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The Emergence of Biofilms: Computational and Experimental Studies
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Summary

The response of biofilms to any external stimuli is a cumulative response aggregated from individual bacteria residing within the biofilm. Any perturbation at a microscopic level manifests response at a macroscopic scale. Therefore, the organizational complexity of biofilm can be studied effectively by understanding the bacterial interaction at cell level. The overall aim of the thesis is to explore the complex evolutionary behaviour of bacterial biofilms subject to external perturbations. This thesis is divided into three major studies based on the type of perturbation analysed in the study. These studies answer the fundamental questions associated with the complexity of biofilm development. The first study analyses the physics behind the development of mushroom-shaped complex structures from the influence of nutrient cues in Pseudomonas aeruginosa biofilms. Glazier-Graner-Hogeweg model is used to simulate the cell characteristics such a motility, proliferation, and adhesion in the study. From the study, it is observed that chemotaxis of bacterial cells towards nutrient source is one of the major precursors for formation of mushroom shaped structures. Also, formation of such cap-and-stalk structures leads to the development and segregation of bacterial antibiotic resistance within the biofilm. The objective of the second study is to analyse the impact of ambient environmental conditions on the inter-biofilm quorum sensing signalling. The study reveals that the dynamics of inter-biofilm bacterial communications is significantly affected by the characteristics of the fluid medium surrounding the biofilm. Using a hybrid convection-diffusion-reaction model, the simulations predict the diffusivity of quorum sensing molecules, the spatiotemporal variations of quorum sensing signal concentrations and consequently, the competition outcome between quorum sensing and quorum quenching mutant bacterial communities present under various environmental conditions. The mechanical effects associated with the fluid-biofilm interaction is addressed in the third study. A novel fluid-structure interaction model based on fluid dynamics and structural energy minimization is developed in the study. Model simulations are used to analyse the detachment and surface effects of the fluid stresses on multi-species biofilms. In addition to the mechanistic models described, a separate study is carried out to estimate the computational efficiency of the biofilm growth model and predict the optimal processor allocation for simulating different stages of biofilm growth.