The contribution of Nicolae Botnariuc to evolutionary biology using systems theory

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Early this year, the Romanian Academy commemorated the centennial birthday of the evolutionary biologist Nicolae Botnariuc (1915-03-13–2011-03-01; Fig. 1). The scientific contribution of Botnariuc has been well recognized within the Romanian community of biologists which fostered influential personalities like Emil G. Racovitza, Constantin Motas¸, and Radu Codreanu (cf. Iftimovici 1977; Negrea 2007). However, many aspects of Botnariuc’s scientific achievements remain largely unknown beyond the Romanian academic space, likely owing to publications with a restricted international distribution — at the time the academic space of Eastern Europe was still constrained ideologically.

Nicolae Botnariuc was a natural historian, with a long career in zoology, ecology, and evolutionary biology. He joined the Department of Biology at the University of Bucharest in 1948 where he served as the head of department for more than 30 years. Botnariuc served also as the editor of the series of academic volumes Romania’s Fauna, an important contribution to the documentation of the biological diversity of fauna in Eastern Europe that resulted in 78 volumes. In 1991 Botnariuc became a member of the Romanian Academy. Over three decades of research and teaching, many generations of students were inspired by the clarity of his lectures, advanced ideas, and generous nature. Botnariuc introduced his students to the evolutionary theory and the systems theory in general biology while extending a strong appreciation for natural history and the history of biology (Negrea and Negrea 2008). He published more than 150 research articles along with a series of seminal books. His first book, printed in 1961 (Botnariuc 1961), portrayed a detailed and attractive history of biology that inspired many generations of students. This early publication was followed by several books (Botnariuc 1967, 1976, 1992, 2003a) in which Botnariuc adopted the general systems theory of Ludwig von Bertalanffy (von Bertalanffy 1932, 1950a, 1950b, 1968) and explored its applications to the evolutionary theory rooted in the neo-darwinian concepts. Botnariuc adopted the view of nature being organised in systems, with each system being formed by a multitude of interconnected parts and having emergent properties that differ from those of the constituent subunits. However, mid-career Botnariuc started reviewing critically the hierarchical systems proposed and debated at the time (e.g., Dice 1955; Odum 1959; Eldredge 1985; Mayr 1998) and recognized the diversity of ideas and the need for a clear definition of the notion of organizational level. In his books, Principles of biology (1967) and later in Systemic conception in general biology (1976), Botnariuc considered that living matter is structured in a series of interactive units forming hierarchical biological systems. For Botnariuc “a level of living matter organization is the assembly of equivalent biological systems, with a character of universality, able to have an independent existence” (Botnariuc 2003b,
Fig. 2. Botnariuc’s view of the hierarchical relationships in the living world (diagram adapted from Botnariuc 2003a, 2003b).

Botnariuc’s interest in the hierarchic organization of the living matter (inter alia, Botnariuc 1985, 2005, 2006, 2008, 2010) is related to the ecological problems of species as systems organized at various level of complexity. His proposed triplet of hierarchies, namely somatic hierarchy, organizational (or systemic) hierarchy, and taxonomic hierarchy (Fig. 2) are interesting for several reasons. First, the somatic hierarchy is the domain that facilitates the exploration of the structure and the functioning of the biological components, which by their relationships generate the living organism. The population, as the next level of the supra-individual hierarchy, is the key component in the organizational hierarchy, because it generates what we call evolutionary changes, as emergent trait, leading to new species. In Botnariuc’s work, the bioocoenosis, the biome, and the global biosphere are hierarchic systems of higher order within which species diversity plays an important role for maintaining the biological systems far from thermodynamic equilibrium. The subindividual somatic hierarchy is naturally coupled to the supra-individual organizational hierarchy. In this way, the examination of the evolutionary processes starts with the subcellular units, such as the genome, and culminates with the examination of the planetary diversity of organisms.

Botnariuc (2003a, 2003b) was deeply interested in the problem of species and considered that species can be viewed not only as taxonomic units belonging to a taxonomic hierarchy but also as biological components of the organizational (i.e., systemic) hierarchy of the living matter (Fig. 2). He noted often that the species represents the only entity that is both taxon and system. Moreover, he acknowledged that phenotypic variation underlined by corresponding genetic variation at the population level represents the material of predilection on which selection operates because “evolution is best understood as the genetic turnover of the individuals in every population from generation to generation” (Mayr 2001, p. 76).

However, Botnariuc (2003a, 2003b) was concerned with the evolution of all biological systems, and discussed in depth the higher systems that are difficult to study using a strict reductionist approach. His proposed definition for evolution — trait of a system — “the process of transformation and diversification (emergence of new entities) of the biological systems, process whose general cause is the development of intrasystemic relations (between subsystems), on the background of the interaction with the biotic and abiotic environmental systems” provided a useful conceptual framework for investigating the evolutionary process across a hierarchical biological system (cf. Botnariuc 2003b, p. 538). The species (population) is an entity with cybernetic properties and with emergent organismic traits due to the action of external and internal selection pressures. These characteristics are visible to sexual species, which form the basis for the Darwinian concept of “variational model of change” (cf. Lewontin 2000), but also in populations or species with asexual reproduction. Botnariuc (1967, p. 226–227) noted that “in agamous species the...
wholeness of populations is a result of the clonal polymorphism”. Selection, “acts in the sense of elaboration and maintenance of the most advantageous clonal composition of the population”. This treatment of species as system entity unites in one definition, populations with sexual and asexual reproduction.

Botnariuc (2003b) followed closely the early ideas on hierarchical interactions proposed by Wilson (1989), Wilson and Sober (1994), and re-evaluated by Gould and Lloyd (1999) to describe natural selection as a multi-level process acting at the organismic level, at the population level, and at interspecific level, within ecosystems. However, similar views of hierarchical interactions are found in his early publications (e.g., Botnariuc 1967, 1976) that preceded many of the seminal contributions of his time. Additionally, he emphasized that natural selection, as an ecosystemic process, can act on the population either bottom-up or top-down within the systemic hierarchy of the living matter (cf. Botnariuc 2003a, p. 214). Further on, Botnariuc (2005, 2006, 2008) considered that species diversity plays an important role for the transformation of energy and the circulation of matter through different compartments of the biosphere, maintaining these components far from a thermodynamic equilibrium.

Four major biological events were considered by Botnariuc (2008) to represent ecological revolutions that allowed the rise of the biological diversity in the biosphere: the appearance of oxygenic photosynthesis, the appearance of the unicellular eukariotes and sexual reproduction, the radiation of metazoans, and finally the diversification of terrestrial plants and animals, especially the insects. Botnariuc also suggested that the expansion of human activities during the Anthropocene imposed in many parts of the world a strong pressure on the biodiversity, with a possible negative effect of turning the biosphere towards a thermodynamic equilibrium. His conservation efforts have remained extensive and meritorious throughout his academic career (cf. Tatole 2005).

The two major topics in Botnariuc’s publications, namely the characterization of species as systems entity (cf. Botnariuc 1967, 1976) and the development of a model for the hierarchical organization of living matter (cf. Botnariuc 1985, 1992, 2003a, 2003b), have particular significance for current progress and research trends in molecular biology as well as evolutionary biology. During recent years, molecular biology research has expanded into systems biology and has experienced a rapid transition from the common reductionist view towards a more holistic one (Westerhoff and Palsson 2004; Bruggeman and Westerhoff 2007). The attention has been placed heavily on understanding the functions of the cell or organism as a whole system rather than characterizing their isolated parts. This includes understanding the structure of the system (networks of gene interactions and biochemical pathways) as well as the dynamics of the system, the way the systems behave and evolve over time. In a similar manner, the rapidly growing field of evolutionary systems biology (ESB) integrates methods from evolutionary biology and system biology. The field has the central goal of understanding the genotype–phenotype relationships at multiple levels of organizational hierarchy (Soyer and O’Malley 2013). For example, ecological genomics techniques are suitable for multi-level selection studies carried out within diverse hierarchical systems (cf. ideas of Okasha 2011). Moreover, biological complexity and the corresponding ecological setting can be inferred through the evaluation of the amount of genomic information (genomics, metagenomics), as genes embody information on organisms and their environment (Adami et al. 2000; Saylor et al. 2013). There are new philosophical aspects and challenges related to the need to integrate data from various “omics” at various levels of organization (cf. Dupré 2004; O’Malley and Dupré 2005; O’Malley et al. 2014, 2015).

In his last publications, Botnariuc (2006, 2008, 2010) proposed an important message: the need for investigation at various scales of the complex biosphere, to understand the evolutionary forces that shape biodiversity, and to find effective solutions to the protection of the amazing diversity of life forms. His proposal focussed towards our ethical mission of transdisciplinary approach to cooperate and further to coordinate the human efforts for maintaining the biosphere far from a thermodynamic equilibrium.

References