Population dynamics for a Daphnia-based biofiltration technology

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Daphnia-based biofiltration is increasingly recognized as an effective and sustainable technology that uses Daphnia (waterfleas) to naturally filter pollutants from water, particularly those whose microscopic size overwhelms many conventional filtration technologies. However, its effectiveness varies with physical and environmental factors like temperature, rainfall, and seasonal medicine use, which affect the Daphnia population density. Maintaining these populations near optimal levels is therefore essential for reliable biofilter performance. We develop a chemostat-type model that describes how nutrient availability affects the adult (reproductive) and juvenile (non-reproductive) densities of Daphnia using the mathematical framework of delay differential equations to model the time it takes for Daphnia to mature. As a key parameter in a water-treatment setting, we investigate how the dilution rate affects the equilibrium structure of the Daphnia dynamics, with the system displaying different qualitative behaviours for different dilution rates, enabling us to predict how to tune the dilution rate to ensure the Daphnia are maintained at an optimal density for effective biofiltration.