Forecasting the robust transient dynamics of nonautonomous ecosystems forced by seasonal climate fluctuations

FLUCTUATIONS are of essence to sustain life: this is arguably the most general principle in biology. At the same time, the 'balance of nature' metaphor still dominates most approaches to environmental problems: from populations to ecosystems, it is generally assumed that the long-term evolution of natural systems, if unperturbed, would settle to an equilibrium with the environment. In dynamical systems theory, this is framed under the mathematical scope of autonomous differential equations. The more time one spends studying a natural system, however, the more evident it becomes that non-equilibrium, transient dynamics govern persistence. Somewhat ironically, asymptoticity vanishes in the long-term. In the current global change scenario the shifting baselines of planetary climatic conditions critically demand the adaptation of autonomous approaches to dissipative, nonautonomous ecosystems. Here, I will apply tools from nonautonomous dynamical systems theory and Bayesian inverse problems and undertake a less-transited path to explore a 'strong' version of non-equilibriumnes, namely non-asymptoticity. I will use skew-product flows fitted to time-series data to reconstruct the global dynamics of a natural competitive three-species chaotic system in which demographic rates are controlled by seasonal temperature fluctuations. In spite of the chaotic nature of the modeled system, the medium-range forecasting abilities of this new approach surpass the predictability of empirical dynamical approaches. I use the Morse-Conley theory to build the global attractor of the system as an evolving object across time: both transient and asymptotic equilibria, and their heteroclinic connections, are constantly changing and causally affecting the dynamics. Critically, the strongest predictability within the nonautonomous flow is driven nearly always by the transient, unstable equilibrium. While the dynamics is permanently transient, it is thus also robust. When equipped with a Bayesian posterior probability distribution, a new mathematical object arises from the global attractor: the nonautonomous transitor. I show that the transitor effectively encapsulates all the history of an ecosystem: the potential and realized community assembly paths, all the invasion and extinction events, and the full collection of transient and asymptotic equilibria approached by the system across time. Transient dynamics, naturally embedded in nonautonomous mathematical approaches, thus arises as a tool for better understanding and predicting natural systems in an ever-changing world.