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

Article in Fragmenta Entomologica - July 2023
DOI: 10.13133/2284-4880/1510

CITATIONS
0

5 authors, including:

Giuseppe Nicolosi
Università degli Studi di Torino
34 PUBLICATIONS 144 CITATIONS

Giorgio Sabella
University of Catania
64 PUBLICATIONS 369 CITATIONS

Pier Mauro Giachino
WBA - World Biodiversity Association onlus
97 PUBLICATIONS 576 CITATIONS

Marco Isaia
Università degli Studi di Torino
234 PUBLICATIONS 3,254 CITATIONS

Some of the authors of this publication are also working on these related projects:

Systematics, Distribution and Ecology of Italian Spiders View project

SHOWCAVE: a multidisciplinary research project to study, classify and mitigate the environmental impact in tourist caves View project
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 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>
<thead>
<tr>
<th>Species</th>
<th>Distribution</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duvalius adelphae</td>
<td>Type locality only: Grotta del Garrone (SIPA160), Monte Pizzuta, Piana degli Albanesi (PA)</td>
<td>silvestrii</td>
</tr>
<tr>
<td>Duvalius aliciae</td>
<td>Type locality only: Grotta del Sughero, Riserva Naturale Orientata “Zingaro”, Scopello, Castellammare del Golfo (TP)</td>
<td>aliciae</td>
</tr>
<tr>
<td>Duvalius hartigi</td>
<td>Two lava caves of Mount Etna</td>
<td>siculus</td>
</tr>
<tr>
<td>Duvalius marii</td>
<td>Ficuzza (PA)</td>
<td>siculus</td>
</tr>
<tr>
<td>Duvalius petriolii</td>
<td>Type locality only: Torre Montaspro, Piano degli Zucchi, Isnello (PA)</td>
<td>siculusw</td>
</tr>
<tr>
<td>Duvalius ribaudoi</td>
<td>Type locality only: Grotta del Garrone (SIPA160), Monte Pizzuta, Piana degli Albanesi (PA)</td>
<td>silvestrii</td>
</tr>
<tr>
<td>Duvalius silvestrii (Gestro, 1896)</td>
<td>Type locality only: Grotta dei Panni, Santa Ninfa (TP)</td>
<td>silvestrii</td>
</tr>
<tr>
<td>Duvalius siculus (Baudi di Selve, 1882)</td>
<td>Gratteri and Isnello, Madonie Mountains (PA)</td>
<td>siculus</td>
</tr>
<tr>
<td>Duvalius patronitii</td>
<td>Type locality only: Grotta del Lauro, Nebrodi Mountains, Alcara Li Fusi (ME)</td>
<td>siculus</td>
</tr>
</tbody>
</table>

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 km² 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/~schapire/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.

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

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 Burro [SICT1024], Catania province (37.826667N, 14.934583E), 1225 m, 16 Jul 2021, among debris on the cave floor, Nicolosi & Isaià 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, Adriano, 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 Arcimis [SICT1031], Catania province (37.687778N, 15.069167E), 1164 m, 18 Jan 2022, Nicolosi leg., 3 ♂; Sicily, Parco dell’Etna, Trecastagni, Grotta di Monte Cicirrello [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 Corruck [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 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 Serracorno I [SICT1065], Catania province (37.756278N, 15.053755E), 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 Forcatu [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, Adriano, Grotta Gallo Bianco I [SICT1193], Catania province (37.72555N, 14.91396E), 1476 m, 2021.
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...
Distribution and bioclimatic suitability of Duvalius hartigi

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 (Biodiversity of Insecta, Nematoda and Tardigrada of Mediterranean Environments).

References


Magrini P., Benelli A., Petrioli A., Degiovanis A. 2019. Un nuovo Duvalius ipogeò della Sicilia nord-orientale (Coleoptera,