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Bifurcation and Chaos Control in a Discrete Predator-Prey Model with Collective Defense

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Abstract

This study investigates a discrete predator-prey model in which prey growth follows a Smith-type law, predator emigration is described by a Holling type II functional response, and a collective defense mechanism among prey is incorporated. The discrete formulation captures essential nonlinear effects arising from density-dependent prey growth, predator saturation, and collective prey behavior. Boundary and interior equilibrium points are determined, and their local stability is analyzed, with particular emphasis on the interior fixed point. Analytical conditions for the occurrence of Neimark-Sacker and period-doubling bifurcations are derived within the biologically feasible region. Numerical simulations validate the theoretical predictions and reveal rich dynamical behaviors, including invariant closed curves, multi-periodic oscillations, and chaotic attractors characterized by positive maximal Lyapunov exponents. Chaos suppression is achieved through the implementation of the Ott-Grebogi-Yorke (OGY) method and a state feedback control scheme, both of which successfully stabilize unstable equilibria and periodic orbits. These findings enhance the understanding of discrete predator-prey dynamics and provide effective strategies for controlling chaos in ecological systems.

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