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SHORT COMMUNICATION

Ecology and biogeography of the endemic scorpion *Euscorpius carpathicus* (Scorpiones: Euscorpiidae): a multiscale analysis

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Abstract. We present a first analysis of the ecology and potential distribution of *Euscorpius carpathicus* (Linnaeus, 1767), a scorpion species endemic to southern Romania, and report on the overwintering habitat selection of this species. Using field data, literature review, species distribution modelling, and habitat selection models, we document the broad scale distribution and ecology of *E. carpathicus,* as well as habitat selection in the foothills of the Curvature Carpathians, including exclusive microhabitat selection of riverine clay banks. In contrast with other species of the genus that inhabit cracks in cliffs or walls, *E. carpathicus* has adapted to cracks in clay.

Keywords: Carpathian scorpion, habitat selection, potential distribution, overwintering ecology, temperate region

Scorpions are a diverse group of invertebrates, with over 1,200 described species. They inhabit all main terrestrial habitats, reaching a maximum species richness in subtropical areas (23–38° latitude) (Hadley 1972; Polis 1990). Distinguishable from this general distribution pattern in hot and dry areas (Cloudsley-Thompson 1962, 1975) are scorpions that inhabit temperate regions (especially taxa in the family Euscorpiidae). For example, several species are found in humid and even cold environments, including mountain tops such as the Alps, Balkans, and Pindos, up to 2500 m above sea level (Fet 2010).

Euscorpius is a European genus of scorpions that comprises at least 20 species (Fet & Soleglad 2002; Fet et al. 2003; Vignoli et al. 2005). Many of the currently accepted species are former subspecies of *E. carpathicus* (Linnaeus, 1767) recently elevated to species status (Fet & Soleglad 2002). *Euscorpius carpathicus* (the Carpathian Scorpion) is the first described species of *Euscorpius* and is endemic to the foothills and mountains of southern Romania (Bunescu 1959; Fet & Soleglad 2002). The ecology of *E. carpathicus* has not been studied yet, most characteristics being extrapolated from its more studied relatives such as *E. italicus* (Herbst, 1800) or *E. flavicaudis* (De Geer, 1778) (Benton 1991a, b, 1992; Colombo 2006).

Unlike scorpions from warmer areas, those in the genus *Euscorpius* adapted their life cycle to withstand extreme seasonal variations from dry, hot summers to cold, snowy winters. Despite the obvious importance of understanding the overwintering ecology of temperate region scorpion species, data regarding this aspect are scarce or missing (as for all species of *Euscorpius*).

In the current paper, we provide an updated overview on the distribution of *E. carpathicus* based on previously published and newly collected data, create a general climatic tolerance profile and map of the climatically suitable areas for the species using occurrence and climatic data, as well as broaden our understanding of ecological mechanisms of temperate region scorpions in regards to overwintering behavioral ecology.

Current distribution.—Distribution data for *E. carpathicus* were obtained from three different sources: literature records (Calinescu 1956; Bunescu 1959; Fet & Soleglad 2002; Fet et al. 2002), field surveys by IG and ASo from 2008 to 2012 in Romania, and personal communications with other biologists. We included in our analysis records with geographic coordinates, if available at a spatial uncertainty < 1 km; localities with spatial uncertainty > 1 km were either validated through field surveys or discarded from the analysis. Of the compiled records, 78.4% were previously known and 21.6% were new records. Our final dataset comprised 60 spatially unique occurrence records (Fig. 1).

The distribution of *E. carpathicus* records is clearly clustered as shown by Moran's I test ($z = 22.4$, $P < 0.0001$) and by GetisOrdGi* spatial statistic ($z = 9.8$, $P < 0.0001$), which indicates that the species has a restricted distribution (Fig. 1). We identified two isolated distribution hotspots, one in the foothills of the Curvature Carpathians, and another one in the Banat Mountains. We used minimum convex polygons to calculate the Extent of Occurrence (EoO) of the entire occurrence dataset and for the two clusters of occurrence points (distribution hotspots). The total EoO of *E. carpathicus* was 29,540 km^2. Due to the presence of a 160 km gap without scorpion observations between the two hotspots, the total EoO of the species decreased by 36.1% after summing the EoO of the two hotspots.

In order to summarize the habitat types in the proximity of *E. carpathicus* occurrences, we created a 5 km buffer around each distribution point and calculated the percentage of habitat type using Corine Biotopes 2000 map (CLC2000). The habitat matrix in which *E. carpathicus* were recorded is mostly composed of broad-leaved forests (41.95 %), pastures (10.39 %), and rural areas (6.16 %), suggesting that the species inhabits regions with moderate anthropogenic impacts. All analyses were done in ArcGIS 10 (ESRI 2011).

Potential distribution.—We downloaded climatic data from the WorldClim database (Hijmans et al. 2005), at a spatial resolution of 1 km to match the spatial uncertainty of occurrence data. We used a jackknife analysis to measure the importance of the variables, increasing model accuracy and reducing the initial set of 19 bioclimatic variables to a subset of seven variables that each contributed $> 5\%$ to model accuracy gain (Table 1). We used Pearson correlation to check for significant correlations among the remaining seven bioclimatic variables (as suggested by Fielding & Haworth 1995) and found no significant correlation ($r > 0.7$).

Table 1.—Variables used for generating the Maxent species distribution model, indicating the percent contribution to accuracy gain of the final model.

Variable	Final model
Precipitation of Warmest Quarter	35.7
Min Temperature of Coldest Month	15.1
Max Temperature of Warmest Month	14.3
Temperature Annual Range	12.8
Isothermality	10.2
Precipitation Seasonality	6.4
Precipitation of Coldest Quarter	5.6

We used Maxent version 3.3.3k (Phillips et al. 2006; Phillips & Dudik 2008) to estimate the potential distribution of the target species from species' occurrence records and environmental data; in evaluating the model performance, random test percentage was set to 25% of the occurrences, and the maximum number of background points was set to 10,000. Because Maxent produces continuous-type predictions, we used a 10% omission error of the training occurrence dataset as threshold to generate a binary prediction (presence/absence).

The model was evaluated using Area Under the Curve (AUC) of the Receiver Operating Characteristic (ROC) calculated in Maxent (Phillips et al. 2006; Phillips & Dudik 2008) and partial AUC (Peterson et al. 2008), calculated using partial-ROC application. In partial ROC we ran 100 iterations in which test occurrence data were bootstrapped to create a null distribution for comparison with our observed value of pAUC using a 10% omission error. We also calculated the omission error, representing the testing occurrence data predicted absent by the binary prediction.

The predictive power of our Maxent model for *E. carpathicus*, as measured by AUC (training AUC = 0.861 and testing AUC = 0.881), as well as partial AUC (mean of 1.34, SD = 0.07, $P < 0.05$) was high. Additionally, the model omitted only 6% of the testing occurrence points. The variables that most contributed to model accuracy gain were precipitation of warmest quarter, minimum temperature of coldest month, and maximum temperature of warmest month, indicating a sensitivity of the species to the amount of precipitation during dry seasons, and to low temperatures during winter months.

Our model found Banat Mountains and Curvature Carpathian climatically suitable for *E. carpathicus* (Fig. 1). In addition, most of the foothills of Western and Eastern Carpathian Mountains, the Moldavian and Getic Plateaus, and parts of Transylvania were also predicted to be suitable (Fig. 1). On the southern side of the Danube River, the climatically suitable area was limited to the Iron Gates Canyon.

Microhabitat and overwintering site selection.—We conducted a field study in the foothills of the Curvature Carpathians in Buzau County in close proximity of Valea Nucului village. Due to the lack of ecological data on *E. carpathicus* and because previously published records only referred to its general distribution (locality records), we selected three types of habitat to survey in the studied area, based on the distance from a stream and general exposure: riparian habitat, meadow, and forest, each one with an approximate area of 2 km^2. Each habitat was surveyed three times, at ten sample points, with approximatively six hours allocated for each survey; we did not find any scorpions in forests or meadows, suggesting a strong association between the scorpions and riparian habitats.

For each surveyed point, we recorded the following variables: presence of bushes, leaf cover, type of soil, slope, distance to the stream, and number, age (juvenile or adult), and sex of individuals found at each location. We used the First Sight Point methodology to characterize the microhabitats (clay, bushes, slope, leaf, aspect, and distance from stream) where we first observed an individual, regardless of the animal remaining at or leaving the site (see Bombi et al. 2009 for more details). We located a total of 20 scorpions during our surveys.

We used General Linear Models (GLM) to explain the overwintering habitat selection by *E. carpathicus* juveniles and adults and an information-theoretic approach to evaluate the relative support of the different models obtained (Anderson & Burnham 2002; Mazerolle 2006). As a result, we selected three of the computed GLMs that

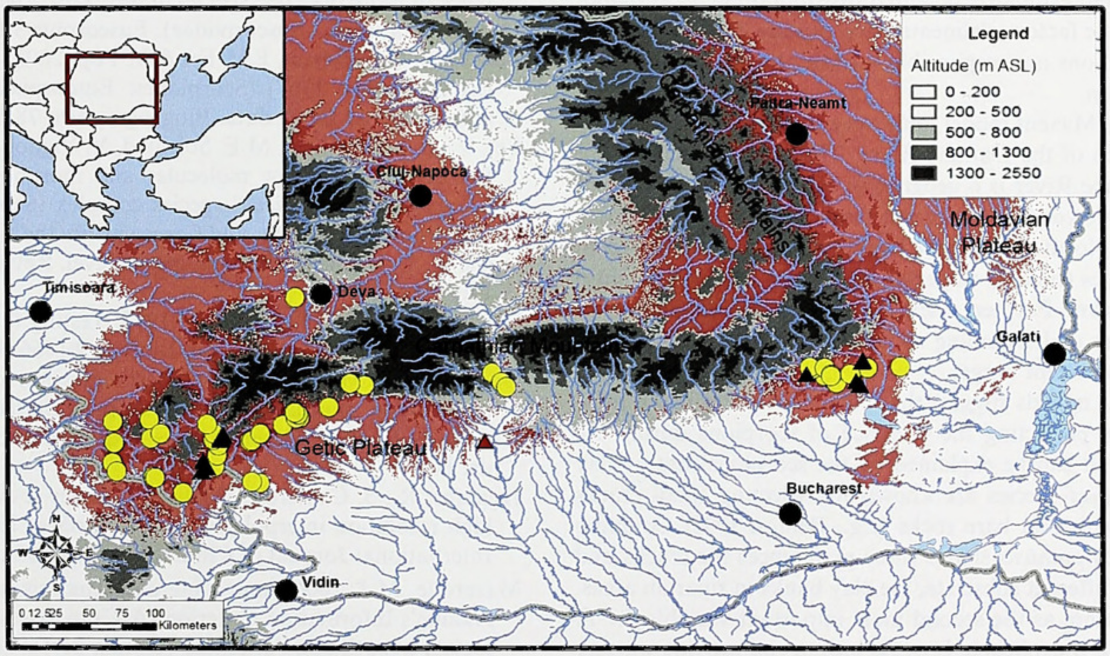

Figure 1.—Occurrence points and climatically suitable areas of *E. carpathicus*. Yellow points show sites with known *E. carpathicus* literature records and triangles show sites with new records, found for the first time during surveys reported here. The light red background color represents climatically suitable area for *E. carpathicus*, as predicted by the Maxent model; elevation is shown in shades of gray.

received the lowest Akaike Information Criterion (AIC) score (e.g., Gagné & Dayton 2002). We also calculated the AIC weights (w), which represent the probability of a model to be the best from the entire set of candidate models (Anderson & Burnham 2002). All statistical analyses were run in R 2.14 using "MuMIn", "MASS", and "bbmle" packages.

Our GLM results showed that the most important habitat variable for both ontogenetic stages of *E. carpathicus* is the presence of clay substratum which was retained in all of the best selected GLMs. Additionally, according to AIC weights, the probability that this variable is the most important was 0.785.

Except for the variable clay, in case of the adults, all GLM models obtained similar AIC values (ΔAIC = 1.6) and presented almost no variability with respect to model variance and weights. Based on these results, we consider that adult *E. carpathicus* randomly select overwintering microhabitats but only in areas where clay substratum is present. For all adults, the best model according to AIC suggested an interaction between presence of bushes and clay. This model explained 81% of the variance of the data (Nagelkerke's R^2), and the probability that this was the best model was 0.80. All other variables only appeared in various combinations with the variable clay across the two age groups. In the case of juveniles, the best-generated GLM models suggest a selection of microhabitats, specifically an interaction between the presence of clay and leaves. This model had an AIC weight of 0.199 and explained 100% of variance of the data (Nagelkerke's R^2).

Euscorpius carpathicus is an endemic species that is found only in Romania, known from records from the Banat Mountains, in the vicinity of the city of Deva, a few isolated locations along the Olt River, and in the foothills of the Curvature Carpathians (Calinescu 1956; Bunescu 1959; Fet & Soleglad 2002). The distribution of this species is divided in two clusters, situated 160 km apart (Fig. 1). Despite our field surveying efforts, we were unable to locate scorpions within this gap. Furthermore, the habitat considered suitable for scorpions (broad-leaf forests, rocks, human settlements, etc.) is continuous along the 160 km long gap, thus we could not find any obvious reason for the absence of scorpions. Fet et al. (2002) suggested that this disjunct distribution might be the result of human influence or relict distribution. However, the Maxent estimated potential distribution of *E. carpathicus*, based on climatic factors, delineated two clusters, thus we propose that climatic conditions are responsible for the absence of scorpions within the gap region.

According to our Maxent model, only very small climatically suitable areas exist south of the Danube River. This finding suggests not only that the Danube River is a geographic barrier for dispersal, but also that the climatic conditions are not favorable for *E. carpathicus* south of the river. Northwards, most likely limitations are related to biology of the species (such as dispersal or perhaps food availability) and remain unknown. Further research on the species' biology is required for a better understanding of its distribution patterns in the northern part of its current range.

The microhabitat models suggest that clay substratum is the most important factor in predicting the presence of scorpions during the winter and this result can be explained by the scorpions' use of clay for shelter. *Euscorpius* species are known for selecting small cracks and holes in the walls and bare rocks (e.g., Benton 1992, Colombo 2006). *Euscorpius carpathicus* shares these preferences for cracks and holes but selects a different substrate, the clay banks in riparian areas. The presence of bushes as the second most important variable for *E. carpathicus* presence is explicable because bushes can provide warmer microhabitats in river valleys during winter. Therefore, by selecting riparian habitats with bush cover, *E. carpathicus* could attain a higher survival rate during the winter.

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