Race to Domination: a community competition study of *Escherichia coli*, *Geobacter sulfurreducens*, and *Rhodoferax ferrireducens*

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Rhodoferax ferrireducens can oxidize both glucose and acetate while *Geobacter sulfurreducens* is dependent on fermenters for acetate. It is surprising that *Rhodoferax ferrireducens* are outnumbered by *Geobacter sulfurreducens* in anaerobic aquifers and sediments. We hypothesize that fermenters and *G. sulfurreducens* form a coculture to out-compete *R. ferrireducens*. Under substrate rich conditions, fermenters first out-compete *R. ferrireducens* for glucose using r-strategy[1], and convert glucose to acetate; then, *G. sulfurreducens* out-competes *R. ferrireducens* for acetate using r-strategy. Under substrate limiting conditions, the coculture lacks sufficient substrate to exploit the r-strategy efficiently, leaving a niche for *R. ferrireducens*.

To investigate the dynamic of microbial community formation in aquifers and sediments, we created a dynamic *in silico* model of *Escherichia coli*, *G. sulfurreducens*, and *R. ferrireducens* triculture to test our hypothesis. Metabolic models that are solely based on flux balances do not take biomass concentration into account, and hence are insufficient for studying microbial competition.[2][3]

Aquifers were modeled with continuous flow while sediments were modeled with intermittent flow. Kinetic parameters were acquired from the literature. Four sets of two-thousand simulations with randomized parameters were performed. The randomized sets are defined by having either high or low maximum glucose feed (1mM/hr vs 0.1mM/hr), and either contain *R. ferrireducens* strain A or strain B. Strain A is assumed to use glucose and acetate simultaneously while strain B is assumed to preferentially use glucose. For the sensitivity analysis, kinetic parameters are varied between 25% and 400% of their literature values.

G. sulfurreducens dominates in the majority of simulations, confirming our observation in nature. *R. ferrireducens* dominates significantly more often in glucose limiting conditions, a result that matches our hypothesis. (Figure 1) Under glucose rich conditions, glucose feed concentration shows the highest positive correlation to G/R* ratio - more glucose allows fermenters to exploit the r-strategy more efficiently. (Figure 2a, 2b) Under glucose limiting conditions, fermenters' r-strategy fails and *G. sulfurreducens* success becomes highly dependent on its own initial concentration. (Figure 2c, 2d)

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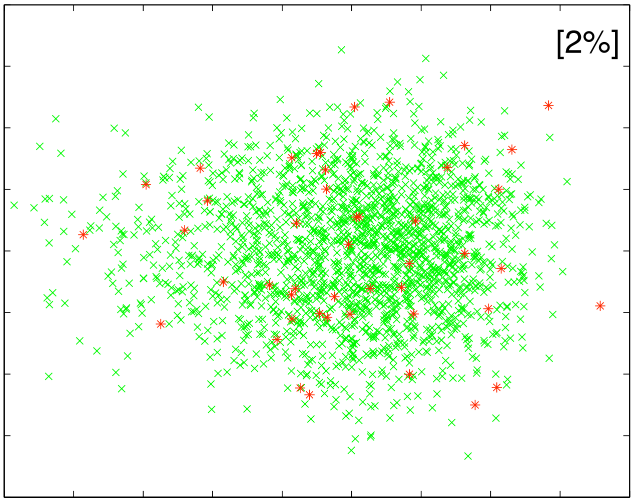
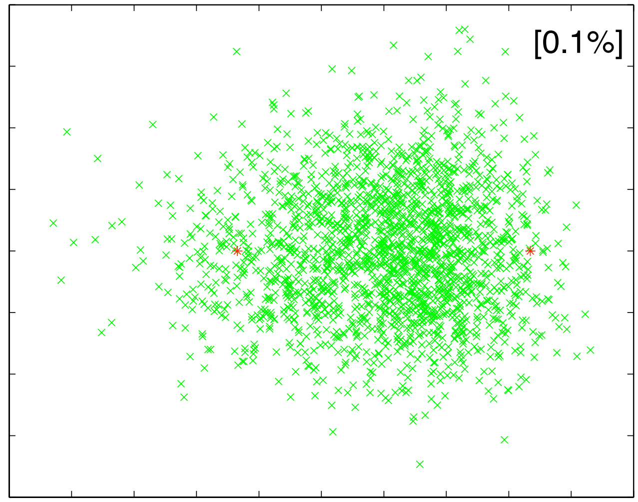
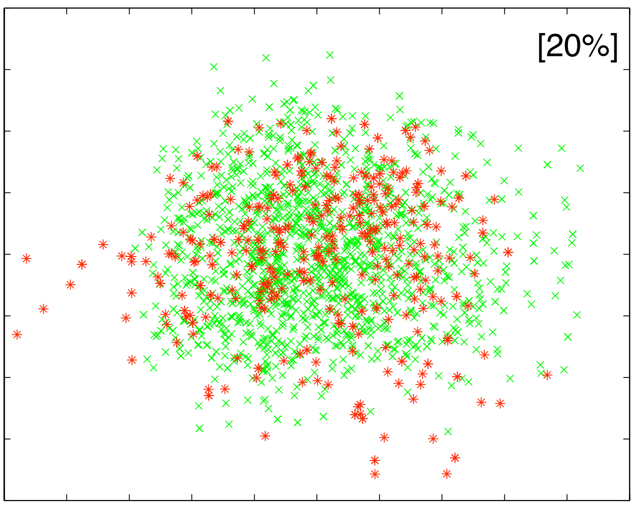
* G/R: G. sulfurreducens to R. ferrireducens ratio



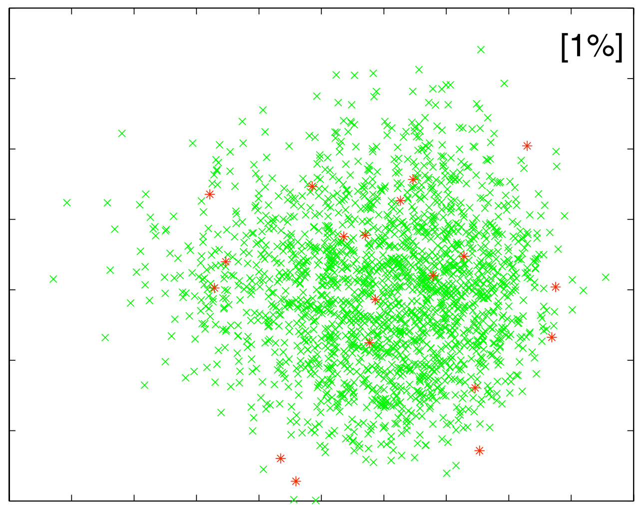
1a. High $[Glc]_{feed\mathbf{MAX}}$, RF strain A



1b. High $[Glc]_{feed\mathbf{MAX}}$, RF strain B



1c. Low $[Glc]_{feed\mathbf{MAX}}$, RF strain A



1d. Low $[Glc]_{feed\mathbf{MAX}}$, RF strain B

Figure 1. PCA visualization of species dominance

Principal component analysis (PCA) is used to compress the multi-dimensional data into 2D for visualization purpose. ✻ represent simulations where *R. ferrireducens* is the dominant population, x represent simulations where *G. sulfurreducens* is the dominant population. The number in [] shows percentage of the simulations in a set that are dominated by *R. ferrireducens*.

Interestingly, *R. ferrireducens* strain A dominates significantly more often than strain B, suggesting that the ability to utilize glucose and acetate simultaneously offers a competitive advantage. We hypothesize that *R. ferrireducens* either has evolved such features already or can be adaptively evolved to do so. This is to be experimentally verified.

[1] B. Rittmann and P McCarthy. Environmental Biotechnology. 2001. p108-109.
[2] R. Mahadevan et al. Characterization of Metabolism in the Fe(III)-Reducing Organism *Geobacter sulfurreducens* by Constraint-Based Modeling. Appl Environ Micro. 2006.
[3] S. Stolyar et al. Metabolic modeling of a mutualistic microbial community. Mol Syst Bio. 2007.

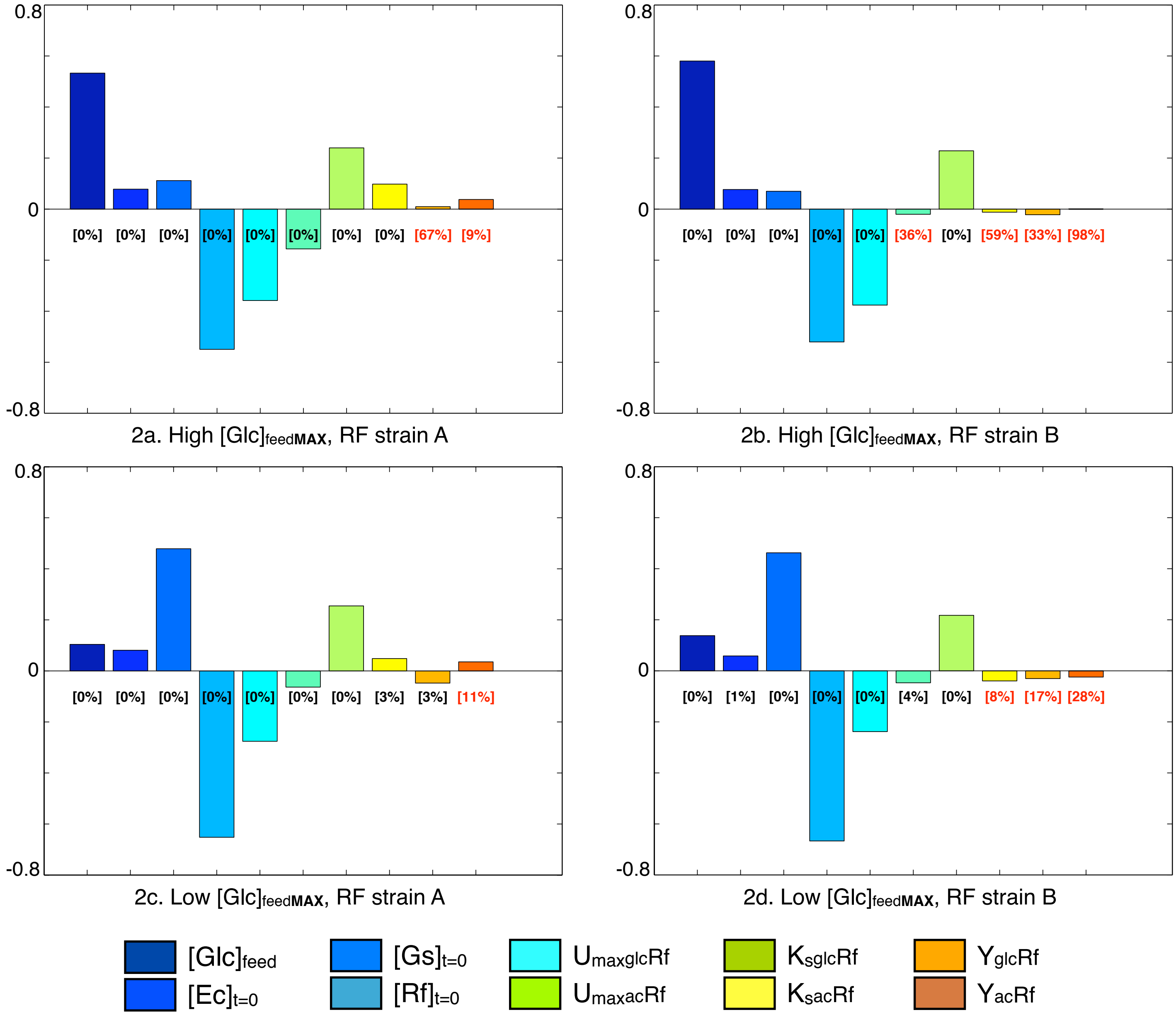


Figure 2. Correlation coefficients with respect to *G.sulfurreducens*:*R.ferrireducens* ratio

A bar height in the positive direction shows positive correlation. The number in [ ] shows the P-values, where a value of lower than 5% shows that the correlation is statistically significant.