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OCCURRENCE OF THE BLACK LACE-WEAVER SPIDER, *AMAUROBIUS FEROX*, IN CAVES

POJAVLJANJE PAJKA *AMAUROBIUS FEROX* *V JAMAH*

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Abstract UDC 595.44:551.435.84

Enrico Lunghi; Occurrence of the Black lace-weaver spider,* Amaurobius ferox*, in caves

Subterranean habitats house a wide range of species which show a number of adaptations to prevailing ecological conditions. Spiders are among the most abundant predators in caves; however, most studies on cave spiders focus on species adapted to these habitats. This is the first study related to the occurrence of the Black lace-weaver spider, *Amaurobius ferox*, in caves. The species lacks adaptations to the subterranean habitats and has been observed within meters from the cave entrance all year round, except in late winter until early spring. Furthermore, its occupancy is positively related to the presence of other three cave-dwelling spiders: *Metellina merianae*, *Meta menardi* and *Tegenaria* sp.

Key words: Arachnids, biospeleology, Italy, occupancy, subterranean habitat.

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Enrico Lunghi: Pojavljanje pajka* Amaurobius ferox *v jamah

V različnih podzemnih habitatih živijo številne živalske vrste, ki so bolj ali manj prilagojene na razmere tamkajšnjega okolja. V jamah so pajki med najštevilčnejšimi plenilci, a večina študij je omejenih na tiste vrste, ki so že izrazito prilagojene na podzemlje. Pajek *Amaurobius ferox* ne sodi mednje, v študiji pa je obravnavano njegovo pojavljanje vzdolž jam. Ta površinska vrsta se pojavlja le v vhodih delih jam v vseh letnih časih, z izjemo pozne zime do začetka pomladi. Njeno pojavljanje v teh delih je povezano s prisotnostjo treh v jamah prebivajočih vrst, in sicer pajkov *Metellina merianae*, *Meta menardi* in *Tegenaria* sp.

Ključne besede: pajkovci, biospeleologija, Italija, zasedenost, podzemni habitat.

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INTRODUCTION

Subterranean environments (from the deep karst system to the Milieu Souterrain Superficiel) hold particular ecological conditions which frequently promote specific adaptations in the resident species (Culver & Pipan 2015; Ficetola *et al.* 2019; Mammola 2019). These conditions include the constant darkness, high microclimatic stability and food paucity (Culver & Pipan 2019). The most studied subterranean habitats are caves (i.e., the large voids suitable for human exploration; Mammola 2019); therefore, the majority of studies on subterranean species deals with species found in caves. Cave-dwelling species are generally subdivided into three main categories according to their degree of adaptation and the ability to complete their lifecycle in subterranean habitats (Howarth & Moldovan 2018; Mammola 2019). Troglobionts are obligate cave-species which show strong adaptations to subterranean life, such as depigmentation, anophthalmia and elongation of appendages; they can only reproduce successfully in subterranean habitats. Troglophiles are facultative cave-dwelling species which can successfully reproduce in both hypogean and epigean environments and may show some specific adaptations. Trogloxenes are occasional visitors in caves and do not reproduce there; they do not show any specific adaptations.

Spiders are among the most abundant predators in caves (Mammola & Isaia 2017). Numerous studies have been performed on cave spiders in recent years (Novak *et al.* 2010; Carver *et al.* 2016; Mammola & Isaia 2016; Lipovšek *et al.* 2018). However, these studies largely focus on species dependant on cave habitats and poorly adapted species are frequently overlooked. Non-obligate cave species can play an important role for the entire ecosystem, as they are often major drivers of allochthonous organic matter; e.g., many bats and crickets come back to the caves after foraging outside, and provide valuable organic matter to local communities through their guano, dead bodies or eggs (Ferreira & Martins 1999; Lavoie *et al.* 2007). More thorough studies on species previously thought to be accidental occurrences have demonstrated that these species actively select subterranean habitats with specific environmental features (Lunghi *et al.* 2014, 2017, 2018), making them important to the local ecosystem.

This is the first study related to the occurrence of the Black lace-weaver spider, *Amaurobius ferox* (Amaurobiidae), in caves (Fig. 1A). This species often occurs within meters from the cave entrance (Mammola *et al.* 2018) and shows a peculiar behaviour which may work as exaptation to subterranean habitats (Hesselberg *et al.* 2019a). After the hatching of spiderlings their mother offers herself as food which is an extreme behaviour (known as matriphagy) useful in habitats with limited food availability (Kim & Horel 1998; Kim 2009). This study contributes to improving the scant knowledge on *A. ferox* ecology.

Fig. 1: Amaurobious ferox *(A) and the other three cave spiders considered in this study:* Metellina merianae (Tetragnathidae) *(B);* Meta menardi (Tetragnathidae) *(C); cf.* Tegenaria sp. (Agelenidae) *(D) (Photo: E. Lunghi).*

METHODS

DATA COLLECTION

During the 2013, 16 caves located in the North of Tuscany (Central Italy, between 43° 52′ 42″ N, 11° 07′ 18″ E and 43° 59′ 51″ N, 10° 13′ 48″ E; altitudinal range 91–948 m a.s.l.) were surveyed monthly: this included 12 natural caves, 3 semi-natural caves (i.e., artificially enlarged natural caves) and one drainage tunnel. Surveyed caves were distributed across the Apennines: Apuan Alps (4), Monti della Calvana (8) and Appennino pistoiese (4). Most of the caves were located in forested areas, while two caves and the drainage tunnel were located between forested and urbanized areas. Each cave was surveyed as deep as possible (average explored length around 24 m, range 6–60 m). Starting from the main entrance, the monitored caves were divided into 3-meter long sectors to perform fine-scale data collection (Lunghi *et al.* 2020). Within each cave sector the following abiotic features were recorded: sector width and height (using a tape meter), average wall irregularity (i.e., presence of protuberances on the cave walls), air temperature (°C) and relative humidity (%) using a Lafayette TDP92 thermo-hygrometer (accuracy: 0.1 °C and 0.1% RH) and average illuminance using a Velleman DVM1300 light meter (minimum recordable illuminance: 0.1 lx). Wall irregularity was estimated by flattening a one meter string on the cave walls to trace their shape; then, with a tape meter, the linear distance between the two extremities of the string was measured (details in Lunghi *et al.* 2014). Within each cave sector, the presence and abundance of *Amaurobius ferox,* on both cave walls and ceiling were assessed by Visual Encounter Survey (VES) (Crump & Scott 1994) adopting a standardized survey effort of 7.5 min/sector to control imperfect species detection (Banks-Leite *et al.* 2014; Lunghi 2018). For additional information on the dataset and sampling methodology refer to Lunghi *et al.* (2017).

STATISTICAL ANALYSES

Data was checked for potential outliers and collinearity between microclimatic covariates prior to analysis (Zuur *et al.* 2010). The presence of outliers was assessed by plotting the data (boxplots). Relative humidity and illuminance had a series of outliers and thus, to improve the linearity of the data, they were angular-transformed and log-transformed, respectively. Correlation between microclimatic variables was low (pairwise Pearson's $r < 0.48$), therefore all variables were included in analysis. Generalized Linear Mixed Models (GLMM) assuming binomial error were used to assess the relationship between the occurrence of *A. ferox* with the environmental features and the occurrence of the three syntopic spider species *Metellina merianae*, *Meta menardi* and *Tegenaria* sp. (Figs. 1B-D) (R packages lme4, MASS, MuMIn; Venables & Ripley 2002; Douglas *et al.* 2015; Bartoń 2016; R Development Core Team 2018). These species are regularly found on the cave walls and ceiling in the cave entrance and twilight zones (Mammola & Isaia 2017; Hesselberg & Simonsen 2019). The presence/absence of *A. ferox* was used as a dependent variable, while the sector morphological (height, width and wall heterogeneity) and microclimatic features (temperature, humidity and illuminance), along with the presence/absence of the other three syntopic spider species were used as independent variables. As multiple surveys were conducted and the time of survey varied, the month of survey along with the cave and sector identity were used as random factors. Models were built using all possible combinations of the independent variables. Models were then ranked following the Akaike's Information Criterion corrected for small sample size (AICc) (Fang 2011). The model with the lowest AICc value was considered the best; nested models and those representing complex versions with higher AICc values than the simpler were not considered as potential candidates (Richards *et al.* 2011). The likelihood ratio test was used to assess the significance of variables included in the best AICc model.

RESULTS

The presence of *Amaurobius ferox* within cave sectors was assessed 44 times in 10 caves. Only one individual per cave sector was observed; thus, presence data also corresponds to observed abundance. Spiders were observed every month, except in February, March and April, and always within the first 6 cave sectors (up to 18 m from the cave entrance). The mean (± SD), min and max values of each feature related to the occupied cave sectors were the following: width, 1.27 ± 1.17 (0.76–8.20) m, height, 2.20 ± 0.83 (0.60–3.25) m, wall irregularity 0.84 ± 0.12 (0.60–0.98), temperature 14.3 ± 4.1 (4–20.2) °C, humidity 86.5 ± 5.8 (68–95.7) %, illuminance 6.5 ± 11.6 (0–51.9) lx.

The best AICc model included sector width, temperature, illuminance and the presence of all the three syntopic spider species while the second best model

Tab. 1: The best five models based on AICc relating the presence of Amaurobius ferox *in caves. Its occurrence was considered as dependent variable. Independent variables were: average wall heterogeneity (Het), humidity (Humid), Height and Width of sectors, means of illuminance (Lx), temperature (Temp), and presence/absence of* Metellina merianae, Meta menardi *and* Tegenaria sp. *Empty cells indicate that the variable is not included into the relative model. Best model is shown in bold.*

Independent variables included into the model									df	AICc	ΔAICc	Weight
Het	Humid	Height	Width	Lx	Temp	*M. merianae*	*M. menardi*	*Tegenaria*				
			-0.33	**0.29**	**0.16**	**1.29**	**0.96**	**1.48**	**9**	**278.6**	**0**	**0.082**
				0.29	0.15	1.30	0.97	1.52	8	278.7	0.08	0.079
	3.38			0.32	0.19	1.28	1.01	1.60	9	279.3	0.75	0.056
	3.16		-0.32	0.32	0.19	1.27	0.96	1.58	10	279.4	0.84	0.054
		0.14	-0.38	0.27	0.16	1.30	0.98	1.49	10	280.1	1.50	0.039

(ΔAICc = 0.08) included the same variables but not the sector width (Tab. 1).The presence of *A. ferox* was positively related to illuminance (β = 0.29, χ^2 = 5.62, *P* = 0.018) and to the presence of the three syntopic spider species (*Metellina merianae*, β = 1.29, χ^2 = 7.73, *P* = 0.005; *Meta menardi*, β = 0.96, χ^2 = 3.86, *P* = 0.05; *Tegenaria* sp., β = 1.48, χ^2 = 9.98, *P* = 0.002); no significant relationship was detected for temperature (β = 0.16, χ^2 = 3.51, *P* = 0.061) and sector width (β = -0.33, χ^2 = 2.10, *P* = 0.147).

DISCUSSION

Amaurobius ferox most likely inhabits caves all year round, selecting specific habitats close to the cave entrance. The lack of species observations during the first part of the year (February-April) may reflect the period in which this spider overwinters inside cave wall crevices. The best model showed that this species mostly inhabits the cave sectors close to the entrance, characterized by higher illuminance and by the presence of all the three syntopic spider species: *Metellina merianae*, *Meta menardi* and *Tegenaria* sp. The difference between the first and the second best model was small (ΔAICc = 0.08), and showed similar results. The only difference between these two models was the inclusion of sector width in the former model; however, this variable was not significant. The inhabited cave sectors by *A. ferox* were those close to the cave entrance, where ecological conditions are most similar to those on the surface (Lunghi *et al.* 2015), and where prey diversity and abundance is higher (Manenti *et al.* 2015; Lunghi *et al.* 2017). Considering the lack of specific adaptations to cope with darkness, *A. ferox* may need to inhabit more illuminated habitats to successfully detect and catch prey using visual cues (Uiblein *et al.* 1992). Furthermore, higher prey abundance may help females to collect sufficient resources for reproduction, which may not be achieved deeper inside caves (Kim & Roland 2000; Kim 2009).

Amaurobius ferox tended to occupy cave sectors in which the other syntopic spiders were present. While *Metellina merianae* and *Tegenaria* spiders distributions are mostly related to the cave entrance (Lunghi *et al.* 2017; Hesselberg & Simonsen 2019), *M. menardi* is often found also throughout the twilight zone (Lunghi *et al.* 2017; Hesselberg *et al.* 2019a). The weak correlation between *A. ferox* and *M. menardi* might be attributed to different ecological requirements in these two species, as the latter occupies deeper cave sectors (Mammola & Isaia 2014; Lunghi *et al.* 2017; Hesselberg *et al.* 2019b). The three syntopic cave spiders are better adapted to subterranean habitats and are usually more abundant than *A. ferox*. Further studies are needed to clarify both coexistence and potential competition of these species.

Although limited, observations reported here provide the first information on the use of caves by the spider *A. ferox*, a spider that regularly inhabits sectors close to the cave entrance. Future studies will strengthen these results and elucidate the importance of this species for the subterranean habitat.

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