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Social copying drives a tipping point for non-linear population collapse

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Abstract

Sudden changes in populations are ubiquitous in ecological systems, especially under perturbations. The agents of global change may increase the frequency and severity of anthropogenic perturbations, but complex responses of populations hamper our understanding of their dynamics and resilience. Furthermore, the long-term environmental and demographic data required to study those sudden changes are rare. Fitting dynamical models with an artificial intelligence algorithm to population fluctuations over 40 years in a social bird reveals that feedbacks in dispersal after a cumulative perturbation drives a population collapse. The collapse is well described by a non-linear function mimicking social copying, whereby dispersal made by a few individuals induces others to leave the patch in a behavioral cascade for decision-making to disperse. Once a threshold for deterioration of the quality of the patch is crossed, there is a tipping point for a social response of runaway dispersal corresponding to social copying feedback. Finally, dispersal decreases with population density likely due to the long times spent in a quasi-extinction state as observed in many populations of social animals after occupying a patch for extended periods. In providing the first evidence of copying for the emergence of feedbacks in dispersal in a social organism, our results suggest a broader impact of self-organized collective dispersal in complex population dynamics. This has also implications for the theoretical study of population and metapopulation non-linear dynamics, including population extinction, and the management of endangered and harvested populations of social animals subjected to behavioral feedback loops.

Significance Statement

Among the complex dynamics arising in all living systems, sudden population collapses are one of the most fascinating. Understanding the mechanisms that may cause these collapses is fundamental to the conceptual study of population dynamics. We fit dynamical models to population fluctuations over 40 years in a social bird that showed an unexpected collapse after a perturbation press that progressively eroded environmental conditions at the world's most suitable breeding patch. We demonstrated that collapse was explained by density-dependence feedbacks related to the simple behavior of social copying for dispersal to other patches. The significance of our study lies in showing that environmental stochastic perturbations may trigger a tipping point by runaway dispersal driving populations to a new state of quasi-extinction.

Main Text

Introduction

Understanding abrupt declines in the responses of populations to environmental perturbations is crucial for the theoretical study of population extinction and for managing harvested and endangered species, especially under the impacts of global change (1–3). Under the conceptual framework of the logistic model, the transition from a population level near carrying capacity to collapse in populations subjected to perturbations should occur through a negative exponential decay, i.e. a density-independent process (4–6). However, the logistic model has several limitations, since it assumes both a linear association between density and growth rate and a lack of time lag in the response of individuals to changes in density (5). Time-lagged responses may generate transient phenomena, which can explain abrupt regime shifts that are not directly associated with environmental changes (7, 8).

Dramatic sudden collapses in populations may be especially likely to occur in social organisms. Social groups are complex systems in which the number of interactions within a group is not additive, but grows in a factorial manner resulting in important behavioral feedback loops, such as those arising for information gathering, social copying and group cohesion. These feedback loops