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Diffusion driven complex dynamics of Bazikin's type prey–predator model in presence of Allee effect in prey and cooperative hunting

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ABSTRACT

This study explores the complexities of Bazikin's type predator–prey model, incorporating the influence of the mate-finding Allee effect on prey population, the impact of cooperative hunting strategies among predators, and the effect of diffusion. It provides a detailed analysis of how these factors influence ecological interactions and affect species dynamics. A detailed theoretical study is carried out to investigate the possible equilibrium states of the temporal model system. This is followed by an analysis of their stability and instability, along with an in-depth analysis of all possible bifurcation scenarios related to various equilibrium points. This model demonstrates saddle-node, Hopf, and Bogdanov–Takens bifurcations about some model parameters. On the other hand, the positivity and boundedness of solutions of the diffusive model are studied. The dynamics of the diffusive model have been investigated, considering linear as well as non-linear analysis. A qualitative analysis using numerical simulations is performed to validate all analytical findings. Numerical simulations demonstrate the development of diffusion-driven patterns, highlighting the emergence of target patterns, chaotic patterns, spots, stripes, and intricate combinations that merge stripes with spots. The simulation outcomes of the diffusive model indicate that multiple factors, including the predator's attack rate, the Allee effect, cooperative hunting behaviors, and diffusion coefficients, shape spatial distributions. The results of the analysis will help us to explore the relevance of various ecological effects and their impact within biology.

This study presents a great extension of Bazikin's type predator–prey model by integrating the effect of mate-finding Allee, cooperative hunting among predators, and spatial diffusion. Such incorporation provides us a more realistic presentation of species interaction and real-world ecological dynamics. The originality of this work lies in how the behavioral cooperation of predators, the mate-finding Allee effect on prey populations, and diffusion collectively shape system stability; the study of various bifurcation phenomena like saddle node, Hopf, and Bagdonov–Takens bifurcation of the temporal model, the Turing bifurcation of the spatiotemporal model, and spatial pattern formation. The emergence of a diverse range of spatial patterns like spots, stripes, a mix of both, target patterns, and chaotic patterns highlights the rich spatiotemporal complexity inherent in the ecological system. Our overall study advances the field of ecological science and species dynamics, offering theoretical insights into both biological and spatiotemporal mechanisms that shape spatiotemporal dynamics and pattern formation phenomena in predator–prey systems.

I. INTRODUCTION

Mathematical biology has long aimed to understand the self-organized spatiotemporal patterns and the mechanisms governing the spatial distribution and movement of interacting populations in their ecological environment.[1] To gain deeper insights into these processes, mathematical models are frequently employed to describe population interactions.[2–9] Initially, Lotka and Volterra[2,10] independently introduced the remarkable Lotka–Volterra model to study the predator–prey model, and later extensive study has been done considering different biological effects likely: different