

Collective behavior in bacteria

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Outline

- Importance
- Our microbial bias
- Quorum sensing
- Biofilms
 - Physiology
 - Development
 - Prokaryotic stab at multicellularity?
- Discussion
 - But ask questions/make comments as we go!

Importance

- Microbial ecology
 - Ecosystem functions, nutrient cycling
 - Agricultural and environmental apps
 - Interactions with eukaryotes
- Microbial cooperation is important!

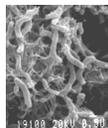
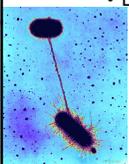
Know your horsemen...

(We'll focus on this
guy today)



Cooperation and disease

- Many bacteria only harmful when *cooperating*...
 - Conjugative plasmid transfer
 - Quorum-sensing
 - Biofilms colonize anything



Medical applications?

- Can this help us understand disease?
 - *Can we find ways to disrupt cooperation?*

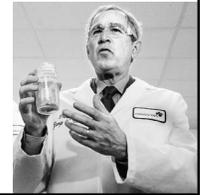
Can they *do* that?

- Bacteria exist?!
 - van Leeuwenhoek, 1676; Ehrenberg, 1838
- Bacteria have genetic material?!
 - Griffiths, 1928; Avery et al., 1944
- Bacteria communicate?!
 - Bassler et al., 1997



Can they *do* that?

- We're making progress
- What do we know? What don't we?



Gene regulation

- Gene expression initially repressed
- De-repression *when appropriate*
 - Often elaborate mechanisms to connect expression to state of cell

Gene regulation

Example: *lac* operon in *E. coli*

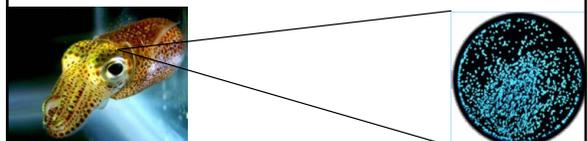
- Lactose binds to repressor so transcription of galactosidase is *possible*
 - No lactose means expression of gene is repressed
- cAMP indicates lack of ATP; binds to CAP, which binds to DNA opening a transcription fork, allowing for RNAP to bind
 - When preferred carbon source is present (glucose), bacterium won't bother with lactose

Gene regulation

Bacterial gene expression can be remarkably well-tuned to the environment

Density-dependence

- First observed in *Vibrio fischeri*
- Cells only glow in sufficient densities
 - Cells glow readily in the presence of filtrate from dense populations!



Mechanism

- Bacteria produce signals that diffuse into the environment
 - *N*-acyl-homoserine lactones (AHLs): gram negative bacteria
 - peptides: gram positive bacteria
 - High specificity

Signal gradients

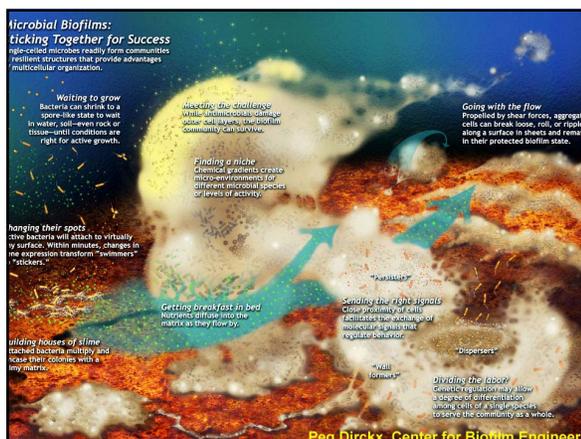
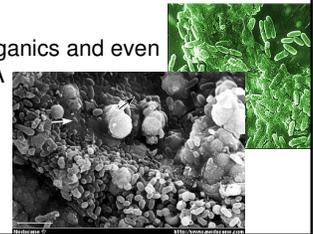
- Signal builds up in environment
 - High densities
 - Low diffusivity
- Signal builds up in cell
 - Changes gene regulation

Importance of QS in disease

- ~10% of *P. aeruginosa* genes controlled by QS
- Virulence factors controlled by QS
 - Avoid host immune system early on?

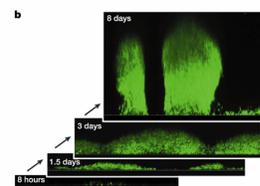
Biofilms: overview

- Sessile microbial communities
- Cells suspended in extracellular polymer (ECP) matrix
 - Metabolites, inorganics and even extracellular DNA
 - Homeostasis?



Biofilms: basic physiology

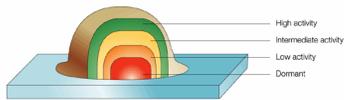
- May be highly differentiated
 - Microcolonies with gaps between them



Nature Reviews | Molecular Cell Biology

Biofilms: basic physiology

- May be highly differentiated
 - Microcolonies with gaps between them
 - May grow together to form a continuous film above the substratum



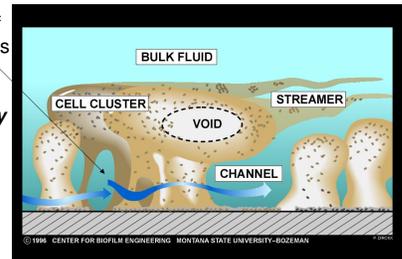
Nature Reviews | Drug Discovery

Biofilms: basic physiology

Channels allow greater infiltration of oxygen and nutrients

Is this a circulatory system?

(No.)



Self-organization and selection

- Many instances of S.O. out of range of selection
 - Behavior of “selfish herd” not adaptive
 - It emerges from tons of selfish individuals
 - Food web structure not selected on
 - It emerges in a selfish community
- *Microbial community assembly and development under selection?*

Crespi (2001)

- “Few links have been made between genetic population structure and social behavior in microorganisms, but little is known supports the idea that high genetic relatedness facilitates cooperation.”
- What about biofilms with multiple founders?
- What about *multi-species biofilms*?

Crespi (2001) on cheating

- “Are there bacterial strains or species specialized for exploitation of the resources produced by other bacteria, in habitats such as biofilms, human infections, and soil?”
- Let's speculate! I say NO.
 - What do you think?

Parsek & Greenberg (2005)

- “If one accepts that mutations in quorum sensing affect the ability of *P. aeruginosa* to form highly structured biofilms, the question of ‘Why?’ still remains.”

Parsek & Greenberg (2005)

- Review of knockout studies
- QS seems important in biofilms
 - Or is it? Pleiotropic effects...
- How reliable are these conclusions?

Parsek & Greenberg (2005)

- "If one accepts that mutations in quorum sensing affect the ability of *P. aeruginosa* to form highly structured biofilms, the question of 'Why?' still remains."
 - Mutant biofilms fragile?
- **Or is quorum sensing "simply insignificant"?**

Outlook

- *Much* left to know
- Many kinds of biofilm
 - Dental biofilms: > 100 spp.
 - Cyanobacterial films: allelopathy and signalling
- People research microbes that hurt people
 - This is likely a very incomplete picture

Outlook (continued)

- Greater understanding of microbial ecology desperately needed!
 - Predictions of theory change based on dispersal, diffusivity, motility...

Discussion: group selection

- Many of our discussions have implicitly made group selection arguments
 - Does this make anyone uncomfortable?

Discussion: multicellularity

- Does anyone have problems with these statements?
 - Biofilms are truly multicellular (in the sense of fungi, animals, plants)
 - Most people/biologists tend to think of transitions to multicellularity as pretty rare events in the history of life
 - Bacteria show that multicellularity is amazingly ancient and 'easy' to evolve

Discussion: prokaryotic limits

- What is so great about eukaryotes?
 - Why no prokaryotic dinosaurs?

Discussion: community selection

- Is anyone outraged by this idea?
- What are criteria?
- Based on what you know, would you say microbes in nature might evolve due to community-level selective pressures?
 - Do they “look” it superficially?
 - Could you explain it if they were?