Experimental Observation of Early Warning Signals for Approaching Population Collapse

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Natural populations can suffer catastrophic collapse in response to small changes in environmental conditions, and recovery after such a collapse can be exceedingly difficult. We use yeast to study early warning signals of extinction in a controlled experimental population. Yeast grow cooperatively in the sugar sucrose, causing a fold bifurcation in population dynamics; falling below a critical population size results in a sudden collapse. We demonstrate the experimental observation of several early warning signals by analyzing fluctuations in the population size. Our comparison of these indicators may help field biologists protect wild populations from extinction.

***Keywords* — extinction, early warning signals, critical slowing down**

I. Background

NEAR tipping points in complex systems, small changes in conditions can result in catastrophic shifts in the system state (e.g. population extinction). In theoretical models, it is known that the approach of these tipping points (bifurcations) will be signaled by changes in the fluctuation pattern of the system, due to a phenomenon called critical slowing down.

Suppose we have a series of observations of the system at different time points. Based on these data we can calculate statistical indicators such as variance to describe how large the fluctuations are, or autocorrelation time to quantify the extent to which a system state is related to its previous states. Theory suggests that these statistical indicators can be used as early warning signals of catastrophic shifts, because they will increase as the system approaches the threshold [1]. Knowing that the system is close to an undesirable transition may allow for policy changes to avoid crossing the transition, for example by limiting logging or issuing fewer fishing permits.

One of the outstanding challenges in this field is to test these early warning signals directly by experiments. A recent study in a zooplankton population demonstrates that extinction of a population in a deteriorating environment is preceded by early warning signals [2]. Although these results are encouraging, the zooplankton population in this experiment does not represent the typical population dynamics in nature. Its population size smoothly fell to zero as the environmental quality was degraded, thus making population size the best "early warning indicator". In nature, many plant and animal populations collapse below some critical size because of the need to find mates, group hunting behaviors, or other cooperative effects. This scenario, named the Allee effect, corresponds to a fold bifurcation in the underlying population dynamics [3].

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II. Objective

We aim to evaluate early warning signals before population extinction in a laboratory population that displays the Allee effect (a fold bifurcation which results in sudden collapse).

III. Approach

Our experimental system is a population of cooperatively growing yeast in sucrose that goes through a death-birth process imposed by daily dilution. Because yeast break down sucrose cooperatively [4], the population is subject to the Allee effect and therefore experiences sudden extinction in a deteriorating environment. The parameters determining population growth can be experimentally controlled by changing death rates and nutrient levels. The cell density at the end of each day is monitored to test the population viability and generate time-series data for statistical analysis.

IV. Results

We experimentally observed sudden extinction events that can be characterized by a fold bifurcation in the cooperatively growing yeast population. The bifurcation diagram can be well fit by a simple model of yeast growth. Our experiments identified a clear increase in the magnitude and correlation of fluctuations near the extinction threshold, in accordance with the prediction from theory and our stochastic simulations. We compared the performance of several early warning signals in environments with different kinds of environmental deterioration.

V. Conclusion

Early warning signals can be experimentally observed before collapse of a laboratory yeast population. Some of the signals are more robust than others and may be applied to predict catastrophic shifts in general complex systems.

References

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