Quorum sensing and bacterial cooperation

Anand Pai
CTMS Graduate Fellow (2010)
Advisors: Lingchong You and Henry Greenside

Quorum sensing (QS) is a cell-cell communication mechanism that enables bacteria to control their cooperative actions based on population density. The cooperative action is often the coordinated secretion of "public good" proteins, which are beneficial to all nearby bacteria. Using mathematical modeling and experiments, we study how QS control of cooperation benefits bacteria.

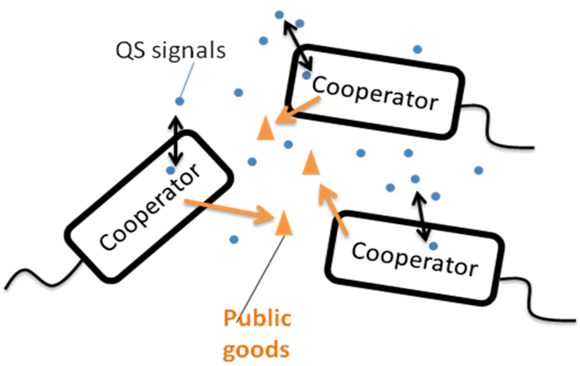

Fig. 1: *Schematic of bacterial communication and cooperation. Bacteria communicate through a QS based signaling mechanism wherein they secrete and sense the concentration of small signal molecules (blue dots). The signal concentration controls the production of beneficial public good proteins that are then secreted into the environment. In this scheme, production of goods is low at low population density (low signal) and high at sufficiently high population density (high signal).*

Cooperative bacteria pay the cost of goods production and, in turn, benefit from the action of the goods, such as proteins that ward of predators or produce nutrients from the environment. Once secreted, however, the goods are diluted in the environment so the overall advantage of cooperation depends on the concentration of goods in the environment and the cost involved in producing them. Mathematically, I model this as

$$\dot{N} = g_N N\left(1 - {N}/{N_m}\right) \text{ where } g_N = B(G) - C(P_G)$$

The equation depicts the dynamics of population density *N* under logistic growth. Its growth rate g_N depends on the benefit *B* gained and cost *C* incurred where *B* depends on the concentration of public goods *G* in the environment and *C* depends on goods production rate P_G.

Using such equations, I study the interplay of cost, benefit and population density. Consider, as example, the growth of two populations starting from the same initial density: cooperators that produce public goods constantly and non-cooperators that do not produce any. Cooperators perform better than non-cooperators starting at sufficiently high density but not when they both start at low density (Fig. 2), demonstrating the critical role of density. This shows the requirement for bacteria to coordinate cooperation based on their density using QS. Such models combined with experiments will provide insight into QS controlled cooperation and its adaptive advantage to bacteria.

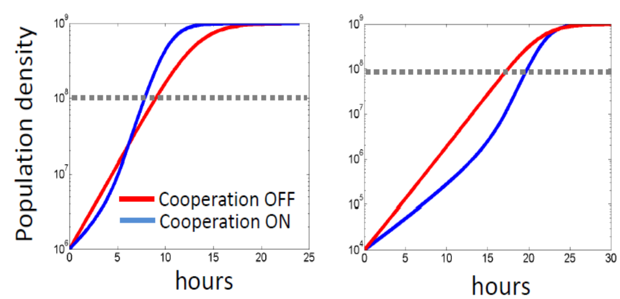

Fig. 2: *Growth of cooperators (blue) and non-cooperators (red) starting from high (left) and low (right) density. Cooperators overtake non-cooperators (measured at stippled line) when starting from high enough density but not when starting from low density.*

QS based cooperation is shown to be critical to the virulence of bacterial pathogens. As such, understanding the role of QS in coordinating cooperation could provide novel therapeutic targets to combat bacterial pathogens.