Allee Effect Enhances Chaos in a Space-Time-Continuous Two-Species Model of Plankton Dynamics

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The pattern formation in plankton communities is widely believed to appear as a result of the interplay between the ocean hydrophysics and the biological interactions between plankton species. Among all biological interactions which can potentially lead to pattern formation, the predator-prey-type interactions between zooplankton and phytoplankton are thought to be the most important [1], in particular, because they act on a smaller time scale. On the other hand, it is known that the spatio-temporal dynamics of the prey-predator system can be strongly affected by the Allee effect, i.e by negative population growth at low population density [2]. In our talk, we consider, by means of mathematical modelling and computer simulations, a possible impact of the Allee effect on pattern formation in a model plankton community. We want to remark that, although there is no clear evidence of the Allee effect for plankton species, the accuracy of available data on the population growth in marine ecosystems is usually rather low so that the existence of the Allee effect can not be excluded. Moreover, we show that, in a marine ecosystem, the negative population growth at small population densities can arise as an indirect consequence of the ocean turbulence.

Mathematically, the system consists of two nonlinear partial differential equations describing predator-prey interaction in homogeneous space. The spatial mixing in a plankton community takes place mainly due to water turbulent motion; thus, we assume that the diffusiviities of phyto- and zooplankton are equal. To take the Allee effect into account, phytoplankton growth is parameterized by a cubic polynomial. For the initial conditions, we assume that, at the beginning, plankton is concentrated inside a single plankton patch; however, the spatial distributions of phyto- and zooplankton inside the patch are not identical.

We show that the Allee effect makes the dynamics of this system remarkably reach. Among many other regimes, the Allee effect can lead to formation of an ensemble of a few solitary quasi-stationary plankton patches separated by large distances of very low plankton densities (as it is often observed in the ocean). The patches are virtually independent of each other and their position do not change with time while their shape can be either stationary or oscillatory. The investigation of the phytoplankton and zooplankton total biomass shows that the Allee effect can lead to chaotic temporal oscillations even when the species spatial distribution is pretty regular. This phenomenon is new compare to what is known about a similar system with logistic growth where temporal chaos is usually associated with spatial irregularity [3]. This spatially regular – temporally chaotic behavior has been observed in a wide region of biologically significant parameters, such as zooplankton death rate, phytoplankton growth rate, and the threshold value of the phytoplankton density.

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References

[1] Levin, S.A. & L.A. Segel, 1976, Hypothesis for origin of planktonic patchiness, *Nature*, 259, 659.

[2] Petrovskii, S.V., A.Yu. Morozov & E. Venturino, 2002, Allee effect makes possible patchy invasion in a predator-prey system. *Ecology Letters*, 5, 345-352.

[3] Petrovskii, S.V. & H. Malchow, 2001, Wave of chaos: new mechanism of pattern formation in spatiotemporal population dynamics, *Theor. Popul. Biol.*, 59, 157-174.