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On Equilibria and Feasibility of Ecological Polynomial Dynamical Systems

by

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Abstract

Explaining and predicting the behavior of ecological systems has been one of the greatest challenges in ecology. One promising route to accomplish this challenge has been based on the mathematical modeling of species abundances over time. However, finding a compromise between tractability and realism has not been easy. Functional responses in 2-species models and higher-order interactions in 3-species systems have been proposed to reconcile part of this compromise. However, it remains unclear whether this compromise can be fulfilled and extended to multispecies models. Yet, answering this question is necessary in order to differentiate whether the explanatory power of a model comes from the general form of its polynomial or from a more realistic description of multispecies systems. Nevertheless, extracting the set of conditions compatible with feasibility (i.e, the necessary conditions for coexistence or of species, stability and permanence), even at the 2-species level, remains a big mathematical challenge. Currently, there is no methodology that can provide us with a full analytical understanding about feasibility for any given model.

Here, we develop a general method to quantify the mathematical consequences of adding higher-order terms in ecological models based on the number of *free*-equilibrium points that can emerge in a system (i.e., equilibria that can be feasible or unfeasible as a function of model parameters). We characterize complexity by the number of free-equilibrium points generated by a model, which is a function of the polynomial degree and system's dimension. We show that the probability of generating a feasible system in a model is an increasing function of its complexity, regardless of the specific mechanism invoked. Our results reveal that conclusions regarding the relevance of mechanisms embedded in complex models must be evaluated in relation to the expected explanatory power of their polynomial forms. Then, we propose a general formalism to analytically obtain feasibility conditions for any population dynamics model of any dimension. From our methodology, we establish mathematically how two or more model parameters are linked—a task that is impossible to perform with simulations. By showing how feasibility can be studied as a function of a given model, we establish the partial conditions for species coexistence, moving us a step closer to the goal of systematically understanding the behavior of ecological systems.

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