Can an artificial cave be a hotspot for mollusc diversity? Overview of land snail biodiversity underneath Paris and surrounding area

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Abstract
Since the birth of biospeleology in the 19th century, researchers have studied all groups of invertebrates living in subterranean ecosystems. Similarly to natural caves, artificial cavities provide suitable habitats for a distinct underground fauna, a big part of which remains poorly understood. Mollusc investigations in underground quarries are indeed limited because of their lower malacological biodiversity. Some 10–40 m underneath Paris, kilometers of passageways are the result of previous exploitation of limestone, chalk and gypsum, establishing an underground network used and visited by underground workers and explorers for centuries. This work presents the first large-scale inventory of the malacological biodiversity in the Parisian underground quarries. Seven eutroglophiles, one endogean and seven trogloxenes taxa were identified. *Oxychilus* species are the most common in quarries and the occurrence of *Zonitoides arboreus* is a new mention for the Paris region. The inventory of molluscan taxa in the Parisian quarries considers the relationship between human activities and the environment in this particular ecosystem to better understand quarries' biodiversity. The organic allochthonous material introduced by man and the molluscan carnivorous occasional feeding behavior seem to be two conditions that favor the presence of eutroglophile molluscs.

Résumé
Une grotte artificielle peut-elle être un hotspot pour la diversité des mollusques ? Aperçu de la biodiversité des escargots terrestres sous Paris et sa région. Depuis l'avènement de la biospéléologie au XIXe siècle, les chercheurs ont étudié tous les groupes d'invertébrés vivant dans les écosystèmes souterrains. Tout comme les grottes naturelles, les cavités artificielles sont des habitats propices à une faune souterraine particulière, dont une grande partie demeure mal connue. En effet, elles sont peu étudiées en raison de leur plus faible biodiversité malacologique. Entre 10 et 40 mètres de profondeur sous Paris et dans les environs, des kilomètres de galeries sont le résultat de l'exploitation antérieure du calcaire, de la craie et du gypse. Pendant des siècles, l'ensemble du réseau souterrain a été utilisé et fréquenté par les travailleurs et les explorateurs. Cette étude présente le premier inventaire à large échelle de la diversité malacologique des carrières parisiennes. Sept taxons eutroglophiles, un endogé et sept trogloxènes ont été identifiés. Les espèces *d'Oxychilus* sont les plus courantes dans les carrières et la présence de *Zonitoides arboreus* est une mention inédite pour la région parisienne. L'inventaire des mollusques dans les carrières parisiennes met en évidence l'importance d'appréhender les relations entre l'homme et l'environnement dans cet écosystème particulier pour mieux comprendre sa biodiversité. La matière organique allochtone apportée par l'homme et le régime carnivore occasionnel de certains mollusques semblent être deux conditions favorables au développement des mollusques eutroglophiles.

1. Introduction
Caves and cavities are suitable environments for the penetration and development of non-marine mollusc populations (GERMAIN 1911; JEANNEL 1943; WEIGAND 2014). However, the community of malacologists still lack an updated and complete synthesis of the land snail species living in the French subterranean environments. In mainland France, they comprise one troglobiont species (*Zospeum bellesi* Gittenberger, 1973; Ellobiidae), several eutroglophiles (such as Agriolimacidae, Arionidae, Discidae, Gastrodontidae, Limacidae, Oxychilidae), some endogeans (*e.g.* Helicodiscidae, Ferussaciidae, Testacellidae), a wide diversity of stygobionts (*e.g.* Bythinellidae, Hydrobiidae, Moitessieridae), and some bivalves (*e.g.* Dreissenidae, Sphaeridae) (GERMAIN 1911; JEANNEL 1943; VANDEL 1964; BERNASCONI & RIEDEL 1994; KERNEY et al. 1999; PRIÉ 2019).

Like natural caves, former underground quarries provide a relevant interface to observe and study subterranean life. Although a review of the literature shows that some mollusc species are known to be occasionally found in different types of underground habitats (VANDEL 1964; BERNASCONI & RIEDEL 1994; WEIGAND 2014; PRIÉ 2019), no specific work has been carried out on the malacofauna of artificial cavities. The pioneering biospeleological work of VIRÉ (1896) in the catacombs of Paris did not mention any occurrence of molluscs (GÉRARDS 1908). BALAZUC et al.

(1951) were the first authors citing malacofauna from the ancient Parisian quarries but only few taxa have been recorded. Unlike natural caves, underground Parisian quarries represent a peculiar anthropogenically modified ecosystem. Since the time of their exploitation, quarries have been regularly visited and transformed. In natural cavities, the vulnerability of subterranean habitats and their fauna to disturbance or pollution is generally accepted (MAMMOLA et al. 2019). We wonder whether the latter factors lead to malacofauna impoverishment through the degradation of habitats. Our objectives were to i) study the extant malacological biodiversity and its distribution, and ii) assess the potential impact of human activities on this taxonomic diversity.

Initiated by Marina FERRAND (second author of this article) in 2016, an extensive and generalist biospeleological inventory has greatly increased our knowledge on the Parisian subterranean invertebrates. Many more locations have been investigated since, allowing the list of identified taxa, including occurrence information, to be significantly extended (*e.g.,* GEOFFROY & FERRAND 2020; DELFOSSE et al. 2020). We note that particular emphasis has been put on molluscs since 2018. We present here the first overview focusing on the land snails living in the former Parisian underground quarries. Our aim was to provide a list of the taxa that commonly dwell in artificial caves and to discuss their distribution in this unique subterranean environment.

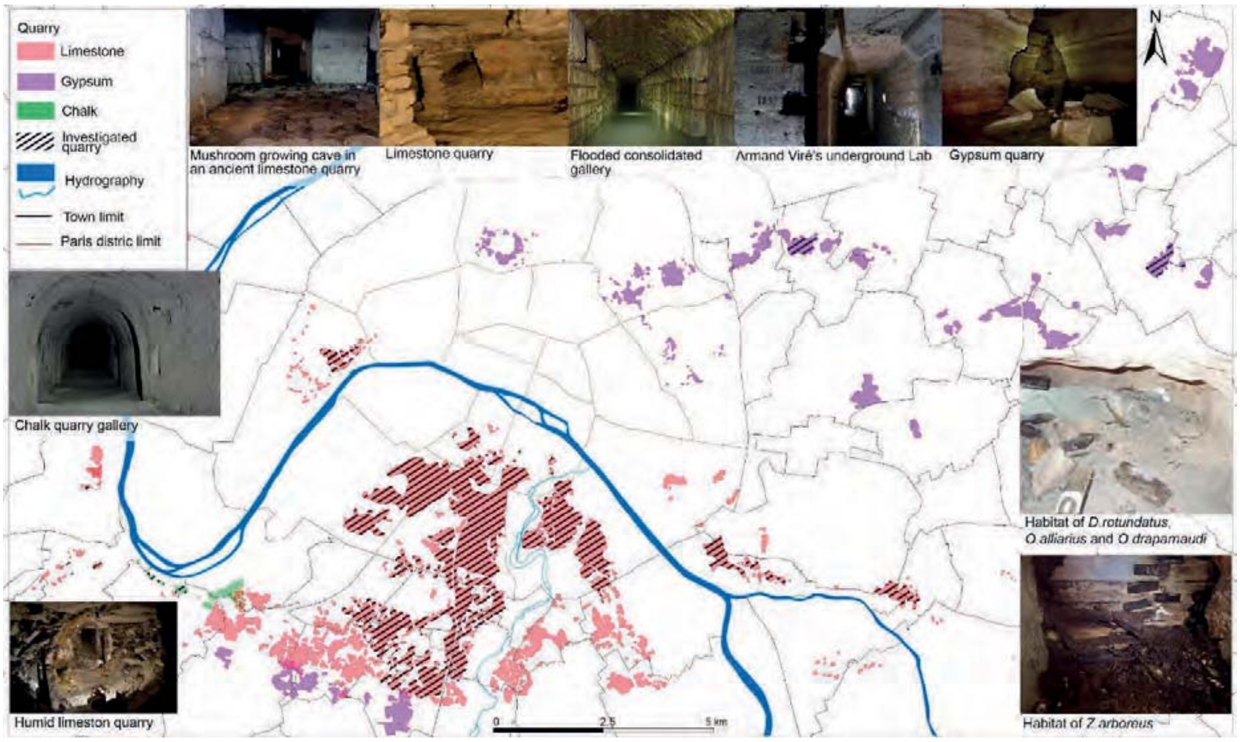

Figure 1: Map of the Parisian quarries (limestone, gypsum and chalk) presenting the context of the study, several types of subterranean environments and molluscs habitats

2. Materials and methods

Tertiary beds in the center of Paris Basin provide many geological resources. Today, at a 10 to 40-meters depth beneath the surface, kilometers-long galleries result from the former exploitation of underground quarries. In Paris and surrounding area, artificial caves of limestone, gypsum, and chalk represent a complex network with a total surface area of than 3000 hectares (limestone: 2349 ha; gypsum 651 ha; chalk: 65 ha; source: IGC https://www.paris.fr/pages/tout-savoir-sur-les-sous-sols-2317, last consultation:12.20) (Fig. 1). Some of them comprise kilometers of galleries whereas others are only hundreds of meters long. In the subterranean environment, physical conditions commonly fluctuate but obscurity is complete. The temperature varies between 12°C and 19°C (c. 14°C on average) and the constant humidity reaches 80%. Water is present in the form of puddles and basins, and in some galleries, water level reaches 1.5 m. Because limestone and chalk are exploited, this environment is commonly calcareous. Most of the organic matter is of human origin (*e.g.,* wood consolidation, underground explorer waste). Indeed, this underground network has been visited for centuries. Since the eighties, cataphiles (*i.e.,* underground explorers) transform parts of the catacombs of Paris for events and activities (*e.g.,* parties, meetings, construction, restoration, art). Knowing that mollusc density is generally low in subterranean ecosystems, our sampling protocol was designed to observe as many species and individuals as possible. To do so, we investigated mollusc diversity mostly focusing on organic-rich and humid areas (Fig. 2A) by favoring a reasoned sampling plan (CUCHERAT & DEMUYNCK 2008). Occasionally, random areas were also investigated (Fig. 2B). We carried out a direct method of collection by hand picking land snails and slugs (Fig.2C).

Figure 2: Biospeleological on A) humid, decayed wood, B) at a random sampling location and C) handpicking specimens.

Live specimens collected were systematically preserved in 96% alcohol for possible future genetic analysis. Concurrently, we developed a citizen science approach involving the cataphile community on social networks (Forums, Facebook, Discord). Observations and pictures done by underground explorers have been gathered and data was checked by the authors. Specimens were identified based on conchological characteristics, using malacological guides (KERNEY et al. 1999; WELTER-SCHULTES 2012). When identification was challenging (for Oxychilidae for instance), specimens were determined after dissection. Dry material and material in alcohol, fully labelled, are curated by Quentin WACKENHEIM and kept in his personal collection.

3. Results

Since 2016, 37 underground quarries from different exploitation types have been investigated (gypsum: 2, chalk: 2, limestone: 33) (Fig.1). They are spread over 15 towns, in Hauts-de-Seine (Bagneux, Châtillon, Malakoff, Meudon, Montrouge, Saint-Cloud, Sèvres), Val-de-Marne (Arcueil, Cachan, Charenton-le-Pont, Saint-Maurice), Seine-Saint-Denis (Gagny, Romainville), and Paris (5th, 6th, 13th, 14th, 15th, 16th city districts).

Altogether 15 molluscan taxa were recovered. They are classified into three groups: the eutroglophiles (7 taxa), the trogloxenes (7 taxa), and the endogeans (1 taxon). We consider a gastropod species to be a trogloxene when it was only found occurring close to the entrance (and not deep in the quarry), whereas a eutroglophile snail is commonly found inside the cave (SKET 2008).

<u>List of the taxa occurring in the former Parisian quarries</u>
<u>Eutroglophile</u>
Discidae
Discus rotundatus (Müller, 1774)
Gastrodontidae
Zonitoides arboreus (Say, 1816)
Oxychilidae
Oxychilus alliarus (Miller, 1822)
Oxychilus cellarius (Müller, 1774)
Oxychilus draparnaudi (Beck, 1837)
Limacidae
Limax maximus Linnaeus, 1758
Arionidae
Arion distinctus Mabille, 1868
<u>Endogean</u>
Ferussaciidae
Cecilioides acicula (Müller, 1774)
<u>Trogloxene</u>
Lauriidae
Lauria cylindracea (Da Costa, 1778)
Valloniidae
Acanthinula aculeata (Müller, 1774)
Clausiliidae
Cochlodina laminata (Montagu, 1803)
Hygromiidae
Trochulus hispidus (Linnaeus, 1758)
Helicidae
Cepaea nemoralis (Linnaeus, 1758)
Cornu aspersum (Müller, 1774)
Helix lucorum (Linnaeus, 1758)

4. Discussions

The considerable surface of former quarries makes it difficult to investigate each gallery extensively. Implementing a citizen science approach by encouraging cataphiles to share their observations of underground invertebrates has improved and enlarged our work. Overall, by listing 15 molluscan taxa, the present study completes the seminal work of BALAZUC et al. (1951) who provided only little information about the malacofauna living in the former Parisians quarries. Mollusc populations appear to be slightly isolated from each other; only one or two species are generally found in the same observation site, more rarely three. However, in some cases, the input of trogloxene species near entrances provides a higher diversity. Most of the molluscs recorded were sampled from rotten wood or humid gallery walls. According to our observations, moisture and the presence of organic matter (mostly dead wood) (Fig. 1) seem to be two ecological factors that determine the presence of eutroglophiles snails and slugs.

Despite its low density, the underground malacological community is characterized by a relative abundance of *Oxychilus* species which appear to be the most common land snails in the Parisian quarries. *Oxychilus draparnaudi* (Beck, 1837) is one of the most widespread and generally inhabits places rearranged by cataphiles or deadwood-rich habitats. The introduced Gastrodontid *Zonitoides arboreus* (Say, 1816) is still poorly known in France. The identification of several populations of *Zonitoides arboreus* under Paris is a new occurrence for this taxon in the north of France and the Parisian region. The discovery in May 2020 of several specimens living on rotten wood used for consolidating an isolated gallery (Fig. 1) supports the link between human activities in quarries and the introduction of allochthonous mollusc species.

The eutroglophiles identified are tolerant and require organic matter. In this peculiar environment, organic matter is provided by human allochthonous input and by the subterranean biomass itself. The occasional carnivorous feeding behaviour of Gastrodontidae, Oxychilidae and slugs favor their adaptation underground.

Furthermore, the anthropic organic input contributes to maintain suitable ecological conditions and to support the food chain. Presence and diversity of surface and subsurface fauna are a prerequisite for the penetration of eutroglophiles molluscs (WEIGAND 2014). Since Paris and surrounding areas are largely urbanized, molluscs' local habitats are restricted and fragmented. Consequently, the Parisian urban malacological diversity tends to be homogeneous and characterized by tolerant species (CLERGEAU et al. 2011; WACKENHEIM 2017). The molluscan underground inventory we compiled is consistent with the latter observation.

5. Conclusions

The mollusc inventory in the Parisian quarries highlights the importance to consider the relations between human activities and the environment in this peculiar ecosystem to better understand its biodiversity. This study leads to the following main conclusions:

- this first overview focused on mollusc diversity in subterranean quarries completes the few data published by BALAZUC et al. (1951): the malacological diversity of the former Parisian underground quarries comprise 7 eutroglophiles, 1 endogean and 7 trogloxenes species.
- involving cataphiles in a citizen science approach improves and expands our investigations.
- *Oxychilus* species are the most common land snails in the Parisian quarries and the occurrence of *Zonitoides arboreus* is a new record for Paris area.
- organic matter provided by human allochthonous input and the molluscs' occasional carnivorous feeding behavior seem to be two conditions that favor the development of eutroglophiles molluscs.

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