The Racovitzan Impediment and the hidden biodiversity of unexplored environments

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ἓν οἶδα ὅτι οὐδὲν οἶδα

I know one thing; that I know nothing (Socrates).

Awareness of our limits has been an incitement to develop knowledge through the history. In the last years, the incompleteness of biodiversity knowledge has been formalized through the definition of a number of "shortfalls", which identify the many facets of biodiversity for which we are far from having exhaustive information (Hortal et al. 2015). For instance, the majority of species on Earth has not yet been described (Linnean shortfall), and the knowledge of geographic distribution is incomplete for most species (Wallacean shortfall). Furthermore, even for described species for which distribution maps are available, there is scarcity of data on evolutionary history, population abundance and dynamics, ecological traits and function, abiotic tolerance and ecological interactions (referred to as Darwinian, Prestonian, Raunkiæran, Hutchinsonian and Eltonian shortfalls) (Hortal et al. 2015; Wilson 2017). Biased and incomplete data hamper the correct identification of evolutionary and ecological processes, strongly impact all aspects of biodiversity research, and can also hinder the progress of species conservation and management. We cannot protect species and populations we are not aware of, and we cannot define management strategies if we do not know how species respond to environmental changes (Hortal et al. 2015).

The Linnean and Wallacean shortfalls refer to the most basic biodiversity knowledge: which species exist, and where they live. However, we can only describe and map species from environments we know and we can access for sampling. We live in an era in which satellites provide images with unprecedented quality and resolution, and even allow remote-sensing measures of ecosystem functioning, functional diversity and threats (Asner et al. 2017; Bastin et al. 2017). Therefore, we generally assume to have a good knowledge of the distribution and extent of most environments: the period when naturalists, exploring unknown lands, came back home with reports of strange animals like platypus or giant turtles, seem to be far beyond us. Still, most of the information we have and the maps we have produced are limited to the surface of the Earth globe. Such two-dimensional view misses a key property of the biosphere, which is the three dimensional volume that supports life. Besides the Linnean and Wallacean shortfalls, we believe that there is a further and even more basal impediment to biodiversity knowledge: we cannot describe, map, analyze and conserve the biodiversity of the environments we

never explored and mapped. We propose to name this as the "Racovitzan impediment", after Emil Racoviță, a Romanian biologist and explorer that is considered to be the founder of biospeleology, but also lead polar and oceanographic expeditions.

Underground environments are a remarkable (but not unique) example of how the lack of exploration hampers biodiversity knowledge. Underground habitats harbor a large yet underestimated portion of Earth species, and it is well known that Linnean and Wallacean shortfalls are particularly evident in these environments (Culver et al. 2012). For instance, the number of known species of carabid beetles in Europe and Northern Africa keeps increasing every year, but the discovery rate is now much slower than one century ago. This fact could suggest that the known species number is not far from reaching an asymptote representing the total number of existing species (Fig. 1, black line). However, the situation is strongly different for cave-specialist carabid beetles. In this case, the species discovery curve remains steeper (Fig. 1, colored lines), suggesting that the proportion of unknown species is likely much higher for underground than for surface beetles (Brandmayr et al. 2013).

A major problem with subterranean habitats is that most of them remain poorly explored or even unmapped: entering in caves can be challenging, underground spaces are often too small to be accessed by researchers, and actually most of them remain unexplored. Cave exploration data provide impressive evidence of how limited is our knowledge of the subterranean domain, where the deepest caves and groundwater aquifers host a fauna rich in highly specialized and endemic elements (Culver & Pipan 2014). For instance, the Classical Karst (also known as the Karst) is among the karstic areas of the world where caves have been explored most intensively over the last 150 years. We reviewed the available literature, including the grey literature and unpublished speleological reports, to obtain information on the known biodiversity within the Italian part of the Classical Karst. The study region corresponds to the area delimited by the course of the Isonzo-Soča River, the Adriatic Sea and the Slovenian border (Fig. 2). Overall, we obtained a database including the distribution of 177 species across 3035 caves, with species records covering the period 1894-2008. We only considered species with a certain degree of specialization to the cave environment (i.e. the so called troglophyles and troglobites), to avoid inflating the dataset with surface species occasionally present in caves (i.e. trogloxenes). From these data, we then obtained the cumulated number of explored caves, and the total number of species recorded to be present in the caves, during each year. We used generalised least squares (GLS) to assess relationships between the number of species known to occur in the explored caves and the number of explored caves, while taking into account temporal autocorrelation (Zuur et al. 2009).

Even in this well-known area, the number of explored caves doubled in the last 40 years (Fig. 2). In the same period, the number of species known to occur in the explored caves showed an impressive increase (Fig. 2), and the match between the number of known species and explored caves was almost perfect ($r = 0.96$; GLS: $t_{40} = 5.22$, $P < 0.0001$). Even today, we can only describe species from caves after they have been explored, and the deepest caves in the world, together with deepest, unexplored aquifers, still constitute a challenge for biodiversity research (Fiser et al. 2014). It is important to remark that underground environments are not limited to caves, which are just the underground habitats that are easiest to survey. Shallow subterranean habitats are often too small for human access but are present all over the globe, even in non-karstic areas, and host an unappreciated biodiversity that can be heavily threatened by global changes (Culver & Pipan 2014; Mammola et al. 2016; Pizzolotto & Brandmayr 2018).

Underground environments are not a unique case. The oceans comprise over 97% of the volume of the biosphere and have an average depth >3,700 m, but we mostly have access to the first meters below the ocean surface (Garrison 2010; Weatherall et al. 2015). Even tough new data are greatly improving our knowledge of seafloor bathymetry (Sandwell et al. 2014; Weatherall et al. 2015), the overall resolution of seafloor maps remains rough, as elements smaller than a few kilometers are rarely mapped, and ~900 ship years of surveys would be required just to complete high resolution maps of the world's oceans (Weatherall et al. 2015). The very hard access to most of underwater environments determines vast ignorance of marine biodiversity (Woolley et al. 2016; Wilson 2017), as for underground systems.

Neglecting an environment does not mean that such environment is unimportant, as unexplored environments are functionally linked to the surface ones. For instance, despite groundwaters are mostly unexplored, especially in the deepest layers, >90% of the world unfrozen freshwater is stored underground, feeds surface ecosystems and we depend on it for drinking, irrigation and several other key ecosystem services (Culver & Pipan 2014). Similarly, deep marine environments have a key role in the global nutrient cycling and in marine food webs, and contain major resources of minerals and energy sources (petroleum, gas) (Ramirez-Llodra et al. 2011). Exploiting resources stored in unexplored environments can have unexpected consequences, which will likely impact the undescribed biodiversity, with potential cascading effects on surface ecosystems functions and services.

We feel we can observe any corner of the globe using tools such as Google Earth[TM]. However, below the surface there are areas of our planet less explored than the surface of the moon, and these areas host a neglected biodiversity. Recognizing the Racovitzan impediment is essential to fill the (huge) knowledge gaps, and to

improve the way we exploit and manage ecosystems that are out of our sight, but must remain in our mind.

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Figure 1. Cave biodiversity is much less known than biodiversity of non-cave species. The black line is the species accumulation curve (mean ± SD) of newly recorded carabid beetles (Coleoptera: Carabidae) per country in Europe and North Africa (species description; redrawn from Schuldt & Assmann 2009). Colored lines are the species accumulation curves of five genera of cave-specialist carabid beetles [from the darkest to the palest color: *Duvalius*, *Geotrechus*, *Aphoenops*, *Orotrechus*, *Anophthalmus;* redrawn from Brandmayr et al. (2013)].
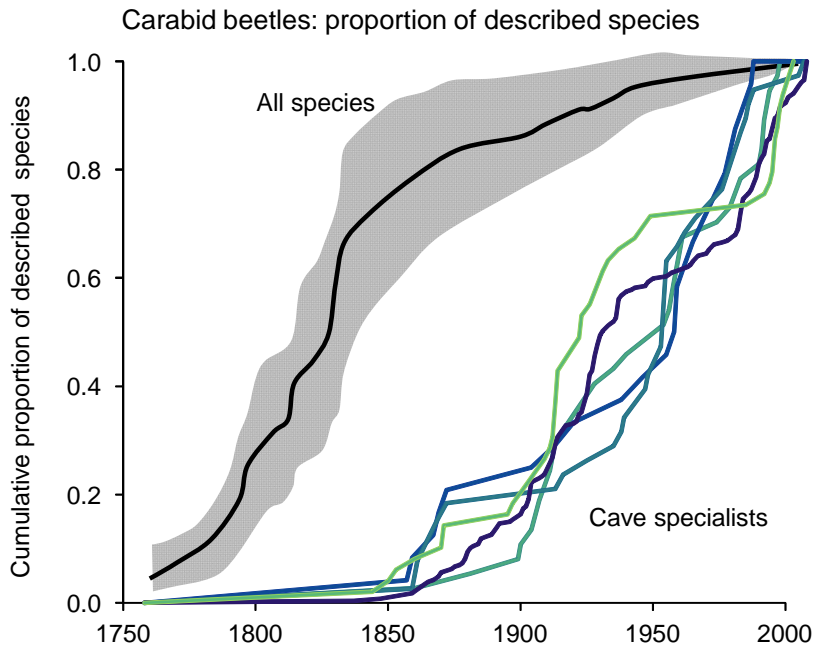

Figure 2. Cumulated number of explored caves, and total number of species recorded from caves of the Italian Karst (inset in the map).