

# Ecological theory of mutualism: Qualitative patterns in two-species population models

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## Abstract

Mutualisms are ubiquitous in nature, provide important ecosystem services, and involve many species of interest for conservation. Theoretical progress on the population dynamics of mutualistic interactions, however, has comparatively lagged behind that of trophic and competitive interactions. Consequently, ecologists still lack a generalized framework to investigate the population dynamics of mutualisms. Here, we review historical models of two-species mutualisms from over the last 90 years. We find that population dynamics of mutualisms are qualitatively robust across derivations, including levels of detail, types of benefit, and inspiring systems. Specifically, mutualisms exhibit stable coexistence at high density and destabilizing thresholds at low density. We distinguish between thresholds resulting from Allee effects, low partner density, and high partner density, and their mathematical and conceptual causes. The dynamics of stable coexistence and thresholds in partner density emerge when benefits of mutualism saturate, whether due to intrinsic or extrinsic density dependence in intraspecific, interspecific, or both. These results suggest that there exists a robust population dynamic theory of mutualism that can make general predictions.

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