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Article *in* Fragmenta Entomologica · July 2023

DOI: 10.13133/2284-4880/1510

Sapienza Università Editrice

E-ISSN 2284-4880
ISSN 0429-288X

Fragmenta entomologica, 55 (1): 37– 44 (2023)

Research article
Submitted: January 20th, 2023 – *Accepted*: May 30th, 2023 – *Published*: June 30th, 2023
DOI: 10.13133/2284-4880/1510

Distribution and bioclimatic suitability of *Duvalius hartigi*, subterranean beetle from the lava caves of Mount Etna (Coleoptera: Carabidae, Trechinae)

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Abstract
Beetles of the genus *Duvalius* are widely distributed in subterranean habitats across the Palearctic, from SW Europe in the West to central Asia and China in the East. The genus is also recorded from Sicily, where nine species are currently known. *Duvalius hartigi* was described in 2006 on material collected in lava caves of Mount Etna and since then no one has ever reported new data about this species. During the years 2020-2022, we conducted a thorough field search in lava caves on Mount Etna, aiming at unraveling the occurrence of new populations. Our work led to the discovery of twenty-two new occurrences, which in turn, allowed us to perform species distribution modeling (SDM) and to explore the bioclimatic suitability of the species, especially in light of future targeted conservation strategies. The species covers a relatively wide altitudinal and thermic range, being found in lava caves from 615 to 1840 meters a.s.l., with temperatures ranging from 3.48 to 14.80°C. According to the SDM results, the suitable area for the species ranges between 500 and 2200 meters a.s.l. with preference for colder and wetter sites, irrespectively to slope orientation. The relatively wide bioclimatic tolerance that we recovered for *D. hartigi* possibly reflects a high ecological plasticity, representing a stimulating topic for further studies.

Keywords: Cave-dwelling beetle, conservation, endemic species, lava tubes, subterranean habitats.

Introduction

Sicily is the largest Italian region and island in the Mediterranean Sea. Due to its biogeographic and human history, climatic diversity and complex geological constitution in which carbonate, evaporite and volcanic terrains coexist simultaneously (Panzica La Manna 1993), the island hosts a great diversity, both from the biological and the geological point of view. Within this frame, the Etna area stands out in Italy and in Europe for its great naturalistic value.

More than 200 volcanic caves are known to open on the slopes of Mount Etna (Centro Speleologico Etneo 1999), being characterized by different ages of formation, from those arising together with the volcano (>30000 years ago) to the ones formed during very recent eruptions.

Although systematic investigations have been conducted by zoologists of the University of Catania (e.g. Caruso 1982), knowledge about volcanic subterranean environments are rather scarce, especially concerning biospeleology.

The genus *Duvalius* Delarouzée, 1859 is widely distributed in the Palearctic, ranging from Spain, to Algeria and France in the West to central Asia and China in the East (Moravac et al. 2003). The genus underwent a remarkable subterranean adaptive radiation in the Palearctic and extant species exhibit narrow distributions. The genus is widely diversified in the Alpine region, where a complex scenario of multiple colonisations of subterranean environments at different geological periods and through different processes has been recently demonstrated (Faille et al. 2013).

The genus is also recorded from Sicily with nine species described, so far belonging to three different lineages (species-groups), named after the three most representative species: *siculus, silvestrii* (sensu Magrini 1997, 1998) and *aliciae* (sensu Magrini et al. 2007) (Table 1).

Table 1 – List of the species of *Duvalius* beetle currently known for Sicily and their known current distribution range. Information on type localities and distribution are derived from Magrini et al. 2006, 2007, 2008, 2010, 2019 and Vanni et al. 1992.

Species	Distribution	Group
Duvalius adelphus Magrini, Petrioli, Degiovanni & Bastianini, 2008	Type locality only: Grotta del Garrone (SIPA160), Monte Pizzuta, Piana degli Albanesi (PA)	*silvestrii*
Duvalius aliciae Magrini, Baviera & Petrioli, 2007	Type locality only: Grotta del Sughero, Riserva Naturale Orientata “Zingaro”, Scopello, Castellammare del Golfo (TP)	*aliciae*
Duvalius hartigi Magrini, Baviera & Vigna Taglianti, 2006	Two lava caves of Mount Etna	*siculus*
Duvalius marii Vanni, Magrini & Pennisi, 1992	Ficuzza (PA)	*siculus*
Duvalius petriolii Magrini, Baviera & Vigna Taglianti, 2006	Type locality only: Torre Montaspro, Piano degli Zucchi, Isnello (PA)	*siculusw*
Duvalius ribaudoi Magrini, Petrioli & Degiovanni, 2010	Type locality only: Grotta del Garrone (SIPA160), Monte Pizzuta, Piana degli Albanesi (PA)	*silvestrii*
Duvalius silvestrii (Gestro, 1896)	Type locality only: Grotta dei Panni, Santa Ninfa (TP)	*silvestrii*
Duvalius siculus (Baudi di Selve, 1882)	Gratteri and Isnello, Madonie Mountains (PA)	*siculus*
Duvalius patronitii Magrini, Benelli, Petrioli & Degiovanni, 2019	Type locality only: Grotta del Lauro, Nebrodi Mountains, Alcara Li Fusi (ME)	*siculus*

All Sicilian species exhibit extremely narrow ranges of distribution and for most of them, the distribution is represented uniquely by the type locality.

The occurrence of beetles of the genus *Duvalius* on Mount Etna has been known since the 1950’s, after an anonymous note (Anonymous 1951) on the basis of material collected by F. Hartig. This anonymous record was then resumed by Vigna Taglianti 1982; Caruso 1982; Vanni et al. 1992; Vanni & Magrini 1995; Magrini 1998, but only the finding of a male in “Grotta dei Ladroni” (1585 m) on the northeast slope of Mount Etna allowed the description of *Duvalius hartigi* Magrini, Baviera & Vigna Taglianti 2006, named after the original collector. The species was subsequently discovered in the “Grotta Piano Porcaria”, 4.5 km as the crow flies from the type locality (Bucolo & Musumeci 2015).

In this work we aim at increasing knowledge about the distribution of *Duvalius hartigi* on Mount Etna based on original data gathered in recent years. On this basis, we aim at identifying the potential bioclimatic range of the species by means of species distribution models (SDMs), in order to provide suggestions for targeted conservation strategies for this species.

Material and methods

Study area

Mount Etna is a stratovolcano of over 3,330 m altitude formed at the beginning of the Quaternary in the northeastern part of Sicily (Rittman 1976). It was declared in 2013 UNESCO World Heritage Site. The volcano has a total area of approximately 2,100 km^2 which is entirely protected under the authority of “Parco dell’Etna” (EUAP0227).

The landscape is characterized by lava flows of different ages, varying from the very recent 2014/2015 flow to the ca 500,000 yr-old tholeitic basalts of a small area on the lower part of the southern flank (Gillot et al. 1994; De Beni et al. 2011). Over 200 lava tubes have been censused on the slopes of the volcano (Centro Speleologico Etneo 1999). Although lava tubes are normally associated with *pahoehoe* lavas, on Mount Etna they also formed in *`a`a* flows (see e.g., Calvari 1999). Opening at different altitudes and in substrates of different ages and composition, lava tubes on Mount Etna exhibit an extremely diversified range of ecological and microclimatic conditions.

Sampling

Field activities have been conducted during the years 2020-2022 in 25 different volcanic caves, ranging from 615 to 1718 meters a.s.l. Caves, mostly horizontal lava tubes of different lengths, were selected among the most accessible and with lower risk (Fig. 1a).

We used pitfall traps consisting of a 500-ml stacked glass container 10 cm high and 10 cm diameter (Fig. 1b). Traps were baited with meat and crushed bones. At each site, one pitfall trap was placed near the entrance, a second one in the innermost section. They were replaced approximately every six months, from summer 2020 to winter 2022.

All collected material was preserved in 70% ethanol and sorted in the laboratory. Identification of *Duvalius* beetles (Fig. 1c) were based on morphological characters. Specimens are stored in P.M. Giachino and P. Magrini personal collections.

Cave air temperature was measured using iButton dataloggers at each sampling site. Lava ages were obtained from Etna Volcano's Geological map (1:50,000 scale) (Branca et al. 2011).

Species Distribution Models (SDM)

The current distribution of *Duvalius hartigi* was modeled in the study area using 19 bioclimatic variables and elevation data to represent current climatic conditions (1950–2000; Hijmans et al. 2005; resolution: 30''; available at: www.worldclim.org). The modeling procedure was carried out in the R 4.2.1 statistical programming environment (R Core Team 2021). We used the maximum entropy model (Maxent version 3.4.3; Phillips et al. 2006); http://www.cs.princeton.edu/wschapire/maxent/) for presence-only data implemented in the 'sdm' package (Naimi & Araújo 2016). Collinearity among bioclimatic layers was reduced by performing a variance inflation factor analysis (VIF) (Marquardt 1970) with the vif function of the 'usdm' package (Naimi 2015). After checking for collinearity, we reduced the set of environmental variables to 5 (BIO04: Temperature Seasonality; BIO07: Temperature Annual Range; BIO16: Precipitation of Wettest Quarter; BIO18: Precipitation of Warmest Quarter; BIO19: Precipitation of Coldest Quarter). Models' validations were performed by using the bootstrapping replication approach with the 'sdm' package developed by Naimi & Araújo (2016). In order to get independent validation statistics, 70% of the collected data was used to train models while 30% was used for validation. We used the area under the Receiving Operator Curve (AUC) to evaluate model performance.

Results

The inferred distribution range of *Duvalius hartigi* is presented in Fig. 2 and detailed in Tab. 2. Our work led to the discovery of twenty-two new occurrences, twenty of them included within Mount Etna Natural Park and only two ("Grotta Forcato" and "Grotta Ampudda di Pisciteddu")

Table 2 – Occurrences of *Duvalius hartigi* on Mount Etna with details on sampling sites. CT is the acronym of the province of Catania.

Locality [cadastral number]	**Municipality (Province)**	**Annual Mean T (°C)**	**Elevation (m a.s.l.)**	**Substrate Age (yrs.)**
Grotta Lunga (di Monpeloso) [SICT1029]	Nicolosi (CT)	NA	820	1721
Grotta di Monte Cicirello [SICT1156]	Trecastagni (CT)	12.62	990	1171
Grotta della Catanese I [SICT1037]	Ragalna (CT)	6.05	905	2521
Grotta di Piano Porcaria [SICT1101]	Linguaglossa (CT)	11.04	1099	>3000
Grotta Forcato [SICT1013]	Mascali (CT)	11.23	670	1001
Grotta del Porcospino [SICT1033]	Linguaglossa (CT)	11.18	982	1321
Grotta di Mezzasciara [NA]	Belpasso (CT)	10.9	776	1021
Grotta del Santo (di San Nicola) [SICT1032]	Adrano (CT)	12.82	1041	>9000
Grotta di Monte Intralio [SICT1007]	Adrano (CT)	5.44	1370	821
Grotta della Neve (dei Ladri) [SICT1117]	Sant'Alfio (CT)	5.5	1558	>9000
Grotta di Monte Corruccio [SICT1056]	Castiglione di Sicilia (CT)	6.49	1389	841
Grotta dei Lamponi [SICT1019]	Castiglione di Sicilia (CT)	3.48	1718	397
Grotta Piano Cavoli [NA]	Castiglione di Sicilia (CT)	8.19	1205	>9000
Grotta delle Femmine [SICT1046]	Castiglione di Sicilia (CT)	8.97	1610	>3000
Grotta del Gallo Bianco I [SICT1193]	Adrano (CT)	6.17	1476	1071
Grotta dell'Immacolata [SICT1244]	Ragalna (CT)	10.69	1455	>3000
Grotta di Monte Arcimis [SICT1031]	Zafferana Etnea (CT)	NA	1164	228
Riconco di Liricio [SICT1192]	Castiglione di Sicilia (CT)	NA	976	>5000
Grotta di Rognone [SICT1018]	Biancavilla (CT)	14.82	935	>30000
Grotta Ampudda di Pisciteddu [SICT1146]	Belpasso (CT)	13.25	615	352
Grotta di Serracozzo I [SICT1065]	Milo (CT)	5.35	1840	50
Grotta dei Rotoli [SICT1239]	Linguaglossa (CT)	8.53	1488	156
Grotta di Monte Dolce [SICT1110]	Castiglione di Sicilia (CT)	8.17	847	>5000
Grotta del Burrò [SICT1024]	Randazzo (CT)	NA	1225	>3000

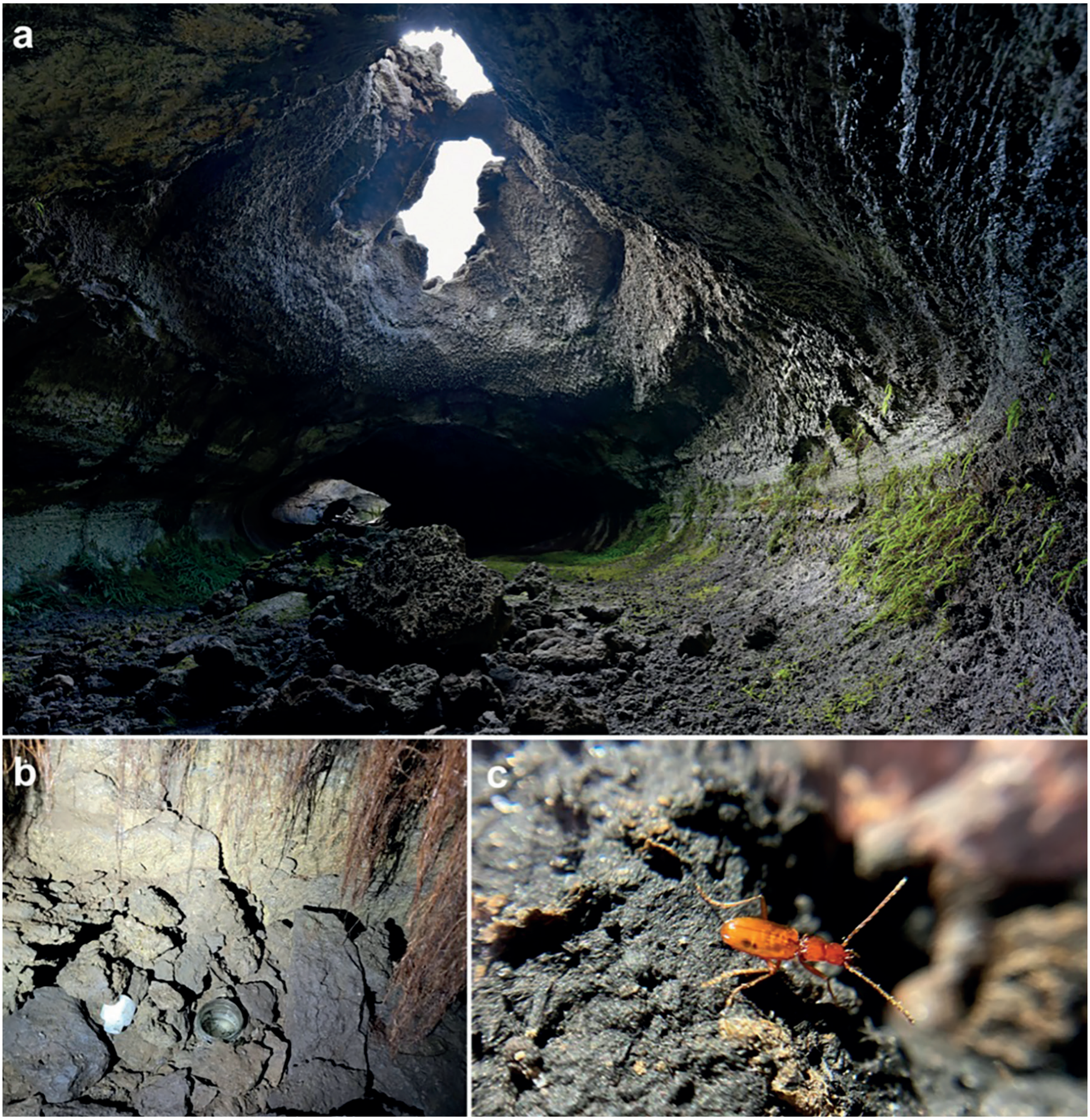

Fig. 1 – a, The sampling site "Grotta dei Lamponi", a lava cave formed during the 1614/24 eruption at 1718 m a.s.l.. Photo: F. Fiorenza; **b**, Pitfall trap placed on the cave floor of "Grotta di Piano Porcaria". Photo: G. Nicolosi; **c**, Specimen of *Duvalius hartigi* on the cave floor of "Grotta del Burrò". Photo: M. Isaia.

falling outside the borders of the Natural Park. Only at one locality the species was visible during the sampling, at all other sites, specimens were collected via pitfall traps only.

Material

All collected in pitfall traps except specified.
***Duvalius hartigi* Magrini, Baviera & Vigna Taglianti 2006** (Fig. 1c)

Italy: Sicily, Belpasso, Grotta Ampudda di Piscit-eddu [SICT1146], Catania province (37.604258N, 14.998219E), 615 m, 21 Jul 2022, Nicolosi leg., 1 ♂; Sicily, Parco dell'Etna, Castiglione di Sicilia, Grotta dei Lamponi [SICT1019], Catania province (37.819444N, 15.011389E), 1718 m, 20 Jul 2021, Nicolosi leg., 2 ♂; same locality, 04 Jan 2022, Nicolosi leg., 3 ♂; same locality, 10 Aug 2022, Nicolosi leg., 47 ♂; Sicily, Parco dell'Etna, Linguaglossa, Grotta dei Rotoli [SICT1239], Catania province (37.789333N, 15.076778E), 1488 m, 28 Aug 2020, Nicolosi leg., 1 ♀, 18 ♂; same locality, 08 Jun 2022, Nicolosi leg., 1 ♂; same locality, 06 Jan 2022, Nicolosi leg., 1 ♂; same locality, 13 Aug 2022, Nicolosi leg., 4 ♂; Sicily, Parco dell'Etna, Randazzo, Grotta del Burrò [SICT1024], Catania province (37.826667N, 14.934583E), 1225 m, 16 Jul 2021, among debris on the cave floor, Nicolosi & Isaia leg., 4 ♂; Sicily, Parco dell'Etna, Linguaglossa, Grotta del Porcospino [SICT1033], Catania province (37.798333N, 15.118E), 982 m, 22 Aug 2020, Nicolosi leg., 1 ♂; same locality, 26 Dec 2021, Nicolosi leg., 4 ♂; same locality, 28 Jul 2022, Nicolosi leg., 5 ♂; Sicily, Parco dell'Etna, Adrano, Grotta del Santo (di San Nicola) [SICT1032], Catania province (37.709182N, 14.875877E), 1041 m, 18 Jun 2021, Nicolosi leg., 6 ♂; same locality, 20 Jan 2022, Nicolosi leg., 1 ♀, 17 ♂; same locality, 02 Aug 2022, Nicolosi leg., 1 ♀, 19 ♂; Sicily, Parco dell'Etna, Ragalna, Grotta della Catanese I [SICT1037], Catania province (37.648333N, 14.939167E), 905 m, 18 Jun 2021, Nicolosi leg., 2 ♂; same locality, 14 Jan 2022, Nicolosi leg., 3 ♀, 38 ♂; same locality, 02 Aug 2022, Nicolosi leg., 5 ♀, 17 ♂; Sicily, Parco dell'Etna, Castiglione di Sicilia, Grotta delle Femmine [SICT1046], Catania province (37.825442N, 15.023594E), 1610 m, 10 Aug 2022, Nicolosi leg., 2 ♂; Sicily, Parco dell'Etna, Ragalna, Grotta dell'Immacolata [SICT1244], Catania province (37.6803N, 14.9588E), 1455 m, 20 Jan 2022, Nicolosi leg., 1 ♂; Sicily, Parco dell'Etna, Adrano, Grotta di Monte Intralio [SICT1007], Catania province (37.720278N, 14.909167E), 1370 m, 20 Jan 2022, Nicolosi leg., 9 ♂; Sicily, Belpasso, Grotta di Mezzasciara, Catania province (37.625447N, 14.963427E), 776 m, 14 Jan 2022, Nicolosi leg., 29 ♂; same locality, 21 Jul 2022, Nicolosi leg., 2 ♂; Sicily, Parco dell'Etna, Zafferana etnea, Grotta di Monte Arcìmis [SICT1031], Catania province (37.687778N, 15.069167E), 1164 m, 18 Jan 2022, Nicolosi leg., 3 ♂; Sicily, Parco dell'Etna, Trecastagni, Grotta di Monte Cicirello [SICT1156], Catania province (37.66979N, 15.07076E), 990 m, 29 Dec 2020, Nicolosi leg., 7 ♂; same locality, 14 Jan. 2022, Nicolosi leg., 1 ♀, 18 ♂; same locality, 21 Jul. 2022, Nicolosi leg., 12 ♂; Sicily, Parco dell'Etna, Castiglione di Sicilia, Grotta di Monte Corruccio [SICT1056], Catania province (37.810389N, 15.075167E), 1389 m, 28 Aug 2020, Nicolosi leg., 2 ♂; same locality, 18 Dec 2020, Nicolosi leg., 3 ♂; same locality, 06 Jan 2022, Nicolosi leg., 1 ♀, 13 ♂; same locality, 22 Jul 2022, Nicolosi leg., 1 ♂; Sicily, Parco dell'Etna, Castiglione di Sicilia, Grotta di Monte Dolce [SICT1110], Catania province (37.853647N, 15.065006E), 847 m, 14 Jul 2021, Nicolosi leg., 1 ♂; Sicily, Parco dell'Etna, Linguaglossa, Grotta di Piano Porcaria [SICT1101], Catania province (37.797806N, 15.107889E), 1099 m, 23 Dec 2020, Nicolosi leg., 1 ♂; same locality, 28 Jul 2021, Nicolosi leg., 1 ♀, 3 ♂; same locality, 26 Dec 2021, Nicolosi leg., 3 ♀, 10 ♂; same

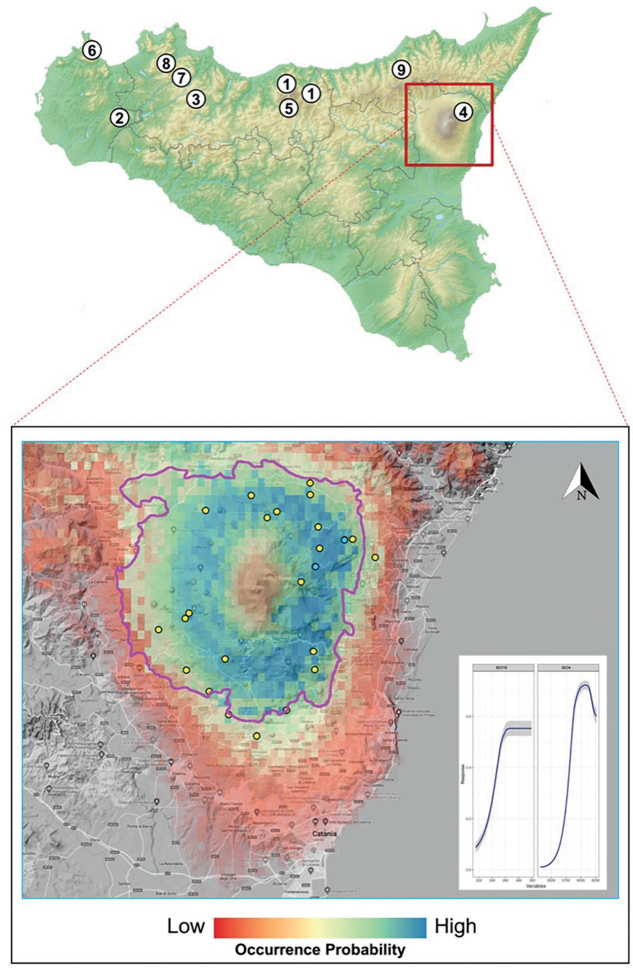

Fig. 2 – Distribution of *Duvalius* beetles in Sicily (above) and predicted current distribution for *Duvalius hartigi* on Mount Etna based on Maxent model. Species of Sicilian *Duvalius* are numbered in order of description year: **1** – *D. siculus*; 2 – *D. silvestrii*; 3 – *D. marii*; 4 – *D. hartigi*; 5 – *D. petriolii*; 6 – *D. aliciae*; 7 – *D. adelphus*; 8 – *D. ribaudoi*; 9 – *D. patronitii*. Blue circles represent literature data and yellow circles represents original data gathered in this work. The pink line represents the boundary of the Etna Park and the inset graph represents the relationships between environmental predictor variables (BIO16, BIO04) and the probability of occurrence of *D. hartigi*.

locality, 14 Aug 2022, Nicolosi leg., 2 ♂; Sicily, Parco dell'Etna, Biancavilla, Grotta di Rognone [SICT1018], Catania province (37.669275N, 14.910659E), 11 Aug 2022, Nicolosi leg., 1 ♂; Sicily, Parco dell'Etna, Milo, Grotta di Serracozzo I [SICT1065], Catania province (37.756278N, 15.05375E), 1840 m, 30 Dec 2020, Nicolosi leg., 1 ♀, 1 ♂; same locality, 08 Jun. 2021, Nicolosi leg., 2 ♂; same locality, 06 Jan. 2022, Nicolosi leg., 2 ♀, 1 ♂; Sicily, Mascali, Grotta Forcato [SICT1013], Catania province (37.780361N, 15.146333E), 670 m, 22 Aug 2020, Nicolosi leg., 6 ♂; same locality, 23 Dec 2020, Nicolosi leg., 5 ♂; same locality, 21 Jan 2022, Nicolosi leg., 3 ♂; same locality, 13 Aug. 2022, Nicolosi leg., 2 ♂; Sicily, Adrano, Grotta Gallo Bianco I [SICT1193], Catania province (37.72555N, 14.91396E), 1476 m, 20

Jan 2022, Nicolosi leg., 12 ♂; same locality, 06 Aug. 2022, Nicolosi leg., 5 ♂; Sicily, Parco dell'Etna, Nicolosi, Grotta Lunga (di Monpeloso) [SICT1029], Catania province (37.629734N, 15.035672E), 820 m, 26 Dec 2021, Nicolosi leg., 1 ♂; Sicily, Parco dell'Etna, Randazzo, Grotta Piano Cavoli, Catania province (37.841389N, 14.991389E), 1205 m, 06 Jan 2022, Nicolosi leg., 1 ♂; Sicily, Parco dell'Etna, Castiglione di Sicilia, Riconco di Liricio [SICT1192], Catania province (37.842122N, 15.065239E), 16 Jul 2021, Nicolosi leg., 4 ♂; same locality, 04 Jan 2022, Nicolosi leg., 5 ♂; same locality, 13 Aug. 2022, Nicolosi leg., 9 ♂.

Habitat preference

In all cases, specimens of *Duvalius hartigi* were collected in the deeper sections of the surveilled caves and never in the vicinity of the entrance. The species is either found in caves of recent and old formation and occurs along a relatively wide altitudinal range, from 615 ("Grotta Forcato") to 1840 m a.s.l. ("Grotta di Serracozzo") (mean ± SD = 1192 ± 342 m). When considering cave temperatures, occurrence sites range from 3.48 ("Grotta dei Lamponi") to 14.80°C ("Grotta di Rognone") (average 8.8 ± 3.1°C; N=22). Furthermore, the species is independently distributed with respect to substrate age, being found in caves of ancient and recent formation.

Species Distribution Modelling

The Maxent model for *Duvalius hartigi* provided an AUC value of 0.83 (±0.07). Temperature Seasonality (Bio04) was the most important contributing variable in the model (41.1%), followed by Precipitation of Wettest Quarter (Bio16) (34.8%). The suitable area for *D. hartigi* is recovered as a continuous circular belt encircling the top of the volcano, starting at approximately 500 meters a.s.l and reaching 2,200 m a.s.l. (Fig. 2).

Discussion

Subterranean habitats in Sicily are environments of great naturalistic value due to their great variety in terms of geological and biological diversity, holding species with high biogeographic significance (Sendra et al. 2019). Despite efforts to foster knowledge on the subterranean fauna living on the island (e.g., Caruso 1982; Sabella, 2019, 2020; D'Urso & Grasso 2009), many areas across the island remain unexplored.

The protection of subterranean ecosystems in Sicily has gained particular significance thanks to the enactment of Regional Laws 98/1981 and subsequent No. 14/1988 (Dimarca 2004). However, subterranean habitats and the fauna living therein are highly threatened by direct and indirect anthropogenic disturbances including land use intensification, agriculture, quarrying, urbanization and climate change, especially in terms of extremization of meteorological events (e.g., Di Maggio et al. 2012; Ferrante et al. 2018; Davis et al. 2020; Nicolosi et al. 2022).

When considering the general lack of biospeleological investigations in caves of Mount Etna, our contribution points out 22 new occurrences of *D. hartigi* in the area, increasing their number from 2 to 24 (Fig. 2; Tab. 2).

Our data show a wide distribution of *Duvalius hartigi*, with occurrences on all slopes of the volcano, spanning from 615 up to 1840 meters. Such a wide altitudinal range encompasses approximately 10°C of thermic range, proving the ability of this species to tolerate a relatively broad range of bioclimatic conditions. Similar results were recently obtained for the congeneric SW-Alpine species *D. carantii* Sella 1874 (Tolve et al. 2022), reflecting a high ecological plasticity for these species, which could also parallel the great morphological variability observed among individuals of the same species (Nicolosi et al., unpublished data).

Compared to previous works, *Duvalius hartigi* has been abundantly and consistently detected in the study area, with relatively high numbers of specimens collected (up to 47 specimens in Grotta dei Lamponi in August 2021). Abundance remained consistent through time, with no apparent declines in captures across the sampling period. Indeed, previous works were based on visual observations alone, which proved insufficient to detect its presence. Our success in documenting this species primarily relied on a watchful use of pitfall traps, suggesting that this species is particularly active in the subterranean habitats of Mount Etna and that lava caves only represent a small fraction of the overall habitat available to this species. Our results clearly exemplify the idea that hypogean arthropods find their natural habitat mainly in the narrow fissures of rocks and not in the underground spaces between the rocks accessible to man, such as caves (see Racovitza 1907, 1983, Racovitza and Serban 1983; Jeannel 1926, 1942, 1943; see Mammola et al. 2016 for a comprehensive review on the topic).

Based on presence data, we modeled the potential distribution of *D. hartigi* under current climatic conditions, aiming at identifying potential new localities within the predicted range. According to our results, the Temperature Seasonality (Bio04) and Precipitation of Wettest Quarter (Bio16) are the most important factors determining the bioclimatic suitability of *Duvalius hartigi* (Fig. 2, inset). More specifically, seasonality (i.e. an expression of the temperature change over the course of the year; O'Donnell & Ignizio 2012), shows a bell-shaped response, with higher suitability at intermediate-high values, thus encompassing areas at intermediate elevations. Moreover, the probability of occurrence increases in areas with higher precipitations in the wettest quarter, suggesting a higher preference for the most humid districts of the volcano. As obtained from the model prediction, the combination of these two variables defines a "*Duvalius hartigi*" belt (shaded blue in Fig. 2), providing a useful reference for targeted conservation strategies focusing on the lava caves opening in this area, which is highly subjected to anthropogenic pressure deriving from tourism and associated activities.

Acknowledgements – We thank the "Ente Parco dell'Etna" that authorized and allowed the carrying out of the scientific research activity in the Park. This research received support also by the University Research Program UNICT 2020-2022 line 2 - BINT (Biodiversityof Insecta, Nematoda and Tardigrada of Mediterranean Environments).

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