

Abstract

This thesis delves into the emergent behaviors arising from the dynamical coupling between ecological processes and evolutionary game dilemmas. Motivated by a growing body of empirical and theoretical evidence that evolution can operate on ecological timescales, the work constructs and analyzes a suite of nonlinear dynamical models to explore how feedback between strategic behavior and ecological context shape population dynamics, cooperation, and biodiversity.

The research builds upon the foundational framework of evolutionary game theory, particularly the Prisoner's Dilemma (PD) and Snowdrift (SD) games, and systematically extends it to incorporate multigame environments, stochastic strategy mutation, ecological feedback through density-dependent variables, and time-delayed interactions. These modifications reflect the heterogeneity and complexity observed in real-world systems, where individuals encounter varying interaction contexts, behave non-deterministically, and respond to both current and past ecological pressures. A central theme is the incorporation of ecological free space as a dynamical variable influencing reproduction and dispersal, which allows the models to reflect realistic environmental constraints and resource limitations.

The first part of the thesis investigates eco-evolutionary dynamics under multigame conditions, where individuals probabilistically engage in either PD or SD games. The inclusion of mutation enables the persistence of strategy diversity, and the coupling with ecological free space reveals rich dynamical regimes, including multiple stable states and coexistence zones. Building upon this, the second part introduces time delays in ecological feedback, showing that temporal lags in payoff realization can induce Hopf bifurcations and oscillatory dynamics, significantly altering cooperation patterns. These analyses demonstrate how the timing of ecological responses is as critical as their magnitude in determining system stability.

In the third section, the thesis examines systems governed by cyclic dominance, particularly inspired by the rock-paper-scissors (RPS) dilemma, modeling the eco-evolutionary interactions of strategic species. This approach uncovers the conditions under which biodiversity is maintained via interior attractors and planar coexistence states, supported by bifurcation analysis and sensitivity computations such as the Sobol indices. The complex basin structures and parameter-driven phase transitions illustrate how eco-evolutionary feedbacks can dynamically select among multiple attractors.

The final part of the thesis generalizes the framework to include hierarchical interactions between species, transitioning from symmetric cyclic games to asymmetric dominance scenarios, including predator-prey systems and models mimicking

rumor spreading phenomena. These systems exhibit a variety of dynamical behaviors, including extinction, strategy exclusion, coexistence, and chaotic oscillations, all modulated by ecological constraints and interaction asymmetries.

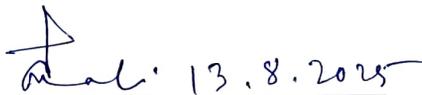
Together, these contributions offer a unified theoretical framework for understanding cooperation and coexistence through the lens of eco-evolutionary dynamics. The models developed capture a spectrum of biological phenomena and reveal mechanisms by which cooperative behavior, often fragile in traditional models, can emerge and stabilize through ecological mediation. By bridging mathematical analysis with ecological realism, the thesis advances both the conceptual and practical understanding of evolutionary dynamics in complex adaptive systems, with implications spanning conservation biology, epidemiology, and social dynamics.

Keywords: Nonlinear dynamics, Eco-evolutionary dynamics, Game theory, Ecology & Evolution, Cooperation, Cyclic dominance.



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