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ANTS OF SARDINIA: AN UPDATED CHECKLIST BASED ON NEW FAUNISTIC, MORPHOLOGICAL AND BIOGEOGRAPHICAL NOTES

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Schifani E., Nalini E., Gentile V., Alamanni F.,ˈAncona C., Caria M., Cillo D., Bazzato E, - Ants of Sardinia: an updated checklist based on new faunistic, morphological and biogeographical notes.

Sardinia is the second largest island in the Mediterranean region, receiving significant attention due to its interesting fauna and flora. The last checklist of Sardinian ants was published more than a decade ago, and, since then, it got outdated by numerous taxonomic and faunistic novelties. As a result of recent collecting efforts across the island, we present the first Sardinian records of *Messor ibericus* Santschi, 1931, *Solenopsis lusitanica* Emery, 1915 (new to Italy), *Temnothorax aveli* Bondroit, 1918 and *Tetramorium atratulum* (Schenck, 1852), while proposing to consider *Solenopsis fugax* (Latreille, 1798) and *Temnothorax affinis* (Mayr, 1855) as absent. We report for the first time a parasite-host association between *Tetramorium atratulum* and *Tetramorium semilaeve* André, 1883, and the conspicuous presence of ergatogynes within a *Solenopsis* colony (*S. lusitanica*). Morphological insights on the little-known *S. lusitanica* and *S. orbula* Emery, 1875 are also discussed. We combined the new findings and previous literature data into an updated checklist of 77 taxa and discuss a first biogeographic analysis of the Sardinian ants aided by chorotypes. Eurasian, European, Euro-Mediterranean and West-Mediterranean taxa are the numerically prevalent groups, while the overall number of species is significantly lower than in the other large Mediterranean islands. Considerable knowledge gaps still remain and some species are known to require additional taxonomic investigation.

KEY WORDS: mirmecofauna; *Solenopsis*; ergatogynes; Tuscan Archipelago

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INTRODUCTION

The Mediterranean basin is an important diversity hotspot worldwide (MÉDAIL & QUÉZEL, 1997; MÉDAIL, 2017), hosting a very large number of unique ant species (BOROWIEC, 2014). Sardinia is the second largest Mediterranean island, covering about 24,000 km^2 and being only slightly smaller (~1.7 km^2) than Sicily. Thanks to its variety of landforms, complex orographic patterns (with hilly lands, plateaus, mountain and plains), heterogeneous geological substrata and climate variability (BAZZATO *et al.*, 2021), the island is characterized by high levels of biodiversity and it is broadly known to host a significant endemic component in its fauna and flora (BACCETTI, 1983; GRILL *et al.*, 2007) in addition to a wide variety of Potential Natural Vegetations (FARRIS *et al.*, 2010; BACCHETTA *et al.*, 2009). Ants (Hymenoptera, Formicidae) are one of the ecologically more impactful insect groups in both natural and anthropogenic ecosystems (HÖLLDOBLER & WILSON, 1990; LACH *et al.*, 2010), including Mediterranean forests and agroecosystems across Italy and Sardinia (e.g. LOI *et al.*, 2012; CAMPOLO *et al.*, 2015; CASTRACANI *et al.*, 2017; GIANNETTI *et al.*, 2019; SCHIFANI *et al.*, 2020a). The oldest checklist of the Sardinian ant fauna was published by EMERY (1915) and included 47 taxa. Later on, this number increased to 57 in the Italian checklist published by BARONI URBANI (1971), and to 68 according to POLDI *et al.* (1995). However, the latest checklist, published by VERDINELLI *et al.* (2007), brought the total number up to 70. Since then, several other species were recorded as a result of few faunistic surveys (RIGATO & TONI, 2011; LOI, 2013), suggesting that further efforts are still needed to uncover the island's true myrmecological diversity. In addition, relevant changes occurred due to taxonomic revisions involving species present in Sardinia (e.g. SEIFERT *et al.*, 2017) and presently, no updated checklist of the island is available.

Different independent collecting efforts on the Sardinian ant fauna were conducted by the authors of this paper, which resulted in a significant amount of new species records and the collection of new or little-known forms and a new parasite-host association in ants. In addition, a review of the relevant taxonomic and faunistic literature allowed us to compile a new and updated checklist to summarize current faunistic knowledge over the island's ants, providing a key source of information to facilitate future investigations on Sardinian and Western-Mediterranean ants and their biogeography.

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MATERIALS AND METHODS

Collecting efforts were conducted in the years 2017-2019 by employing both direct sampling and pitfall traps filled with wine-vinegar saturated by sodium chloride as preservation method (see AGOSTI *et al.*, 2001; BRANDMAYR *et al.*, 2005) across four of the five administrative regions of Sardinia: the Metropolitan City of Cagliari (CA) (see PALUMBO *et al.*, 2020), and the provinces of Nuoro (NU), Oristano (OR) and South Sardinia (SU). In addition, we consulted material stored at the Milan Natural History Museum (Museo Civico di Storia Naturale, Milan, Italy - MSNM) and in authors personal collections, from Sardinia and also from neighboring regions whenever relevant. All specimens were identified under stereomicroscopes. Relevant taxonomic sources are mentioned for each taxon. Whenever geographic coordinates of the sampling sites are given, error range is estimated to be < 15 m.

Morphometric characters presented in this paper for *Solenopsis* refer to the morphometries used by GALKOWSKI *et al.* (2009), but French acronyms were abandoned in favour of the English-based acronyms proposed by SEIFERT (2018). Therefore, the following characters and acronyms were used (French equivalents are indicated in brackets): CW, maximum head width, across the eyes (LaT); CL, maximum head length in median line (LoT); SL, maximum scape length as a straight line, excluding the articular condyle and its neck (LoSc); EL, maximum diameter of the compound eyes, including unpigmented ommatidia (Diam. oeil); ML, maximum length of the mesosoma (LoM); MW, maximum width of the mesosoma (LaM); Mh, maximum height of the mesosoma (HM); PeH, maximum height of the petiole (HP); PPH, maximum height of the postpetiole (HPP); PW, maximum width of the petiole (LaP); PPW, maximum width of the postpetiole (LPP). These measurements were obtained using the software ImageJ (SCHNEIDER *et al.*, 2012) and high quality pictures of the specimens taken at up to 10x magnification using a Canon EOS 1300D camera and micro photography lens.

To facilitate a first biogeographic analysis of the checklist, we attempted to rely on the most broadly utilized chorotypes model proposed by VIGNA TAGLIANTI *et al.* (1999). However, in the framework of ant biogeography, we found highly limiting to miss chorotypes defining Maghrebian and South-Western European distributions, both disappearing under the wider Western-Mediterranean chorotype *sensu* VIGNA TAGLIANTI *et al.* (1999). PARENZAN (1994) proposed to use the acronyms NAW and ESW to refer to these distributions, so we follow his nomenclature for these two types. As a result, the following chorotypes were used: ASE, Asiatic-European; EME, East-Mediterranean; ESW, South-West European; EUR, European; CEM, Central Asiatic-European-Mediterranean; MED, Mediterranean; NAF, North-African; NAW, South-Western Mediterranean; SACO, Sardo-Corsican endemic; SARD, Sardinian endemic; SEU, South-European; TEM, Turano-European-Mediterranean; TUE, Turano-European; TYRR, Tyrrhenian endemic; WME, West-Mediterranean. Chorotypes were assigned to each taxon mainly on the basis of species distribution data from AntMaps (see JANICKI *et al.*, 2016; GUÉNARD *et al.*, 2017).

NEW SPECIES RECORDS

Messor Forel, 1890
Messor ibericus Santschi, 1931

Examined material - Sardinia: All the specimens are stored in the University of Cagliari collection deposited in the Zoological Research Museum Alexander Koenig (Bonn, Germany): Sa Guardia Lada, Simbrizzi, Quartu Sant'Elena (CA), 16.VII-03.XII.2018, 12 workers, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. Sirigragiu, Corongiu, Maracalagonis (CA), 22.VIII.2018, 3 workers, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. C. D'Aquila, Stagno di Quartu, Quartu Sant'Elena (CA), 16.VII.2018-II.2019, 4 workers, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. Riu Piscina Nuxedda, Maracalagonis (CA), 17.VII-25.IX.2018, 9 workers, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. Bingia Spada, Stagno di Quartu, Quartu Sant'Elena (CA), VII-VIII.2018, 2 workers, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. Via Belgio, Sant'Antonio, Quartu Sant'Elena (CA), II.2019, 1 worker, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani.

Remarks: This species appears to be sole representative of the *Messor structor* complex in the Western Mediterranean region, where it was known under the name *M. structor* until recently (STEINER *et al.*, 2018). All Sardinian specimens we examined were expectedly identified as *M. ibericus* according to the discriminant function proposed by STEINER *et al.* (2018). Under these conditions, all previous records of *M. structor* from the island should provisionally be attributed to *M. ibericus*, removing *M. structor* from the Sardinian checklist. According to the few verified data (STEINER *et al.*, 2018; SCHIFANI & ALICATA, 2018; SCHÄR *et al.*, 2020), *M. ibericus* may be the sole species of this complex also in the rest of Italy, while some recent mentions for the peninsula (RIGATO & WETTERER, 2018; SCUPOLA, 2018) refer to identifications prior to the taxonomic revision of STEINER *et al.* (2018).

Solenopsis Westwood, 1840
Solenopsis lusitanica Emery, 1915

Examined material - Sardinia: Domus de Maria (SU), 38.945720, 8.813108, 05.IX.2018, 63 males, 4 queens, 20 ergatogynes, 210 minor workers, 143 major workers, E. Nalini legit, det. E. Nalini & E. Schifani, E. Nalini collection. Iglesias (SU), 19.IX-03.X.2006, 1 queen and 1 male, G. Chessa legit, det. E. Nalini, Museo Civico di Storia Naturale di Milano (MSNM) – published in RIGATO & TONI (2011). Narcao (SU), 02.X.2018, 1 queen and 1 male, E. Nalini legit, det. E. Nalini, E.

Nalini collection. Pantaleo (SU), 39.090699, 8.802370, 09.IX.2018, 27 males, 28 queens, 98 minor workers, 18 major workers (two colonies), E. Nalini legit, det. E. Nalini, E. Nalini collection.

In addition to the abovementioned Sardinian material, further Italian specimens belonging to the same morphospecies were found from the Tuscan Archipelago, representing a significant novelty that we also report on: Isola d'Elba, 17.IX-03.X.2000, 1 queen and 2 males, P. Scaramozzino legit, det. E. Nalini, MSNM. Isola di Montecristo, 1 queen (15-26.IX.1999) and male (15-25.IX.2000), F. Strumia legit, det. E. Nalini, MSNM. Isola di Pianosa, 15-26.IX.2000, 1 queen and 2 males, P. Scaramozzino legit, det. E. Nalini, MSNM.

Remarks: This species is new to Italy (POLDI *et al.*, 1995). However, attribution of the examined material to this taxon bears an inevitable degree of uncertainty until a proper taxonomic revision of the group is produced. GALKOWSKI *et al.* (2010) started to revise the nomenclatural chaos that reigns over the difficult taxonomy of Mediterranean *Solenopsis*, a genus that includes a wide amount of very poorly described taxa whose identity is difficult to delimit. The *S. lusitanica* group appears distinguishable among the *Solenopsis* of South-Western Europe by morphological characters provided by GALKOWSKI *et al.* (2010). At the same time, no distinction is actually possible between *S. lusitanica* and the other valid taxa of the same group, *S. balachowsky* Bernard, 1959 and *S. gallica* Santschi, 1934, both considered of uncertain identity (GALKOWSKI *et al.*, 2010). For this reason, and since *S. lusitanica* is also the sole of the three currently considered present in any nearby region (see the Corsican checklists by BLATRIX *et al.*, 2018; 2020) we provisionally name the Sardinian *Solenopsis* material belonging to the *S. lusitanica* group as *S. lusitanica* until a proper taxonomic revision assesses the validity of *S. balachowsky* and *S. gallica*. Further information on this identification is given in the morphological section of this paper. Considering the extreme uncertainty around the true identity of *S. fugax* (Latreille, 1798) until recently (GALKOWSKI *et al.*, 2010), it is unsurprising that all the Sardinian material previously identified as *S. fugax* we managed to examine (see RIGATO & TONI, 2011) corresponds to *S. lusitanica* instead. In a similar fashion, recent attempts to find *S. fugax* in Sicily yielded no results, as only a form tentatively named *S. latro* Forel, 1894 was recovered by SCHÄR *et al.* (2020). While we have verified records of *S. fugax* from other regions of Italy (at least across the Po Plain - Emilia-Romagna: SCHIFANI et al., 2020a; Lombardy: CASTRACANI *et al.*, 2020, and also Trezzo sull'Adda (MI), 45.612021, 9.522218, 10.IX.2019, E. Nalini leg., E. Nalini personal collection; Veneto: Bovolone (VR), 27.VIII.2014, E. Nalini leg. and Spinea (VE), 14.IX.2017, D. Vallotto leg., E. Nalini personal collection), we provisionally propose to remove this species from the Sardinian checklist. The findings of *S. lusitanica* in the Tuscan Archipelago (biogeographically close to both Corsica and the Tuscan coast, see FATTORINI, 2009; DAPPORTO *et al.*, 2017) may suggest its presence on mainland Italy, perhaps unnoticed due to misidentifications with *S. fugax*. A proper assessment over the identity and distribution of the Italian *Solenopsis* spp. is evidently required, but it depends on a satisfactory resolution of at least some of the taxonomic problems affecting this genus in the Mediterranean region.

Temnothorax Mayr, 1861
Temnothorax aveli **(**Bondroit, 1918)

Examined material - Sardinia: Piscinas, Arbus (SU), 0 m, 39.5404, 8.4521, 25.V.2006, P. Cornacchia, M. Bardiani, D. Birtele & D. Whitmore legit, 1 worker labeled as *Temnothorax affinis*, det. E. Schifani, Bosco Fontana Natural Reserve ant collection (Lombardy) - published in RIGATO & TONI (2011).

Remarks: Current uncertainty over the separation of *T. aveli* from *T. italicus* (Consani, 1952) complicates naming of the Sardinian population: populations from France (including Corsica) and Iberia have been traditionally identified as *T. aveli* (or as one of its junior synonyms, see for example BUSCHINGER *et al.*, 1988; COLLINGWOOD & PRINCE, 1998; ARNAN *et al.*, 2007; HERNÁNDEZ CUBA *et al.*, 2006; PLATEAUX & CAGNIANT, 2012; ESPADALER *et al.*, 2013; TINAUT, 2016; BLATRIX *et al.*, 2018), while those of the Italian peninsula and North-Western Balkans as *T. italicus* (e.g. BRAČKO, 2007; 2017; SCHULZ *et al.*, 2006; CASTRACANI *et al.*, 2010; RIGATO & WETTERER, 2018; SCUPOLA, 2018; GIANNETTI *et al.*, 2019; 2021; SCHIFANI *et al.*, 2020a). *Temnothorax aveli* was described from France (BONDROIT 1918), while *T. italicus* from Central/Northern Italy (CONSANI & ZANGHERI 1952). However, none of the few qualitative characters provided by CONSANI & ZANGHERI (1952) to separate *T. italicus* from *T. aveli* appears fully reliable following a comparison of French *T. aveli* (type material and other material generously shared with us by C. Galkowski and R. Blatrix) and Italian material of *T. italicus* (published in GIANNETTI *et al.*, 2019; SCHIFANI *et al.*, 2020a), and the two taxa have been suggested to be potential synonyms (SCUPOLA, 2018). While an attempt to shed light over this taxonomic uncertainty is ongoing, we provisionally decided to use the name *T. aveli* due to the lack of darkened antennal clubs typical of *T. italicus* according to CONSANI & ZANGHERI (1952). The examined specimen had previously been identified as *T. affinis* (RIGATO & TONI, 2011): while there are evident similarities in shape and color between *T. affinis* and *T. aveli/T. italicus*, *T. affinis* is characterized by an evidently much coarser body sculpture (SEIFERT, 2018) and by a much less prominent subpetiolar process. As a result of our new identification, which was further aided by direct comparison with several *T. affinis* workers from Italy and Central Europe, *T. affinis* is provisionally excluded from the Sardinian fauna.

Tetramorium Mayr, 1855
Tetramorium atratulum (Schenk, 1952)

Examined material - Sardinia: Dorgali (NU), 21.VIII.

2018, 1 queen and 1 male from a *T. semilaeve* nest, M. Plumari legit, det. V. Gentile, V. Gentile collection. Dorgali (NU), 21.VIII.2018, 1 queen and 1 male from a *T. semilaeve* nest, M. Plumari leg., det. V. Gentile, M. Plumari collection. Narcao (SU), 39.1670, 8.6628, 2.IX.2018, 1 queen and 1 male from a *T. semilaeve* nest, E. Nalini legit, det. E. Nalini, E. Nalini collection.

Remarks: Inquiline social parasite ants as *T. atratulum* are very easily overlooked during faunistic surveys, sometimes severely hinder a correct understanding of their rarity, distribution and conservation status (ESPADALER & LÓPEZ-SORIA, 1991; SCHIFANI, 2017). Although still treated as Vulnerable in the IUCN Red List (SOCIAL INSECTS SPECIALIST GROUP, 1996), *T. atratulum* is one of the few exceptions: records of this species are quite numerous and its geographic range widely extends from the West Palearctic, where it is native, to the Neartic region, where it was introduced alongside one of its host species, *Tetramorium immigrans* Santschi, 1927 (DASH & SANCHEZ, 2009: SEIFERT, 2018; ZHANG *et al.*, 2019). Interestingly, there are many different *Tetramorium* host species that *T. atratulum* is known to exploit. Three belong to the *T. caespitum* complex (WAGNER *et al.*, 2017), one to the *T. chefketi* species complex and one to the *T. ferox* species complex (SANETRA *et al.*, 1999; for complexes definitions see CSŐSZ *et al.*, 2005; CSŐSZ & SCHULZ, 2010). The most interesting aspect of this first Sardinian record is that in all findings the host species was *T. semilaeve* André, 1883, which does not belong to any of these complexes and was never recorded as a host for *T. atratulum* before. SANETRA *et al.* (1999) had speculated that *T. semilaeve* could be a host for *T. atratulum* in Italy but no findings ever occurred. It is worth mentioning that the Sardinian populations of *T. semilaeve*, somewhat similarly to those of Calabria and Sicily (Fig. I; SCHÄR *et al.* 2020), at least chromatically sometimes deviate from the definition given by BOROWIEC *et al.* (2015) ("never dark brown"). In addition, none of the known host species of *T. atratulum* is known to occur in Sardinia, with the sole exception of *T. immigrans* which is probably introduced on the island (see WAGNER *et al.*, 2017; CASTRACANI *et al.*, 2020).

MORPHOLOGICAL NOTES

Solenopsis lusitanica Emery, 1915

There are at least two reasons that make worth offering a morphological overview of the Sardinian material we identified as *S. lusitanica*. First is obviously the scarceness of information currently available over the morphological identity of this taxon and the taxonomic confusion which reigns over the *S. lusitanica* complex, hindering a proper biological and biogeographical understanding. Second, the extraordinary finding of 20 ergatogynes within one of the examined *S. lusitanica* colonies (Fig. II), which represents an unexpected and very rare case within *Solenopsis*.

As mentioned above, the original description of *S. lusitanica* is almost completely useless to its identification (see EMERY, 1915) and the sole information available was provided by GALKOWSKI *et al.* (2010), consisting in a brief description and morphometric characterization of one queen and one male specimen (alongside 1 queen and 1 male of *S. balachowsky*). However, we compared our material with the definition and morphometric data provided by GALKOWSKI *et al.* (2010) and to some *S. lusitanica* specimens from Spain kindly sent to us by C. Galkowski. In order to do so, we recorded the 12 morphometric characters used by GALKOWSKI *et al.* (2010) on 31 specimens from 3 colonies (Tab. 1). Despite past confusion, *Solenopsis lusitanica* males and queens are much smaller than those of *S. fugax*, and queens lack the longitudinal rugae running from the frons to the ocelli in *S. fugax* (Fig. II). Distinction of workers appears to be considerably more difficult, especially for minors. Major workers have darkened heads (often slightly darkened near the vertex in minors too), and both minors and majors appear to be less hairy than *S. fugax* (Fig. III). It is worth noting that the type worker of *S. lusitanica gaetula* Santschi, 1936 (AntWeb CASENT0913907), an even more ambiguously defined taxon from Morocco (SANTSCHI, 1936), is clearly outside any imaginable intraspecific variation of the form we examined, and may instead be more closely related to the *S. orbula* complex.

Regarding the collected ergatogynes, these showed a significant morphological diversification, encompassing individuals more closely resembling queens and others more closely resembling workers (Fig. III). Ergatogynes represent one of the several different morphological mosaics found in ants (SCHIFANI *et al.*, 2020b). They are classified as either intercastes (i.e. rarely generated hybrid phenotypes usually unable to reproduce) or ergatoids (a distinct kind of specialized reproducers which may be even more common or replace queens in some species) (PEETERS, 1991). The very high number of ergatogynes found within a single nest in our case timidly suggests that they may represent functional ergatoids, however documentation of ergatogynes in *Solenopsis* is almost non-existent, recommending prudence in taking interpretations (GLANCEY *et al.*, 1980). Further investigation should aim to see whether ergatogynes are routineously produced by the colonies of this species.

Solenopsis orbula Emery, 1875

Examined material - Sardinia: Mari Ermi, Cabras (OR), 05.VII.2017, 2 queens and 1 male, Emilio Villani legit, det. V. Gentile, V. Gentile collection. Specimens stored at the in the University of Cagliari collection deposited in the deposited in the Zoological Research Museum Alexander Koenig (Bonn, Germany): Sirigragiu, Corongiu, Maracalagonis (CA), 1.VI-18.VII.2018, 2 workers, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. Piscina Nuxedda, Quartucciu (CA), 18.VII-21.VIII.2018, 2 workers, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. Str. Comunale Cani Nieddu, Quartu Sant'Elena (CA), 17.VII-21.VIII.2018,

1 worker, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. Riu Monte Nieddu, Maracalagonis (CA), 17.VII-21.VIII.2018, 1 worker, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. Via Lago di Varese, Quartu Sant'Elena (CA), I.2019, 1 worker, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. Via Pizzetti, Is Arenas, Quartu Sant'Elena (CA), 16.VII-29.X.2018, 3 workers, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani. Via Riccione, Porticciolo, Quartu Sant'Elena (CA), 20.VIII-30.X.2018, 28 workers, E. Bazzato, D. Cillo, M. Caria & Cesare Ancona legit, det. E. Schifani.

Fig. I - *Tetramorium semilaeve* worker from a Sardinian colony hosting *Tetramorium atratulum*. 1: lateral view, 2: dorsal view, 3: head view. Scale bar: 0.5 mm. Photos by Elia Nalini.

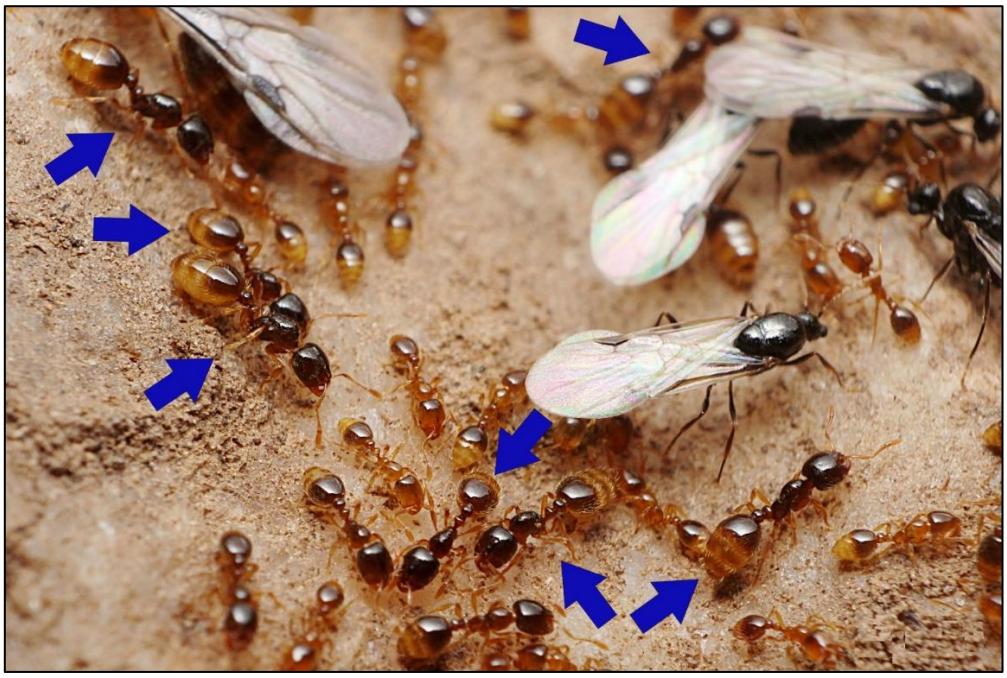

Fig. II - *Solenopsis lusitanica* colony from Sardinia. Blue arrows indicate ergatogynes, while the rest of wingless individuals are workers of different size and winged individuals are one queen (upper right side) and four males (on the left). Photo by Elia Nalini.

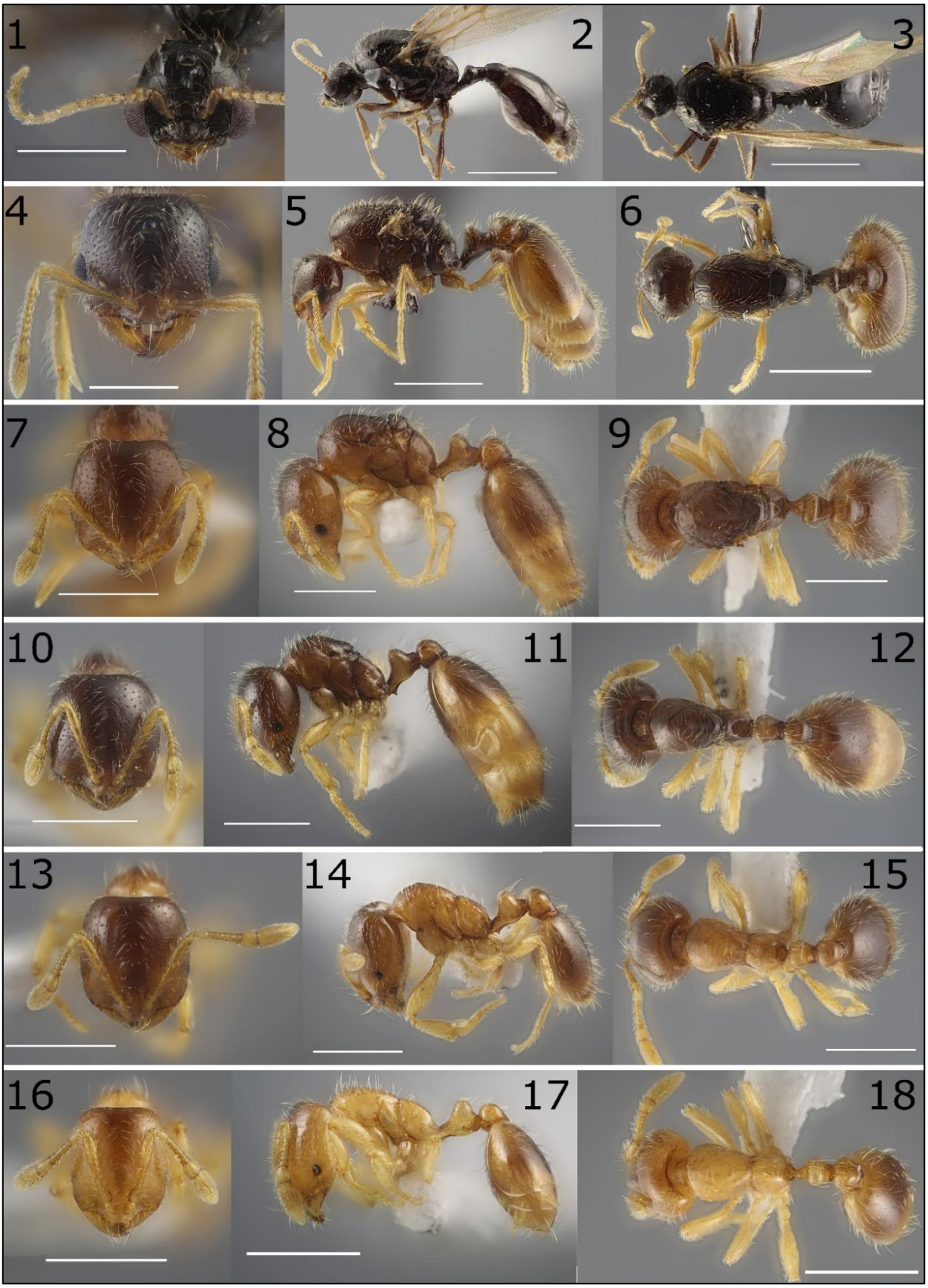

Fig. III - *Solenopsis lusitanica* from Sardinia. 1-3: male, 4-6: queen, 7-12: ergatogynes, 13-15: major worker, 16-18: minor worker. Scale bars 1 mm (images 2,3,5,6) and 0.5 mm (others). Photos by Elia Nalini.

Table 1 - Morphometric characters of examined *Solenopsis lusitanica* specimens. Definition of morphometric characters follows GALKOWSKI *et al*. (2010), nomenclature adapted to the English standard proposed by SEIFERT (2018) and French equivalents in parentheses when possible. Values are given in µm (mean ± standard deviation (minimum – maximum).

	males (7 specimens, 3 colonies)	**queens (6 specimens, 3 colonies)**	**ergatogynes (5 specimens, 1 colony)**	**minor workers (7 specimens, 1 colony)**	**major workers (6 specimens, 1 colony)**
CW (LaT)	600±18 (570 - 621)	808±23 (785 - 845)	566±34 (539 - 623)	400±12 (381 - 418)	475±36 (439 - 537)
CL (LoT)	470±33 (429 - 528)	745±27 (713 - 779)	600±31 (570 - 643)	475±12 (456 - 488)	544±21 (511 - 571)
SL (LoSc)	126±7 (113 - 133)	512±13 (493 - 529)	370±24 (329 - 392)	308±8 (294 - 319)	347±14 (335 - 368)
SL/HW	0.21±0.01 (0.18 - 0.22)	0.63±0.01 (0.61 - 0.65)	0.66±0.07 (0.52 - 0.59)	0.77±0.03 (0.70 - 0.80)	0.73±0.03 (0.68 - 0.78)
SL/HL	0.27±0.03 (0.22 - 0.31)	0.69±0.03 (0.65 - 0.74)	0.62±0.06 (0.51 - 0.66)	0.65±0.02 (0.61 - 0.77)	0.64±0.01 (0.63 - 0.64)
CW/CL	1.28±0.07 (1.18 - 1.40)	1.08±0.05 (1.01 - 1.16)	0.94±0.02 (0.92 - 0.97)	0.84±0.01 (0.83 - 0.86)	0.87±0.04 (0.86 - 0.94)
EL (Diam œil)	230±5 (223 - 236)	217±9 (207 - 232)	75±11 (60 - 87)	40±4 (34 - 45)	53±7 (47 - 65)
Ocellus diameter	78±5 (69 - 84)	83±17 (68 - 117)	-	-	-
ML (LoM)	1235±70 (1154 - 1332)	1502±55 (1410 – 1563)	710±37 (649 - 747)	481±19 (456 - 508)	565±35 (536 - 606)
MW (LaM)	841±38 (789 - 880)	826±48 (751 - 874)	370±32 (323 - 412)	252±6 (246 - 260)	291±19 (266 - 307)
MH (HM)	795±42 (714 - 840)	943±55 (870 - 992)	441±57 (349 - 483)	-	-
PeH (HP)	215±12 (195 - 227)	372±21 (339 - 400)	211±19 (182 - 229)	161±3 (157 - 166)	186±5 (181 - 193)
PPH (HPP)	261±25 (220 - 286)	364±24 (320 - 384)	188±24 (150 - 213)	124±9 (114 - 137)	153±9 (138 - 165)
PW (LaP)	230±16 (206 - 254)	326±21 (308 - 366)	181±15 (161 - 197)	127±3 (124 - 132)	150±9 (138 - 164)
PPW (LPP)	265±6 (259 - 275)	367±17 (338 - 380)	196±14 (183 - 217)	142±7 (135 - 157)	158±10 (149 - 177)

The identity of this peculiar species has long been vague. It was originally described from Corsica on the basis of its worker caste (EMERY, 1875a; a separate description also in EMERY, 1875b) and then ANDRÉ (1883) provided a brief description of a *S. orbula* queen from Algeria. Later on, FOREL (1905) described the subspecies *S. orbula terniensis* Forel, 1905 from some Algerian workers and a Spanish queen. However, differences between the two subspecies remain barely defined and only described for the worker caste (e.g. EMERY, 1909; 1916). As a result, the status of ssp. *terniensis* continued to be dubious (e.g. MEI, 1995), while significant morphological data from the type population of Corsica were more recently provided by GALKOWSKI *et al.* (2010) for all three castes. Despite these long-lasting taxonomic uncertainties, the name *S. orbula* s.l. and *S. orbula terniensis* have been widely used in the Mediterranean region: in Sardinia (EMERY 1916, ssp. *orbula*), Sicilian Channel (EMERY, 1916, ssp. *terniensis*), peninsular Italy (POLDI, 1992), Maltese Islands (SCHEMBRI & COLLINGWOOD, 1981), mainland France (CASEVITZ-WEULERSSE & GALKOWSKI, 2009), Spain (COLLINGWOOD & YARROW, 1969), Tunisia (FOREL, 1890; 1905, as ssp. *terniensis* in the latter), Lybia (FINZI, 1940, ssp. *terniensis*), Egypt (GRANDI, 1935, ssp. *terniensis*), Israel (VONSHAK & IONESCU-HIRSCH, 2009, ssp. *terniensis*), Lebanon (TOHMÉ, 1969), Syria (TOHMÉ & TOHMÉ, 1980), Turkey (AKTAÇ, 1988), Crete and in some Aegean Islands (SALATA & BOROWIEC, 2018). Moreover, in North Africa, several other vaguely defined taxa show similar morphological traits to *S. orbula*: *S. atlantis* Santschi, 1934, *S. longiceps* Forel, 1907, its subspecies *S. longiceps barbara* Santschi, 1934 (FOREL 1907; SANTSCHI 1934), in addition to the aforementioned *S. lusitanica gaetula*. The only North-African species similar to *S. orbula* but at the same time safely distinguishable on the basis of the existing literature is the Egyptian *S. cooperi* Donisthorpe, 1947 thanks to the efforts of SHARAF *et al.* (2009). Due to biogeographical reasons, the conspecificity of the Sardinian population with that of Corsica has never been questioned (EMERY, 1916; VERDINELLI *et al.*, 2007). On the other hand, at least some of the abovementioned Mediterranean records probably belong to different species. For example, TOHMÉ & TOHMÉ (1980) described in detail a Syrian 'variety' of *S. orbula* which clearly looks morphologically different from the Corsican *S. orbula* (also see GALKOWSKI *et al.*, 2010). A quite different form of *Solenopsis* from Afghanistan was also described as a subspecies of *S. orbula* by PISARSKI (1967), and only later recognized as a different taxon, *S. knuti* Pisarski, 1967 (DLUSSKY & RADCHENKO, 1994). In the case of most records though, doubts cannot be solved

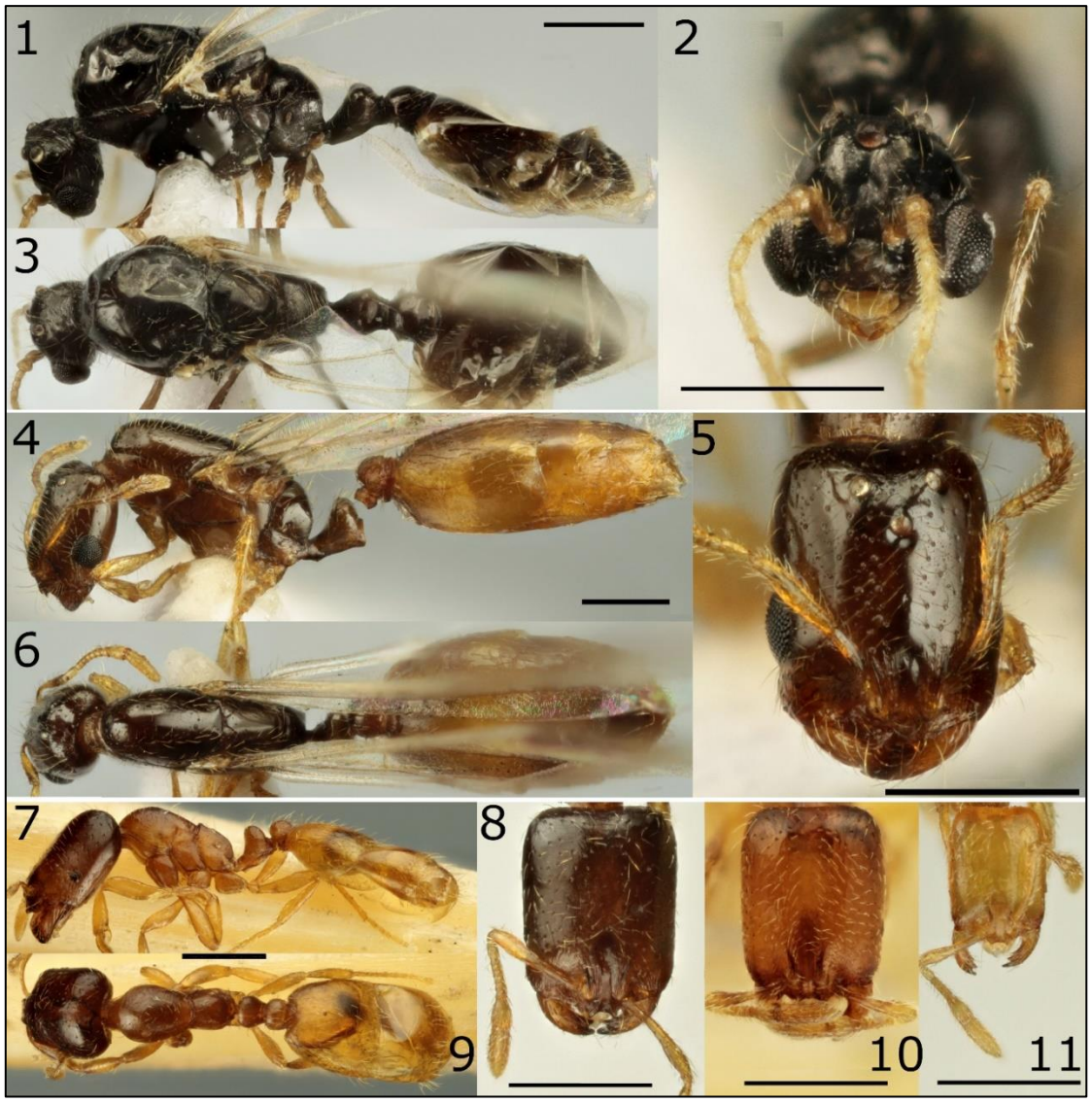

Fig. IV - *Solenopsis orbula* from Sardinia. Up to bottom: male, queen, workers. Scale bars: 0.5 mm. 1-3: male, 4-6: queen, 7-9: major worker, 10: medium-sized worker, 11: minor worker. Photos by Enrico Schifani.

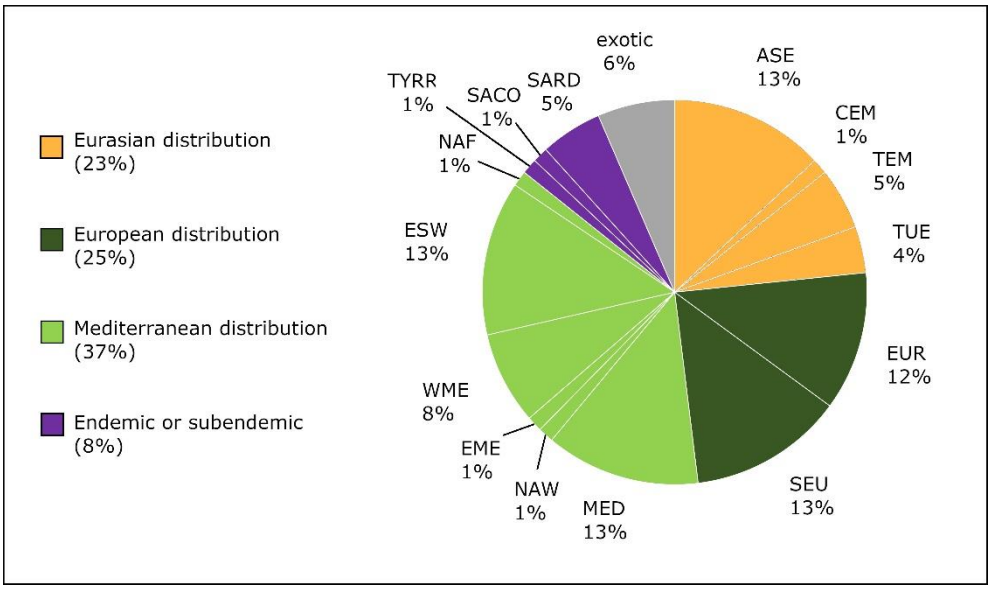

Fig. V - Biogeographic components of the Sardinian ant fauna according to chorotypes.

from the scarce indications published.

The material we collected in Sardinia included swarming sexuals collected in July (the same period reported for nuptial flights in Tuscany by POLDI (1992)) and allows us to highlight a number of peculiar morphological characteristics of this species, hopefully providing some useful indication for the study of other Mediterranean populations until a proper taxonomic revision of the group is produced. The following morphological traits seem particularly distinctive of this taxon (Fig. IV):

- Small-sized queen caste characterized by a remarkably thin mesosoma (visibly much thinner than the head), an elongated rectangular-shaped head, a mostly dark-colored body contrasting with a yellowish gaster and feeble sculpture.
- Polymorphic workers with elongated, rectangular-shaped heads and a relatively characteristic mesosoma profile with a high and long propodeum. The occiput is not excavated as in species like *S. cooperi*. Most of the workers are uniformly yellow but the largest workers possess a contrasting dark head. This characteristic is visually impressive and clearly distinctive, but seems surprisingly neglected in the existing literature where is almost never reported (e.g. not in GALKOWSKI *et al.*, 2010). The Corsican population possess the same habitus of the Sardinian specimens (see https://www.myrmecofourmis.fr/Solenopsis-orbula, accessed: 23.06.2020) and so does the Maltese one according to BARONI URBANI (1968). A comparison with pictures from the Balearic Islands (kindly shared with us by JOSEALBERTO FERNÁNDEZ) also appears to testify there the presence of the exact same form.

Finally, male morphology (Fig. III) may also be quite distinctive, but the lack of information over the morphological traits of most other species does not allow us to elaborate further.

CHECKLIST AND BIOGEOGRAPHY

By reviewing the existing literature, and especially those new records or taxonomic changes that were published since 2007, and in consideration of the novelties proposed in this paper, we list a total of 77 taxa (Tab. 2). In comparison to the checklist by VERDINELLI *et al.* (2007), we add 10 new species, 4 of which are the result of data presented in this study. Moreover, 5 other species are removed. Most of the species forming the Sardinian ant fauna belong to the subfamily Myrmicinae Lepeletier de Saint-Fargeau, 1835 (57%), about one third to Formicinae Latreille, 1809 (30%) while Dolichoderinae Forel, 1878 and Ponerinae Lepeletier de Saint-Fargeau, 1835 are much smaller groups (about 5% each) and finally Leptanillinae Emery, 1910 represent less than 3%.

Tapinoma magnum Mayr, 1861 is added on the basis of the records published by SEIFERT *et al.* (2016). This species was previously considered under the name *Tapinoma nigerrimum* Nylander, 1856 in Italy (POLDI *et al.*, 1995). VERDINELLI *et al.* (2007) had not included *T. nigerrimum* in their checklist without providing any explanation, however records of this species on the island exist at least since a century (EMERY, 1914). On the other hand, the presence of the rarely collected inquiline social parasite *Plagiolepis xene* Stärcke, 1936, whose host is *P. pygmaea* (Latreille, 1798), was discovered recently (LOI, 2013). *Camponotus universitatis* Forel, 1890, *Formica clara* Forel, 1886 *Lasius platythorax* Seifert, 1991 and *Tapinoma madeirense* Forel, 1895 were recorded for the first time by RIGATO & TONI (2011) (alongside *T. affinis*, but see the new species records section). The presence of *T. madeirense* in Sardinia (recorded by RIGATO & TONI, 2011) was then implicitly questioned by the following description of its cryptic species *T. subboreale* Seifert, 2012 from continental Europe (SEIFERT, 2012) but data later published by SEIFERT *et al.* (2016) confirmed the presence of the true *T. madeirense* in Sardinia. At the same time, *Aphaenogaster fiorii* Emery, 1915 and *A. subterranea* (Latreille, 1798) were considered absent in Sardinia by ALICATA & SCHIFANI (2019) and GALKOWSKI *et al.* (2019) respectively. Moreover, RIGATO & TONI (2011) suggested that all past records of *Formica rufibarbis* Fabricius, 1793 from Sardinia should be attributed to *F. clara* instead. In addition, *Ponera sulcitana* Stefani, 1970 (a supposed endemism) was declared to be a junior synonym of the tramp species *Hypoponera punctatissima* (Roger, 1859) (BOLTON & FISHER, 2011) and *Leptothorax exilis specularis* Emery, 1916 a junior synonym of *Temnothorax exilis* (SALATA *et al.*, 2018). Finally, WAGNER *et al.* (2017) recorded *T. immigrans* and SEIFERT (2020) recorded *Lasius grandis* Forel, 1909 for the first time.

Biogeographically (see Fig. V), the Sardinian ant fauna contains a large number of widely-distributed species (48%): 23% of the Sardinian species fall into the Palearctic distribution category (ASE+CEM+TEM+TUE) and 25% in the European category (EUR+SEU) *sensu* VIGNA TAGLIANTI *et al.* (1999). It may be worth mentioning that widely distributed European species account for a smaller proportion of taxa among Sardinian ants in comparison to what they do in the context of other faunistic assemblages (STOCH & VIGNA TAGLIANTI, 2005). Mediterranean species are only slightly less numerous, amounting to about 45% of Sardinia's ant species. These are dominated by species with a Western Mediterranean distribution amounting to 32% of the fauna (WME, 8%; ESW, 13%; SARD: 5%; NAW, TYRR and SACO combined: 6%) and circum-Mediterranean species (13%, MED). The distinction between Maghrebian and South-Western European species is highly informative, as 10 species belong to the latter category and only 1 to the first. The prevalence of Sardinian endemics to Sardo-Corsican ones is 4:1 and well-reflects the general traits of the Sardinian biogeography (BACCETTI, 1983). Among endemic taxa, it is worth noting that *S. sardoum* was until recently erroneously considered to extend its distribution to mainland Europe (see RIGATO, 2011). Eastern-Mediterranean influences are about completely absent as expected (SCHIFANI & ALICATA, 2019). Exotic species are not particularly numerous (6%), although the status of some taxa such as *C. mauritanica* or even *L. niger* is unclear and targeted investigations in anthropo-

genic and urban areas are likely to discover additional taxa (SCHIFANI, 2019; BLATRIX *et al.,* 2020).

Table 2 - Checklist of Sardinian ants and chorotypes of each species. Subfamilies are indicated by letters: D (Dolichoderinae), F (Formicinae), L (Leptanillinae) and M (Myrmicinae).

Sf	Species	Ch	Sf	Species	Ch
D	*Linepithema humile* (Mayr, 1868)	exotic	M	*Monomorium subopacum* (Smith, F., 1858)	MED
D	*Tapinoma madeirense* Forel, 1895	ESW	M	*Myrmecina graminicola* (Latreille, 1802)	EUR
D	*Tapinoma magnum* Mayr, 1861	WME	M	*Myrmecina melonii* Rigato, 1999	SARD
D	*Tapinoma simrothi* Krausse, 1911	MED	M	*Myrmica spinosior* Santschi, 1931	ESW
F	*Camponotus aethiops* (Latreille, 1798)	SEU	M	*Pheidole pallidula* (Nylander, 1849)	ESW
F	*Camponotus fallax* (Nylander, 1856)	TEM	M	*Solenopsis lusitanica* Emery, 1915	WME
F	*Camponotus gestroi* Emery, 1878	MED	M	*Solenopsis orbula* Emery, 1875	MED
F	*Camponotus lateralis* (Olivier, 1792)	MED	M	*Stenamma debile* (Foerster, 1850)	EUR
F	*Camponotus piceus* (Leach, 1825)	ESW	M	*Stenamma sardoum* Emery, 1915	SARD
F	*Camponotus universitatis* Forel, 1890	SEU	M	*Stenamma striatulum* Emery, 1895	SEU
F	*Camponotus vagus* (Scopoli, 1763)	CEM	M	*Strongylognathus testaceus* (Schenck, 1852)	TUE
F	*Colobopsis truncata* (Spinola, 1808)	TEM	M	*Strumigenys argiola* (Emery, 1869)	SEU
F	*Formica clara* Forel, 1886	ASE	M	*Strumigenys baudueri* (Emery, 1875)	SEU
F	*Formica cunicularia* Latreille, 1798	ASE	M	*Strumigenys membranifera* Emery, 1869	exotic
F	*Formica lugubris* Zetterstedt, 1838	exotic	M	*Strumigenys tenuipilis* Emery, 1915	SEU
F	*Lasius bicornis* (Foerster, 1850)	ASE	M	*Temnothorax aveli* (Bondroit, 1918)	ESW
F	*Lasius brunneus* (Latreille, 1798)	ASE	M	*Temnothorax exilis* (Emery, 1869)	SEU
F	*Lasius flavus* (Fabricius, 1782)	ASE	M	*Temnothorax kraussei* (Emery, 1915)	SEU
F	*Lasius emarginatus* (Olivier, 1792)	EUR	M	*Temnothorax lichtensteini* (Bondroit, 1918)	SEU
F	*Lasius grandis* Forel, 1909	ESW	M	*Temnothorax mediterraneus* Ward et al. 2014	ESW
F	*Lasius lasioides* (Emery, 1869)	MED	M	*Temnothorax nylanderi* (Foerster, 1850)	EUR
F	*Lasius niger* (Linnaeus, 1758)	ASE	M	*Temnothorax parvulus* (Schenck, 1852)	EUR
F	*Lasius paralienus* Seifert, 1992	EUR	M	*Temnothorax ravouxi* (André, 1896)	EUR
F	*Lasius platythorax* Seifert, 1991	ASE	M	*Temnothorax recedens* (Nylander, 1856)	MED
F	*Plagiolepis pallescens* Forel, 1889	ASE	M	*Temnothorax sardous* (Santschi, 1909)	SARD
F	*Plagiolepis pygmaea* (Latreille, 1798)	ASE	M	*Temnothorax tuberum* (Fabricius, 1775)	ASE
F	*Plagiolepis xene* Stärcke, 1936	ESW	M	*Temnothorax unifasciatus* (Latreille, 1798)	TEM
L	*Leptanilla doderoi* Emery, 1915	SARD	M	*Tetramorium atratulum* (Schenck, 1852)	TUE
L	*Leptanilla revelierii* Emery, 1870	WME	M	*Tetramorium brevicorne* Bondroit, 1918	SACO
M	*Aphaenogaster ichnusa* Santschi, 1925	ESW	M	*Tetramorium caespitum* (Linnaeus, 1758)	EUR
M	*Aphaenogaster sardoa* Mayr, 1853	NAW	M	*Tetramorium immigrans* Santschi, 1927	exotic
M	*Aphaenogaster senilis* Mayr, 1853	ESW	M	*Tetramorium meridionale* Emery, 1870	MED
M	*Aphanogaster spinosa* Emery, 1878	TYRR	M	*Tetramorium semilaeve* André, 1883	WME
M	*Cardiocondyla mauritanica* Forel, 1890	NAF	M	*Cryptopone ochracea* (Mayr, 1855)	TUE
M	*Crematogaster scutellaris* (Olivier, 1792)	WME	P	*Hypoponera eduardi* (Forel, 1894)	MED
M	*Messor capitatus* (Latreille, 1798)	WME	P	*Hypoponera punctatissima* (Roger, 1859)	exotic
M	*Messor ibericus* Santschi, 1931	SEU	P	*Ponera coarctata* (Latreille, 1802)	TUE
M	*Messor minor* (André, 1883)	MED	P	*Ponera testacea* Emery, 1895	EUR
M	*Messor wasmanni* Krausse, 1910	EME			

CONCLUSIONS

The present study offers several faunistic novelties and a comprehensive summary over the Sardinian ant fauna, in addition to morphological information of general interest for the difficult study of the Mediterranean *Solenopsis*. While the understanding of some ant genera in Sardinia seems quite satisfactory (perhaps even for the enigmatic genus *Leptanilla*, see LEO & FANCELLO, 1990), the overall picture is definitely far from being conclusive. The number of 79 taxa currently considered to be present is not particularly high. In comparison, Sicily, which is about the same size of Sardinia, is grossly estimated to be inhabited by about 150 species (SCHIFANI & ALICATA, 2018) and the nearby Corsica, less than one third of the size of Sardinia, hosts 91 species according to the latest checklist (BLATRIX *et al.*, 2018; 2020). Even the much smaller island of Crete is thought to be home to 100 taxa (SALATA *et al.,* 2020), while there is no recent estimate for Cyprus. The reason behind this comparatively smaller number is most likely explained in part by still insufficient investigation. The considerable number of new species records recently produced by relatively limited investigation efforts reinforce this idea. At the same time, a role was likely also played by higher biogeographic isolation of Sardinia in comparison with both Corsica and Sicily. Viable connections between Corsica and Tuscany and between Sicily and Calabria are important to explain their current ant fauna assemblages. Many continental species are not found in Sardinia but inhabit Corsica, Sicily or both (e.g. *Myrmica sabuleti* Meinert, 1861, *Aphaenogaster italica* Bondroit, 1918, *A. subterranea* - see VERDINELLI *et al.*, 2007; SCHIFANI & ALICATA, 2018; SEIFERT, 2018; GALKOWSKI *et al.,* 2019). In addition, Sicily's high number of species may be explained by Maghrebian and Balkan influxes only marginally able to reach Sardinia (ALICATA & SCHIFANI, 2019; SCHIFANI & ALICATA, 2019; CENTORAME *et al.,* 2020). In particular, *Aphaenogaster sardoa* and *Myrmecina melonii* are the only two elements of the Sardinian fauna that testify an ancient colonization of Southern-Tyrrenian species (SCHIFANI *et al.,* 2020c). On the other hand, it is notable that both

Corsica and Sardinia entirely lack the subfamily Proceratiinae, which is found elsewhere in all neighbouring Mediterranean regions.

Taxonomic uncertainty is already quite evident for some species inhabiting Sardinia (in addition to those mentioned in this paper, see for example the Sardinian *Formica cunicularia* Latreille, 1798 according to SEIFERT & SCHULZ, 2009). Moreover, BLATRIX *et al.* (2020) proposed to consider the Corsican *T. unifasciatus* populations as a cryptic species [*T. cordieri* (Bondroit, 1918)] due to spines length and mtDNA differences and suggested that the local form chromatically similar to *L. emarginatus* and morphometrically clustering within *L. grandis* (see SEIFERT, 2020) may be an undescribed cryptic species. Among the endemic species, the status of *T. sardous* requires a proper assessment, as different authors have been treating it either as a good species or as a subspecies of *T. rottenbergii* (Emery, 1870) without presenting any proper argument or discussion (see KRAUSSE, 1912; EMERY, 1914; 1916; 1924; BONDROIT, 1918; BARONI URBANI, 1971; BOLTON, 1995; 2003; POLDI *et al.*, 1995; BOROWIEC, 2014; VERDINELLI *et al.*, 2007; LEBAS *et al.*, 2016 - in this paper we simply followed the choice made in the last Sardinian checklist by VERDINELLI *et al.*, 2007). Moreover, there are a number of old species records that we maintained in the list but that clearly need to be verified due to the taxonomic advancements of the last years. Good examples can be found for the genera *Lasius*, *Ponera* and *Temnothorax* which witnessed major taxonomic improvements over the last few decades (e.g. SEIFERT, 2020; CSŐSZ & SEIFERT, 2003; CSŐSZ *et al.*, 2015). The old, isolated finding of *H. punctatissima* could potentially represent instead *H. ergatandria* (Forel, 1893), a cryptic tramp species whose presence in Italy has never been checked for despite being recorded across Europe (SEIFERT, 2013).

While many novelties are expected from further investigation, the figure regarding the main biogeographical traits of the Sardinian ant fauna that were identified in this paper is unlikely to change dramatically. The present checklist will offer a useful and solid basis to direct future researches.

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