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Zooplankton effect on the dynamics of competing phytoplankton species

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Motivation and Aim: The phenomenon of phytoplankton blooming expressed as a dramatic increase in phytoplankton density is currently under active research. At that toxic blooming negatively affects aquaculture, coastal tourism, and human health. The most interesting results in modeling phytoplankton bloom were obtained based on a modification of the classical system of phytoplankton and zooplankton interaction. The modifications use delayed equations, as well as piecewise continuous functions with a delayed response to intoxication processes, making it possible to obtain adequate phytoplankton dynamics like in nature. Recurrent equations, which are widely used in modeling populations and communities [e.g., reviews 1, 2] and which allow us to describe lag effects naturally, are practically not used for modeling plankton communities' dynamics. Using the classical modeling technique, we propose a discrete-time three-component model of the plankton and zooplankton community. The community consists of zooplankton and two phytoplankton species competing for resources: toxic and non-toxic. This work continues our previous study [3], where a simple model of a phytoplankton-zooplankton community consisting of two equations with discrete-time has been proposed.
Methods and Algorithms: We propose a three-component model of the phytoplankton-zooplankton community with discrete-time, in which toxic and non-toxic species of phytoplankton compete for resources. We use the Holling functional response of type II to describe an interaction between zoo- and phytoplankton. Also, we use the Ricker competition model to describe the restriction of phytoplankton biomass growth by the availability of external resources (mineral nutrition, oxygen, light, etc.). Many phytoplankton species, including diatom algae, are known not to release toxins if they are not damaged. Zooplankton pressure on phytoplankton is shown to decrease in the presence of toxic substances. For example, Copepods are selective in their food choices and avoid consuming toxin-producing phytoplankton [4]. Therefore, in our model, zooplankton (predator) consumes only non-toxic phytoplankton species being prey, and toxic species phytoplankton only competes with non-toxic for resources. We carried out an analytical and numerical study of the proposed model, including stability analysis, the construction of phase and parametric portraits, and bifurcation analysis. We use dynamic mode maps to study stability domains of fixed points, bifurcations, and the evolution of the community.
Results: Based on methods of mathematical modeling we estimated a zooplankton influence on the dynamics of phytoplankton species coexistence. The study analyzed scenarios of the transition from stationary dynamics to fluctuations in the size of phytoplankton and zooplankton for various values of intrapopulation parameters

determining the nature of the dynamics of the species constituting the community, and the parameters of their interaction. The focus is on exploring the complex modes of community dynamics. In the framework of the model used for describing the dynamics of the phytoplankton community in the absence of interspecific interaction, phytoplankton dynamics undergoes a series of period-doubling bifurcations. At the same time, with zooplankton appearance, the cascade of period-doubling bifurcations in phytoplankton and the community as a whole is realized earlier (at lower reproduction rates of phytoplankton cells) than in the case when phytoplankton develops in isolation. The proposed dynamic model of the phytoplankton and zooplankton community allows us to observe long-period oscillations, which is consistent with the results of field experiments. As well, the model has multistability areas, where a variation in initial conditions with the unchanged values of all model parameters can result in a shift of the current dynamic mode.

Conclusion: In the absence of zooplankton, the proposed model transforms to the two-species competition model proposed by A.P. Shapiro [5] in 1972 and by R. May [6] in 1974 yrs. Detailed study of this model showed [7] that the dynamics of two species competing for a resource can be extremely various and complicated having multistability regions as well. With strong interspecific competition of phytoplankton species for resources, both the ratio of reproduction rates and initial conditions determine their survival. As a result, zooplankton removing a part of one phytoplankton species abundance changes the current population sizes of the competitors thus allowing the population with the lower reproductive potential to eliminate the more fecundate competitor. With weak interspecific competition of phytoplankton species and sufficiently high growth rates of their populations, it is difficult to predict the scenario of community development, although the species will coexist. The zooplankton changing the initial condition can shift the dynamic mode and oscillation phase observed in the phytoplankton community.

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