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Does the diversity of an ecosystem increase with dormancy?

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Chaire MMB – 18 June 2025

Outline

Introduction: What is dormancy?

1. Introducing a multi-species model of dormancy
2. Dormancy and heterogeneity
3. Dormancy and self-regulation

Conclusion

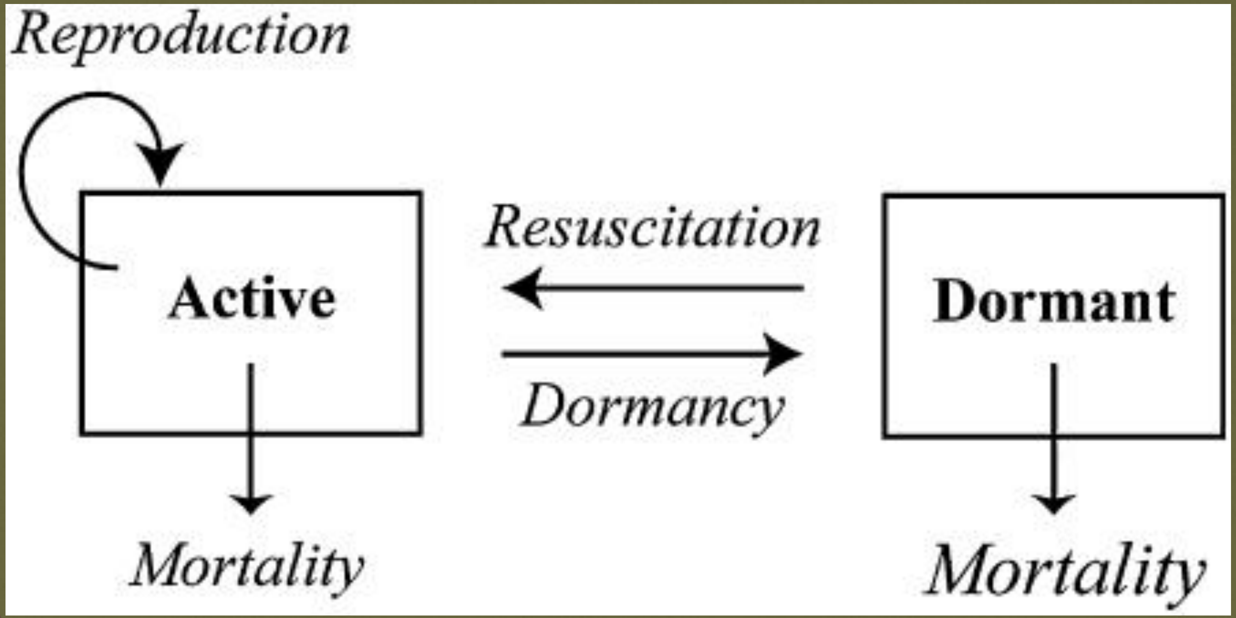
What is dormancy?

- State of low metabolic activity
- Exists in both plants and microbes
- Conflictual definition

→ Little or no growth while dormant

→ Reduced mortality

→ Stronger resistance to stress

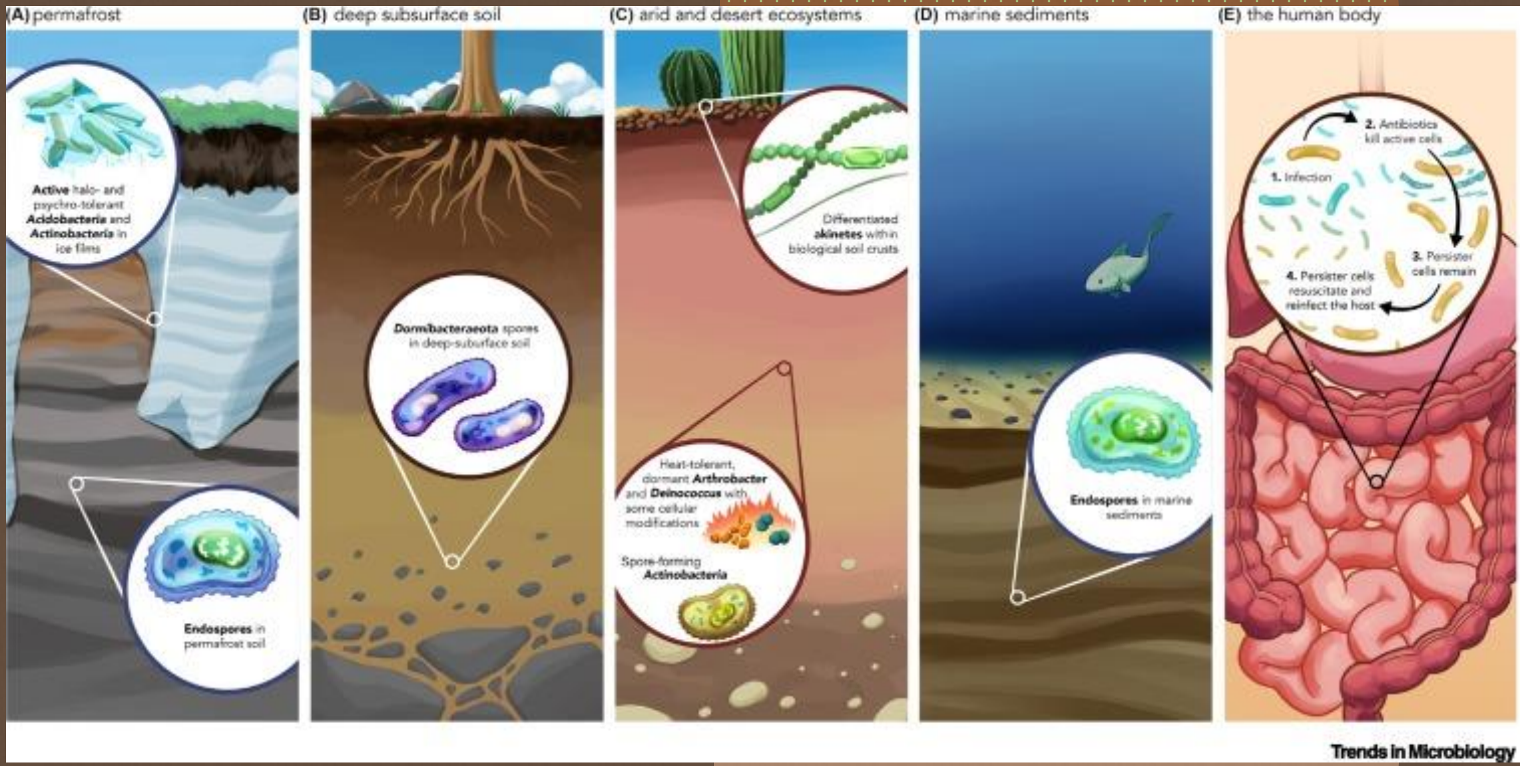


Life cycle of a microbial cell that can go dormant
(Jones and Lennon, *Proc Natl Acad Sci USA*, 2010)

Where does dormancy occur?

- For plants: most plant seeds can enter dormancy
- For microbes: extreme environments

→ Notably in the soil and the gut



Environments with many dormant microbes (McDonald, *Trends in Microbiology*, 2024)

Dormancy and diversity

Consensus that dormancy "increases" or "maintains" diversity

→ What do theoretical models say?

PNAS ARTICLES FRONT MATTER AUTHORS TOPICS +

RESEARCH ARTICLE | BIOLOGICAL SCIENCES

Dormancy contributes to the maintenance of microbial diversity

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Edited by David Karl, University of Hawaii, Honolulu, HI, and approved February 22, 2010 (received for review November 04, 2009)

March 15, 2010 | 107 (13) 5881-5886 | https://doi.org/10.1073/pnas.0912765107

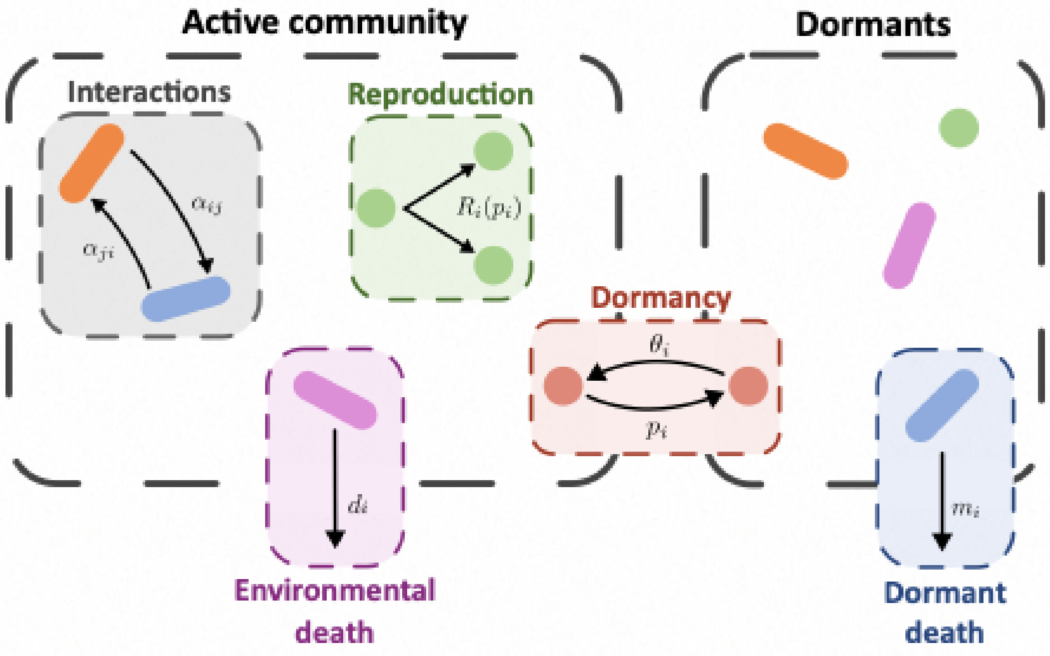
Many microorganisms can persist in a reversible state of reduced metabolic activity called dormancy. Dormancy allows microbes to survive unfavorable conditions, disperse and migrate widely, **broaden community diversity**, extend lifespan, and preserve genetic information for future generations. 22 oct. 2024

ASM Journals
https://journals.asm.org › Journal › msystems

Microbial Dormancy - ASM Journals

1. Introducing a multi-species model of dormancy

- Very large number of species
- Interactions between active species
- Reproduction of active species
- Transitions from active to dormant states



Framework of the Generalized Lotka-Volterra (GLV) model (no dormancy)

For each species i

$$\frac{\mathrm{d}N_i}{\mathrm{d}t} = N_i\left(G_i - N_i - \sum_{j\neq i}^{S} A_{i,j} N_j\right)$$

- “Giant” Lotka-Volterra with S species (S >> 1)
- Gaussian distribution of the independent growth rates G_i of species i (mean G and variance V)
- Competition interactions A_{ij} between species i and j are assumed to be random and independent, with:

$\langle A_{ij} \rangle = \frac{\mu}{S}$ and $\mathrm{Var}(A_{ij}) = \frac{\sigma^2}{S}$

→ **System characterized by 4 parameters: G, V, μ and σ**

Equilibrium properties

- **Diversity ϕ of species:** proportion of surviving species at equilibrium

- Abundance of species at equilibrium

→ Diversity is a function of $\frac{G}{\sqrt{V}}$, μ and σ:

$\phi(\frac{G}{\sqrt{V}}, \mu, \sigma)$

→ Diversity increases with $\frac{G}{\sqrt{V}}$, decreases with the strength of competitive interactions μ and σ

$$N_i^* = max\left(0, G_i - \sum_{j\neq i} A_{ij}N_j\right)$$

$$\sum_{j\neq i} A_{ij}N_j \sim \mathcal{N}\left(\mu\langle N\rangle, \sigma\sqrt{\langle N^2\rangle}\right)$$

$$\phi = \int_0^{+\infty} \frac{e^{-\frac{(t-G+\mu\langle N\rangle)^2}{2(V+\sigma^2\langle N^2\rangle)}}}{\sqrt{2\pi(V+\sigma^2\langle N^2\rangle)}}dt$$

$$\langle N\rangle = \int_0^{+\infty} \frac{te^{-\frac{(t-G+\mu\langle N\rangle)^2}{2(V+\sigma^2\langle N^2\rangle)}}}{\sqrt{2\pi(V+\sigma^2\langle N^2\rangle)}}dt$$

$$\langle N^2\rangle = \int_0^{+\infty} \frac{t^2e^{-\frac{(t-G+\mu\langle N\rangle)^2}{2(V+\sigma^2\langle N^2\rangle)}}}{\sqrt{2\pi(V+\sigma^2\langle N^2\rangle)}}dt$$

Adding dormancy to the GLV model

Regular GLV: reproduction of active individuals and interactions

Dormant individuals who awaken

Active individuals who go to sleep

$$\frac{\mathrm{d}N_i^a}{\mathrm{d}t} = N_i^a\left(G_i(p) - N_i^a - \sum_{j\neq i}^{S} A_{ij}N_j\right) + \theta_i N_i^d - f_i(\vec{N}^a)N_i^a$$

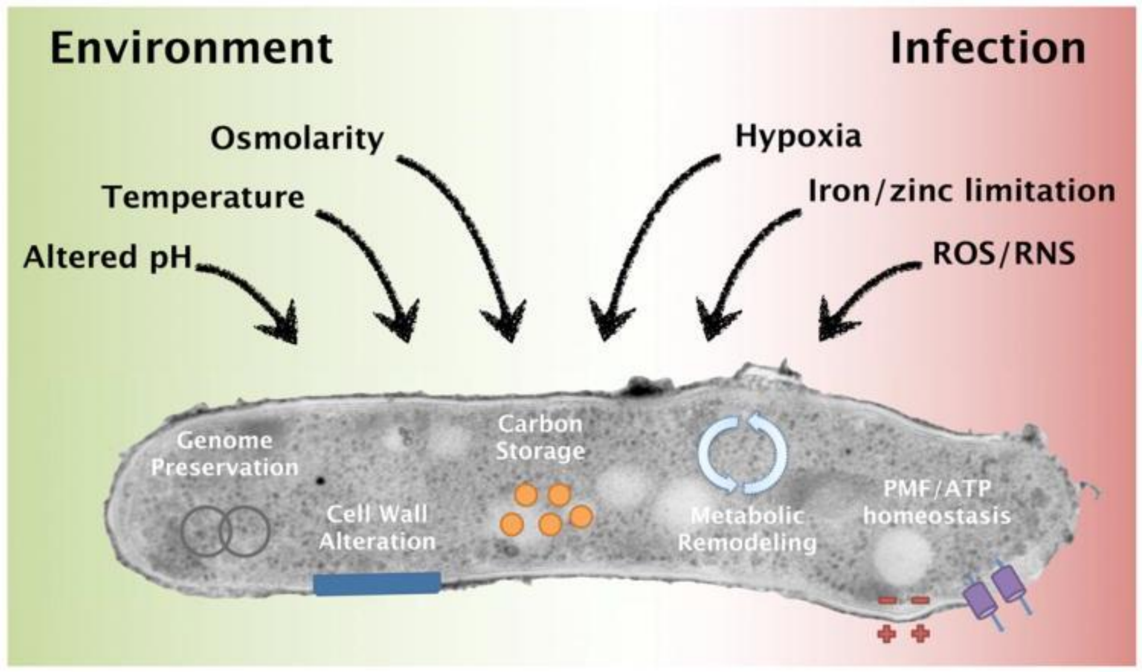
$$\frac{\mathrm{d}N_i^d}{\mathrm{d}t} = \tilde{f}_i(\vec{N}^a)N_i^a - (\theta_i + d_i)\,N_i^d$$

Death of dormant individuals

Many different types of dormancy

→ Dormancy can be triggered by many different factors

- Completely random dormancy (bet-hedging): common in plants, but also observed in micro-organisms
- Dormancy linked to abiotic factors (temperature, acidity, etc.)
- Dormancy linked to nutrient availability and/or competition
- Dormancy linked to the presence of antibiotics



Factors that can trigger dormancy and cell responses in microbes (Rittershaus, *Cell Host Microbe*, 2013)

Modeling several types of dormancy

- Focus on 2 types :

1. Bet-hedging/random dormancy in plants
2. Dormancy triggered by the strength of intra-specific competition

→ Expressing the diversity of species as a function of G (and R), V, μ, σ and p

$$
\begin{aligned}
\frac{\mathrm{d}N_i^a}{\mathrm{d}t} &= N_i^a\left(G_i+(1-p)R_i-N_i^a-\textstyle\sum_{j\neq i}^S A_{i,j}N_j^a\right)+\theta_i N_i^d \\
\frac{\mathrm{d}N_i^d}{\mathrm{d}t} &= pR_iN_i^a-(\theta_i+d_i)N_i^d
\end{aligned}
$$

Bet-hedging dormancy in plants

$$
\begin{aligned}
\frac{\mathrm{d}N_i^a}{\mathrm{d}t} &= N_i^a\left(G_i-N_i^a-\textstyle\sum_{j\neq i}^S A_{i,j}N_j^a\right)+\theta_i N_i^d-p(N_i^a)^2 \\
\frac{\mathrm{d}N_i^d}{\mathrm{d}t} &= p(N_i^a)^2-(\theta_i+d_i)N_i^d
\end{aligned}
$$

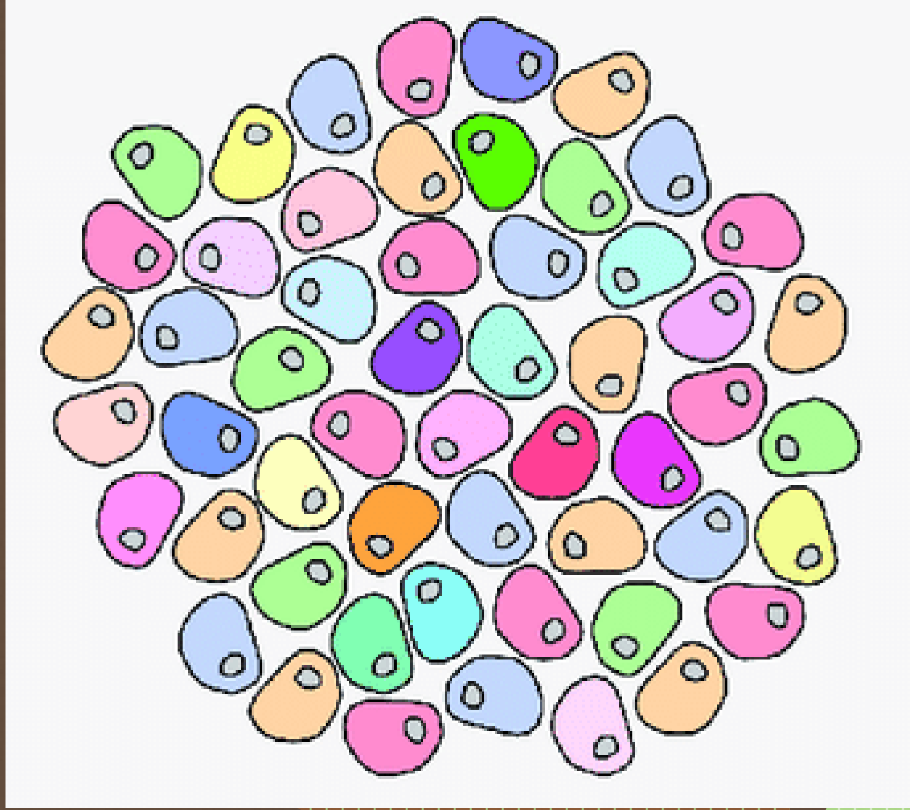
Dormancy triggered by intra-specific competition

2. Dormancy and heterogeneity

- Heteregeneous and homogeneous communities are defined as follows:

→ "Homogeneous" population: all individuals have similar growth rates G_i and R_i (similar strategies, $V << 1$)

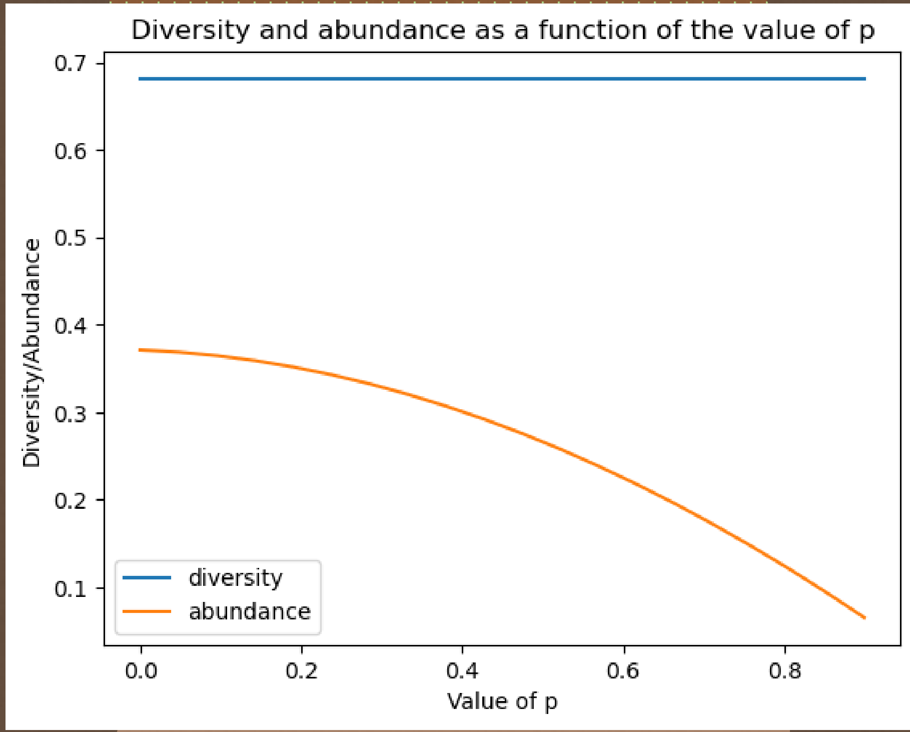
→ "Heterogeneous" population: individuals have very different growth rates G_i and R_i (different strategies, large V)



In a “homogeneous” community (1)

- “Homogeneous” population: all individuals have similar growth rates G_i (similar strategies, V << 1)

$$\frac{dN_i^a}{dt} = N_i^a(G + (1-p)R - N_i^a - \sum_{j\neq i}^{S} A_{i,j}N_j^a) + \theta N_i^d$$
$$\frac{dN_i^d}{dt} = pRN_i^a - (\theta + d)N_i^d$$



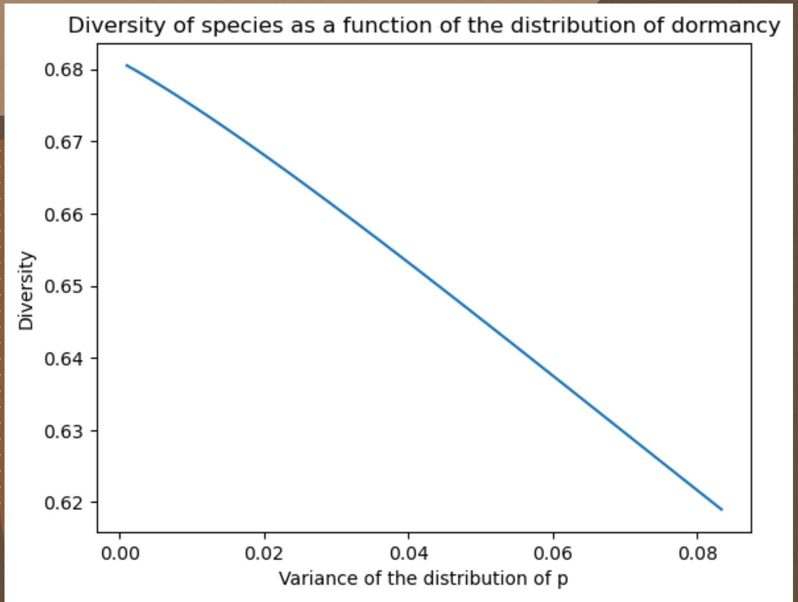
- If different species all have the same value of p, then dormancy has **no effect** on diversity in both models

In a "homogeneous" community (2)

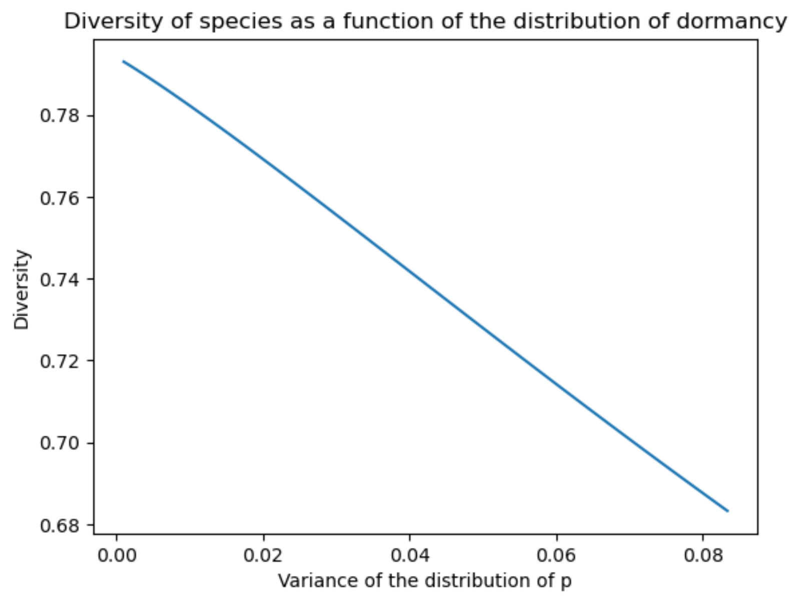
- With varying values of p ($Var(p_i) > 0$)

$$\frac{dN_i^a}{dt} = N_i^a(G + (1 - p_i)R - N_i^a - \Sigma_{j \neq i}^S A_{i,j} N_j^a) + \theta N_i^d$$
$$\frac{dN_i^d}{dt} = p_i R N_i^a - (\theta + d) N_i^d$$

- If different species can have different values of p, then dormancy will **always make diversity decrease** in a homogeneous community

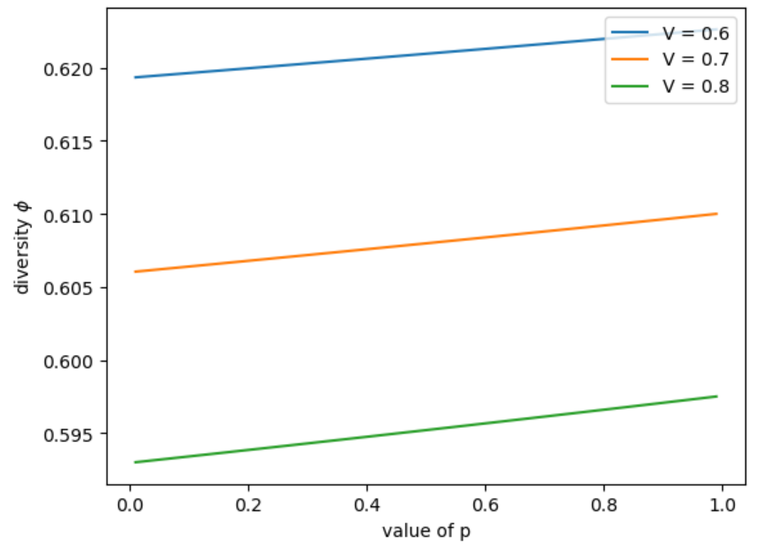


σ = 1



σ = 0.8

In a "heterogeneous" community (1)
Same value of p for all species



- Very little happens in "homogeneous" communities: what about "heterogeneous" ones?

→ Depending on the values of G, R, Var(R_i) and Var(G_i) as well as on the values of θ and d, diversity **can** increase with dormancy

Diversity will increase with dormancy if:

There exists $p_0 \in]0,1[$ such that:

$$\frac{G+(1-\frac{dp_0}{\theta+d})R}{\sqrt{Var(G_i)+(1-\frac{dp_0}{\theta+d})^2 Var(R_i)}} > \frac{G+R}{\sqrt{Var(G_i)+Var(R_i)}}$$

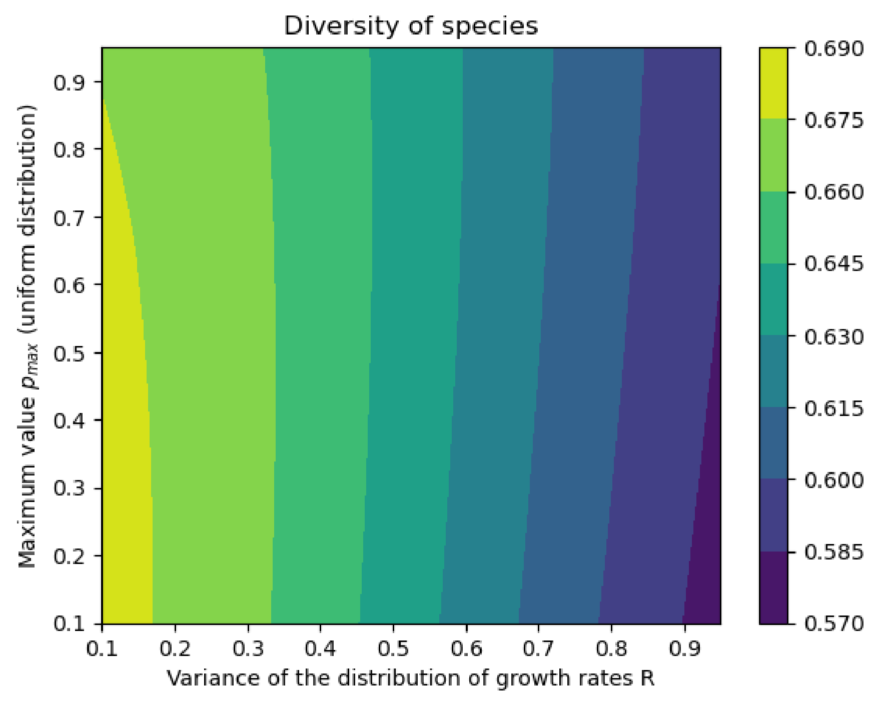
$$\frac{\mathrm{d}N_i^a}{\mathrm{d}t} = N_i^a(G_i+(1-p)R_i - N_i^a - \Sigma_{j\neq i}^S A_{i,j}N_j^a) + \theta_i N_i^d$$

$$\frac{\mathrm{d}N_i^d}{\mathrm{d}t} = pR_iN_i^a - (\theta_i+d_i)N_i^d$$

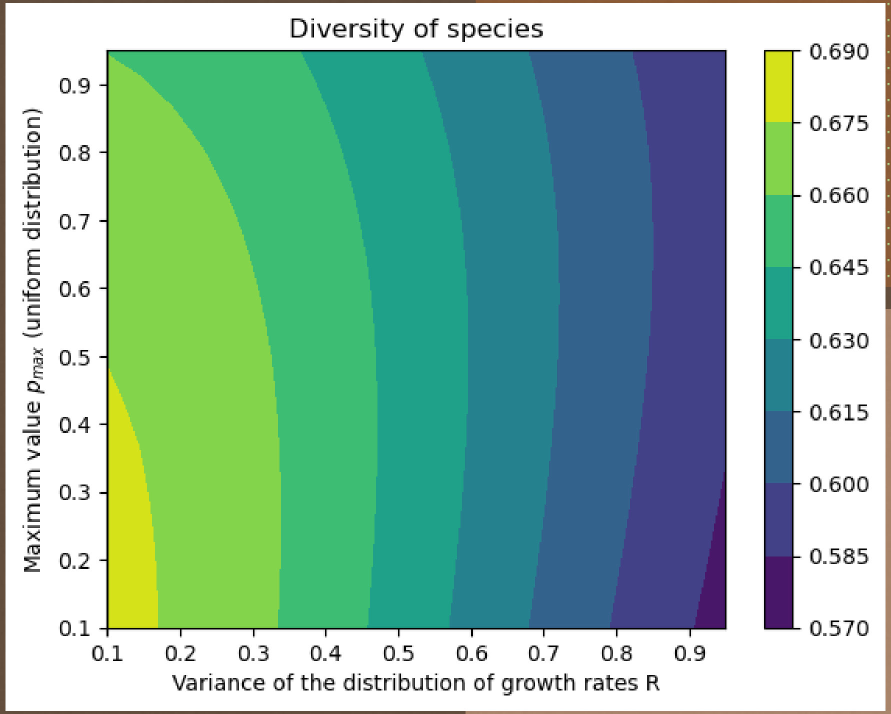
In a "heterogeneous" community (2) Different values of p

→ Increase of diversity: condition between the variance of the production of seeds, the variance of intrinsic growth and the variance of dormancy rates

→ High influence of d and θ



$d = 0.01$, $\theta = 0.01$, $Var(G_i) = 0$



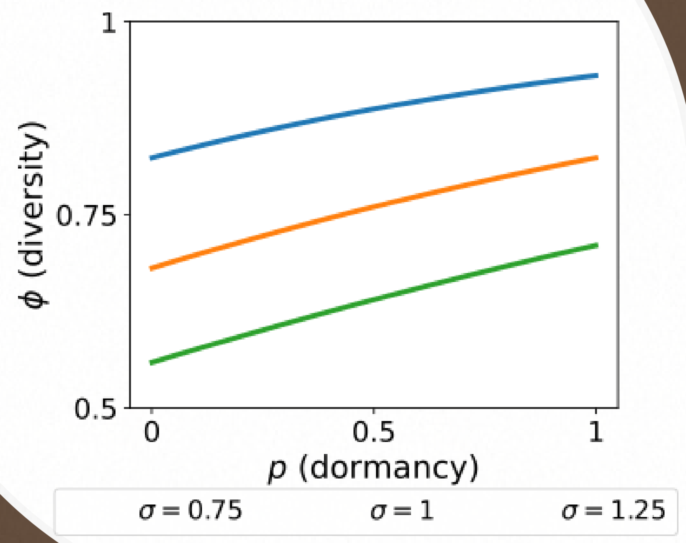
$d = 0.1$, $\theta = 0.01$, $Var(G_i) = 0$

3. Dormancy and auto-regulation

- One case where dormancy **always** makes diversity increase: dormancy triggered by intra-specific competition

$$\frac{\mathrm{d}N_i^a}{\mathrm{d}t} = N_i^a\left(G_i - N_i^a - \sum_{j\neq i}^{S} A_{i,j}N_j^a\right) + \theta_i N_i^d - p(N_i^a)^2$$
$$\frac{\mathrm{d}N_i^d}{\mathrm{d}t} = p(N_i^a)^2 - (\theta_i + d_i)N_i^d$$

- Much stronger increase than in the previous example



Conclusion

- Theoretical link between dormancy and diversity is not always clear
- In our model, diversity increases with dormancy when dormancy has a "homogeneizing" effect (and vice versa diversity will decrease if dormancy has a disruptive effect)
- The type of dormancy modelled plays a huge role
- Limitations/Perspectives: only random awakening (no quorum-sensing), no environmental variation

Thanks a lot for your attention!