The Emergence of Chaotic Dynamics in Complex Microbial Systems: Fully Mixed vs. 1-D Models

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Several recent publications (e.g., Becks et al. 2005, *Nature Letters*; Graham *et al* 2007, *Int. Soc. Microb. Eco. J.*; Beninca *et al* 2008, *Nature Letters;* Saleh, 2011, IJBAS) have supported the breakthrough discovery that deterministic chaos occurs in relatively simple biochemical systems. This was accomplished through a series of experiments that produced time series of data (microbe populations, substrate concentrations, etc.), which were then analyzed using recently developed methods of nonlinear dynamics and chaos. For an overview, see Molz & Faybishenko, 2013, and Faybishenko & Molz, 2013, *Procedia Environ. Sci*. The chaotic dynamics may arise from nonlinear interactions within the system being studied, not induced by time-varying boundary conditions. Chaotic dynamics of the system resulted in the formation of strange attractors that may be viewed as representation of a type of emergent behavior. In their mathematical analysis of a fully mixed, predator-prey system (2 microbes, 1 food source), based on Monod growth kinetics, Kot *et al* (1992, *Bull. Mathematical Bio.*) showed that chaotic dynamics could not occur unless chemostat substrate availability was varied sinusoidally. In order to study the internal dynamics of a slightly more complex system, we generalized the Kot *et al* model to have a spatially-dependent food source, in which case it simulated substrate diffusion into a growing biofilm composed of a feeding microbe and a predator. With parameters identical to Kot et al. (1992) we were able to generate chaotic dynamics even with constant boundary conditions, which implied a fully internal self-organization of chaos. In this presentation, we also discuss the self-organization and complexity of the system generated using a modified Kot et.al. model by means of calculations of the information entropy. We are applying these concepts to help understand why a coupled microbial Kot *et al* model with spatial dependence, resulting in a system of PDEs, appears to favor the occurrence of chaos as compared to a fully mixed model.