EMILE G. RACOVITZA (1868–1947): HIS VIEWS ON THE ADVANCEMENT OF BIOSPELEOLOGY ARE STILL USEFUL TODAY

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Abstract. The views of EMILE G. RACOVITZA proposed in his *Essay on biospeleological problems* (1907) represent a scientific revolution. The major contribution of RACOVITZA to the development of biospeleology, as modern research, is exemplified through excerpts from his publications dealing with various aspects of taxonomy and systematics of cave fauna. We show that RACOVITZA considered taxonomy an important factor for the advancement of biospeleological research. The present contribution documents the long-term effort of RACOVITZA to establish robust taxonomic methods which support the development of new directions in biospeleology, related to the origin and evolution of those organisms. This essay offers a snapshot of the original ideas of RACOVITZA and in this way contributes to keep alive the legacy of a remarkable scientist.

Key words: biospeleology, research methods, taxonomy, systematics, phylogenetics.

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1. INTRODUCTION

EMILE G. RACOVITZA[1] (1907) in his famous *Essai sur les problèmes biospéologiques* (English version *Essay on biospeleological problems*, CULVER & MOLDOVAN 2006) argued that studies dealing with life within the cave environment should be recognized as a special domain of scientific research, for which ARMAND VIRÉ (1904) coined the name *Biospéléologie*. For this area of research, RACOVITZA (1907) discussed a rational research program proposing that the biodiversity of subterranean organisms sampled in caves be the backbone of biospeleology.

Before starting a deeper discussion on biodiversity, in general, RACOVITZA (1907) recognized the necessity to define what cavernicolous animals are and how one can recognize them. Elaboration of a classification of animals related to their degree of specialisation to the cave environment appeared as a priority. Intuitively, RACOVITZA (1907) anticipated the existence of a large number of cavernicolous species all around the globe. Because of this expectation, it was suggested that students exploring caves and/or studying cavernicolous organisms in future should make their studies carefully, avoiding premature generalisations of their observations. The research program looking at the biological diversity of cavernicolous organisms described in the *Essay* considered three different kinds of investigations: (1) point studies which should better explain the origin and adaptation of selected organisms; (2) analysis of small groups of cave organisms with results presented in monographs reflecting aspects of their comparative morphology and biology; such monographic studies should allow the reconstruction of the biological history of those groups; (3) rigorous experimentation with selected cave organisms should follow as much as possible.

The question of the extensive colonisation and the degree of diversification of the cave fauna and flora was characterized in the Racovitza's *Essay* as follows: "cave beings represent an element that cannot be neglected in the population of the globe. This is proved by the respectable number of already known forms despite the relatively restricted number of researches" (RACOVITZA, 1907, p. 438). The *Essay* reviews extensively the kinds of cave animals and flora known at the beginning of the 20th century.

[1] In this essay, we adopted the following conventions: the Romanian name EMIL G. RACOVIȚĂ will be used with the French transliteration EMILE G. RACOVITZA, as it is used by this scientist in his publications. For the terms *Spéologie* and *Biospéologie*, favoured by Racovitza (1907, p. 381), we use the English version *Speleology* and *Biospeleology*. For this latter decision we adopted the arguments of SKET (2006, p. 119). Illustration representing E. G. R. in 1925, as honorary President of the "Société Zoologique de France" (from *Bulletin de la Société Zoologique de France*, 1925, **50**: 64).

The number of biospeleological studies during the next 50 years after the publication of the *Essay* increased tremendously. This can be observed when inspecting the first book dealing with biospeleology (VANDEL 1964, English version 1965). In this compendium of more than 500 pages, approximately 200 pages deal with information on various cavernicolous organisms, demonstrating the extensive progress in the documentation of diversity of cave dwelling biota. This is also a proof that the success of speleology in general increased, and especially studies dealing with various aspects of cave life represent an important part of scientific interest. This is visible *inter alia* also if one examines *Encyclopedia of caves* (CULVER & WHITE, 2005). Since the publication of the Racovitza's *Essay* new directions of research emerged, *inter alia* groundwater ecology (GIBERT *et al*., 1994) and the ecology of shallow subterranean habitats (CULVER & PIPAN, 2014). Additionally, the ideas of E. G. Racovitza, especially his *Essay*, greatly stimulated generations of naturalists and work on the general ecology of caves and on the evolution of their organisms expanded steadily. Here are some examples of monographic contributions: GINET & DECOU, 1977; CAMACHO 1992; CULVER *et al*., 1995; WILKENS *et al*., 2000; AUSTIN *et al*., Ed. 2008; MOLDOVAN *et al.*, 2018; MALARD *et al.*, 2023. These positive trends have led to a redefinition of biospeleology. CULVER & PIPAN (2023, p. 277) consider now that "biospeleology can be construed as the taxonomic and distribution aspects of the biology of caves while speleobiology can be construed as the aspects pertaining to general biological principles such as evolution".

Within the new reformulation of biospeleology framework as proposed by CULVER & PIPAN (2023), the conceptual ideas exposed by Racovitza during the period which followed the publication of the *Essay* (RACOVITZA, 1913; 1926a) continue to be relevant, especially for the education of new generations of biospeleologists. Reexamination of Racovitza's ideas relating to biodiversity of cave animals is particularly valid within the context of recent views exposed by FICETOLA *et al.* (2018). These latter authors considered that the progress of our present state of knowledge on the general biodiversity of caves is greatly impeded by our impossibility to have full access to the complicated structure of cave systems as habitats. Humans have limited access to caves and most of the cavernicolous fauna, especial those of small size (so-called meiofauna or microfauna), remain unattainable to researchers due to the technical difficulty to sample those deep karstic habitats. This claim, even if not directly critical to the Racovitza efforts to make progress with solid information on subterranean biodiversity of animals, calls for a rebuttal. We will show below that Racovitza's efforts to document biodiversity were placed on a completely different research plane, namely in the way taxonomy and systematics of cavernicolous biota can be improved.

2. RACOVITZA'S ARGUMENTS FOR THE NECESSARY ADVANCEMENT OF BIOSPELEOLOGY

2.1. WHAT IS BIOSPELEOLOGY?

Racovitza considered speleology as a synthetic science and the biological aspects were subsumed as biospeleology (RACOVITZA, 1907). In his presentation on his reception into the Romanian Academy, RACOVITZA (1926b, p. 35) expressed this idea as follows: "the new synthetic disciplines take as their object the comprehensive study of a certain portion of this world, with all its energetic factors and material creatures. These disciplines therefore strive to integrate into an orderly and harmonious whole all the scattered knowledge gained by analytical disciplines in their respective fields. Such disciplines are: oceanography – the science of the seas, limnology – the science of freshwater, pedology or agrogeology – the science of cultivable terrestrial environments and among them, of course, speleology – the science of the subterranean domain". Within this framework, RACOVITZA (1907, p. 379–380) recognised the complexity of the general cave fauna. He defined it as follows: "What does the word «cavernicolous» mean? Only this: living in the underground domain. The only thing these beings have in common is their habitat. Cave fauna is, in fact, an entirely heterogeneous mixture of very different forms in terms of origin, hereditary abilities, degree of organization, and the time of immigration into caves, etc… thus, one should be cautious about generalizations, study …each species individually, and generalise only after thorough analyses."

The next step to be addressed was about the importance of studying subterranean fauna.

In the *Essay*, RACOVITZA (1907) stated that ancient forms are not rare in the underground domain, and often they are relics of groups that disappeared from earth surface habitats.

Later, in the response presented for his reception into the Romanian Academy, RACOVITZA (1926b, p. 29–30) noted that "the subterranean domain reveals itself as a true museum of relics, and the question arises as to why this domain is more favored in this respect than many others? The answer would require lengthy developments, so I will limit myself to indicating the predominant factors: the relative constancy of the environment and the absence of competition in the struggle for life, resulting from the simplicity of the specific composition of the fauna". Additionally, RACOVITZA (1926b, p. 32), wrote: "troglobites are not only valuable material for phylogenetic studies; they also provide important data for paleogeography, for establishing geographic maps of various geological epochs. These witnesses of time are chronological milestones for the transformations of various life forms over time and also topographical milestones for the spatial extent of lands and seas of a certain period."

2.2. HOW SHOULD BIOSPELEOLOGICAL RESEARCH BE CONDUCTED?

In addition to the three major research-actions we mentioned in the introduction, Racovitza added on various occasions the way he considered it important to pursue a research program. In his discourse to the Romanian Academy (1926b, p. 17–18) he stressed: "I have never aimed at simple collection of facts, but rather at linking them into generalizations; I have sought to understand, that is, to reduce complicated things to the simpler form from which they derive… I have come to realize that only by comparing as many related groups as possible can one arrive at understanding. I set out to gather material, therefore to identify it, to find out the names given to it in the science of systematics, and to determine to which specific species it belongs."

Considering one specific taxon belonging to a crustacean group, the Isopoda, Racovitza explained how to describe such a taxonomic unit, namely taking account of many morphological details and in a comparative way. This approach becomes necessary if one searches to understand also the origin and evolution of the given zoological group. RACOVITZA (1923, p. 83–84) commented that "it is not enough to find the origin and explanation of a structure; to derive the maximum scientific benefit from it, one must study it comparatively in various homogeneous lineages, and this cannot be done with the materials currently published". It is interesting to note that the type of comparative study recognised by this biologist is also not common nowadays.

In his research, Racovitza always verified his observations multiple times to avoid and eliminate errors. In this way, he was able to realise that some species like the aquatic crustacean *Asellus aquaticus*, considered a common and well-known species, actually represented a taxonomic error. RACOVITZA wrote (1919, p. 33): "Afflicted with a tendency probably congenital to skepticism, I have only a mixed confidence in traditions, oracles, and plebiscites. I cannot help but «go and see» whenever possible. And when I have seen, I see again, then look once more, for a painful experience has taught me how easy it is to make mistakes. So, I had the audacity to verify the diagnoses of my fellow carcinologists on a batch of *Asellus*, and the result of this verification is summarized in the title of this chapter. It is unexpected and distressing".

On different occasions Racovitza pointed out that hasty generalizations should not be made. Generalizations must be well verified. Therefore, he suggested (RACOVITZA, 1923, p. 88) using the epistemic method of objectivity where the deductive approach is gradually developed within a logical way as follows: "Questions of comparative morphology must first be studied individually in homogeneous lineages and without preconceived ideas. The comparison of the obtained results will allow for generalization, applicable only to the group to which these lineages belong, a working hypothesis or a first approximation that must be verified with the other lineages of the group and modified if necessary. These «group hypotheses» can now be compared to each other to give rise to «higher group hypotheses» and so on, step by step. Nevertheless, the only cautious and

reliable way to advance the progress of morphological discoveries is to first address the least specialized lineages, which are likely to have best preserved traces of the primitive organization".

Racovitza asserts that research traditions adopted from important personalities is a major aspect for future research developments. As an example, RACOVITZA (1937, p. 57) mentions his master Henri Lacaze-Duthiers with the following words: "He knew how to choose and encourage his students, he knew how to instill in them the strict discipline of order in research, the rigor in observation and experimentation, which he advised you to repeat before drawing conclusions. He inspired distrust of hypotheses and *a priori* theories and urged to have confidence only in rigorously established and conscientiously verified facts."

Cooperation between researchers for the advancement of biospeleology was repeatedly mentioned by RACOVITZA (e. g. 1913, 1926a) when promoting the enterprise *Biospeologica*. This aspect is discussed in DANIELOPOL (1996) as well as in TABACARU *et al.* (2018). *Biospeologica* was conceived as a cooperative project working at different levels. Racovitza, in 1920, initiated the first research Institute in Romania at the University of Cluj (RACOVITZA, 1926a) with a coherent biospeleological programme and an international research group. Besides Valeriu Puscariu and Radu Codreanu from Romania, the French René Jeannel and the Swiss Pierre-Alfred Chappuis were appointed. Extensive exploration of caves both in Romania and abroad, and an intensive study of subterranean insects (Coleoptera) and Crustacean (Copepoda and Isopoda) built the major axis of research at the Racovitza's Institute during many years. *Biospeologica* developed also as an international coordination and communication center. Specialists from various countries received zoological material sampled during various campaigns of cave exploration in order to study them in deep (RACOVITZA, 1926a). In this way the biospeleological research expanded in the world as a recognised international activity. The tradition of such activities was continued at the Speleological Institute at Cluj and Bucharest by the next generations of biospeleologists. TABACARU & DANIELOPOL (2020) offered with the occasion of the centennial anniversary of the Speleological Institute of Racovitza a synthetic picture of the scientific achievements of the researchers who worked at this institute.

2.3. TAXONOMY AND SYSTEMATICS OF CAVERNICOLOUS ANIMALS, THE BACKBONE OF BIOSPELEOLOGY

RACOVITZA (1920, p. 62–63) stressed the importance of taxonomy for biospeleology as follows: "…taxonomy is, for those who want to reflect, one of the most synthetic biological disciplines. The taxonomist who aims to contribute scientifically must make use of all the results from other disciplines that deal with living beings. To achieve this goal, he must take into account all the characteristics of organisms, whether they are morphological, anatomical, histological, ontogenetic, physiological, ecological, ethological, whether their discovery is due to observation

or experimentation. For characteristics, the only relevant distinction is between those that are usable and those that are not; he must strive to place his species as accurately as possible in both space and time, because a species is essentially a historical entity".

Racovitza stressed, repeatedly, the importance of taxonomy for the correct understanding of biological diversity on both the surface of the earth as well within the subterranean realm. Here an excerpt from RACOVITZA (1929, reprinted in 1964, p. 668): "If research in anatomy, histology, physiology, biology, psychology, phylogeny, paleontology, and so on, has any meaning and can be used in science, it is because the subject, the organism that has been the subject of these research endeavors, can be identified, and a name recognisable by all scientists can be given to it. And this name that living beings bear is the name of their species. With this name, they are «legitimised», this name constitutes their necessary and sufficient civil status". Racovitza was also a forerunner of the phylogenetic systematics approach developed years later by W. HENNIG (1966). For a discussion and practical application of the phylogenetic method of Hennig see TABACARU *et al.* (2018, p. 13–20). However, it should be noted that Racovitza already considered in 1908 that a good classification should be natural, meaning it should be based on the true relationships between animals.

Later on, RACOVITZA (1912, p. 204) affirmed his personal conviction as follows: "the main purpose of taxonomic studies, the only one that interests me, is, in my opinion, the natural classification of animals, that is, a classification that reflects as accurately as possible the real relatedness of various animal lineages. Understood in this way, taxonomy becomes one of the branches of general biology, as it provides material for studying the laws and modalities of evolution".

RACOVITZA (1925, p. 617) reached the conclusion that taxonomy cannot be anything other than applied phylogeny: "That this taxonomy should be different from the traditional one, which is akin to philately and other «obsessions» involving the gathering of more or less similar things and arranging them in an arbitrary order, I have already indicated many times, that taxonomy cannot be anything other than applied phylogeny, that it is therefore one of the most synthetic sciences in biology, I have maintained for a long time that there is a serious danger of error in not following its precepts, methods, and teachings".

2.4. THE NOTION OF SPECIES AND THE WAY TO DESCRIBE TAXA

During the time of Racovitza, as nowadays, the definition of species was a debatable philosophical concept. Long discussions persisted on the question whether this epistemic category reflects a natural entity or is just a human construct (GODFREY-SMITH, 2014; REYDON & KUNZ, 2019; DANIELOPOL, 2023). For RACOVITZA (1912, p. 208) there was no doubt that species are natural entities, a product of organismal evolution: "the definition of the species as a taxonomic unit can only be: an isolated colony of consanguineous individuals". A very similar

view of the Racovitza's species concept appears in TEMPLETON (1989, p. 25) who defined it as a cohesion concept: "species is the most inclusive group of organisms having the potential for genetic and/or demographic exchangeability". Within the same approach MALLET (2020, p. 1403) viewed species as a "genomic cluster".

A better expression of similar ideas on species were mentioned by RACOVITZA (1926a, p. 48) as follows: "to conceive the species as a purely current phenomenon is certainly a serious mistake... The species must be considered as an entity that is both morphological, historical, and geographical. Taxonomy can only be applied phylogeny. The definition of a species must include the synthesis of its morphological characters, its geographical distribution, and its genealogy; otherwise, it is impossible to correctly position this biological entity within the system and to use it without inevitable errors for specialized studies or generalizations". Racovitza's argument continues in the same publication (p. 49): "We have seen that for a complete definition of a species, phylogenetic data are indispensable".

Whether one reconstructs the history of a species using fossils or, in their absence, using comparative morphology and morphogenesis, the result is the same: we move beyond the notion of current, more or less rigorous specific discontinuity to arrive at the notion of continuity over time; inevitably, specific delimitations fade, and a more comprehensive entity asserts itself with force: the lineage. It seems to me that popularizing the notion of *lineage* as a biological unit, and having clarified its meaning and demonstrated its great utility through numerous concrete examples, is a highly appreciable scientific gain. First and foremost, by substituting the concept of *lineage* for the concept of *species* in all biological speculations, especially in phylogeny and biogeography, we undoubtedly get closer to the truth".

During taxonomical research over many years, Racovitza expressed his view on the way taxonomical research should be done. For instance (RACOVITZA, 1908, p. 240–241) says: "I have pushed the analysis of characters very far because my goal is not to create a simple catalog of cave-dwellers, but to reach biogeographical conclusions... These biogeographical studies, so important due to their impact on paleogeography and phylogeny, cannot be attempted without having a good classification at one's disposal. However, a «good» classification must be natural, based on the real relatedness of animals, and furthermore, the hierarchy of its various taxonomic categories must be established in such a way that all categories of the same name are strictly equivalent".

RACOVITZA (1912, p. 206) commented: "the task of taxonomists is clear if they want to take part in this renewal, if they want to contribute to the immense work that is being prepared. Above all, they must establish the exact filiation of the forms they study.

Distinguishing species is no longer enough; it is necessary to rediscover homogeneous lineages and reconstruct their geological history". He continues (p. 207–208): "Setting the limits of species through diagnoses, then grouping species by lineages, and distributing these lineages into hierarchically organised categories based on the historical distances that separate them from the common trunk is the

primary task that the modern taxonomist must undertake. Therefore, the starting point is the species, the taxonomic unit *par excellence*".

2.5. THE IMPORTANCE OF GEOGRAPHICAL AND ECOLOGICAL ISOLATION FOR THE ORIGIN AND EVOLUTION OF SPECIES

RACOVITZA (1912, p. 208) stressed out that "for there to be subdivision of lineages, and therefore speciation, some form of isolation is essential but not sufficient. Morphological differentiation is a fatal consequence of isolation. A colony that isolates itself and will evolve independently of others introduces a new factor into the history of the world. Given these premises, the conclusion will be that the definition of a species as a taxonomic unit can only be *an isolated colony of consanguineous individuals*".

Racovitza appreciated the work of his disciple and collaborator René Jeannel, highlighting the effectiveness of the method he used, namely tracking the overlap of the succession of morphological and paleogeographic phenomena along homogeneous lineages in time and space. Racovitza emphasized the necessity of studying the history of morphological transformations and geographic distribution along homogeneous phylogenetic lineages and not through the biogeographical study of large heterogeneous groups.

2.6. THE CHOICE OF MORPHOLOGIC CHARACTERS AS DIAGNOSTIC TRAITS FOR AN EFFECTIVE TAXONOMY

Another aspect upon which Racovitza insisted is the way one has to examine and to further use the morphologic characters for species definition. In his monograph dealing with crustacean Monolistrini, RACOVITZA (1910, p. 632–633) considers as an important aspect of taxonomy the necessity to "examine the taxonomic characters of the group from the standpoint of their history and phylogenetic significance to achieve a precise understanding of their classification... It is thus necessary to examine the particular history of each character". Additionally, in the same publication (p. 637), he mentions that "the characters of species must also be grouped into characters of filiation and characters of adaptation.

Moreover, they must be ranked according to their relative antiquity and the role they play in the biology of each form. Only then can a truly *natural* classification be established."

Additionally, Racovitza drew attention to the frequency of cases of parallelism and convergence and the danger of using such characters in taxonomy. For instance, considering the Monolistrini, cited above, he mentioned (RACOVITZA, 1910, p. 707) that "cases of parallelism and convergence are more frequent than one might think. Many, I would say most, of the characters used in current systematics are similar characters of parallel evolution or convergence, and not characters of filiation, which are the only ones that can be used to establish natural classifications".

3. CONCLUDING DISCUSION – WHAT ONE CAN LEARN FROM RACOVITZA'S IDEAS AND ACHIEVEMENTS?

1. The program of research proposed by RACOVITZA (1907) in his *Essay* represents a change of paradigm compared to the previous situation where subterranean biota were poorly morphologically and biologically characterised.

2. Taxonomy and systematics of cavernicolous fauna represent one of the major aspects within the development of modern biospeleology proposed by Racovitza.

3. A new style for taxonomic descriptions based on detailed and accurate morphological descriptions, represented progress for the documentation of subterranean biodiversity. This approach contributed to the development of a solid biospeleology on which new aspects of research as those related to evolutionary biology could be articulated.

4. Some of Racovitza's concepts and methods of study were anticipatory to those similar approaches commonly used nowadays. For example, the analysis of morphological traits of species for reconstruction of phylogenetic lineages, an approach now known as Phylogenetic Method of Hennig. The definition of the species as an "isolated colony of consanguineous individuals" is nowadays known as "cohesion species-concept" or "genotypic cluster".

5. The methods of taxonomic research proposed by Racovitza merit adoption for the scientific education of a new generation of biospeleologists.

6. A cooperative ethos necessary to distribute information on the biodiversity of cave fauna, within a coherent scientific structure named *Biospeologica* by Racovitza, remains a positive factor for the future advancement of biospeleology.

7. The biodiversity studies of Racovitza based on the description of relict fauna documents the richness of this fauna as well as its originality when integrated within world biodiversity. This view differs from the claim that our knowledge on the richness of cave fauna is largely impeded nowadays due to the methods of study and the structure of the karst systems.

8. One of us (IGT) in a speech delivered at the scientific session of the Romanian Academy dedicated to Racovitza on the occasion of his 150th birth anniversary offered the following statement (TABACARU, 2019, p. 21): "I can affirm with certainty that in approaching the study of Isopods, I learned from Racovitza's work – starting from how to collect and preserve Isopods, how to dissect, prepare, examine, and illustrate the structures of an Isopod, how to describe a species, and, most importantly, the purpose of these research endeavors. I learned from Racovitza how to reconstruct the history of morphological evolution of these beings, their adaptation to the environment, and their distribution. I learned from Racovitza that troglobiont species are, for the most part, relics of special phylogenetic and biogeographic significance".

Finally, we should mention the point made by Professor Constantin Motaş, one of the illustrious Romanian biologists who in 1948 was elected in the place of Emile G. Racovitza at the Romanian Academy. Motaş mentioned to one of us (IGT) that the most beautiful tribute that one can pay to a scientist is to continue his

work. This message applies very well to our contribution to keep alive the memory of EMILE G. RACOVITZA.

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