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Rediscovery of the enigmatic solifuges (Arachnida: Solifugae) at Lampedusa Island (Italy)

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Abstract

Solifuges were recorded in Italy for the first time in 1956, on the island of Lampedusa (Strait of Sicily), and classified as *Biton ehrenbergi* Karsch, 1880 and *Biton velox* Simon, 1885. More than 60 years later, we carried out the first targeted investigation of these little-known animals. A survey conducted during both spring and autumn 2017 confirmed the presence of solifuges on Lampedusa Island. We identified all specimens as *B. velox* and not *B. ehrenbergi*. We concluded that *B. ehrenbergi* is absent from the island, on the basis of both newly collected data and a re-evaluation of the past records. Morphology and taxonomic position of the examined specimens are discussed in light of the unresolved state within the family Daesiidae Kraepelin 1899. Fifteen potentially suitable habitats were investigated across the entire island during 240 transects with standardised time-constrained searches (TCSs) of 30 minutes each. The survey documented a current habitat specificity of the solifuge population, as they were recorded only in the south-eastern coasts, where the local phrygana association, rich in endemic plant species, is still intact.

Keywords: *Arachnida*, *Biton*, *Daesiidae*, *habitat degradation*

Introduction

Solifuges (Solifugae Sundevall, 1833) are a little-known order of arachnids that consists of 12 families, about 140 genera and 1100 species mainly distributed in the deserts of Africa, the Middle East, and South and North America (Harvey 2003; Prendini 2011; Bird et al. 2015), and are well adapted to semi-arid and arid habitats, of which they are significant indicators (Schmoller 1970).

The marginal distribution of solifuges in the Palaearctic limits their presence to a few taxa in southern Europe (Harvey 2013). The Balkan Peninsula reveals the highest diversity, with representatives of Daesiidae Kraepelin, 1899, Galeodidae Sundevall, 1833 and Karschiidae Kraepelin, 1899 inhabiting Bulgaria, Greece and Macedonia (Harvey 2013; Hristovski et al. 2015). In addition, a few species of

the genus *Galeodes* are present outside the Balkans, i.e. in European Russia and Ukraine (Harvey 2003). In south-western Europe, only the family Daesiidae has been recorded, with *Gluwia dorsalis* (Latreille, 1817) known from Portugal and Spain (Grosso-Silva 1998; González-Moliné et al. 2008; Hrušková-Martišová et al. 2010) and two species of *Biton* Karsch, 1880 from Italy (Zavattari 1957; Roewer 1961). Besides the presence of *Biton*, two other very old records for Italy were provided by Lichtenstein and Herbst (1797), who described *Solpuga scenica* Lichtenstein, 1797 and *S. tarda* Lichtenstein, 1797 from Apulia and Sardinia. However, these records were based on a compilation of ancient literature, from Aristotle to Cetti (1778), and today appear to be of questionable validity; thus, they have been treated as *nomina dubia* by Harvey (2003). Therefore, the only reliable, and so far unique,

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records of solifuges in Italy are represented by three female specimens of *B. ehrenbergi* Karsch, 1880 plus two males and eight females of *B. velox* Simon, 1885, collected at Lampedusa Island in 1956 (Zavattari 1957; Roewer 1961). Little is known about either species, currently reported from several countries of Africa, Europe and the Middle East. Yet the overall distribution of the family is still controversial since only part of the past record is certainly based on males, the only sex considered valid for the taxonomic diagnosis of Daesiidae (Delle Cave & Simonetta 1971; Bird et al. 2015). Since Zavattari's collection, despite the biogeographical and ecological interest of these scarcely known arachnids, and although some general assessments on insects and other arthropods have been conducted (Massa 1995; Nicolini et al. 2008), no specific research targeting solifuges has been carried out in Lampedusa. Thus, since 1956, no other specimen was found. Only in 2008, a female *Biton* sp. was occasionally collected during an investigation on the island araneofauna (Italiano et al. 2008). Due to this current poor knowledge, in 2017 we decided to carry out a targeted field survey in order to fill the gap about solifuge presence and ecology in Lampedusa.

Materials and methods

Study area

Lampedusa is the major island of the Pelagie archipelago (Strait of Sicily). It is a sedimentary element of the African Plate (Grasso & Pedley 1985), 138 km distant from Africa and 215 km from Sicily. With a rectangular shape, an area of ~20 km² and ~40 km of coasts, it is fairly sloped from NW to SE and reaches a maximum altitude of 133 m above sea level (Albero Sole, NW). The northern coast is characterised by high cliffs, while the southern face presents lower cliffs, several bays and beaches. The island is dominated by a xerothermic Mediterranean climate (Bagnouls & Gausson 1957), and the rainfall is concentrated from October to February (average: 295 mm/year), while the mean monthly temperatures range from 13.5°C (January–February) to 26.5°C (August), with an annual average of 18.9°C (Nicolini et al. 2008). Colonised by humans at least since the Neolithic (Radi 1972), until the mid-19th century Lampedusa was covered by a dense Mediterranean scrub (Gussone 1839), later destroyed by intense human deforestation (Baccetti et al. 1995). Agricultural activities declined after the Second World War; since then the landscape has been primarily altered by soil erosion, due to water run-off (Morgan 1992) and desertification (Vittorini 1973; Zampino

et al. 1997), as well as by anthropogenic pressure (mainly urbanisation for tourism) (Nicolini et al. 2008; Mei et al. 2016). About 68% of the island area is protected and included in the Natura2000 network as a Site of Community Importance (SIC ITA040002 – Isola di Lampedusa e Lampione), which enlarged a former Natural Reserve of the Sicilian Region. Low soft-leaved scrubland (phrygana) and steppes dominate the areas most exposed to the wind, while remains of the ancient Mediterranean scrub can still be found within the steep valleys (Nicolini et al. 2008). The most intact habitats are located along the shoreline where the action of the sea aerosol is determinant (Pasta 2002). The island is still home to over 550 plant species, including several endemic species, while the invertebrate fauna includes 25 endemic taxa (Muscarella & Baragona 2017). Many of these organisms are indicative of an ancient link with Africa (Corti et al. 2002).

Field methods

To maximise the sampling during the survey we searched for information about the seasonal life cycle of Daesiidae. Unfortunately, very little information is available (Belozarov 2013), as *G. dorsalis* is the only species whose life cycle has been investigated (Hrušková-Martišová et al. 2010). *Gluvia dorsalis* inhabits the Iberian Peninsula, mainly occurring in Mediterranean pseudosteppes and scrublands, and is most active during the arid season (< 35 mm of precipitation) from May to October. Mating and oviposition take place in early summer, with the first-instar nymphs appearing approximately 2 months after egg deposition and then hibernating as early juveniles in autumn. These nymphs grow up during the next year, hibernating a second time as late juveniles and becoming adults the third year after hatching, thus showing a biennial life cycle. Based on measurements collected in the field, Hrušková-Martišová et al. (2010) suggested that adults are present in spring and vagrant early/late juveniles are present in autumn. Both past records (Zavattari 1957; Italiano et al. 2008) came from specimens collected in May–June. Field surveys were consequently conducted over the whole island for a total of 20 days, first in spring (from 26 April to 6 May 2017) and then repeated in autumn (from 3 to 13 October 2017).

We used the habitat map (1:10,000) provided by Nicolini et al. (2008) with the aim of searching the entire spectrum of habitat diversity of the island. Based on the Corine Biotopes European

classification systems (Moss et al. 1990; adopted by the Habitats Directive 92/43/EEC), the habitat map allowed us to select 15 habitat units where we could carry out the survey inside the protected SIC area. Four other units were a priori discarded as unsuitable for solifuges (i.e. sandbanks and reefs permanently covered by sea water, and embryonic sand dunes) or inaccessible to us (halo-nitrophilous scrub on steep northern rocky cliffs). Outside the SIC boundaries, where detailed habitat mapping was not available, the habitat units were visually inferred and validated during the field surveys, by observation of key plant species indicated in Nicolini et al. (2008). Our sampling design aimed at a standardised collection to assess solifuge presence and abundance; therefore, we performed transects with uniform and time-constrained searches (TCSs) of 30 minutes in equal numbers within every habitat unit during consecutive days. Since the habitat units are fragmented in the island, the transects were randomly allocated among different fragments of the same habitat, and inspection of same-habitat fragments was carried out on different days in order to increase the probability of finding the solifuges. The collectors walked slowly, maintaining the same speed for every transect, spending a total of 30 minutes in searching by looking under stones, logs and low vegetation. All the time invested in extra activities other than searching, such as collecting and labelling specimens, taking photographs, etc., was not clocked. A total of 240 TCSs (i.e. 120 hours of net searching) were carried out during the day (8:00–18:00 GMT+2), equally distributed between the two periods of the survey, i.e. 120 TCSs and 60 hours each in spring and autumn (Figure 1). The position of each animal was georeferenced using a portable GPS device (Garmin eTrex® 30x) to the closest 10 seconds; then the specimens were photographed, collected and stored in a labelled vial with 99% v/v ethanol.

Specimen examination

Current solifuge taxonomy is mainly based on the works of Roewer (1932, 1933, 1934). Despite being a milestone, Roewer taxonomy has proven to be unsatisfactory since the diagnosis of many taxa, from subfamilies to species, was made on the basis of a few, or even single, easily countable characters (e.g. the numeric sequence of tarsal spiniform setae), whose intra- and inter-specific variation has not been verified (Brignoli & Raffaelli 1978; Bird et al. 2015). For this reason, numerous authorities (Vachon 1950; Delle

Cave & Simonetta 1971; Wharton 1981; Harvey 2003; Reddick et al. 2010) have recommended the comprehensive revision of the entire order. Consequently, and according to Wharton (1981), Roewer's taxonomic framework below the family level was not used throughout our identification process of the specimens; and we made a direct and critical comparison among genera and species of Daesiidae existing in the literature. Moreover, following the cautions of Delle Cave and Simonetta (1971) and Bird et al. (2015), females were not determined, for their lack of reliable diagnostic characters. Adult male solifuges were distinguished from females and juvenile stages by both the presence of the flagellar complex and the modified dentition of chelicerae (Bird et al. 2015). Morphological terminology follows Bird et al. (2015) for chelicerae, Shultz (1989) and Bird and Wharton (2015) for leg and pedipalp descriptions. Chelicerae were coded as FD (fixed finger); FM (fixed finger medial tooth); FP (fixed finger proximal tooth); FSM (fixed finger submedial tooth); PF (profondal teeth); MM (movable finger); MP (movable finger proximal tooth); or MSM (movable finger submedial tooth). According to Botero-Trujillo (2014), the so-called “spines” of legs and pedipalps are here referred to as “spiniform setae”, and their pattern has been described following the formula proposed by Iuri et al. (2014), in a proximal to distal order.

The specimens were examined and identified with a Leica MZ6 stereomicroscope at the Esapolis Invertebrate Museum (Padova). Measurements of the body length, from the anus to the tip of the chelicerae, were taken under the stereomicroscope using a digital calliper (0.01 mm precision).

Habitats and specimens in nature were photographed using a Nikon D3200 reflex with AF-S DX Nikkor 18-105 mm f/3.5-5.6G ED VR. Images of preserved specimens were taken using a Canon 1300D reflex and MP-E 65 mm f/2.8 1-5x Macro Photo lens. Helicon Focus 6.7.1, method C, was used to fuse images taken at different focal planes into single images with greater depth of field. The photographs were edited in Adobe Photoshop 2015 CC.

Voucher specimens have been deposited in the Arachnological Collection of the Museum of Zoology of Padova University (MZUPD). Two males and two females, including the single female collected in 2008, are deposited in Palermo, in the LZPC (Laura Zanca personal collection).

Results

In total, 24 solifuges (18 adult males, plus six adult and/or late juvenile females) were collected during

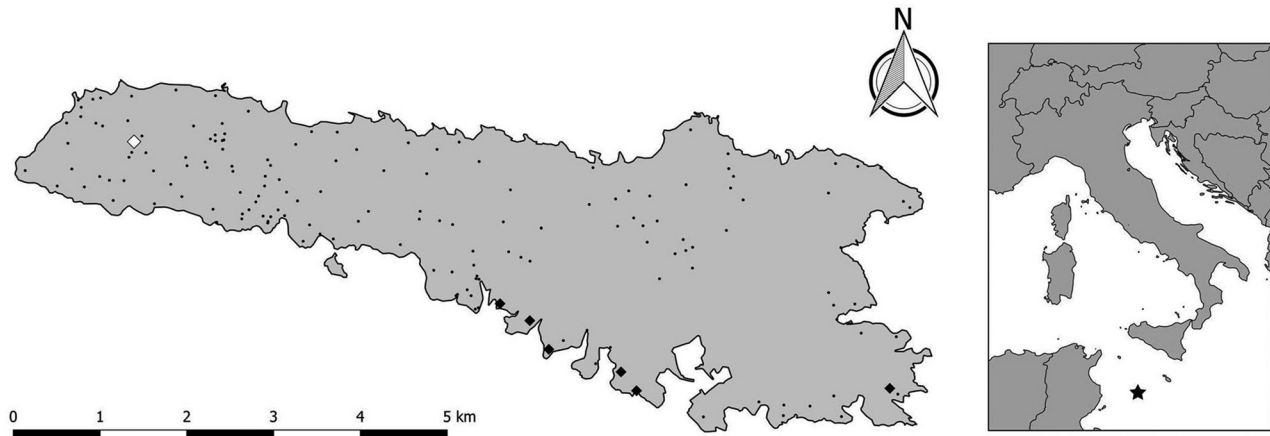


Figure 1. Map of Lampedusa Island in the Strait of Sicily (Mediterranean Sea). Black points and diamonds show the 240 transects carried out in April–May and October 2017 in search of solifuges. Black diamonds designate the presence sites, while the white diamond is the place of 2008 collection. The Zavattari's collection site in year 1956 is near the rightmost black diamond. All transect positions have been slightly modified (geographically shifted) for conservation purposes.

April–May, while only one late juvenile was found in October. Our findings both confirm the area where Zavattari (1957) first recorded the solifuges and add five more localities in Lampedusa (Figure 1).

Systematics

Order **Solifugae** Sundevall, 1833
 Family **Daesiidae** Kraepelin, 1899
 Genus ***Biton*** Roewer, 1941

Species: *Biton velox* Simon, 1885: Simon 1885: 47; Roewer 1933: 402, fig. 276.

Daesia velox (Simon, 1885): Kraepelin 1901: 96.

Biton (Biton) velox Simon: Harvey 2003: 225.

Diagnosis. Figure 2 illustrates the diagnostic characters of the species. All the collected specimens, including the female of 2008, have been attributed to the family Daesiidae on the basis of the following characters: the absence of claws on telotarsus of leg I; telotarsus of legs II and III with two tarsomeres, leg IV with three tarsomeres (tarsal formula 1.2.2.3); and males with a membranous, husk-shaped and paraxially movable composite flagellum (Kraepelin 1899; Roewer 1934; Bird et al. 2015; Figure 2(a,b)).

Males present all the conventional diagnostic traits of *Biton* species as described hereafter: telotarsus of legs II and III with 1.1/0 ventrolateral spiniform setae (unpaired setae on prolateral aspect), while leg IV has 2.2/0/2/0 ventrolateral spiniform setae. Basitarsus of legs II, III and IV

with 1.2 ventrolateral spiniform setae (unpaired seta on prolateral aspect). The pedipalp basitarsus has six ventral spiniform setae (2.2.2), while the telotarsus is bare. The chelicerae fixed-finger dentition is represented by three large FD, FM and FP teeth (with the FD longer and more developed than the others), a tiny FSM tooth and four PF teeth. The chelicerae movable-finger dentition shows the two MM and MP teeth markedly separated from each other, and a tiny MSM tooth (Figure 2(c,f)). Female chelicerae dentition is equal to that of *B. velox* males (Figure 2(d)). Opisthosoma without ctenidia.

Males have been identified as *B. velox* by the absence of the mucron organ in the FD, a diagnostic character instead present in *B. ehrenbergi*, plus the different shape of the flagellum and pattern of chelicera dentition as reported in Roewer (1933) and Delle Cave and Simonetta (1971).

Taxonomic remarks. The presence of three tarsomeres (Figure 2(e)) – together with their setal formula – in the telotarsus of leg IV defines the sub-Saharan genus *Eberlanzia* Roewer, 1941, which coincidentally is very similar to *Biton* (Roewer 1941; Lawrence 1962). Nevertheless, Lawrence (1962) suggested that the distinction between *Biton* and *Eberlanzia* should be based, beyond the telotarsal constitution of leg IV, also on the distinctive presence in *Eberlanzia* of numerous spiniform setae on the pedipalp basitarsus and telotarsus. This character does not match with our specimens which, instead, present the same setal pattern of *B. velox* as well as all the other abovementioned diagnostic characters of this species (Simon 1885; Kraepelin 1901; Roewer 1933). We thus considered the incongruence of

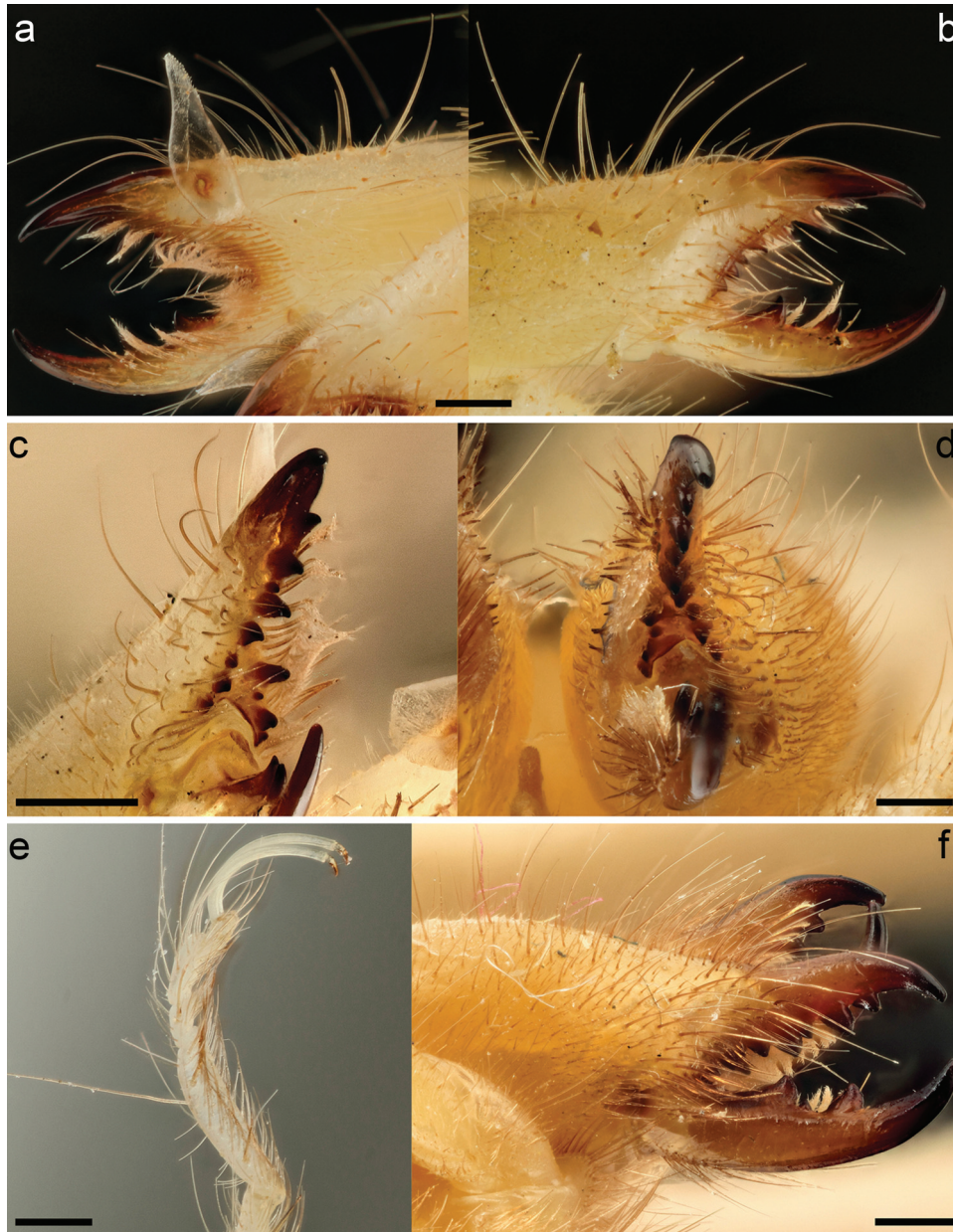


Figure 2. *Biton velox* from Lampedusa. (a) Male chelicera, mesal view, with the flagellar complex useful for sex and species discrimination. (b) Male chelicera, external view. (c) Male chelicera, ventral view of fixed finger. (d) Female chelicera, ventral view of fixed finger. (e) Female tarsal structure of leg IV. (f) Female chelicera, external view. Photos by Enrico Schifani. Scale bars: 0.5 mm.

the tarsal formula an example of the problems with Roewer's taxonomy, so focused on tarsal spinal formulas (see Discussion), and we concluded that the specimens collected on Lampedusa represent *Biton velox*.

A questionable separation (Harvey 2003) of the subgenus *Biton* (*Bitonissus*) present in Iran and Armenia from *Biton* (*Biton*) has been made in Birula (1936). Furthermore, *Biton velox* is polytypic, as *B. v. dmitrievi* has been described and separated from the nominal *B. v. velox* (Birula, 1905). Delle Cave and

Simonetta (1971) commented on the uncertain status of this subspecies. Given the confusing taxonomy still surrounding the Daesiide species, we feel that it is premature to allocate the specimens collected to either subgeneric or subspecific ranks.

We consider the presence of a second species on the island to be unlikely given the small size of Lampedusa. Besides, the previous report of *B. ehrenbergi* on Lampedusa is dubious, given the more eastern Mediterranean distribution of this species (Harvey

2013) and the specific attribution based only on female specimens (Roewer 1961). According to Roewer (1933), females of *B. velox* and of *B. ehrenbergi* should be distinct merely by body length (i.e. 10–12 mm in *B. velox* and 18 mm in *B. ehrenbergi*). However, the taxonomic value of this character looks very weak, when considering both the limited number of specimens examined by Roewer (1933) and the difficulties in distinguishing between adult females and juveniles. In our sample the body length varies between 15.7 and 18.8 mm in females and 11.4 and 14.8 mm in males, respecting the sexual size dimorphism (Punzo 1998).

Distribution. Europe (Lampedusa Island), Northern Africa (Tunisia, Libya), Central Africa (Ethiopia, Somalia, Kenya), Middle East (Israel). We suggest that such a distribution, drawn from the available past literature, might change after a modern taxonomic revision employing exclusively male specimens, the only sex considered valid for the taxonomic diagnosis of Daesiidae (Delle Cave & Simonetta 1971; Bird et al. 2015).

Ecology. Sampling of solifuges in their diurnal hides beneath stones or decaying vegetation can be used to assess microhabitat preferences or when pitfalls and nocturnal searches cannot be employed (Punzo 1998). Although related to two limited spring and autumn slots within 1 year, our diurnal stratified random sampling covered most of the island surface and provided first data on these animals' ecology. Among the 15 investigated habitat units, only the 1240/5320 unit revealed the presence of solifuges, which were always detected at a distance of 40–150 m from the sea (Figure 3). This habitat mosaic provides the connection between the “Mediterraneo-Pontic sea-cliff communities” (i.e. the 1240 unit), closer to the sea, and the inland phrygana, by the contribution of the intermediate “coastal *Helichrysum* garrigue” (i.e. the 5320 unit). The vegetation is mainly characterised by low-shrub endemic species,

such as the dominant *Limonium lopadusanum* Brullo and *Thymelaea hirsuta* (L.) End. (Nicolini et al. 2008), adapted to the sea aerosol, the xeric conditions and the soil scarcity of the calcareous cliffs.

All the solifuges were found in their diurnal hides, while they were resting under pebbles and stones, in small delimited spaces of terra rossa (Muhs et al. 2010) among the bedrock and low shrubs (Figure 4(a–c)). Only in one case did we find a more elaborate burrowing cell, which was occupied by a seemingly moulting individual (Figure 4(d)). No more than one solifuge was found under each stone, although most of the specimens appeared to be in close proximity, staying just a few metres from one another. In addition, we noted that any shore habitat littered by urban waste and building debris was devoid of solifuges.

The results of our field survey, the seasonal (24 individuals in spring vs one in autumn) and habitat (all the individuals in the 1240/5320 unit vs zero in all the other units) distribution of records, gave a first indication, without need of statistical analysis, about the phenology and ecological preference of the solifuge population in Lampedusa. An exception is represented by the 2008 specimen collected in a completely different habitat unit (Figure 1). In 2017, we conducted exhaustive searches in the same locality without achieving any result; however, this record suggests that more field sampling is needed to fully establish the abundance and distribution of Lampedusa solifuges.

Discussion

Our survey confirms the presence of a living population of solifuges at Lampedusa more than 60 years after its first published record. The determination of our sample was not free of problems in the context of the unresolved taxonomy within the Daesiidae family. Above all, it is puzzling that Roewer (1961) did not notice the discrepancy in the tarsal formula –



Figure 3. Habitat of *Biton velox* along the south-eastern shoreline of Lampedusa (a, b). Photos by Enrico Schifani (a); Umberto Devincenzo (b).



Figure 4. Live specimens of *Biton velox* in their natural habitat in Lampedusa (late April). (a, c) Two males. (b) A female. (d) A male in its burrowed cell, probably during moulting. Photos by Umberto Devincenzo.

established by him to discriminate between Daesiidae genera – when he determined that the Lampedusa specimens belonged to the genus *Biton*. This fact may be justified by Roewer's focus on diagnostic characters now considered of little taxonomic value (cf. Helversen & Martens 1972; Brignoli & Raffaelli 1978). Besides, we consider completely unreliable the record of *B. ehrenbergi*, which Roewer (1961) based only on a few females and on the unverified taxonomic value of body-size. We too argue for a taxonomic revision of Daesiidae. However, the current state of solifuge taxonomy allowed us to identify the taxon living in Lampedusa exclusively as *B. velox*.

Thanks to our survey, the solifuge distribution inside the island begins to be better understood, as a quite clear habitat preference would be currently supported. Such a preference for coastal areas characterised by a well-defined habitat type may likely come from adaptation to the local ecological conditions of the insular environment. Unfortunately, as ecological preferences have rarely been studied in Southern Europe, there are not enough data available to draw wider conclusions on this topic, and much remains to be discovered about the biology of Lampedusa solifuges. Their life cycle remains substantially unknown because, for instance, contrary to our expectation based on the available information about the Daesiidae life cycle (Hrušková-Martišová et al. 2010), we did not find first-instar individuals or early juveniles in either period of research.

In terms of conservation, a serious risk for the Lampedusa solifuges cannot be excluded, as the population seems to be restricted to a small portion of unaltered territory, much of which is not protected by the Natural Reserve. Anthropogenic degradation of coastal habitats due to urbanisation and a massive influx of tourists may threaten their future presence on the island.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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