Cooperative behavior between soil bacteria

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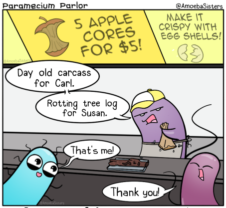
Introduction

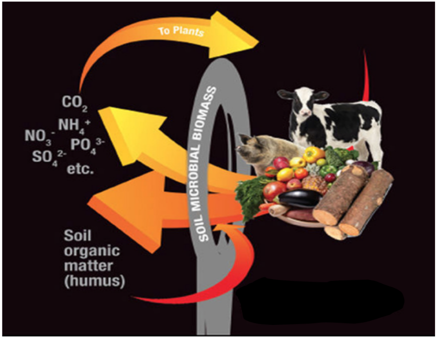
- Bacterial role in carbon cycle ?



Decomposer Cafe was a surprisingly popular spot in the food chain.

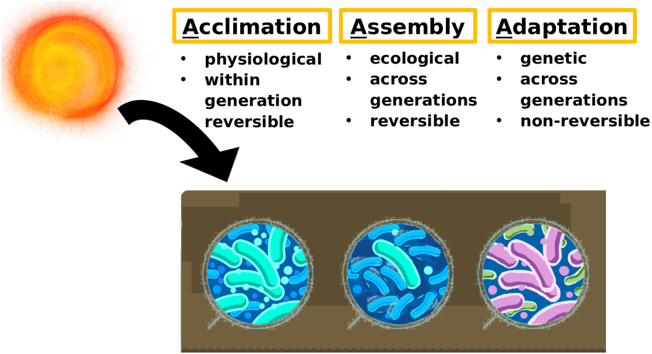
"The eye of the needle through which all organic matter entering the soil must pass"
Jenkinson 1977

Microbial C biomass = 50-80% labile C
Microbial respiration = 10x human emissions



Tate 2017, World Scientific

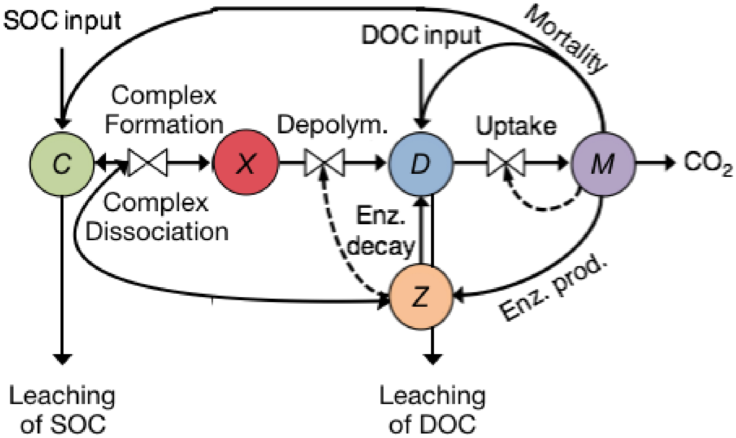
Response to changes



- Rapid evolution
- Same scale as climate change
- Not introduced in climate models

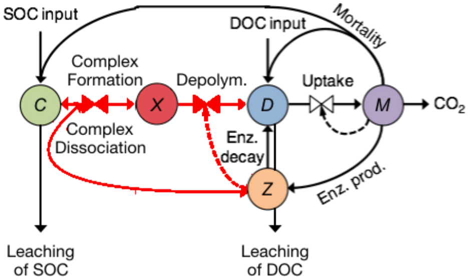
Stochastic modeling

How does enzyme production evolve ?



- Individual based-model (Fournier and Méléard 2004, Champagnat 2006, ...)

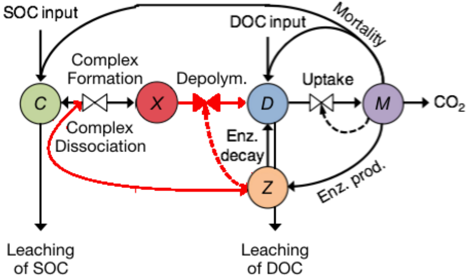
Stochastic modeling



Enzymatic reaction :

- Complex formation : rate λZC
- Complex dissociation : rate $\lambda_{-1}X$
- Decomposition : rate μX

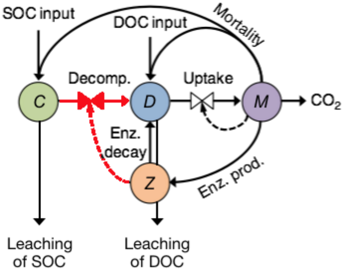
Stochastic modeling



Enzymatic reaction : fast events (Frankowicz et al. 1987)

- Complex formation : rate $\lambda Z C$
- Complex dissociation : rate $\frac{1}{\varepsilon}\lambda_{-1}X$
- Decomposition : rate $\frac{1}{\varepsilon}\mu X$

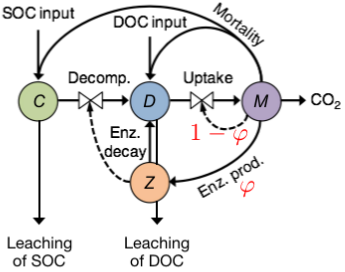
Stochastic modeling



Simplification of the model when $\varepsilon \to 0$

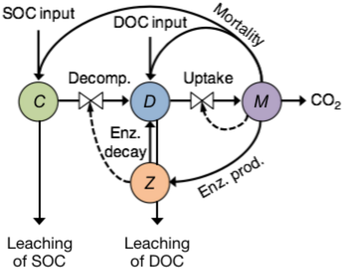
- Complex formation : rate $V_{mD}ZC = \lambda \frac{\mu}{\lambda_{-1}+\mu} ZC$

Stochastic modeling



- mortality : rate d_M with release of
  - $p\alpha/\beta$ SOC
  - $(1-p)\alpha$ DOC
- growth : rate $N(1-\varphi)\gamma_M V_{mU} \frac{D}{K_{mU}+D}$
  - growth of $\frac{1}{N}$
  - disappearance of $\frac{\alpha}{\gamma_M N}$ DOC
- enzyme production : rate $\varphi\gamma_Z V_{mU} \frac{D}{K_{mU}+D}$

Stochastic modeling



- Enzyme deactivation : rate d_Z
- Leaching of SOC, DOC : rates l_C, l_D
- SOC input : constant rate I_C

Model simplification

Counting atoms of carbon :

- A bacteria is α-times larger than a DOC molecule
$$\alpha = 10^{10}$$
- A bacteria is α/β-times larger than a SOC molecule or an enzyme
$$\alpha/\beta = 10^{7}$$
- Events associated to M are slower.
- SOC, DOC and enzymes are more numerous.

Model simplification

Theorem

When $\alpha \to +\infty$ and $N \to \infty$, convergence to a PDMP where M evolves randomly according to

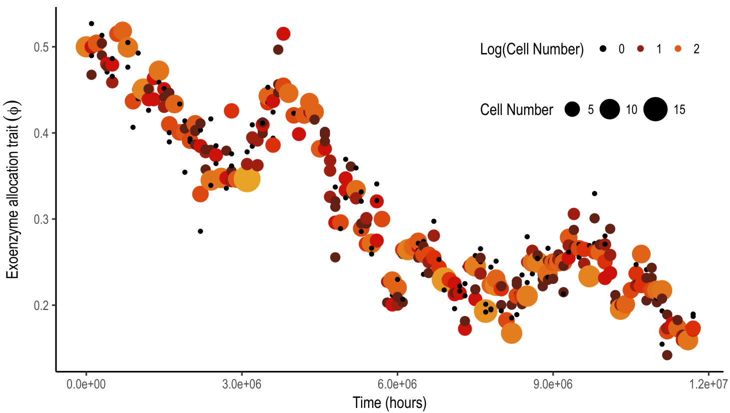
- *mortality : rate d_M with release of DOC and SOC*

between two jumps of M : (z, c, d, Δ) follow (in carbon biomass)

$$\begin{cases} z'(t) = \varphi\omega_M\gamma_Z \dfrac{V_{mU}d}{K_{mU}+d}M - d_Z z \\ c'(t) = I_C - l_C c - V_{mD}zc \\ d'(t) = I_D - l_D d + V_{mD}zc + (1-l)d_Z z - \omega_M \dfrac{V_{mU}d}{K_{mU}+d}M \\ \Delta'(t) = \omega_M(1-\varphi)\gamma_M \dfrac{V_{mU}d}{K_{mU}+d}, \end{cases}$$

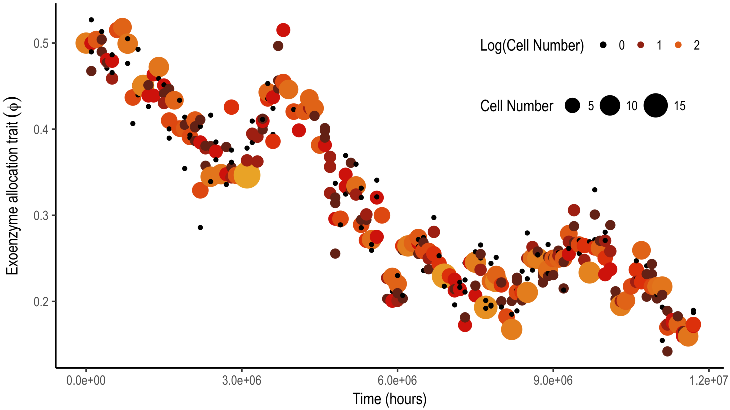
Public good dilemma

Assumptions of rare mutations on φ



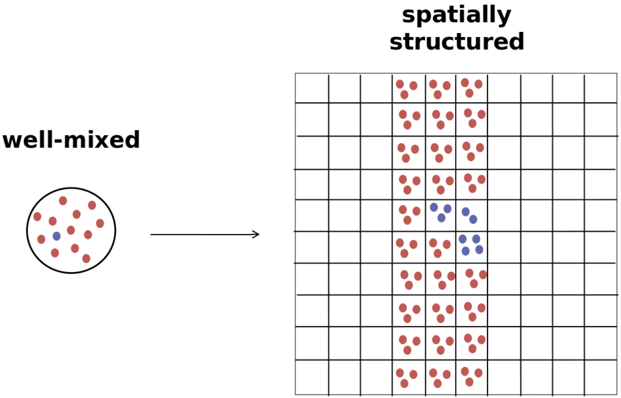
Public good dilemma

Assumptions of rare mutations on φ



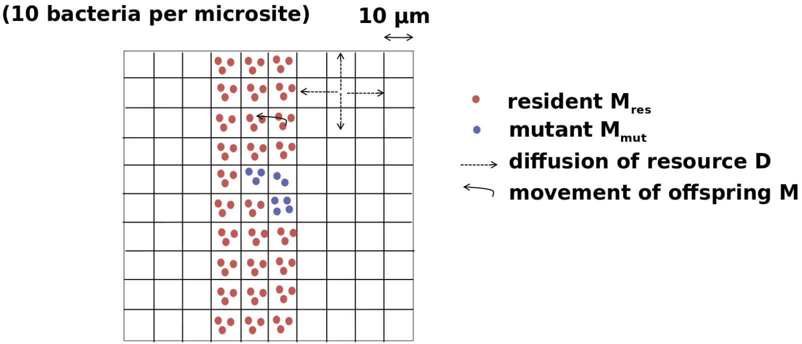
In a well-mixed environment, enzyme production is counter-selected :
Public good dilemma

Spatial model



Abs, Ferriere, Leman (in prep.)

Spatial model



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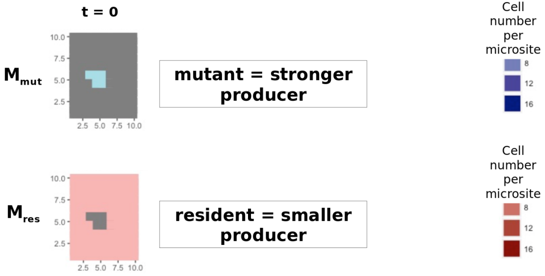
Example of dynamics



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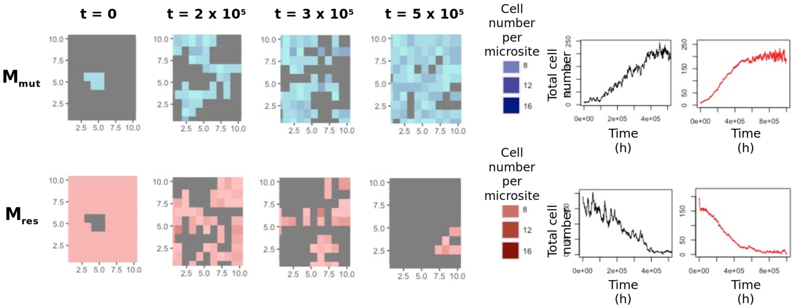

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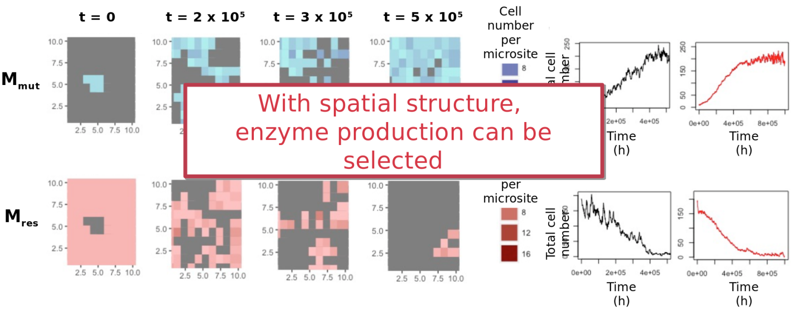
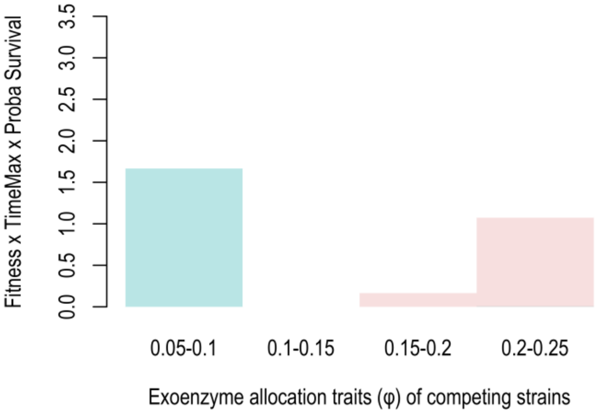


With spatial structure, enzyme production can be selected

Abs, Ferriere, Leman (in prep.)

Evolutionary response



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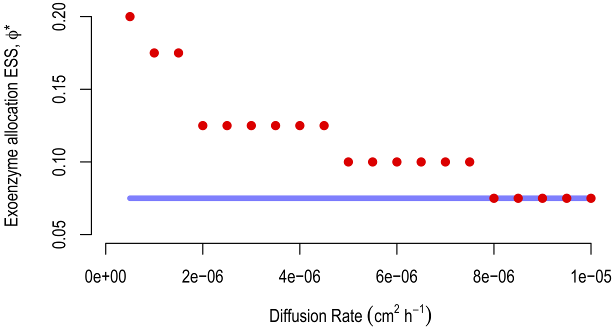

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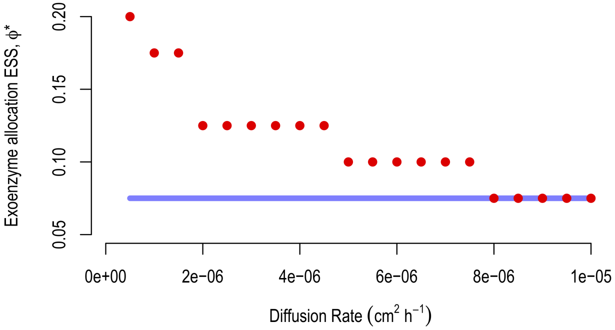
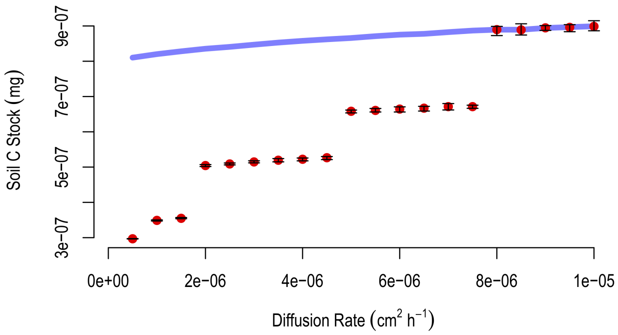


The effect of spatial structure is strongly modulated by diffusion of resources D

Effect on soil C stock



Perspectives

- Simplify spatial dynamics
- Spatial continuous setting
- Introduction of the model in a global setting

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Thank you for your attention