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AGE-CLASS SEGREGATION AND MICROHABITAT SELECTION IN FOREST SALAMANDERS: APPLICATION OF A TWO-SPECIES N-MIXTURE MODEL

SUMMARY

Some studies investigated age-class segregation of *Speleomantes strinatii,* in underground environments, showing a clear spatial segregation. We investigated the spatial distribution of *S. strinatii* on the forest floor, on 111 plots surveyed three times per season, in autumn 2017 and spring 2018. We modeled co-abundance of adults and juveniles, using a two-species N-mixture model with directional interactions, incorporating environmental covariates. In contrast with what observed in underground environments, we recorded no spatial segregation between age-classes of *S. strinatii*, while we found that adults and juvenile responded differently to environmental features.

Key words: Plethodontidae, N-mixture model, spatial segregation, soil moisture.

RIASSUNTO

Segregazione spaziale e selezione del microhabitat nei geotritoni in ambiente forestale: applicazione di modelli N-mixture a due specie. Svariati studi hanno investigato la segregazione spaziale in popolazioni ipogee di *Speleomantes strinatii*, dimostrando una chiara segregazione spaziale. Abbiamo studiato la distribuzione spaziale di *S. strinatii* in ambiente forestale, all'interno di 111 plot campionati tre volte per stagione in autunno 2017 e primavera 2018. Abbiamo analizzato i conteggi usando un modello N-mixture per due specie con interazioni direzionali, modellando l'abbondanza di giovani e adulti in funzione delle variabili ambientali. Non abbiamo osservato segregazione spaziale, contrariamente a quanto osservato in ambienti ipogei, mentre abbiamo osservato come giovani e adulti rispondano in modo diverso ai fattori ambientali.

Parole chiave: Plethodontidae, N-mixture model, segregazione spaziale, umidità del suolo.

INTRODUCTION

Some studies investigated the population structure and spatial distribution of the European cave salamander *Speleomantes strinatii* (Aellen, 1958) (e.g., SALVIDIO, 1993; LINDSTROM, 2010; FICETOLA *et al.*, 2012). This species is a fully terrestrial plethodontid found in northwestern Italy and southern France on the forest floor and also within underground habitats such as natural caves or man-made tunnels (LANZA, 2007). In underground habitats, some studies have shown an age-related spatial segregation, with juvenile salamanders more present in the external sectors, while the adults disperse in the inner parts of the caves (SALVIDIO & PASTORINO, 2002; FICETOLA *et al.*, 2013; SALVIDIO *et al.*, 2020). Researchers have provided various explanations for this arrangement: e.g., prey distribution, social processes, microhabitat selection, but none fully explained the causes of this evident spatial segregation (SALVIDIO & PASTORINO, 2002; FICETOLA *et al.*, 2013). Here we investigated the spatial distribution and age-class segregation of *S. strinatii* on the forest floor, and the effect of environmental features on local abundance and surface activity.

MATERIALS AND METHODS

We selected three sampling sites between the Liguria and Piemonte regions, included within the same mountain massif (Mount Antola), and placed 26 to 57 permanent square plots (30 m^2 each – 5.5 m side) in each site, following a systematic random positioning, with a minimum distance of 20 m from each other, according to a meta-population design (i.e. the individual observations are replicated in space and time; ROYLE, 2004), obtaining a total of 111 plots. We counted adults and juveniles of *S. strinatii* at all sites during three repeated surveys in a short period, and considered as juveniles all individuals measuring less than 55 mm SVL and showing no sexual characters, while we considered all remaining as adults (SALVIDIO, 1993; FICETOLA *et al.*, 2013). We sampled the same plots during autumn 2017 and spring 2018. Using a digital soil moisture meter, we measured the average soil moisture retention for each plot (*MOIST*). From a Digital Elevation Model, we calculated two covariates: the duration of direct insolation (*INSOL*), expressed in hours and not taking into account the tree cover, and the Topographic Position Index (*TPI*), representing landforms such as hilltops or depressions. For each sampling session, we recorded the day of the year (*DAY*), the air temperature of the survey (*TEMP*) and the cumulated rain in the 72 hours prior to sampling (*RAIN*) from local weather stations. We then employed count data to model co-abundance of adults and juveniles, using a two-species N-mixture model with directional interactions (Brodie *et al.*, 2018). N-mixture models estimate latent abundance state N at site i (N_i), assuming $N_i \sim Poisson(\lambda)$, where λ is the expected abundance per sample unit, by using repeated counts C at site i during survey j (C_{ij}) to estimate individual detection probability p, assuming $C_{ij}|N_i \sim Binomial(N_i, p)$. We modelled the detection process of both adults and juveniles as follows:

$$logit(p_{ij}) = \alpha_0 + \alpha_1 * day_{ij} + \alpha_2 * temp_{ij} + \alpha_3 * rain_{ij} + \text{™}_{ij}$$

where α_0 is the intercept, α_1- α_3 are covariate effects and ™ is a random effect, assuming normal distribution. For the abundance of adults and juveniles we built the following models:

$$log\,(\lambda^A_i) = \beta^A_0 + \beta^A_1 * moist_i + \beta^A_2 * insol_i + \beta^A_3 * tpi_i + \sum_i$$

$$log\,(\lambda^J_i) = \beta^J_0 + \beta^J_1 * moist_i + \beta^J_2 * insol_i + \beta^J_3 * tpi_i + \gamma_0 * n^A_i + \gamma_1 * moist_i * n^A_i + \gamma_2 * insol_i * n^A_i + \gamma_3 * tpi_i * n^A_i + \sum_i$$

where the superscripts A and J stand for adults and juveniles, respectively, β_0 is the intercept, β_1- β_3 are covariate effects, N^A_i is the latent abundance of adults at site i, γ_0 is the co-abundance effect of adults on juveniles, $\gamma_{1-}\ \gamma_3$ are covariate effects on the relationships between juveniles' abundance and environmental features and $\sum$ is a site-level random effect. Capture permits were issued by Italian Ministry of Environment (13862/PNM/2016; 8453/T-A31/2017).

Results and Discussion

In autumn we detected a total of 340 salamanders, of which 278 are adults and 62 juveniles. In spring, we met a total of 395 salamanders: 248 adults and 147 juveniles. The estimated abundance of adults per-site was slightly higher in autumn ($\lambda = 1.68$) than in spring ($\lambda = 1.24$), while juvenile the abundance was lower than that of adults, in both seasons ($\lambda = 1.07$ and 0.56 for autumn and spring, respectively). *MOIST* had a significant positive effect on local abundance of both age-classes. *TPI* had a significant negative effect on the abundance of adults. Detection probability for adults remained almost constant ($p = 0.27$ and 0.31 for autumn and spring, respectively), increasing from autumn to spring for juveniles ($p = 0.13$ and 0.33 for autumn and spring, respectively). In autumn, all covariates included in the detection model of adults had a significant effect. For what concerns juveniles, in the same season, only *TEMP* and *RAIN* had a significant positive effect on p. During spring, all detection covariates on the adult model remained significant, but *DAY* and *TEMP* shifted their effect on *p.* In spring only one covariate showed a significant effect on juveniles' detection probability: *RAIN* had a positive effect on *p*. Finally, the term co-abundance effect ($\gamma 0$) was not significant in both seasons, indicating a lack of spatial segregation and an absence of relationship between adults and juveniles' abundance.

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