CellPress

Review

Convergence in Multispecies Interactions

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The concepts of convergent evolution and community convergence highlight how selective pressures can shape unrelated organisms or communities in similar ways. We propose a related concept, convergent interactions, to describe the independent evolution of multispecies interactions with similar physiological or ecological functions. A focus on convergent interactions clarifies how natural selection repeatedly favors particular kinds of associations among species. Characterizing convergent interactions in a comparative context is likely to facilitate prediction of the ecological roles of organisms (including microbes) in multispecies interactions and selective pressures acting in poorly understood or newly discovered multispecies systems. We illustrate the concept of convergent interactions with examples: vertebrates and their gut bacteria; ectomycorrhizae; insect–fungal–bacterial interactions; pitcher-plant food webs; and ants and ant–plants.

Trends

We present a framework for exploring how selection shapes multispecies associations.

We provide examples of functional convergence in species interactions.

Convergent interactions can be used to predict the ecology of unknown symbioses.

Convergent interactions can help elucidate the ecological roles of microbes.

Convergence in Evolution and Ecology

The word convergence typically describes convergent evolution, the independent evolution of similar traits in different lineages resulting from strong selective pressures: '[a]nimals, belonging to two most distinct lines of descent, may readily become adapted to similar conditions, and thus assume a close external resemblance' [1]. Although convergent evolution is primarily a descriptor of morphological features of animals and plants, it can be used to describe microbes and physiological processes as well (e.g., convergent evolution of transcriptional regulation of gene circuits in bacteria and fungi; see [2]).

Convergence is also recognized in ecological assemblages; for example, in high-altitude plant communities of the Andes, Alps, and Himalayas [3]. The homogeneity of vegetation in geographically distant biomes was discussed early in the history of ecology [4,5]. The resemblance of high-altitude plant communities, or whole communities of plants, birds, and lizards in the Mediterranean climates of California, Chile, South Africa, and the Mediterranean Basin, are examples of community convergence, defined as the physiognomic similarity of assemblages of co-occurring plants or animals resulting from comparable physical and biotic selective pressures [6–8]. Community convergence focuses on community structure and functional traits but does not explicitly investigate interactions among species.

Convergent Interactions

We define convergent interactions as the independent emergence of multispecies interactions with similar physiological or ecological functions. We define ecological function as the role a species plays in an interaction, community, or ecosystem; for example, the excretion of essential amino acids by an endosymbiotic bacterium or the decomposition of dead leaves by an insect detritivore. Our definition of convergent interactions is purposefully broad and can be used to generate hypotheses about many kinds of ecological relationships. The concept might be

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especially useful when thinking about symbioses and microbes; for example, the ecology of microbial gut communities in independently evolved herbivores with similar gut morphology, including kangaroos and bighorn sheep [9]. Using convergent interactions as a framework for studying associations is likely to bring new clarity to nascent and dynamic studies of symbioses among microbes and other organisms (reviewed in [10]).

Convergent interactions are often associated with convergently evolved morphological structures and specialized morphologies can aid in the identification of ecological functions. For example, any fungus forming a 'Hartig net' within a root tip is likely to be participating in an ectomycorrhizal (ECM) mutualism with a plant [11]. Moreover, research on convergent interactions in one location can illuminate similar reciprocal selective pressures acting in analogous systems. For example, experiments with ants and ant–plants in Africa are likely to inform our understanding of independently evolved ants and ant–plants in South America or Asia, not unlike using a 'prior' in Bayesian inference.

We suggest that explicitly recognizing convergent interactions will provide a heuristic method to predict: (i) the functions of multiple associated species, such as the metabolic capacities of microbes in a herbivore gut; (ii) the ecological role of a symbiosis involving newly discovered or poorly described species, such as an ECM symbiosis recently found in a tropical habitat; and (iii) selective pressures acting in one system based on data from a different system, such as among ant–plants found on different continents. Although convergence of multispecies interactions has been implicitly discussed in recent papers (e.g., [12–14]), the concept has never before been explicitly defined or formally explored.

Situating Convergent Interactions

Our use of convergent interactions differs from current uses of convergent evolution and community convergence. Convergent evolution is defined strictly by phylogeny and concerns individual species, not interactions. By contrast, convergent interactions focus on the ecology and behaviors of multiple interacting species; moreover, the independent evolution of all of the interacting species is not required. For example, symbioses of two oak species with distantly related and independently evolved lineages of ECM fungi (e.g., truffles and boletes) can still be considered convergent although the capacity of the oaks to form ECM associations is a synapomorphy: the associated fungi evolved the ECM habit independently. Community convergence describes similarities in the distribution, diversity, and morphologies of geographically disparate sets of co-occurring species in relation to similarities of their habitats (e.g., shrubs or lizards from California and Chile [6,7]) but does not specifically address interspecific interactions. Typically, community convergence focuses on a particular guild. By contrast, convergent interactions emphasize relationships among multiple organisms and trophic levels and often across different kingdoms. In certain circumstances, convergent interactions can appear as community convergence; for example, if the mammalian gut is defined purely as a habitat and not as part of an organism. However, we think that an association among living organisms (e.g., bacteria and a human gut) will have fundamentally different evolutionary dynamics than an association of organisms with an abiotic environment (e.g., bacteria and a sewer pipe), because of the potential for coevolution.

A different framework, the geographic mosaic of coevolution, is useful for understanding how natural selection and coevolutionary processes differ among populations [15]. By contrast, convergent interactions encompass interactions among groups of different species emerging independently from different lineages and in different regions of the world (e.g., ant–plant interactions in Africa, Southeast Asia, and South America). Convergent interaction takes a broader perspective than the geographic mosaic of coevolution because it compares different groups of species across regions; however, geographic mosaics are likely to act within each group of species in a region (e.g., within Kenyan ant–plant interactions).