered by vegetation. (2) Elevation, with the use of a GPS device. Elevation was measured because previous studies show that it affects the presence at least of *I. gualterianus* (Moreno-Rueda, 2006c). (3) Rocky substrate. In the study area, substrate may be divided basically into bare soil and rocky substrate. I measured the type of substrate, because it has been proved to be important for the distribution of *I. gualterianus*

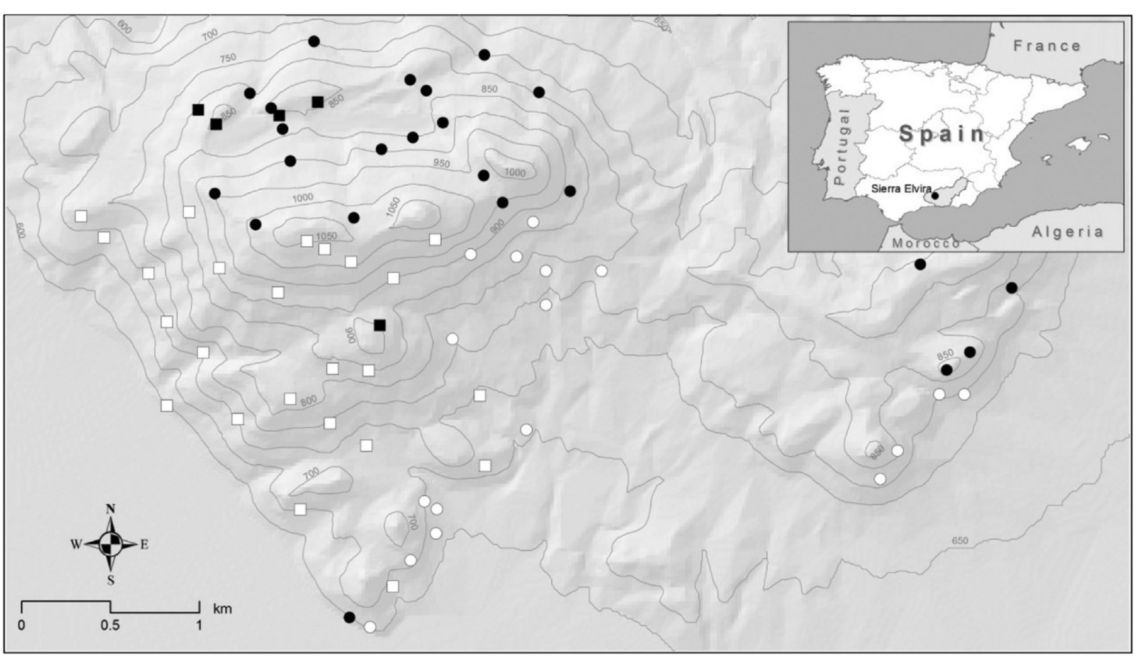

Fig. 1. Geographic location of study quadrats in Sierra Elvira mountain range (SE Spain). White indicates quadrats in which *Sphincterochila candidissima* was present, black in which *S. candidissima* was absent, squares indicate that *Iberus gualterianus* was present, while circles indicate that it was absent.