Checklist and distribution of the groundwater crustacean fauna from Sicily, Italy

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ABSTRACT

Owing to the "Racovitzan impediment", the groundwater fauna of most biogeographical regions is currently inadequately known, thus hampering our understanding of subterranean biodiversity and its protection. Based on an extensive bibliographical review accompanied by fieldwork to localize occurrence sites, a checklist of crustacean taxa reported to date from Sicilian groundwater is provided, and their distribution is described. Among the 63 taxa recorded to date, 43 belong to the class Copepoda (orders Cyclopoida and Harpacticoida), 15 to the class Malacostraca (orders Amphipoda, Bathynellacea, Isopoda, and Thermosbaenacea), and 5 to the class Ostracoda (order Podocopida). Conversely, to date, no representatives of the copepod order Calanoida nor species of the class Branchiopoda have been recorded from groundwater habitats on the island. Several taxa require accurate taxonomic revision or are yet to be formally described and are thus at present left in open nomenclature. Finally, the date of publication of several copepod and amphipod taxa is amended. A high incidence of stygobites (*i.e.*, obligate groundwater dwellers) has been observed in malacostracans, whereas nearly half of the recorded copepods were non-stygobites. This pattern is mirrored by the incidence of endemic species, which is higher in malacostracans than in copepods. The only non-stygobitic crustacean species endemic to Sicily observed in the frame of the present review is the asellid isopod *Proasellus montalentii*. The paucity of information currently available on the Sicilian groundwater ostracods prevents us from drawing conclusions regarding this crustacean group. The origin and composition of Sicilian groundwater crustacean fauna can be explained by considering three major faunal assemblages: the presence of ancient paleoendemic taxa, likely of Miocene origin, the colonization of the groundwater of the island during late Pliocene and Pleistocene land connections with peninsular Italy, and the direct colonization of these environments from the sea; no species of African origin have been discovered to date. Based on currently available data, the groundwater of southeastern Sicily hosts the highest species richness and some of the most biogeographically interesting taxa. Unfortunately, a progressive lowering and salinization of the local aquifers possibly due to climate change and its overexploitation threats this fauna, and several taxa are disappearing even before their discovery and description.

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INTRODUCTION

The Crustacea are often the dominant taxon in aquatic habitats (*i.e.*, oceans, inland surface waters, and groundwater; Huys and Boxshall, 1991; Zagmajster *et al.*, 2018), although they also occur in terrestrial and semi-terrestrial habitats (Bliss and Mantel, 1968). Crustaceans are the most represented invertebrate group in groundwater in terms of both abundance and diversity (Danielopol *et al.*, 2000; Galassi *et al.*, 2009; Zagmajster *et al.*, 2014), thus contributing to the faunal and ecological value of these poorly known habitats (Saccò *et al.*, 2019; Iannella *et al.*, 2021).

The current geographical distribution of the Italian stygobites (*i.e.*, obligate groundwater dwellers) is mainly attributed to paleogeographic and paleoclimatic events and allows us to divide the Italian territory into macro-areas (*i.e.*, biogeographical provinces) characterized by faunal homogeneity. Currently, seven provinces have been described for the Italian stygofauna (*i.e.*, the Dinaric, Alpine, Padane, Apennine, Apulian, Tyrrhen-

ian, and Sicilian provinces) (Pesce, 1985; Stoch, 2001). However, the available information is unevenly distributed, and recent data are missing for some areas (Ruffo and Stoch, 2006a). The existing knowledge gaps are due to several sampling problems, including the inaccessibility of groundwater outside small "windows" such as wells, caves, artificial cavities, and interstitial habitats. These problems are referred to as 'the Racovitzan impediment' (Ficetola *et al.*, 2019).

Between the 1970s and the 2000s several studies were carried out on the Italian stygofauna (*e.g.*, Pesce, 1985; Stoch, 2001; Deharveng *et al.*, 2009), thus increasing our knowledge of these challenging environments. However, in the early 2000s, a slowdown in the number of published papers related to these topics occurred, which was probably due to a lack of specialists. The same applies to the Sicilian stygofaunistic province, where a wide knowledge gap remains to be filled, leading to significant Linnean and Wallacean shortfalls (Hortal *et al.,* 2015), which prevent us from having an accurate knowledge of the actual biological diversity and its distribution in Sicilian groundwater.

In this paper, our goal is to present a review of available data on the occurrence and distribution of crustaceans in Sicilian subterranean waters.

METHODS

Study area

Sicily, the largest Mediterranean island, spans an area of over 25,700 km^2 and is known for its high level of biodiversity in the Mediterranean Basin (Hupalo *et al.,* 2021; Marrone and Naselli-Flores, 2022). The hydrogeological setting of this biogeographic province is shown in Fig. 1. The northern and north-eastern parts of Sicily are occupied by mountain ranges, such as Madonie, Nebrodi, and Peloritani, which are composed of various rock formations, including limestones, sandstones, and igneous and metamorphic rocks. In the southeast, the karstic Hyblean Massif is home to perennial streams, large aquifers, and numerous caves. The central part of the island is mainly composed of gypsum formations with poor and intermittent surface hydrography and well-developed caves. In the eastern part of Sicily, Mount Etna volcano, 3,350 m above sea level, is the highest peak on the island. Moreover, Sicily is surrounded by smaller islands and archipelagos, which consist of the Egadi Islands (carbonate), the Island of Ustica (volcanic), the Aeolian Islands (volcanic), Pantelleria (volcanic) and the Pelagie Islands (Linosa, volcanic, and Lampedusa, carbonate).

Bibliographic review and data validation

A review of bibliographical data on Sicilian groundwater crustacean fauna was conducted based on an extensive literature search. In addition, the data stored in the CKmap (Ruffo and Stoch, 2006a) and PASCALIS (Deharveng *et al.,* 2009) databases were revised and included in this study. The localization of several sites was assessed in the field. Examples of the groundwater habitat types sampled are shown in Fig. 2.

Based on the collected data, we produced a checklist of the crustacean taxa reported to occur in the Sicilian groundwater. Although crustaceans living in subterranean waters are often di-

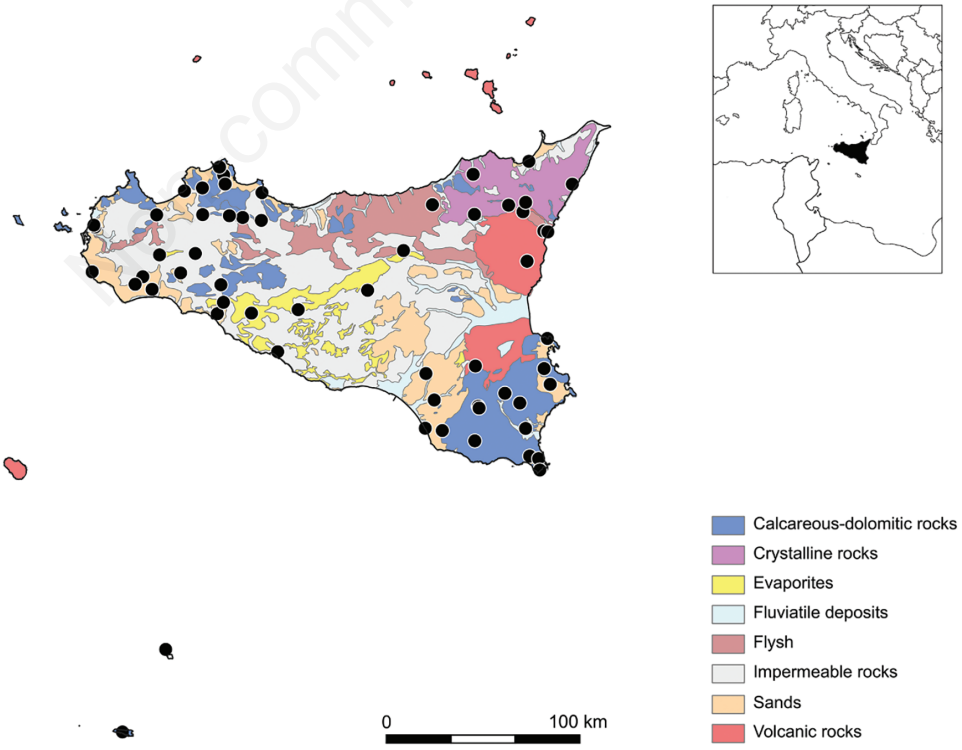

Fig. 1. Distribution of the sites where stygobitic species have been reported according to the literature (black dots) superimposed to the hydrogeological units of the island.

vided into stygobitic, stygophilic, and stygoxenic species according to their adaptations and specialization to life in groundwater, a clear-cut separation of stygophiles *vs* stygoxenes is often impossible (see Galassi, 2001); therefore, we opted to distinguish only between stygobitic and non-stygobitic taxa.

The occurrence localities of stygobionts have been reported and mapped (Fig. 1), along with an exhaustive regional bibliography for each species. References are provided separately for the epigean and subterranean occurrence localities of non-stygobitic taxa. Occurrence record data were also uploaded to the Global Biodiversity Information Facility (GBIF) and are available at: (https://doi.org/10.15468/mjh525).

RESULTS

Overall, 31 papers provided primary occurrence data on groundwater crustaceans in Sicily, belonging to the Copepoda, Ostracoda, and Malacostraca. We did not include here papers lacking precise information about the origin of the data and\or location of the sampled sites (Pesce, 2002, 2003). The Copepoda are the most investigated group, whereas apart from the mention of unidentified Cladocera by Galletti (2000, 2004) from Hyblean springs, no records of Branchiopoda are available to date for Sicilian groundwater. Overall, 63 taxa attributed to 18 families were found to occur in Sicilian groundwater (Tabs. 1 and 2). Copepoda Cyclopoida and Harpacticoida are the most represented orders in Sicilian groundwater (no representatives of the order Calanoida are reported up to now), with 21 and 22 taxa each, followed by Amphipoda, Ostracoda, and Isopoda (ten, five and three taxa, respectively). Thermosbaenacea and Bathynellacea are known to date with only one species each (Fig. 3). The list of all the Sicilian occurrence localities known for stygobitic crustacean species is reported in *Tab. S1*.

The identity of the asellid isopods recorded from several localities, such as *Proasellus coxalis* (Dollfus, 1892) by Pesce (1987) and Pesce and Galassi (1987a), could not be ascertained. *P. coxalis* s. str. does not occur in Sicily, where it is replaced by *P. banyulensis* (Racovitza, 1919), *P. montalentii* Stoch, Valentino and Volpi, 1996, *P. wolfi* (Dudich, 1925) (Stoch *et al.,* 1996), and an undescribed species reported as *Proasellus* sp. in Eme *et al*. (2017) and Saclier *et al*. (2024). Since the identity of these populations cannot be checked, we did not include their occurrence localities. Conversely, new samplings gave the opportunity to verify that *Proasellus coxalis* reported for Grotta di Santa Ninfa by Caruso and Costa (1978) is to be assigned to *P. montalentii* (Stoch and Marrone, unpublished data).

Reviewing the bibliographical data, we noticed that Pesce and Galassi (1987a) mentioned species described in 1988; these are: *Attheyella (N.) paranaphtalica* Pesce and Galassi, 1988, *Stammericaris trinacriae* (Pesce, Galassi and Cottarelli, 1988), and *Proserpinicaris kalypso* (Pesce, Galassi and Cottarelli, 1988); the last two species are reported in Pesce and Galassi (1987a) under the genus *Parastenocaris*. This inconsistency is due to the fact that Animalia volume 14 (1/3), where the paper by Pesce and Galassi (1987a) has been published, is dated 1987 (imprint date) but, as reported in the volume itself, it was actually printed in December 1988 (actual date); its colophon reads: '*Finito di stampare presso "La Nuovografica" di Ugo Tringali – Catania nel mese di Dicembre 1988*". In accordance with articles 21 and 22 of the International Code of Zoological Nomenclature (ICZN, 1999), the correct date of publication of the copepod taxa described by Pesce and Galassi (1987a), namely, *Eucyclops ibleicus*, *Eucyclops longispinosus*, *Diacyclops crassicaudis lagrecai*, and *Diacyclops crassicaudis trinacriae*, is thus 1988.

Fig. 2. Subterranean habitats considered in this paper (see Tab. 1). (a) Artificial gallery (Sorgenti del Gabriele, province of Palermo); (b) ancient well in unconsolidated sediments (province of Palermo); (c) spring captured to feed a fountain (province of Enna); (d) cave (gypsum cave of Santa Ninfa, active meander, province of Trapani).

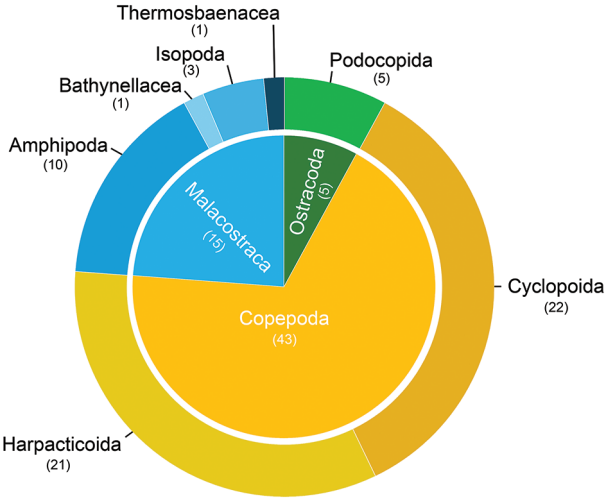

Fig. 3. Taxonomic composition of the groundwater crustacean fauna of Sicily. The number of taxa for each class and order is reported among brackets.

Tab. 1. Checklist of the non-malacostracan crustaceans to date known in Sicilian groundwater.

	Stygobitic taxon	Endemic taxon
Class Ostracoda		
Order Podocopida		
Family Candonidae		
Cryptocandona sp.	n.a.	n.a.
Fabaeformiscandona sp.	n.a.	n.a.
Mixtacandona idrisi Mazzini & Rossetti, 2017	Yes	Yes
Pseudocandona sp.	n.a.	n.a.
Family Ilyocyprididae		
Ilyocypris sp.	n.a.	n.a.
Class Copepoda		
Order Cyclopoida		
Family Halicyclopidae		
Halicyclops troglodytes Kiefer, 1954	Yes	No
Family Cyclopidae		
Eucyclops (*Denticyclops*) *ibleicus* Pesce & Galassi, 1988	Yes	Yes
Eucyclops (*Denticyclops*) *longispinosus* Pesce & Galassi, 1988	Yes	Yes
Eucyclops (*Eucyclops*) *serrulatus* (Fischer, 1851)	No	No
Macrocyclops albidus (Jurine, 1820)	No	No
Paracyclops fimbriatus (Fischer, 1853)	No	No
Tropocyclops prasinus (Fischer, 1860)	No	No
Cyclops divergens Lindberg, 1936	No	No
Diacyclops bisetosus (Rehberg, 1880)	No	No
Diacyclops clandestinus (Kiefer, 1926)	Yes	No
Diacyclops crassicaudis lagrecai Pesce & Galassi, 1988	Yes	Yes
Diacyclops crassicaudis trinacriae Pesce & Galassi, 1988	Yes	Yes
Diacyclops lubbocki (Brady, 1869)	No	No
Megacyclops viridis (Jurine, 1820)	No	No
Metacyclops planus (Gurney, 1809)	No	No
Metacyclops sp.	Yes	Yes
Microcyclops varicans (G.O. Sars, 1863)	No	No
Speocyclops italicus Kiefer, 1938	Yes	No
Speocyclops sp.1	Yes	Yes
Speocyclops sp.2	Yes	Yes
Thermocyclops stephanidesi Kiefer, 1938	No	No
Order Harpacticoida		
Family Miraciidae		
Schizopera (*Schizopera*) *lagrecai* Pesce, 1988	Yes	Yes
Family Ameiridae		
Nitocra lacustris lacustris (Schmankevitsch, 1875)	No	No
Nitocrella stammeri Chappuis, 1938	Yes	No
Family Canthocamptidae		
Attheyella (*Attheyella*) *crassa* (Sars G.O., 1863)	No	No
Attheyella (*Neomrazekiella*) *paranaphtalica* Pesce & Galassi, 1988	Yes	No
Bryocamptus (*Bryocamptus*) *minutus* (Claus, 1863)	No	No
Bryocamptus (*Echinocamptus*) *echinatus* (Mrázek, 1893)	No	No
Bryocamptus (*Rheocamptus*) *pygmaeus* (G.O. Sars, 1863)	No	No
Bryocamptus (*Rheocamptus*) *stillae* Cottarelli & Bruno, 2012	Yes	Yes
Bryocamptus (*Rheocamptus*) *zschokkei* (Schmeil, 1893)	No	No
Canthocamptus (*Canthocamptus*) *staphylinus* (Jurine, 1820)	No	No
Elaphoidella elaphoides elaphoides Chappuis, 1923	Yes	No
Elaphoidella cf. *phreatica* (Chappuis, 1925)	Yes	No
Elaphoidella plutonis Chappuis, 1938	Yes	No
Family Leptopontiidae		
Psammopsyllus maricae Cottarelli, Saporito & Puccetti, 1983	n.a.	No
Family Parastenocarididae		
Cottarellicaris luciae (Cottarelli, Bruno & Berera, 2008)	Yes	Yes
Proserpinicaris kalypso (Pesce, Galassi & Cottarelli, 1988)	Yes	Yes
Stammericaris destillans Bruno & Cottarelli, 2017	Yes	Yes
Stammericaris diversitatis (Cottarelli & Bruno, 2012)	Yes	Yes
Stammericaris similior Cottarelli & Bruno, 2023	Yes	Yes
Stammericaris trinacriae (Pesce, Galassi & Cottarelli, 1988)	Yes	Yes
Family Phyllognathopodidae		
Phyllognathopus viguieri (Maupas, 1892)	No	No

n.a., not attributable.

Tab. 2. Checklist of the malacostracan crustaceans to date known from Sicilian groundwater.

	Stygobitic taxon	Endemic taxon
Class Malacostraca		
Order Amphipoda		
Family Gammaridae		
Pectenogammarus sicilianus s.l. (Karaman & Tibaldi, 1972)	No	Yes
Rhipidogammarus rhipidiophorus (Catta, 1878)	No	No
Tyrrhenogammarus catacumbae (Karaman & Ruffo, 1978)	Yes	Yes
Family Ischyroceridae		
Jassa slatteryi Conlan, 1990	No	No
Family Niphargidae		
Niphargus longicaudatus s.l. (Costa, 1851)	Yes	No
Family Pseudoniphargidae		
Pseudoniphargus adriaticus s.l. Karaman, 1955	Yes	No
Pseudoniphargus duplus Messouli, Messana & Yacoubi-Khebiza, 2006	Yes	Yes
Pseudoniphargus inconditus Karaman & Ruffo, 1990	Yes	Yes
Pseudoniphargus italicus Karaman & Ruffo, 1990	Yes	Yes
Pseudoniphargus sodalis Karaman & Ruffo, 1990	Yes	Yes
Order Bathynellacea		
Family Bathynellidae		
Meridiobathynella sp.	Yes	Yes
Order Isopoda		
Family Asellidae		
Proasellus montalentii Stoch, Valentino & Volpi, 1996	No	Yes
Proasellus sp.	Yes	Yes
Family Cirolanidae		
Typhlocirolana cf. *moraguesi* Racovitza, 1905	Yes	???
Order Thermosbaenacea		
Family Monodellidae		
Tethysbaena siracusae Wagner, 1994	Yes	Yes

Based on this evidence, we also checked the imprint and actual date of Animalia volume 4, where the amphipod *Tyrrhenogammarus catacumbae* was described (Karaman and Ruffo, 1977), and Animalia volume 16, where some Sicilian *Pseudoniphargus* species were described (Karaman and Ruffo, 1989). The colophon of Animalia volume 4 (1-2) reads: "*Finito di stampare nel mese di Febbraio 1978 con i tipi de "La Nuovografica" Via Pasubio Catania*", and the colophon of Animalia volume 16 reads: '*Finito di stampare presso "La Nuovografica" di Ugo Tringali – Catania nel mese di Dicembre 1990*". In accordance with the aforementioned articles of the ICZN (1999), the correct date of publication for *Tyrrhenogammarus catacumbae* is 1978, not 1977, and the correct date of publication for *Pseudoniphargus italicus*, *P. inconditus*, and *P. sodalis* is 1990, not 1989. The same applies to *Tyrrhenogammarus sardous*, described in the same paper but not present in our study area and thus not treated below.

A commented checklist and bibliography of the recorded taxa is reported below.

Class Ostracoda

Order Podocopida

Family Candonidae Kaufmann, 1900

Genus *Cryptocandona* Kaufmann, 1900

***Cryptocandona* sp.**

Remarks: an unidentified *Cryptocandona* species was reported by Nicolosi *et al.* (2022) in the gypsum cave of Monte Conca. This is the only record in Sicily of the genus *Cryptocandona*, which is represented on Italian mainland by two species (Rossetti, 2021).

Groundwater occurrence localities: gypsum cave of Monte Conca, province of Caltanissetta (Nicolosi *et al.,* 2022).

Genus *Fabaeformiscandona* Krstić,1972

***Fabaeformiscandona* sp.**

Remarks: an unidentified *Fabaeformiscandona* species was reported by Nicolosi *et al.* (2022) in the gypsum cave of Monte Conca. Two species belonging to this genus are to date reported for Sicily: *Fabaeformiscandona subacuta* (Yang, 1982) and *Fabaeformiscandona* cf. *holzkampfi* (Hartwig, 1900), both occurring in permanent, surface water bodies located in south-western Sicily, province of Trapani (Curry *et al.,* 2016; Pieri *et al.,* 2020). *F. subacuta* is considered a non-native species in Sicily (Pieri *et al.,* 2020).

Groundwater occurrence localities: gypsum cave of Monte Conca, province of Caltanissetta (Nicolosi *et al.,* 2022).

Genus *Mixtacandona* Klie, 1938

Mixtacandona idrisi Mazzini and Rossetti, 2017 in: Mazzini *et al.* (2017)

Remarks: Stygobitic species, endemic to Sicily. It is currently only known from its type locality (Mazzini *et al.,* 2017; Pieri *et al.,* 2020).

Groundwater occurrence localities: Grotta degli Spiriti, Contrada Petrazzi, province of Palermo, Italy (Mazzini *et al.,* 2017).

Genus *Pseudocandona* Kaufmann, 1900

***Pseudocandona* sp.**

Remarks: an unidentified *Pseudocandona* species was reported

by Nicolosi *et al.* (2022) in the gypsum cave of Monte Conca. The only *Pseudocandona* species to date known from Sicily is *Pseudocandona albicans* (Brady, 1864) (Pieri *et al.,* 2020).

Groundwater occurrence localities: gypsum cave of Monte Conca, province of Caltanissetta (Nicolosi *et al.,* 2022).

Family Ilyocyprididae Kaufmann, 1900
Genus Ilyocypris Brady and Norman, 1889
***Ilyocypris* sp.**

Remarks: an unidentified *Ilyocypris* species was reported by Nicolosi *et al.* (2022) in the gypsum cave of Monte Conca. Several congeners are currently known from Sicily (Pieri *et al.,* 2006, 2020).

Groundwater occurrence localities: gypsum cave of Monte Conca, province of Caltanissetta (Nicolosi *et al.,* 2022).

Class Copepoda
Order Cyclopoida
Family Halicyclopidae Kiefer, 1927
Genus *Halicyclops* Norman, 1903
Halicyclops troglodytes Kiefer, 1954

Remarks: stygobitic, brackish water/anchialine species with a Mediterranean distribution.

Groundwater localities: In Sicilian mainland, the species has been found in the hyporheic habitat of the Salso River (province of Enna, Pesce and Galassi, 1987a). Pesce and Galassi (1987a) reported the species also for Lampedusa Island). Its occurrence in brackish water wells in Portopalo di Capo Passero, reported by Pesce (2002, 2003) is doubtful and requires confirmation.

Family Cyclopidae Rafinesque, 1815
Subfamily Eucyclopinae Kiefer, 1927
Genus *Eucyclops* Claus, 1893
Eucyclops* (*Denticyclops*) *ibleicus Pesce and Galassi, 1988 *nec* 1987

Remarks: stygobitic species, endemic to Sicily. Animalia volume 14 (1/3), where the paper by Pesce and Galassi (1987a) was published, is dated 1987 (imprint date) but, as reported in the volume itself, it was printed in December 1988 (actual date). In accordance with articles 21 and 22 of the ICZN, the correct date of publication of *Eucyclops ibleicus* is thus 1988.

Groundwater localities: freshwater well in Scoglitti (province of Ragusa) (Pesce and Galassi, 1987a). The occurrence of the species in brackish wells in Portopalo di Capo Passero (Siracusa) (Pesce 2002, 2003) is doubtful and requires confirmation; no material of this species was found studying Pesce's collection in L'Aquila by FS, and there are no further literature citations.

Eucyclops (Denticyclops) longispinosus Pesce and Galassi, 1988 *nec* 1987

Remarks: stygobitic species, endemic to Sicily. Animalia volume 14 (1/3), where the paper by Pesce and Galassi (1987a) was published, is dated 1987 (imprint date) but, as reported in the volume itself, it was printed in December 1988 (actual date). In accordance with articles 21 and 22 of the ICZN (1999), the correct date of publication of *Eucyclops longispinosus* is thus 1988.

Groundwater localities: to date, the species is known to occur in the eastern part of the island in a freshwater well in "località Fleri" (province of Catania) (Pesce and Galassi, 1987a). Conversely, the occurrence of the species in the anchialine systems in the karstic area of Portopalo di Capo Passero (Siracusa) (Pesce, 2002, 2003) is doubtful and requires confirmation (see the remark on *E. ibleicus* above).

Eucyclops (Eucyclops) serrulatus (Fischer, 1851)

Remarks: non-stygobitic species; it is one of the most ubiquitous cyclopoids with widespread distribution, inhabiting both hypogean and epigean habitats (*e.g.*, Dussart, 1969; Alekseev *et al.,* 2006; Alekseev and Defaye, 2011).

Groundwater localities: In Sicily, this taxon has been reported to occur in brackish waters, caves, and freshwater wells throughout the island (Pesce, 1987; Pesce and Galassi, 1987a; Nicolosi *et al.,* 2022).

Other occurrence localities in Sicily: Margaritora *et al.,* 1982; Calvo *et al.,* 1993; Marchese *et al.,* 2022.

Genus *Macrocyclops* Claus, 1893
Macrocyclops albidus (Jurine, 1820)

Remarks: non-stygobitic species, widespread and euryecious (Dussart, 1969).

Groundwater localities: freshwater well in Acate (province of Ragusa) (Pesce and Galassi, 1987a).

Other occurrence localities in Sicily: Margaritora *et al.,* 1982; Schifani *et al.,* 2019; Marchese *et al.,* 2022.

Genus *Paracyclops* Claus, 1893
Paracyclops fimbriatus (Fischer, 1853)

Remarks: non-stygobitic species, widely distributed in the Palearctic region (Dussart, 1969). Its possible confusion with the congeneric *P. imminutus* Kiefer, 1929, inhabiting hyporheic and subterranean water as a non-stygobitic taxon, poses some doubts about the actual identity of the material identified so far from Sicily.

Groundwater localities: Numerous records of this taxon are available for both slightly brackish and freshwater wells in Sicily (Pesce and Galassi, 1987a) and in a cave (Nicolosi *et al.,* 2022).

Other occurrence localities in Sicily: none.

Genus *Tropocyclops* Kiefer, 1927
Tropocyclops prasinus (Fischer, 1860)

Remarks: non-stygobitic species. It inhabits both epigean and subterranean aquatic environments (Dussart, 1969; Kiefer, 1978).

Groundwater localities: Its distribution across the island is broad, with a wide range of ecological habitats (from brackish to freshwater wells and hyporheic and interstitial habitats) (Pesce and Galassi, 1987a).

Other occurrence localities in Sicily: records of the species are also available in surface water bodies throughout the island (Margaritora *et al.,* 1982; Calvo *et al.,* 1993; Troia *et al.,* 2016; Marchese *et al.,* 2022).

Subfamily Cyclopinae Rafinesque, 1815
Genus *Cyclops* O.F. Muller, 1776
Cyclops divergens Lindberg, 1936

Remarks: non-stygobitic species, typical of astatic water bodies.

This species is widespread in western Palearctic (Hołyńska, 2008; Hołyńska and Wyngaard, 2019).

Groundwater localities: freshwater wells in Vizzini (province of Catania) and Canicattini Bagni (province of Siracusa) (Pesce and Galassi, 1987a).

Other occurrence localities in Sicily: see Margaritora *et al.,* 1982 (*sub C. abyssorum*); Calvo *et al.,* 1993 (*sub C. strenuus*); Hołyńska, 2008; Troia *et al.,* 2016; Marchese *et al.,* 2022.

Genus *Diacyclops* Kiefer, 1927

Diacyclops bisetosus (Rehberg, 1880)

Remarks: non-stygobitic species, subcosmopolitan (Dussart, 1969), frequent in ephemeral temporary waters and seepages, sometimes found in caves and wells, and even in brackish waters (Stoch, 1995).

Groundwater localities: slightly brackish water wells in Montallegro and Petrosino (province of Agrigento and Trapani, respectively) and a hyporheic zone of the Salso River (confluence of the Mandre stream, province of Enna) (Pesce and Galassi, 1987a, 1987b).

Other localities in Sicily: see Margaritora et al. (1982), Troia et al. (2016), Marchese et al. (2022).

Diacyclops clandestinus (Kiefer, 1926)

Remarks: stygobitic species, widely distributed in the groundwater of continental Italy (Stoch, 2006). Its taxonomic confusion with *Diacyclops paolae* Pesce and Galassi, 1987, which is widespread in the Mediterranean area (Stoch, 1995), prevents a better definition of its distribution, even in Sicily, where *D. paolae* could possibly replace *D. clandestinus*.

Groundwater localities: freshwater wells in Acate (province of Ragusa), Niscemi (province of Catania), and slightly brackish water wells in Castell'Umberto (province of Messina) and Brucoli (province of Siracusa) (Pesce and Galassi, 1987a).

Diacyclops crassicaudis lagrecai Pesce and Galassi, 1988 *nec* 1987

Remarks: stygobitic taxon, endemic to Sicily. It inhabits freshwater unconsolidated aquifers (Pesce, 1994). Animalia volume 14 (1/3), where the paper by Pesce and Galassi (1987a) was published, is dated 1987 (imprint date) but, as reported in the volume itself, it was printed in December 1988 (actual date). In accordance with articles 21 and 22 of the ICZN (1999), the correct date of publication of *Diacyclops crassicaudis lagrecai* is thus 1988. In a recent description of a new *Diacyclops* from Siberia (Novikov *et al.,* 2024), this subspecies and the following are listed among the 'major synonyms' (sic!) of *Diacyclops crassicaudis* (Sars, 1863). No explanation of its synonymy is provided, and the redescription of *Diacyclops crassicaudis* (terra typica: Sweden) is based on material collected in Tatarstan (Russia). At the present state of our knowledge, and pending a formal revision of this species complex, the proposal by Novikov *et al.* (2024) of a single species widely distributed in the Palearctic is not considered herein.

Groundwater localities: freshwater wells in Baucina and San Cipirello (province of Palermo) (Pesce and Galassi, 1987a); Scrivilleri cave, province of Siracusa (Bruno *et al.,* 2023).

Diacyclops crassicaudis trinacriae Pesce and Galassi, 1988 *nec* 1987

Remarks: stygobitic taxon, endemic to Sicily. It was found in an anchialine karstic aquifer. Animalia volume 14 (1/3), where the paper by Pesce and Galassi (1987a) was published, is dated 1987 (imprint date) but, as reported in the volume itself, it was printed in December 1988 (actual date). In accordance with articles 21 and 22 of the ICZN, the correct date of publication of *Diacyclops crassicaudis trinacriae* is thus 1988. As reported for the previous taxon, *D. crassicaudis trinacriae* was considered by Novikov *et al*. (2024) junior synonym of *D. crassicaudis* (see the considerations reported above).

Groundwater localities: brackish water well near Pachino, province of Siracusa (Pesce and Galassi, 1987a).

Diacyclops lubbocki (Brady, 1869)

Remarks: non-stygobitic species with a Palearctic distribution, occurring in both hypogean and epigean aquatic environments, including brackish water ponds and pools (Dussart, 1969). Stoch (1996) considered it a valid species and a senior synonym of *Diacyclops bicuspidatus odessanus* (Schmankevitch 1975). However, some authors (*e.g.*, Hołyńska *et al.,* 2023) doubt that this species should be considered valid given the doubts on the alleged morphological inconsistencies found between *Diacyclops lubbocki* and the congeneric *D. bicuspidatus*. Pending taxonomic revision based on molecular data, we prefer to maintain the traditional taxonomic distinction, mainly based on the number of antennulary articles (*i.e.*, 14 articles in *D. lubbocki*, 17 in *D. bicuspidatus*).

Groundwater localities: hyporheic habitats (*i.e.*, Salso River, confluence of the Mandre stream, and Gaggera River, province of Enna and Trapani, respectively), freshwater wells in Selinunte, Fiso (a hamlet of Valderice), and Marausa (province of Trapani), in slightly brackish water wells in the western part of the island (*i.e.*, Trapani and Agrigento), in freshwater wells in Zafferana Etnea and Vizzini, province of Catania (Pesce and Galassi, 1987a).

Other occurrence localities in Sicily: see Margaritora *et al.,* 1982; Marrone and Naselli-Flores, 2004; Marchese *et al.,* 2022.

Genus *Megacyclops* Kiefer, 1827

Megacyclops viridis (Jurine, 1820)

Remarks: non-stygobitic species, widely distributed in the Palearctic (Dussart, 1969).

Groundwater localities: it has been recorded in both brackish and freshwater wells in the province of Trapani (Pesce and Galassi, 1987a).

Other occurrence localities in Sicily: Margaritora *et al.,* 1982; Troia *et al.,* 2016; Marchese *et al.,* 2022.

Genus *Metacyclops* Kiefer, 1927

Metacyclops planus (Gurney, 1809)

Remarks: non-stygobitic species with circum-Mediterranean distribution. The species typically inhabits temporary and astatic water bodies of both natural and anthropogenic origin (Dussart, 1969).

Groundwater localities: to date, the species has been reported to occur only in a freshwater well in Montelepre (province of Palermo, Pesce, and Galassi, 1987a).

Other occurrence localities in Sicily: Margaritora *et al.,* 1982; Calvo *et al.,* 1993.

***Metacyclops* sp.**
Remarks: presumably stygobitic species, currently pending a formal description (Bruno *et al*., 2023).
Groundwater localities: Grotta Scrivilleri, province of Siracusa (Bruno *et al.,* 2023)

Genus *Microcyclops* Claus, 1983
Microcyclops varicans (G.O. Sars, 1863)
Remarks: non-stygobitic species, widespread in ponds and rivers, and occasionally present in groundwater (Dussart, 1969).
Groundwater localities: the species has been found in slightly brackish and freshwater wells in the north-western part of the island (province of Trapani and Palermo; Pesce and Galassi, 1987a), and in a cave (Nicolosi *et al.,* 2022).
Other occurrence localities in Sicily: Margaritora *et al.,* 1982; Pesce and Galassi, 1987a; Marchese *et al.,* 2022.

Genus *Speocyclops* Kiefer, 1937
Speocyclops italicus Kiefer, 1938
Remarks: stygobitic species, endemic to peninsular Italy and Sicily (Galassi and de Laurentiis, 2004; Stoch, 2006).
Groundwater localities: a single occurrence site has been reported in Sicily (Grotta Conza, Palermo Province: Cottarelli *et al.,* 2012; Bruno *et al.,* 2018).

***Speocyclops* sp.1**
Remarks: unidentified cyclopoid species belonging to the stygobitic genus *Speocyclops*. It is likely a species new to science, pending a formal description (Cottarelli, *in litteris*).
Groundwater localities: Zubbia del Cavallo cave, province of Agrigento (Bruno *et al.,* 2018)

***Speocyclops* sp.2**
Remarks: unidentified cyclopoid species belonging to the stygobitic genus *Speocyclops*. It is likely a species new to science, pending a formal description (Cottarelli, *in litteris*).
Groundwater localities: hyporheic habitat of the Alcantara river, province of Catania (Bruno *et al.,* 2018)

Genus *Thermocyclops* Kiefer, 1927
Thermocyclops stephanidesi Kiefer, 1938
Remarks: non-stygobitic species with a Mediterranean distribution that occurs mostly in hypogean habitats, although not eyeless and usually pigmented (Pesce and Galassi, 1987a). *T. stephanidesi* (terra typica: Island of Corfu, Greece) was considered by Pesce and Galassi (1987a) as a synonym of *T. oblongatus* (a species described from South Africa and distributed in the African continent northward until Niger, where a different subspecies, *T. oblongatus nigerianus* Kiefer, 1932, occurs). Synonymy was not recognized by Stoch (2006). In the present catalogue we followed WoRMS (Walter and Boxshall, 2024), where *T. stephanidesi* is considered a good species.
Groundwater localities: several localities have been recorded for this taxon throughout the island both in brackish and fresh groundwater systems (Pesce, 1987; Pesce and Galassi, 1987a, sub *T. oblongatus* (Sars, 1927)).
Other occurrence localities in Sicily: none.

Order Harpacticoida
Family Miraciidae Dana, 1846
Genus *Schizopera,* G.O. Sars, 1905
Schizopera (Schizopera) lagrecai Pesce, 1988 *nec* 1987
Remarks: stygobitic species endemic to Sicily.
Groundwater localities: the species occurs in brackish water wells in the provinces of Agrigento and Catania, and in the hyporheic habitat of the Salso River, province of Enna (Pesce, 1987; Pesce and Galassi, 1987a).

Family Ameiridae Boeck, 1865
Genus *Nitocra* Boeck, 1864
Nitocra lacustris lacustris (Schmankevitsch, 1875)
Remarks: a widespread surface species in Europe (with different subspecies described in the Palearctic), inhabiting lakes, slow flowing rivers, and brackish waters (Defaye and Dussart, 2011).
Groundwater localities: hyporheic habitat of the Salso River at the confluence between Torrente Mandre and Salso River (Pesce and Galassi, 1987a)
Other occurrence localities in Sicily: none.

Genus *Nitocrella* Chappuis, 1924
Nitocrella stammeri Chappuis, 1938
Remarks: stygobitic species with a peri-Mediterranean distribution (Defaye and Dussart, 2011).
Groundwater localities: this species is one of the most represented among groundwater harpacticoids throughout the island (Caruso and Costa, 1978; Cottarelli and Fasano, 1979; Caruso, 1982; Pesce, 1985, 1987, 2003; Pesce and Galassi, 1987a; Wagner, 1994; Bruno *et al.,* 2018).

Family Canthocamptidae Brady, 1880
Genus *Attheyella* Brady, 1880
Attheyella (Attheyella) crassa (Sars G.O., 1863)
Remarks: non-stygobitic species, with a wide Palearctic distribution (Defaye and Dussart, 2011).
Groundwater localities: this species has been reported in groundwater and hyporheic habitats (Pesce, 1987; Pesce and Galassi, 1987a; Bruno *et al.,* 2018; Nicolosi *et al.,* 2022).
Other occurrence localities in Sicily: Marrone and Naselli-Flores (2004).

Attheyella* (*Neomrazekiella*) *paranaphtalica Pesce and Galassi, 1988
Remarks: stygobitic species, endemic to Italy; the synonymy with the widespread, epigean *Attheyella* (*Neomrazekiella*) *wulmeri wulmeri* (Kerhervé, 1914), proposed by Karanovic (1999), is unreliable and the correct subgeneric allocation was established by Özdikmen and Pesce (2006).
Groundwater localities: collected from hyporheic habitats in the provinces of Trapani and Agrigento, (Pesce and Galassi, 1987a; 1988).

Genus *Bryocamptus* (Chappuis, 1929)
Bryocamptus (Bryocamptus) minutus (Claus, 1863)
Remarks: non-stygobitic species, widespread and euryecious, broadly distributed in Italy (Berera *et al.,* 2006) and occasionally present in groundwater (Defaye and Dussart, 2011).
Groundwater localities: found in the hyporheic environment of

the Manghisi River, province of Siracusa (Pesce and Galassi, 1987a).
Other occurrence localities in Sicily: none.

Bryocamptus (Echinocamptus) echinatus (Mrázek, 1893)
Remarks: non-stygobitic species. It is considered a stenothermic species of cold waters, inhabiting springs, mosses, subterranean waters, and lakes in Europe and Asia (Defaye and Dussart, 2011).
Goundwater localities: hyporheic habitat at the spring 'Sorgente Serra del Re' (Pesce and Galassi, 1987a).
Other occurrence localities in Sicily: none.

Bryocamptus (Rheocamptus) pygmaeus (G.O. Sars, 1863)
Remarks: non-stygobitic species, euryecious and widely distributed in Italy, especially in mosses and marshes, but also common in springs, brooks, and interstitial waters (Berera *et al.,* 2006; Defaye and Dussart, 2011).
Groundwater localities: reported in hyporheic habitats in the provinces of Palermo and Enna (Pesce and Galassi, 1987a), and in a cave in the province of Caltanissetta (Nicolosi *et al.,* 2022).
Other occurrence localities in Sicily: none.

Bryocamptus (Rheocamptus) stillae Cottarelli and Bruno, 2012 in: Cottarelli *et al.* (2012)
Remarks: stygobitic species endemic to Sicily, known only from a single locality.
Groundwater localities: Grotta Conza (percolating waters), Palermo province (Cottarelli *et al.,* 2012).

Bryocamptus (Rheocamptus) zschokkei (Schmeil, 1893)
Remarks: Non-stygobitic species with a Holarctic distribution, often confused with *Bryocamptus (Rheocamptus) tatrensis* (Minkiewicz, 1916); the Sicilian populations need to be re-examined.
Groundwater localities: reported in interstitial waters in the province of Messina (Pesce and Galassi, 1987a), and in drip pools in the cave "Zubbia del Cavallo", province of Agrigento (Bruno *et al.,* 2018).
Other occurrence localities in Sicily: none.

Genus Canthocamptus Westwood, 1836
Canthocamptus (Canthocamptus) staphylinus (Jurine, 1820)
Remarks: non-stygobitic species, widely distributed in the Palearctic region (Defaye and Dussart, 2011). *Canthocamptus staphylinus* has a wide ecological tolerance and occurs in different habitat types (*e.g.*, lakes, reservoirs, marshes, rivulets, and temporary waters, occasionally found in hyporheic and phreatic waters).
Groundwater localities: reports of the species in underground environments are limited to a single observation in a freshwater well located in the province of Palermo (Pesce and Galassi, 1987a).
Other occurrence localities in Sicily: Troia *et al.,* 2016; Marchese *et al.,* 2022.

Genus *Elaphoidella* Chappuis, 1929
Elaphoidella elaphoides elaphoides Chappuis, 1923
Remarks: stygobitic species, widely distributed in Europe in both hypogean and marginal habitats (Defaye and Dussart, 2011).
Groundwater localities: this species is known from freshwater wells in Palermo and Trapani provinces (Pesce *et al.,* 1987; Pesce and Galassi, 1987a), and in Scrivilleri cave, province of Siracusa (Bruno *et al.,* 2023). Pesce (2002, 2003) reported the occurrence of this species from brackish water wells in the province of Siracusa, but this record is doubtful and requires confirmation.

Elaphoidella* cf. *phreatica (Chappuis, 1925)
Remarks: *E. phreatica* is a stygobitic species, widely distributed in Eastern Europe and in Italy (Chappuis, 1925; Mori and Brancelj, 2008).
Groundwater localities: reported for the karst system of Monte Conca, province of Caltanissetta (Nicolosi *et al.,* 2022), and for the cave Zubbia del Cavallo, province of Agrigento, in pools of percolating water (Bruno *et al.,* 2018).

Elaphoidella plutonis Chappuis, 1938
Remarks: stygobitic species occurring in peninsular Italy and Sicily (Berera *et al.,* 2006).
Groundwater localities: on the island the species has been found in a single freshwater well in Giarratana, province of Siracusa, and reported as *E. rossellae* Pesce, Galassi and Apostolov, 1987 (Pesce and Galassi, 1987a). *Elaphoidella rossellae* was synonymized with *E. plutonis* by Galassi (1997).

Family Leptopontiidae Lang, 1948
Genus *Psammopsyllus* Nicholls, 1945
Psammopsyllus maricae Cottarelli, Saporito and Puccetti, 1983
Remarks: Numerous specimens of *P. maricae* were collected along with the parastenocaridid *Cottarellicaris luciae* from the type-locality of this last species. Members of these genera are commonly found associated in estuarine interstitial communities (Cottarelli *et al.,* 2008)
Groundwater localities: hyporheic habitat of the Cerasella stream (province of Palermo; Cottarelli *et al.,* 2008)
Other occurrence localities in Sicily: none.

Family Parastenocarididae Chappuis, 1940
Genus *Cottarellicaris* Schminke, 2013
Cottarellicaris luciae (Cottarelli, Bruno and Berera, 2008)
Remarks: stygobitic species endemic to Sicily.
Groundwater localities: found only in the hyporheic habitat of the Cerasella stream (province of Palermo; Cottarelli *et al.,* 2008).

Genus *Proserpinicaris* Jakobi, 1972
Proserpinicaris kalypso (Pesce, Galassi and Cottarelli, 1988)
Remarks: stygobitic species endemic to Sicily.
Groundwater localities: two brackish water wells near Petrosino, in the province of Trapani (Pesce and Galassi, 1987a, Pesce *et al.,* 1988).

Genus *Stammericaris* Jakobi, 1972
Stammericaris destillans Bruno and Cottarelli, 2017 in: Bruno *et al.* (2017)
Remarks: stygobitic species endemic to Sicily.
Groundwater localities: found only in Grotta Molara, province of Palermo (Bruno *et al.,* 2017).

Stammericaris diversitatis (Cottarelli and Bruno, 2012) in: Cottarelli *et al.* (2012)
Remarks: stygobitic species endemic to Sicily.
Groundwater localities: found only in Grotta Conza (province of Palermo, Cottarelli *et al.,* 2012), in percolating waters.

Stammericaris similior Cottarelli and Bruno, 2023 in: Bruno *et al.* (2023)
Remarks: stygobitic species endemic to Sicily.
Groundwater localities: this species has been described for Scrivilleri cave, province of Siracusa (Bruno *et al.,* 2023).

Stammericaris trinacriae (Pesce, Galassi and Cottarelli, 1988)
Remarks: stygobitic species endemic to Sicily.
Groundwater localities: the species has been recorded few times in the island in both slightly brackish and fresh-water wells in province of Trapani, and in Grotta di Entella near Contessa Entellina, province of Palermo (Pesce and Galassi, 1987a; Pesce *et al.,* 1988; Bruno *et al.,* 2018).

Family Phyllognathopodidae Gurney, 1932
Genus *Phyllognathopus* Mrázek, 1893
Phyllognathopus viguieri (Maupas, 1892)
Remarks: non-stygobitic, cosmopolitan species, rather common in wet soils and seepages (Defaye and Dussart, 2011).
Groundwater localities: in Sicily, the species was found in the interstitial waters of the "Fiumara di Floresta", province of Messina (Pesce and Galassi, 1987a).
Other occurrence localities in Sicily: none.

Class Malacostraca
Order Amphipoda
Family Gammaridae Latreille, 1802

Genus *Pectenogammarus* Reid, 1940
Pectenogammarus sicilianus **s.l.** (Karaman and Tibaldi, 1972)
Remarks: non-stygobitic species complex, which is currently considered endemic to Sicily, where it exhibits high genetic structuring (Hupało *et al.,* 2023). The date of publication of the species was erroneously reported as 1973 in Ruffo and Stoch (2006) and in the GBIF database (https://www.gbif.org/species/4417135)
Groundwater localities: the species complex is reported from Grotta di Santa Ninfa, province of Trapani (Karaman and Ruffo, 1989), and from Grotta del Salto near Modica, province of Ragusa (Caruso and Costa, 1978; Ruffo and Stoch, 2006b).
Other occurrence localities in Sicily: The species is widespread in Sicilian streams, rivers, and springs (Karaman and Tibaldi, 1972; Galletti, 2000, 2004; Ruffo and Stoch, 2006b).

Genus *Rhipidogammarus* Stock, 1971
Rhipidogammarus rhipidiophorus (Catta, 1878)
Remarks: non-stygobitic species, circum-Mediterranean, commonly found in coastal habitats, including hyporheic and phreatic groundwater.
Groundwater localities: the species has been reported to occur in the Egadi Islands and Cefalù, province of Palermo (Ruffo, 1982; Ruffo and Stoch, 2006b).
Other occurrence localities in Sicily: none.

Genus *Tyrrhenogammarus* Karaman and Ruffo, 1990 *nec* 1989
Tyrrhenogammarus catacumbae (Karaman and Ruffo, 1978 *nec* 1977)
Remarks: stygobitic species, endemic to Sicily. Animalia volume 4 (1-2), where the paper by Karaman and Ruffo (1977) was published, is dated 1977 (imprint date) but, as reported in the volume itself, it was printed in 1978 (actual date). In accordance with articles 21 and 22 of the ICZN, the correct date of publication of *Tyrrhenogammarus catacumbae* is thus 1978.
Groundwater localities: Groundwater of the Hyblean area in the Catacombs of Noto (Karaman and Ruffo, 1977; Caruso, 1982; Ruffo and Stoch, 2006b); brackish water wells in Portopalo di Capo Passero, province of Siracusa (Caruso and Costa, 1978; Caruso, 1982; Ruffo, 1982), and some Hyblean springs: Sorgente Corchigliato, Sorgente Passolatello, and Sorgente San Corrado (Galletti, 2000, 2004).

Family Ischyroceridae Stebbing, 1899
Genus *Jassa* Leach, 1814
Jassa slatteryi Conlan, 1990
Remarks: non-stygobitic species of marine origin, originally described as an endemic species, *Jassa trinacriae* Krapp, Grasso and Ruffo, 2010, and later synonymized with *J. slatteryi* by Conlan *et al.* (2021).
Groundwater localities: "Grotta Conza" cave, province of Palermo, *sub J. trinacriae* (Krapp *et al.,* 2010).
Other occurrence localities in Sicily: Sampieri, province of Ragusa (Krapp *et al.,* 2010)

Family Niphargidae Bousfield, 1977
Genus *Niphargus* Schiödte, 1849
Niphargus longicaudatus **s.l.** (Costa, 1851)
Remarks: Stygobitic species complex widely distributed in Italy, including its islands (Ruffo, 1982; Ruffo and Stoch, 2006b).
Groundwater localities: the species is rather widespread in caves, wells, and springs of central and eastern Sicily (Caruso and Costa, 1978; Caruso, 1982; Pesce and Galassi, 1987a; Ruffo and Stoch, 2006b; Eme *et al.,* 2017; Nicolosi *et al.,* 2022).

Family Pseudoniphargidae Karaman, 1993
Genus *Pseudoniphargus* Chevreux, 1901
Pseudoniphargus adriaticus **s.l.** Karaman, 1955
Remarks: stygobitic species complex broadly distributed in the western Mediterranean and Adriatic Sea (Bréhier and Jaume, 2009). In Italy, the species has been reported to occur in peninsular coastal groundwater of the Adriatic Sea as well as in Sicily (Caruso and Costa, 1978). Despite its alleged broad distribution, the species complex occurs within the study area only on the Pelagie islands (Ruffo, 1982). However, it is very likely that these islands are inhabited by a different species (Hupało *et al.,* 2021).
Groundwater localities: this species has been reported to occur in wells of Linosa and Lampedusa (Caruso and Costa, 1978; Caruso, 1982; Ruffo, 1982).

Pseudoniphargus duplus Messouli, Messana and Yacoubi-Khebiza, 2006
Remarks: stygobitic species, endemic to Sicily.
Groundwater localities: the species has been found in a single site (well in contrada Cavarra, reported as "Casa Cavanna" by

Messouli *et al.* (2006), near Portopalo di Capo Passero, province of Siracusa (Messouli *et al.,* 2006).

Pseudoniphargus inconditus Karaman and Ruffo, 1990 *nec* 1989
Remarks: stygobitic species, endemic to Sicily. Animalia volume 16, where the paper by Karaman and Ruffo (1989) was published, is dated 1989 (imprint date) but, as reported in the volume itself, it was printed in 1990 (actual date). In accordance with articles 21 and 22 of the ICZN, the correct date of publication of *Pseudoniphargus inconditus* is thus 1990.
Groundwater localities: reported from Fiumedinisi, interstitial habitat (province of Messina; Karaman and Ruffo, 1989).

Pseudoniphargus italicus Karaman and Ruffo, 1990 *nec* 1989
Remarks: stygobitic species, endemic to Sicily, originally described as a subspecies of *Pseudoniphargus africanus* Chevreux, 1901. Animalia volume 16, where the paper by Karaman and Ruffo (1989) was published, is dated 1989 (imprint date) but, as reported in the volume itself, it was printed in 1990 (actual date). In accordance with articles 21 and 22 of the ICZN, the correct date of publication of *Pseudoniphargus italicus* is thus 1990.
Groundwater localities: To date, this species has only been reported (*sub P. africanus italicus*) for Vallone Sant'Agata (province of Palermo; Karaman and Ruffo, 1989).

Pseudoniphargus sodalis Karaman and Ruffo, 1990 *nec* 1989
Remarks: stygobitic species, endemic to Sicily. Animalia volume 16, where the paper by Karaman and Ruffo (1989) was published, is dated 1989 (imprint date) but, as reported in the volume itself, it was printed in 1990 (actual date). In accordance with articles 21 and 22 of the ICZN, the correct date of publication of *Pseudoniphargus sodalis* is thus 1990.
Groundwater localities: this species has been reported to occur in the gypsum cave of Santa Ninfa, province of Trapani (Karaman and Ruffo, 1989).

Order Bathynellacea
Family Bathynellidae Grobben, 1905
Genus *Meridiobathynella* Serban, Coineau and Delamare Deboutteville, 1971
***Meridiobathynella* sp.**
Remarks: abundant material of a bathynellid species was collected by Bruno *et al.* (2018) in Grotta Conza, near Palermo. The species is currently pending a formal description. All Bathynellacea are stygobitic. The report of a *Bathynella* sp. in the area of Portopalo di Capo Passero (Pesce, 2003) lacks information on the source of the record and is possibly erroneous.
Groundwater localities: Grotta Conza, Palermo (Bruno *et al.,* 2018).

Order Isopoda
Family Asellidae Latreille, 1802
Genus *Proasellus* Dudich, 1925
Proasellus montalentii Stoch, Valentino and Volpi, 1996
Remarks: non-stygobitic species, endemic to Sicily, common in springs and brooks (Stoch *et al.,* 1996). Eme et al. (2018), based on DNA sequences, reported that two distinct clades exist in Sicily; their taxonomic status is still unresolved.
Groundwater localities: this species occurs in spring, freshwater wells, and caves (provinces of Enna, Caltanissetta, Trapani, and Palermo; Caruso and Costa, 1978 *sub P. coxalis*; Stoch *et al.,* 1996, 2006; Nicolosi *et al.,* 2022; Saclier *et al.,* 2023).
Other occurrence localities in Sicily: records of the species are also available for surface water bodies throughout the island (Stoch *et al.,* 1996, 2006; Saclier *et al.,* 2023).

***Proasellus* sp.**
Remarks: stygobitic species, yet undescribed.
Groundwater localities: Sorgenti del Gabriele, province of Palermo (Eme *et al.,* 2018; Saclier *et al.,* 2023).

Family Cirolanidae Dana, 1852
Genus *Typhlocirolana* Racovitza, 1905
Typhlocirolana* cf. *moraguesi Racovitza, 1905
Remarks: stygobitic species. It was first described from Mallorca but later reported to occur also in Sicily (Caruso and Costa, 1978; Caruso, 1982; Argano, 1979; Argano *et al.,* 1982). However, the Sicilian population appears to be genetically different from the Balearic populations, and further studies aimed at its characterization are needed (Caccone *et al.,* 1986; Baratti *et al.,* 2010).
Groundwater localities: brackish water wells near Portopalo di Capo Passero (province of Siracusa) (Caruso, 1982: Argano *et al.,* 1982; Stoch *et al.,* 2006).

Order Thermosbaenacea
Family Monodellidae Taramelli, 1954
Genus *Tethysbaena* Wagner, 1994
Tethysbaena siracusae Wagner, 1994
Remarks: stygobitic species, endemic to Sicily.
Groundwater localities: found only in freshwater wells located near Pachino and in contrada Guardiani at Portopalo di Capo Passero (province of Siracusa) (Caruso and Costa, 1978, sub *Monodella* sp.; Wagner, 1994; Ruffo, 2006).

DISCUSSION

Diversity patterns

Although the crustacean fauna of Sicilian surface inland waters is to date satisfactorily known (Marrone *et al.,* 2006 and Marrone and Mura, 2006 for branchiopods; Calvo *et al.,* 1993, Alfonso *et al.,* 2021, Vecchioni *et al.,* 2019a, 2019b, 2021, Marchese *et al.,* 2022, and Stoch *et al.,* 2023 for copepods; Hupało *et al.,* 2021 and Vecchioni *et al.,* 2019c, 2022 for malacostracans; Pieri *et al.,* 2020 for ostracods; see also Marrone and Naselli-Flores, 2022 for an overview), the available information about the crustaceans occurring in the groundwaters of the island is unevenly distributed among taxa. It is noteworthy that no branchiopod species have to date been reported in Sicilian groundwater. Branchiopoda include relatively few true stygobitic species; however, the occurrence of non-stygobitic species is usually high groundwater (Dumont and Negrea, 1996). The report of some unidentified cladocerans in samples collected from the Hyblean springs (Galletti, 2004) likely refers to surface species that are not linked to groundwater. The same holds for Ostracoda, which are currently represented in Sicily by a single endemic stygobitic species; four additional taxa were identified

at the genus level. The occurrence of stygobitic branchiopods and ostracods in Sicilian groundwater may have been severely underestimated because of a lack of research.

Copepoda is the most species-rich taxon in the Sicilian groundwater where it is represented by the orders Cyclopoida and Harpacticoida. To date, no representatives of the order Calanoida are known for the Sicilian stygofauna, which is in agreement with the rare occurrence of this taxon in Italian groundwater (Alfonso *et al.,* 2021) and worldwide (Brancelj and Dumont, 2007). Species richness and incidence of true stygobitic species were almost equally distributed between Cyclopoida and Harpacticoida. Of the 21 cyclopoid taxa (species and subspecies), 10 (47.6%) were true stygobites, and 13 out of the 22 harpacticoid species (59.1%) were strictly stygobitic. This is mirrored by the incidence of endemic species, which accounted for 33.3% of Cyclopoida and 36.3% of Harpacticoida, all of which being stygobites.

Among the class Malacostraca, 10 amphipods, 3 isopods, 1 bathynellacean, and 1 thermosbaenacean species are present in the island; a high incidence of stygobites was found among Amphipoda (70%, 7 out of 10 Sicilian species). According to the current taxonomy (see below), at least six amphipods, one bathynellacean, two isopods, and one thermosbaenacean, are endemic to the island. Interestingly, the isopod *Proasellus montalentii* is the only Sicilian endemic non-stygobitic taxon reported in this study.

Taxonomical issues

The taxonomic identity of some taxa which have been recorded from the Sicilian groundwater is doubtful. Among them, the harpacticoid *Elaphoidella* cf. *phreatica* and the isopod *Typhlocirolana* cf. *moraguesi* are very likely species new to science, and an accurate revision of the available specimens is needed. In addition, the amphipods *Pectenogammarus sicilianus* s.l., *Niphargus longicaudatus* s.l., and *Pseudoniphargus adriaticus* s.l. are species complexes whose taxonomy is currently under revision (cf. Hupało *et al.,* 2023), and it is likely that the Sicilian populations currently assigned to these complexes are actually new, possibly cryptic, species endemic to the island. The occurrence of *Pseudoniphargus* sp., *Proasellus* sp., and "*Proasellus ragusani*" in Hyblean springs, reported by Galletti (2004), should be added to the checklist. Unfortunately, no information on the species-level identity of the first two taxa was provided by Galletti (2004), and the baffling "*Proasellus ragusani*" is a *nomen nudum* (see also Hupało *et al.,* 2021), whose identity is to date unknown. Unfortunately, the spring where this alleged new species was collected ("Sorgente Oro", Cava della Misericordia, Ragusa) has recently been interested by heavy pollution, and no individuals of this isopod have been collected in the last decades (I. Galletti, *pers. com.*).

Origin of the Sicilian groundwater crustaceans

According to La Greca (1957), the Sicilian fauna might be ascribed to five biogeographical assemblages: widely distributed, Western Mediterranean, Eastern Mediterranean, Afro-Sicilian, and endemic elements. Among these endemics, he also identified 'paleoendemics' that likely originated from the complex post-Oligocene paleogeographic history of the island. Conversely, Massa *et al.* (2011) proposed the alternative hypothesis that, apart from the terrestrial phase experienced during the Miocene Messinian salinity crisis, which would have been followed by a complete submersion, the current Sicily emerged from the sea only in the Pliocene (4 Ma). However, a consensus has been reached regarding the existence of narrow emerged bridges, allowing a direct connection between Sicily and Europe through the Strait of Messina during the Pleistocene (Antonioli *et al.,* 2014).

Based on available data on Sicilian stygobitic crustaceans, the persistence of emerged land corresponding to the current Sicily from the late Miocene to the Holocene seems to be supported. Baratti *et al.* (2010) suggested that the divergence between *Typhlocirolana* cf. *moraguesi* and *T. moraguesi* s.str. occurred approximately 15 Mya. This separation has thus occurred prior to the Pliocene emergence of Sicily proposed by Massa *et al*. (2011). The same scenario applies to the thermosbaenacean *Tethysbaena siracusae*, as its relatives are found on the Balearic Islands and Monte Argentario (Tuscany, peninsular Italy), which are well-known Miocene relict lands (Ruffo, 2006). Following Cánovas *et al*. (2016), an early Tortonian (10.7 Ma) origin for the Balearic and Italian *Tethysbaena* clade is supposed, *i.e.*, a far more ancient origin than the sea level regressions occurred during Pliocene and Pleistocene. Moreover, the bathynellacean *Meridiobathynella* sp. belongs to an ancient stygobitic group restricted to inland waters (Camacho adn Valdecasas, 2008), and recent marine colonizations can be excluded for this taxon. These data make La Greca's (1957) hypothesis of the existence of Sicilian 'paleoendemics' relevant again, as also suggested based on vertebrate fossil evidence (Bonfiglio *et al.,* 2003, Masini *et al.,* 2008, and references therein).

The presence of several stygobitic copepod species included in the genera *Diacyclops*, *Speocyclops*, *Elaphoidella*, and *Attheyella*, as well as of the amphipod *Niphargus longicaudatus* s.l. distributed in both Peninsular Italy and Sicily, supports the hypothesis of their colonization of the island thanks to the direct connections between these landmasses occurred during the Pleistocene. Conversely, there are no known relict species from the Pelagie Islands, where a fauna with a clear African origin was expected (Massa *et al*., 2011; Muscarella and Baragona, 2017; Faraone *et al*., 2020), and the stygobitic amphipod *Pseudoniphargus adriaticus* s.l. is probably a thalassoid element (*i.e.*, a stygobyte of marine origin: Ruffo and Stoch, 2006b), like all the other species of the genus present in Sicily.

The desirable realization of DNA-based studies (already in progress for some isopod and amphipod genera: Eme *et al.,* 2018; Saclier *et al.,* 2023) may allow a better understanding of the composition and origin of Sicilian groundwater crustaceans.

CONCLUDING REMARKS

Despite the significant extent of karstic areas and high number of explored caves, the actual species richness of the Sicilian stygofaunistic province remains undetermined. Notwithstanding the limitations of the available data, it is evident that the Sicilian province is home to a high incidence of stygobitic and endemic species, with no recorded instances of alien species (Marrone and Naselli-Flores, 2019; Nicolosi *et al.,* 2023).

The area that exhibits the highest species richness, and is consequently a local stygodiversity hotspot, is Portopalo di Capo Passero (Siracusa, southeastern Sicily). However, the excessive exploitation of the aquifer for agricultural purposes, combined with altered climatic conditions, has resulted in progressive low-

ering and salinization of the aquifer (Rapti and Vaccaro, 2003). As a result, several stygobitic species in this region are likely to be threatened, even before they are discovered and described. It is essential to conduct systematic surveys in this area to mitigate the potential losses of these species.

The checklist presented in this study provides the first comprehensive overview of the crustacean fauna in Sicilian subterranean waters, although the absence of precise geographic coordinates for some of the sampled sites hinders mapping of the occurrence of some taxa. This paper aims to pave the way for future faunistic and phylogeographic studies that will provide a more comprehensive understanding of the composition and origin of the groundwater crustacean fauna in Sicily, with a particular focus on the species and communities that need management strategies to prevent their loss.

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Online supplementary material:

Tab. S1. List of the occurrence localities of the stygobitic crustaceans currently known from Sicily.