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The Mystery Behind Predator-Prey Cycles in a Glass of Water

Haihui Yan

McGill University, 845 Sherbrooke St W, Montreal, Quebec, Canada.
**Corresponding author. Email: Haihui.yan@mail.mcgill.ca*

ABSTRACT

Ecological models such as predator-prey cycles are one of the most fundamental ecological phenomena. The original theory proposed by Alfred J. Lotka has frequently been used to describe the dynamic of biological systems. A variety of deterministic mathematical models indicate that these variations are caused by internal nonlinear interactions among species, which would provide fundamental insights into and predictions of interacting populations' dynamics. This paper describes a literature review (LR) of journal articles published in 2019 by Gregor F. Fussmann from McGill University and his team researchers from the Universities of Oldenburg and Potsdam in long-term cyclic persistence in an experimental predator–prey system. The researchers employed a microbial experimental system to see if these predator-prey population cycles occur naturally because of the two species' interactions or if they are caused by external factors. The microcosm experiments over 10 years have now successfully confirmed that the regular oscillation predator-prey cycle can persist over a long period of time[1][2]. The findings demonstrate that predator and prey populations can persist eternally under a cyclic dynamic regime that is resilient in the face of unanticipated events, and a potential mathematical model that the stochasticity for the non-coherent oscillations.

Keywords: *Predator and Prey, dynamic biological system, cyclic dynamics, coherent/non-coherent oscillations, stochastic.*

1. INTRODUCTION

Predator-prey cycles exist among all life forms on Earth, and it is the foremost essential notion, it discusses the interactions between two species where one is the food source for the opposite. It is the dominant theme in ecology. Ecological systems are characterised by population cycles that continue over time and are coordinated throughout geography; however, the fundamental reasons have long been a mystery. Lots of papers from previous experiments were conducted to examine the complex population oscillations synchronization which is restricted to only a few cycle periods. Theoretically, the predator-prey cycles would have indefinite persistence in real communities[3][4][5]. When researchers look through the literature review for the published research papers on the dynamics of the prey-predator model, we notice that there are multiple numbers of good research works on the dynamics of prey and predators but with limitations as mentioned before[6][7].

As a result, in this paper, the researcher discussed and analyzed the recent work and attempted to solve the open topic of how long cyclic dynamics in real communities can be self-sustaining. and if the cyclic dynamics could be run in a closed laboratory predator-prey system. A detailed explanation of experiments and methods; analysis of the data is presented to understand if these predator-prey population cycles occur naturally through the interaction of the two species or if there exist any external drivers that cause it. The biological implications of the analytical and numerical findings are also discussed in this study. The significance of the study is to help researchers to understand various predator-prey cycles, and discuss the ecosystem from different perspectives.

2. ANALYSIS

The main topic is to understand the dynamics of populations and communities by isolating the key mechanisms at each level of organization, how it would demonstrate the validity of ecological concepts and ideas using controlled and empirical systems and the importance of ecology and evolution for community dynamics. The importance of such research would resolve the question of long-term persistence of predator-prey cycles cultured in the laboratory. Moreover, it is quite unexpectedly challenging to illustrate the persistent predator-prey cycle in the laboratory. Here are the details of their experiments design:

a) Experiments set up

To test out whether cyclic dynamics could be carried out in the laboratory and the pattern behind it. The first step is to use a chemostat to set up several independent experimental systems. Chemostat is an excellent experimental apparatus where the chemical environment can be maintained static and nutrient availability can be controlled by the experimenter. The chemostat experiments were run with parthenogenetic rotifers (B. calyciflorus sensu strictu[8], a small freshwater zooplankton species) as predators and unicellular algae (M. minutum or C. vulgaris) as prey under the constant temperature of 23 °C and permanent illumination. Then, researchers conducted the experiments in the same well-maintained climate chamber. External disturbances from all potential sources that can be measured such as temperature and irradiance remained constant throughout the experimental runs. For inoculation, the researchers used stock cultures originally raised from a single individual and added B. calyciflorus 10 days after the algae had reached a biomass that enabled rotifer growth. The chemostats received a rate of 0.55 of sterile medium per day at a constant rate.

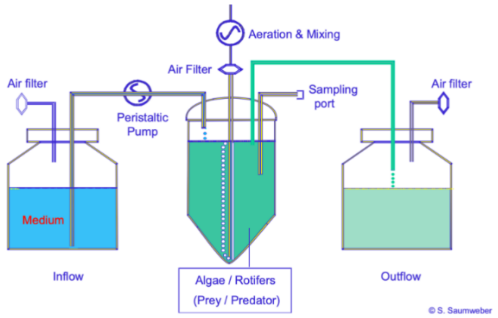

Figure 1 Chemostat Experimental System

Under this steady state, the predator and prey would grow at a constant rate and all other parameters remain constant.

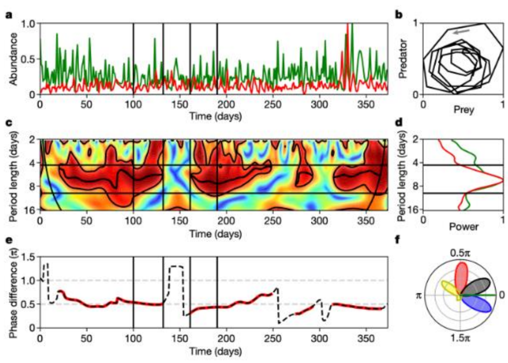

Figure 2 Phase analysis of a year-long, oscillatory predator–prey time series

The first experimental system is in a homogeneous environment without any external stimuli for over a year, resulting in more than 50 cycles. 50 cycles are about the same as 300 predator and prey generations. (See Figure 2a).

Then there are 4 additional and replicated independent chemostat experiments with the same species, and 2 additional experiments with different algal prey species. (See Figure 3). The cyclic succession and distribution of phase differences in measured time series were quantified using power analysis and phase analysis (bivariate wavelet analysis) (see Method). With the help of these methods, the researchers found out that the mean period length between the dynamics of predator and prey densities in the experiments was 6.7 days. (Fig. 2d)

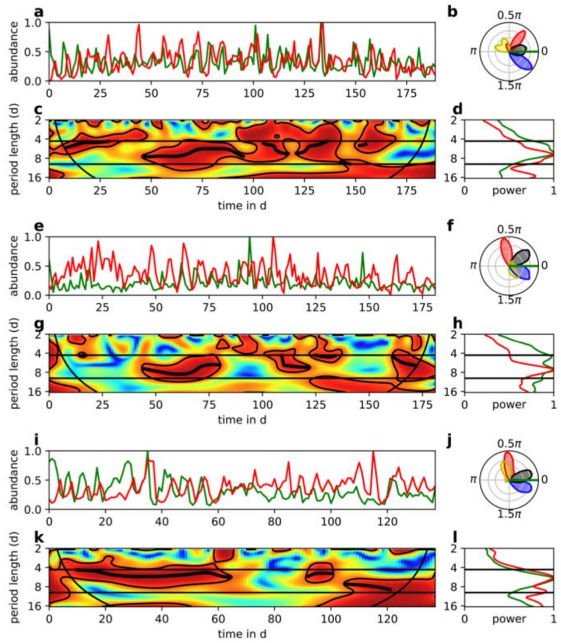

Figure 3 Three more experimental time series in a constant environment were studied for their dynamics and phase relationships.

The results confirmed the theoretical concept of self-generated predator-prey cycles and demonstrated that these two species could coexist for up to around 50 cycles or approximately 300 predator generations without external stimuli. Interestingly, they observed 2 different dynamic regimes on the graph. The major type of dynamics is the regular oscillations in the cycle with the most constant intervals, which is consistent with the classical predator-prey cycle (Fig.3). Demonstrated by the phase lag of about $\theta = 0.5\pi$ (equals 90°). For example, in Fig.3a, the time interval between day 100 and 131 and between days 37 and 66 (Fig.3c, d) showed regular period lengths sustained cycles and the constant phase lag between predator and prey densities. The prey-predator phase plane's anticlockwise motion showed in Fig.2b also verified the constant sustained cycles.

However, what is noteworthy is that within the coherent oscillation, there existed a short, irregular period in which both populations would lose their phase relationship and then resumed to its original in-phase states independently without any external intervention (days 132-161 and days 67-97).

Finally, the researchers also observed that the system was resilient, and predator-prey phase differences would be re-established without any external intervention.

Together with these experiments, the overall percentage is comprised with 66% of a typical regime duration of 58 days as coherent oscillations and the remaining 34% of the experiments, which oscillating without a well-defined phase relationship (as non-coherent regimes, 23 days).

The pattern they observed here are quite interesting, they then performed additional experiments to gain an insight into the coherent oscillations and the breaks in the phase signature. The following part discussed the additional analyses.

b) Additional Experiments

First, they included the predator life-history stage in the phase analysis and secondly; formulated and analysed a mathematical model for the predator's stage structure. Since the predator in the system is the rotifer Brachinous calyciflorus[8]. It is a small metazoan that live in freshwater where it reproduces asexually in the chemostats and undergoes a stage-structured life cycle. The female usually carries 1-5 eggs and hatch and grow to adulthood without any larval stages and adults would die after the last egg has hatched. By this additional analysis of all these stages, Gregor F. Fussmann and his team observed that the life-history stage such as egg, sexually mature, and dead) is also fluctuated periodically, demonstrating persistent cycles that were in lockstep with the abundance of prey (See Fig.4a). The phase differencesremained consistent across all experimental replicates.

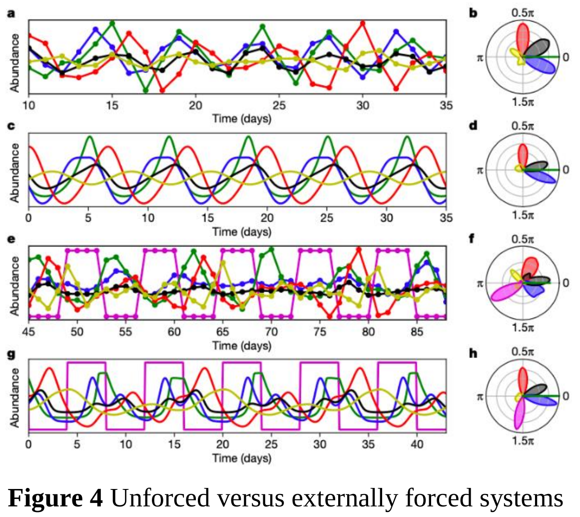

Figure 4 Unforced versus externally forced systems have different dynamics and phase relationships.

Lastly, 3 additional experiments were performed by changing the nutrient concentrations in 2 experiments and one in the nutrient exchange rate to find out if the phase relations were influenced by external forcing or would cause the system from oscillatory to equilibrium dynamics. The results propose that stochasticity is likely the main reason for the sudden shift from coherent to noncoherent oscillations. Only when the researchers introduced stochasticity to the model, they observe similar patterns.

Overall, these findings give assurance that the persistent cycles can be consistent with the reality of simple ecological systems in the laboratory with no external influences. More importantly, it can persist for up to around 50 cycles or approximately 300 predator generations. Meanwhile, the researchers found that there are 2 types of dynamics: one with regular, coherent oscillations and the second one is shorter, irregular, non-coherent oscillations with no phase relationship. Even though it has an out of phase, it would return to the dominant dynamical regime in a short period of time, proving the resilience of the ecological system. In addition, by using the mathematical model to further analysis, it suggested that the stochasticity is probably responsible for managing the reversible shift from coherent to non-coherent oscillations.

c) Method

The experiments were not randomized. Daily subsamples were collected to determine the abundance of predator and prey. An electronic particle counter (CASY) was used to analyze the algal abundance. The total number of rotifers was recorded and the same as the asexually produced subitaneous eggs and the dead. Males or sexually reproducing females were not existed or were observed throughout the experiment.

All the measured signals were analyzed using phase analysis due to the large variability. The phase analysis would help the researchers to rely on the fact that the regulatory dependence between state variables is often encoded in their phase relationship, whereas the amplitudes may be highly erratic and uncorrelated [9]. Wavelet method [10] is also applied to allow the researchers to assess transient correlations between two non-stationary signals by extracting ideally resolved phase information from ecological time series. In addition, lots of ordinary differential equations and other mathematical formulas were used to better interpret the data: continuous wavelet transformation; wavelet cross-spectrum; wavelet coherence; dominant phase difference; significance testing; circular phase distribution and more [11][12]. Most importantly, the researchers developed a mathematical model: numerical simulation according to the stage-structured predator-prey community in a chemostat [13][14].

3. CONCLUSION

Persistent and coherent predator–prey oscillations, as predicted by fundamental theory, are a potential dynamic regime that allows predator and prey populations to coexist for a long time. A causal association between persistent cycles and predator–prey interactions are supported by four lines of evidence: dominated cyclic patterns; suppression of the cycle caused by planned experimental interventions; recurring changes characteristics; regular phase-locked succession pattern.

In real world, the stochasticity and the external environmental change would reflect on the erratic oscillations. Gregor F. Fussmann and his colleagues' work broadens our understanding and gave other scientists a great starting point in the search for more discovery of transient dynamics in natural systems.

While some research has been done on predator and prey patch selection in heterogeneous environments, more research is needed. When one or both species have two or more traits that influence predation rate, previous theoretical work has largely ignored evolution and coevolution. The resource(s) of the prey species, as well as any higher-level predators or parasites that attack the focal predator, would be included in a more complete model. By simply introducing density-independent prey growth, some of the effects of the prey's resource can be represented. In the future, it will be important to explore how other factors (such as temperature) that are present in the real ecosystem might affect the predator-prey cycles and with the previous experience, it is possible to identify interactions between different species and cyclic or seasonal sequences in complex sets of data.

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