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ORIGINAL PAPERS

Ecology as a Systemic Science

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Abstract. *The work discusses the two revolutions which took place in the study of the living world, both caused by a change of vision concerning the way this world is organized. The first revolution started when scientists became aware of the fact that organisms were not isolated, but lived in communities occupying a nonliving environment. The second revolution came with the recognition of the organization of life in systems of different sizes, integrated one in another, into a hierarchy which comprises them all. The place and the role of ecology in this hierarchy are specified; a definition of ecology, consistent with the systemic approach, is proposed.*

Keywords: revolutions in the study of the living world, ecology as a science of the hierarchy of living systems.

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1. Introduction

According to Thomas Kuhn [62], scientific progress is achieved by: A – long periods of "normal science", characterized by an accumulation of data and by the establishment of paradigms (more or less accepted by the scientific community), and B – revolutionary periods, when, in a certain scientific field, new insights concerning phenomena occur; consequently, paradigms are reconsidered and are replaced by new ones.

This cyclicity is applicable to sciences concerning the living world, too. The fact is obvious when considering the development of one of these sciences – ecology.

Ecology has a long history. Observations regarding the non-living environment inhabited by plants and animals go back to the XVIIIth century (Linné 1739, Buffon 1767, E. Darwin, 1794 [in 69].

Since the beginning of the XIXth century, all sylviculture treatises and textbooks of silvical botanic contained descriptions concerning the non-living environments naturally inhabited by woody species [19], [48], [54]. Even in Romania, a work on silvical botanic describing the relations of 60 woody species with the soil, the light, the heat, with precipitations and winds was published [4]. The same goes for agronomy, hydrobiology etc.

Naturalists participating in the great expeditions of investigating the continents collected and published a huge amount of data concerning the adaptation of plants and animals to different factors such as climate, soil, continental and marine water [21], [53].

But it was only in the second half of the XIXth century that ecology was defined as the science of the relations between organisms and their surrounding environment [47] [12)]. Basically, this definition is correct, but it is too general, taking into account that the relations between organisms exist in all forms of life, although they manifest themselves through different structures and processes.

For almost a century, ecology strongly developed on the side of autecology, since it was considered a biological science: emphasis was put on establishing the ecological adaptations of species and on describing the environmental conditions they live in. Many detailed works, as well as textbooks [16], [36], [59], [72], [76], [78], [83], were published. Most key books for plants and animals, as well as treatises concerning flora and fauna contained data on the relations of species with climate, soil, living places – but only as complements to taxonomic aspects. Nevertheless, a series of works dealing with the significance of plants as environmental indicators have also been published [20], [30], [34], [61], [82],

Towards the end of the XIXth century, the first ideas regarding the life of species as part of communities [40] appeared, and even a definition of the biocenosis was advanced [68].

At the beginning of the XXth century, the first revolution concerning ecology occurred, with the defining of the forest as an association between different species and the non-living environment they occupy and utilize [71]. It is asserted that « We must understand that a forest is, essentially, not only a community of woody plants bonded by reciprocal relations, but also this environment, this arena in which special processes take place, processes that we assemble, as in a focal point, in the concept of **forest ».** And, detailing, the author adds : « … all the aspects of life in a forest, the living and dead character of soil, the act of fructifying and the regeneration, the resistance to threats caused by animals, by parasites, the living cover, the blanket of moss, all are under the iron reign of the

[1] It is amazing how inspired E. Haeckel was when choosing for the new science the term « ecology », for the prefix eco derives from the Greek word oikos, meaning ambiance, home/house, household, living place – in which, in his opinion, organisms lived and interacted.

local surrounding environment, meaning the geographical environmental conditions [71].

This is already the concept of ecosystem, which will be later named so by A. Tansley [88].

A new vision on the way living world is organized and functions – through communities of organisms (species) associated in a non-living environment they interact with – appeared. A new direction in the ecological research was born – synecology.

Almost at the same time, another form of collective existence of life was identified – the population, as « a group of organisms from the same species, populating a biocenosis » [32] ; consequently, another direction in the study of ecology was initiated, demecology.

Yet, it was ascertained that this unit participates not only in ecological processes: within it, genetic processes also occur – reproduction, adaptation, evolution of species (hence, of biocenoses). Consequently to the incessant increase of the importance of genetical research, in this science, too, a new direction apeared – ecological genetics [39].

Regarding synecology, botanists and zoologists worked at first independently, identifying plant [14], [17], [22] or animal [2], [36], [84], associations. Soon, the complex study of biocenoses – including all their living components and, implicitly, the correlation between these components and their environment – started [1], [37], [38], [50], [55], [66], [74], [86], [87], [94].

In the years that followed, very many works, treatises and textbooks on populations, biocenoses and ecosystems were published. Great research programs were carried out, both at a national and an international level (e.g., The International Biological Program) [35].

Meanwhile, geographical studies regarding spatial units consisting of biocenoses (ecosystems) were initiated. Landscape science was born [89].

Data on bioregions, biozones, the biosphere, as well as on their non-living environments, were also published [52], [65], [77], [92], 93].

About the middle of the XXth century, L. von Bertalanffy formulated the theory of systems, according to which the whole Universe consists of systems – ensembles of interacting elements [8], [9]. By applying this theory to the living world, an entirely different insight – a more complex and complicated one – regarding the way this world is organized appeared. For the first time, living world was considered a a whole, consisting of systems which are organized on several levels and integrate one into the other. The author of the theory himself affirmed : « We found in nature a tremendous architecture in which subordinate systems are united, at subsequent levels, in increasingly superior and large systems » [9]. As a biologist, L. von Bertalanffy launched his systems theory based precisely on biological aspects, although this theory expanded subsequently to many other sciences.

This was at that moment when the second great scientific revolution took place, not only in ecology, but in all sciences dealing with the living world. As a result, the entire knowledge and edifice of sciences had to be reconsidered and set on systemic coordinates.

When considering the spheres and the forms of the living world which were studied until the theory of systems appeared, one can see that, basically, the sciences of life were naturally oriented, from the start, towards the main categories of systems : « classical » biology on individual systems (organisms), ecology on communities (species, populations, biocenoses), biogeography on space units of different sizes (bio landscapes, bioregions, biozones, the biosphere).

This means that the huge amount of data on the living world accumulated by these sciences can be utilized – with the necessary corrections – in the new systemic vision. Yet, sciences will have to be delimited with more precision, some concepts regarded as paradigms will have to be reconsidered and changes in the research methods will have to be made. As a consequence, even the definitions of these sciences will have to be reformulated. This is valid for ecology, too.

Elements for differentiating ecology as a systemic science

In order to define ecology as a systemic science, it is necessary to establish its field of activity within the hierarchy of living systems, the systems it is dealing with, the structure and the specific processes of these systems, as well as their role in the hierarchy. Attention must also be paid to the current definitions and to the relations between the systems in question. Such an endeavor has been undertaken after the Romanian ecologist N. Botnariuc [12] stated that living systems belonging to each level of organization have specific structures and functions and must be approached as distinct units.

In several previous works, we made clarifications regarding the systemic units belonging to the multi-individual levels of organization. When analyzing the way populations, species and biocenoses were defined, one can notice that, in many cases, an important fact was ignored : this units are not only genetical, but also ecological and they interact within a biocenosis and in its non-living environment, ensuring the existence of life, not only its perpetuation and evolution [28].

The special part played by the biocenosis and its non-living environment (i.e., the part of the ecosystem) in the hierarchy of living systems has been emphasized [26].

The multi individual systemic units (the population, the species and the biocenosis, as well as their habitat (hence, the ecosystem) [27] have been characterized and a new form of hierarchy of the living systems was advanced. [25].

Current definitions of ecology

In the current definitions of ecology, the diversity of opinions is as considerable as in the case of the population and the species [28] or in the way the hierarchy of living systems is conceived [25].

The initial definition proposed by the creator of ecology [47] is found in many previous works – and, surprisingly so, in current ones, in a simplified form: “ *the science of the relations between organisms and their environment* [15], [18], [24], [33], [43], [73], [85].

But even since the previous century, attention was drawn on the fact that in this definition the topic of ecology is not specified and that, practically, its application area is unlimited (Richards 1939, Oosting 1948, Egler 1951] [3]. These remarks are accurate: the definition does not specify the living units and the processes ecology deals with.

When a more thorough study of populations and biocenoses (as well as of their environment) began, and the processes ecology is dealing with were specified, ecology was defined as the science of ecosystems [6], [23], [30], [66], [57], [74], [94]. Consequently, the field of ecology was restricted to the study of pluri-individual living systems and their environment. But it was not taken into account that ecology is not the only science dealing with ecosystems and that genetics studies genetical processes, which occur in ecosystems, too.

After the theory of systems was applied to the living world, it was considered that ecology was dealing with all the supra-individual levels of organization. [11], [13], [44], [45], [56], [58], [64], [67], [70], [74], [91]. Once more, the field of ecology expanded [81], since scientists seemed to ignore the fact that, at each level of organization, living systems have different structures and that functional sciences dealing with these levels existed already for a long time [5], [41], [49], [65], [77], [90],

Some definitions refer to the distribution and the abundance of organisms [60] ; others are rather vague and concern mainly the philosophy of biology [42].

Some authors still consider that ecology is a branch of biology [10], [24]. But contrary opinions are also advanced [46].

It is obvious that, until now, no consensus has been reached regarding the field of ecology, the units within the hierarchy of living systems and the processes it deals with.

Yet, it is worth noting that, as a rule, the current definitions make no mention of the processes ecology is dealing with – ecological processes which ensure the ongoing of life, not only within populations, species or biocenoses, but in all living systems.

The research field of ecology in the hierarchy of living systems

We established this field based on a general systemic paradigm formulated by N. Botnariuc [12]:

"The systems within each level of organization have their own structural and functional features, their own internal interactions and contradictions which result in the occurrence of emerging characteristics, specific to the given level".

According to this paradigm, each level of organization within the hierarchy of living systems must make the object of a distinct science, given the multitude of aspects specific to systems within a given level. For, according to Thomas Kuhn [62], science means the study of structures and processes of an increasingly individualized phenomenon. And, in conformity to the above mentioned paradigm, the systems belonging to each level are well individualized.

The difficulty consists in the fact that no consensus have yet been reached regarding the organization levels within the hierarchy of living systems and the systems included in each level. There are many heterogenous, inconsistent propositions, mentioning, beside living systems, mixed living-non living ones (ecosystems, landscapes) or parts of systems (atoms, molecules, tissues, organs and organ systems) [25].

A hierarchy concerning solely living systems has therefore been proposed, consisting of eight organisation levels, each one including a single system: three individual levels (prokaryotic unicellular organisms, eukaryotic unicellular organisms, eukaryotic pluricellular organisms), one multi individual level (communities of organisms – biocenoses consisting of populations belonging to several species with different ecological functions) and four levels containing spatial (multicenotic) systems : bio landscapes, bioregions, biozones and the biosphere [25], [29].

After the first revolution in ecology took place, research was oriented towards synecology – the study of biocenoses and species, of populations and their environment – and strongly developed in this field. This natural, systemic orientation must be maintained. Ecology has to remain the science of systemic units included in the multi individual level of organization (the species, the biocenosis and the population), but only taking into account their permanent correlation with the non-living environment. The amount of research regarding this level is so large that it is neither appropriate nor effective for ecologists to study systems belonging to other levels.

Systemic units belonging to the multi individual organization level as research topics in ecology

The systemic units included in the multi individual organization level are the species and the biocenosis, as well as their common subsystem, the population.

Throughout the evolution of the living world, the first to appear were the individual systems – the organisms – which had two basic functions : metabolism (responsible for the maintenance of life) and reproduction (resulting in the perpetuation of life). The number of organisms increasing, the first multi individual systemic units – populations and species – emerged.

Yet, since the very first stages of evolution, the adaptive ecological differentiation (both structural and physiological) of organisms, populations and species started: they became producers and consumers of biomass, or decomposers of necro mass [12]. Since organism, after their differentiation, could no more live separately, but only integrated in biocenoses (moreover, needing a space large enough to contain them all), ecosystems developed, as mixed – living and non-living – systems. Within ecosystems, the ecological process of production and consumption of biomass, as well as consumption and decomposition of necro mass, was generated, as an emerging, mass phenomenon. This process was the consequence of the relations within and between the populations included in the biocenosis, as well as their relations with the non-living environment; it ensures, from both the energetic and material points of view, the antientropic existence of all living systems.

The ecosystem is also the place where, simultaneously (and in correlation with this process), genetical processes occur at the populational level.

The living cover of the planet – the biosphere – consisted (and still does) of biocenoses, as pluri-individual systems, within which the other two systemic units (the species, via its populations) are integrated.

Biocenoses and their environment will remain the main research topic of ecology, regarding the emerging ecological structures and functions which ensure the existence of all living systems. Yet, the study of adaptations, of the ecological structures and functions specific to each population (hence, to the species they belong to) is equally important.

Genetical processes of populations included in ecosystems will be also sudied, but by another science – genetics.

The special role of the biocenosis in the hierarchy of living systems

The biocenoses, as a living open system, needs an environment, large enough to allow the association of many ecologically differentiated populations and to provide the energy and matter these populations need.

The biocenosis is the first living system to have such an environment, with which it interacts within the ecosystem.

As we showed in a recent work [26], individual living systems – organisms – acquire a non-living environment only within an ecosystem, via their populations (which constitute the biocenosis); here, they participate in the necessary, emerging ecological process ensuring their existence. Living systems superior to biocenoses (bio landscapes, bioregions, biozones and the biosphere), consisting of territorial ensembles of biocenoses of different sizes, exist on account of the energy and matter provided by the composing biocenoses.

Consequently, the whole hierarchy of living systems depend on the ecological processes taking place within biocenoses and their non-living environment, i.e., within the multi individual level of this hierarchy.

A possible definition of ecology as a systemic science

Considering the above-mentioned reasons, the following definition of ecology as a systemic science may be formulated:

Ecology is the science which studies systemic units belonging to the multi individual level of organization within the hierarchy of living systems – the population, the species and the biocenosis, in correlation with their non-living environment (hence, in ecosystems) and the adaptations, the structures and the ecological processes –production and consumption of biomass, consumption and decomposition of necro mass – which ensure the energy and the vital elements necessary to the antientropic existence of all living systems.

The definition mentions the sphere of activity of ecology – the systemic units it deals with, the specific aspects and the functional and interacting (livig-non living) processes within these units, as well as the result of these processes.

A more simple definition would be:

Ecology is the science which studies the adaptations, the structures and the ecological processes of the multi individual systemic units – population, species *and biocenosis, in correlation with their non-living environment (i.e., within ecosystems).*

Is ecology a branch of biology?

Taking into account the paradigm regarding the structural and functional specificity of systems belonging to each level of organization within the hierarchy of living systems, each level must be the field of a distinct science. This is also the case of ecology, which studies the systems belonging to the multi-individual level, unlike biology, which deals with systems belonging to the individual level (organisms) and biogeography, concerned by systems within the spatial organization levels (Fig. 1).

Conclusions

Two revolutions took place in the study of the living world: the first one, when the study of organisms was followed by the study of communities, and the second one, when living world started to be considered as a hierarchy of several organization levels, consisting of dissimilar systems (both in their structure and their functions).

The work brings forward arguments that, in this hierarchy, the research topic of ecology must consist in the systems included in the multi-individual level of organization – the biocenosis, the species and their common subsystem, the population – as well as their non-living environment, but only with regard to structures, adaptations and ecological processes ensuring the maintenance of all living systems, as well energetically as materially.

We also advance an appropriate definition of ecology as a systemic, well individualized science, which deals with the level of systemic organization of the living world through which the survival of this world – including human society – is ensured, both energetically and materially.

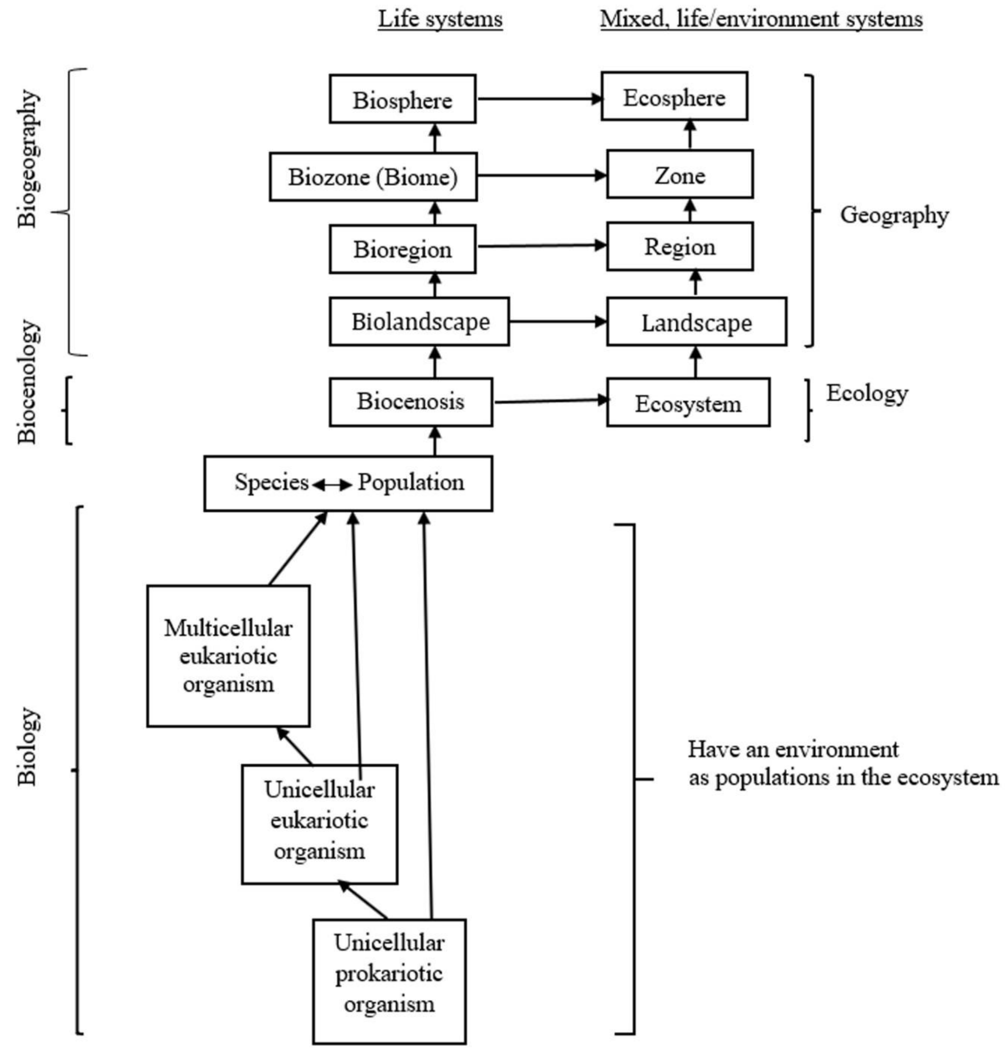

Fig. 1 - The hierarchy of living systems and the hierarchy of mixed (living and non-living) systems actually occurring in nature.

<u>Explanation</u>

The hierarchy of living systems comprises eight levels of organization: three are individual ones (the prokaryotic unicellular one, the eukaryotic unicellular and the eukaryotic multicellular one); one level is multi individual, having two systems: the biocenosis, composed by the populations of the other system (the species); four levels are spatial, multicoenotic ones: the bio landscape, the bioregion, the biozone and the biosphere, all composed by ensembles of different types of biocenoses.

The hierarchy of the mixed systems comprises only five organization levels, since the individual systems come into contact with the non-living environment only after they are integrated in the biocenoses occurring in such environments (i.e., in ecosystems).

The way systems are integrated one into the other is indicated by arrows. Some remarks:

- the unicellular individual systems may be integrated in the biocenosis after they integrate one into the other or directly, through their populations;

- at the multi individual organization level, the populations – as subsystems – are forming, on the one hand, the species – and species are forming the biocenosis, through the same populations.

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