Bacterial warfare

A curious story of evolutionary strategies

Hari Prasad Sreekrishnapurath Variyam

Part I : Evolution and Ecology of Bacterial Warfare

Current Biology
Review

The Evolution and Ecology of Bacterial Warfare

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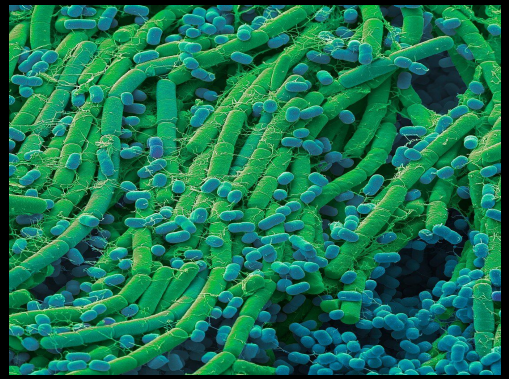
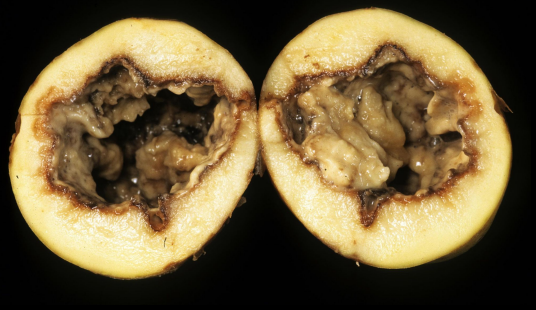
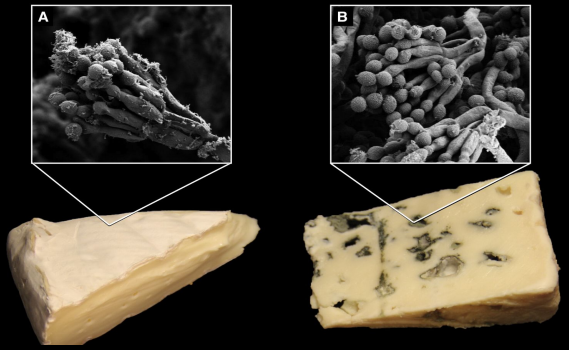
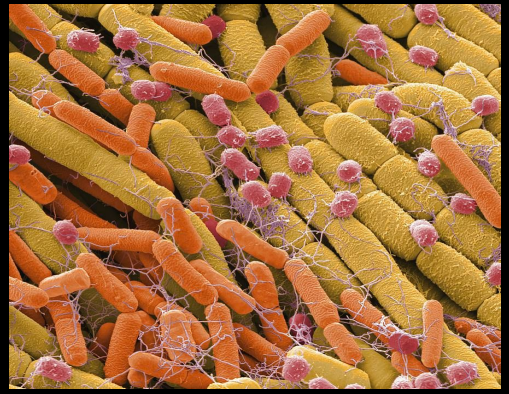
Granato et al. Curr. Bio 2019

The dense microbiome



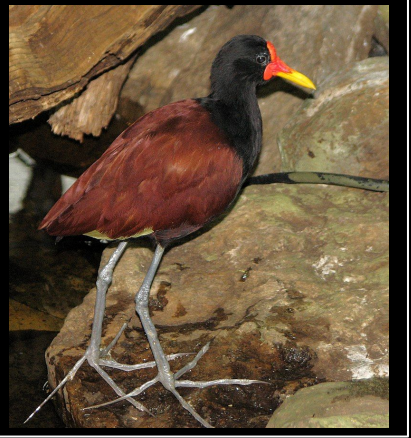






The core social animal behaviours

Effect on actor \ Effect on recipient	+	−
+	mutualism	selfishness
−	altruism	spite



Hamilton's relation of kin selection and Spite

J. Theoret. Biol. (1964) **7**, 1–16

The Genetical Evolution of Social Behaviour. I

W. D. HAMILTON

The Galton Laboratory, University College, London, W.C.2

(*Received* 13 *May* 1963, *and in revised form* 24 *February* 1964)

J. Theoret. Biol. (1964) **7**, 17–52

The Genetical Evolution of Social Behaviour. II

W. D. HAMILTON

The Galton Laboratory, University College, London, W.C.2

(*Received* 13 *May* 1963, *and in revised form* 20 *March* 1964)

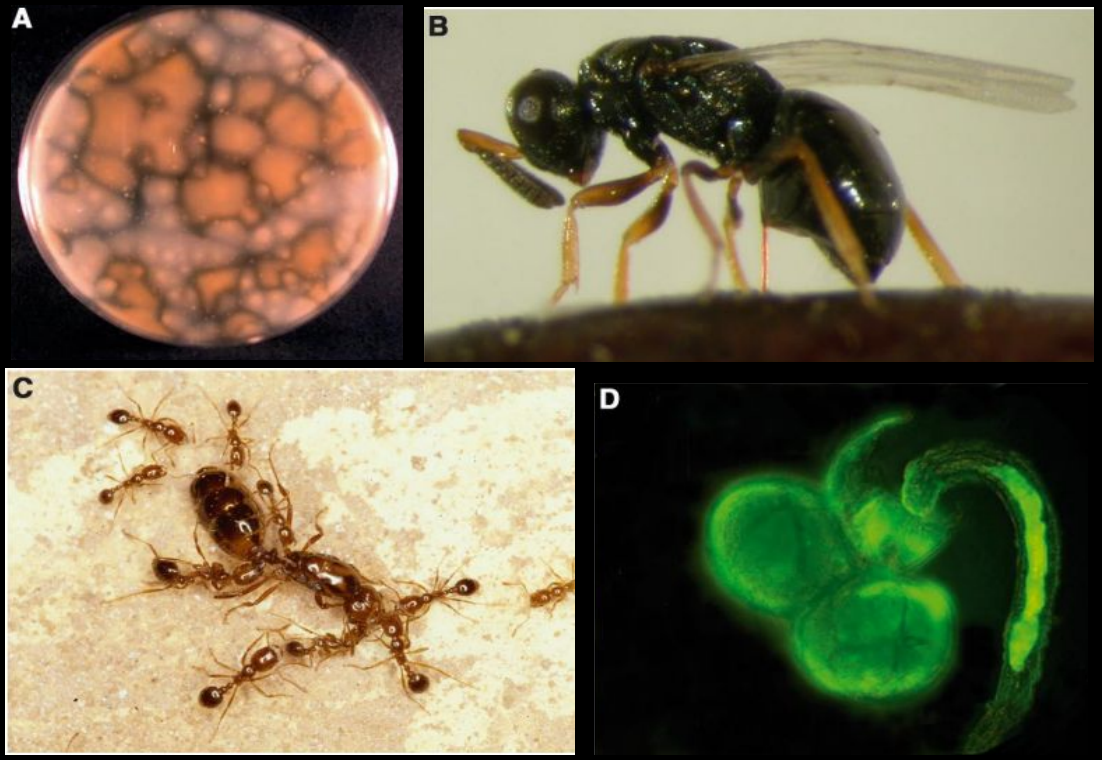
Costly to actor → Beneficial to recipient

$$r > \frac{c}{b}$$

$$r < 0 \rightarrow Spite!$$

Bucci et al. The American naturalist. 2011.

Spite - Common Examples



A. Two strains of the bacterium Photorhabdus luminescens (pink versus orange) engage in chemical warfare

B. The bacterium Wolbachia causes males to spitefully sterilize females in many species of insects

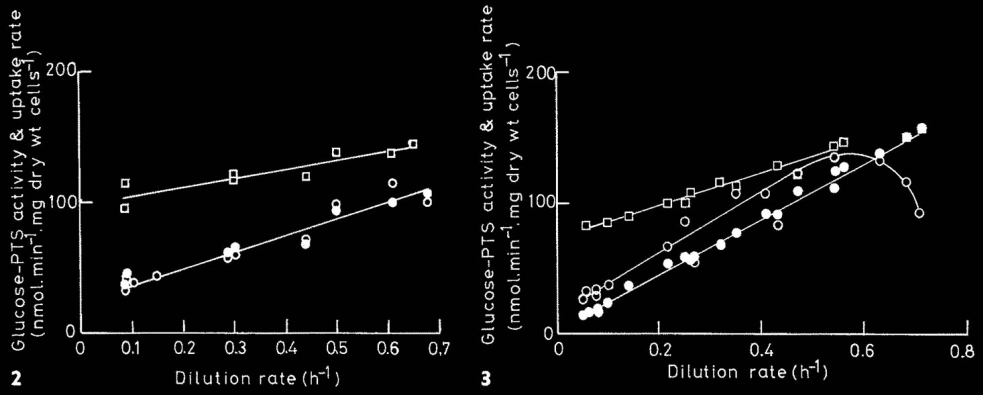
C. Red fire ant workers execute a queen who carries the wrong genes

D. A suicidal soldier of the parasitoid wasp Copodisoma floridanum murders and eats her embryonic hostmate

Gardner et al. Curr. Bio 2006

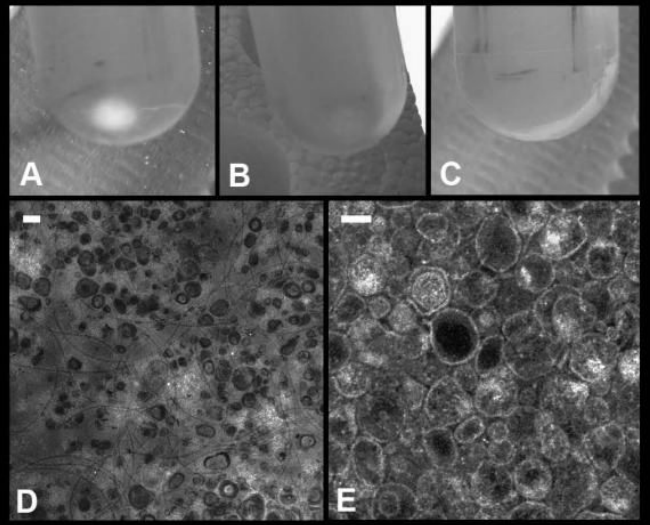
Competition between the bacterial communities

Exploitative competition



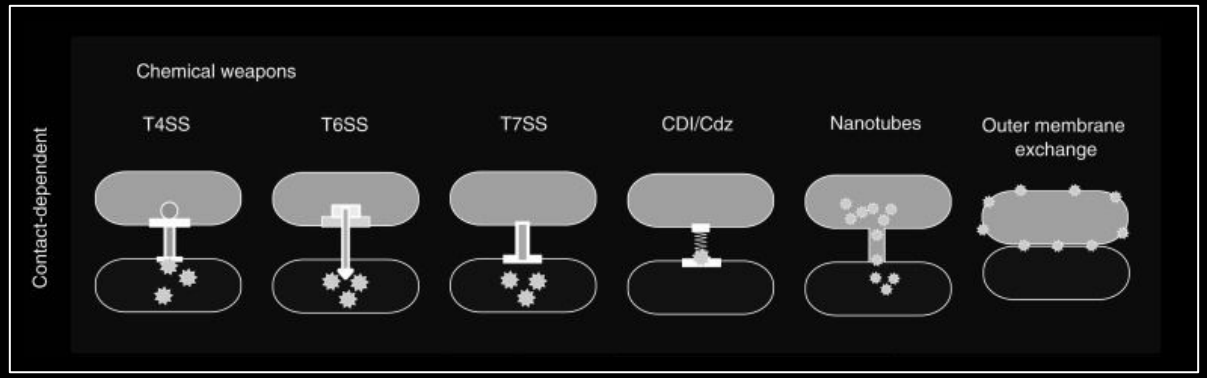
Neijssel et al. 1980

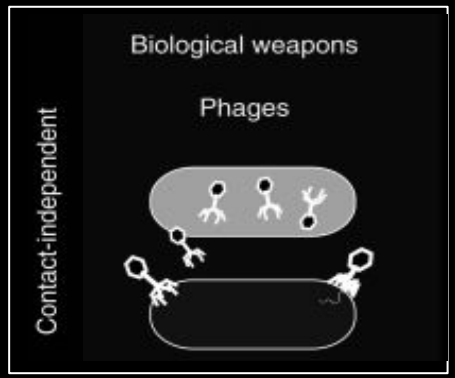
Interference competition

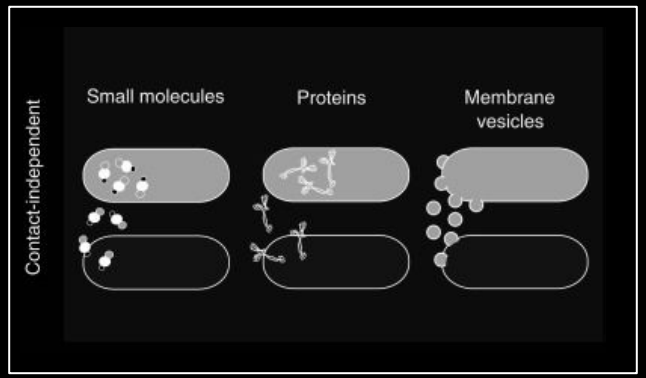


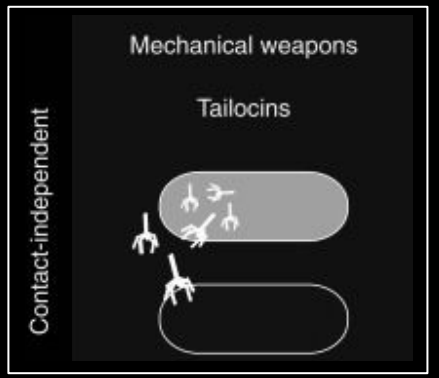
Brown et al. 2014

A plethora of defence mechanisms



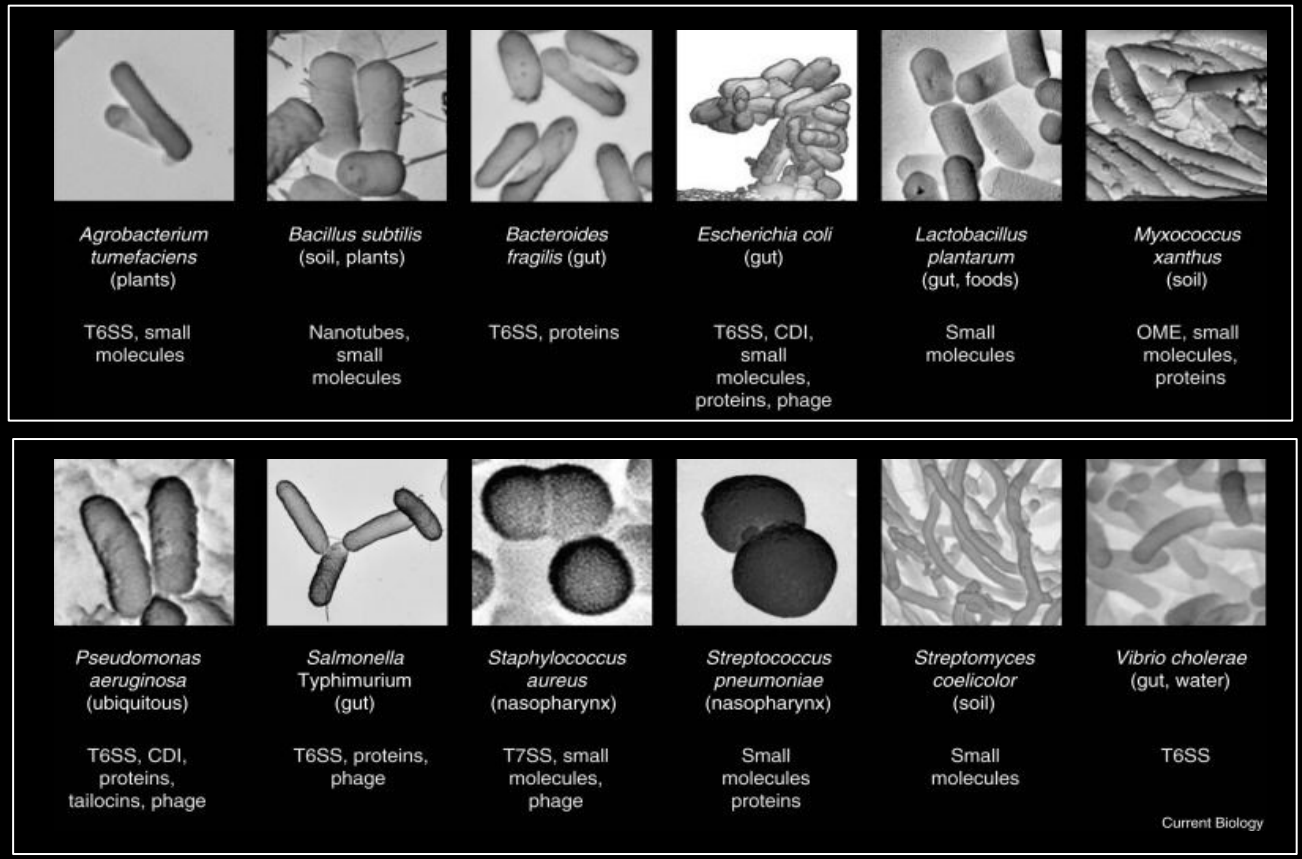






Granato et al. Curr. Bio 2019

A plethora of examples!



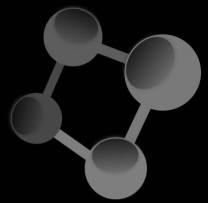
Granato et al. Curr. Bio 2019

Why evolve warfare mechanisms?

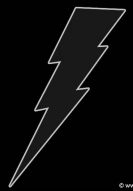
Competition for resources

Density and frequency dependance

Nutrient conditions

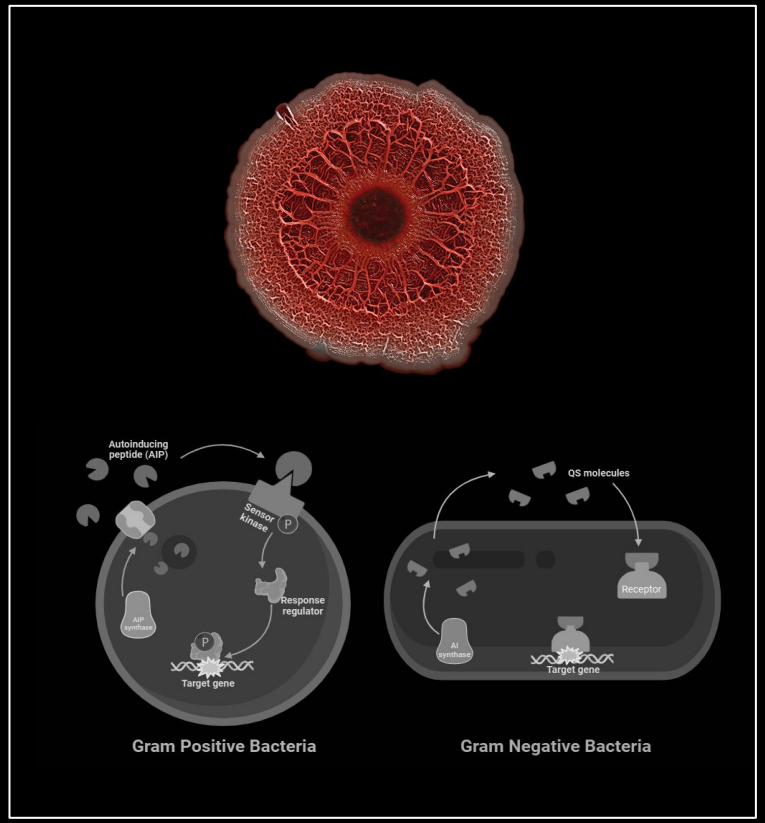


Spatial structure



Spiteful behaviours

Uniqueness of bacterial warfare



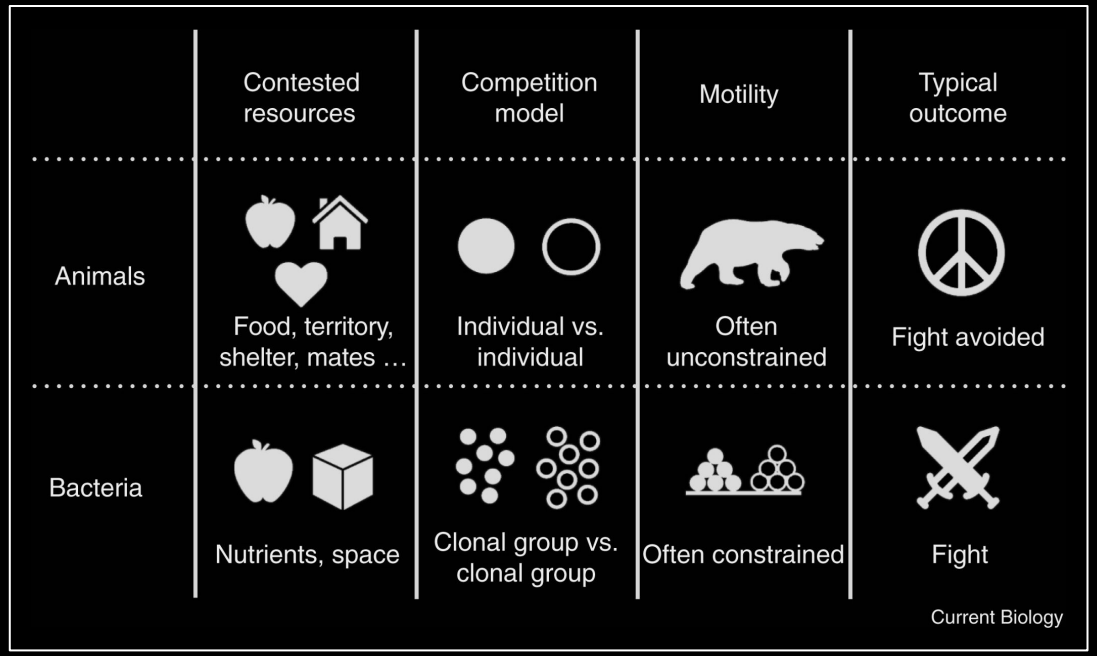
Clonal groups and Quorum sensing

Sessility

Sacrifice

Comparisons to animal contests

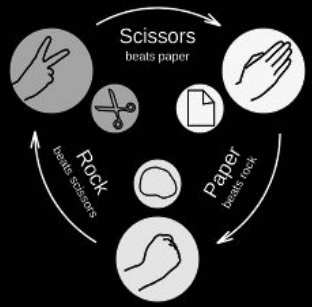
- Lethal combat
- Limited ability of dispersal → Intense aggression



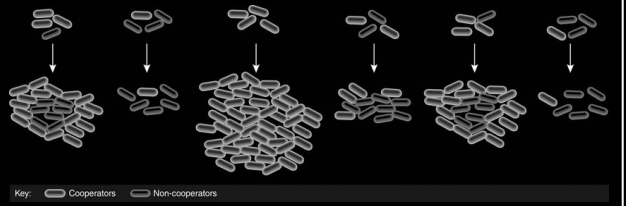
Granato et al. Curr. Bio 2019

Long term consequences

Arms-race evolution



Cyclical co-evolution and Diversity



Multilevel selection

Horizontal gene transfer

Ecological impacts

Part II : Exploring Spatial Dynamics : A Foundational Model

Allelopathy in Spatially Distributed Populations

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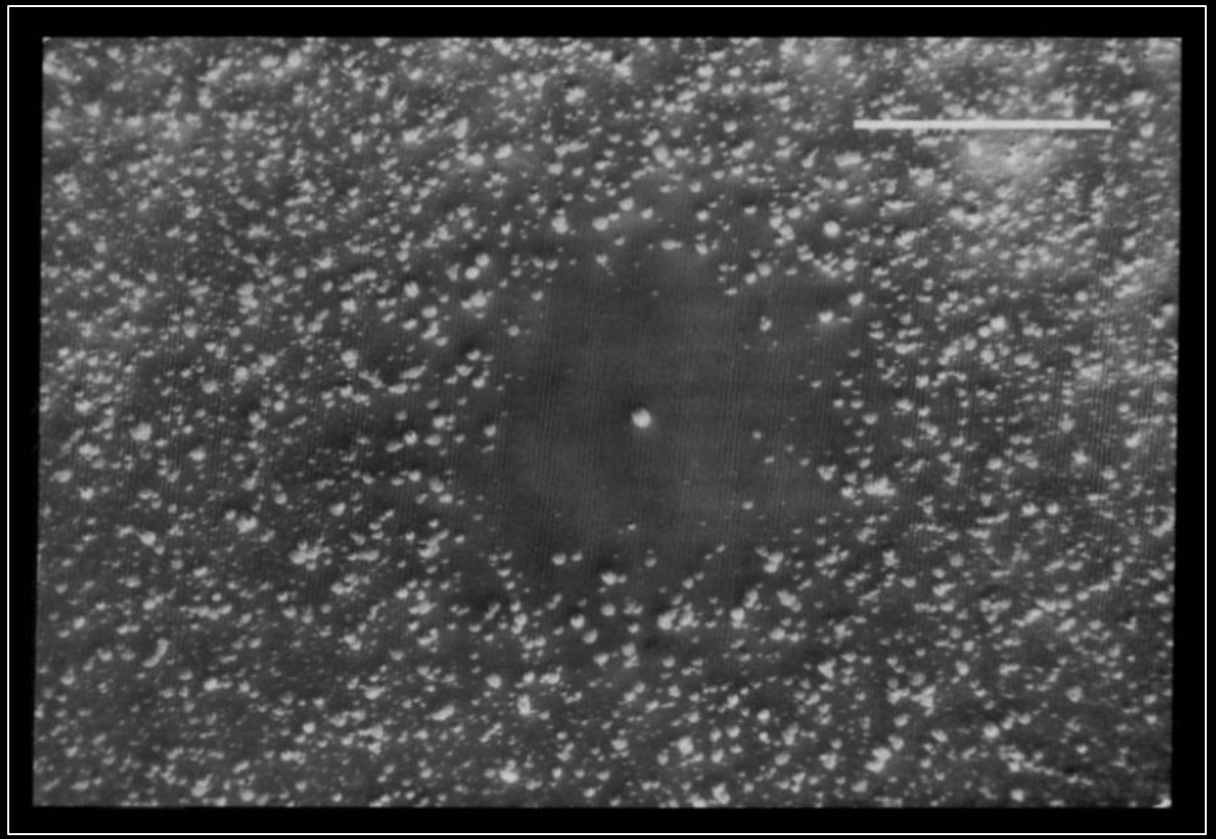
(Received on 4 April 1996, Accepted in revised form on 24 September 1996)

Durret et al. J. theor. Biol

Experimental observations



Chao & Levin 1981.

A look through ‘deterministic nonspatial’ eyes

- Assume the population of the bacteria is large and homogeneously mixing.
- Let $\mathbf{u_1}$ and $\mathbf{u_2}$ be be the densities of the ***Colicin-producing*** and ***Colicin-Sensitive*** bacteria

$$\frac{du_i}{dt} = \beta_i u_i(1 - u_i) - \delta_i u_i$$

A Two species competition model

$$\frac{du_1}{dt} = \beta_1 u_1 (1 - u_1 - u_2) - \delta_1 u_1$$

$$\frac{du_2}{dt} = \beta_2 u_2 (1 - u_1 - u_2) - \delta_2 u_2 - \gamma u_1 u_2$$

Two locally stable boundary equilibria given :

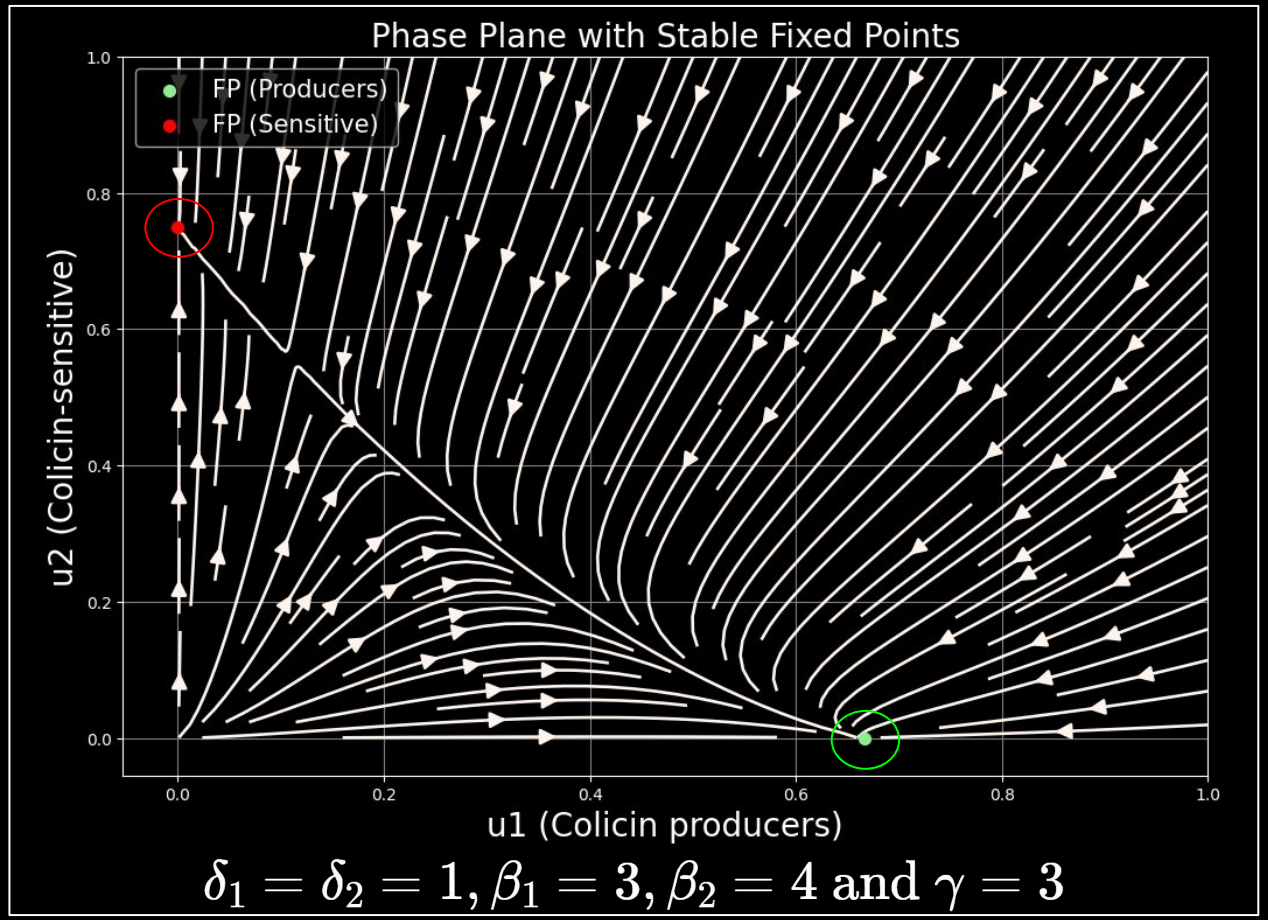
$\delta_1 < \beta_1$

$\frac{\delta_2}{\beta_2} < \frac{\delta_1}{\beta_1}$

$\frac{\delta_1}{\beta_1} < \frac{\delta_2 + \gamma}{\delta_1 + \gamma}$

$$\left(1 - \frac{\delta_1}{\beta_1}, 0\right) \& \left(0, 1 - \frac{\delta_2}{\beta_2}\right)$$

Stability analysis



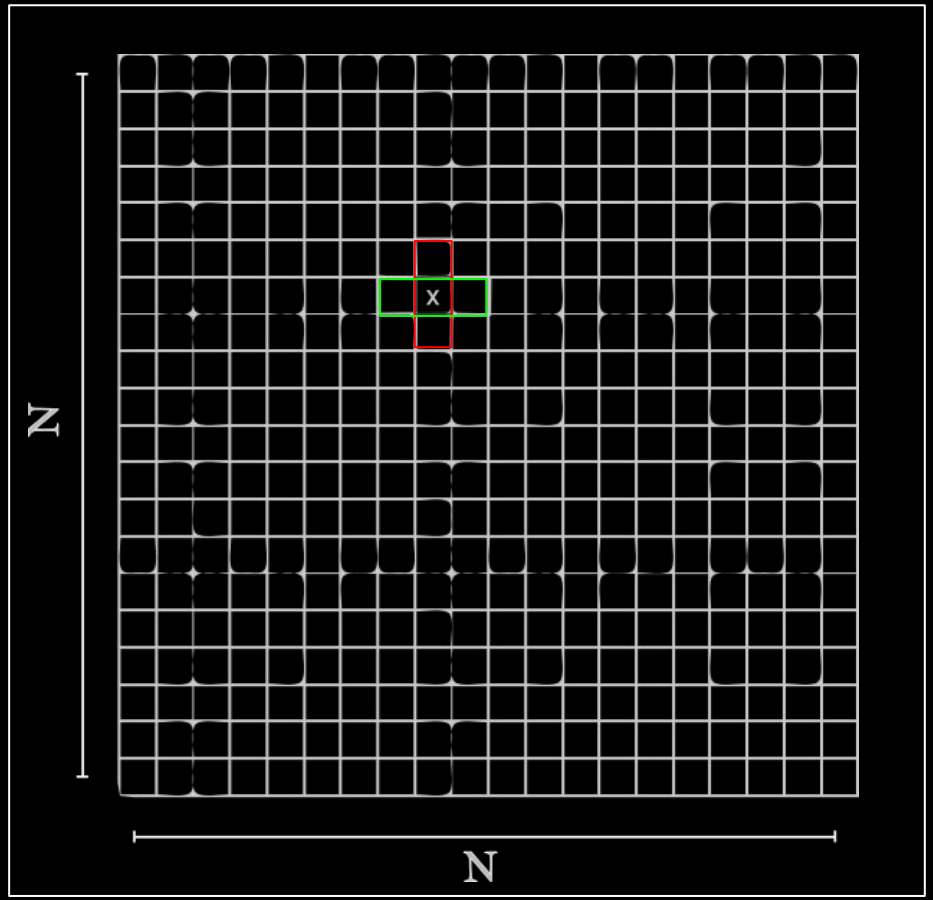
$\delta_1 = \delta_2 = 1, \beta_1 = 3, \beta_2 = 4$ and $\gamma = 3$

Spatial model

Agent based modelling approach

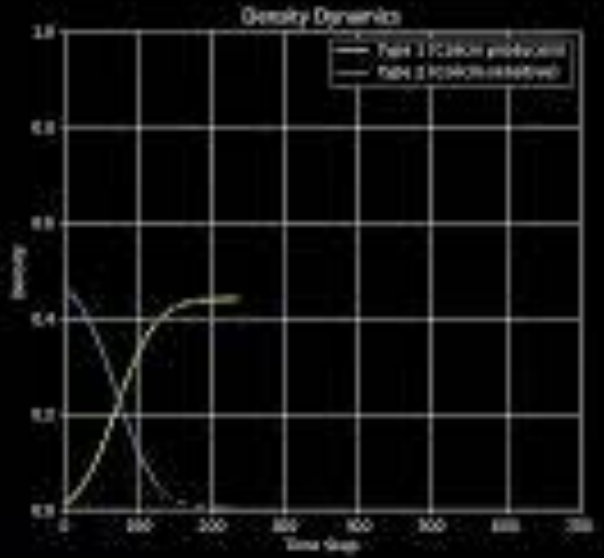
$$\zeta_t : \mathcal{Z}^2 \rightarrow \{0, 1, 2\}$$

birth	rate	death	rate
$0 \rightarrow 1$	$\beta_1 f_1$	$1 \rightarrow 0$	δ_1
$0 \rightarrow 2$	$\beta_2 f_2$	$2 \rightarrow 0$	$\delta_2 + \gamma f_1$



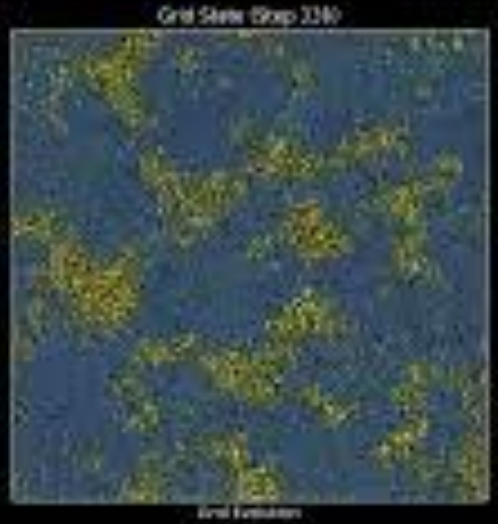
f_i - Fraction of neighbours of kind 'i'

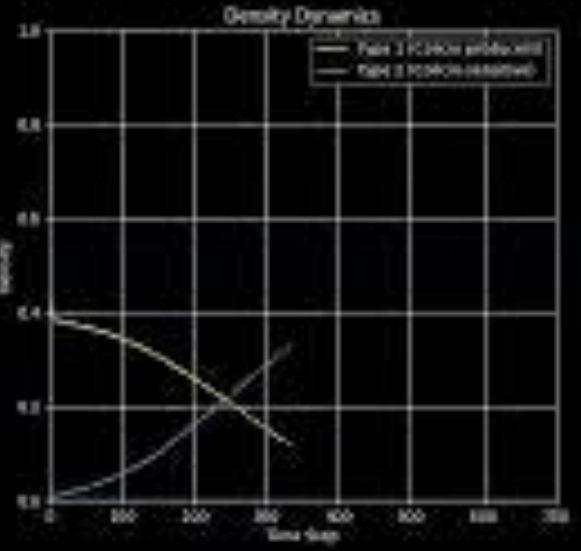
Results – Producer strain wins



$$\delta_1 = \delta_2 = 1, \beta_1 = 3, \beta_2 = 4 \text{ and } \gamma = 3$$

Results – Sensitive strain wins





$$\delta_1 = \delta_2 = 1, \beta_1 = 3, \beta_2 = 4 \text{ and } \gamma = 1$$

The End

Acknowledgements : Dr. Rotem Gross

References

1. Granato, E. T., Meiller-Legrand, T. A., & Foster, K. R. (2019). The evolution and ecology of bacterial warfare. Current Biology, 29 (11)

2. Durrett, R., & Levin, S. (1997). Allelopathy in spatially distributed populations. Journal of Theoretical Biology

3. Bucci, V., Nadell, C. D., & Xavier, J. B. (2011). The evolution of bacteriocin production in bacterial biofilms. The American Naturalist

4. Chao, L., & Levin, B. R. (1981). Structured habitats and the evolution of anticompetitor toxins in bacteria. Proceedings of the National Academy of Sciences.