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

*S Department of Chemistry, Life Sciences & Environmental Sustainability, University of Parma, Parco Area delle Scienze 11/a, 43124 Parma, Italy
*b Department of Biosciences, University of Milan "la Statale", Via Giovanni Celoria 26, 20133 Milan, Italy
*c Corso Umberto I 301, 80058 Torre Annunziata (NA), Italy
*d Department of Life and Environmental Sciences, University of Cagliari, Via Sant' Ignazio da Laconi 13, 09123 Cagliari, Italy
*e Via Mascagni 3, 09020 Ussana (CA), Italy
*f Via Zeffiro 8, 09130 Cagliari (CA), Italy
*Corresponding Author: Enrico Schifani; enrsc8@gmail.com

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 The last checklist of Sardinian ants was published more than a decade ago, and, since then, it got outdated by numerous taxonomic and faunistic novelties.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 axelli* 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

INTRODUCTION

The Mediterranean basin is an important diversity hotspot worldwide (*MEDAIL & QUÉZEIL, 1997; MEDAIL, 2017*), hosting a very large number of unique ant species (*BOROWIEC, 2014*). Sardinia is the second largest Mediterranean island, covering about 24,000 km² and being only slightly smaller (~1.7 km²) 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 (*HÖLLODOBLER & 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. *SEIFFERT 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.
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 (English 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, Tyrrenian 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


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; SCHAR 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


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 (POLDT 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. balachowskyi 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. balachowskyi 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 SCHAR 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, Arbùs (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; PLATEAU & CIGNANT, 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. BRACKO, 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 (BONDROT 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 (SEIFFERT, 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 atratum (Schenk, 1952)

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

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. cheffkiti* species complex and one to the *T. ferox* species complex (SANETRA et al., 1999; for complexes definitions see CSÖSZ et al., 2005; CSÖSZ & 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. balachowskyi*). 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., 2020). 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 routinely produced by the colonies of this species.

*Solenopsis orbula* Emery, 1875


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.
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, 1916; Santschi, 1934, ssp. orbula terniensis (2009), mainland France (Casevitz-Weulersse & Galkowski, 2009), Spain (Collingwood & Yarrow, 1969), Tunisia (Forel, 1890; 1905, as ssp. terniensis in the latter), Libya (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 (SLATA & 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. latistiana 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; Verdenelli 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.

Table 1 - Morphometric characters of examined Solenopsis latistana 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).

<table>
<thead>
<tr>
<th></th>
<th>males (7 specimens, 3 colonies)</th>
<th>queens (6 specimens, 3 colonies)</th>
<th>ergatogynes (5 specimens, 1 colony)</th>
<th>minor workers (7 specimens, 1 colony)</th>
<th>major workers (6 specimens, 1 colony)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW (LaT)</td>
<td>600±18 (570 - 621)</td>
<td>808±23 (765 - 845)</td>
<td>566±34 (539 - 623)</td>
<td>400±12 (381 - 418)</td>
<td>475±36 (439 - 537)</td>
</tr>
<tr>
<td>CL (LaT)</td>
<td>470±33 (429 - 528)</td>
<td>745±27 (713 - 779)</td>
<td>600±31 (570 - 643)</td>
<td>475±12 (456 - 488)</td>
<td>544±21 (511 - 571)</td>
</tr>
<tr>
<td>SL (LaSc)</td>
<td>136±7 (113 - 133)</td>
<td>512±13 (493 - 529)</td>
<td>370±24 (329 - 392)</td>
<td>308±8 (294 - 319)</td>
<td>347±14 (335 - 368)</td>
</tr>
<tr>
<td>SL/HW</td>
<td>0.21±0.01 (0.18 - 0.22)</td>
<td>0.63±0.01 (0.61 - 0.65)</td>
<td>0.66±0.07 (0.52 - 0.59)</td>
<td>0.77±0.03 (0.70 - 0.80)</td>
<td>0.73±0.03 (0.68 - 0.78)</td>
</tr>
<tr>
<td>SL/IL</td>
<td>0.27±0.03 (0.22 - 0.31)</td>
<td>0.69±0.03 (0.65 - 0.74)</td>
<td>0.62±0.06 (0.51 - 0.66)</td>
<td>0.65±0.02 (0.61 - 0.77)</td>
<td>0.64±0.01 (0.63 - 0.64)</td>
</tr>
<tr>
<td>CW/CL</td>
<td>1.28±0.07 (1.18 - 1.40)</td>
<td>1.08±0.05 (1.01 - 1.16)</td>
<td>0.94±0.02 (0.92 - 0.97)</td>
<td>0.84±0.01 (0.83 - 0.86)</td>
<td>0.87±0.04 (0.86 - 0.94)</td>
</tr>
<tr>
<td>EL (Diam ocell)</td>
<td>230±5 (223 - 236)</td>
<td>217±9 (207 - 232)</td>
<td>75±11 (60 - 87)</td>
<td>46±4 (34 - 45)</td>
<td>53±7 (47 - 65)</td>
</tr>
<tr>
<td>Ocellus diameter</td>
<td>78±5 (69 - 84)</td>
<td>83±17 (68 - 117)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ML (LaM)</td>
<td>1235±70 (1154 - 1332)</td>
<td>1502±55 (1410 - 1563)</td>
<td>710±37 (649 - 747)</td>
<td>481±19 (456 - 508)</td>
<td>565±35 (536 - 606)</td>
</tr>
<tr>
<td>MW (LaM)</td>
<td>841±38 (789 - 880)</td>
<td>87±48 (751 - 874)</td>
<td>323±12 (323 - 412)</td>
<td>246±20 (246 - 260)</td>
<td>291±19 (266 - 307)</td>
</tr>
<tr>
<td>MH (HM)</td>
<td>795±42 (714 - 840)</td>
<td>943±55 (870 - 992)</td>
<td>441±57 (349 - 483)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PPH (HPP)</td>
<td>261±25 (220 - 286)</td>
<td>364±24 (320 - 384)</td>
<td>188±24 (150 - 213)</td>
<td>124±9 (114 - 137)</td>
<td>153±9 (138 - 165)</td>
</tr>
<tr>
<td>PW (LaP)</td>
<td>230±16 (206 - 254)</td>
<td>326±21 (308 - 366)</td>
<td>181±15 (161 - 197)</td>
<td>127±3 (124 - 132)</td>
<td>158±9 (138 - 164)</td>
</tr>
<tr>
<td>PPW (LPP)</td>
<td>265±6 (259 - 275)</td>
<td>367±17 (338 - 380)</td>
<td>196±14 (183 - 217)</td>
<td>142±7 (135 - 157)</td>
<td>158±10 (149 - 177)</td>
</tr>
</tbody>
</table>
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 habits of the Sardinian specimens (see https://www.myrmecofournis.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 FERNANDEZ) 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 Plagiopilus xene Stärcke, 1936, whose host is P. pygmaea (Latreille, 1798), was discovered recently (LOI, 2013). Camponotus universitatis Forel, 1890, Formica clara Forel, 1886 Lasius plathythorax Seifert, 1991 and Tapinoma madeirensire 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. madeirensire 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. madeirensire in Sardinia. At the same time, Aphaenogaster fiorii Emery, 1915 and A. subtomanae (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 saliciana 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 (APE=CEM=TM+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. maurititica 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).

<table>
<thead>
<tr>
<th>Sf</th>
<th>Species</th>
<th>Ch</th>
<th>Sf</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Linepithema humile (Mayr, 1868)</td>
<td>exotic</td>
<td>M</td>
<td>Monomorium sobopucum (Smith, F., 1858)</td>
</tr>
<tr>
<td>D</td>
<td>Tapinoma madeirensense Forel, 1895</td>
<td>EUR</td>
<td>M</td>
<td>Myrmecina graminicola (Lateille, 1802)</td>
</tr>
<tr>
<td>D</td>
<td>Tapinoma magna Mayr, 1861</td>
<td>SARD</td>
<td>M</td>
<td>Myrmecina melonii Rigato, 1999</td>
</tr>
<tr>
<td>D</td>
<td>Tapinoma simrothi Krausse, 1911</td>
<td>MED</td>
<td>M</td>
<td>Myrmica spinosior Santschi, 1931</td>
</tr>
<tr>
<td>F</td>
<td>Camponotus aethiops (Lateille, 1798)</td>
<td>SEU</td>
<td>M</td>
<td>Pheidole pallidula (Nylander, 1849)</td>
</tr>
<tr>
<td>F</td>
<td>Camponotus fallax (Nylander, 1856)</td>
<td>TEM</td>
<td>M</td>
<td>Solenopsis lusitanica Emery, 1915</td>
</tr>
<tr>
<td>F</td>
<td>Camponotus gestroi Emery, 1878</td>
<td>MED</td>
<td>M</td>
<td>Solenopsis orbula Emery, 1875</td>
</tr>
<tr>
<td>F</td>
<td>Camponotus lateralis (Oliveir, 1792)</td>
<td>MED</td>
<td>M</td>
<td>Stenamma deblie (Foerster, 1850)</td>
</tr>
<tr>
<td>F</td>
<td>Camponotus piceus (Leach, 1825)</td>
<td>EUR</td>
<td>M</td>
<td>Stenamma sardoun Emery, 1915</td>
</tr>
<tr>
<td>F</td>
<td>Camponotus univittatus Forel, 1890</td>
<td>SEU</td>
<td>M</td>
<td>Stenamma striatulum Emery, 1895</td>
</tr>
<tr>
<td>F</td>
<td>Camponotus vagus (Scopoli, 1763)</td>
<td>CEM</td>
<td>M</td>
<td>Strongylognathus testaceus (Schenck, 1852)</td>
</tr>
<tr>
<td>F</td>
<td>Coleopapis truncata (Spinola, 1808)</td>
<td>TEM</td>
<td>M</td>
<td>Stramigenys argoila (Emery, 1869)</td>
</tr>
<tr>
<td>F</td>
<td>Formica clara Forel, 1886</td>
<td>EUR</td>
<td>M</td>
<td>Stramigenys baudueri (Emery, 1875)</td>
</tr>
<tr>
<td>F</td>
<td>Formica cuculicatriz Lateille, 1798</td>
<td>EUR</td>
<td>M</td>
<td>Stramigenys membranifer Emery, 1869</td>
</tr>
<tr>
<td>F</td>
<td>Formica lugubris Zetterstedt, 1838</td>
<td>exotic</td>
<td>M</td>
<td>Stramigenys tenuiplis Emery, 1915</td>
</tr>
<tr>
<td>F</td>
<td>Lasius bicornis (Foerster, 1850)</td>
<td>ASF</td>
<td>M</td>
<td>Temnothorax aetical (Bondroit, 1918)</td>
</tr>
<tr>
<td>F</td>
<td>Lasius brunneo (Lateille, 1798)</td>
<td>MED</td>
<td>M</td>
<td>Temnothorax exilis (Emery, 1869)</td>
</tr>
<tr>
<td>F</td>
<td>Lasius flavus (Fabricius, 1782)</td>
<td>EUR</td>
<td>M</td>
<td>Temnothorax krausei (Emery, 1915)</td>
</tr>
<tr>
<td>F</td>
<td>Lasius emarginatus (Oliveir, 1972)</td>
<td>EUR</td>
<td>M</td>
<td>Temnothorax lichtensteinii (Bondroit, 1918)</td>
</tr>
<tr>
<td>F</td>
<td>Lasius laevides (Emery, 1869)</td>
<td>MED</td>
<td>M</td>
<td>Temnothorax nyländeri (Foerster, 1850)</td>
</tr>
<tr>
<td>F</td>
<td>Lasius niger (Linnaeus, 1758)</td>
<td>EUR</td>
<td>M</td>
<td>Temnothorax parvalus (Schenck, 1852)</td>
</tr>
<tr>
<td>F</td>
<td>Lasius paraliemus Seifert, 1992</td>
<td>EUR</td>
<td>M</td>
<td>Temnothorax revolutus (André, 1896)</td>
</tr>
<tr>
<td>F</td>
<td>Lasius platyphoros Seifert, 1991</td>
<td>EUR</td>
<td>M</td>
<td>Temnothorax recedens (Nylander, 1856)</td>
</tr>
<tr>
<td>F</td>
<td>Plagiolepis pallescens Forel, 1889</td>
<td>EUR</td>
<td>M</td>
<td>Temnothorax sardous (Santschi, 1909)</td>
</tr>
<tr>
<td>F</td>
<td>Plagiolepis pygmaea (Lateille, 1798)</td>
<td>EUR</td>
<td>M</td>
<td>Temnothorax taberum (Fabricius, 1775)</td>
</tr>
<tr>
<td>F</td>
<td>Plagiolepis sene Stärcke, 1926</td>
<td>EUR</td>
<td>M</td>
<td>Temnothorax unifasciatus (Lateille, 1798)</td>
</tr>
<tr>
<td>L</td>
<td>Leptanilla doideroy Emery, 1915</td>
<td>EUR</td>
<td>M</td>
<td>Tetramorium atratulum (Schenck, 1852)</td>
</tr>
<tr>
<td>L</td>
<td>Leptanilla wulferi Emery, 1870</td>
<td>EUR</td>
<td>M</td>
<td>Tetramorium brevicorne Bondroit, 1918</td>
</tr>
<tr>
<td>M</td>
<td>Aphaenogaster ichnusa Santschi, 1925</td>
<td>EUR</td>
<td>M</td>
<td>Tetramorium caespitum (Linnaeus, 1758)</td>
</tr>
<tr>
<td>M</td>
<td>Aphaenogaster sardous Mayr, 1853</td>
<td>EUR</td>
<td>M</td>
<td>Tetramorium immigrans Santschi, 1927</td>
</tr>
<tr>
<td>M</td>
<td>Aphaenogaster sene Mayr, 1853</td>
<td>EUR</td>
<td>M</td>
<td>Tetramorium meridionale Emery, 1870</td>
</tr>
<tr>
<td>M</td>
<td>Aphaenogaster spinosa Emery, 1878</td>
<td>EUR</td>
<td>M</td>
<td>Tetramorium semlae Andre, 1883</td>
</tr>
<tr>
<td>M</td>
<td>Cardiocondyla mauritanica Forel, 1890</td>
<td>EUR</td>
<td>M</td>
<td>Cryptopone ochracea (Mayr, 1855)</td>
</tr>
<tr>
<td>M</td>
<td>Cremaugaster secuelaris (Oliveir, 1792)</td>
<td>EUR</td>
<td>M</td>
<td>Hyponopona eduardii (Forel, 1894)</td>
</tr>
<tr>
<td>M</td>
<td>Messor capitatus (Lateille, 1798)</td>
<td>EUR</td>
<td>M</td>
<td>Hyponopona punctatissima (Roper, 1859)</td>
</tr>
<tr>
<td>M</td>
<td>Messor ibericus Santschi, 1931</td>
<td>EUR</td>
<td>M</td>
<td>Ponerinae coeritura (Lateille, 1802)</td>
</tr>
<tr>
<td>M</td>
<td>Messor minor Andre, 1883</td>
<td>EUR</td>
<td>M</td>
<td>Ponera testaceus Emery, 1875</td>
</tr>
<tr>
<td>M</td>
<td>Messor wasmanni Krausse, 1910</td>
<td>EUR</td>
<td>M</td>
<td>Ponera testaceus Emery, 1875</td>
</tr>
</tbody>
</table>

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 italicus 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 influences only marginally able to reach Sardinia (Alica & Schifani, 2019; Schifani & Alicata, 2019; Centorame et al., 2020). In particular, Aphaenogaster sardous and Myrmecina melonii are the only two elements of the Sardinian fauna that testify an ancient colonization of Southern-Tyrrhenian species (Schifani et al., 2020). 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. rottenbergorii* (Emery, 1870) without presenting any proper argument or discussion (see KRAUSSE, 1912; EMERY, 1914; 1916; 1924; BONDROIT, 1918; BARONI URBANI, 1971; BOLTON, 1995; 2003; FOLDI et al., 1995; BOROWIEC, 2014; VERDINELLI et al., 2007; LEVAS 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; CSÖSZ & SEIFERT, 2003; CSÖSZ et al., 2015). The old, isolated finding of *H. punctatissima* could potentially represent instead *H. ergatandra* (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.

ACKNOWLEDGEMENTS

We wish to thank Fabrizio Rigato (Museo Civico di Storia Naturale, Milan, Italy) and Ilaria Toni (Bosco Fontana Natural Reserve, Italy) for giving us access to the ant collections of their respective institutions. We also very grateful to the Supervisor Prof. Michela Marignani of Erika Bazzato, PhD project in ‘Earth and Environmental Sciences and Technologies’ of the University of Cagliari, for providing the financial support to fieldwork in the Metropolitan City of Cagliari.

REFERENCES


BACCETTI B., 1983 – Biogeografia sarda venti anni dopo. - Biogeografia, 8: 859-870.


BONDROIT J., 1918 – Les fourmis de France et de Belgique. - Annales de la Société Entomologique de


PEETERS C.P., 1991 – Ergatoid queens and intercastes in ants: two distinct adult forms which look


SCHIFANI E., 2017 – *First record of the vulnerable social parasite ant Plagiolepis grassei in Italy (Hymenoptera: Formicidae)*. - Fragmenta entomologica, 49: 61-64.

SCHIFANI E., ALICATA A., 2018 – Exploring the myrmecofauna of Sicily: thirty-two new ant species recorded, including six new to Italy and many new aliens (*Hymenoptera, Formicidae*). - Polish Journal of Entomology, 87: 323-348.


SEIFERT B., 2018 – *The Ants of Central and North Europe*. - Lutra Verlags- und Vertriebsgesellschaft:
Tauer, Germany.

SEIFERT B., 2020 – A taxonomic revision of the Palaearctic members of the subgenus Lasius s. str. (Hymenoptera, Formicidae). - Soil Organisms, 92: 15-86.


