

Biogeographic provinces of karstic areas in Italy

faunistic affinities with southern France (e.g., among the isopods, *Proasellus* gr. *cavaticus*) and the Alps on one hand, and with Appennine and Tyrrhenian areas on the other. Biogeographically, therefore, this is a transition area which has little in common with the Alpine and pre-Alpine karst: we find rich specialized fauna and many endemic species belonging, for example, to various genera of isopods (*Proasellus*), diplopods (*Glomeris*, *Spelaeoglomeris*), carabids (*Duvalius*, *Agostinia*) and catopids (*Parabathyscia*).

- Appennines. The caves of the Appennine karst have troglobitic fauna which is generally poorer and more monotonous than that in the Prealps, although in some regions this may be due to lack of research until now. These are areas with endemic species (for aquatic fauna, in particular, the Ligurian Appennines, Alburni mountains, Gran Sasso massif; and the Latium-Campania pre-Appennine area for terrestrial examples). But there are others, where endemic species are, with few exceptions, almost absent (Apuan Alps, Calabria). The faunal monotony between Liguria and Campania may be due to the fact that the karstism in these areas is younger, and perhaps to the “peninsular effect” which definitely hindered colonization of the Appennines, but this is still a hypothesis. Novelties emerging from research conducted in the last twenty years have not substantially changed this picture, although new species of troglobites and eutroglophiles belonging to genera widespread in Italy have been added, like pseudoscorpions (*Neobisium*), carabids (*Duvalius*) and leptodirines (*Bathysciola*). Aquatic fauna have revealed interesting exceptions in the Gran Sasso and Alburni mountains, with the discovery of probable marine relics of Miocene age (copepod crustaceans of the genus *Pseudoectinosoma*).

Also of interest is recent research in the gypsum caves of the Emilian and Bolognese Appennines: the terrestrial fauna is mainly composed of a few eutroglophiles, while aquatic fauna is rich in stygobites (copepods and amphipods), although none is exclusively cave-dwelling (that is, they are also found in the interstitial environment), signalling the fact that colonization of these caves is recent.

Biospeleological research has also been carried out in the gypsum (Messinian evaporites) in Calabria (province of Crotona) and, here too, although interesting data have come to light (for example, a new species of *Niphargus*), troglobites are infrequent. This may be due to a combination of unfavourable factors, like the greater compactness of gypsum formations with respect to carbonatic ones (and thus, a lower degree of fissuration) and the young age and rapid evolution of pseudokarstic phenomena.

- Apulian karst. Very different from the Appennine karst, the Apulian version is

rich in endemic species and its cave-dwelling fauna is highly specialized. Of the thirty-odd troglobite species known, about twenty are exclusive to Apulia, some of which are genera or families in their own right. Aquatic fauna, still relatively poorly studied, contains exceptional endemic forms such as the sponge *Higginsia ciccaresei*, the mysids of the genera *Spelaeomysis* and *Stygiomysis*, the decapod *Typhlocaris salentina*, and many highly specialized copepods, isopods and amphipods. This is where we find some of the most exceptional and enigmatic examples of Italian fauna, like the amphipod *Metaingolfiella mirabilis*. Among terrestrial troglobites are the isopod genera *Murgeoniscus* and *Castellanethes* and the carabid *Italodytes stammeri*, of probably ancient colonization, next to more recent ones like *Aegonethes* and *Pseudanapis*.

The richness of endemic, specialized species is due not only to the extent and antiquity of karstic phenomena, but also to the geological history of the area, considered by paleogeographers as part of the Aegeis or in any case belonging to a microplate of different origin to that which gave rise to the remaining portion of the Italian peninsula.

- Sicily. Biogeographically composite, the cave-dwelling fauna of Sicily is still little known, particularly its aquatic forms. Sicily contains both karstic and lava caves. Various types of faunal research have been carried out in the volcanic caves, but have not revealed cave-dwelling forms of particular interest, due to the relative “youth” of such caves and to the structure of lava, which does not allow the creation of that indispensable system of crevices which troglobites use. Instead, interesting endemic forms are known in caves opening in carbonatic rocks: examples are the pseudoscorpion *Roncus siculus*, the amphipod *Tyrrhenogammarus catacumbae*, and isopods of the the genus *Spelaeoniscus*. Also endemic to the island are some species of trechine beetles of the genus *Duvalius*.

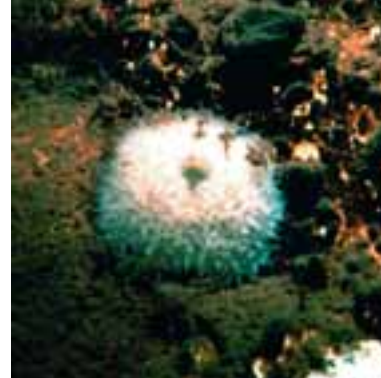
- Sardinia. The karstic territory of Sardinia is a world in itself: it is rich in cave-dwelling species (more than 300 have been reported until now), many of them endemic, and it has faunal affinities with Provence and the Pyrenees on one hand and with Corsica and Tuscany on the other.

This faunal originality derives from the paleo-geographic vicissitudes of the island, which was once part, with the areas mentioned above, of a paleo-continent called Tyrrhenis. After its fragmentation, which started in the Oligocene, Sardinia and Corsica became detached from the Provençal area and migrated towards Italy with a slow, clockwise rotating movement. Like great rafts, they brought with them ancient elements of the Tyrrhenic fauna, called for this reason paleo-Tyrrhenic.

Classic examples are genera with clearcut affinities with the Pyrenées (*Scotoniscus*, *Catalauniscus*, *Typhloblaniulus*), Cataluña-Provence (*Spelyngochthonius*, *Stygioglomeris*, *Oritoniscus*), eastern Spain and the Balearic islands (*Parablothrus*, *Syniulus*, *Speomolops*, *Ovobathysciola*, *Patriziella*), southern France and the Tuscan coast (*Stenasellus*), next to genera with endemic species (*Sardostalita*, *Sardaphaenops*). There are also more widespread forms in the Italian peninsula, revealing more recent phases of colonization.



Entrance to Grotta Zinzulusa, on Salento coast (Apulia)



Higginsia ciccaresei

Porifers. Porifers, or sponges, are primitive metazoa, mainly marine, although there are a few fresh-water members (spongillids). Some species have been reported in subterranean waters, generally as stygoxenes or stygophiles, exceptionally as stygobites. In Italy, although cave-dwelling sponges have been found in some coastal grottoes - *Petrosia pulitzeri* in the Gulf of Naples, Sicily and the Adriatic, *Myrmekioderma spelaea* in Apulia, and *Petrobiona incrustans* in the Grotta del Presepe at Santa Maria di Leuca - they are probably all eustytophile species. The most recent and exceptional finding is that of *Higginsia ciccaresei*, collected by a diver from the Zinzulusa cave (Apulia), about 250 metres from the entrance and at a depth of 12 metres, in total darkness. Its morphological characteristics and environment indicate that it is a stygobitic species.

Hydrozoa. Cave-dwelling hydrozoa are extremely rare. The siphons of some springs and shafts may reveal species of *Hydra*, solitary polyps which lack the medusa-like generation typical of this class of cnidarians: little or nothing is known of their ecology. The only hydrozoan considered to be a true stygobite and cave-dweller is *Velkovrhia enigmatica*, widespread in caves in the Dinaric karst from Slovenia to Herzegovina. Its possible presence in Italian territory has not yet been ascertained.

Triclad. Triclads, or planarias, include many species widespread in both sea



Troglophile triclad of genus *Dugesia*

and fresh waters and in damp soil. Some genera are frequently found in the interstitial environment and karstic springs (*Dugesia*, *Dendrocoelum*, *Polycelis*). Stygobitic species are

characterized not only by depigmentation (also found in some above-ground populations), reduction or disappearance of sight organs, and slowness of the reproductive cycle and respiratory processes, but also by a high number of chromosomes. A few infrequent cave-dwelling species are known in Italy, including definite stygobites like *Dendrocoelum collinii* in the Julian Prealps (also reported doubtfully in other parts of Italy), *D. italicum* in the Lombard Prealps, *Atrioplanaria morisii* near Cuneo, *A. racovitzai* in Sardinia and central-southern Italy, and *Polycelis benazzii* in Liguria.

Temnocephalids. This taxon, usually ascribed to turbellarians, includes, in Italian caves, ectoparasitic species of troglobitic crustaceans of the genera *Niphargus* (amphipods) and *Troglocaris* (decapods), which suck hemolymph. These tiny organisms (less than 2 mm long) have tentacles and suckers with which they attach themselves to their host's gills. In Italy, they have only been reported in the phreatic waters of the Gorizia and Trieste karst, where they are sometimes found in abundance on shrimps of *Troglocaris*. Three genera (*Bubalocerus*, *Scutariella*, *Troglocaridicola*) have been reported, but the taxonomy of the entire group is controversial. Research has recently been undertaken on the spermatozoa of the Italian species, with the aim of reconstructing their phylogenetic affinities.

Nematodes. This is a highly diversified phylum (possibly including more than 100,000 species), represented in

benthos, fresh and salt waters, and the soil, or as species parasitic on vertebrates or other invertebrates. Due to the sometimes very high number of specimens, even in caves, their role appears to be essential to the functioning of Italian cave ecosystems, but no studies have yet been carried out. Taxonomic difficulties in studying these organisms have prevented the preparation of exhaustive lists for Italian caves. An ongoing study in northern Italy has identified many species found in pools and subterranean streams, genera being *Aphanolaimus*, *Dorylaimus*,



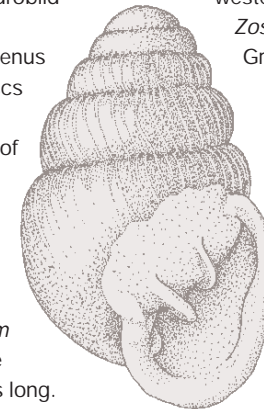
Nematomorphs (gordiaceans)

Eudorylaimus, *Paractinolaimus* and *Trypila*. Our knowledge is still too sketchy to enable us to state definitely whether some species may be considered troglobitic.

Nematomorphs. Nematomorphs make up a small taxon similar to nematodes. Adults generally live in slow-flowing streams, wells and drinking-places. They are filamentous in appearance, about 10 cm long, and only about 1 mm thick.

Their filaments are sometimes so twisted that they look like the Gordian Knot, from which they derive one of their names (gordiaceans). The larvae are endoparasitic in various arthropods. They are occasionally found in cave streams in northern Italy, but they are presumably stygoxene or perhaps stygophile species. No studies have been carried out on Italian cave-dwelling nematomorphs.

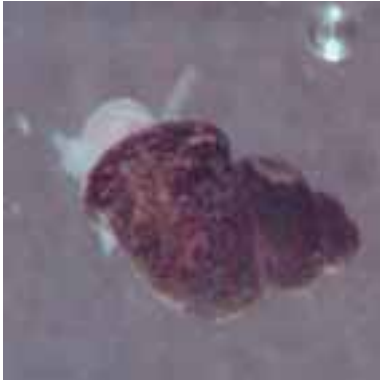
Molluscs. Of the molluscs, only snails and bivalves colonized underground environments and waters. But accumulations of debris and mud mixed with the shells of many species may sometimes be found in caves. However, as these materials were carried down from the surface environment through water circulation and percolation, true troglobitic species are in fact only represented by the genus *Zospeum*. Another ellobiid, belonging to the genus *Carychium*, which normally lives in other habitats in the external environment, likes very damp litter and isolatedly appears underground, whereas many zonitids are true stygophiles. Subterranean waters are mainly colonized by hydrobiid prosobranchs; bivalves are represented by the single genus *Pisidium*. Troglobitic molluscs also underwent transformations as a result of living underground: the shell is white and transparent, and the diaphanous animal has no eye-spots. The shell in the various species of *Zospeum* (see drawing) is never more than a couple of millimetres long.



These animals live in the dampest areas, or inside cracks, scraping the walls. The shell may be very varied according to where the specimens live and also within the same population.

Interest in this species goes back to around the mid-19th century. Since their size makes them difficult to identify, Pollonera, the famous researcher who was among the first to study the species, advised the cave explorers of those times to pass delicate brushes over the walls of caves, holding boxes underneath to catch specimens as they fell, or to search for them in the sediments of rivers flowing from karstic areas. In this way, many species and subspecies were discovered and described in Italy, Austria and the western Balkans, from Slovenia to Herzegovina. They have also recently been found in the Pyrenées.

The genus *Zospeum* was revised in the 1970s for Slovenia and, similarly, a meticulous census has been made of all sites and findings in Italy, and an interpretation of the various forms described in the literature has been proposed, from the Brescia area to the Isonzo basin. It appears that all the westernmost populations of *Zospeum*, as far as the Monte Grappa massif, present a single outer fold, whereas forms with two folds prevail to the east. In the latter specimens, the shell is also ribbed. It seems that the more westerly species should be grouped as *Zospeum globosum* and the more easterly ones as *Z. issellianum* and *Z. spelaum*, which is also found in Slovenia. Instead,

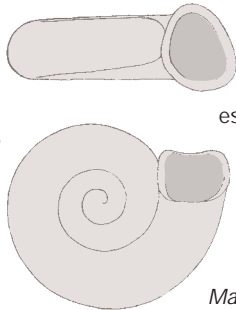


Plagigeyeria stochi

Z. alpestre is almost exclusively found in Slovenian territory, although it has recently tentatively been identified in some caves in the Monte Musi chain (Julian Prealps).

Among predatory troglophile molluscs, the genus *Oxychilus* is very widespread, although some species are more frequent in some regions than in others. *O. draparnaudi* is almost ubiquitous throughout Italy. *Aegopsis gemonensis* is another troglophile form frequently found in the caves of the central-eastern Prealps. Sometimes the genus *Argna*, with the species *A. biplicata*, typically found below ground, appears in the cave habitat.

Among fresh and brackish water snails, the hydrobiid family is the most numerous as regards number of genera and species. They are mainly found in karst springs or underground and interstitial waters. Some species, particularly those of the genus *Iglica*, are even today



known only by the morphology of their shell, because only already empty shells reach the outside from springs and hyporheic waters. This indicates that these animals prefer the deepest subterranean, poorly accessible habitats, sometimes far from the places in which their shells are found. Hydrobiid shells are very variable in aspect: high spiral forms prevail, but there are also genera with flattened spirals like *Hauffenia*, *Hadziella* (see drawings) or *Islamia*. They are always very small.

Some stygophile species are found quite extensively, like *Graziana pupula* in the Eastern Alps, *G. alpestris* in the central-western sector, and *Bythinella schmidtii*, which ranges from the Alps to the Appennines, as far south as Campania. Most of the strictly stygobitic species are more limited in their distribution, like many species of *Alzoniella*, *Pseudavenionia*, *Iglica*, *Paladilhopsis*, *Phreatica* and *Hauffenia* in the Alps; *Avenionia*, *Fissura*, *Pezzolia* and *Islamia* in the northern Appennines; and *Moitessieria*, *Sardhoratia* and *Sardopaladilhia* in Sardinia.

For some of these, like *Istriana mirnae* in the flyschoid areas of Venezia Giulia and Istria, and *Plagigeyeria stochi* in the underground parts of the Timavo, known distribution is reduced to only a few locations.

Polychaetes. Polychaetes are essentially marine annelids and some species colonize grottoes along the coast. Species suited to continental fresh waters are very rare. In Italy, the stygobitic species *Marifugia cavatica* is found in the

phreatic waters of caves in the Gorizia and Trieste Karst. This is a diaphanous worm, depigmented and eyeless, which lives in a more or less calcified tube, sometimes more than 1 cm long. It forms large colonies which coat the walls of the large galleries of the subterranean Timavo near Trieste, and a rich microfauna, composed of protozoa, gastropods, oligochaetes and crustaceans inhabits the spaces between the tubules or inside abandoned ones. *M. cavatica* ranges from the river Isonzo to the border with Albania. It has been hypothesized as a very ancient relic of marine origin, presumably going back to the Miocene.

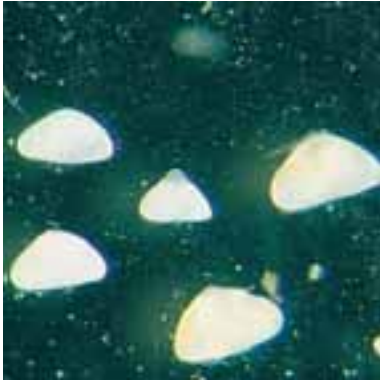
Oligochaetes. These are annelids with long bodies, composed of a succession of metamers without appendages, but bearing transversal rows of bristles, the form and arrangement of which is of taxonomic value. The main species are detritivorous or microphagous. Caves frequently contain some aquatic families (lumbriculids, naidids, tubificids) or ones of semi-aquatic or terrestrial type (enchytraeids, lumbricids).

The terrestrial species, very common in damp soil and the deposits of organic matter at the bottom of karstic shafts, are generally believed to be regular or simple subterranean troglonexes (e.g., *Allolobophora rosea*, *Octolasion cyaneum*, *Dendrobaena cognetii*). Some aquatic species, however, showing affinities exclusively with marine genera or collected until now only in subterranean karstic waters, are to be considered true stygobites. Species known until now only in caves are *Haber monfalconensis*, found at the Bocche del

Timavo in the Trieste Karst; *Rhyacodrilus gasparoi* from a cave in the Julian Prealps; *R. dolcei* from small pools in a cave in the Trieste Karst; *Tubifex pescei*, frequent in phreatic waters in the Marches and Umbria and in a Slovenian cave; and *Abyssidrilus cuspsis*, collected from phreatic waters in Umbria and caves in Liguria and Friuli-Venezia Giulia, a stygobitic species belonging to a genus which also has marine members.

Hirudineans. Hirudineans, or leeches, are not often found in Italian subterranean waters, where they are mostly stygoxenitic; only *Dina krasensis*, inhabiting springs on marly-sandstone terrains in the most easterly part of the Julian Prealps and around Trieste, penetrates caves, where it is sometimes found regularly and locally abundantly, and may be considered as a stygophile. Troglotic species have been reported in caves in Herzegovina, Montenegro and Turkey, but not in Italy. The species in Italian caves do not suck blood, as one would immediately think, but prey on other aquatic invertebrates.

Tardigrads. These small animals (rarely exceeding 1 mm in length), are transparent, and usually have four pairs of unjointed legs. There are marine and fresh water species, and terrestrial ones. They mainly frequent moss, where as many as 2 million specimens have been reported in one square metre. Tardigrads are active only in a thin sheet of water (e.g., after rain, or as dew); otherwise, they enter a stage of immobility (cryptobiosis) which may last for several years. Although data on cave-dwelling tardigrads are scarce, according to



Troglolithic ostracods of genus *Pseudocandona*

ongoing research, the most common species in this environment are *Macrobiotus cf. richtersi* and *Diphyscon nobilei*, sometimes abundant in small hollows in clay, but some have also been found in litter and moss.

Ostracods. These crustaceans are unmistakable, with their bodies enclosed in a generally ovoid, bean-shaped or trapezoidal bivalve carapace, sometimes ornated with tubercles or hollows. They are small (most stygobitic species do not exceed 1 mm in length), widespread in all fresh or salt waters, from small pools in tree-holes, to puddles, ponds and lakes, where they are usually benthic or interstitial, very rarely planktonic. Still very little is known about this group in Italian subterranean karstic waters, although it is very widespread in cave streams and siphons. Recent collections reveal richly diversified fauna, with many blind, depigmented species new to science: among these, most belong to the vast candonid family. One new species (*Cypria cavernae*) has recently been

described from the caves in the Gorizia and Trieste Karst, the only stygobitic species of the genus, common in the slow-moving waters of the phreatic zone. One very special species, which deserves to be mentioned for its life-style, is *Sphaeromicola stammeri*. This commensal lives exclusively on various abundant isopod stygobitic crustaceans, and is found clutching the appendages of its host. Its distribution follows that of its host species and it is thus found from Herzegovina to Lombardy.

Instead, *S. sphaeromicola* lives on the large cave-dwelling cyrolanids of the genus *Sphaeromides*, recently found also in Italy.

Cladocerans. These are very common crustaceans found in fresh surface waters, where they populate seasonal pools, lakes and slow-flowing watercourses; over a hundred species are known in Italy. They are frequently found in the waters of Italian caves, generally as stygoxene forms. Their scarce presence in subterranean waters is probably due to their feeding habits (many species are associated with the presence of phytoplankton and submerged vegetation) and to their definite preference for eutrophic waters. However, two stygobitic species have recently been described (*Alona stochi*, *A. sketi*), blind, diaphanous, and small (0.5 mm). As the latter were found in springs in Slovenian caves only a few hundred yards from the frontier with Italy, it is therefore probable that they also live this side of the border.

Copepods. These are generally small (0.2-0.5 mm) crustaceans, widespread in



Troglolithic cyclopoids of genus *Diacyclops*

both marine and freshwater environments. In Italian continental waters, they are essential components of lacustrine zooplankton, occupying both flowing and standing waters, and often prevail in subterranean aquatic communities. In Italy, several hundred species exist and, of the ten orders known, only three (calanoids, harpacticoids, cyclopoids) have troglolithic members widespread in vadose and phreatic waters.

- Calanoids: planktonic copepods, found in lakes and slow-flowing watercourses. The only stygobitic and definitely troglolithic species, *Troglodiptomus sketi*, lives in the Gorizia and Trieste Karst caves in Italy, and also in Slovenia and Croatia. It is common in the siphons of karstic caves and shafts associated with the underground course of the Timavo.
- Cyclopoids: very widespread in surface waters, there are many stygobitic species, mainly benthic and interstitial, found throughout all Italian regions, although many must still be described in detail. The cyclopoids of Italian caves are distinguished into three categories on the

basis of their ecology: mainly planktonic (e.g., *Metacyclops*, reported in the caves of Venezia Giulia, Apulia and Sardinia); benthic, exclusive to the phreatic zone, or sometimes interstitial (e.g., stygobitic species of *Eucyclops*, *Diacyclops* and *Acanthocyclops*), and species inhabiting the vadose zone, where they live in the network of tiny crevices in carbonatic rocks (numerous species of *Speocyclops*).

The most frequently found cyclopoids in subterranean waters belong to the *languidoides* group of the genus *Diacyclops*. This is a set of species, many of which have not yet been described, populating both karstic areas and alluvial soils. Among the other species of cyclopoids, north-eastern Italy hosts some endemics (such as *Metacyclops gasparoi*) or species which show a distribution restricted to the Julian-Slovenian (including the common *Diacyclops charon*, *Metacyclops postojnae*, *Speocyclops infernus*) or Illyrian-Balkan areas (e.g., *Acanthocyclops troglophilus* and *A. gordani*). The Prealps and Alps generally host species more widespread in both karstic and non-karstic systems of southern Europe (e.g., *Eucyclops graeteri*, *Acanthocyclops kieferi*, *Graeteriella unisetigera*); the cave-dwelling fauna of the Apennines is much less well known. Worthy of note is the occurrence of *Acanthocyclops agamus*, an exceptional species endemic to the Castelvita cave (Alburni massif). The fauna of the Sicilian and Sardinian caves is still poorly known. Some species are associated with anchialine caves, recently described in Sardinia (but also reported in the

Balearic and Canary islands).

It should not be forgotten that, next to stygobitic species, substygophile and stygoxene forms are widely found in Italian subterranean waters, where they may be abundant (e.g., *Eucyclops serrulatus*, *Paracyclops fimbriatus*, *P. imminutus*).

• Harpacticoids: this order includes many benthic and interstitial species, very common in caves. Stygophile species include members of *Bryocamptus* and *Attheyella*, although there are also some eustygophile (*B. typhlops*) and stygobitic forms (*B. balcanicus*, *A. paranaphthalica*). Stygobitic species also contain many endemic forms in restricted karstic areas, belonging to *Nitocrella*, *Elaphoidella*, *Lessinocamptus*, *Moraria*, *Morariopsis*, *Paramorariopsis*, *Ceuthonectes* and *Parastenocaris*. Here, many species have only recently been discovered and are still being described, some being known only in a single cave: they generally inhabit crevices in limestone and small pools or percolation rivulets in cave. This type of habitat (which functions in a certain sense as an "island" inside a certain karstic system) and the isolation of the various carbonatic massifs as karstism progressed, presumably favoured speciation mechanisms which gave rise to such a high number of endemic species.

Genera such as *Elaphoidella* and *Lessinocamptus* probably colonized subterranean waters starting from surface waters or semi-terrestrial habitats through "corridors" such as, for example, hyporheic environments. Instead, members of *Nitocrella* and *Parapseudoleptomesochra* presumably colonized subterranean continental

waters starting from marine ancestors. Two different species belonging to *Pseudectinosoma*, which until now had only contained a single Atlantic marine



Aquatic isopods of genus *Monolistra*

species, were recently found in the internal karstic systems of central-southern Italy (Gran Sasso massif, Abruzzo, Alburni massif, Campania). This finding becomes even more important if we consider that the genus is unknown anywhere else in the Mediterranean basin and that these stygobitic, freshwater species may be the representatives of an ancient fauna of the Mediterranean, which disappeared from its original marine environment during the Messinian salinity crisis.

Isopods. This order of malacostracan crustaceans has reached an exceptional degree of adaptative radiation, with more than 10,000 species covering terrestrial, fresh and salt water environments, or adapted to a parasitic life-style. Isopods presumably colonized Italian caves starting from the sea (during the Miocene and Pliocene regressions: cyrolanids, microparasellids, perhaps spheromatids) (see box for more details on this controversial hypothesis), from surface

fresh waters (asellotes) or from soil and litter (oniscoids). The adaptations and life-styles of isopods, and the evolutionary history of their various families is so varied that each of them constitutes a microcosm in its own right.

• Spheromatids: the genus *Monolistra* occurs in Italy, with many species in caves in the Prealpine belt from the Italian-Slovenian border to the Lake of Como. Every species or subspecies is to be viewed as endemic to a restricted karstic massif. *M. (Microlistra) schottlaenderi*, exclusive to some springs in the Isonzo Karst, and one species still being described, found in the extreme eastern end of Venezia Giulia, are the Italian representatives of the subgenus *Microlistra*, widespread in Slovenia and Croatia. All the species of this subgenus have large dorsal tubercles, sometimes extending to form long spines and interpreted as efficient defence structures, particularly when the animal curls up to protect itself from predators or to allow itself to be transported by water currents. Instead, *M. (Monolistra) coeca julia* is the only Italian representative of the subgenus *Monolistra* and is endemic to the Julian Prealps. The remaining species and subspecies in Italy belong to the subgenus *Typhlosphaeroma* (or perhaps to several similar subgenera) and occur in the Trieste and Gorizia Karst, and in the Carnic, Veneto (Lessini Hills, Brenta massif, Beric Hills) and Lombard Prealps.

• Cirolanids: a family mainly containing marine species, only discovered recently in Italian groundwaters. *Typhlocirolana* aff. *moraguesi* (identified by means of molecular biology techniques as closely related to but

distinct from *T. moraguesi* from Majorca), found in artificial wells along the coast near Siracusa in Sicily, presumably colonized subterranean waters during the marine regressions of the Pliocene, as indicated by datings using molecular techniques. *Sphaeromides virei*, found in caves in the Gorizia and Trieste Karst, Istria and Dalmatia, is a very large predator, more than 3 cm long, which is at the apex of the food chains of simple subterranean cave ecosystems: it may be found along the coastline of Dalmatia (Illyrian distribution), and its many endemic subspecies indicate that it colonized the subterranean waters of the Dinaric karst in very remote times.

• Microparasellids: small (a few mm) isopods, generally interstitial. They were originally marine species, whose distribution recalls the ancient coastlines of the Tertiary seas. Six Italian species of the genus *Microcharon* are known, but none has as yet been collected in caves.

• Asellids: a family including many freshwater species, in both surface and underground waters, with specialized life-forms in both phreatic and cave environments. The family is found in Eurasia, North Africa and northern and central America, but its affinities with



Proasellus franciscocoli

Among the stygobites best known from the taxonomic and evolutionary viewpoints are two genera of isopod crustaceans (*Monolistra* and *Coecosphaeroma*), belonging to the family of spheromatids. Biospeleological interest has focused on them for the following important reasons:

- their closest relatives are all, without exception, marine (*Sphaeroma*, which groups species very common in lagoons and along pebbly beaches); no similar genera exist in fresh surface waters;
- the geographic distribution of the genera faithfully follows the limits of Tertiary seas, as already hypothesized by several research-workers a hundred years ago
- their size and frequency measured by molecular analysis (electrophoresis) reveal that the origin of *Monolistra* and of some of its species can be dated very precisely, and coincides with the salinity crisis of the Mediterranean which led to its almost total drying-up during Messinian times (Upper Miocene).

All these facts mean that monolistrines are highly suitable "models" for formulating and testing hypotheses on the origin and evolution of cave-dwelling organisms. However, here too, there are controversies, substantially as follows: the marine origin and distribution of the group appear to be congruent with the "regression model",



which presumes that these organisms are relics which adapted themselves to the subterranean environment after the marine regression of the Miocene. Colonization thus followed a direct route from the sea to subterranean karstic waters, probably independently for the two genera (*Monolistra*, of Mediterranean origin, and *Coecosphaeroma*, Atlantic). This theory has recently been criticized, in that it presumes that the animals were

"obliged" to colonize subterranean waters as a result of adverse environmental conditions, i.e., increased salinity. Recent, still unpublished data, and the discovery of great numbers of Tertiary spheromatid fossils in surface streams and rivers, have given rise to the following, more modern hypothesis:

- the marine species of *Sphaeroma* freely colonized fresh surface waters, occupying available niches;
- the Messinian salinity crisis interrupted the gene flow with marine populations, giving rise to a process of speciation;
- karstification of the territory

favoured active colonization of subterranean waters, where empty niches were available, together with less competitive pressure, since insects did not colonize groundwaters;

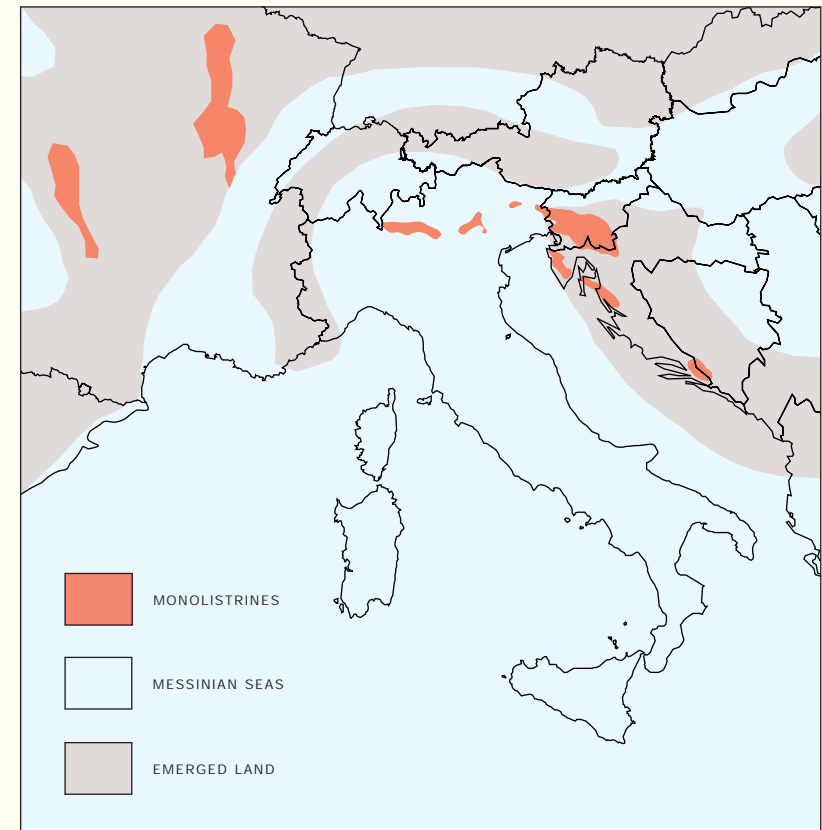
- progressive karstification isolated many massifs and favoured processes of allopatric speciation; currently, every hydrographic basin has its own species

or subspecies of *Monolistra*;

- climatic variations or other processes led to the disappearance of surface-living species.

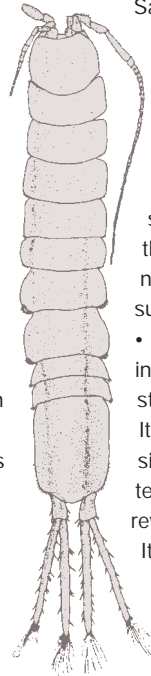
Monolistrines have developed sometimes exceptional defence mechanisms, particularly in *Monolistra*, with long, sharp spines or tubercles; their natural enemies are mainly large amphipods of *Niphargus* or olms. Another defence mechanism adopted by

these animals is their ability to curl themselves up completely, thus protecting their appendices and the underside of their bodies from predators. Recent studies support the hypothesis that curling up is not only a defence mechanism but also a means of being transported more rapidly by water currents, the animals being rolled along together with small pebbles and gravel.



Present-day distribution of monolistrines, plotted on paleogeography of Messinian seas

other marine isopod families give rise to doubts: subterranean waters were definitely colonized starting from surface waters. Populations of above-ground species have also been found in caves, depigmented, and with reduced eyes (microphthalmic), denoting a still ongoing phase of active colonization of the underground domain. Almost all the stygobitic species are endemic to Italy and have small areas of distribution. Within the ambit of the genus *Asellus*, Italy has *A. cavernicolus*, which lives in the basin of the Timavo in the province of Trieste and has recently been studied with molecular techniques by a Slovenian team of researchers. It is presumably a relic of pre-glacial colonization of the Julian and Slovenian karstic areas by the similar surface-living species, *A. aquaticus*. The single species *Chthonasellus bodoni* is the only member of the genus *Chthonasellus*, endemic to Italy (province of Cuneo). It has affinities only with the French genus *Gallasellus* and with American species, revealing a perhaps very ancient origin. There are, instead, many more representatives of *Proasellus*, with many stygobitic, cave-dwelling and interstitial species, throughout Italy; some of these must still be described. Among the most interesting cave-dwelling species are *P. ligusticus*, found in Liguria and the Apuan Alps; *P. pavani* in a cave near Brescia; *P. cavaticus* in western Piedmont, Liguria and France; and *P. franciscocoli* from caves in Liguria



and near Cuneo, together with very many other species still not defined in detail, known until now under the collective name of *P. patrizii*, exclusive to caves in Sardinia. Also for the stygobitic species of *Proasellus*, which have surface-living species in Italy, various hypotheses have been formulated regarding their origin as relics, i.e., derived from populations which found refuge in subterranean waters as a result of the instability of surface water networks, or as active colonizers of subterranean waters.

- Stenasellids: a widespread family, including exclusively very ancient stygobitic species. The number of Italian species is not known exactly, since recent refinement of molecular techniques is leading to extensive revision of traditional systematics. In Italy, the family is limited to Tuscany and Sardinia; the best-known species is *Stenasellus racovitzae* (see drawing), found in Tuscan caves; the Sardinian fauna is undergoing revision. Biochemical techniques have identified at least six different endemic species in Sardinia. Two of these (until now attributed to *S. racovitzae*) show affinities with French species, and another two (*S. nuragicus*, *S. assorgia*) with East European species. Lastly, two species, identified in the province of Nuoro, are similar to those of Spain, revealing the complex paleogeographic vicissitudes undergone by Sardinia.
- Microcerberids: present in Italy in continental fresh waters with the single stygobitic species *Microcerberus ruffoi*, from the phreatic water-table of the river



Titanethes dahli

Adige, but never found in caves; other species are of littoral marine type.

- Oniscoids: terrestrial isopods have many families with troglobite representatives in Italy (styloniscids, trichoniscids, buddelundiellids, trachelipids, spelaeoniscids, armadillids). These organisms are not usually capable of dispersing easily and thus endemic species are frequent. Their distribution is of great interest for biogeographers, since it reveals many of the paleogeographic events undergone by the Italian peninsula. In north-western Italy, for example, we find species which also populated the French Alpes Maritimes (sometimes troglophile in one part of the area and troglobite in another): typical of this area are *Trichoniscus voltae* and *Alpioniscus feneriensis*. Also of interest is the concentration of endemic species of *Buddelundiella* in the French Alpes Maritimes and Liguria. Proceeding from west to east along the Alpine arch, cases become more complex and taxonomy intricate: prevailing species belong to the subgenus *Dentigeroniscus* of the genus *Androniscus*, with a prevalence of *A. dentiger*, presumably eutroglophile. Lastly, in Venezia Giulia, we find

troglobitic species with Illyrian affinities: *Titanethes dahli*, *Androniscus stygius* and *Alpioniscus (Illyronethes) strasserii*. The Appennines have a smaller number of species (*Miktoniscus patrizii* in Latium, *Trichoniscus callorii* in the Monti Lepini), with the exception of Apulia, with interesting endemic (*Castellanethes sanfillippoii*, *Murgeoniscus anellii*) or trans-Adriatic species (*Aegonethes cervinus*). Sicily instead has a few endemic species, but they belong to genera which mainly live above ground, like *Armadillium lagrecai*. Lastly, Sardinia offers perhaps one of the most interesting faunal frameworks for biogeographers, due to the occurrence of paleo-Tyrrhenian species like *Scotoniscus janas*, *Catalaunicus hirundinella* and *C. puddui*.

Amphipods. Like isopods, amphipods too are a rich order of mainly marine and freshwater species, with a very small number of subterrestrial ones. Amphipods colonized subterranean waters from the sea or from fresh surface waters, where they differentiated into a very high number of species, in some cases (e.g., *Niphargus*) showing splendid examples of adaptative radiation. Italy has almost a hundred species living in subterranean waters, most of them in caves, others in interstitial habitats in alluvial plains, in the interstices of marly-sandstone rocks, and even in cracks in igneous and metamorphic rocks. Here, we describe only the main families with stygobitic members.

- Bogidiellids: mostly interstitial species, sometimes littoral (euryhaline or definitely marine), occasionally collected in grottoes (e.g., *Bogidiella calicall* from the

Grotta del Fico on the island of San Pietro (off south-western Sardinia).

- Gammarids: inhabiting mainly superficial fresh or marine waters, quite frequent in caves, particularly in illuminated stretches of subterranean streams in karst springs and chasms, as stygoxenes (*Gammarus*, *Echinogammarus*). Specimens of *Rhipidogammarus* and *Tyrrhenogammarus* have been found in grottoes and coastal karst springs. The only definitely stygobitic Italian species, *Ilvanelia inexpectata*, lives in phreatic and karstic systems on the island of Elba and in Tuscany.
- Hadziids: species of the genus *Hadzia*, presumably relics of the Tethys, are



Niphargus gr. *speziae*

mainly associated with interstitial and littoral marine habitats. But there are also cave-dwelling species, like *Hadzia fragilis stochi*, an endemic subspecies, recently discovered in the Bocche del Timavo and in some caves in the Isonzo Karst: they are definitely troglobites, with very long, delicate appendages, denoting specialization to a habitat composed of the phreatic waters of karstic conduits. Other Italian species are *Hadzia minuta*,

found in caves in the Salento, and *H. adriatica* in Apulia.

- Metacrangonictids: a family only discovered very recently in Italy, it includes phreatic and cave species of the Mediterranean basin, Morocco and Fuerteventura in the Canary Isles. In Italy, only *Metacrangonyx ilvanus* is found, endemic to Elba, where it is found in a single shaft, in alluvial soil.
- Niphargids: The systematics of the genus *Niphargus* (more than 250 known species, all - with very few exceptions - stygobites) is very intricate and controversial, and is perhaps one of the most problematic Italian groups from the taxonomic viewpoint. Italy has more than 60 species (but many others are currently being described), with differences which are often based on minute morphological details. The distribution of *Niphargus* is of southern European type, with an eastward extension as far as Iraq, whereas in the west it only marginally affects Spain; the genus is absent from North Africa. The northern limit is clearly marked by the maximum expansion of the Würmian glaciers, with rare examples of recolonization of glaciated areas by widespread species. According to its distribution characteristics, the genus is presumed to have colonized European freshwaters starting from the basins of the Paratethys in Tertiary times, although a more ancient origin has recently been postulated. The Alpine region has the greatest biodiversity in Italy, and contains many endemic species of *Niphargus*, referring to the groups *stygius* (East European) and *longicaudatus* (more southerly). Species of the *stygius* group may be found as far as central Italy along the



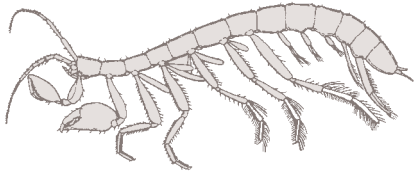
Niphargus julius

Appennines and in the islands of the Tuscan archipelago, where species similar to *Niphargus speziae* (Liguria) are found. Southern Italy, Sicily and Sardinia are much poorer in species, and the *longicaudatus* group predominates. Another interesting group is the *arcinus* group, which includes large species widespread in southern Italy, the Balkans and the Middle East; in Italian territory some species penetrate from the Balkans into the Trieste and Isonzo Karst. In Italian caves, there are yet other representatives of other groups, of complex taxonomy, all widespread in Europe (groups *aquilex*, *kochianus*, *bajuvaricus*, *puteanus*), or endemic species of uncertain affinity (e.g., *Niphargus stefanellii*, known in central-southern Italian caves with affinities only with one species inhabiting Istria and Dalmatia). From an ecological viewpoint, *Niphargus* members occur in almost all caves where minimal amounts of water are found. They play an important role within the framework of subterranean ecosystems, where they act as predators or detritivores; they may be very large (up to 4 cm in length) and are therefore at the apex of the food pyramids in these

habitats. They occupy all available niches, from interstitial environments to tiny clefts in carbonatic and non-carbonatic rocks, watercourses, subterranean pools and siphons, and large kastic conduits. Some species are very resistant to water stress (e.g., if their water supplies dry up) and can survive in hollows in damp soil. This great variety of micro-habitats corresponds to a considerable variety in size (from 2 to 40 mm) and body shape, ranging from globular forms, as in species with tendencies towards curling up, to long vermiform shapes in interstitial species. Their structure may be massive and stubby, as in species of the *arcinus* group, with large front legs of pincer type (gnathopods) or thin and long, with small gnathopods, as in some species of the *longicaudatus* group.

- Pseudoniphargids: this family is not closely connected with niphargids, although their name suggests it. But, like niphargids, it has produced extraordinary adaptive radiation in subterranean waters. For example, in most of Spain, *Pseudoniphargus* replaces *Niphargus* in caves, occupying the same ecological niches. In Italy, four species are known, of which the most common is *P. adriaticus*, found both in interstices and in caves not far from the coast.
- Salentinellids: the genus *Salentinella* is widespread in regions along the Mediterranean coastline, and is presumed to be ancient (perhaps paleo-Mediterranean). Unknown marine ancestors probably colonized subterranean waters, perhaps on several occasions from the Middle Miocene onwards, as the distribution of the genus follows ancient coastlines.

The taxonomy of the Italian species of *Salentinella* requires revision. The commonest species, *S. angelieri*, typically interstitial and frequent in



weakly brackish waters not far from the coast, is also reported in caves in isolated karstic rocks, in typically mountain environments. Presumably, in these karstified areas there are distinct and endemic taxonomic units, already described previously as true species. Instead, one definitely separate, endemic species, *S. gracillima*, inhabits phreatic cave waters in Apulia.

- Ingolfiellids: small stygobitic amphipods, with long bodies, mainly living in interstices, in both salt and fresh water. Only one species is found in Italy, in fresh water: this is *Ingolfiella (Tyrrenidiella) cottarellii*, only found in a cave on the island of Tavolara (Sardinia).
- Metaingolfiellids: *Metaingolfiella mirabilis* (see drawing) is one of the most exceptional animals among Italian cave-dwelling fauna.

The species has been collected only once (but a large number of specimens were caught) from a well in the Salento, pumping water from a deep karstic fault, and was described by Ruffo in 1969. Since then, despite much biospeleological research in the Apulian karst, no other examples of this endemic species have been found, and it is considered extremely rare. This

crustacean is probably one of the oldest components of all Italian fauna.

Bathynellacea. More than 200 species of these crustaceans are known, all stygobites. Some researchers believe that they form a group of very ancient origin, perhaps already well diversified in the Paleozoic. At that time, bathynellacea were widespread in the littoral coastal waters, lagoons and estuaries of Laurasia, from which they colonized Gondwana in the Permo-Triassic, before Pangea split up, thereafter becoming widespread in continental subterranean waters. This fascinating hypothesis, not yet supported by objective proof, indissolubly links taxonomic study of these organisms with the great paleogeographic events of our planet. In Italy, syncarid fauna has not been greatly studied. The genera *Bathynella*, *Anthrobathynella*, *Meridiobathynella*, *Sardobathynella* and *Hexabathynella* have been found, mainly containing interstitial species. However, rich populations of syncarids belonging to several species of *Bathynella* have recently been found in cave pools in the Lessini Hills, Julian Prealps and the Gorizia and Trieste Karst, where they presumably inhabit crevices in carbonatic rocks. Since this finding was due to new sampling methods in these special environments, syncarids are probably much more widespread in Italian caves than hitherto believed.

Thermosbaenacea. In this case too, the order is of very ancient origins, and includes about thirty stygobitic species spread over five continents. The evolutionary history of these



Spelaeomysis bottazzii

crustaceans is associated, as for bathynellacea, with the marine regression of the Tethys, and followed its vicissitudes. In Italy, the following species are found in subterranean karstic waters (rarely in interstitial waters): *Limnosbaena finki*, in the Gorizia and Trieste Karst (also known in Bosnia); *Monodella stygicola*, endemic to Apulian caves and wells; *Tethysbaena argentarii*, endemic to a cave on Monte Argentario (Tuscany), and *T. siracusae*, endemic to wells in Sicily.

Mysids. Mysids now number more than 800 species, mainly living in marine or brackish waters; only a few live in fresh subterranean waters. Most stygobitic species are found along coasts, proving their presumably recent origin from marine ancestors. In Italy, two stygobitic species occur in caves and wells with phreatic waters in Apulia: *Spelaeomysis bottazzii* and *Stygiomysis hydruntina*. Both species, which may live together, are endemic to Italy. If their adaptation to subterranean waters, as suggested by recent electrophoretic research, is a relatively recent event (Pliocene), the wide geographic distribution of these genera (embracing Mediterranean, American and Indo-

Pacific areas) reveals their considerable antiquity in continental waters and a presumably Tethyan origin.

Decapods. 170 stygobitic species of decapods are represented in the subterranean waters of the world. In Italy, two cave-dwelling genera are known: *Troglocaris* (Isonzo and Trieste Karst) and *Typhlocaris* (Salento). Although Italy also contains three species of shrimps of *Troglocaris* belonging to the *anophthalmus* group, they are "sibling species", i.e., morphologically indistinguishable but clearly different on the basis of molecular biology. According to paleogeographic reconstructions and approximate dating of the time of divergence by means of the molecular clock, it is believed that the three species



Typhlocaris salentina



Troglocaris gr. anophthalmus

differentiated between 700,000 and 1,700,000 years ago, after hydrogeological barriers formed between the subterranean waters of the Isonzo Karst (associated with the basin of that river), the Trieste Karst (associated with the basin of the Timavo) and small local basins in the Istrian Karst, of which a tiny tongue extends into Italy. These hydrogeological barriers partly no longer exist, and it is for this reason that, in some localities, two of the three *Troglocaris* species live together without cross-breeding. The other Italian species, *Typhlocaris salentina*, is endemic to caves in Apulia; the other two known species of *Typhlocaris* live in subterranean waters in Israel and Libya.

Mites. Mites are small or very small arachnids, ranging in size from 0.1 mm to 3 cm, mostly terrestrial, with some fresh-water species and a very few marine



Specialized mites of genus *Rhagidia*

ones. They are found in almost all environments, and may be predators, necrophages, phytophages, or commensals of mammals and birds, consuming hairs, feathers, skin debris, or fatty secretions, or parasitic on other animals, both invertebrates and vertebrates.

There are many terrestrial mites which live in caves, on guano or other organic matter, on the soil, or in rock fissures. As a few of them are associated with this habitat, they are considered as cave-dwellers. Italian caves contain members of various families, e.g., macrochelids (*Geholaspis mandibularis*); parasitids (*Pergamasus quisquiliarum*), widespread throughout Italy and its islands; polyaspidinids (*Uroseius sorrentinus*), a species found in central-southern Italy; and ragidiids, with many species including *Troglocheles strasseri*, apparently associated with cave habitats in north Italy, France, Switzerland, Austria and ex-Yugoslavia. Then there are several species of the oribatid order, living on soil and guano.

The position of a parasite living on bats, *Ixodes vespertilionis* (ixodid family) is of great interest and has been the subject of lengthy debate. Many authors consider it a troglobite, since it is often found inside caves without its host and in all stages of development. Others consider it an occasional cave-dweller associated with bats.

Palpigrads. These small blind arachnids, with a long flagellum at the tip of the abdomen, are certainly the least known of the cave-dwellers. The facts that all palpigrads are colourless and lacking sight organs, that they live both in caves



Palpigrad of genus *Eukoenia*

and outside them, and that there are very few ecological data regarding this order of arthropods, all mean that it is very difficult to fit the species found in caves into one of the ecological categories normally used for cave-dwellers. Palpigrads preferably eat spring-tails and other small arthropods which they find at the base of stalagmites or under pebbles on the ground. Ten species have been found in Italian caves, all belonging to the genus *Eukoenia*. Of these, seven have been collected exclusively in the cave environment. Of particular interest are *E. gasparoi* in Venezia Giulia, *E. brignolii* in Apulia, and *E. patrizii* and *E. grafitii* in Sardinia, which have adopted special strategies suited for cave life. Other species are known in some caves in the Alps.

Pseudoscorpions. Pseudoscorpions, small arachnids similar to true scorpions but lacking the famous tail with its poisonous spine, are very well represented in Italian caves and in those of many areas in Europe, Asia and the Americas. They show sometimes highly

accentuated adaptations particularly suited to life underground. They vary in size from 2 mm (above-ground forms, found under dead leaves in the undergrowth, under tree bark or deeply buried pebbles) to 7-8 mm in the most highly specialized cave-dwelling forms. In caves, they are found under pebbles or on the ground, while they wait for their prey, small invertebrates which they catch with pincers on their pedipalps, which are particularly long in troglobitic species.

Of the approximately 210 species known until now in Italy, 124 are found in caves, and 80 of these are considered true cave-dwellers. The caves in which pseudoscorpions have been found number more than 440 and the best-known regions are Liguria, Veneto, Friuli-Venezia Giulia and Sardinia. Little or nothing is known about their occurrence in Val d'Aosta, Marche,



Neobisium lulense

Umbria or Molise.

Italian cave-dwelling scorpions belong to three separate families. One of these is the chthonids, with the genera *Chthonius*, *Spelyngochthonius* and *Troglochthonius*, of which the last two are considered relics of a very ancient population going back to the Pre-Quaternary.

Among the neobisiids is the genus *Neobisium*, found throughout the peninsula with many ground-living species, and a few species of the subgenera *Blothrus* and *Ommatoblothrus*, respectively found in caves in the Veneto and Friuli-Venezia Giulia and central-southern Italy; *Roncus*, generally less associated than the



Harvestman of genus *Ischyropsalis*

previous one with central-southern Italian caves, is represented by troglobitic species in the Alps and northern Apennines; *Acanthocreagris*, for which, for Italy, three troglobitic species are currently known in northern Italy and Sardinia; and, lastly, *Balcanoroncus*, with *B. boldorii* in the Lombard and Veneto Prealps.

Syarinids are represented by *Hadoblothrus*, in Italian caves only in Apulia by *H. gigas*, and *Pseudoblothrus*, with *P. ellingseni* in Piedmont caves: the

species of these last two genera, relics of ancient populations, have undergone considerable modifications to suit them to the underground environment.

Phalangids (harvestmen). Arachnids known for their long legs, phalangids, or harvestmen, are easily confused with spiders. But more careful observers will note that the abdomen of phalangids is not attached to the rest of the body by a thin peduncle, as in spiders, but across its whole width. Although these animals are mainly active predators, in some cases they do not disdain carrion. There are many species of phalangids living in Italian caves, but only some are considered true troglobites or in any case eutroglophiles. Among those showing the closest links with the cave environment is the travuniid, *Buemarinoa patrizii*, which inhabits some caves in the province of Nuoro (Sardinia). In the same caves lives *Mitostoma patrizii* which, together with *M. anophthalmum* in the Lombard Prealps, are the troglome representatives of the nemastomatid family. Another family, including various cave-dwelling species, is that of the ischyropsalidids to which, among many others, belong *Ischyropsalis ravsainii* (Veneto and Friuli), *I. muellneri* (Alps and Julian Prealps) and *I. strandi* (Monte Baldo and the Lessini Mountains). There are also other species of this genus, not truly troglobitic, but in any case closely associated with underground habitats, like *I. adamii* in Appennine caves, probably a recent colonizer. All the cave-dwelling species of *Ischyropsalis* prefer environments with rather low temperatures. They normally eat snails, which they capture with their powerful pincers.



Nesticus eremita

Spiders. Spiders are the best-known of the large arachnid orders, which in Italy contains more than 1400 species, 200 of which are found in caves, although only some of them are considered true cave-dwellers. Many surface-living species are highly mobile, and easily (voluntarily or accidentally) enter the first stretches of caves, where they make up a quite large fraction of the troglome fauna.

These formidable predators colonize all parts of the underground environment, from the entrance, where hydrophile and light-avoiding forms weave sometimes large webs on walls or among pebbles on the ground, to the more internal parts, inhabited by more specialized forms, which hunt by weaving webs or wandering in debris



Stalita taenaria

or on calcitic concretions.

Spiders normally have eight or six simple eyes which, in cave-dwelling species, tend to be reduced or to disappear altogether. However, this reduction is not random: the central eyes are the first to disappear; the lateral ones are only absent in the more highly specialized forms.

Parallel with the disappearance of eyes is the development of trichobotria, long bristles which allow the animal to sense air movements and the surrounding environment.

Inside caves, there are many areas in which spiders are found: cave-dwelling species often show close relationships with those living in moist habitats like forest litter, in rocky areas with little vegetation, or under stones in the ground.

The main families found in the cave environment are:

- **Dysderids:** these are the most highly specialized troglobitic forms, all wandering predators. In Italy, they are represented by *Stalita nocturna* and *S. taenaria* (Venezia Giulia) and *Sardostalita patrizii* (central-eastern Sardinia).
- **Leptonetids:** members of this family are five troglome species of the genus *Leptoneta* (Liguria and Sardinia) and the troglobitic *L. baccettii* (Elba), the only blind species. *Paraleptoneta spinimana* is a troglome widespread along the Tyrrhenian flank of Italy, Sicily and Sardinia. Leptonetids capture their prey using small webs strung between pebbles on the ground or in cracks in cave walls.
- **Pholcids:** small species with very long legs: the only member associated partly with caves is the troglome *Pholcus*

phalangioides, widespread in numerous Italian caves where it captures its prey by weaving irregular webs; it is a synanthropic species, and is also found in cellars and other human habitations.

- Tetragnathids: there are three cave-dwelling species belonging to the wall fauna: *Metellina merianae*, widespread throughout Italy; *Meta menardi*, larger than the previous species and only found on the Italian mainland, and *M. bourneti*, also large, and found on both mainland and islands.

- Linyphids: these small spiders weave horizontal webs, are widespread in Italy, and have the highest number of cave-dwelling species. Many species of *Troglohyphantes* live in Alpine caves and in one in the Ligurian Appennines. This genus contains about 30 species, mainly not particularly specialized, although some are considered troglobites, like *T. konradi* (Piedmont), *T. bolognai* and *T. bonzanoi* (Liguria), *T. caporiaccoi*, *T. cavadinii* and *T. regalini* (Lombardy), *T. exul* (Veneto) and *T. juris* and *T. scientificus* (Friuli). The same family also contains the genus *Porrhomma*, not particularly associated with underground environments, of which the best-known and most widespread member is

P. convexum; *Lepthyphantes*, represented by troglophile species and found all over Italy; and *Centromerus*, composed of small spiders, of which the only Italian troglotic member is the tiny *C. cottarellii*, known from a Ligurian cave.

- Nesticids: seven species of this genus are known in Italy, all cave-dwelling. In two cases, these trogliphiles are not very specialized: *N. eremita*, found in Mediterranean Europe and very common in Italian caves (except for Sardinia) and

N. cellulanus, very common in central-northern and western Europe, but found in Italy only in the Alpine region. The other five species, found in small areas and characterized to various extents by a reduction in eyes, are considered troglobites or specialized trogliphiles.

These are *N. idriacus* (Friuli, and in a few locations in the Veneto), *N. morisii* (found in an artificial cave in Piedmont), *N. menozzii* (Liguria), *N. speluncarum*



Lithobiid of genus *Eupolybothrus*

(found in a small area between Liguria, Emilia and Tuscany) and *N. sbordonii* (a cave in Latium).

- Agelenids: represented by the genera *Tegenaria*, not particularly specialized, the characteristic funnel-shaped webs of which are easily seen in caves, and *Histopona*, the only Italian specialized agelenid, *H. palaeolithica* (Liguria).

- Lycocranids: the presence of *Cybaeodes molaria*, a microphthalmic species exclusive to Sicily, has been reported in two caves on the island.

Chilopods. Chilopods (or centipedes) are easily recognizable by the number of legs

on each of the body segments: each segment has a single pair of legs (15 or more in adults). Many centipedes are associated with damp or lapidiculous environments, very similar to cave habitats, which they often colonize. Italian caves have about 70 species of centipedes, most belonging to the lithobiid family with genera *Lithobius*, *Eupolybothrus* and *Harpolithobius*.

Although these fast-moving predators are frequent in underground environments, only very few of them have been found only inside natural caves, including: *Lithobius scotophilus* (Ligurian Alps and French Alpes Maritimes); *L. doderoi* (province of Nuoro, Sardinia) and *L. electrinus* (Tomba del Polacco cave in the Bergamo Prealps, also found however above ground in the Como area). Of all the species present in Italy, only two are true troglobites: *L. sbordonii*, blind, depigmented, with very long antennae, living in some caves in eastern Sardinia, and *Eupolybothrus obrovensis*, in Slovenia and recently found also in the Trieste Karst. Among the scolopendromorphs there are the representatives of the cryptopid family, all blind but not generally troglitic. Inside caves, only a few species belonging to *Cryptops* are found. Although they are quite common in Italian caves, they do not have particularly evident adaptational features.

Diplopods. Diplopods, or millipedes, are distinguished immediately from centipedes because they have two pairs of legs on each trunk segment. These animals are closely associated with damp environments, and are therefore frequent both above ground and inside caves,

although it is not often easy to identify the species belonging to the subterranean environment. Diplopods considered to be true troglobites show the classic morphological adaptations to cave life, being depigmented, blind, and with long antennae. Most of them eat decaying vegetal and occasionally animal remains. In caves, they may be seen near rotting



Polydesmus troglobius



Chersolulus sphinx



Plectogona sanfilippoi bosseae

wood or leaves, under stones, or walking on the dampest walls. About 150 species are known in Italy which, variously, have relations with the cave environment.

They are:

- Glomerids and trachyspherids: with a reduced number of segments and the capacity to roll up into small balls (behaviour which may at first be confused with that of some oniscoid isopods); the most interesting genera in Italy are *Spelaeoglomeris* (Ligurian Alps and Alpes Maritimes) and *Trachysphaera*.
- Polydesmids: all blind, both cave- and surface-living, with sometimes keeled rings, well represented in Italian caves by *Polydesmus*, *Serradium*, *Mastigonodesmus*, *Sardodesmus* and *Schedoleiodesmus*.
- Craspedosomatids: a very widespread family in Italy and Sardinia, with various genera and many species. They often have lateral processes on each body segment and a pair of spinnerets for secreting silk.
- Callipods: again with spinnerets, these carnivores are present with the genus *Callipus* throughout Italy and Sardinia, *Sardopus* being endemic to the island. Despite their preference for subterranean environments, these millipedes do not have particular morphological adaptations to cave life.
- Julids: present in Italian caves with various species belonging to *Troglolulus* (northern Italy), *Typhlolulus* (some species in northern Italy and one in Latium) and *Syniulus* (endemic to Sardinia).

Spring-tails. This class is the oldest group of hexapods known. Spring-tails are all small (1-2 mm long) and, although they are perhaps the most numerous



Spring-tail of genus *Pseudosinella*

arthropods found in caves, they have not been studied in depth. In spring-tails, depigmentation and the reduction or disappearance of eyes are not exclusive characteristics of troglobitic species: however, in the latter, longer claws have been noted, probably to facilitate movement on damp surfaces covered with a film of water, together with other adaptations typical of troglobites (slowed metabolism, reduced fertility, reduced capacity for retaining water, greater resistance to lack of food).

About 50 species are known in Italy, all found solely or with a certain frequency in caves, although the degree of preference for this environment has not been established in most of them.

These species belong to many families: hypogastrurids, such as *Bonetogastrura cavicola* (Apulia) and *B. subterranea*, both probably recent colonizers of the subterranean environment, and several species of *Mesogastrura*; onychiurids with several species of the genus *Onychiurus*; isotomids, to which belongs *Isotomurus subterraneus*, found in the Trento area; entomobryids, with more specialized species, with longer legs and claws, antennae, and the sense organs associated with them. Among the most

interesting species are *Pseudosinella alpina*, *P. insubrica* and *P. concii*, found in the Alps from Piedmont to the Veneto. Of great interest is definitely the tomocerid *Troglopedetes ruffoi*, found in the cave named l'Abisso, near Castro Marina in Apulia. Lastly, there is the arrhopalitid family, with some species of the genus *Arrhopalites*, and the sminthurid family to which belongs



Campodeid dipluran

Disparrrhopalites patrizii found in caves on the mainland and in Sicily.

Diplurans. This class of hexapods contains about 800 species which mainly prefer hot and temperate areas. They are mainly depigmented and have long antennae. Of the five Italian families, only two contain species associated with caves.

- Campodeids: with long antennae, and two long multi-jointed cerci departing from the last abdominal segment. Of all the areas of the world, central and southern Europe are those richest in cave-dwelling campodeids. Italy has some species of *Campodea*, mainly in

central-southern regions and Sardinia and, in the Appennine caves, *Plusiocampa*. This genus contains the highest number of cave-dwelling campodeids (almost 40 species in Europe). Of particular interest is the presence in Sardinia of the endemic *Patrizicampa sardoa*, a troglobite with a high degree of specialization.

- Japygids: in the members of this family, the cerci are formed of a single joint and are transformed into a sort of pincer, which is used partly for defence but mainly for capturing prey - mites and other small arthropods. Less widespread than campodeids and associated with very high humidity, japygids do not seem to be particularly suited to cave life, although they are quite frequently found in caves. Known in Italy are *Metajapyx moroderi patrizianus* (Sardinia), an endemic subspecies of a species known only in a few other caves in Spain, and *M. peanoi*, a cave-dweller of northern Italy, with particularly long antennae.

Orthopterans. Orthopterans, or hoppers, include crickets and grasshoppers. They are phytophagous insects (i.e., they eat vegetal matter), saprophages (eating decaying organic matter), or predators: the cave-dwelling species are generally saprophagous, although some cases of predation and cannibalism have been observed. Other adaptations in cave-dwelling orthopterans are the classic reduction in pigmentation, long palps, and reduction or disappearance of wings. In natural and artificial caves in Italy, orthopterans are represented by the rhabdophorid and gryllid families, containing more or less troglophile species.



Dollichopoda calabra



Troglophilus neglectus



Gryllomorpha dalmatina

- **Rhaphidophorids:** the genera *Dollichopoda* and *Troglophilus* are found in Italy. The former contains about ten species, including *Dollichopoda ligustica* (Liguria, Piedmont and Lombardy), *D. laetitiae* (central-northern Italy), *D. schiavazzii* (Tuscan coast and Elba), *D. geniculata* (from Latium to Apulia) and *D. calabra* (Calabria). The Sicilian *D. palpata* was described in 1776 by a German author, to whom several specimens from a cave near Siracusa had been sent, but it has never been found since then. Of interest is the finding of a large population of *Dollichopoda* in a Veneto cave (Grotta della Poscola, on the Lessini Mountains near Vicenza), which appears to have been introduced accidentally by man. Three species of *Troglophilus* are found in Italy: *T. neglectus* (Friuli-Venezia Giulia, Veneto, and Trentino-South Tyrol); *T. cavicola* (extending to Lombardy), and *T. andreinii* (only in Apulia, with two subspecies, relics of an ancient population which existed before the separation of this region from the neighbouring Balkan peninsula).

- **Gryllids:** species found in Italy are *Gryllomorpha dalmatina*, widespread; *Gryllomorphella uclensis*, found in artificial and natural caves, damp areas and cellars; and *Petaloptila andreinii*, typically found in woodland litter but also in several Apennine caves (this species is dark brown in colour and has two small scaly wings). *Acroneuroptila puddui* and *A. sardoa* are very characteristic orthopterans because, although being exclusively cave-dwellers, they have conserved very short scaly wings but show marked depigmentation.



Stenophylax mitis

The genus seems to be exclusive to Sardinia.

Trichopteran (caddis flies). These insects, winged when adult, are aquatic in the larval stage. Adults are commonly found in caves as subtroglaphiles, whereas the larvae, with their typical "larval cases", are found in the entrance areas of caves with internal watercourses. In Italian caves, trichopteran are found from February to November, with peaks in spring and summer, and may be a quite important component of the wall fauna. About 15 species of stenophylacines are found in Italy as subtroglaphiles, including *Stenophylax permistus*, the largest cave-dwelling stenophylacine and the most widespread in caves on mainland and peninsular Italy and Sardinia; *S. vibex*, quite rare in Italy, known in some caves in the central-northern Apennines; and *S. mucronatus*, *S. crossotus* and *S. mitis*. Passing to the genus *Micropterna*, we find *M. lateralis* (northern Italy), *M. nyctobia*, which seems to prefer high-altitude caves between 1000 and 2500 metres; *M. sequax*, *M. malatesta*, *M. testacea* and *M. fissa*, which is the most abundant trichopteran species in

Italy and for which mating has been observed from March to September. *Mesophylax* contains three cave-dwelling species: *M. aspersus* (from northern Italy to Apulia, and the only species currently reported in Sicily); *M. sardous* (endemic to Sardinia); and *M. impunctatus* (a species reported from a few caves in northern Italy).



Scoliopteryx libatrix

Lepidopteran (butterflies and moths). For many lepidopteran, caves are a stable refuge in space and time. Some of them spend the winter on cave walls, others stay there in summer, and yet others use caves during the day or night, and in bad weather. Although no species may truly be considered troglomite, many butterflies are constantly found in caves. Some microlepidopteran, associated with guano, spend their entire lives in caves where bat droppings accumulate; their caterpillars live on the guano, eating fungi, the guano itself, and occasionally small invertebrates. Lepidopteran are an important source of nourishment for many troglomatic animals, both as food, once dead, for saprophages, and as prey for several types of spider or for snails of the genus

Oxychilus, suited to eating arthropods such as butterflies of the genus *Scoliopteryx*, on which active predation has been observed several times. In Italy, about 15 species belonging to various families have been quite frequently found in caves.

Some of these are:

- Psychids: *Psyche casta*, a small moth whose females, like all those of this family, have no wings and wait for the males inside the "larval cases" made of vegetal fragments, in which they spend the larval period; inside caves, it has been observed only in Italy.
- Tineids: mostly notorious for the damage which some members of the family cause to clothes and other fabrics. *Monopis rusticella* is also known in some caves in central-eastern Europe.
- Acrolepids: represented in Italy by *Digitivalva (Inuliphila) granitella*, often found in large numbers at cave entrances.
- Alucitids: *Alucita*, with typically feathery wings, has many subtroglophile species in several European countries.
- Geometrids: *Triphosa dubitata*, whose adults fly in summer and may be found by day in summer months, or hibernating during the winter; and *T. sabaudiata*, found summering or wintering in Italian and all European caves.
- Arctiids: the Appennine populations of *Nudaria mundana*, a species found throughout peninsular Italy, have recently been studied. In some caves in the Gran Sasso, they have been found constantly inside caves, in all phases of their life-cycle.
- Noctuids: most lepidopterans found in Italian caves belong to this group: *Rhyacia simulans* and *Apopestes*

spectrum are widespread in all Italian caves; *Scoliopteryx libatrix* passes the winter in caves, only to come out during spring; *Autophila dilucida* and *Hypena obsitalis* are found in Italy, Slovenia and Croatia.

- Nymphalids: among these butterflies we quite often find *Inachis io* and *Aglais urticae*, which may winter inside caves.

Dipterans. Well-known to be equipped with a single pair of wings (the second pair is very small and transformed into balancing organs), the dipterans number about 100,000 known species, of which about a hundred are quite frequently found in natural and artificial caves in temperate areas.

In Italian caves, several species are more or less closely associated with the subterranean environment. The most widespread is *Limonia nubeculosa* (limonid family), subtroglophile, very common on the walls of caves near the entrance and more rarely further inside.



Limonia nubeculosa

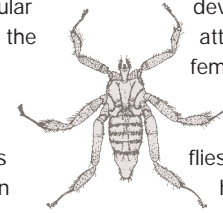
This species is mainly abundant during summer, when sometimes hundreds of specimens per square metre may be counted.

In winter, on cave walls, we find species

of the culicid family, in particular the females of *Culex pipiens*, the common mosquito.

The most interesting, and perhaps only true troglomite among the Italian dipterans is *Allopnixia patrizii* (sciariids). In this species, known only from a cave near Rome, the male is very small (less than 1 mm long) with very small wings (but equipped with balancing organs and ocelli), whereas the female is much larger, about 2.5 millimetres long, without wings or balancing organs. The ocelli too, in the female, are absent, and the abdomen is enormously developed, about three times longer than the rest of the body. Both sexes are depigmented and their eyes are greatly reduced (8 compound eyes in the male and 4 in the female). The larva of this species is still unknown.

In cold, high-altitude caves, we frequently find tipulids (crane-flies) of the genus *Chionea*, cryophilous, wingless, but apparently not particularly associated with caves, which they mainly use for refuge. Cave-dwelling heleomyzids include the so-called "guano fly", *Thelida atricornis*, a troglomite mainly found near guano but also the excrement of other mammals and small carrion. It may be found in caves throughout the year in various stages of its life-cycle. Phorids, in both natural and artificial Italian caves, are represented by some species of *Triphleba*, often near guano. Other families regularly or occasionally found in Italian caves are mycetophilids, chironomids, psychodids and phorids. Separate mention must be made of nycteribiids (see drawing), ectoparasitic on bats, wingless, blind, with well-



developed legs and claws suitable for attaching the animal to its host. Only females, before laying their eggs, and juveniles in search of their first host, leave the bat. Streblids (bat-flies) are also parasitic on bats, but have wings and are less closely associated with their hosts.

Coleopterans (beetles).

- Carabids: carabids are one of the largest families of beetles, with more than 40,000 species throughout the world, mainly predators (although they sometimes exploit other food sources). Hundreds of species of carabids have been described in various subterranean environments. Their morphological and physiological adaptations are often very evident, from long legs and antennae, well-developed sensory bristles on wing covers, and chemoceptors and olfactory organs, to the disappearance of circadian rhythms, slowed metabolism, and reduced number of eggs. Together with the leptodirines, they represent the best-studied and best-represented group of Italian cave-dwelling fauna. In the various species of this family, all stages towards the conquest of the underground environment may be observed: from species with typical features of surface-living animals, through various stages of adaptation, until the many troglomorphic species, called "ultra-evolved". Italian cave-dwelling carabids belong to four tribes: clivinines, trechines, sphodrinines and molopinines. Among the clivinines is only one troglomorphic, *Italodytes stammeri*, endemic to Apulia, where it is found in the Murgia and Salento areas.

Most numerous are definitely the trechines, which form the majority of the cave-dwelling carabids, with eleven genera currently known in Italy, of ancient paleo-Aegeic or paleo-Mediterranean origin.

Typhlotrechus bilimeki is a eutroglophilic species known in caves of the Trieste Karst and more commonly in Slovenia



Orotrechus muellerianus



Italaphaenops dimaioi



Duvalius apuanus

and Croatia. *Orotrechus* includes more than 30 species, of which at least 20 are partly cave-dwelling and partly surface-living, found from the Verona Lessini Mountains as far as Austria, Slovenia and Croatia. Most species of this genus are endemic to the eastern Italian Alps and Prealps, and many overlap.

On the western Alps is the endemic genus *Doderotrechus*, with three species: *D. ghiliani* and *D. crissolensis*, often found together, both above and below ground; and *D. casalei*, more strictly cave-dwelling. Close affinities with *Doderotrechus* are evident in *Boldoriella* (central Alps), with a group of species living above ground and infrequently or never found inside caves, together with another more strictly cave-dwelling group, which also shows a higher degree of morphological specialization. *Italaphaenops dimaioi*, endemic to the Veronese Lessini Mountains, found for the first time during an exploration inside the Spluga della Preta, is the largest cave-dwelling trechine in the world. Colonization of caves by this troglobitic may go back to before the last glaciations. Other extremely interesting troglobitic are the three currently known species of *Lessinodytes*, endemic to the Veronese Lessini Mountains and Brescian Prealps and also systematically isolated from other cave-dwelling trechines. The difficulty in finding specimens in the caves in which they are known indicates that the preferred environment of these animals is not that of true caves, but of the surrounding superficial subterranean environment. The most numerous of Italian cave-dwelling trechine genera, *Duvalius*, is represented by more than 60

species, in several groups.

This genus is widely distributed in the Alps, Appennines, Sicily and Sardinia. Some species seem to belong to a fauna of older origin and are more highly specialized and isolated geographically; others are more recent in origin.

Agostinia launoi, the only species of the genus in Italy, is endemic to Monte Marguareis in the Ligurian Alps, where it inhabits colder caves and lives together with some species of *Duvalius*. Instead, the genus *Anophthalmus* includes many species, both cave- and surface-dwelling, with various degrees of adaptation to cave life. It is found in Croatia, Slovenia and north as far as the river Drava: Italy has about ten species, also with various levels of specialization, found in the Julian Alps.

Last on the list of trechines is *Sardaphaenops supramontanus*, highly specialized, with Betic-Pyrenean affinities. It is endemic to eastern Sardinia, where it lives in various caves in Supramonte di Orgosolo, Oliena and the Urzulei mountains.

Most eutroglophilic carabids belong to the sphodrine tribe; troglobitic sphodrine are not known in Italian territory.

This tribe contains *Sphodropsis ghiliani*, endemic to the western Alps, where it is known in many caves and, in some high-altitude locations, also in surface environments and in marmot lairs.

The genus *Laemostenus* also belongs to the sphodrine tribe; it is subdivided into two subgenera (until some time ago, considered separate genera):

Antisphodrus, inhabiting central-eastern Alpine caves, and *Actenipus*, found in caves in the western Alps, central-southern Appennines and Sardinia.

The molopines belong to several ground-living species but there is also a troglobe of particular importance:

Speomolops sardous, endemic to Sardinia, where it inhabits a few caves in the province of Nuoro. Its systematic affinities with other genera of the Balearic islands and Spain set it in that category of animals which reveal the links between Sardinian and western Tyrrhenian fauna.

- Cholevids: this beetle family probably originated in the Jurassic (or even earlier), inhabiting the forests which covered the southern part of the only continent then existing, Pangea. The splitting up of Pangea and the later dispersal of the continental blocks



Sphodropsis ghiliani

which resulted, led to the present-day arrangement of emerged land which partly explains the current distribution of animals which originally lived in the single ancient continent. There are eight subfamilies of these coleopterans, most of which live in the soil. Some of them are associated with various subterranean environments, from true caves to the network of cracks inaccessible to man, to more superficial networks and artificial caves. All the cholevids have feeding habits of

saprobic type, eating decaying organic matter. Together with the carabids, they show the most extraordinary and deeply studied examples of adaptation to underground life. The most evident aspect is regression of the eyes, already very advanced in subterranean species but taken to extremes in troglobites, in which the total disappearance of ganglionic optic centres has been observed in some cases. The absence of body pigment and membranous wings and the lengthening of legs are also well-known forms of adaptation, found in these insects too. Several leptodirine colevids and trechine carabids also have a particularly rounded form of the wing covers, called "false physogastry", an adaptation associated with the need to maintain a high degree of humidity for respiration through the dorsal surface of the abdomen (see section on troglobitic adaptations).

Many studies on the ecology and ethology of leptodirines have revealed adaptational strategies, including reduction in number of eggs, disappearance of circadian rhythms, slowed metabolism, and the exploitation of special aggregation pheromones in response to the scarcity of food and particular living conditions inside terrestrial caves.

Of the eight subfamilies into which the cholevids are divided, only two are found in Italy, and not all of them have the same preference for subterranean habitats. The nemadine subfamily, in fact, although including some cave-dwelling species found in Anatolia, Afghanistan, Pakistan and Arizona, is

not represented in Italian caves by any species associated with this particular environment. The same may be said of the ptomophagines, of which many eutroglophile and troglobitic species are known in various parts of the world, but they are only very rarely found inside Italian caves and never with species exclusive to them. The same discourse applies to the anemadines. There are also some groups which, although not strictly cave-dwelling, are frequently found in Italian caves. They include *Catops speluncarum* (Sardinia), three species belonging to *Choleva* (peninsular Italy), and *Apocatops monguzzii* (northern Italy).

Lastly, the leptodirines represent about half the cholevid species known in the world, and are those most closely linked with the underground environment. Among them we find the most extreme examples of adaptational strategies, both as regards single organisms and entire populations.

In Ligurian caves, there are many troglobitic and ground-living species of the genus *Parabathyscia*, representatives of which are also found in the French Alpes Maritimes, Corsica and England, as well as in Piedmont



Leptodirine beetles mating

and peninsular Italy (some parts of Tuscany, Latium, Campania and Calabria) where, however, they are not found inside caves but only above on the ground. In Piedmont, on the eastern slopes of the Alpine arch, two species of *Dellabeffaella* are found: *D. olmii*, living in the superficial subterranean environment of the Cottian Alps, and *D. roccai*, in caves in the Graian Alps. Three other species are found in the caves and superficial underground environment of Piedmont: *Canavesiella lanai*, *C. casalei* and *Archeoboldoria doderoana*. In Lombardy, there are: *Insubriella*, with a single species (*I. paradoxa*) of the superficial subterranean environment near Brescia; many species of *Pseudoboldoria*; three troglobite and one ground-living species of *Viallia* near Bergamo; and many species of *Boldoria*, many of which are troglobites, extending their habitat as far as Monte Baldo in the Veneto.

In the eastern Alps, the boundary of which with the western Alps is clearly marked, as regards leptodirines, by the Adige valley, the situation is definitely more complex and variegated. Many genera with varying degrees of specialization and differing phylogenetic affinities occur: examples are *Monguzziella grottoloi*, belonging to the phylogenetic series of *Boldoria*, the only component of the eastern Alps showing affinities with the western genera; and *Neobathyscia*, which includes several species concentrated mainly in the Lessini caves in the Veneto, which have an interesting distribution depending on altitude between 500 and 1100 metres. Two species of *Lessiniella* are found in the province of Vicenza, and two

belonging to the troglobitic genus *Cansiliella* live respectively in a cave on the Cansiglio and in one on Monte Ciaurlec (Friuli), mainly found walking on the thin film of water which covers concretions. In caves in the Tridentine Prealps, Lessini Hills and the Altopiano dei Sette Comuni (Veneto), generally in high altitude caves, are five known species of *Halbherria*. Species of *Orostygia* are found in caves in the Veneto and Friuli Prealps - mainly troglobites which, in particular environmental conditions of high stable humidity, e.g., in the Cansiglio forest, are also found above ground. Of interest also is *Oryotus*, in the Prealps from the Veneto to Slovenia: in the eastern areas of this territory they are also found in high caves with ice.

Of the three species and as many as 15 subspecies belonging to the genus *Aphaobius*, only one reaches Italy, *A. milleri forojulensis* in Friuli; the others are distributed in Slovenia and Croatia. This genus is closely related with the two preceding ones and with *Cansiliella*. The Italian genus of leptodirines which shows the greatest degree of morphological modification in adapting to the subterranean environment is



Leptodirus hohenwarthi reticulatus

undoubtedly *Leptodirus*.

This genus, with only one species, is found in a cave in the Trieste Karst, subspecies *L. hohenwarthi reticulatus*, but occurs more extensively in Slovenia and Croatia. As already mentioned, this was the first insect to be discovered inside a cave.

As well as the already-mentioned *Parabathyscia*, species of *Bathysciola* are found in the Appennines, Piedmont, Liguria, the Veneto and Sicily. They are, however, mainly ground-living species and only a few are troglobites: interesting examples of cave-dwellers, like *Bathysciola sisernica*, *B. sbordonii* and *B. delayi*, are found in the Preappennines in Latium and Campania.

Other interesting examples of troglitic leptodirines are found in Sardinia: the endemic genera *Ovobathysciola* and *Patriziella*, and *Speonomus*, also common in the Pyrenees. The distribution of this last genus is an indication of the paleogeographic vicissitudes of the island.

- Staphylinids (rove beetles): A family of beetles easily recognizable by their long bodies and very small wing covers, it has few representatives in the cave environment. Trogliphile species are *Atheta spelaea* and *Quedius mesomelinus*, typical of the guanobe association; *Lathrobium alzonai* is endemic to the caves of the Berici Hills. Today, also ascribed to the staphylinids are the pselaphids (as subfamily pselaphines), small (less than 2.5 mm), avoiding light and hydrophile. Outside caves they are found in ant-hills, termite nests, litter, decaying vegetal matter and rotten wood. They are all predators,

mainly eating spring-tails. Italy has about ten species dwelling in or near caves, whereas others are only found in caves occasionally. The definitely cave-dwelling species belong to the genera *Tychobythinus* (species in caves in peninsular Italy and Sardinia); *Bryaxis* (in some north-eastern Italian caves); *Machaerites* (with *M. ravasinii* in the Trieste Karst and Slovenia, one of the most highly specialized forms of cave life in Italian fauna); *Bythoxenus* (with *B. italicus* reported only from one cave in the province of Udine); and *Gasparobythus* in the Trieste Karst.

- Histerids: these beetles, mainly round or oval in shape, live in dung, carrion, under the bark of dead or decaying trees, rotten wood, decaying fungi, and in other decomposing materials. They are also found in birds' nests and the lairs of mammals, and are associated with ants of various species. They prey on other arthropods, in both larval and adult stages.

Only a few histerids have colonized the cave environment. Five troglitic species are currently known in Italy: *Spelaeabraeus agazzii* (with three subspecies), *S. giorgii*, *S. infidus* and *S. tormenei*, only found in some caves in north-eastern Italy), and *Sardulus spelaeus* (endemic to a cave in the province of Nuoro, Sardinia). All these species show total regression of eyes, absence of wings, fusion of wing covers, and partial lengthening of legs. Occasionally in caves but more frequently near the entrance, other histerids may be found, mainly species of *Gnathoncus* which, however, do not present any of the morphological adaptations typical of cave life and



Curculionids of genus *Otiorhynchus* mating

cannot therefore be considered as trogliphiles.

- Curculionids (weevils): easily recognizable thanks to the great lengthening of the head, which gives them a snout-like aspect. Weevils are phytophages: many are highly specialized for this type of food, to the extent that they are associated solely with some parts of specific plants. It is precisely this feeding characteristic which has prevented them from colonizing caves on a grand scale. The species most frequently found in caves are those which eat roots and wood, i.e., more associated with the soil and the underground environment.

Most of these species belong to the genus *Otiorhynchus* (subgenera *Trogloorhynchus* and *Lixorhynchus*) and are frequent in (or exclusive to) caves in central-northern Italy. However, southern Italy does have *O. (L.) monteleonii* in the Campo Braca well and a second species, again of *Lixorhynchus*, still undescribed, in a cave in the Monti Alburni. In Sardinia, *O. (L.) doderoi* has been found in the cave of Sos Turritas (Golfo Aranci), although it may be collected in great numbers by sieving in the Mediterranean maquis.

Other genera represented in Italian caves are *Absoloniella*, with *A. reitteri* (two caves in the Trieste Karst), *Amaurorhynchus caoduroi* and *Pselactus caoduroi* (two caves in Apulia) and *Pararaymondynimus mingazzini* (Emilia Romagna).

Amphibians. Excluding trogliphile species, which sometimes (like *Salamandra salamandra*, the spotted salamander) successfully breed in streams in caves, the species belonging to the plethodontids and proteids are considered to be cave-dwellers.

- Plethodontids: this is a family of caudates without lungs, with a very



Speleomantes

particular distribution. America has 250 species; in Europe there are at least seven relict species found in Italy (Ligurian Alps, central-northern Appennines, Sardinia) and south-eastern France. The species of *Speleomantes* (cave salamanders) are one of the most important naturalistic features of Italy. They live in cliff habitats, very variable but all characterized by little direct exposure to the sun and high relative humidity, and are always associated with interstices in rocks or underground caves, from which

they seldom move far. Although during the night and on the wettest days they may sometimes be found even above-ground, it is easier to observe them inside karst caves, where they are very numerous even on vertical, subvertical, or jutting rocky surfaces. On these damp surfaces, often exposed to constantly dripping water, cave salamanders move slowly, exploiting both the air-water interface and the adhesive capacity of their webbed feet. These animals are quite opportunistic as regards food. Even in total darkness, they capture invertebrates of various taxonomic groups, using their sticky, mushroom-shaped tongues which are rapidly projected outside their mouths. In Italian caves, the following species are commonly recognized:

Speleomantes ambrosii (provinces of La Spezia and Massa Carrara, less so in the north-western parts, where the



Speleomantes strinatii

following species are found): *S. strinatii* (south-western Piedmont, Liguria, provinces of Savona, Genoa and Imperia); *S. italicus* (Garfagnana, Apuan Alps, provinces of Reggio Emilia, Lucca, Pesaro and Pescara, introduced into the area near Siena); *S. flavus* (province of Nuoro); *S. genei* (Sulcis-Iglesiente, province of Cagliari, Sardinia);

S. imperialis (Nuoro, Oristano and Cagliari); *S. supramontis* (Oliena, Nuoro). Cave-dwelling salamanders are protected by the Bern Convention and are included in the Habitat Directive of the European Community. Their limited distribution, sometimes circumscribed to a few systems of underground caves, makes them vulnerable, since in these conditions they cannot survive radical transformations of their habitat. For this reason, some species are also included in the Red List of the IUCN (International Union for the Conservation of Nature).

• Proteids: the only European representative of this family, and the only troglobitic amphibian of Italian fauna, is *Proteus anguinus*, the proteus, or olm. The other genus of the family, *Necturus*, is American and lives on the surface in rivers and lakes. The olm is certainly one of the cave-dwellers best-known to the public. The history of its discovery goes back as far as 1689, the year in which Valvasor reported seeing a "pétit dragon" in the caves of Postumia (now in Slovenia).

The first exact scientific description was given by Laurenti in 1768.

Olms have an eel-shaped body and the eyes, in adults, are atrophied and hidden under the skin; the front feet have three toes and the back ones two. The colour is whitish, or slightly pink, but exposure to sunlight induces weak, temporary pigmentation. Among the characteristics which make the olm an exceptional species among Italian fauna is undoubtedly the phenomenon of neoteny. Neotenic animals are those which reach sexual maturity and reproduce although still retaining morphological features typical of larvae.



Proteus anguinus

The phenomenon is frequent in some caudates, like newts, which sometimes maintain the external gills typical of the larval stage even when they are fully grown. However, although in newts metamorphosis may be induced by natural stimuli or in the laboratory, in the olm neoteny is obligatory and irreversible.

The reproduction of the olm has long been a mystery. Once, there were opposing theories which led to a controversy as to whether it was viviparous or oviparous. In fact, the olm is oviparous: in the natural state, eggs are laid one at a time over a period of about one month, numbering from 20 to 80. Normally, they are attached to each other on rocks and stones, and the larvae are born at ambient temperature after 13-20 weeks. Surprisingly, the larvae, greyish in colour, possess clearly distinct eyes until the age of about 2 months. Measuring 16-22 mm at birth, the larvae grow slowly and until the age of 3 months are nourished exclusively by their yolk-sacs; only later do they become predators. In nature, reproduction rarely occurs before the tenth year of age (11-14 in males, 15-18 in females). Adult olms are predators

and mainly eat aquatic oligochaetes and crustaceans; in Italy too, cases of olms moving to the surface to prey on small arthropods have been reported.

The origin of the olm and the antiquity of its colonization of subterranean waters are often debated. Fossil remains (of *Hylaeobatrachus croyi*) found at Bernissart in Belgium, together with those of iguanodonts, going back to the Lower Cretaceous, indicate that proteids lived in surface waters in those times. The most accredited theory in the past was that the above-ground populations of proteids persisted in European superficial waters at least until the mid-Miocene, when the areas where the olm currently lives were in a pre-karstic phase and there was still an extensive surface water network. With progressive karstism in the Pliocene, the olm presumably actively colonized the subterranean waters of the Dinaric karst. However, this theory was recently confuted by Slovenian researchers, after the discovery of a new subspecies (*Proteus anguinus parkelj*, described in 1994). Specimens with a flatter muzzle, eyes, and pigmentation, were found in the Bela Krajina karst, and genetic analysis demonstrated that they are very similar to the troglobitic species of the same area, so that a much more recent colonization of the underground domain was postulated. However, recent studies have shown that there may in fact be more than one species of olm in the Dinaric area (in 1850, as many as seven subspecies, according to the number of vertebrae, were described), thus again raising the possibility of pre-Quaternary colonization of underground waters. But the genetic distance between the

populations of Bela Krajina and those of Postumia date the divergence to the Upper Miocene, i.e., the old hypothesis is sustained.

The olm is found from the river Isonzo (province of Gorizia) as far as Montenegro, and also in the hinterland of Slovenia, Croatia and Bosnia. In Italy, it is known in many caves in the Isonzo and Trieste Karst where, although threatened by recent pollution and disturbance of its habitat, it is, fortunately, still common. There is also an isolated colony in the Grotta Parolini at Oliero (Valstagna, province of Vicenza). It is known, however, with certainty that this population derives from the introduction, in 1850, of some Slovenian specimens, which acclimatized well. Due to its exceptional nature and the restricted area it occupies in the present-day territory of the European Community, the olm is protected by various international norms and, in particular, is on Annexe II of the Habitat Directive and the IUCN Red List.

Bats. Although bats are not always closely associated with caves, the collective image attributes to them a special link with underground caverns. There are almost one thousand species, all greatly varying in aspect, size and habits. As well as being able to fly by means of the wide flaps of skin spread between the phalanges of the "hand", hind legs and tail, the most spectacular feature of bats is their capacity for echo location. Although many other mammals use ultrasound for communication, to locate prey, or to perceive the topography of their surroundings (whales, shrews, etc.), in insect-eating



Plecotus auritus

microchiropterans this capacity has been brought to a point of exceptional refinement, since bats use it constantly, even during their most rapid aerial acrobatics. In a whole series of activities, they emit rapid sequences of ultrasonic clicks and use the return echoes both to locate their prey in flight, to capture it, and to orient themselves in the absence of light and thus avoid obstacles. For this reason, they cannot hunt during rain, and generally take refuge in their hiding-places a few minutes before the onset of any downpour.

European bats generally have some capacity for thermoregulation. This condition, known as imperfect homeothermy, is quite widespread among mammals in temperate climates (hedgehogs, dormice, marmots, a few carnivores, etc.) and allows them to conserve metabolic energy both during periods of rest during the day and in winter, when the environment is particularly lacking in resources. In this period, the animals sleep inside a hibernacle with constant temperature



Myotis myotis

and humidity, in which they may also mate. The places chosen for hibernation are usually cavities in cliffs or trees, cracks in ceilings or badly fitting doors and windows, or abandoned buildings, and differ according to species. Although some bats (e.g., barbastels) like cold well-ventilated cavities, they generally choose places which are deep, damp and preferably constant in temperature even during winter. Inside these hibernation cells, gregarious bats may gather in impressive numbers. Dwarf bats (*Pipistrellus pipistrellus*), for example, gather in very crowded hibernacles, sometimes hundreds or thousands of them, all heaped one on top of the other. In one Roumanian cave, one of these colonies was estimated to number 100,000 bats. However, their hibernation is far from being continuous. If they are disturbed, or if the temperature falls drastically, the bats wake and actively seek better places. These winter movements may be very spectacular, sometimes involving hundreds of animals in search of new locations in which to spend



Myotis myotis hibernating

the winter.

The reproductive cycle of bats is also very peculiar. The mating period begins when the mature females scatter from the nursery, between the end of August and autumn. Mating may last all winter and include most of the spring, but it often occurs inside the hibernacles (*Myotis*). However, in various species of the genus *Nyctalus* and *Pipistrellus*, the males actively defend true harems of 2-5 females, which group together at the beginning of the mating season and are defended by the same male for several years running. Births occur around mid-June, when the pregnant females have already grouped into large nurseries, sometimes numbering hundreds or thousands of pregnant or nursing mothers and small numbers of males. Knowledge about Italian bats is still scanty. In Italy, there is no specific tradition of studies on bats, although in the late 1980s the attention of researchers did focus on these animals. In Italy, there are about 30 species of bats, only some of which are closely associated with underground caves



Bat colony

(horseshoe-nosed bats, miniopterans, barbastels, and several species of *Myotis*). Some also frequently use various types of buildings or cavities in trees at different moments of their life-cycle. Tracing the boundaries between troglaphiles, anthropophiles and forest-loving bats is thus really very difficult, mainly because buildings are true replacements for cliff habitats, which would otherwise be quite scarce for most of the anthropophile species. To give only one example, the great biological success of Kuhl's bat (*Pipistrellus kuhlii*) is due to its capacity to use both urban and suburban buildings, which are very common, where crowded bat nurseries may reach great densities.

During a cave excursion, it is easy to see signs of bats. In many cases, these are small heaps of droppings under their favourite resting-places. It is not always easy to actually see them, either because they hide inside tiny cracks or because the droppings may be old and are only a souvenir of their past activity. Large accumulations of guano are invariably the result of late spring or summer reproduction. Outside their short reproductive period, the same cavities are not used and are deserted. Inside Italian caves in summer, it is quite

easy to locate the nurseries of various troglaphile species.

The most common are:

Miniopterus schreibersii (colonies of thousands of bats, hanging by all four feet, often two or three layers deep, and often associated with various species of *Myotis* or *Rhinolophus*; *Myotis myotis* and *Myotis blythii* (dozens of animals close together, hanging by their hind legs, sometimes inside buildings); *Myotis daubentonii* (dozens of bats close together, hanging by their hind legs, sometimes in buildings, near water); *Rhinolophus hipposideros*, *R. ferrumequinum*, and *R. euryale* (dozens of specimens hanging by their hind legs, neatly folded in their wing-flaps, and not in contact with each other).

In winter months, it is easier to see the various hibernating species. They are not necessarily definitely troglaphiles. Apart from the great bats, or noctules (gen. *Nyctalus*), most European bats may hibernate underground. In order to reproduce or hibernate, bats need peace and quiet. Even during monitoring and measurements, humans should not impose their presence for more than five minutes consecutively.

*Rhinolophus hipposideros*

The only European vertebrate perennially associated with water in subterranean caves is, as we have seen, the typical subspecies of the olm. In Italy and in some French caves, there are some caudate amphibians closely associated with the cool, damp environment typical of caves, cave salamanders (*Speleomantes*), but they are not rigorously associated with the darkness of caves and, at nightfall, may sometimes be found on the surface, where they frequent well-fissured cliff habitats, cool, shady and damp, preferably with dripping water.

Bats too frequent underground caves, but only temporarily, either to sleep during the day in the breeding season, or (for some species) to hibernate.

Some strigiforms (tawny owls), columbiforms (wild pigeon), rodents (dormice, fieldmice, black rats) and carnivores (wild cats, foxes, badgers, bears, pine-martens) are also seen near the entrances to large caves, but in this case their presence is temporary, almost always connected with their resting periods during the day, or else reproduction. All these species



Tawny owl

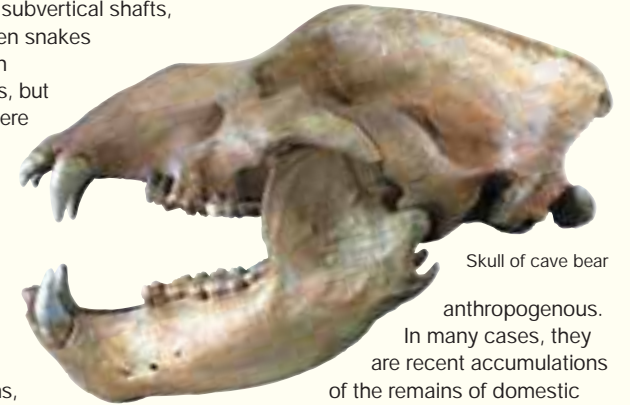
are defined as troglophiles and their activity inside caves, although frequent, is never exclusive. Signs of their presence are easy to see during a visit to a cave - if not the actual animal, then traces of its activity or its remains.

Excrement may reveal recent underground activity, and in certain cases, it is surprising to find droppings in places sometimes very far from the entrance to the cave (fieldmice, black rats, pine-martens). The explanation here is very often that the caves have tiny openings, sometimes unknown or very far from those officially known to man and entered by speleologists, and the animals habitually use them.

However, although clear signs of predatory activity by troglophiles (bones of small mammals regurgitated by owls, dormouse droppings, remains of fox's prey)

may be found at the entrance to a cave, the presence of Lataste's frogs, European frogs, green frogs, newts or spotted salamanders - all surface-living animals - must be explained in some other way. Typically, these animals are involuntarily carried into caves during their larval or adult stages, and are all mainly found in caves after extraordinary events, such as sudden floods,

accidental falls into subvertical shafts, etc.. Sometimes even snakes remain imprisoned in underground cavities, but they are generally there in a spontaneous search for somewhere to spend the winter. Caves may also contain bones of uncertain origin and attribution. They are often fossilized or subfossilized remains, but may often appear very recent. When they are true fossil remains, they have a particularly high specific weight. Their internal structure is often completely mineralized, so that if they are exposed to a naked flame they do not burn or emit the smell typical of burning fresh or subfossil bones. In certain cases, they are the remains of past underground activities of now extinct troglophile species (e.g., the cave bear, *Ursus spelaeus*). But not all accumulations of bones found inside caves are there as a result of their use by past troglophile species, intrusive or living in clefts. For example, Isabelle Pathou, a French researcher who has attempted to establish the origin of the remains of subfossil bones of marmots in some Pyrenean caves, reached the conclusion that they were the remains of meals by ancient populations of hunter-gatherers. By carefully examining the surfaces of these bones, she found scratches, cuts and non-parallel abrasions, certainly made by primitive but sharp stone instruments. The most frequent origin of bone deposits near the entrances of most caves is



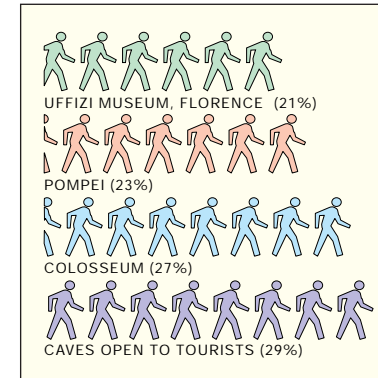
Skull of cave bear

anthropogenous. In many cases, they are recent accumulations of the remains of domestic animals, mostly dogs, but also sheep, goats, cattle and pigs, which were thrown into shafts and subvertical holes in the ground. In some areas in the Trieste and Gorizia Karst, but also in Sardinia, Sicily and the central-southern Appennines, this habit was common among rural populations, who were thus able to get rid of sometimes large amounts of waste quickly. This rapid waste elimination system was (and still is) used in Prealpine areas by hunters and poachers, and in caves in the Julian Prealps and the Karst the remains of chamois, roe deer and boar are quite often found. The skeleton of a jackal (*Canis aureus*) was recently found in a small shaft near Doberdò del Lago (Gorizia), where it had been illegally killed and hidden by poachers. It lay on top of a large number of skeletons of dogs, the silent witnesses of a long tradition of using that particular shaft for the purpose. In some places, these shafts (notoriously called *foibe* in Italian) were also exploited in wartime. It was a simple matter to throw unwanted persons or prisoners awaiting execution, alive or dead, down them.

Protection and conservation of the underground environment

MAURO CHIESI · LUCA LAPINI · FABIO STOCH

■ Exploitation of caves for tourist, speleological and conservation purposes



Extent of cave tourism in Italy in 1998

The extent and distribution of underground tourism. Caves and underground environments in general are entered by two types of visitors: speleologists and tourists. The 800 large accessible caves in the world are visited by about 170 million people every year, and play a definite socio-economic role in providing earnings to more than 10 million people.

In Italy, subterranean tourism in natural and artificial caves involves about 2.5 million people every year, and is a considerable source of revenue and of

potential naturalistic interest which cannot be neglected.

Most of these people (about 1.5 million per year) visit about 70 “show caves” and consequent environmental problems only concern a few dozen caves: about 0.3% of currently known natural caves (there are more than 33,000 in Italy). Show caves are large-scale infrastructures where income from “cave management” must co-exist with the proper conservation of the very place which produces that revenue.

Parallel with this influx of visitors, there are very many enthusiasts of speleological excursions who visit all the remotest corners of the “non-tourist” caves. Including those who follow courses and visit caves as tourists, it is estimated that about 12,000 speleologists organize excursions every year: if this activity were homogeneously distributed over the 33,000 known caves, the relative environmental damage would be negligible. But this is not so: there are caves all over Italy which have been explored by so many thousands of people that they have sometimes been seriously and irreversibly damaged.



Caves at Monsummano Terme (Tuscany) used for thermal spa purposes

Speleologists and show caves. With the growth of interest in speleology, and in view of the delicate equilibrium of karstic environments, the first signs of excessive exploitation began to become apparent - precisely in those places visited not only for their beauty and integrity, but also for their vulnerability and the peculiarly fragile environmental mechanisms which created them. Thus, parallel with the growth of environmental awareness of speleology, there arose the need to place restrictions on “direct

consumption” (the caves themselves, and removal of concretions) and the unconscious exploitation (the impact of humans) of karstic territories. It became apparent that there is a “tolerability threshold” even as regards the number of visitors - whether they are tourists or speleologists or occasional visitors - to a single cave or just part of one.

Speleologists, despite great technical difficulties, may spend hours inside caves, emerging with the impression that, during their sojourn underground, they have touched the centre of the Earth. Conversely, the more easily accessible parts of certain relatively shallow caves are suitable for tourist visits: pathways can be laid out, galleries excavated, and lighting of all kinds installed, to enable the cave to be exploited as a place in which, as in no other, a set of fantastically shaped concretions may be seen and admired. Over the years, techniques have been refined, courses in speleology are now offered in places where, a few decades ago, they had never been heard of. No material or waste of any kind must be abandoned in caves, just as it must not be abandoned on paths on the surface. Caves have turned out to be much larger than previously believed, but also much less capable of tolerating the impact of those who wish to explore them.

Attractive “show caves” have also shown themselves to be very fragile and vulnerable: they deteriorate under the impact of millions of visitors. The parallel pathways - speleology in itself, and tourist exploitation of the subterranean world - have begun to converge and even meet: now we know that caves must be protected both from careless visitors and from ignorant speleologists.

Those speleologists who have an aversion towards “show caves” are

concerned about the damage which tourists cause and about the unconscious mass-tourist concept of “consumption” and thus of the irreversible destruction of natural beauties - the object of the original tourist attraction itself - and known precisely thanks to the work of exploration and documentation provided by speleologists.

All visits to underground environments, even sporadic, cause alterations to the ecosystem. They may be temporary, with a general increase in energy to the system, or permanent, like that abominable habit of ignorant persons who break off concretions and take them away as souvenirs. Pollution and destruction are caused by ignorance or under-estimation of the damage resulting from certain actions.

Only by studying the effects of mass exploitation of show caves can we begin to understand what, and to what extent, damage may be caused to the fragile subterranean world.



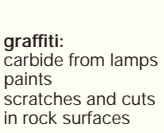


The “energy level” of a cave. The concept of a cave’s *energy level* (developed by Heaton in 1986) is an essential parameter which allows us to predict, approximately, the relative “weight” of the influence of man on the subterranean environment. There are three different levels, decreasing in degree:

1. *high-energy caves*: periodically involved in large-scale events like floods;
2. *medium-energy caves*: energy is supplied by small watercourses, wind, and animals;
3. *low-energy caves*: the flow of energy is practically reduced only to the dripping of water.



San Giovanni d’Antro: church at entrance to fortified cave with spring

Obviously, people can enter the caves of the first category without causing problems: the periodic natural supplies of energy are capable of cancelling any changes caused by the presence of visitors. Instead, medium-energy caves, rich in concretions, may be seriously disturbed by great numbers of visitors, when the consequent energy supply becomes comparable with the energy balance of the cave itself. Lastly, low-energy caves should not be visited: the very presence of humans can irreversibly disturb their general equilibrium.

HUMAN CAUSES · SPELEOLOGISTS		DETERIORATION	
<p>contamination: waste carbon batteries clothing dyes</p> 	<p>removals (thefts): concretions archeological deposits minerals fauna</p> 	<p>physical damage: breaking off of concretions people treading everywhere explosions vandalism widening of narrow points</p>	<p>graffiti: carbide from lamps paints scratches and cuts in rock surfaces</p> 
SERIOUS DAMAGE TO CAVES			
ANIMAL FARMING · POPULATION		PARTIAL DESTRUCTION	
<p>quarrying and mine explosives</p>	<p>pollution by farming waste</p> <p>pollution by industrial waste</p>	<p>illegal dumping of waste</p> 	
DESTRUCTION OF CAVES			
INDUSTRY		TOTAL DESTRUCTION	
<p>caves "eaten away" by quarrying and mining</p>	<p>caves filled with: solid urban waste inert aggregate cement industrial waste farming and food wastes hydrocarbons sewage remains of dead animals</p> 		

Main causes of degradation in natural caves

The concept of the "receptive capacity" of caves. From the viewpoint of the flow of energy or mass, most caves are almost isolated environments: with the aim of keeping environmental disturbance under an acceptable threshold level of reversibility, their basic environmental parameters must be changed as little as possible. The "receptive capacity" of a cave may be defined as: "... *the maximum number of visitors acceptable over a certain period of time and in defined conditions, which does not imply any permanent change in any significant parameter*". (A. Cigna). This definition may be applied to all underground environments. Recognizing that environmental parameters undergo natural oscillations in time, attention must be paid to those variations which, due to visitors, move too far away from these natural trends. In this way, we can determine which "critical" parameters must constantly be checked with especial care. This is why preliminary monitoring of any project for tourist purposes is indispensable. We must measure the natural reference values and establish the natural dynamics (i.e., the energy) of the system, which is exclusive and characteristic to every cave or underground environment.

Putting the "speleologist" and the "tourist" in the same boat is not an exaggeration. From the viewpoint of the cave ecosystem there is no substantial difference, either as regards the scale of the problem (in our case, a single cavity) or the analysis of possible factors of deterioration. On the scale of a single cave, the quality of damage which may be produced is basically the same: damage increases according to the numbers of people who pass through the various "sensitive" areas of the cave. Its adaptation for tourist purposes therefore, mainly concerns the *quantity* rather than the *quality* of the damage - obviously, except for caves in which tourist adaptation corresponds to actual infrastructures inside them (pathways, removal of "obstacles", widening, opening of new entrances, etc.) and external ones (construction of access roads, car-parks, etc.), which are gross and irreversible. Possible answers to these problems are in fact identical, and all concern:

- prior assessment of environmental conditions preceding explorations or visits;
- minimization of anthropic impact;
- code of ethical and deontological behaviour, and need for surveillance.

■ **Environmental degradation and water pollution**

Today, karst aquifers represent about 40% of our sources of water supply (for drinking and other uses) in the Mediterranean basin, and they always tend to be increasingly exploited, in spite of the fact that these sources of supply are

poorly known, poorly studied, and even more poorly protected. Their peculiar characteristics mean that they are generally very vulnerable to pollution and greatly exposed to the risk of contamination, both accidental and permanent. Some of the main sources of pollution and contamination are waste products from industry, farms and agriculture, as well as deliberate dumping of solid urban and industrial waste and, last but not least, permanent or accidental pollution due to emissions of fumes from traffic.

The dynamic characteristics of karstic aquifers are such that they can do very little to combat the spread of polluting substances: they have fast-flowing waters and very little capacity for self-depuration.

From the surface to the surface again, the course of a polluting substance is as follows:

- the pollutant enters the system;
- it migrates to an unsaturated (vadose) zone;
- its propagates in the saturated (phreatic) zone;
- it is sent back to the outside world.

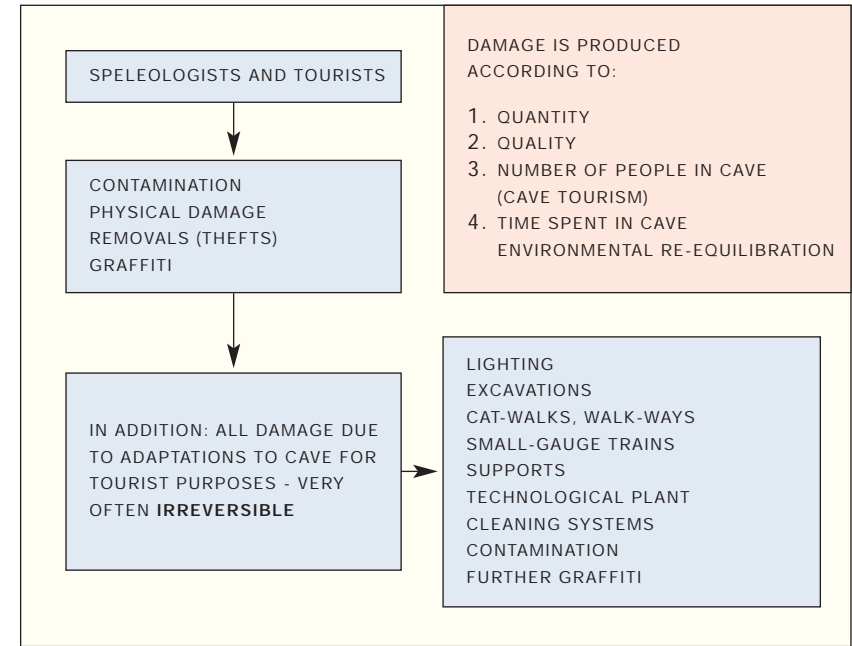
If the karst cover (where present) can reduce the effects of pollution, in the course from the vadose zone to the phreatic zone it is flow velocity which determines self-purifying capacities directly, influencing sedimentation and oxygenation and thus the overall biological conditions (bacterial and antibiotic actions, closure of the biological food cycle by predatory organisms). These phenomena, essential in self-depuration of surface waters, are far less active and efficacious in the non-saturated karst zone.

In the phreatic zone, in the absence of oxygenation, purifying power is practically limited to possible dilution from non-polluting sources.

Lastly, the return of the pollutant depends on the overall hydrogeological features: if the aquifer runs mainly in conduits, its response is extremely rapid and concentrated. In systems of networks of cracks, the polluting load arrives slowly and is diluted, often to a considerable extent, over time. It is interesting to note how the time factor acts differently according to type of pollutant: it is important in the case of pathogenic bacteria but has no influence in other cases, e.g., chlorides.

Simplifying again, extremely unfavourable factors are the absence of vegetal cover, the presence of active vertical shafts, and the outflow of rapidly-moving waters.

Polluting load being equal, the size and shape of the aquifer directly influence its degree of vulnerability: springs which drain waters from very large areas with very thick non-saturated areas (karstic massifs) are less vulnerable than quite thin aquifers with phreatic networks located only a few dozen metres



Degradation induced in underground environments as a result of visits by humans

under the surface. This is the case of all aquifers in gypsum which, for example, makes up about one-third of the thirsty Sicilian provinces of Agrigento, Enna and Caltanissetta.

Lastly, mention must be made of the “tamping” effect in karstic aquifers in cases of flood. It may act directly both favourably, by diluting a pollutant (if clean waters are “jettisoned” from the network of cracks in the aquifer). Vice versa, it may act very negatively (in the case of the large-scale removal of pollutants trapped in siphons and bodies of waters in the vadose zone), since concentrated waves of polluting substances are returned to the surface.

Safeguarding the quality of subterranean waters also means conserving the integrity of its delicate animal community, both to protect that animal life, and for practical reasons, since organisms play an essential role in recycling organic matter and thus in purifying waters. When water quality is referred to the integrity of its populations, we speak of biological quality.

Methods for assessing the biological quality of surface waters have been routinely used to assess their degree of pollution for about 20 years. The advantages of these methods, based on study of benthic macroinvertebrates

(bottom-living organisms larger than 1 mm), are known to be better than chemical or microbiological methods. Aquatic organisms, being sensitive to even slight degrees of pollution and living all their lives in a watery environment, record variations in water quality with considerable precision and may successfully be used even when chemical analysis does not supply adequate results (e.g., in cases of intermittent or episodic polluting events).

The use of bio-markers in the study of underground water quality is more complex, due to a series of problems which are difficult to solve:

- lower biodiversity (insects being almost completely missing) means that identification of organisms must be made at species level and not at that of genus or family, as happens in surface waters; in addition, meiofauna (i.e., organisms between 0.3 and 1 mm in size) must be examined;

- the need for special techniques for sampling, study and identification of specimens is often time-consuming and based only on specialized literature.

This last point is further complicated by two more factors:

- we have insufficient knowledge of the taxonomy and distribution of species living in Italian underground waters, in which species new to science or to Italy are discovered every year;

- endemic species tend to form rapidly, so that the fauna may be different in each single karstic massif.

In spite of these technical problems, French, Dutch and American studies have shown the efficiency of this method in the ecological surveillance of aquifers, and techniques suitable for interstitial waters have been developed. For karstic waters, the problem of sampling is more complex and techniques are still being perfected. In Italy, they are rarely applied to cave and karst spring waters. In general, in cases of slight organic pollution, it has been noted that the number of stygobites, which are the most sensitive organisms, decreases in favour of stygophiles and stygoxenes, which cover a larger ecological valency, until we reach threshold situations in which stygobites disappear completely, to give way to dense populations of stygoxenes which take advantage of the accumulations of decaying organic matter. This phenomenon was recently observed in a study on the fauna of the Lessini Hills where, in a cave with a high degree of organic pollution (Spurga di Peri), only ordinary stygoxene species of tubificid oligochaetes, copepods and ostracods were found, accompanied by cladocerans and dytiscid beetles which are infrequent in subterranean waters. This encouraging result means that the populations of underground karstic waters allows us to assess the state of biological integrity of their ecosystems, and reveals the possibility of creating indices of water quality in the very near future.

■ Norms for protection and discipline in speleological practice

For a country in which more than one-third of the territory is karstified and more than 40% of water resources for drinking purposes comes from karstic aquifers, the current overall norms for local and regional protection of these special and essential resources are not simply inadequate - they are unacceptable.

Little or nothing concrete has been done to safeguard Italian karst areas - neither to prevent the consequences of the impact of public and private works on both superficial and subterranean karstic sites, nor to remedy those consequences, if possible. Every time pollution of a karstic aquifer has to be investigated, the possible ways and means of acting are uncertain. For example:

- Italian law no. 1089 of 1939 (recently substituted by legislative decree no. 490 of October 29 1999), which safeguards assets of artistic, historical, archeological, ethnological and paleontological interest, is only applicable to those caves (quite numerous) which contain assets of those types: i.e., it protects the "contents" but not the "container" (the karst landscape, the surface area, the cave itself, and the aquifer);

- law no. 1497 of 1939 (recently substituted by legislative decree no. 490 of October 29 1999) precludes the possibility of protecting superficial karstic areas which do not have peculiar landscape or geological characteristics - whereas we know that a landscape without these "peculiarities" may be of essential importance in draining surface waters in covered karst. But even in cases of constraint under this law, it is only the external aspect of the cave (and only that), for which any modification must be authorized by the local authorities (*Soprintendenza*). If the law is not observed, penal regulations apply (Art. 734 of the Italian Penal Code, destruction of or damage to classified natural beauties), involving fines from 1 to 6 thousand euro;

- law no. 319 of 1976, dealing with water pollution, aimed at disciplining and regulating waste dumping in water, soil and subsoil, but even in its later articles and assignments to local government, it never constituted a valid response to the peculiar needs of karstic aquifers and their protection. There are innumerable cases of dumping of sewage, apparently lawful, which daily accumulates inside karstic caves and which, every so often, simply returns concentrated pollutants with the next outflow. And what can be said of the waste dumps, controlled and uncontrolled, scattered over the plains of Apulia? A perfect example of an aquifer in very rapid and irreversible degradation, partly due to excessive pumping of water, has given rise to permanent invasion by seawater over enormous areas - and that water cannot



Hall with concretions in Grotta Mitica (Julian Prealps, Friuli)

even be used for agricultural irrigation. In this framework, therefore, it is not surprising that, in order to protect these natural resources, frequent appeals quote Royal Decree no. 1016 of 1939 (a happy year, evidently for legislation protecting the beauties of Italy, but now too far removed from present-day reality). The decree also contains norms regulating hunting, in which Art. 38 covers special protection for bats. Again, the legislative decree of December 12 1923 concerns hydrogeological constraints, and royal decree no. 1443 of the 1927 laws covers mining.

In Italy, there is no national law which sanctions, by safeguarding their integrity, the peculiarities of karstic environments containing aquifers providing water for drinking and agricultural purposes. This situation has required measures on the part of various regional authorities - sometimes well-defined but in themselves poorly organized and sometimes, for this reason, ineffective. The very regional laws "favouring speleological activities", already operational in some regions since 1972, do not safeguard the karstic environment. The only practical impetus resulting from these legislative instruments has been the *Catasto delle Grotte*, the Cave Registry, an essential and dynamic instrument for proper knowledge of the territory.

Laws for national parks and others deriving from legislation providing for regional and provincial territorial landscape plans, again due to the lack of a national law safeguarding the karstic environment, would represent a unique opportunity to make up for lost time and delays, and would fill many gaps. But there are very few cases in which this has happened - all linked to the fortuitous but combative presence of speleologists among those responsible for regional planning. Further progress was made with legislative decree no. 152 of May 11 1999, concerning measures for protecting waters from pollution, including subterranean waters. However, this law too, like its predecessors, considers waters according to their use by humans (for drinking purposes, agricultural or industrial use) and not according to the interest which their environment may hold.

■ The Habitat Directive and the subterranean environment

Directive 92/43/CEE of the European Community, dated May 21 1992, regarding conservation of natural and semi-natural habitats and wild flora and fauna, is called the "Habitat Directive". It has recently been integrated (by Directive 97/62/CE of October 27 1997, updated to reflect technical and scientific progress with respect to the original directive), and finds its applicational regulation in Italy in DPR no. 357 of September 8 1997. These

powerful instruments aim at guaranteeing the conservation of natural habitats and of the karstic environment, together with its flora and fauna.

The Directive has as its aim the safeguarding of habitats and species of interest to the European Community, and supplies clearcut criteria of selection, according to the presence of rare, endemic, vulnerable or at-risk species. Although information on the state of risk is scanty, rarity and endemism are criteria which may be applied perfectly to troglobite and stygobite species, and therefore many may be included in any forthcoming normative updating among the species of Community interest. Not only this: the Directive already supplies lists of habitats and species of interest to the European Community.

Of essential importance is Annexe I of the Habitat Directive (Annexe A of DPR 357), which lists the types of natural habitats of Community interest, conservation of which requires the designation of special conservation areas. Art. 8 of the 97/62/CE Directive indicates "Rocky habitats and caves", and includes:

- 8310 (65 of the preceding norms): caves not yet exploited for tourist purposes;
- 8320: lava fields and natural cavities;
- 8330: submerged or semi-submerged sea grottoes.

Clearly, member states are specifically required to safeguard these environments. But the caves included in sites of Community or national interest (Natura 2000 network and Bioitaly sites) are limited in numbers, with the exception of those in some autonomous regions or provinces (e.g., the Trentino) which have listed many sites to be protected. The weak point of decisions taken until now has certainly been that of protecting mainly single caves and not entire karstic areas or water networks; but the protection programme has now been started and cannot be stopped. As regards fauna, Annexe II (Annexe B in DPR 357) lists animal and plant species of Community interest, the conservation of which requires the designation of special areas, and Annexe IV (Annexe D in DPR 357) (animal and vegetal species of Community interest which require strict protection). Among the vertebrates we find all the bats frequenting Italian caves (and particularly all species of the genus *Rhinolophus* in Annexe II, the words "All species" of microchiropterans in Annexe IV) and, among the amphibians, cave salamanders (*Speleomantes*) and the olm (*Proteus anguinus*). The list of invertebrates, in which there are practically no troglobites, is highly deficient. Clearly, caves with bats, newts and olms can be proposed as sites to be protected according to the Habitat Directive.

Art. 8 of DPR 357 states that, for species in Annexe D (i.e., all bats, newts and olms), it is forbidden to capture or kill specimens of these species in the natural environment; to disturb them, particularly during all stages of their breeding, or during hibernation, wintering or migration; to damage or destroy their breeding or

resting areas (i.e., all caves in which these species may do no more than rest). Their possession, transport, exchange or marketing in the natural environment is also forbidden, except for specimens legally collected before the coming into force of the DPR. Both speleologists and biospeleologists must be clearly aware of these restrictions.



■ Strategies for protecting bats

The equilibrium of predators with low reproductive rates is fragile. If for some reason their numbers are critical, they may be threatened by even slight situations of disturbance, which in optimal conditions could more easily be well tolerated or even ignored. Bats enter this category and are currently

viewed as among the vertebrates with the highest risk of extinction in many industrialized countries. Bats are particularly delicate animals, partly because of their imperfect homeothermy, i.e., they are very sensitive to even slight climatic and seasonal oscillations. For example, prolonged rainfall during the breeding season of various species may lead to very high neonatal mortality (miniopterans, minor horseshoe-nosed bats) and their distribution may even be influenced by recent changes in the climate, at least partly caused by man.

Although information on the current situation of European bat populations is still scanty, there are various anecdotal data referring to the past, which hypothesize that bat populations have been in a critical state for a long time. These data are often discontinuous but common to various central European countries (Great Britain, France, the Low Countries, Switzerland, Germany), and appear to agree on the general trend towards reduced numbers of most large bat colonies which have been monitored for longest. Although previous comparative data are available on limited local situations and few species, the bats most at risk appear to be the major and minor horseshoe-nosed bats (central Europe), major vespertilionids (Germany), barbastels and dwarf bats. The situation is not homogeneous, since signs of recovery are noted for some species in some areas (Daubenton's bat), but the relative density of bat populations is declining everywhere.

The causes for this are still not completely clear, but may be grouped into categories, all associated with recent developments in man's activities.

The origin of this decline in bat numbers is probably mainly due to the transition between an agricultural economy of traditional type, and its more modern version, which aims at improving crop yields. This has led to extensive use of biocides, to reduce on one hand losses due to fungi and insects, and, on the other, to limit competition by weeds.

Reduction in the quantity of insects to prey upon, and the accumulation of pesticides in the fatty tissues of bats, which are very small predators, have affected both forest-dwelling and troglophile species.

Accumulation of pesticides in subcutaneous fat in bats has not been studied in depth, but it is certainly known to cause great damage. It is revealed in periods of greatest energy demand, when absorption of fats by the organism is intense, thus interfering with reproduction, suckling, and waking from hibernation.

This situation of generalized crisis is aggravated by a whole series of more or less serious circumstances of disturbance, always associated with exploitation of the territory by man. For example, the continuous rejuvenation of forestal cenoses as a result of various types of reforestation, and the tree health measures and applications associated with it, represent a double-edged weapon: on one hand, the number of holes in trees available to the more forest-dwelling species (various species of noctules and vespertilionids) has fallen; on the other, the disturbance of subterranean caves for tourist purposes prevents troglophiles from gathering in them, both during the breeding season and during hibernation (horseshoe-nosed bats, miniopterans, various species of vespertilionids).

Even anthropophile bats have suffered, due to recent widespread changes in building criteria, but the great adaptative responses of some species and the number of buildings available appear to have limited the damage in some cases (see the previously mentioned case of Kuhl's bat). In spite of this, the species most closely associated with old buildings constructed partially in wood (major vespertilionids, long-eared bats, some horseshoe-nosed bats) have abandoned them, partly due to their demolition and partly due to modern chemical treatments applied to the wood of the buildings still available.

Most European bats are specifically protected by international treaties (e.g., Bern and Bonn Conventions) and, as we have seen, all species are listed in the Habitat Directive.

Many of them are on the Red Lists of the IUCN (International Union for the Conservation of Nature), in various levels ranging between LR (low risk) to VU A2c (exposed to serious risk of extinction due to a 20% reduction predicted over the next 10 years or in the next three generations, due to a decline in occupied surface area and/or quality of the habitat).

In Italy, all species are also protected by law no. 157 of 1992, which forbids them to be killed or disturbed. Various ways of reducing the impact of man's activities on bat populations have been suggested, but in many cases they are simply proposals or declarations of intent. In view of the great variability of direct and indirect possibilities of conflict between the logistic and economic needs of man and those of these delicate animals, few of these measures are really effective or sustainable.

If they were properly applied, they would influence the very models of development of Western societies, by drastically restricting the use of chemicals in agriculture, imposing different criteria on buildings, and providing for proper forestry management. Even the distribution of nesting-boxes in

certain areas is merely a palliative, since they are only

used by a few species and are in any case very

limited, mainly as supports to research

programmes. However, as regards bats

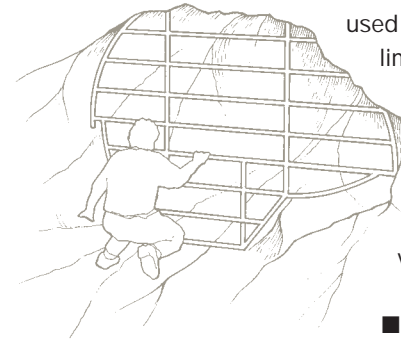
breeding in caves, the most practical and

functional protective measure against

direct disturbance by man is to deny

physical access to the most frequently

visited caves (see drawing).



■ The ethics of speleology

Mountains belong to everybody. Speleologists, who are beginning to know them inside too, have some rights but also many more obligations. Every conscientious speleologist is obliged to prevent and correct any damage to caves and to the water resources which they contain.

Some recommended ethical and deontological rules are shown below.

Prevention of damage to the external environment

- Request authorization for visits whenever possible, scrupulously respecting the arrangements made by owners or managers of natural parks and reserves;
- Always inform others about the particular dynamics and vulnerability of karstic aquifers, mentioning their special capacity for accumulating pollutants, their incapacity for self-depuration, and the possibilities of mass (concentrated) pollutants which have already accumulated, in order to avoid possible contamination of drinking waters;
- Avoid publicizing the discovery of a new cave before the necessary protective measures have been taken: this will avoid attracting simply the

curious (inexperienced people who may also risk accidents) and illegal collectors of concretions, mineralizations, fauna or anything else, who would probably irreparably damage the integrity of the new cave;

- Place great importance on ecological education supplied during courses on speleology and on proper training of guides taking visitors on cave excursions;
- Give “underground tourists” all useful information on proper understanding of the importance of conserving subterranean assets and karstic aquifers.

Preventing damage to the subterranean environment

- Avoid too many visits, even though the most delicate caves are the ones which are most attractive. If possible, discourage visits by large groups, reserving information on the less delicate caves to speleology courses;
- Always avoid walking about too much all over caves, even when they are very large: a simple ribbon of red cotton on the ground means that everyone can walk along the same track and limit damage elsewhere.

■ Strategies for choosing karstic caves and areas for faunal protection

The urgent need to safeguard at-risk karstic caves and their surroundings poses serious problems regarding the criteria to be used to select caves believed to have “priority”, out of the more than 33,000 Italian caves registered until now.

Obviously, improvisation or other people’s opinions are of little value, but scientifically rigorous methods must be used to quantify the value of each karstic area, so that it may be protected properly.

As regards fauna, objective methods are required to identify the “hot spots” of biodiversity, rarity and endemism. In particular, it has been shown that the points of major interest are those with a high rate of endemism, which only partially coincides with the points of major biodiversity.

Modern statistical techniques and GIS programmes (Geographic Information Systems, computerized cartography) now available to researchers are extremely powerful tools, and allow experts to select, map and attribute parameters for territorial conservation and to identify priority sites. But although they are powerful and sophisticated, they cannot be based on a weak, incomplete data-bank. To apply any kind of statistics, proper knowledge of the territory is required - knowledge that can only be acquired by speleologists and biospeleologists who must collaborate closely if their aims are to be achieved.

■ Why protect caves?

This volume has described all the most salient characteristics of the Italian karstic environment, and given a brief overview of the zoological groups with cave-dwelling members, their origin, distribution and ecology. A detailed examination has also been made of the problem of strategies to protect caves, legislative deficiencies, and also progress made in the last few years. But although speleologists are thoroughly aware that caves and karstic areas deserve immediate safeguarding, the reasons why these environments are of such extraordinary importance must be clearly illustrated to those who have never set foot underground.

There are three main reasons why Italian caves must be protected and why such protection can no longer be postponed.

Intrinsic value of caves. First, caves inherently contain the same scientific and cultural values which make them the patrimony of all mankind: their geology, mineralogy, hydrogeology, landscape, archeology, and paleontology, and the fact that they are habitats for rare and sometimes unique species in the worldwide faunal panorama.

Economic and social value. Caves also have economic and social value, both as regards tourism (which, as we have seen, provides considerable revenue) and recreation, and because they supply drinking-water to very large numbers of people.

Ethic-aesthetic value. There is a third, more profound, aspect, rooted in the very essence of the human spirit, too often neglected in plans for protection and exploitation of the natural patrimony.

This aspect deals with feelings: we appreciate caves and the strange creatures which inhabit them for what they are, without the need for scientific or economic support.

We consider them as natural monuments which, like architectural ones, are important inasmuch as they exist and, for this reason, they deserve to be safeguarded.

Science and economics can supply indispensable indicators for planning choices and orienting efforts at protection, but our emotions and the sense of marvel which many of us feel when we enter a cave, listening to the sound of its waters and observing the strange, white, blind creatures which live and move in total darkness - these things alone justify the need for safeguarding.

Suggestions for teaching

MARGHERITA SOLARI

Study of subterranean karstic phenomena is often viewed as a specialized subject, suitable only for universities or the last years of high school. This is not in fact so: the approach to peculiar and richly fascinating environments, like dolinas and caves, may intimidate some children but at the same time attract them, and may represent a very useful instrument for training the young to know and understand the land they live in. Interest in caves, also as regards prehistory and archeology, immediately create that multidisciplinary link which allows us to study an environment from many points of view and to enrich the minds of our students. It was for these reasons that here, at the end of this volume, we present two teaching suggestions for all those who are interested in introducing others to the fascinations of speleology.

■ Topography of a dolina

- Aims of a topographic exercise: to stimulate knowledge of one's own territory; to develop capacities for observation, analysis and abstract thought; to learn to interpret symbols used on maps.
- Field work: excursions in the field, to compare expectations and reality.
- Scholastic level: last years of junior school and middle school (children of 7-8 years upwards); the depth of teaching is directly linked with the children's level of preparation (see box on dolinas, page 24).

STUDY PHASES

1. Study topographic maps of karstic areas, preferably Technical Maps, scale 1:5,000 (or 1:25,000) and identify the most interesting areas where both superficial forms of karstism (dolina, polje, uvala, etc.) are widespread and mapped, and underground ones (entrances to caves); names of villages and towns are particularly useful for a multidisciplinary approach to mapping.
2. Once a particularly significant map area has been identified, supply students with scale copies; a few other instruments (rulers, goniometers, squared graph paper, pencils) are sufficient for the exercise.
3. Organize individual work by each student on the toponyms referring to morphology: various symbols which represent water networks, reliefs,



escarpments, vegetation, villages and towns, communications networks, paths, etc..

4. Observe and compare various cartographic representations of superficial karstic forms: for example, dolinas may be shown as concentric level curves, wedges placed in a circle, or simply altimetric references.

5. Exercises: identify dolina perimeters, represented by concentric contour lines and definition of gradients; deduce unspecified altitudes with the help of level curves; similarly, deduce altitudes of valley bottoms, if unspecified.

6. Identify the maximum diameter of a dolina, i.e., the segment joining the two most distant points of the perimeter, and the minimum diameter perpendicular to it; calculate the direction of the diameter with respect to compass north, using a goniometer.

7. Draw the profile of a dolina: draw the maximum diameter of the dolina and, using graph paper, mark on it the distances of the points intersecting with contour lines; mark main contours (every 25 m) for large dolinas and secondary curves (every 5 m) for smaller ones (or even 1-m contour lines) for minor forms.

8. Sketch of the dolina: make a drawing and complete it with symbols for vegetation; interpret the key and extrapolate information on the "landscape"; prepare proper symbols and represent vegetation indicating species (trees, vineyards, open-field crops, etc.) and density; note possible diversities in the vegetal cover on the four flanks of the dolina.

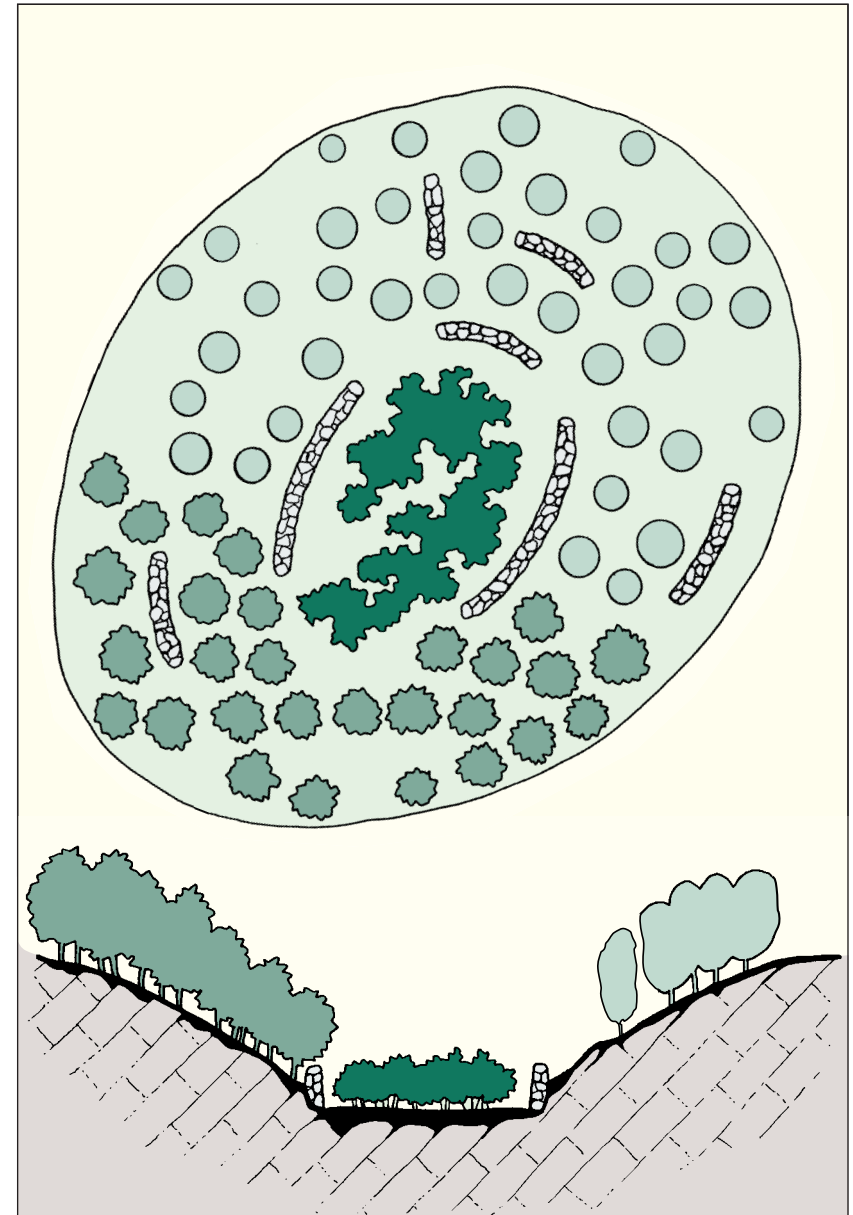
9. Additional exercise: analyse and compare the representation of a small relief; draw its profile; examine problems of cartographic representation.

FURTHER WORK

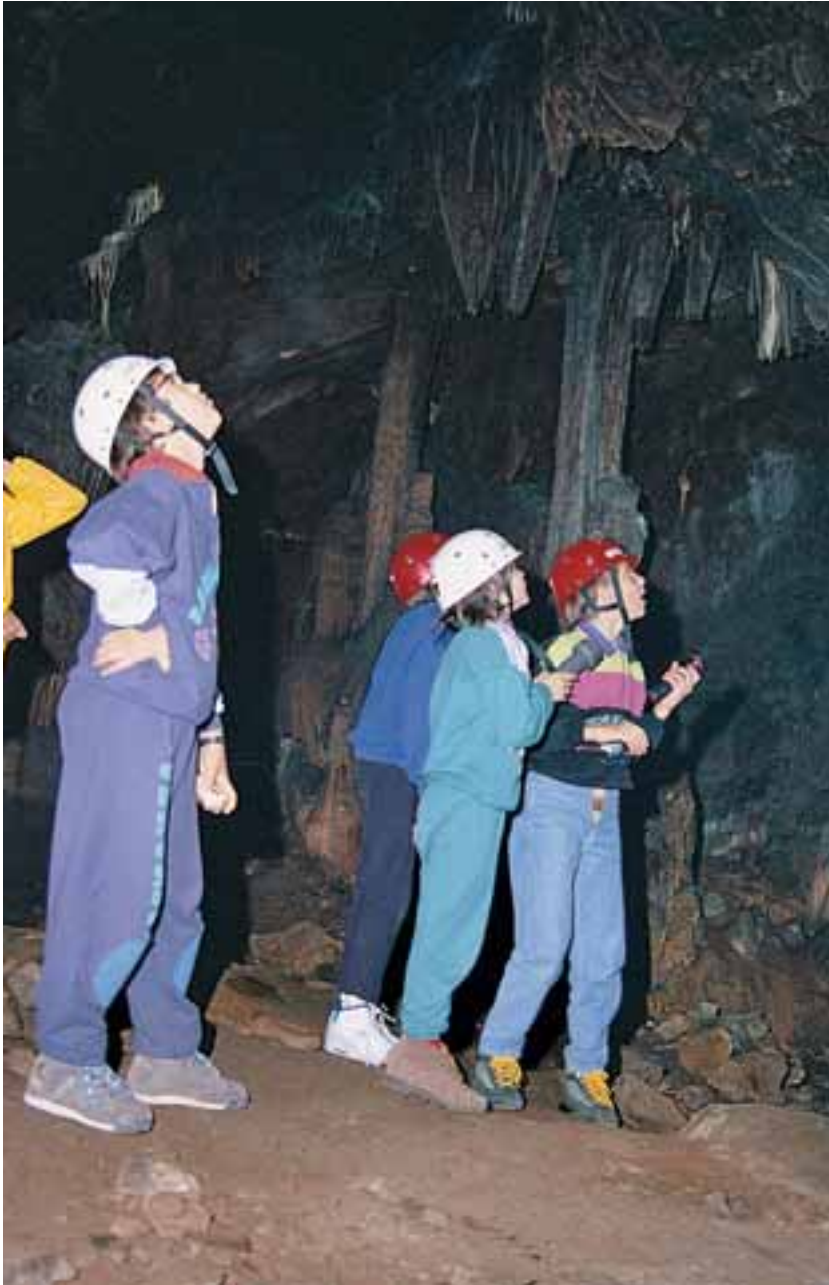
10. Last field excursion: verification of expectations, comparison between real landscape and that deduced from topographic map; exercises in orientation: identification of cardinal points and maximum diameter of landform; if possible, descent into the dolina in groups, identifying points which served for drawing its profile (intersection of diameter with contour lines) and reconstruction of contour lines shown on topographic map by means of ribbon or cord; guided observations on natural environment, with particular emphasis on vegetation on flanks and bottom and surrounding territory.

■ A tour of a cave

- Aims of visiting a natural cave: to go further into the themes covered by teaching; to develop capacities for exploration, orientation and observation,



Plan and cross-section of a large dolina in Trieste Karst, showing changes in vegetation according to microclimate: from left to right (i.e., from south to north), cool-loving, water-loving and heat-loving woodland



essential for fixing acquired knowledge firmly in the memory; to complete taught material with direct experience and to strengthen knowledge by clearly defining experienced situations; to combine amusement and study ("business with pleasure") in a multidisciplinary research. Before beginning to organize this type of activity, check if any students suffer (or may suffer) from claustrophobia: in this case, only try to create motivations for overcoming slight fears, but do not force any student.

- Level: junior school, middle school (from 7-8 years of age), although initiatives of this type, suitably modified and prepared, are possible with even younger children.

According to aims and students' capacities, various levels of excursions may be organized, according to their past experience of guided tours:

- visit to a tourist cave (wearing gym shoes or trainers, and windjackets), focusing on general observations of the underground environment, which may be anthropized and degraded in this case;
- visit to a natural cave presenting slight difficulties;
- full-scale visit, with special equipment.

For the choice of which cave to explore and the behaviour to adopt, see section on the ethics of speleology.

- Essential help: preferably, contact a speleological association capable of supplying both logistic support and, if one of its members is specialized in teaching speleology, ask for specific useful information.

Come to an arrangement with the speleologists on which cave to visit, ascertain any difficulties in its itinerary, according to the needs of the group, and plan for an adequate number of support staff (in general, one accompanying person for every 3-4 students is recommended for a visit of medium difficulty).

- Equipment: for a cave of medium difficulty, all visitors must be properly equipped with: helmets with lamps, rubber boots or stout shoes, woollen or insulated clothing. If the environment is muddy, a change of clothes can be left at the entrance to the cave.

PRELIMINARY ACTIVITIES

1. General theoretical introduction to the phenomenon of karstism and the importance of the subterranean environment, to create expectations and stimulate curiosity and interest.
2. Choice of cave, suited to students' capacities.
3. Pre-visit check-up by organizer and support staff.
4. Bibliographic and cartographic study, in class, to identify the cave.

5. Class debate to organize material necessary for the excursion, choice of route to reach the cave, setting-up of working groups assigned with various tasks (general preparation, survey charts, preparation of notes on cave itinerary, etc.). Information on correct behaviour to be adopted in caves: follow staff indications, do not leave waste of any kind, do not touch (OR BREAK OFF) concretions, and so on.
6. Preparation of excursion equipment by groups.

EXCURSION

7. Check route: the group with this task guides everyone to the entrance to the cave.
8. Notes on the itinerary, for later preparation of reports: type of path, altitude, orientation, vegetation present, time taken to reach cave, geomorphology, any forms of superficial karstism:
9. When the entrance to the cave has been found, take notes on morphological, physical and biotic data, e.g.:
- shape and orientation of entrance, possible presence of water indicating that the cave is active (cave or spring);
 - variations in temperature, light, vegetation, presence of material (branches or leaves) from the exterior;
 - possible signs of degradation: presence of waste, carbide residues from lamps, state of conservation of concretions, etc..
10. After entering the cave, note variations in amount of light perceived, and check temperature variations with a thermometer.
11. Take notes on the itinerary, observing significant elements helping orientation: forks, watercourses, etc.. Try out initial preparation of a planimetric relief with compass and cord marked off in metres, at least along one stretch of the itinerary.
12. Guided observations on:
- environment: possible presence of draughts indicating secondary entrances or large open spaces inside the cave; sound made by flowing water, dripping water, or streams; presence of humidity (small clouds of water vapour after breathing out);
 - vegetation: observations on seriation (point out interesting parallels with evolution); abundant vegetation at the entrance, gradually becoming less with less light (e.g., *Parietaria*, *Lunaria annua*, etc.);
 - cave morphology: the cross-section is mainly determined by water flowing in conduits and by tectonic factors in galleries; observation of the ground, possible fractures, faults, landslides and collapses; various types of

concretions (stalactites and stalagmites, solution pans, columns, draperies, etc.) from viewpoints of both morphological and mineralogical composition (generally, but not always, calcitic); possible relationships between characteristic forms of concretions and tectonic structures; in the first few yards, note presence of rocks and landslides; ceiling vaults of galleries and halls (visitors always tend to look at the ground and walls, forgetting that the ceiling is in fact the first part of any cave to form);

- fauna: presence of guano, indicating bat colonies; animals living on the walls: orthopterans, dipterans, lepidopterans, spiders; search for possible troglobites and observation of their typical colours.

13. Observation of one's own movements: how does one have to move in a cave? (crawling, climbing, etc.)

14. Observation of the simplicity and fragility of the subterranean ecosystem, importance of respecting the environment, and on one's capacity to appreciate it without removing anything from it or damaging it; recovery of all waste.

15. Moment for relax, during lunch interval: perhaps (if possible), allow all lights to be turned off and sit in absolute silence, trying to experience the natural environment without adding one's own outside impressions to it; sharing impressions and feelings.

16. Consultation and interpretation of notes taken during the visit, in order to find the way back to the entrance.

17. Sharing of impressions once outside the cave again, particularly as regards sensations of light and smells in the outside environment.

CONCLUSIVE ACTIVITIES IN CLASS

18. "Reprocessing" in class: preparation of maps, scientific reports on the cave, preparation of essays on personal impressions of the new experience, etc..

CONTINUATION OF WORK

19. The set of observations made during a visit to a natural cave takes on further significance when re-interpreted in comparison with a superficial environment.

The diversities between the two focus on the particular fragility of the subterranean environment and on the need to protect it. To complete the experience and go deeper into these topics, the excursion may later be combined with a visit to a museum with a section on karstism, or a subterranean biology laboratory (found throughout Italy: Trieste, Vittorio Veneto, Verona, Brindisi, Rome, and many others).



Select bibliography

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An ample, complete treatise prepared by the Italian Speleological Society, devoted to all aspects of speleology. Although somewhat out-of-date as regards some specific parts (e.g., description of karstic areas), it is still extremely valid for general topics.

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A manual devoted to this particular aspect of speleological activity, complete with descriptions of the areas containing the most interesting grottoes in Italy and the most interesting cave siphons.

FORNASARI L., VIOLANI C. & ZAVA B., 1997 - I Chiroteri italiani. *Epos*, Palermo.

An attractive volume, useful for teaching those who are interested in the world of bats, without going into excessive detail.

JUBERTHIE C., DECU V. (eds.), 1994 - Encyclopaedia Biospeologica. *Société de Biospéléologie, Moulis (C.N.R.S.), Academia Roumaine*, vol. I, Bucharest.

The first volume in an extensive series devoted to biospeleology. Vol. I deals with numerous invertebrate taxa on a worldwide scale, and examines troglobitic fauna in America and Europe. One chapter is devoted to the fauna of Italian caves.

JUBERTHIE C., DECU V. (eds.) 1998 - Encyclopaedia Biospeologica. *Société de Biospéléologie, Moulis (C.N.R.S.), Academia Roumaine*, vol. II, Bucharest.

In this second volume, ample space is devoted not only to some minor taxonomic groups, but also to cave-dwelling insects (particularly beetles), vertebrates and flora. Vol. 3 is in preparation.

LANZA B., 1983 - Anfibi, rettili. Guide per il riconoscimento delle specie animali delle acque interne italiane. 27. *CNR*, Rome.

This work, a mix between scientific literature and clearly presented, simpler information, contains good descriptions of olm, cave salamanders, and other species of amphibians found in Italian caves.

MINELLI A., RUFFO S., LA POSTA S., 1993 - Checklist delle specie della fauna italiana (*Checklist of species of Italian fauna*). *Calderini*, Bologna.

Lists all known species of Italian fauna, allowing correct, standardized nomenclature to be used. Series composed of 110 sections bound in 24 booklets.

TOSCHI A. & LANZA B., 1959 - Fauna d'Italia. IV. Mammalia (Generalità, Insectivora, Chiroptera). *Calderini*, Bologna.

In this volume on the fauna of Italy, a very large part (pp. 187-473) is devoted to Italian bats, with explicit references to cave-dwelling species. Do not be deceived by the date of publication: this work is still today an excellent scientific reference work for all those who want to learn about bats.

VIANELLI L., 2000 - I fiumi della notte. *Bollati Boringhieri*, Turin.

A valuable work, also from the photographic point of view, examining the various characteristics of underground waters and their essential role in the development of karstism. Some of the most important subterranean rivers and karstic aquifers in Italy are described.

Much more information may be obtained from the numerous journals devoted to speleology published in Italy. Examples are the publications of the Società Speleologica Italiana ("Speleologia" and "Le Grotte d'Italia"), the journals "Atti e Memorie della Commissione Grotte E. Boegan", "Mondo Sotterraneo" and "International Journal of Speleology" (sections on biology and earth sciences), and many bulletins published by local speleological groups.

Glossary

> Allopatría: condition of complete separation of the areas in which one or more species live; allopatric speciation is the differentiation of new species due to the isolation of some populations of a common progenitor.

> Benthic organisms: organisms living in water, always in very close relationship with the bottom substrate.

> Dissolution: a chemical process giving rise to the solubilization of limestone by water enriched in carbon dioxide.

> Endemic: an adjective indicating a species exclusive to a certain relatively small geographic territory; caves are among the environments richest in endemic species.

> Biotic interactions: general interactions among all kinds of living organisms (e.g., competition, predation, etc.).

> Phreatic zone: the permanently water-saturated area in a karstic massif, in which horizontal flow of subterranean waters prevails.

> *Gour*: French term, used to indicate a pool.

> *MMS*: acronym used by French authors to indicate the soil layer mainly resulting from dismantling of underlying rocks (*Milieu Souterrain Superficiel*); it is considered to be an intermediate habitat when a cave environment is colonized.

> Plankton: organisms living in suspension in waters.

> Speleothemes: various types of deposits in a cave (concretions, etc.).

> Speciation: evolutionary process leading to the differentiation of new species.

> Stygobites: organisms exclusive to subterranean waters (karstic or otherwise), in which they spend their entire life-cycle; they always present special adaptations to underground life.

> Stygophiles: organisms found in subterranean waters (karstic or otherwise), where they may reproduce, but they are not exclusive to these environments, since they may complete their life-cycle partly in superficial waters.

> Stygoxenes: organisms living in superficial waters but also occasionally found in subterranean waters, as a result of passive transport or because they seek special conditions in some phases of their life-cycle.

> Troglabites: organisms exclusive to caves, where they spend their entire life-cycle; they always present special adaptations to underground life.

> Troglaphiles: organisms regularly found in caves, where they may reproduce, but they are not exclusive to these environments; in some cases (eutroglaphile organisms) they may present partial adaptations to underground life.

> Troglaxenes: surface-living organisms occasionally or accidentally found in subterranean environments; in some cases, they frequent caves during particular phases of their life-cycle or in some seasons (regular troglaxenes).

> Vadose zone: that part of a karstic massif in which vertical flow of waters prevails (unsaturated zone), with dripping and percolation of various intensity.

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