How Quorum Sensing Interactions Affect Population Structure

02-712 Final Project

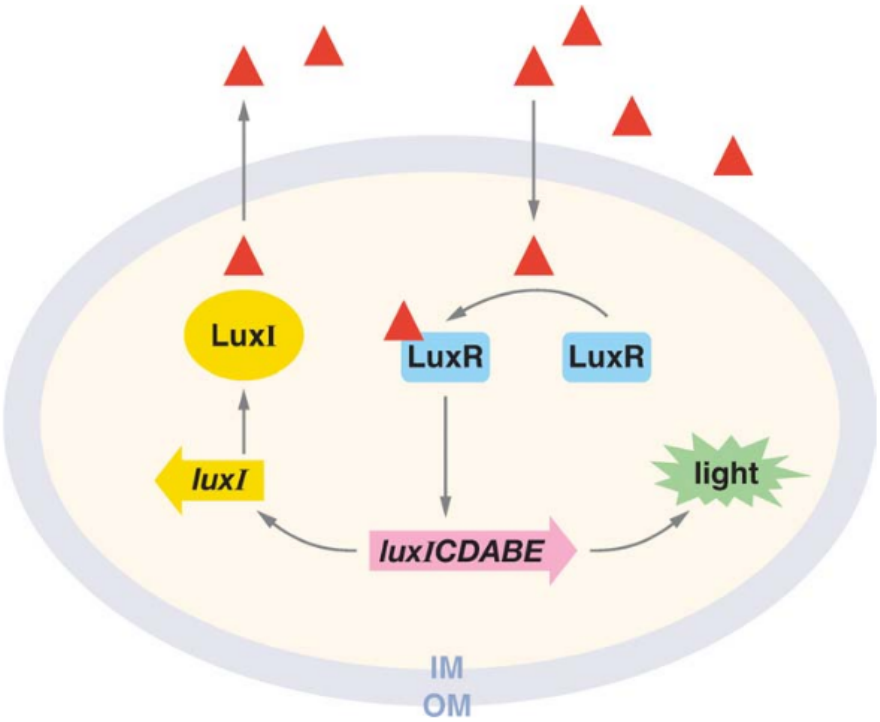
Sid Reed, Neel Mehtani, Sarah Wenger, Deepika Yeramosu, Evan Trop

Computational Biology Department, Carnegie Mellon University

November 30, 2021

Background

Quorum-Sensing Systems



- Signal-Receptor molecule pairs that modulate gene expression

Figure 1: Waters and Bassler (2005)

Quorum-Sensing Systems

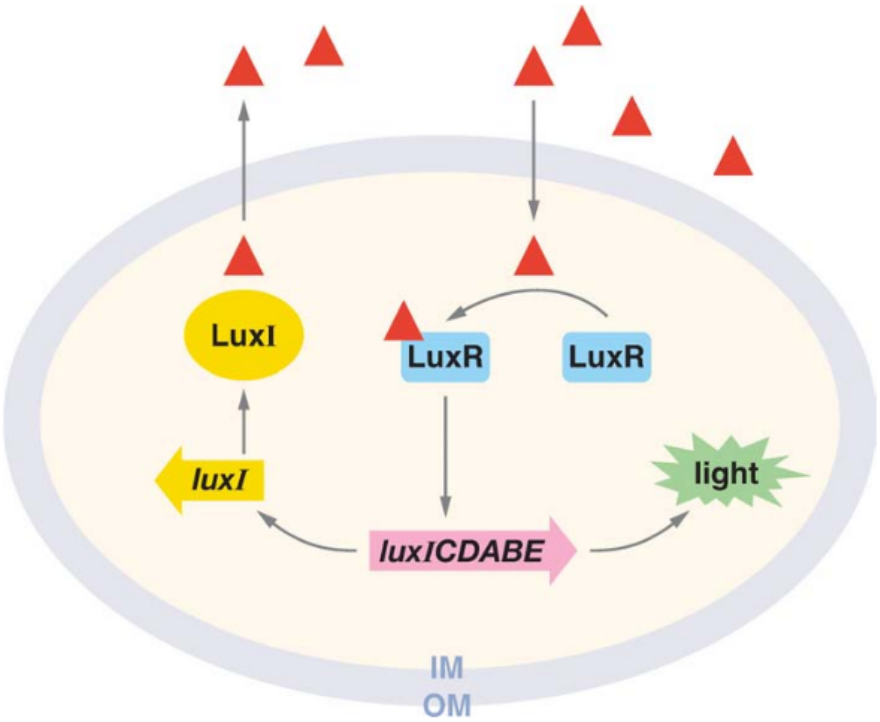
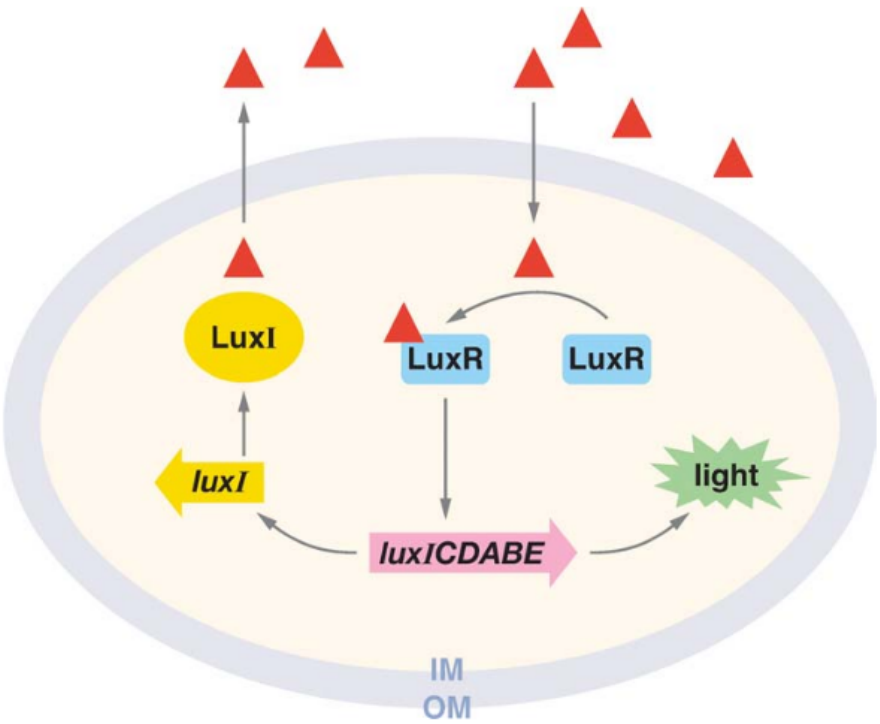


Figure 1: Waters and Bassler (2005)

- Signal-Receptor molecule pairs that modulate gene expression
- Once threshold density is reached, enough signal is received to upregulated target genes

Quorum-Sensing Systems



- Signal-Receptor molecule pairs that modulate gene expression
- Once threshold density is reached, enough signal is received to upregulated target genes
- Can lead to biofilms, antibiotic production etc.

Figure 1: Waters and Bassler (2005)

Public Goods and Cheating

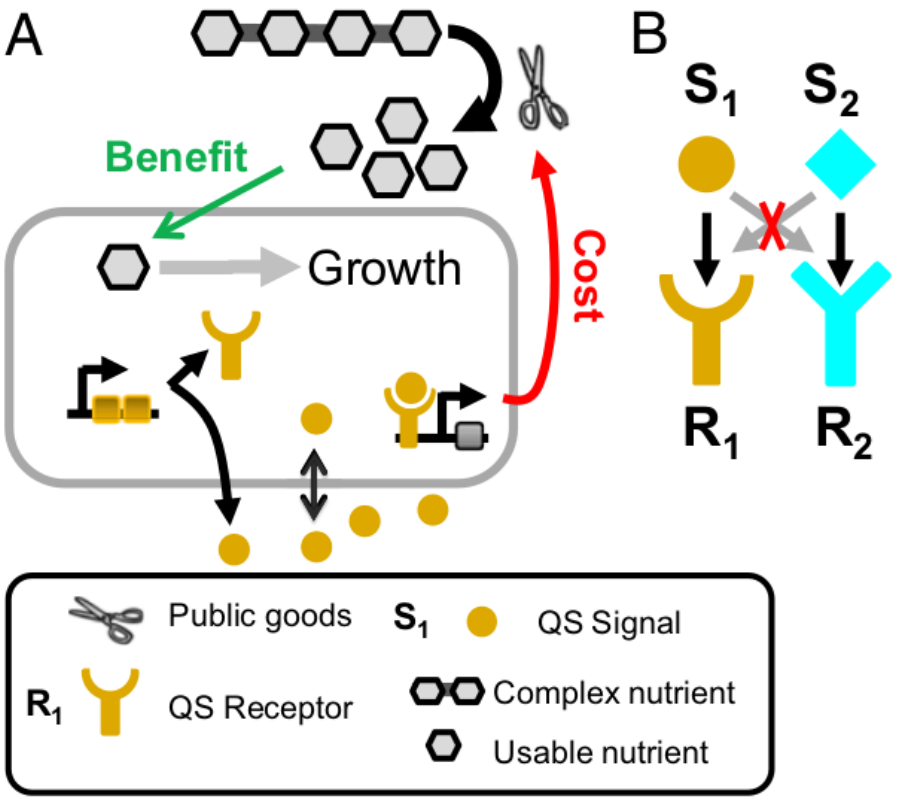


Figure 2: Eldar (2011)

- When quorum is reached, bacteria produce a "public good"

Public Goods and Cheating

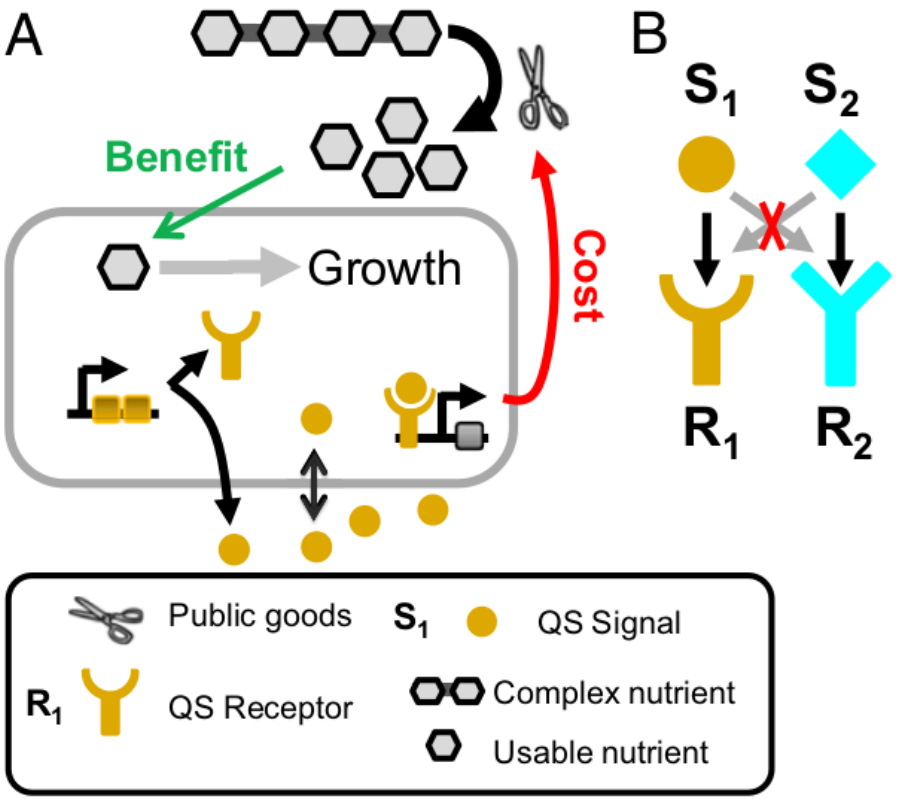


Figure 2: Eldar (2011)

- When quorum is reached, bacteria produce a "public good"
- Everyone benefits from this even if they don't contribute

Public Goods and Cheating

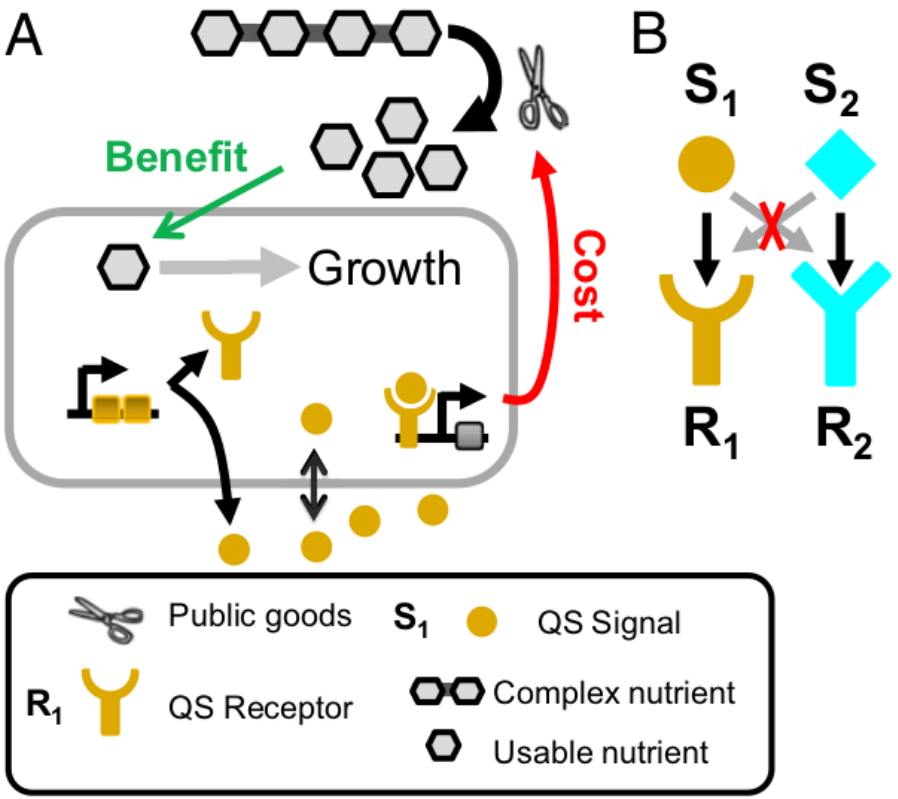


Figure 2: Eldar (2011)

- When quorum is reached, bacteria produce a "public good"
- Everyone benefits from this even if they don't contribute
- Must produce the receptor, signal molecule and good to contribute

Public Goods and Cheating

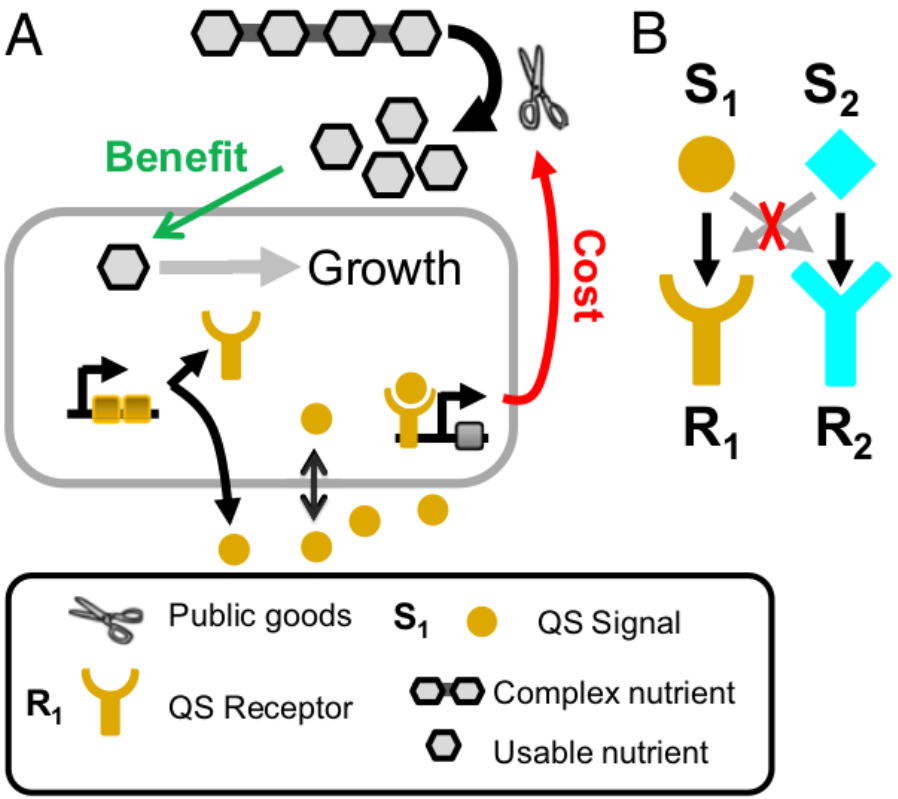


Figure 2: Eldar (2011)

- When quorum is reached, bacteria produce a "public good"
- Everyone benefits from this even if they don't contribute
- Must produce the receptor, signal molecule and good to contribute
- Cheaters DO prosper (if you are a bacterium)

Who Cares?

- check the discussion from Eldar (2011) for references

Maintaining Freeloaders as a Diversity Reservoir

Who Cares?

- check the discussion from Eldar (2011) for references

Maintaining Freeloaders as a Diversity Reservoir

Kin Recognition for Strains

Who Cares?

- check the discussion from Eldar (2011) for references

Maintaining Freeloaders as a Diversity Reservoir

Kin Recognition for Strains

Designing Cheaters to Disrupt Pathogen Growth

Model

Signal-Receptor Activation Matrix K_{ac}

- Represents all receptors-signal pairs ($R_i S_i$) present in at least 1 OTU in the population

Signal-Receptor Activation Matrix K_{ac}

- Represents all receptors-signal pairs ($R_i S_i$) present in at least 1 OTU in the population
- Different sets of receptor-signal combinations can produce the same K_{ac}

Signal-Receptor Activation Matrix K_{ac}

- Represents all receptors-signal pairs $(R_i S_i)$ present in at least 1 OTU in the population
- Different sets of receptor-signal combinations can produce the same K_{ac}
- K_{ac} is of dimension $|R| \times |S| = |N| \times |N|$

Facultative Cheaters

Matrix for 2 strains R_1S_1 and R_2S_2

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Facultative Cheaters

Matrix for 2 strains R_1S_1 and R_2S_2

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Obligate Cheater

Matrix for 2 strains R_1S_1 and R_0S_0

$$\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$$

Facultative Cheaters

Matrix for 2 strains R_1S_1 and R_2S_2

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Obligate Cheater

Matrix for 2 strains R_1S_1 and R_0S_0

$$\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$$

Custom Matrix

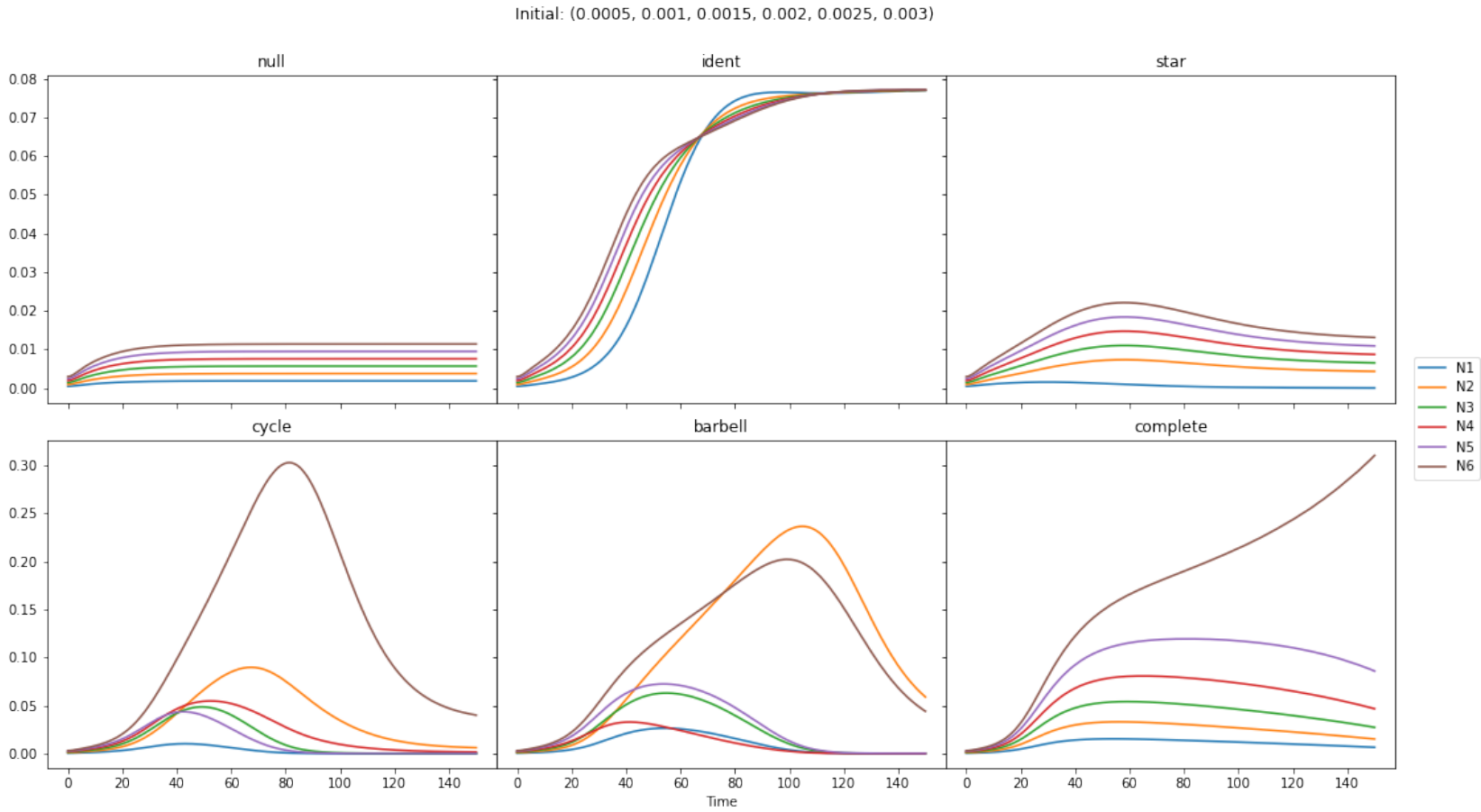
Matrix for 2 strains $R_1R_2S_1$ and R_2S_2

or 3 strains R_1S_1, R_2S_1 and R_2S_2

$$\begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$$

Results

Comparing Different K_ac Matrices



How K_ac Sparsity Affects Population Structure

Simulating With Human Gut Microbiome Data

Discussion

Chaining $K_a c$ has strong effects on model dynamics

- changes can occur independent of sparsity

Discussion

Chaining $K_a c$ has strong effects on model dynamics

- changes can occur independent of sparsity
- decreasing sparsity does . . .

Bibliography I

Aggarwal, Surya D., Hasan Yesilkaya, Suzanne Dawid, and N. Luisa Hiller. 2020. "The Pneumococcal Social Network." *PLOS Pathogens* 16 (10). https://doi.org/10.1371/journal.ppat.1008931.

Calle, M. Luz. 2019. "Statistical Analysis of Metagenomics Data." *Genomics &Amp; Informatics* 17 (1). https://doi.org/10.5808/gi.2019.17.1.e6.

Dimitriu, Tatiana, Frances Medaney, Elli Amanatidou, Jessica Forsyth, Richard J. Ellis, and Ben Raymond. 2019. "Negative Frequency Dependent Selection on Plasmid Carriage and Low Fitness Costs Maintain Extended Spectrum Beta-Lactamases in Escherichia Coli." *Scientific Reports* 9 (1). https://doi.org/10.1038/s41598-019-53575-7.

Bibliography II

Eldar, A. 2011. "Social Conflict Drives the Evolutionary Divergence of Quorum Sensing." *Proceedings of the National Academy of Sciences* 108 (33): 13635–40. https://doi.org/10.1073/pnas.1102923108.

Pérez-Escudero, Alfonso, and Jeff Gore. 2016. "Selection Favors Incompatible Signaling in Bacteria." *Proceedings of the National Academy of Sciences* 113 (8): 1968–70. https://doi.org/10.1073/pnas.1600174113.

Bibliography III

Pollak, Shaul, Shira Omer-Bendori, Eran Even-Tov, Valeria Lipsman, Tasneem Bareia, Ishay Ben-Zion, and Avigdor Eldar. 2016. "Facultative Cheating Supports the Coexistence of Diverse Quorum-Sensing Alleles." *Proceedings of the National Academy of Sciences* 113 (8): 2152–7. https://doi.org/10.1073/pnas.1520615113.

Waters, Christopher M, and Bonnie L. Bassler. 2005. "Quorum Sensing: Cell-to-Cell Communication in Bacteria." *Annual Review of Cell and Developmental Biology* 21: 319–46. https://doi.org/10.1146/annurev.cellbio.21.012704.131001.