Non-stationary dynamics in a complex marine biogeochemical model

Guido Occhipinti[*,**], Cosimo Solidoro[**], Roberto Grimaudo[***], Davide Valenti[***], and Paolo Lazzari [**]

[*] *Dipartimento di Matematica e Geoscienze, Università degli Studi di Trieste, Via Valerio 12, Trieste, I-34127, Italy #*

[**] *National Institute of Oceanography and Applied Geophysics - OGS, via Beirut 2, Trieste, I-34014, Italy #*

[***] *Dipartimento di Fisica e Chimica Emilio Segré, Università degli Studi di Palermo, Viale delle Scienze, Ed. 18, Palermo, I-90128, Italy #*

Abstract. Although non-stationary dynamics have been observed in nature, it is still unclear if these behaviors are inherent of ecological systems or whether they are the result of external forcings. In order to comprehend how rarely non-stationary dynamics occur in ecosystems, we analyzed a complex biogeochemical model. It was discovered that half of the possible choices of parameter and initial conditions of the model lead to non-stationary dynamics, even if the bulk of such trajectories show relatively tiny oscillations. Such trajectories can resonate with an external noise, making them significant. By altering how the model describes the structure of the food web, we looked for the reasons of its stability. We discovered that traits like omnivory and center of gravity are essential to the stability of the web. Our results support the widely accepted hypothesis that predators that can feed on a variety of prey, potentially at multiple trophic levels, are associated with stable ecosystems.

Introduction

The importance of investigating not stationary dynamics (such as periodic or chaotic behaviours) in ecological systems stems from the abundant evidence of the existence of periodic changes in population densities. However, it is still not clear whether such periodic fluctuations are intrinsic of ecological systems or due to an external forcing. Many studies show that simple models exhibit periodic cycles and chaotic behaviour [1, 2]. Other studies indicate that real natural population systems are unlikely to behave chaotically unless forced by an external factor, such as human actions, even if the seeds of chaos are present [3]. Moreover, it is known that strong oscillations can be induced by stochastic forcing. One of the most important examples of resonance between stochastic noise and internal oscillation modes is reported in [4], where it is demonstrated that glaciation cycles can be described by resonance of stochastic noise with the periodicity of astronomical forcing. In this work, we investigate the presence of internal model oscillations in a complex biogeochemical model to examine the conditions under which resonance with stochastic fluctuations can occur and whether this phenomenon can be considered rare or common.

Results and discussion

We found that half of the possible parameters and initial conditions choices lead to very small fluctuations in the solutions of the model. Such solutions, which we have defined as quasi-stationary, can resonate with stochastic noise and can be the *seeds of chaos* thought to exist in nature. However, only 3% of the perturbed samples has exhibited large fluctuations. This confirms the notion that complex models are stable.

Therefore, we searched for the causes of food web stability. We found that the most important features characterizing food web stability are omnivory and center of gravity. However, omnivory alone is not able to stabilize a web; on the contrary, in long chains it plays a destabilizing role. This can be explained by the fact that predation of top predators at different levels of a food chain enhances the predation at the lowest levels, destabilizing the whole chain. Instead, a low center of gravity, i.e. the presence of alternative prey species, especially at the lowest trophic levels, is a very effective mechanism for reducing unstable dynamics.

References

[1] Y. Takeuchi, Global Dynamical Properties of Lotka-Volterra Systems, World Scientific, 1996. doi:https://doi.org/10.1142/2942.

[2] G. F. Fussmann, S. P. Ellner, K. W. Shertzer, N. G. H. Jr., Crossing the hopf bifurcation in a live predator-prey system, Science 290 (5495) (2000) 1358–1360. doi:10.1126/science.290.5495.1358.

[3] A. Berryman, J. Millstein, Are ecological systems chaotic — and if not, why not?, Trends in Ecology & Evolution 4 (1) (1989) 26–28. doi:10.1016/0169-5347(89)90014-1.

[4] R. Benzi, G. Parisi, A. Sutera, A. Vulpiani, Stochastic resonance in climatic change, Tellus 34 (1) (1982) 10–15. doi:10.3402/tellusa.v34i1.10782.