DSTA 2021 dys-ta.com
16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line

Influence of periodic nutrient advection on a simple ecosystem

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Abstract: ***In this paper, we study the time evolution of a simple NPZ system, with periodic physical forcing. We address the effect of this forcing on the limit cycle of the ecosystem dynamics.***

Keywords: ecosystem modeling, NPZ, periodic forcing

1. Introduction

Ecosystem dynamics have often been studied in applied mathematics, with several formulations starting from the simple Lotka-Volterra predator-prey system, up to complex oceanic biogeochemical systems. Most studies determined the time evolution of the individual elements of the ecosystem, determined the existence of steady states or of limit cycles and their stability. Fewer papers were concerned by the interaction of the physical evolution of the environment with the ecosystem internal dynamics [1,2]. Our study is concerned with a NPZ (nutrient-phytoplankton-zooplankton) ecosystem controlled by a nutrient flux, which can be varied according to the physical inflow into the system. Our aim is first to study the stability of the ecosystem, the fixed points, their stability and the limit cycles without physical influence. Then we introduce a small-amplitude, periodic modulation of the nutrients on a period equal to that of the limit cycle or half this value to trigger harmonic or subharmonic resonance. The equations for the system are

$$dN/dt = D(t)(N_0(t) - N) - f(N) \qquad \textbf{(1)}$$

$$dP/dt = \alpha f(N) P - D_1 P - g(P) Z \qquad \textbf{(2)}$$

$$dZ/dt = \beta g(P) Z - D_2 Z \qquad \textbf{(3)}$$

The model is composed of three ordinary differential equations which represent the evolution the concentration of respectively nutrient available in the system, Phytoplankton and Zooplankton according to time. The model used for our study also neglects the remineralization of phytoplankton and zooplankton into dissolved organic matter via decomposition. The parameters of the model and the initial conditions of all variables are positive. To simplify the model further, the function f(N) is continuous and follows a Michaelis-Menten form

$$f(N) = \mu_{max} N/(K+N) = b\,N/(a+N) \qquad (4)$$

$$g(P) = c\,P/(1+d\,P) = c'\,P/(d'+P) \qquad (5)$$

The parameters and structure of the equations are similar to those of [3,4,5,6]. The equations were solved numerically with a 4^{th} order Runge-Kutta scheme.

2. Results and Discussion

For fixed D and N0, steady states with only N or only N and P have been calculated; their stability has been found; this is obtained by solving a second degree equation which yields the region for instability in parameter space. When N, P and Z are all present, a limit cycle can be obtained when taking large values of N0. From this limit cycle, we can compute the period of oscillation and force either D on the half period to obtain sub-harmonic resonance or N0 on the full biological period to obtain harmonic resonance.

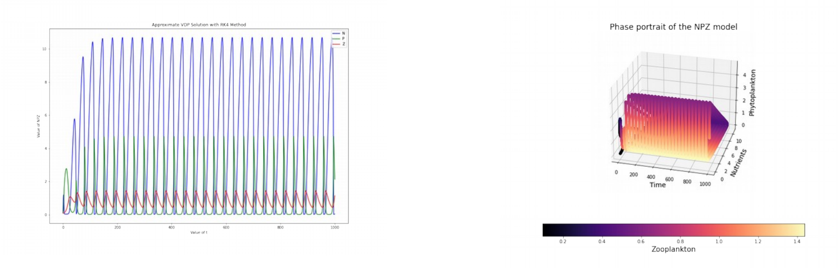

Fig. 1. (left) time oscillation of N,P Z in the limit cycle; (right) phase portrait of N,P Z in the limit cycle

3. Concluding Remarks

The time variability of the physical inflow of nutrients is essential to ecosystems in particular in the case of resonance between the physical and biological timescales.

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