

Article

Coevolution: A synergy in biology and ecology

WenJun Zhang¹, GuangHua Liu²

¹School of Life Sciences, Sun Yat-sen University, Guangzhou, China; International Academy of Ecology and Environmental Sciences, Hong Kong

²Guangdong AIB Polytech College, Guangzhou 510507, China

E-mail: zhwj@mail.sysu.edu.cn, ghliu@gdaib.edu.cn

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Abstract

Synergy refers to that in an open and complex system consisting of a large number of subsystems, far from equilibrium, its subsystems interact in a nonlinear way to produce synergistic effects and thus make the system generate a self-organization structure in space/time with certain functions. Biologists and ecologists, tend to use coevolution/coadaptation to represent the terminology “synergy”. Coevolution and research methodology were briefly discussed in present paper.

Keywords synergy; coevolution; coadaptation.

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1 Introduction

Synergy refers to that in an open and complex system, made of a large number of subsystems, far from equilibrium, and having matter and energy exchange with outside the system, its subsystems interact in a nonlinear way to produce coherent and synergistic effects and thus make the system generate a self-organization structure in space/time with certain functions. Due to both fierce competition and close synergy between populations in the same environment populations, synergetics can and has been used in ecology and biology (Haken, 1978, 1983, 2004; Bjumenefld, 1985). Between-species ecological interactions can be divided into three cases, competition, predation/parasitization, and symbiosis. Each of the three interactions must maintain a dynamic equilibrium in order to adapt the environment. Applying synergetics to biological morphology, the morphogenesis is interpreted as that the diffusion and reaction of certain chemical substances form a so-called morphological source field. Morphological source field governs genes to control cell differentiation, thus forms the organism.

2 Synergy and Competition

In his book, *The Origin of Species*, Darwin (1911) first used the terminology “competition”, and considered

competition as part of the struggle for existence. Since Darwin, many biologists believed that the struggle for existence had promoted the biological evolution under natural selection. Integrating various definitions of biological competition (Begon et al., 1994; Grime 1997), we may consider the competition as the between-individual or between-population negative interaction due to resource constraints. In ecology and biology, synergy refers to mutual collaboration and mutual adaptation either between organisms or between organisms and the environment. Compared to competition, synergy enables organisms to exist and reproduce at the minimum cost (i.e., maximum fitness). Synergy and competition can mutually transform under certain conditions, which helps to enhance the self-organization, orderly and biodiversity of ecosystems. Competitors try to reduce niche overlap and adapt to the evolution, which is called disruptive coevolution (Wilson and Lee, 1994). Generally, biologists and ecologists, tend to use coevolution/coadaptation to represent the terminology “synergy” (Williams 1992).

3 Coevolution

3.1 Coevolution

The terminology “coevolution” was first proposed by Ehrlich and Raven (1964) in their research on mutual influence between plants and herbivorous insects in the evolution. Hereafter, Roughgarden (1979) defined coevolution as the simultaneous evolution of multiple interactive species. Jazen (1980) defined coevolution as that the traits of a species evolve as a reaction to the evolution of the traits of another species, and vice versa. The definition considers the specialty, mutuality and simultaneity, and is thus called pairwise coevolution. However, the pairwise coevolution is only found in certain pairs of symbiotic, parasitic or competitive species, for example, mimicry in butterflies, insect and flowering plants/pollinating insects, etc. Contrary to pairwise coevolution, the diffuse coevolution is most widely used and is usually equivalent to the evolution. Diffuse coevolution is defined as a mutual evolution that the traits of one or more species evolve under the influence of the traits of other multiple species (Futuyma and Slatkin, 1983). Different from pairwise coevolution, the diffuse coevolution does not meet simultaneity.

In a broad sense, coevolution refers to the mutual dependence between species and between species and the environment in the evolution (Luo and Zhang, 2014). Compared to Darwin’s theory, coevolution stresses the between-species interactions and the adaptation of species to their biological environments rather than physical environments. Coevolution occurs at the molecular/ /cellular/individual/population/ecosystem levels. However at the population level is the focus. Organisms have certain ecological investment strategies in the growth process. A large number of experiments have shown that each of the energy investment strategies are trade-off among ecological costs (Stinchcombe, 2002; Strauss et al., 2002), i.e., an increase of an ecological cost means the decrease of another ecological cost. For example, a great energy cost in reproduction and growth, which enhances the organism’s competitiveness, may lead to no more energy used to withstand adverse environment, and the organism’s ability to escape predators will be reduced. Pursuing excessive energy cost will lead to degradation of the entire species. As a consequence, coevolution/coadaptation becomes a realistic evolutionary strategy. Establishment of biological communities and ecosystems is the result of coevolution of species-species and species-environment. Interactions and coevolution of animals, plants and microorganisms maintain the stability and functions of the ecosystems.

3.2 Research methodology of coevolution

There are various types of synergies/coevolution, e.g., the large scale synergy, threshold effect, functional complementation, integrated environmental conditions, risk/cost ratio, information sharing, swarm intelligence, symbiosis, and complex divisions of works in biological systems. Most of synergies can be measured and quantified, and most of them are directly concerned with the survival and reproduction (Corning, 2014). The

following briefly describes some research methodology of coevolution.

(1) Make a long-term observation to some of the traits possibly caused by coevolution between species to investigate the relationship between genetic variation, for example, Pimentel's study on housefly-parasitoid relationship, and Barertt's study on pathogen virulence and plant resistance (Futuyma and Slatkin, 1983). This method is appropriate for two species with pairwise coevolution.

(2) Use historical fossils and written material to analyze the long-term evolution of species, and to speculate the possibility of producing coevolution. This is a method often used by paleontologists. These data can be used to analyze the reasons for massive extinction of species. We can also reconstruct the ancient climate change through some biological residual material (such as phytoliths).

(3) Use phylogenetic methods to study the long-term evolutionary process of species. This method is mainly used to research of coevolution between insects and plants.

(4) Make in-depth research on the physical structure, morphology, as well as some behaviors of species to reveal potential coevolution. This helps to understand the mechanism of behavioral responses between coevolved species.

(5) Study of the mutual adaptive behaviors between geographical populations and biological habitats in different environments helps to explain the coevolution between organisms and the environment. For example, similar geographical environments or habitats will usually produce the communities with similar species composition and structure.

(6) Develop ecological models to approach between-species coevolution and draw biological interpretations. Interspecific competition models, predator-prey models, etc, are most often used.

(7) Explore the changes of different trophic levels between species in the community. This helps to reveal the mechanism of coevolution in maintaining the community stability.

Corning (2014) summarized four categories of experiments to study the biological synergy: (1) removal test. Remove some parts from a system and observe the changes of the system; (2) biological econometric method. Under different situations, calculate the cost/benefit of changing an adaptive trait; (3) comparative experiments. This can accurately measure synergies; (4) classical ecological experiments, namely multi-factor control experiments, which consider the interactions between various factors.

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