

## THE GROUNDWATER FAUNA OF ITALY: A SYNTHESIS

BY

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### SUMMARY

After a brief historical review of the stygobiological research in Italy, stygobionts or eustygophiles from the groundwaters of this country are listed and discussed.

Through systematic and biogeographic analysis and relationships within the most significant taxonomic groups, a subdivision of the Italian territory into five stygofaunal provinces, viz. Alpine, Apennine, Sardinian, Apulian, and Sicilian, is proposed.

### RÉSUMÉ

Après un succinct aperçu historique sur les recherches stygobiologiques en Italie, on présente une liste commentée des stygobies ou des eustygophiles des eaux souterraines de ce pays.

Une analyse systématique et biogéographique ainsi que l'étude des relations à l'intérieur des groupes taxonomiques les plus significatifs, permettent de proposer une division du territoire de l'Italie en cinq provinces stygofaunistiques: Alpine, Apennine, Sarde, d'Apulie, et Sicilienne.

### INTRODUCTION AND HISTORICAL REVIEW

The extensive nature of karstic phenomena, as well as the diversified geomorphology, hydrography and climate, have resulted in a remarkable range of different groundwater environments in Italy, viz. inland and coastal caves, superficial and deep phreatic networks, interstitial and hyporheic substrates and other infiltration zones (fig. 1).

This situation has led, long since, Italian and some foreign scientists to take a great interest in the Italian underground habitat and organisms.

As far as we know, the first discovery of aquatic subterranean animals in Italy, as well as in the World, is dated as far back as 1550, when Trissino referred to small eyeless shrimps found in subterranean waters of the cave "Covoli di Costozza" in Venetia (north Italy); these animals were much later identified as amphipod crustaceans by Schellenberg (1935), who described them as *Niphargus stygius costozzae*.

More than two centuries later, Pollini, in his little book "Viaggio al lago di Garda e al monte Baldo" (1816), reported the discovery of another amphipod crustacean from the same region, as "*Cancer pulex*" (= *Niphargus bajuvaricus grandii* Ruffo). Successively, Garbini (1895, 1896) published some preliminary notes regarding his investigations on the stygofauna of wells in Verona

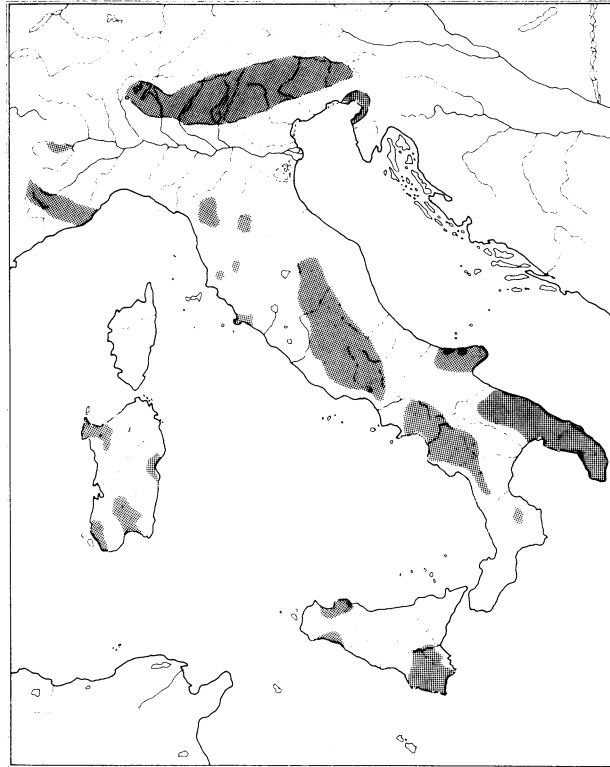


Fig. 1. Distribution of main karstic areas in Italy.

(Venetia), but this author didn't continue his studies. Other scattered information on Italy's stygofauna, at that time, can be found in the papers by Costa (1857), Brian (1914), Parona (1880) and Bensa (1900).

Subsequently, in the following years, important researches on the stygofauna of Italy were promoted and carried out by Bottazzii a.o., Stammer, Benedetti, Gerlach and Ruffo, who intensively investigated interstitial, hyporheic and cave waters in Venetia, Tuscany and Apulia, discovering numerous remarkable stygobionts among crustaceans (cyclopid and harpacticoid copepods, ostracods, Thermosbaenacea, Mysidacea, amphipods, isopods, decapods), water mites, nematods, gastropods and triclad turbellarians. The above material was later on studied and published by numerous authors, such as Caroli (1923, 1924, 1937); Bottazzi et al. (1923); Razzauti (1925); Stammer (1930, 1932, 1935); Arcangeli (1938); Klie (1938); Kiefer (1938, 1955, 1957); Chappuis (1938, 1953, 1954); Ruffo (1937, 1938, 1947, 1949, 1952, 1953, 1955, 1958); Viets (1939); Benedetti (1942); Lombardini (1944); Gerlach (1952); Andrassy (1959, 1962), who described or recorded most interesting stygobiont species of cyclopid copepods (*Metacyclops stammeri* Kiefer, *Metacyclops subdokus* Kiefer, *Metacyclops minutus* (Claus)), harpacticoid

copepods (*Nitocrella stammeri* Chappuis and *Bryocamptus dentatus* Chappuis), ostracods (*Pseudolimnocythere hypogaea* Klie), isopods (*Stenasellus racovitzai* Razzauti and *Microcerberus remanei* (Chappuis & Delamare), mysids (*Spelaeomysis bottazzii* and *Stygiomysis hydruntina*, both described by Caroli), palaemonid decapods (*Typhlocaris salentina* Caroli), amphipods (*Niphargus longidactylus* Ruffo, *N. bajuvaricus grandii* Ruffo, *N. longicaudatus* Costa, *Bogidiella albertimagni* Hertzog, *Salentinella gracillima* Ruffo and *Hadzia minuta* Ruffo), thermosbaenaceans (*Monodella stygicola* Ruffo) and water mites (*Lohmanella stammeri* Viets).

During 1938, occasional investigations in cave habitats of north Apulia (south Italy) were carried out by Pomini; some papers were produced by Ghirardelli & Cricca Gordini (1947), Sciacchitano (1948) and Ruffo (1948), but no remarkable new discoveries were made.

It was not until the years 1950 to 1975 that the stygofauna of Italy received special consideration, and the number of investigators of the aquatic underground systems of this country proliferated greatly. Through these years, in fact, many systematic and faunistic researches were organized, and valuable papers were published by several authors, such as Ruttner-Kolisko (1956), who investigated interstitial waters of north Italy, discovering the curious primitive microanellid *Rheomorpha neiswestnovae* Lastockin; Stella (1951, 1957) and Stella & Baschieri (1953) explored cave waters of Tuscany, discovering the thermosbaenacean *Monodella argentarii* Stella in the cave "Punta degli stretti"; Cottarelli (1969-1975) who executed intensive studies on the harpacticoid fauna from interstitial waters of the central Apennines, Sardinia and Apulia; Ruffo (1961-1968) promoted important research on hyporheic and phreatic waters of Venetia, including the noteworthy discovery of the amphipod *Metaingolfiella mirabilis* Ruffo from phreatic waters of south Apulia; Ruffo & Vigna Taglianti (1968, 1975) and Vigna Taglianti (1966-1975) accurately studied the amphipods from cave and phreatic systems of Italy, comprising, besides other interesting species, the new genus *Ivanella* from the island of Elba (Tuscany); Delamare Deboutteville (1960) recorded the first syncarid from this country, viz. the bathynellid *Bathynella natans* Vejdovski forma *stammeri* (= *Antrobathynella stammeri* (Jacobi)) from the interstitial waters of Venetia; Argano (1968) and Argano et al. (1975) conducted important research on isopods from groundwaters in Italy; Pesce & Vigna (1975) investigated coastal groundwater of east Italy; Sbordonni et al. (1971, 1975) reported on the cave fauna of the central Apennines; Del Papa (1973) and De Beauchamp (1955) recorded stygobiont triclad turbellarians from caves in the Abruzzes and Liguria; Kiefer (1963, 1967, 1968) executed systematic studies on the cyclopid and harpacticoid copepods from interstitial waters of north Italy; Sambugar (1970) continued the work of Ruffo on the interstitial waters in Venetia.

During the same time, other authors (Franciscolo, 1955; Sanfilippo, 1953; Conci, 1951; Patrizi, 1954; Lanza, 1961; Parenzan, 1965; Cerruti, 1968; Martinotti, 1968; Boscolo, 1968, 1969, 1972, 1974; Puddu & Pirodda, 1973;

Capolongo et al., 1974) provided some general reviews regarding the stygofauna of certain regions, such as Liguria, Piedmont, Venetia, Tuscany, Sardinia, Latium and Apulia, as well as defined the distribution or the "status" of some systematic groups in the groundwaters of Italy. Other authors (Brian, 1955; Arcangeli, 1952; Noodt, 1955; Argano & Henry, 1972; Serban, 1973 a, b; Karaman, 1975) published notes on the taxonomy of syncarids, amphipods, asellid isopods and copepods.

In later years, from 1975 onward, stygobiological research in this country was successfully continued by some very active zoological institutes or laboratories and Museums (Roma, L'Aquila, Padua, Catania, Naples, Verona, Siena) which incorporated stygological investigations in their programs.

During the last few years the literature contains very many papers by numerous scientists, who very much enlarged the knowledge of the stygofauna of Italy. Among these, important contributions are due to the following authors: Ferrarese & Sambugar (1976) and Braioni et al. (1980) on the hyporheic biocoenoses of some rivers of north Italy, as well as taxonomy of Rotatoria, oligochaetes and harpacticoid copepods; Riolfatti et al. (1976), who firstly examined the problem of pollution in groundwaters of Italy; Caruso & Costa (1978), who reviewed the stygofauna of wells, volcanic and karstic caves in Sicily; Karaman & Ruffo (1977) on groundwater amphipods of Sicily; Argano & Pesce (1979), Pesce (1976-1980) and Pesce et al. (1978a, 1978b, 1979), who intensively investigated phreatic habitats in central and southern Italy; Cottarelli et al. (1978-1981) on harpacticoid copepods; Benazzi & Gourbault (1977) on triclad turbellarians; Bodon (1980) and Giusti et al. (1980, 1981, 1982) on the systematics of hydrobioid gastropods; Bodon & Argano (1982) on asellid isopods; Dumnicka (1980) on oligochaetes; Kiefer (1981) on cyclopid and harpacticoid copepods; Danielopol (1981) on ostracods; Serban (1977) on syncarids; and Ariani (1982), reviewing Apulia's stygofauna.

These studies have contributed to a very large number of species new to the country and several taxa new to science. In particular, very interesting findings are those concerning the amphipods, with numerous new species of the genus *Niphargus* and the species *Sarothrogammarus catacumbae* Karaman & Ruffo, *Bogidiella silverii* Pesce, *B. aprutina* Pesce and *Hadzia adriatica* Pesce; the isopods, with the species *Typhlocirolana* cf. *moraguesi* Racovitza, *Stenasellus assorgiai* Argano, *S. nuragicus* Argano, *Proasellus acutianus* Argano & Henry, *P. vignai* Argano & Pesce, *P. amiterninus* Argano & Pesce, *P. adriaticus* Argano & Pesce, *P. ligusticus* Bodon & Argano; the syncarids, with the species *Sardobathynella cottarellii* Serban; the gastropods with the new genus *Arganiella* and several species of the genera *Bythiospeum*, *Avenionia*, *Pseudavenionia* and *Moitessieria*; the oligochaetes with the species *Peloscolex pescei* Dumnicka; the thermosbaenaceans with a *Monodella* species from Sicily; the ostracods with the species *Mixtacandona cottarellii*; and, finally, the copepods with a great number of stygobiont species

of different genera, such as *Acanthocyclops*, *Nitocrella*, *Diacyclops*, *Graeteriella*, *Parapseudoleptomesochra*, *Parastenocaris*, *Elaphoidella*, *Ceuthonectes*, *Ichnusella*, *Arenopontia*, *Delamarella*, *Kliopsyllus*, *Apodopsyllus*, etc.

From the above survey it appears that many papers have been produced on the stygofauna of Italy in past years and that extensive research is still in progress. Nevertheless, we actually dispose of enough information only for certain regions (Liguria, Venetia, Tuscany, Sardinia and Apulia); for other ones, such as the Abruzzes, Campania, Latium, Sicily, Molise, Calabria, Basilicata, Umbria, etc. we still have no, or scattered and incomplete, data. However, we dispose already of a large amount of information about numerous and significant stygobiont groups (cyclopid and harpacticoid copepods, ostracods, isopods, amphipods, syncarids, thermosbaenaceans, mysids, decapods, gastropods, triclad turbellarians, water mites, amphibians) to outline a provisional, faunistical picture, as well as a biogeographical subdivision of Italy from a stygofaunistical standpoint.

The author well realizes that the following survey could be far from complete and that some chances of error or omission have not been successfully avoided, but it is hoped, as well, that the present report could be a workable basis for future studies, and will lead to additional discoveries and to a full understanding of Italy's stygofauna.

#### ACKNOWLEDGEMENTS

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#### TAXONOMIC REVIEW

##### *Copepods*

This group of crustaceans is widely distributed in about all kinds of underground aquatic habitats of Italy, viz. interstitial, phreatic, hyporheic, spring and cave waters. Many stygobionts, or eustygophiles, may be found amongst the harpacticoids, a lower number are known among the cyclopids, which nevertheless, include a great amount of stygophiles or stygoxenes; nothing is known until now on stygobiont or eustygophilic calanoid copepods from this country.

As to the origin, different models of colonization could be proposed for the Italian groundwater cyclopid and harpacticoid copepods. Some genera are directly sea-originated, either through the coastal, interstitial habitat (*Halicyclops*, *Metacyclops*, *Nitocrella*, *Parapseudoleptomesochra*, *Parastenocaris*) or through karstic environments (*Laophonte*, *Psyllocamptus*); other ones (*Diacyclops*,



Fig. 2. Distribution of the cyclopoid copepod *Diacyclops antrincola* Kiefer.

*Eucyclops*, *Graeteriella*, *Speocyclops*, *Bryocamptus* s.l., *Elaphoidella*, *Moraria*) colonized the groundwater systems of Italy directly from superficial fresh waters, during different geologic epochs as a result of drastic climatic changes. Among the sea-originated species, a few, such as *Nitocrella stammeri* and *Parapseudoleptomesochra italica* could have dispersed actively to previously uncolonized areas due to their high degree of salinity tolerance (“active migration model”); some genera (*Schizopera*, *Halicyclops*) could be considered “thalassoid”. The origin of other genera, such as *Thermocyclops* and *Ceuthonectes* is difficult to understand since, up to now, they show discontinuous and doubtful distributions, or they include only isolated groundwater species.

The present knowledge of copepods fauna of Italy is fairly complete and satisfactory, thanks to the work and the papers of numerous authors, such as Kiefer (1938-1981), Chappuis (1938-1954), Cottarelli et al. (1969-1981), Lindberg (1956), Noodt (1955), Pesce & Fabrizi (1979), Pesce & Maggi (1979), Pesce & Petkovski (1980) and Stella (1957).

Up to now, the following stygobiontes or eustygophiles are known from groundwater of Italian territory:

- Halicyclops dalmatinus* Petkovski (phreatic waters, Apulian province)
- Halicyclops troglodites* Kiefer (phreatic waters, Apulia, Sardinia)
- Eucyclops subterraneus* (Graeter) (phreatic waters, central Apennines)
- Eucyclops subterraneus damianae* Petkovski (phreatic waters, central Apennines)
- Cyclops (Microcyclops) sanfilippoi* Brian (cave waters, north-west Apennines)
- (= cop. IV of *Diacyclops* sp.?)

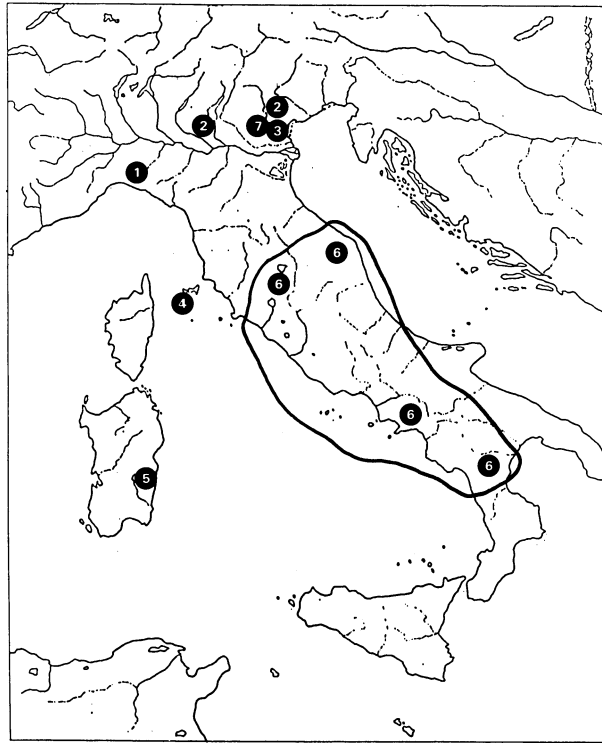


Fig. 3. Distribution of the cyclopid genus *Speocyclops* Kiefer in Italy: 1, *S. franciscoi* (Brian); 2, *S. cf. demetiensis* (Scourfield); 3, *S. infernus* (Kiefer); 4, *S. species*; 5, *S. sardus* Lindberg; 6, *S. italicus* Kiefer; 7, *S. species incerta*.

- Acanthocyclops agamus* Kiefer (cave waters, south Apennines)  
*Acanthocyclops venustus italicus* Pesce & Maggi (phreatic waters, central Apennines)  
*Acanthocyclops sambugarae* Kiefer (hyporheic waters, north-east Alpine region)  
*Acanthocyclops brachypus* Kiefer (phreatic waters, Sardinia)  
*Diacyclops languidoides languidoides* (Lilljeborg) (interstitial, cave and phreatic waters, widely distributed, except Sardinia and Sicily)  
*Diacyclops languidoides hypnicola* (Gurney) (phreatic waters, widely distributed, except Sicily)  
*Diacyclops languidoides clandestinus* (Kiefer) (interstitial waters, widely distributed, except Sardinia and Sicily)  
*Diacyclops languidoides italianus* (Kiefer) (interstitial and cave waters, Alpine region)  
*Diacyclops languidoides goticus* (Kiefer) (cave waters, Alpine region)  
*Diacyclops languidoides zschokkei* (Graeter) (cave and phreatic waters, north-central Apennines)  
*Diacyclops languidoides aprutinus* Pesce & Fabrizi (phreatic waters, central Apennines)  
*Diacyclops languidoides nagysalloensis* Kiefer (phreatic waters, south Apennines)  
*Diacyclops crassicaudis* var. *cosana* Stella & Baschieri Salvadori (cave waters, Tuscany)  
*Diacyclops antrincola* Kiefer (cave and phreatic waters, central-south Apennines)  
*Diacyclops ruffoi* Kiefer (interstitial waters, north-east Alpine region)  
*Metacyclops stammeri* Kiefer (cave and phreatic waters, Apulia)  
*Metacyclops subdolos* Kiefer (cave and phreatic waters, Apulia, Sardinia)  
*Thermocyclops oblongatus* (Sars) (cave and phreatic waters, central and south Apennines)  
*Speocyclops infernus* (Kiefer) (interstitial waters, Alpine region)  
*Speocyclops demetiensis* (Scourfield) (interstitial waters, north Apennines)

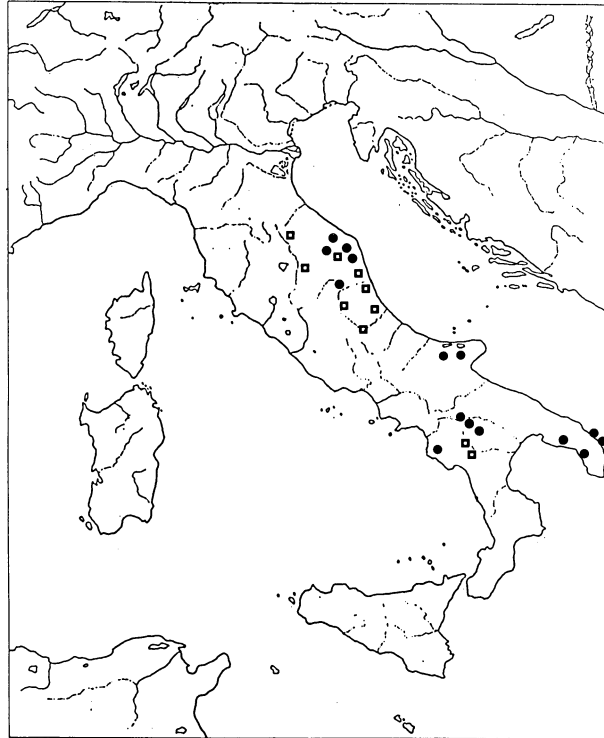


Fig. 4. Distribution of the harpacticoid copepods *Parapseudoleptomesochra italica* Pesce & Petkovski (circles) and *Elaphoidella elaphoides* (Chappuis) (squares) in Italy.

- Speocyclops italicus* Kiefer (cave and phreatic waters, central-south Apennines)  
*Speocyclops franciscocoli* (Brian) (cave waters, west Apennines)  
*Speocyclops sardus* Lindberg (cave waters, Sardinia)  
*Graeteriella unisetigera* (Graeter) (interstitial waters, Alpine region and central Apennines)  
*Nitocra intermedia* Pesce (phreatic waters, Apulian Province)  
*Paramesochra brevifurca* Galhano (hyporheic waters, Sardinia)  
*Moraria michilietoae* (?) Brian (cave waters, Alpine province)  
*Moraria varica* (Graeter) (phreatic, interstitial water, widely distributed)  
*Moraria insolete* Chappuis (cave waters, Alpine province)  
*Nitocrella stammeri* Chappuis (phreatic and cave waters, central Apennines, Apulia, Sicily and Sardinia)  
*Nitocrella juturna* Cottarelli (phreatic waters, central Apennines)  
*Nitocrella psammophila* Chappuis (interstitial waters, east Alpine region and central Apennines)  
*Nitocrella achaiae* Pesce (phreatic waters, central Apennines)  
*Nitocrella beatricis* Cottarelli (interstitial waters, Sardinia)  
*Nitocrella morettii* Pesce (phreatic waters, central Apennines)  
*Parapseudoleptomesochra italica* Pesce & Petkovski (phreatic and cave waters, central-south Apennines)  
*Parapseudoleptomesochra minoricae* (Chappuis & Rouch) (phreatic waters, Sardinia)  
*Elaphoidella gracilis* (Sars) (interstitial waters, Apennines, Sardinia)  
*Elaphoidella elaphoides* (Chappuis) (phreatic waters, central-south Apennines)  
*Elaphoidella plutonis* (Chappuis) (cave and interstitial waters, south Apennines)  
*Elaphoidella plutonis quadrispinosa* Chappuis (cave waters, south Apennines)



- Elaphoidella ruffoi* (Chappuis) (interstitial waters, east Alpine region)  
*Elaphoidella pseudophreatica* (= *E. phreatica*) (Chappuis) (interstitial and phreatic waters, Alpine region, Apennines)  
*Elaphoidella dubia* Kiefer (interstitial waters, east Alpine region)  
*Elaphoidella bidens* (Schmeil) (interstitial waters, Alpine region)  
*Elaphoidella bidens coronata* (Sars) (interstitial waters, Apennines)  
*Elaphoidella oglasae* Cottarelli & Torrisi (interstitial waters, Sardinia)  
*Elaphoidella tiberina* Pesce (interstitial waters, central Apennines)  
*Elaphoidella* sp. (phreatic waters, Tuscany, central Apennines)  
*Arenotesella germanica* Kunz (coastal interstitial waters, widely distributed)  
*Ichnusella eionae* Cottarelli (hyporheic waters, Sardinia)  
*Ichnusella pasquinii* Cottarelli (coastal groundwater, central Apennines)  
*Arenopontia nesaie* Cottarelli (coastal groundwater, Sardinia)  
*Arenopontia subterranea* Kunz (hyporheic waters, Sardinia)  
*Arenopontia achanta* Chappuis (interstitial waters, widely distributed)  
*Delamarella galatae* Cottarelli (coastal groundwater, Sardinia)  
*Kliopsyllus minutus* Masry (coastal groundwater, central Apennines, Tuscany)  
*Apodopsyllus lynceorum* Cottarelli (interstitial waters, central Apennines)  
*Ceuthonectes serbicus* Chappuis (interstitial waters, Alpine province)  
*Ceuthonectes* sp. (hyporheic waters, Sardinia)  
*Psyllocamptus monachus* Chappuis (cave waters, Apulia)  
*Bryocamptus unisaetosus* Kiefer (interstitial waters, Alpine province)  
*Bryocamptus dentatus* Chappuis (cave waters, Apulia)  
*Laophonte spelaea* Chappuis (cave waters, Apulia)  
*Parastenocaris calliroe* Cottarelli (hyporheic waters, Sardinia)  
*Parastenocaris proserpina* Chappuis (interstitial waters, central and southern Apennines)  
*Parastenocaris italica* Chappuis (interstitial waters, Alpine province and central Apennines)  
*Parastenocaris pasquinii* Cottarelli (interstitial waters, central Apennines)  
*Parastenocaris amyclaea* Cottarelli (interstitial waters, central Apennines)  
*Parastenocaris hera* Cottarelli (hyporheic waters, south Apennines)  
*Parastenocaris orcina* Chappuis (interstitial waters, central and southern Apennines)  
*Parastenocaris tyrrhenidis* Cottarelli (hyporheic waters, Sardinia)  
*Parastenocaris amatheia* Cottarelli (hyporheic waters, Sardinia)  
*Parastenocaris ruffoi* Chappuis (interstitial waters, Alpine province)  
*Parastenocaris acherusia* Noodt (interstitial waters, Alpine province)  
*Parastenocaris gertrudae* Kiefer (hyporheic waters, Alpine province)  
*Parastenocaris veneris* Cottarelli & Maiolini (interstitial waters, central Apennines)  
*Parastenocaris stellae* Cottarelli a.o. (hyporheic waters, Sardinia)  
*Parastenocaris admète* Cottarelli a.o. (hyporheic waters, Sardinia)  
*Parastenocaris sardoa* Cottarelli & Torrisi (hyporheic waters, Sardinia)  
*Echinocamptus pilosus* (VanDouwe) (interstitial waters, Alpine province)  
*Echinocamptus georgevitchi* (Chappuis) (interstitial waters, Alpine province)  
*Psammopsyllus maricae* Cottarelli (hyporheic waters, coastal and southern Apennines, Sardinia)

### Ostracoda

Although ostracods are largely distributed in about all kind of subterranean habitats, those of Italy are still very poorly known. Moreover, the few available data relate only to some regions of north Italy, to Sardinia and Apulia; for other regions of central and southern Italy, as well as for Sicily, we dispose of no or very doubtful information. Our present knowledge of these interesting underground crustaceans is due solely to the papers of Klie (1938) and Danielopol (1981), and to the handbook by Ghetti & McKenzie (1981) treating both the ground- and surfacewater ostracod fauna of Italy.

Up to now, the following species are known from groundwaters of Italy:

*Pseudolimnocythere hypogaea* Klie (cave and phreatic waters, Apulia)

*Sphaeromicola stammeri* Klie (cave and hyporheic waters, Alpine province; stygophil?)

*Cryptocandona vavrai* Kaufm. (cave waters, Alpine province; stygophil?)

*Mixtacandona stammeri* Klie (cave waters, Apulia)

*Mixtacandona cottarellii* Danielopol (hyporheic waters, Sardinia)

*Mixtacandona* sp.gr. *chappuisi-laisi* (hyporheic waters, Sardinia)

*Pseudocandona* sp.aff. *parallela* (Löff) (hyporheic waters, Sardinia)

### *Isopods*

The isopods, as a whole, constitute a group of crustaceans quite adaptable and specialized to almost all types of groundwater habitats. They are widely distributed in Italy, where six families, with numerous stygobiont species and subspecies, are known, viz.: Asellidae, that comprise species derived directly from surface fresh-waters; Cirolanidae, Sphaeromatidae, Microcerberidae, Microparasellidae and Stenasellidae, comprising species directly sea-originated, some of which colonized the aquatic underground systems at a rather recent age; some genera that belong to the Stenasellidae, Cirolanidae, Microparasellidae and Sphaeromatidae are assumed to be "thalassoid" elements, that migrated before the Quaternary in the interstitial coastal waters, as it is shown by their peculiar "mediterranean" distribution and ecology ("Regression model evolution", Stock, 1977). According to this model, the above groups, as well as many other Italian crustaceans that will be discussed below (mysids, amphipods of the genera *Pseudoniphargus* and *Hadzia*, Thermosbaenacea and the prawn *Typhlocaris*), got gradually adapted to continental groundwaters through stranding in the coastal interstitial habitat because of the Mediterranean regressions during the Tertiary period. This model has been recently supported, for the Monilistrinae isopods from the Italian groundwaters, by studies on divergence time between the genera *Monolistra* and *Sphaeroma* (Caccone et al., 1982); this work confirmed, as well, that cladogenetic events that led to the separation of the above genera and that the speciation in *Monolistra* occurred from the Messinian (Mediterranean salinity crisis) to the upper Pliocene.

The asellid, *Proasellus coxalis* (Dollfus) s.l. is frequently found, as stygophilous or stygoxenous element, in Italian groundwaters, but sometimes with populations (Sardinia) showing varying levels of morphological adaptations, viz. depigmentation and eye reduction, that suggest different phases of groundwater invasion. According to Pesce & Argano (1980) these populations, that could be quite isolated from epigeal ones of the same species, migrated into groundwaters, through phreatic interstices, due to the unstableness of the surface aquatic systems of such islands; similar situations are reported from Crete (Greece), Turkey and Poland, for the epigeal *Asellus aquaticus* (L.) (Argano & Pesce, 1978; Skalski, 1981). Some of the populations from Sardinia

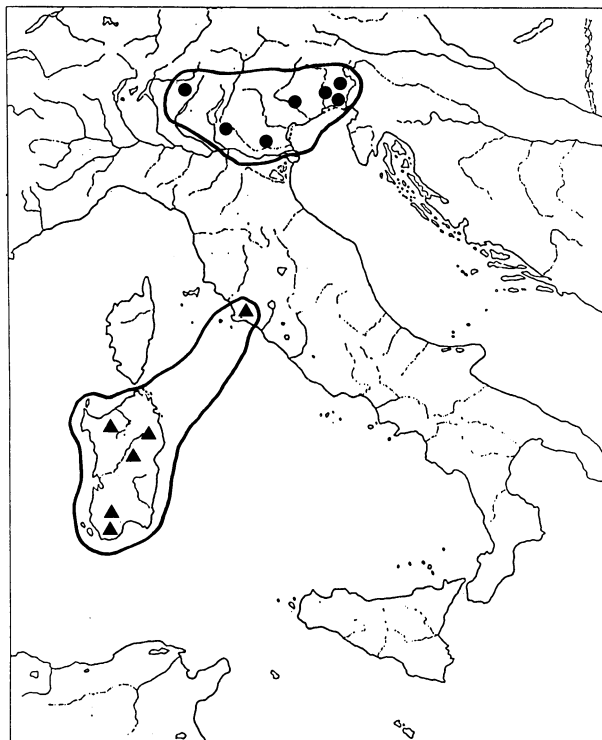


Fig. 5. Distribution of Stenasellidae (triangles) and Monolistrinae (circles) isopods in Italy.

are still under study (Argano, pers.com.). At present, the following species and subspecies are known for the Italian territory; but some other ones (genera *Proasellus* and *Stenasellus*) from the groundwaters of Sardinia and the central Apennines (Umbria) are in course of description or publication.

- Proasellus cavaticus* (Leydig) (cave waters, Alpine province)
- Proasellus franciscocoli* (Chappuis) (cave waters, Alpine province)
- Proasellus amiterminus* Argano & Pesce (phreatic waters, central Apennines)
- Proasellus gardinii* Arcangeli (phreatic waters, Alpine province)
- Proasellus patrizii* Arcangeli (cave waters, Sardinia)
- Proasellus adriaticus* Argano & Pesce (phreatic waters, central Apennines)
- Proasellus vignai* Argano & Pesce (hyporheic waters, central Apennines)
- Proasellus pavani* Arcangeli (cave waters, Alpine province)
- Proasellus deminutus* Sket (hyporheic waters, Alpine province)
- Proasellus acutianus* Argano & Henry (hyporheic waters, Tuscany and Latium)
- Proasellus ligusticus* Bodon & Argano (karstic spring, Apennines)
- Typhlocirolana* cf. *moraguesi* Racovitza (coastal phreatic waters, Sicily)
- Monolistra caeca julia* (Feruglio) (cave waters, Alpine province)
- Monolistra berica* (Fabiani) (cave waters, Alpine province)
- Monolistra boldori boldori* Brian (cave waters, Alpine province)
- Monolistra boldori bergomas* Arcangeli (cave waters, Alpine province)
- Monolistra pavani* Arcangeli (cave waters, Alpine province)
- Monolistra racovitza* Strouhal (spring waters, Alpine province)
- Monolistra schottlaenderi* Stammer (cave waters, Alpine province)

- Microcerberus remanei* Chappuis & Delamare (interstitial waters, widely distributed)  
*Microcerberus arenicola* Chappuis & Delamare (coastal groundwaters, south Apennines)  
*Microcerberus ruffoi* Chappuis (phreatic waters, Alpine province)  
*Microcharon arganoi* Pesce & Teté (phreatic waters, Apulia)  
*Microcharon marinus* Chappuis & Delamare (coastal groundwaters, central Apennines, Sardinia)  
*Angeliera phreaticola* Chappuis & Delamare (interstitial waters, central Apennines, Sardinia)  
*Stenasellus racovitzaei* Razzauti (cave and phreatic waters, central Apennines and Sardinia)  
*Stenasellus nuragicus* Argano (cave and phreatic waters, Sardinia)  
*Stenasellus assorgiai* Argano (cave and phreatic waters, Sardinia)  
*Sphaeromides virei* (Brian) (cave waters, Alpine province)

### *Amphipoda*

An important and strongly diversified fauna occurs in Italy. The present knowledge of this interesting group of specialized crustaceans is complete enough, due first of all to the extensive studies by Ruffo (1937-1982) and those by some other authors, such as Karaman (1976-1980), Vigna Taglianti (1966-1975), Sket (1972) and Pesce (1979, 1980, 1981).

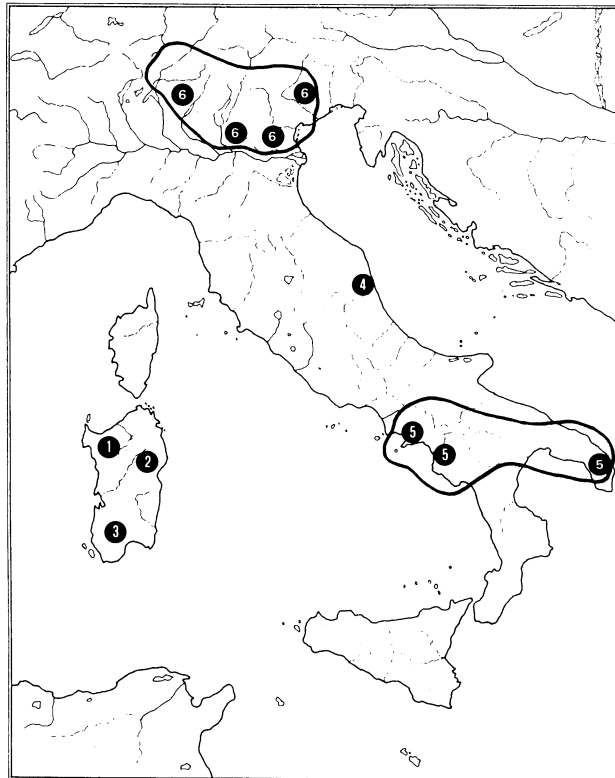


Fig. 6. Distribution of the amphipod genus *Bogidiella* s.l. Hertzog in Italy: 1, *B. ichnusae* Ruffo & Vigna Taglianti; 2, *B. vandeli* Coineau; 3, *B. silverii* Pesce; 4, *B. aprutina* Pesce; 5, *B. chappuisi* Ruffo; 6, *B. albertimagni* Hertzog.

Amphipods of the Italian stygofauna, coastal groundwaters species included, are referred to 11 genera, viz.: *Niphargus*, including the greater part of the known species of the Italian amphipods, *Rhipidogammarus*, *Sarothrogammarus*, *Ilvanellella*, *Pseudoniphargus*, *Hadzia*, *Carinurella*, *Salentinella*, *Bogidiella*, *Metaingolfiella* and *Orchestia*.

As regards to the origin, some genera and species (*Niphargus*, *Ilvanellella*, *Carinurella* and *Sarothrogammarus*) reached underground aquatic habitat directly from epigeal fresh waters; others (*Hadzia*, *Salentinella*, *Bogidiella*) colonized Italian groundwaters from the sea, through the mesopsammic-interstitial habitat, long ago; still others (*Rhipidogammarus*, *Orchestia*, *Pseudoniphargus*), due to their peculiar distribution and ecology, could be considered "thalassoid" elements.

The genus *Niphargus* is the most widely distributed, both in the continental and insular parts of Italy, with more than 20 species and subspecies which concentrate in the Alpine region.

The following species and subspecies are, at present, known from Italy:

- Niphargus ambulator* Karaman (cave waters, Alpine region)  
*Niphargus aquilex* Schiödte (cave and phreatic waters, Alpine region and central Apennines)
- Niphargus bajuvaricus grandii* Ruffo (hyporheic waters, Alpine region)  
*Niphargus bihorensis* Schellenberg (cave waters, Alpine region)  
*Niphargus canui* Karaman (cave waters, Alpine region)  
*Niphargus costozzae* Schellenberg (cave waters, Alpine region)  
*Niphargus danconai* Benedetti (interstitial waters, Alpine region)  
*Niphargus duplus* Karaman (interstitial waters, Alpine region)  
*Niphargus galvagnii* Ruffo (cave waters, Alpine region)  
*Niphargus longicaudatus* Costa (cave and phreatic waters, widely distributed)  
*Niphargus longidactylus* Ruffo (interstitial waters, Alpine region)  
*Niphargus microcerberus* Sket (interstitial waters, Alpine region)  
*Niphargus orcinus* s.l. Joseph (cave and phreatic waters, central and southern Apennines)  
*Niphargus parenzani* Ruffo & Vigna Taglianti (cave and phreatic waters, central and south Apennines)  
*Niphargus pasquini* Vigna Taglianti (phreatic waters, central Apennines)  
*Niphargus patrizii* Ruffo & Vigna Taglianti (cave waters, central Apennines)  
*Niphargus pupetta* (Sket) (interstitial waters, Alpine region)  
*Niphargus ruffoi* Karaman (cave waters, Alpine region)  
*Niphargus* gr. *speziae-romuleus-tatrensis* (cave waters, widely distributed, except Apulia, Sicily and Sardinia)  
*Niphargus stefanellii* Ruffo & Vigna Taglianti (cave and phreatic waters, central Apennines)  
*Niphargus stygius* s.l. Schiödte (cave waters, Alpine region)  
*Niphargus stygocharis italicus* Karaman (interstitial waters, Alpine region)  
*Niphargus tamaninii* Ruffo (cave waters, Alpine region)  
*Niphargus transitivus* Sket (interstitial waters, Alpine region)  
*Rhipidogammarus rhipidiophorus* (Catta) (cave and phreatic waters, widely distributed)  
*Rhipidogammarus karamani* Stock (cave and phreatic waters, central Apennines and Apulia)  
*Sarothrogammarus catacumbae* (Karaman & Ruffo) (phreatic waters, Sicily)  
*Ilvanellella inexpectata* Vigna Taglianti (phreatic waters, Tuscany)  
*Pseudoniphargus adriaticus* Karaman (phreatic waters, Tuscany, Apulia) (\*)

(\*) Caruso & Costa (1978) reported this species also from Sicily, but the taxonomic status of the record is still doubtful.

*Hadzia minuta* Ruffo (cave and phreatic waters, Apulia)  
*Hadzia adriatica* (Pesce) (cave and phreatic waters, Apulia)  
*Carinurella paradoxa* (Sket) (hyporheic waters, Alpine region)  
*Salentinella angelieri* Ruffo & Delamare (cave and phreatic waters, widely distributed along coasts)  
*Salentinella gracillima* Ruffo (cave and phreatic waters, Apulia)  
*Bogidiella chappuisi* Ruffo (coastal phreatic waters, southern Apennines)  
*Bogidiella aprutina* Pesce (phreatic waters, central Apennines)  
*Bogidiella ichnusae* Ruffo & Vigna Taglianti (hyporheic waters, Sardinia)  
*Bogidiella silverii* Pesce (phreatic waters, Sardinia)  
*Bogidiella vandeli* Coineau (hyporheic waters, Sardinia)  
*Bogidiella albertimagni* Hertzog (interstitial and phreatic waters, Alpine region)  
*Metaingolfiella mirabilis* Ruffo (phreatic waters, Apulia)  
*Orchestia remyi* Schellenberg (cave waters, Sardinia)

### *Mysidacea*

At present, two stygobiont species are known from Italy, viz. *Spelaeomysis bottazzii* Caroli and *Stygiomysis hydruntina* Caroli, both from coastal caves and phreatic waters of Apulia (south Italy).

In contrast with previous interpretation (Ruffo, 1955), genetic divergence and variability estimates among its populations (De Matthaeis et al., 1982), suggests a recent (Pliocene) groundwater colonization by *Spelaeomysis bottazzii*, and this consideration is according to Stock's (1977, 1980) hypothesis that these crustaceans, as well as other "thalassoid" animals, colonized groundwaters owing to Pliocene regression of the Mediterranean sea. On the contrary, the other species, *Stygiomysis hydruntina*, is an ancient immigrant in the underground aquatic systems of the Apulia region, which lives in isolated phreatic systems, but can occasionally migrate in superficial phreatic networks; such a condition is most similar to that of the amphipod *Metaingolfiella mirabilis*, also from phreatic groundwaters, which can occasionally reach more superficial systems, as happened when it was, by a mere change, first discovered.

*Spelaeomysis bottazzii* Caroli (cave and phreatic waters, Apulia region)  
*Stygiomysis hydruntina* Caroli (cave and phreatic waters, Apulia region)

### *Syncarida*

Syncarid crustaceans are certainly the most characteristic members of freshwater interstitial biocoenoses of Italy.

Once known only throughout the Palaearctic region, at present this group shows a wide distribution, since several species and numerous new genera fairly recently have been discovered and described from South America, Australia, New Zealand and Africa.

In Italy syncarids are represented by four genera, viz. *Antrobathynella*, *Bathynella*, *Meridiobathynella* and *Sardobathynella*, the first two from interstitial waters of the Alpine province, the last two from interstitial waters of the central Apennines and Sardinia; also from the central Apennines (Umbria) we recent-

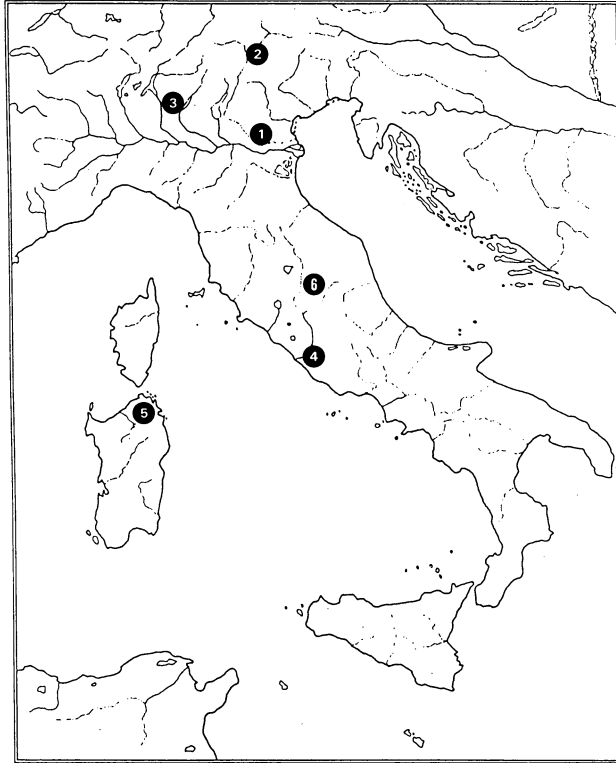


Fig. 7. Distribution of syncarids in Italy: 1, *Antrobathynella stammeri* (Jacobi); 2, *Bathynella ruffoi* Serban; 3, *Bathynella lombardica* Serban; 4, *Meridiobathynella* cf. *rouchi* Serban; 5, *Sardobathynella cottarellii* Serban; 6, *Meridiobathynella* sp.

ly collected material of the genus *Meridiobathynella* from phreatic waters (wells). Notwithstanding that this material is still in course of description (Schminke, in litt.), its discovery is of great interest since it proves that Italian syncarids could live also in phreatic waters, likewise it suggests that these remarkable crustaceans could be more widespread in Italy than previously thought.

Up to now, the following species are known for the Italian territory:

- Antrobathynella stammeri* (Jacobi) (interstitial habitat, Alpine province)  
(= *Bathynella natans* Vejdovsky forma *stammeri* Jakobi)
- Bathynella ruffoi* Serban (interstitial waters, Alpine province)
- Bathynella lombardica* Serban (interstitial waters, Alpine province)
- Meridiobathynella* cf. *rouchi* Serban, Coineau & Delamare Deboutteville (interstitial waters, central Apennines)
- Sardobathynella cottarellii* Serban (interstitial waters, Sardinia)
- Meridiobathynella* spec. (phreatic waters, central Apennines)

#### *Thermosbenacea*

This group of rare “living-fossils” is represented in Italy’s groundwaters by two species, viz. *Monodella stygicola* Ruffo, from coastal, brackish groundwaters

of the Apulian province (Salentine peninsula), and *M. argentarii* Stella, from coastal cave waters of the central Apennines (Tuscany). The former is an endemic of the Apulia; on the contrary, the latter shows a wide, pan-mediterranean distribution (west Italy, Yugoslavia, Greece).

Both species most likely originated from marine ancestors at the end of the "Tethys period", as happened to many other stygobionts from the Italian territory, such as mysidaceans, stenasselline isopods, amphipods of the genus *Hadzia*, etc., which actually show wide distributions, Indo-Pacific parts of the Tethys sea included.

Recently, during biospeleological research in the Sicilian province, promoted by the Institute of Zoology of the University of Catania, with the collaboration of the Zoological Institute of the University of Rome, some material of a *Monodella* species has been collected from brackish, artesian wells. This material, though it is still in study, proves, as well, that this group is more widely distributed in Italy.

#### *Decapoda*

Decapod crustaceans are poorly represented in Italian groundwaters, from which only two species, belonging to the families Atyidae and Palaemonidae, are at present known, viz.: *Troglocaris anophthalmus anophthalmus* (Kollar), reported from cave waters of Venetia, and *Typhlocaris salentina* Caroli, which is an endemic of Apulia (coastal cave waters) and one of the most extraordinary elements of the stygofauna of this province, as well as of the Italian territory.

#### *Gastropoda*

Although this group is scarcely represented in groundwaters, several blind and unpigmented gastropods have been recently recorded from both cave and phreatic waters of Italy (Bodon, 1980; Conci, 1951; Giusti, 1975, 1976; Giusti & Bodon, 1980, 1981; Giusti & Pezzoli, 1980, 1981, 1982; Bodon & Giusti, 1982; Pezzoli, 1969, 1978; Pezzoli & Giusti, 1980).

Groundwater gastropods of Italy belong to the superfamily Hydrobioidea, including the following true stygobiont or eustygophilous genera: *Bythiospeum*, *Phreatica*, *Iglica*, *Hadziella*, *Arganiella*, *Avenionia*, *Pseudavenionia*, *Moitessieria* and *Islamia*, which concentrate in the west Alpine region as well as in the north-west and central Apennines; as far as we know, no or very few data are, at present, available on stygobiontes from south Italy, from Sicily and Sardinia. Other genera, such as *Hauffenia*, *Bythinella*, *Pauluccia* and *Belgrandiella* are to be considered stygophiles (crenophiles?), viz. frequently occurring in underground aquatic habitats, but living both in superficial and subterranean waters; the species belonging to these genera will be not considered here.

With regard to the origin, the gastropods of the Italian groundwaters colonized the underground water networks directly from surface waters, before



the Quaternary, in search of lower temperature, as well as for avoiding competition with larger species (Giusti & Pezzoli, 1982).

From a biogeographical point of view, the greater part of the Italian gastropods are endemic or limited to extremely reduced areas, some species showing close affinities with west Mediterranean (France) or north- and east-European faunas.

At present time the following true stygobionts or eustygophiles are known from Italy; however, extensive research on this group is still in progress (Giusti, in litt.) and this could lead to a better understanding of the distribution of groundwater gastropods in Italy, especially in the southern Apennines as well as in the islands of Sardinia and Sicily.

- Bythiospeum cornucopia* (De Stefani) (karstic waters, Alpine region and central Apennines)  
*Bythiospeum forumjulianum* (Pollonera) (cave waters, Alpine region)  
*Bythiospeum vobarnensis* Pezzoli & Toffoletto (karstic waters, Alpine region)  
*Bythiospeum vallei* Giusti & Pezzoli (karstic waters, Alpine region)  
*Bythiospeum* (?) *fabrianensis* (Pezzoli) (cave waters, central Apennines)  
*Bythiospeum pezzolii* (Boeters) (cave waters, Alpine region)  
*Iglica* (?) *tellinii* (Pollonera) (karstic waters, Alpine region)  
*Hadziella ephippiostoma* Kuscer (hyporheic and spring waters, Alpine region)  
*Islamia pusilla* (Piersanti) (cave waters, south Apennines)  
*Arganiella pescei* Giusti & Pezzoli (phreatic waters, central Apennines)  
*Aveniona ligustica* Giusti & Bodon (cave and spring waters, north-west Apennines and Tuscany)  
*Aveniona parvula* Giusti & Bodon (spring waters, north-west Apennines)  
*Pseudavenionia pedemontana* Bodon & Giusti (spring waters, Alpine region and north-west Apennines)  
*Moitessiria* cf. *simoniana* (De Charpentier) (cave waters, Alpine region)

#### *Triclad Turbellarians*

The discovery of stygobiont turbellarians in groundwaters of Italy is due to Vialli (1937) who described the species *Dendrocoelum* (*Dendrocoelides*) *italicum* on material from the cave "Buco del Budrio" in the Alpine province (Lombardy). Later, other species belonging to the family Dendrocoelidae, as well as to the family Planariidae, were described or recorded from cave or spring waters of the Alpine province, the central and southern Apennines and Sardinia (Benazzi, 1938, 1955; Benazzi & Gourbault, 1977; De Beauchamp, 1955; Del Papa, 1952, 1959, 1973); no information is available on stygobiont or eustygophilous triclads from the southern Apennines as well as from Sicily.

Up to now, the following species are known for the Italian territory:

- Atrioplanaria morisii* Benazzi & Gourbault (cave waters, Alpine province)  
*Atrioplanaria* cf. *racovitzai* (De Beauchamp) (cave waters, Sardinian province)  
*Phagocata* spec. (interstitial, Tuscany)  
*Polycelis benazii* De Beauchamp (cave waters, Alpine province)  
*Dendrocoelum* (*Dendrocoelides*) *italicum* Vialli (cave waters, Alpine province)  
*Dendrocoelum* (*Dendrocoelides*) *collini* De Beauchamp (cave waters, Alpine province)  
*Dendrocoelum* (*Dendrocoelides*) *benazii* Del Papa (cave waters, central Apennines)  
*Dendrocoelum* species (cave waters, Alpine province)

Besides the above species, others (eustygophiles?) frequently occur in Italian groundwaters (cave and wells), showing a remarkable preadaptation (“passive adaptation”) that could be advantageous in the groundwater environment. These uncommon and interesting species are:

*Polycelis felina* Dalyell (cave waters, Alpine province)

*Crenobia teratophila* (Syeinmann) (interstitial habitat, south-Apennine region)

*Crenobia alpina* (Dana) (interstitial waters, Alpine province)

*Dugesia gonocephala* s.l. (Dugès) (cave waters, widely distributed both in the Alpine and Apennine provinces)

#### *Water mites*

Water mites, although widely distributed both in surface and underground waters (phreatic, interstitial, hyporheic and cave habitats) of Italy, belonging to several families, e.g. Hydrachnellae and Trombidiidae, Porohalacaridae, Halacaridae and Tyroglyphidae, are still very poorly known. Up to now, in fact, the only available pertains to the following truly stygobiont or eustygophilous species:

*Lohmannella stammeri* Viets (cave waters, Apulia province)

*Soldanellonyx monardi* Walter (ground- and epigeal waters, widely distributed in Italy)

*Lobohalacarus weberi* (Romijn & Viets) (cave waters, south Apennines)

*Kawamuracarus vardaricolus* Viets (interstitial waters, Alpine province)

*Acherontacarus cicolanii* Bader (phreatic waters, Sardinia)

*Acarochelopodia delamarei* Angelier (coastal groundwaters, central Apennines)

However, systematic and faunistic research promoted by Dr. Cicolani of our Institute, in collaboration with Prof. Bader of the Museum of Natural History of Basel, seems to indicate that more stygobionts and eustygophiles could live in Italy's groundwater. So, the knowledge of this very interesting, specialized group of groundwater animals may greatly be enlarged during the coming years.

#### *Amphibia*

Amphibians, as well as other vertebrates, are scarcely represented in groundwaters of Italy. Up to now, one true stygobiont species, viz. *Proteus anguinus* Laurentius, from cave waters in Carso (Trieste), is known of this country. Other species of amphibians, such as *Salamandra salamandra* (L.), *Euproctus platycephalus* (Gravenhorst) and *Bufo bufo* (L.), that frequently occur in Italian caves, are undoubtedly stygoxenes or, at most, stygophiles.

The species of the genus *Hydromantes*, despite their wide distribution in groundwaters of Italy, cannot be discussed herein owing to their terrestrial reproductive habits.

#### *Other groups*

Other groups of organisms that frequently occur in the Italian underground aquatic systems are: Bacteria, Protozoa, Rotatoria, Cladocera, Archianellida,

Oligochaeta, Nematoda, Gastrotricha, Bivalvia and insect larvae. However, these groups include, for the most part, only stygoxenous or stygophilous species or genera, as well as they are not, or not well investigated so far. Some incomplete information is available only for the oligochaetes and the nematods.

Among the oligochaetes three stygobiont species are known from the Alpine province and the central Apennines, viz. *Haber monfalconensis* Hrabe, 1966 (cave waters of S. Canziano; spring of the Monfalcone brook, near Trieste), *Haber zavreli* (Hrabe) (phreatic waters, Marche) and *Peloscolex pescei* Dumnicka also found in phreatic waters of Marche (central Apennines). Other species, all from groundwaters of the Apulia province, viz. *Pristina idrensis* Sperber, *Pristina longiseta* Ehrenberg, *Pristina foreli* (Piguet), *Enchytraeus buchholzi* Vejdovsky and *Haplotaxis gordioides* (Hartmann) are to be considered eustygophiles.

As for the nematods, only three species could be considered stygobiontes (or eustygophiles), viz. *Stenonchulus troglodytes* Schneider, *Mylonchulus cavensis* (Schneider) and *Anatonchus tridentatus* (De Man), all from interstitial habitats of the Alpine province.

#### ORIGIN AND ZOOGEOGRAPHY

Through systematic, faunistic and zoogeographic relationships among the most significant stygobionts and eustygophiles, more than one route of colonization, as well as different temporal derivations, can be suggested for the groundwater fauna of Italy.

As to the origin, as far as we know, four models of colonization could be pointed out:

1) "Regression model evolution" (according to Stock's proposition) regarding such ancient stygobionts as the thermosbaenaceans, the mysids, the microparasellid, cirrolanid and monolistrine isopods, the decapod genus *Typhlocaris*, the gammarids *Bogidiella*, *Hadzia* and some *Salentinella* species, and, maybe, the ostracod *Pseudolimnocythere hypogaea*, that originated gradually from marine ancestors that got stranded and adapted to inland groundwaters during regression periods of the Tertiary; these groups, up to now, are distributed mainly in areas once covered by Tertiary seas, as well as they show a wide distribution and plastic ecology; 2) "Active migration model" that regards those stygobionts or eustygophiles, such as numerous cyclopid and harpacticoid copepods, the amphipods *Pseudoniphargus*, *Orchestia* and *Rhipidogammarus* and some water mites, that dispersed in inland uncolonized areas from the sea, through the brackish-water environments, due to their high degree of salinity tolerance; 3) "Sea — surface fresh water — groundwaters migration model" that concerns some Italian stygobionts, such as the amphipods of the genera *Sarothrogammarus* and *Carinurella* and the syncarids, that followed a route of colonization leading them from the sea into surface fresh waters and from there into underground aquatic systems; 4) "climatic refugium model" that is

related to numerous Italian stygobionts and eustygophiles (asellid isopods, ostracods, except *Pseudolimnocythere*, the copepod genera *Speocyclops*, *Graeteriella*, *Elaphoidella* and other representatives of the family Canthocamptidae, the amphipods *Niphargus*, *Ivanella* and the hydrobioid gastropods) that colonized the groundwaters directly from surface fresh waters, somewhere at the end of Pliocene, owing to drastic surface climatic changes (e.g. the Quaternary cooling).

Some species, such as the amphipod *Bogidiella chappuisi* and the microparasellid isopod *Microcharon marinus*, as well as harpacticoid copepods of the Ectinosomidae and Cylindropsyllidae, cannot properly be placed in the above models since they have living marine ancestors or they are still colonizing the underground freshwater systems through mixohaline interstitial environments.

From a zoogeographical point of view, the Italian territory is characterized by a composite stygofauna, that includes both northern (Central-European) and southern elements, numerous species with eastern (Balkan) or western affinities, as well as a great amount of endemism. According to the biogeographical analysis, Italy could be divided in five main stygofaunistic provinces, viz.: 1) Alpine province, comprising the territory north to the river Po and the west Alps; 2) Apennine province, the western part of Tuscany and Apulia excluded; 3) Sardinian province, including part of Tuscany; 4) Apulian province; 5) Sicilian province.

The Apennine province can be subdivided in the north-west, central and southern regions; the Apulian province, as well, can be subdivided in two stygofaunistic districts, viz.: the Gargano and the Salento-Murge complex (fig. 8).

The greatest species richness in stygobionts or eustygophiles occurs in the Alpine and Apulian provinces; on the other hand, a remarkable paucity of groundwater animals is peculiar to the Sicilian province and the southern Apennine region.

From a geological point of view, the Alpine province is marked by a noteworthy extent of karstic areas, especially in the eastern part, by a great number of caves, superficial phreatic and interstitial networks and large underground aquatic systems. This area is likewise characterized by a high number of ancient, specialized cave-dwelling, interstitial and phreatic species, that belong to different taxonomic groups, such as cyclopid and harpacticoid copepods, asellid and sphaeromatid isopods, amphipods (mainly *Niphargus*), syncarids, decapods, water mites, triclad turbellarians, ostracods, gastropods and amphibians. Most stygobionts of this province are northern elements, that show close affinities with Central-European groups; others are endemics or of uncertain affinity; a few species show Mediterranean features or similarity with the East-Balkan stygofauna; the western part of this province is marked by a high percentage of southern (Apennine) elements.

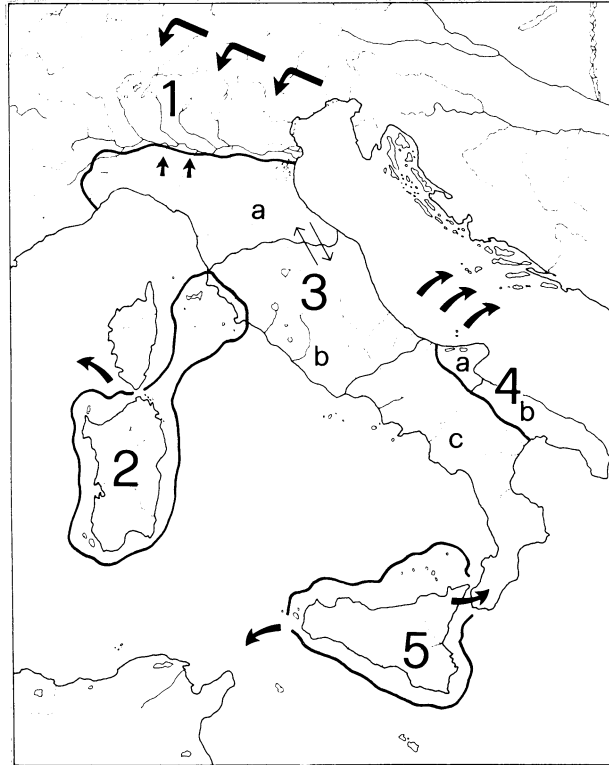


Fig. 8. Map of stygofaunal provinces in Italy: 1, Alpine province; 2, Sardinian province; 3, Apennine province (a, north Apennine region; b, central Apennine region; c, southern Apennine region); 4, Apulian province (a, Gargano district; b, Murge-Salento district); 5, Sicilian province.

This stygofaunistic area is well defined and easily distinguishable from the Apennine one, as well as from the others, mainly by its amphipod fauna, with a great number of species of *Niphargus* (about 20), some of them endemic for this province, by other specialized amphipods such as *Carinurella paradoxa* and *Bogidiella albertimagni*, exclusive cyclopoid and harpacticoid copepods (*Acanthocyclops sambugarae*, *Diacyclops ruffoi*, *Diacyclops languidoides italianus*, *Diacyclops languidoides goticus*, *Speocyclops infernus*, *Parastenocaris ruffoi*, *Parastenocaris acherusia*, *Parastenocaris gertrudae*, *Elaphoidella ruffoi*, *Elaphoidella dubia*, *Elaphoidella bidens*, and the doubtful *Moraria michilettoae*), asellid isopods (*Proasellus cavaticus*, *Proasellus franciscoi*, *Proasellus pavani*, *Proasellus deminutus*), sphaeromatid isopods (all the species of the genus *Monolistra*), the interesting decapod *Troglocaris anophthalmus*, gastropods of the genus *Bythiospeum* (with the exception of *B. fabrianensis*) and the species *Moitessiera simoniana*, the triclad turbellarians (*Polycelis benazzi*, *Atrioplanaria morisii* and the species of the genus *Dendrocoelum*), the specialized water mite *Kawamuracarus vardaricolus* (that represents the second species of the genus), the remarkable stygobiont amphibian *Proteus*

*anguinus* and, at last, by a high concentration of syncarids (*Bathynella ruffoi*, *Bathynella lombardica* and *Antrobathynella stammeri*).

The Apennine province also includes many karstic areas, especially in its central part, numerous deep caves, underground rivers, springs and other infiltration zones. This province, as a whole, is characterized by a significant amount of stygobionts and by a great number of eustygophiles and "thalassoid" elements, that are widely distributed, mainly along the Adriatic sea coasts. In particular, it is interesting to point out that in this province the amphipods of the genus *Niphargus* strongly decrease, and they are replaced by the species of the "orcinus" complex; such a diminution is accentuated in the southern Apennines where only the species *Niphargus longicaudatus* is the only known for this genus. However, the northern part of the province is characterized by less stygobionts in comparison with the central part, as well as by a high frequency of northern elements, such as gastropods of the genera *Avenionia* and *Pseudavenionia*, cyclopoid copepods of the "Rassenkreise" *Diacyclops languidoides*, triclads of the genus *Polycelis*, some amphipods of the genus *Niphargus*, and asellid isopods.

The central Apennines have a rich and diverse invertebrate stygofauna, with a balanced proportion of northern and southern elements; moreover, in this region we can find elements with West-European affinities, such as the gastropod *Arganiella pescei* that is close to the French species *Valvata exilis*; species that show trans-adriatic affinities, viz. the amphipods of the "orcinus" complex; other species, such as the asellid isopod *Proasellus vignai* and the cyclopoid copepod *Graeteriella unisetigera* show affinities with north-west Apennine or Alpine species. This part of the Apennines is characterized by a striking number of endemics or rare species, among the following groups: asellid isopods (*Proasellus acutianus*, *P. adriaticus*, *P. amiterninus*, *P. vignai* and a *P. sp.* that we recently collected in phreatic waters of Umbria); cyclopoid copepods (*Eucyclops subterraneus*, *Acanthocyclops venustus italicus*, *Diacyclops languidoides aprutinus*); syncarids (*Meridiobathynella cf. rouchi*, *M. sp.*); triclads turbellarians (*Dendrocoelum benazzii*) and oligochates (*Peloscolex pescei* and *Haplotaxis gordioides*). Besides the above groups and species, a most significant feature of this region is the high number of stygobiont harpacticoid copepods, many of them endemic for the central Apennines: *Nitocrella juturna*, *N. achaiiae*, *N. stammeri*, *N. morettii*, *Parastenocaris pasquinii*, *P. proserpina*, *P. amyclaea*, *P. veneris*, *Elaphoidella tiberina*, *Kliopsyllus minutus*, *Ichnusella pasquinii*, *Apodopsyllus lynceorum*.

For the most part the stygobionts of this region colonized the groundwaters at a rather recent age (Pleistocene) directly from surface fresh waters, due to the dry climate that occurred during the interglacial periods; other ones are directly sea-originated or "thalassoid" species.

The southern Apennines includes a composite stygofauna, that is characteristically very scarce in stygobionts, some groups (amphipods of the genus *Niphargus*, asellid isopods, gastropods and triclads turbellarians) becom-

ing very rare. On the other hand, many stygophiles and “thalassoid” species, as well as some very interesting stygobionts or eustygophiles, may be found among the copepods (*Acanthocyclops agamus*, *Speocyclops italicus* and *Diacyclops languidoides nagysalloensis*), the microcerberid isopods (*Microcerberus arenicola*) and the water mites (*Lobohalacarus weberi*).

The Sardinian province, notwithstanding the limited and discontinuous extent of karstic areas is remarkable due to the great diversity and old age (Palaeozoic and Mesozoic) of the Sardinian karst, which gave rise to a considerable number of different, sometimes well separated underground aquatic systems, viz. inland and coastal caves, deep and superficial phreatic networks, large hyporheic systems, underground rivers, etc.

From a biogeographical point of view, this province holds a typical western stygofauna, that shows close affinities with French groundwater fauna, sharing with this country some stygobionts such as the copepods *Acanthocyclops brachypus*, *Halicyclops troglodites*, *Metacyclops subdolos*, *Parapseudoleptomesochra minoricae* and the amphipod *Salentinella angelieri*; it includes, as well, a great number of exclusive or rare species among different taxonomic groups, such as: cyclopid copepods (*Speocyclops sardus*); harpacticoid copepods (*Nitocrella beatrix*, *Elaphoidella oglasae*, *Ichnusella eionae*, *Arenopontia nesaie*, *A. subterranea*, *Delamarella galatae*, and a considerable number of species of the genus *Parastenocaris*); ostracods (*Mixtacandona chappuisi*, *M. cottarellii*); asellid isopods (*Proasellus patrizi*); stenasellid isopods (*Stenasellus nuragicus*, *S. assorgiai*); amphipods (*Ilvanella inexpectata*, *Orchestia remyi*, *Bogidiella vandeli*, *B. silverii*, *B. ichnusae*); syncarids (*Sardobathynella cottarellii*) and water mites (*Acherontacarus cicolanii*); other species which can be found in this province are southern elements or vicariant species, that are assumed to be recent immigrants in the groundwater of this province, whose colonization is supposed to coincide with the quaternary connection between Sardinia and continental Italy (Tuscany).

The Apulian province shows a marked individuality due to the large extent and the peculiar characteristics of its carbonate rocks, as well as to the different groundwater systems that have evolved in them. The distribution of stygobionts in this province demonstrates the continuity of the Salentine peninsula and the Murge groundwaters as well as the difficulty of faunal exchanges between this area and the Gargano district (Ariani, 1982). In this respect, we must stress that a remarkable richness of groundwater animals, for the most part stygobionts and endemics, occur in the Salento-Murge complex; on the other hand very few stygobionts can be found in the Gargano district, from which mainly stygophiles or stygoxenes, sometimes “thalassoid” elements, have been reported.

The Apulian province, as a whole, is characterized by a strikingly abundant and differentiated groundwater fauna, with a great number of ancient, specialized and rare stygobionts, the majority of them exclusive for this area and representing the most ancient and important elements of Italy's stygo-

fauna. With the Apennine province, the Apulia shares only a few, recent stygobionts or eustygophiles, such as some cyclopid and harpacticoid copepods (*Diacyclops antrincola*, *Thermocyclops oblongatus*, *Diacyclops languidooides* s.l., *Nitocrella stammeri*, *Parapseudoleptomesochra italica*), the amphipods *Niphargus longicaudatus*, *N. orcinus* s.l., *Rhipidogammarus rhipidiophorus* and *Salentinella angelieri*, and numerous stygophiles or stygoxenes.

The stygobionts of Apulia show different origin and geological age: the most ancient stygobionts, such as the species of the genera *Mixtacandona*, *Monodella*, *Speleomysis*, *Stygiomysis*, *Hadzia*, *Microcharon*, *Metaingolfiella*, *Typhlocaris*, *Salentinella* (only the species *S. gracillima*), are palaeomediterranean elements, that colonized the groundwater of this province during the "Tethys" period; other ones, such as the cyclopid copepods *Halicyclops dalmatinus*, *Diacyclops antrincola*, *Thermocyclops oblongatus*, *Metacyclops stammeri* and *Laophonte spelaea* and the amphipods *Niphargus orcinus* s.l., *Pseudoniphargus adriaticus*, *Salentinella angelieri* and *Rhipidogammarus karamani*, colonized the underground aquatic environments of Apulia at a rather recent age, as it is shown by their marked euryhalinity and wide perimediterranean distribution; moreover, a significant number of species, both stygobiontes or eustygophiles, are assumed to have colonized the Apulian groundwaters according to the "regression model evolution" (Stock, 1977). As regards the origin of the remarkable ostracod *Pseudolimnocythere hypogaea*, according to Danielopol (1980) two current hypotheses can be proposed, viz. this species could have colonized the Apulian groundwaters during Miocene marine regressions, or in the course of a Pleistocene regressive phase; according to the author, none of the above hypotheses could be refuted.

The Sicilian province, in spite of its great speleological interest, due to the presence of some extensive karstic areas, as well as several karstic and volcanic caves and other diversified groundwater habitats, is, up to now, still very poorly known from a stygofaunistic standpoint. In particular, there are surprisingly few recorded data concerning stygobionts of this province, the most information being available on stygophiles, stygoxenes or terrestrial groups of animals (Karaman & Ruffo, 1977; Cottarelli & Fasano, 1978; Caruso & Costa, 1978; Caruso, 1982).

To date, as far as we know, true stygobionts from this province are only the amphipods *Sarothrogammarus catacumbae* and *Niphargus longicaudatus*, the harpacticoid copepod *Nitocrella stammeri*, the isopod *Typhlocirolana* cf. *moraguesi* and a thermosbaenacean species (*Monodella* sp.).

Nevertheless, this list will be certainly extended, since recent stygofaunistic research in this province, carried out by the Zoological Institutes of the Universities of Catania and Rome, seem to indicate that the stygofauna of Sicily could be more rich and diversified than previously thought.



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