Exploiting phototaxis mechanisms to engineer coordinated communities of cyanobacteria

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Short Abstract **— Multi-cellularity allows for cellular specialization and function at length scales beyond the capacity of single cells. Cyanobacteria accurately sense light direction and quality to undergo complex pattern formation into fingers of sub-communities through a mechanical surface modification. With this work, a multi-disciplinary approach will be applied to first deduce principles governing phototaxis and functionalities of its various components by manipulating intracellular networks that integrate the extracellular environment and signals. The ability of a cell to concisely gain preference toward one direction by nullifying adversary signaling pathways will be tested. Using this molecular information, I will design optically controlled, spatially heterogeneous multi-cellular communities of cyanobacteria.**

I. Background

Many unicellular photosynthetic organisms such as cyanobacteria display oriented movement with respect to light (phototaxis), thus harnessing light energy for carbon fixation [1]. By coupling metabolism and behavior, phototaxis allows a cell to quickly adapt to changing environmental conditions, governing the active migration of cells in response to shifting light gradients and contributing to community spatial organization. Cyanobacteria play a crucial ecological role in primary production and global biogeochemical cycling of nutrients, and have been targeted as possible biofuel sources using synthetic biology [2].

The phototaxis response can be categorized into three subsystems: a light-sensing module such as photoreceptors [3] or photopigments, an intracellular regulatory signaling module, and a motility module organized around multi-functional TFP [4]. Several photoreceptors have been characterized and are now workhorses for optogenetics [5], though cyanobacteria employ other light-sensing modes that have yet to be characterized. Access to a diverse collection of mutants in each of the three modules can be used to reveal the minimal set of molecular players.

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II. Specific Aims

In recent years, bacteriology has undergone a paradigm shift from reductionist “single-cell” biology toward the investigation of the complexity of interacting communities. We will elucidate the mechanisms underlying cyanobacterial phototaxis at the level of individual cells, allowing us to engineer coordinated communities with complex spatiotemporal movement. We will utilize an interdisciplinary genetics, microscopy, and biophysical modeling approach for:

1) Genetic identification of novel signaling elements that couple positive and negative phototaxis to regulate cell decision-making capabilities
2) Characterization of the localization and dynamics of the type-IV pilus (TFP) machinery in individual cyanobacteria and in multi-cellular communities
3) Reconstitution of a minimal phototaxis system in a non-phototactic bacterium

III. Conclusion

Experimental data will be utilized to develop quantitative models of cyanobacterial phototaxis that can identify key variables responsible for the spatial structure of multi-cellular communities and cellular decision-making. In the future, organized communities of a mixture of species could be used to perform synthetic or syntrophic functions and to model behavior in ecologically relevant environments. This study has potential applications in the design of synthetic environmental remediation communities and multi-cellular architectures such as macroscopic scaffolds.

References

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