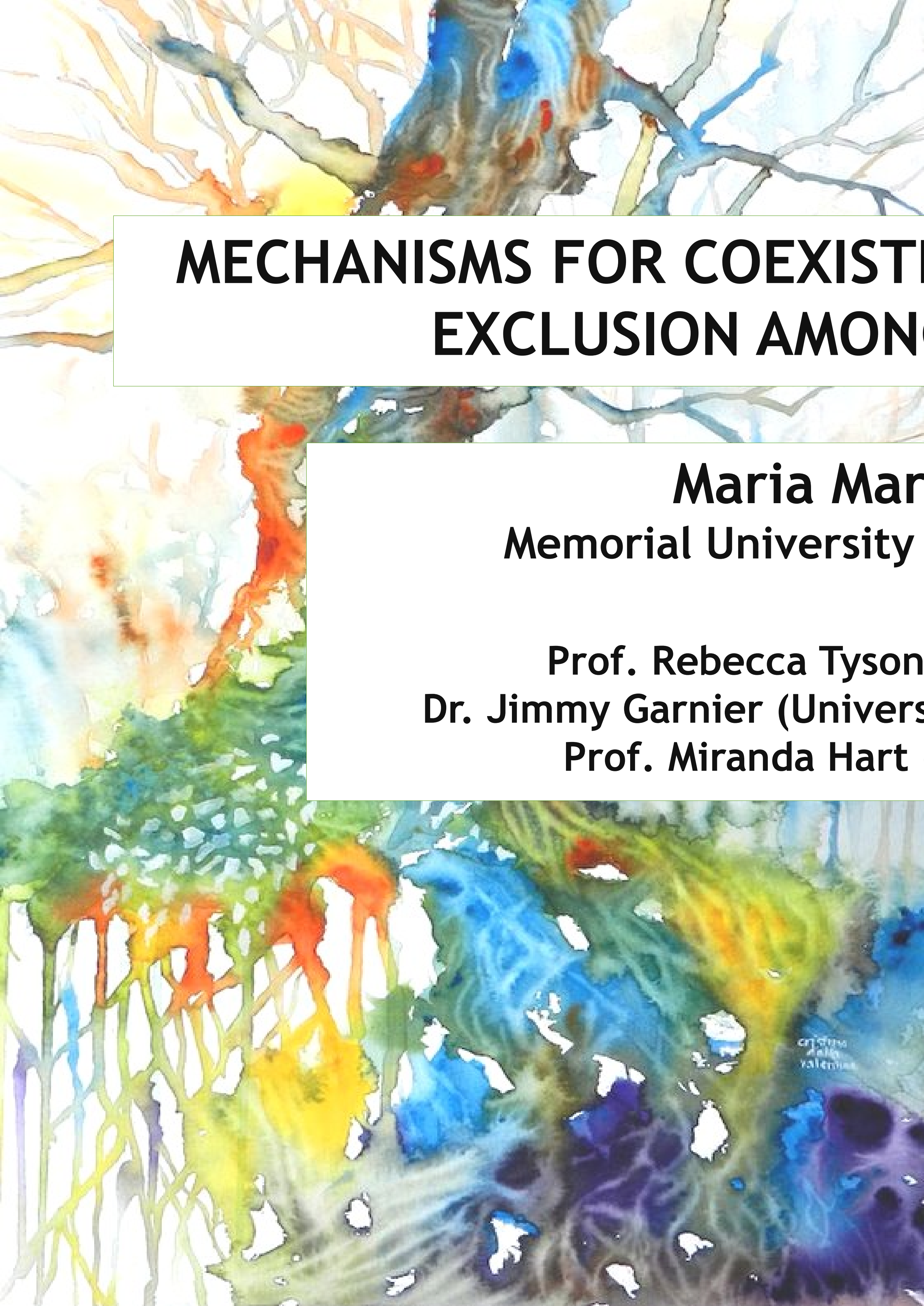

MECHANISMS FOR COEXISTENCE AND COMPETITIVE EXCLUSION AMONG MUTUALISTS

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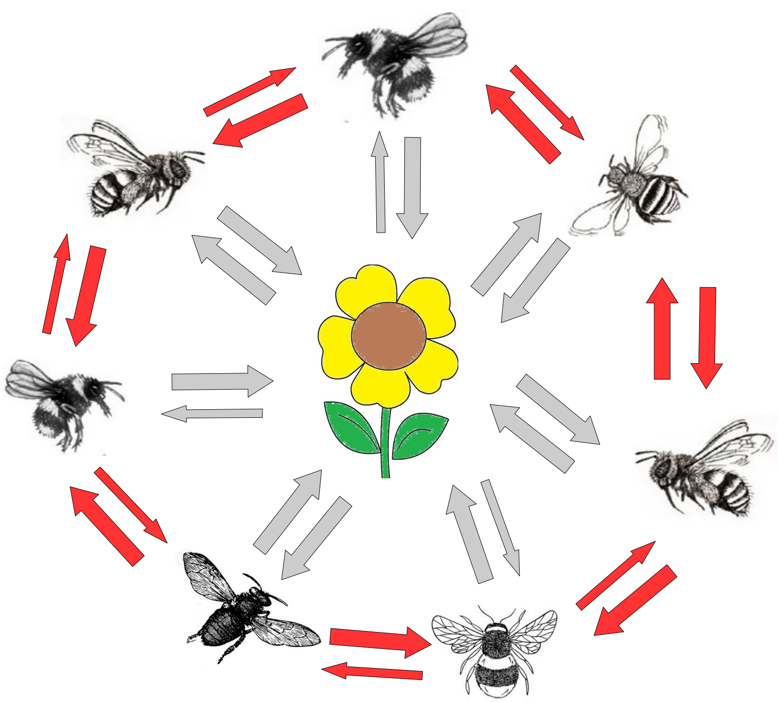
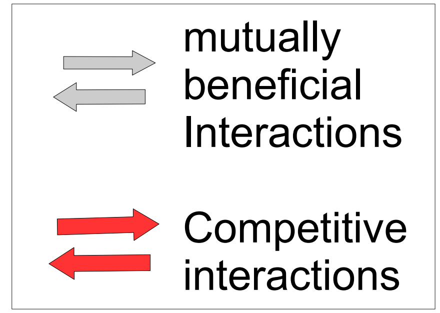
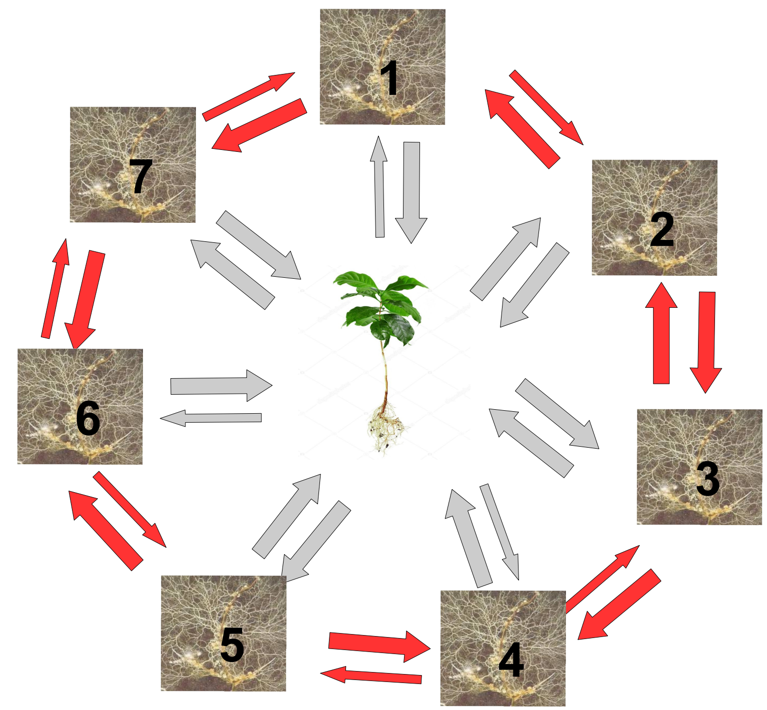
Winter Workshop on Competition Dynamics in Biology
Dec 15-17, 2021
Ohio State University

Multiple mutualists compete for a common resource supplied by the same host/partner species







POLLINATION

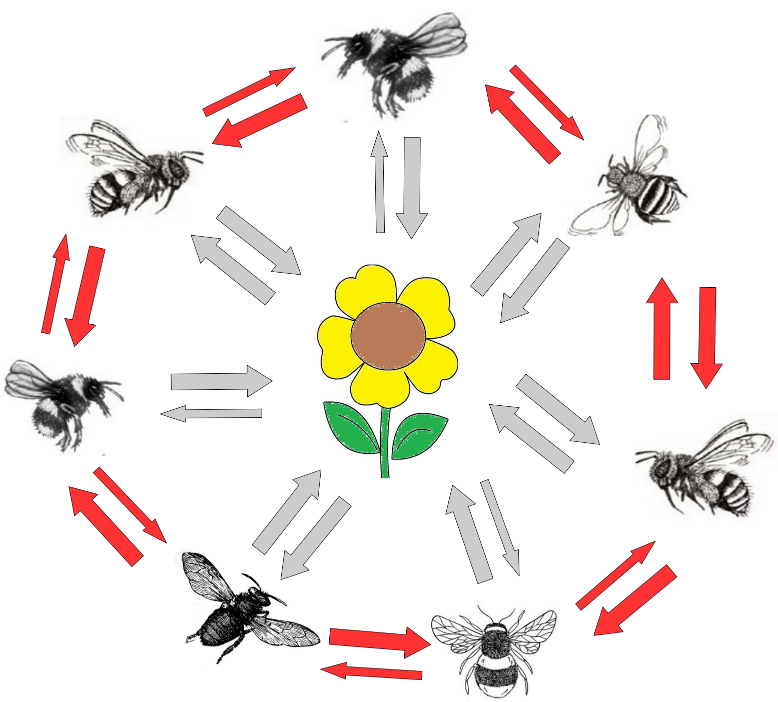
PLANT-MICROBE SYMBIOSIS
(ex. mycorrhiza: plant-fungi symbiosis)

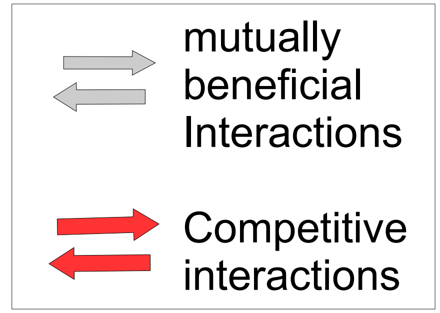
Mechanisms leading to coexistence and competitive exclusion among mutualists are poorly understood:

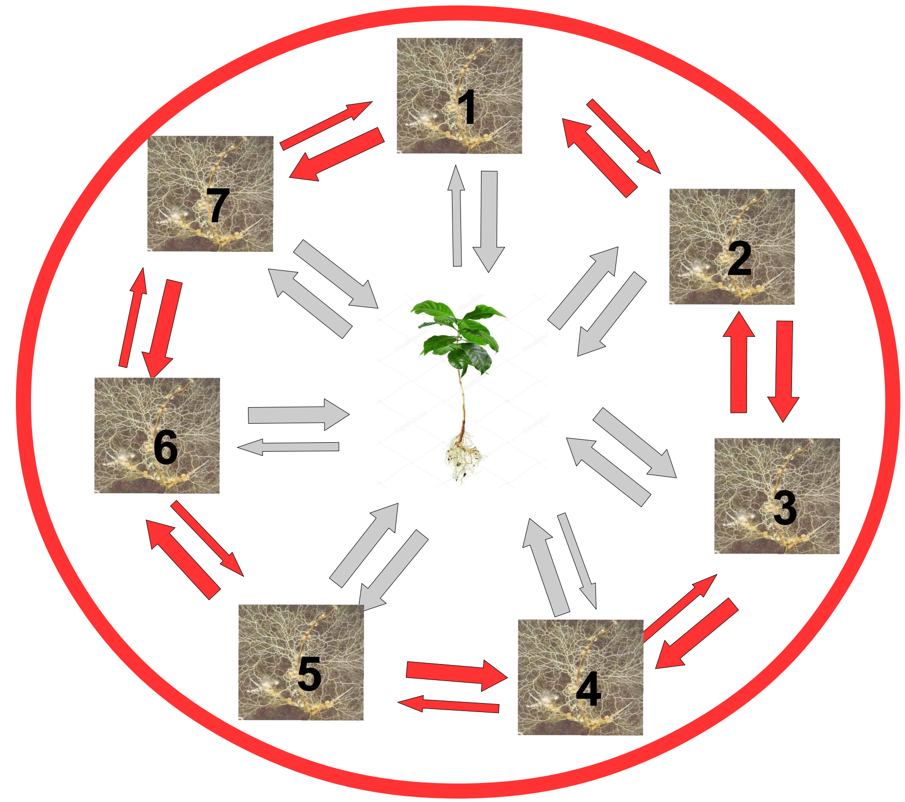
- What happens if we add/remove a mutualist from the system?
(Survival and coexistence? Competitive exclusion?)
- How does the guild composition affects plant growth (productivity)?

→ Crucial for agricultural management

Multiple mutualists compete for a common resource supplied by the same host/partner species







POLLINATION

MYCORRHIZA
Plant-fungi symbiosis

Mechanisms leading to coexistence and competitive exclusion among mutualists are poorly understood:

- What happens if we add/remove a mutualist from the system? (Survival and coexistence? Competitive exclusion?)
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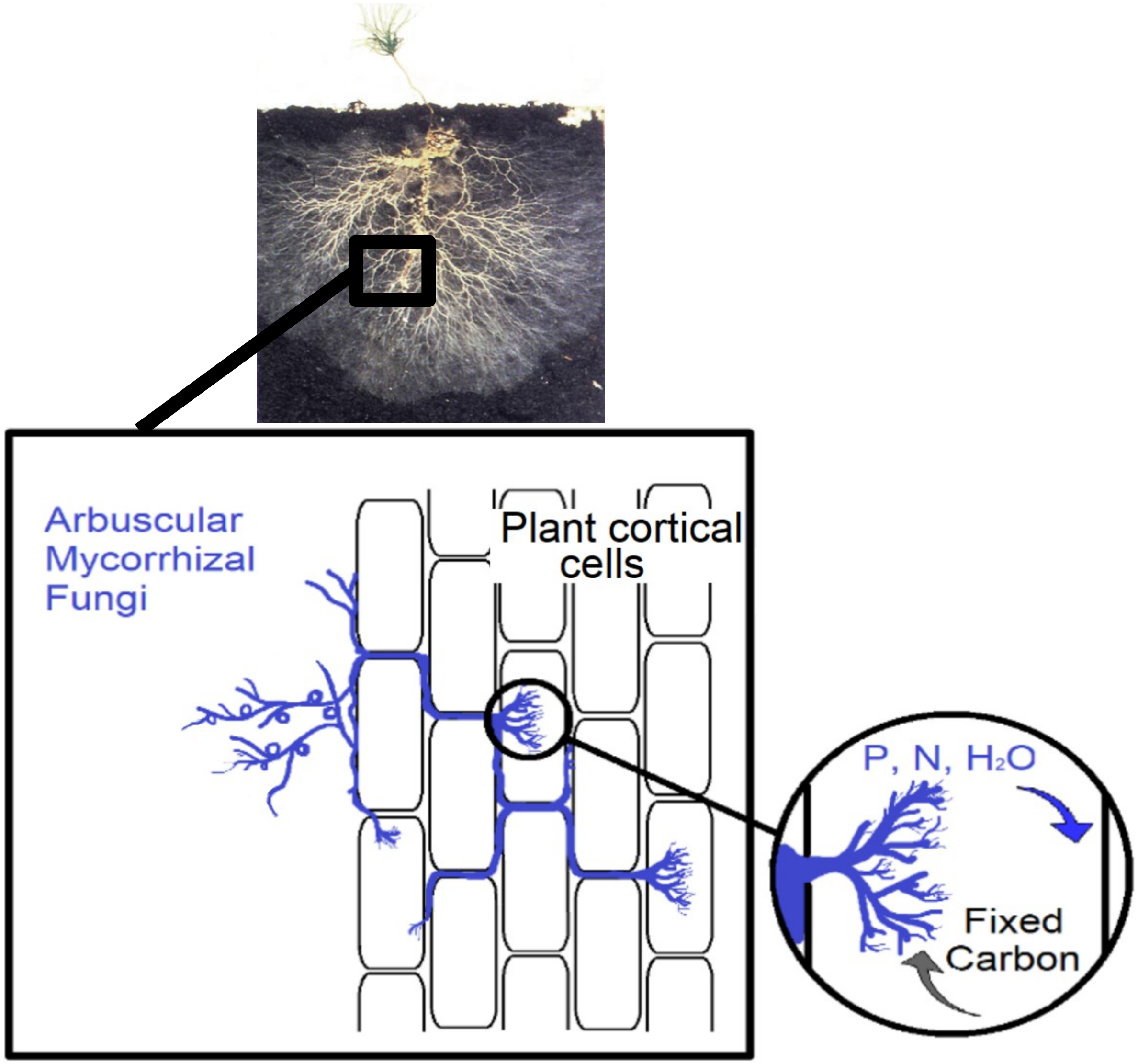
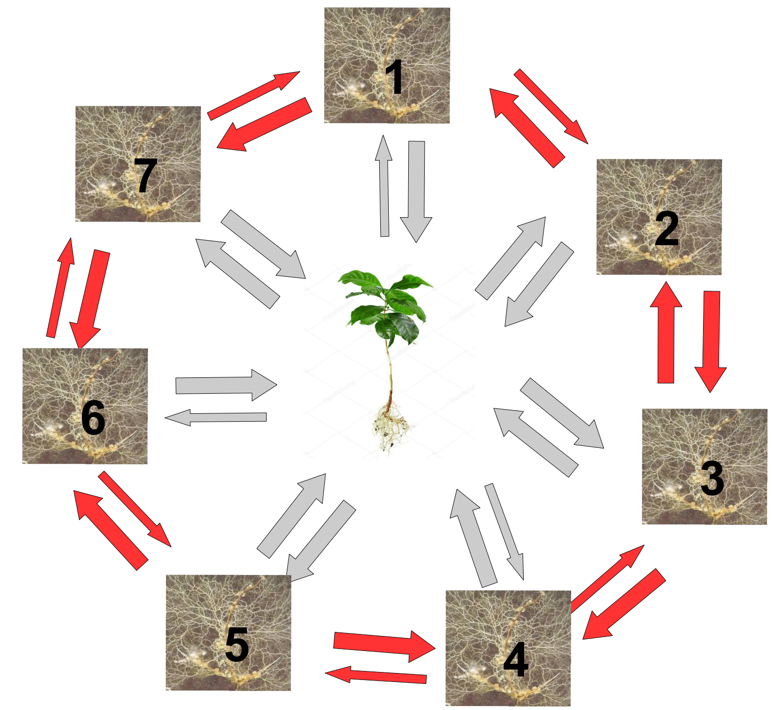
→ Crucial for agricultural management

MYCORRHIZA:
plant-fungi symbiosis





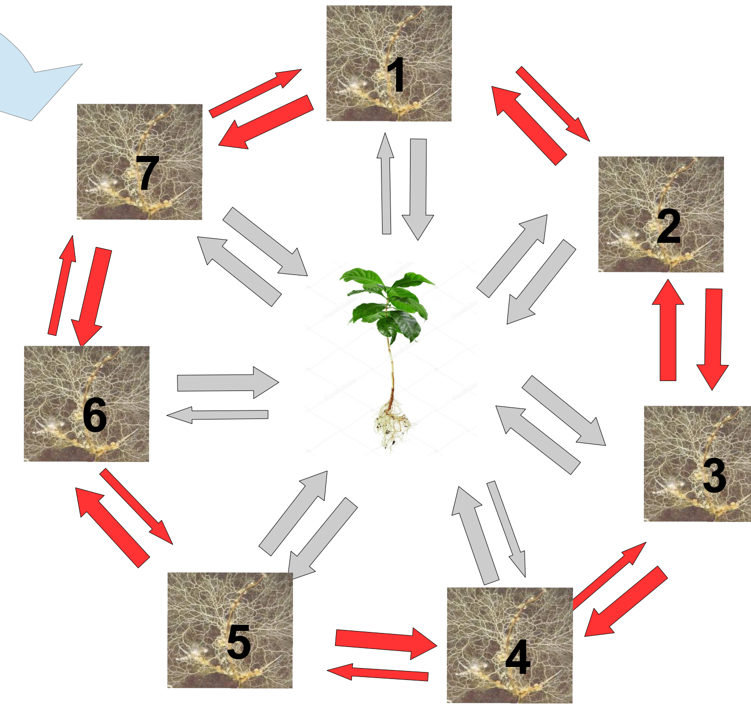
ARBUSCULAR MYCORRHIZAL FUNGI (AMF):

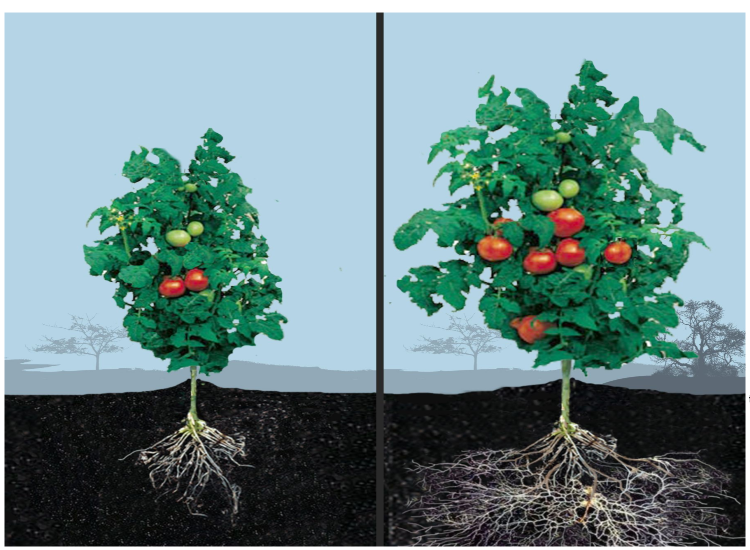
- 90% of terrestrial plants (e.g. maize, wheat, soybeans, tomatoes, strawberries,...)
- Increase in root system surface area of up to 1000 times!
- Extremely beneficial for plant fitness and health

MYCORRHIZA: plant-fungi symbiosis

AMF are used as commercial fertilizer !

**Contains approximately 100,000 endomycorrhizal spores/lb and 110,000,000 ectomycorrhizal spores/lb.



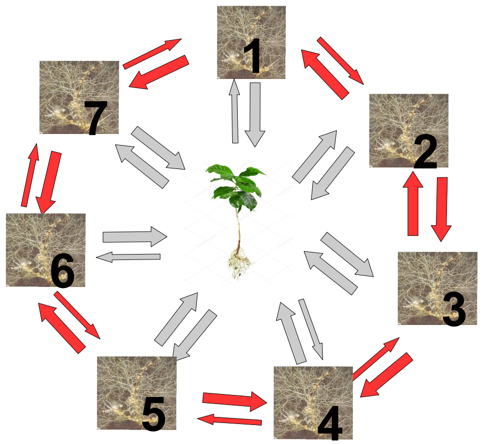


Questions:

- What happens if we add/remove a mutualist from the system?
- How does the guild composition affects plant growth (productivity)?

Can the inoculated fungal species become invasive?

Mathematical model: 1 plant and multiple fungi (ODE)



$$\frac{dp}{dt} = \overbrace{q_{hp} r_p p}^{\text{Intrinsic growth}} + q_{hp} \overbrace{\left(\sum_j \alpha_j m_j\right) \frac{p}{d+p}}^{\text{phosphorus received}} - q_{cp} \overbrace{\left(\sum_j \beta_j m_j \left[1 - \frac{\sum_{i\neq j} m_i}{a_j + \sum_{i\neq j} m_i}\right]\right) p}^{\text{carbon supplied}} - \overbrace{\mu_p p^2}^{\text{maintenance}}$$

$$\frac{dm_j}{dt} = \underbrace{q_{cm_j} \beta_j p m_j \underbrace{\left[1 - \frac{\sum_{i\neq j} m_i}{a_j + \sum_{i\neq j} m_i}\right]}_{\text{Reduction in carbon uptake due to competition}}}_{\text{carbon received}} - q_{hm_j} \underbrace{\alpha_j \frac{p}{d+p} m_j}_{\text{phosphorus supplied}} - \underbrace{\mu_{m_j} m_j^2}_{\text{maintenance}} .$$

Competition depends on species identity and abundance

where $$a_j = \sum_{i\neq j} a_{ij} \frac{m_i}{\sum_{i\neq j} m_i}$$

p : plant biomass	**α_j/ β_j** : Mutualist quality of a fungal species
m_j : fungal biomass	**a_{ij} :** Competitive effect of fungal species j on i

2 mutualists

3 mutualists

N mutualists

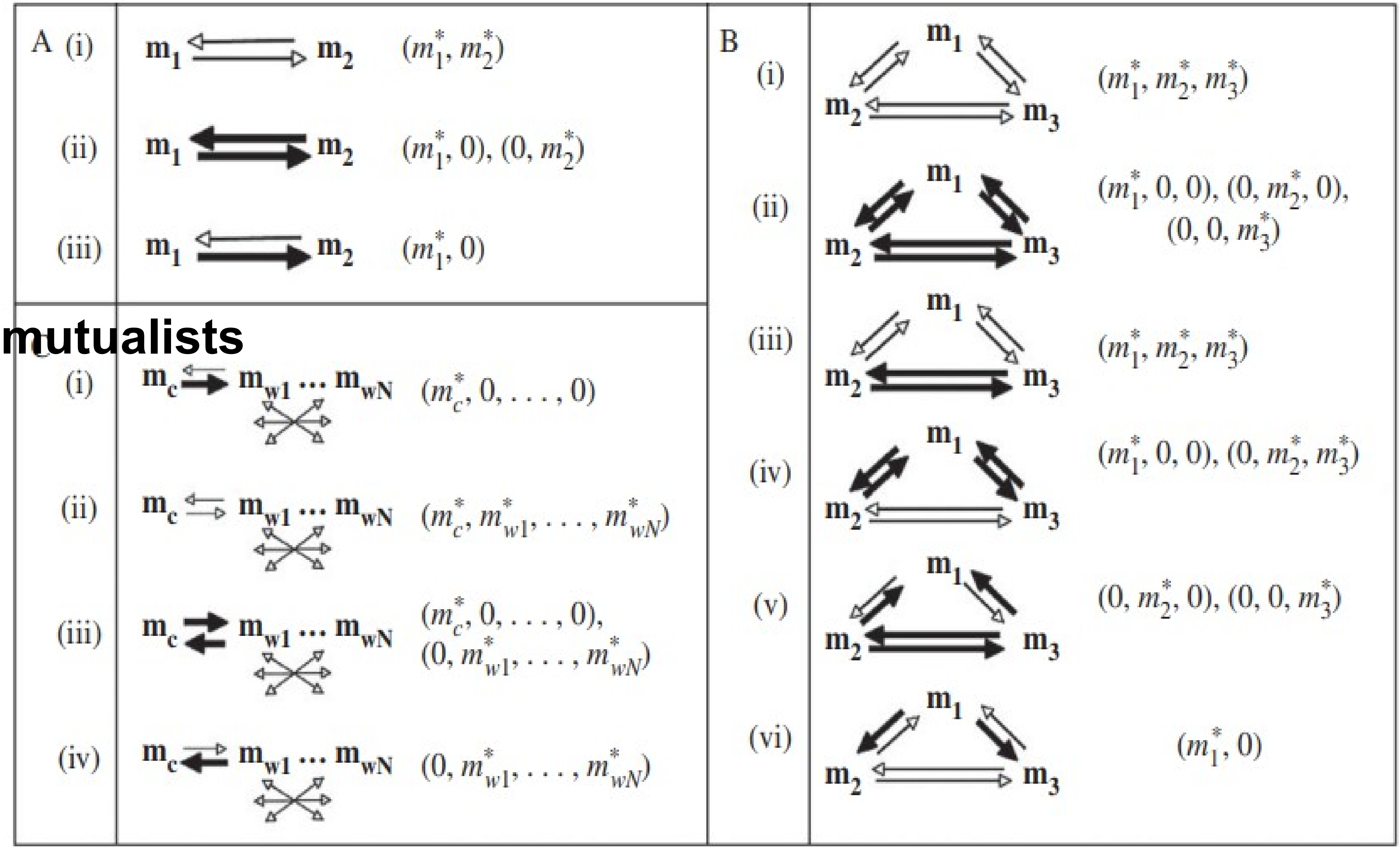


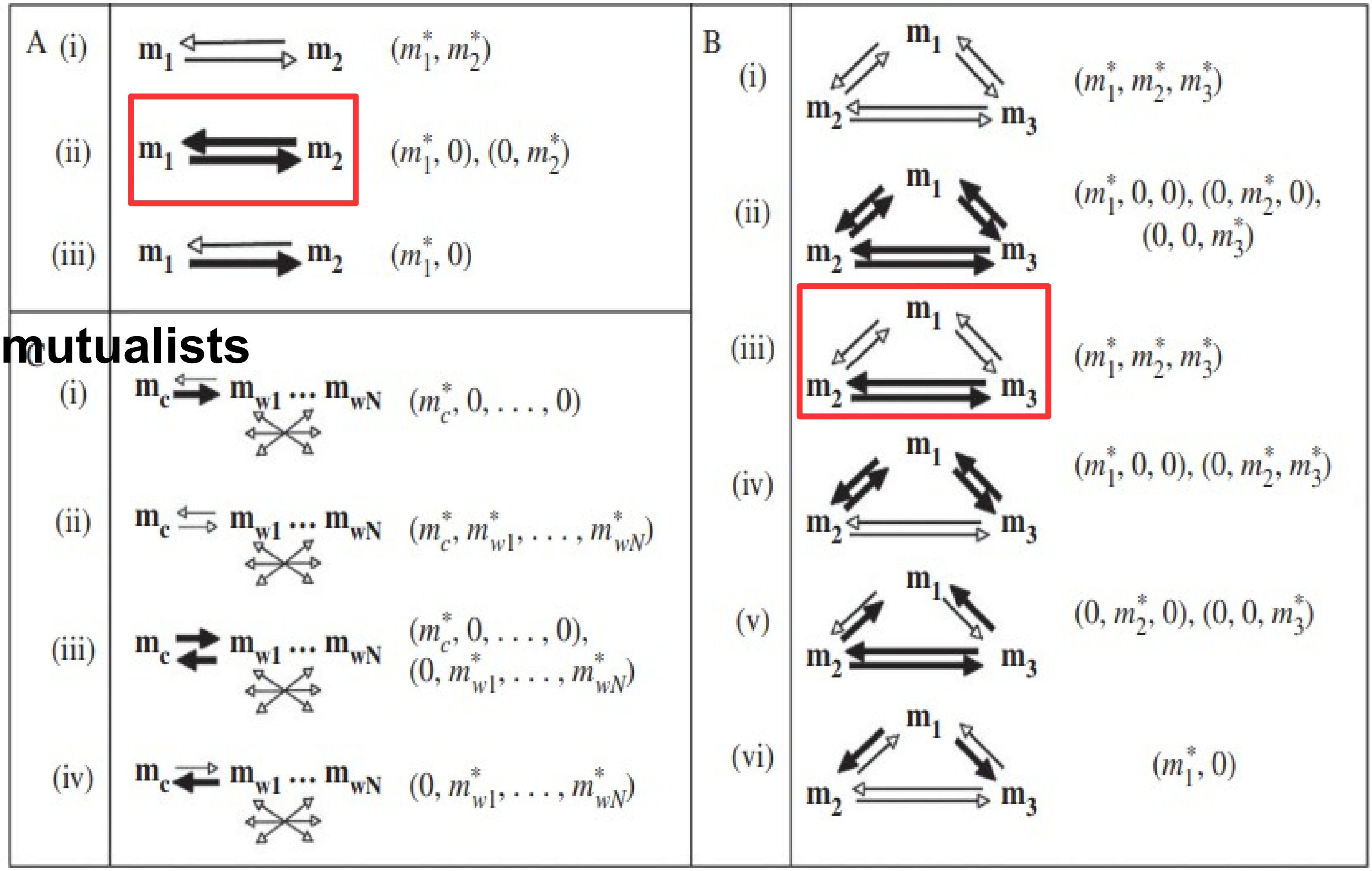
Figure 1. Representation of the direct interactions between fungal species (m_i) sharing a resource supplied by the same host plant (not included in the figure), and corresponding steady state stability (presented in the electronic supplementary material). Arrows indicate competition between mutualists where competition can be weak (thin arrows) or strong (thick arrows).

M.M. Martignoni, R.C. Tyson, M.M. Hart, J. Garnier (2020), Diversity within mutualist guilds promotes coexistence and reduces the risk of invasion from an alien mutualist, PRSB

2 mutualists

3 mutualists

N mutualists



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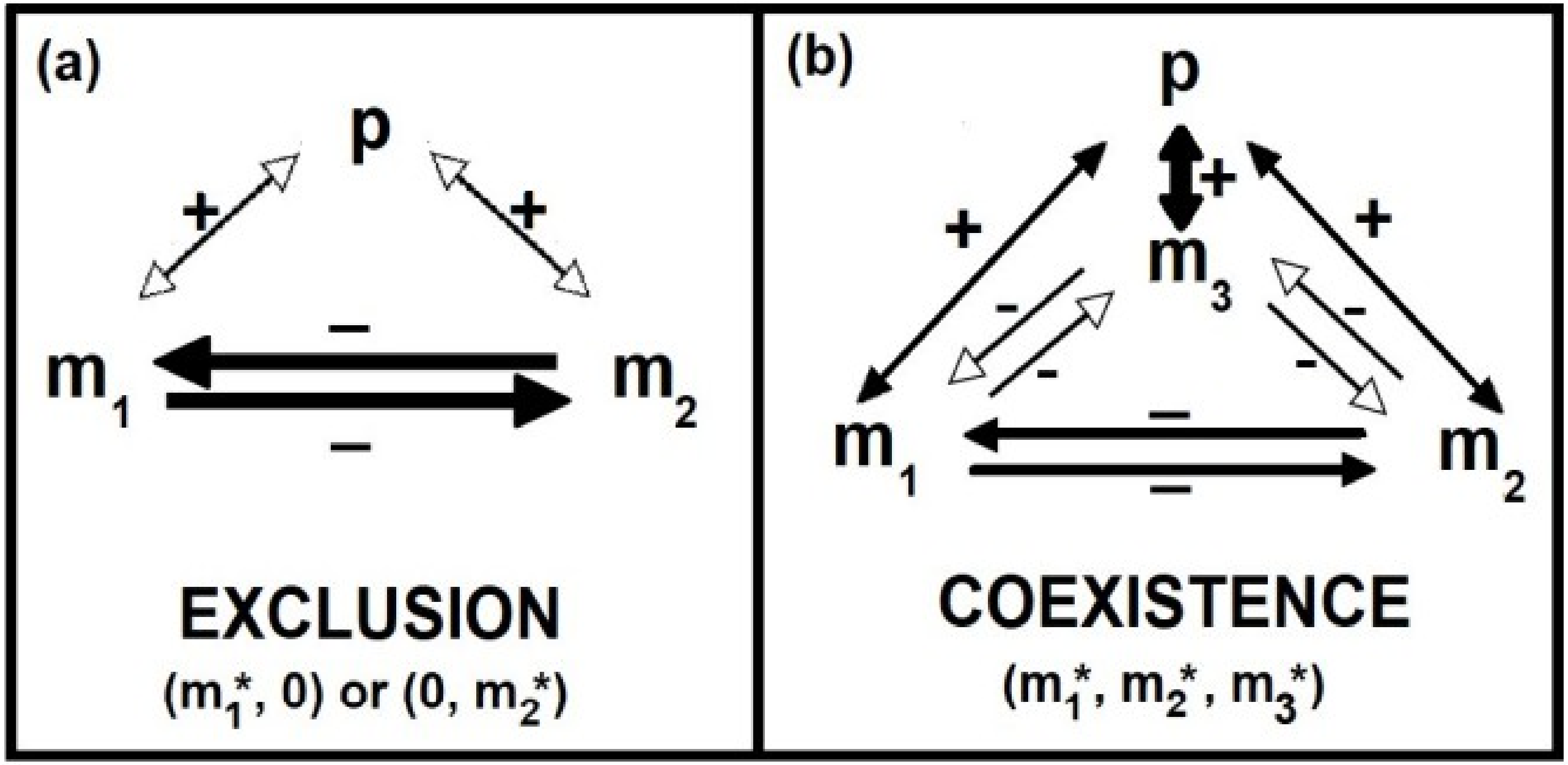


Removal of a weak competitor (m3) in a community of strongly competing mutualists (m1 and m2), may cause the extinction of other mutualists in the guild (either m1 or m2).

--> Diversity promotes coexistence of species that would otherwise competitively exclude each other!

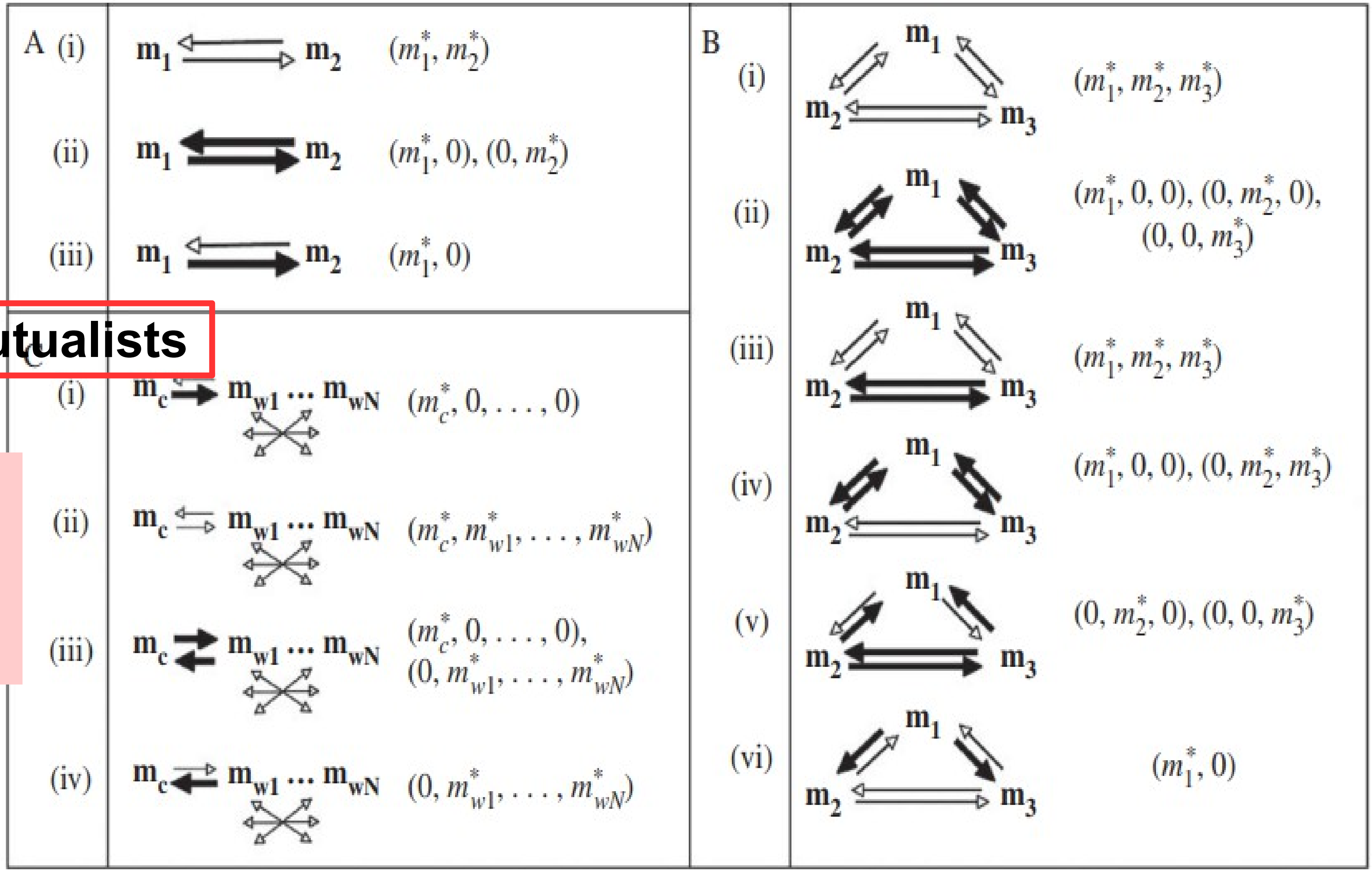
M.M. Martignoni, R.C. Tyson, M.M. Hart, J. Garnier (2020), Diversity within mutualist guilds promotes coexistence and reduces the risk of invasion from an alien mutualist, PRSB

2 mutualists

3 mutualists

N+1 mutualists

Group of N native fungi + 1 introduced species



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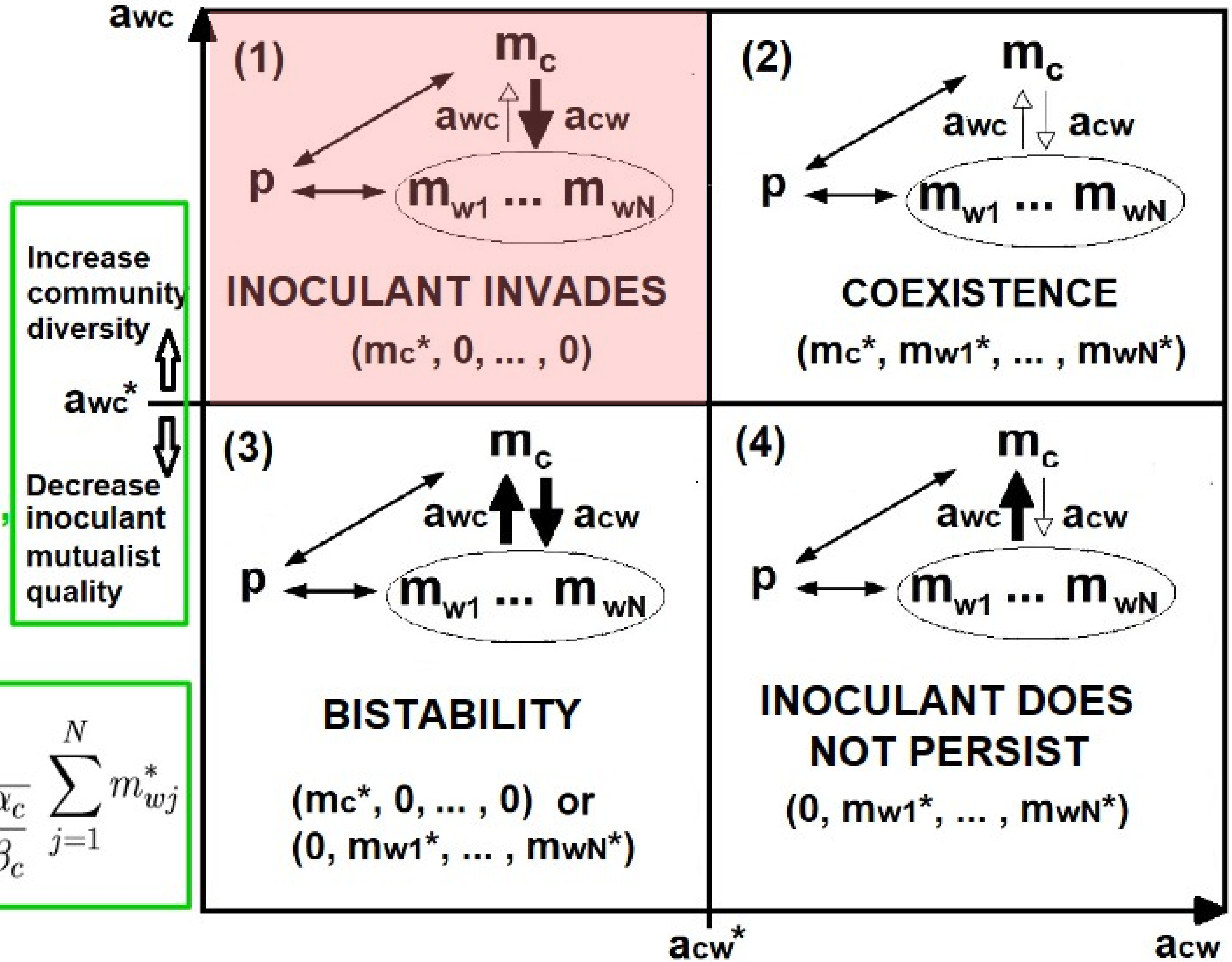
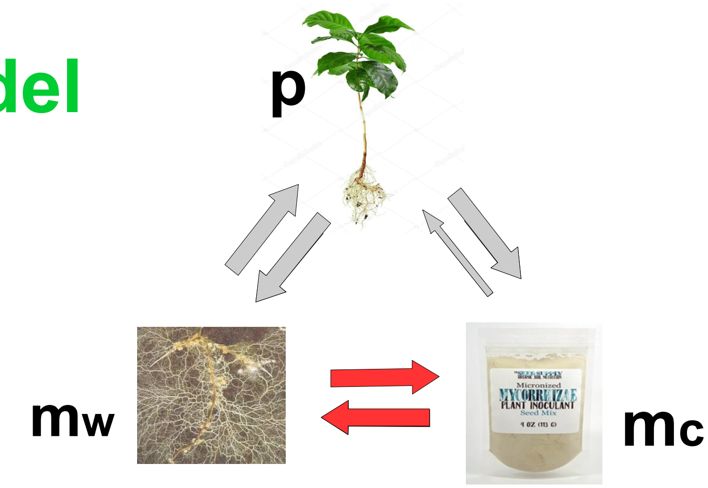


Quantitative, measurable criteria

$$a^*_{wc} = \frac{\rho_w \dfrac{\alpha_c}{\beta_c}}{1 - \rho_w \dfrac{\alpha_c}{\beta_c}} \sum_{j=1}^{N} m^*_{wj}$$

M.M. Martignoni, R.C. Tyson, M.M. Hart, J. Garnier (2020), Diversity within mutualist guilds promotes coexistence and reduces the risk of invasion from an alien mutualist, PRSB

Impact on a landscape scale? --> PDE model



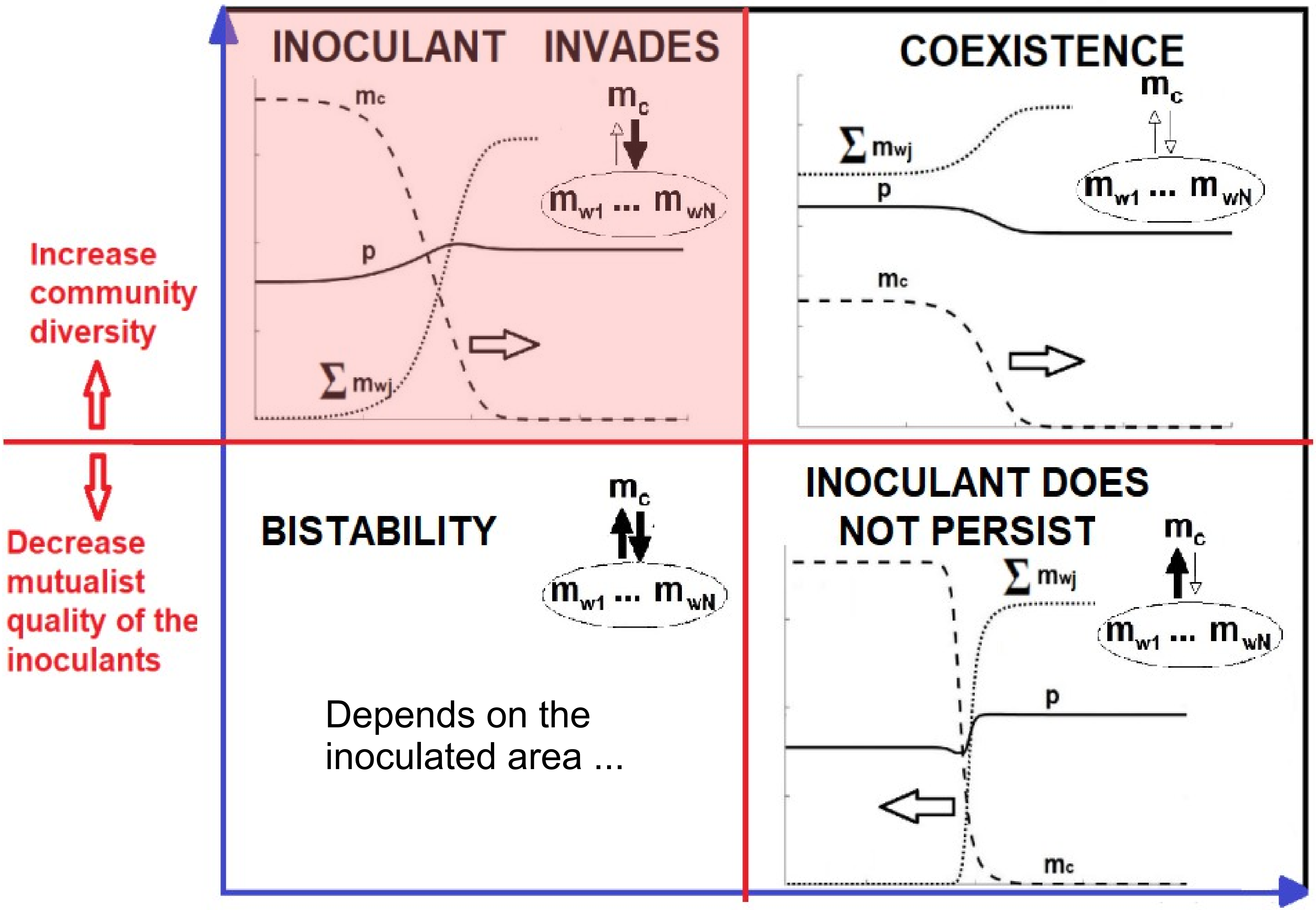
$$\partial_t \, p(x,t) = f_p(p, m_c, m_{w_j}) \, ,$$

$$\partial_t \, m_c(x,t) = D_c \, \partial_x^2 \, m_c + f_{m_c}(p, m_c, m_{w_j})$$

$$\partial_t \, m_{w_j}(x,t) = D_{w_j} \partial_x^2 \, m_{wj} + f_{m_j}(p, m_c, m_{w_j})$$

Spread of fungi

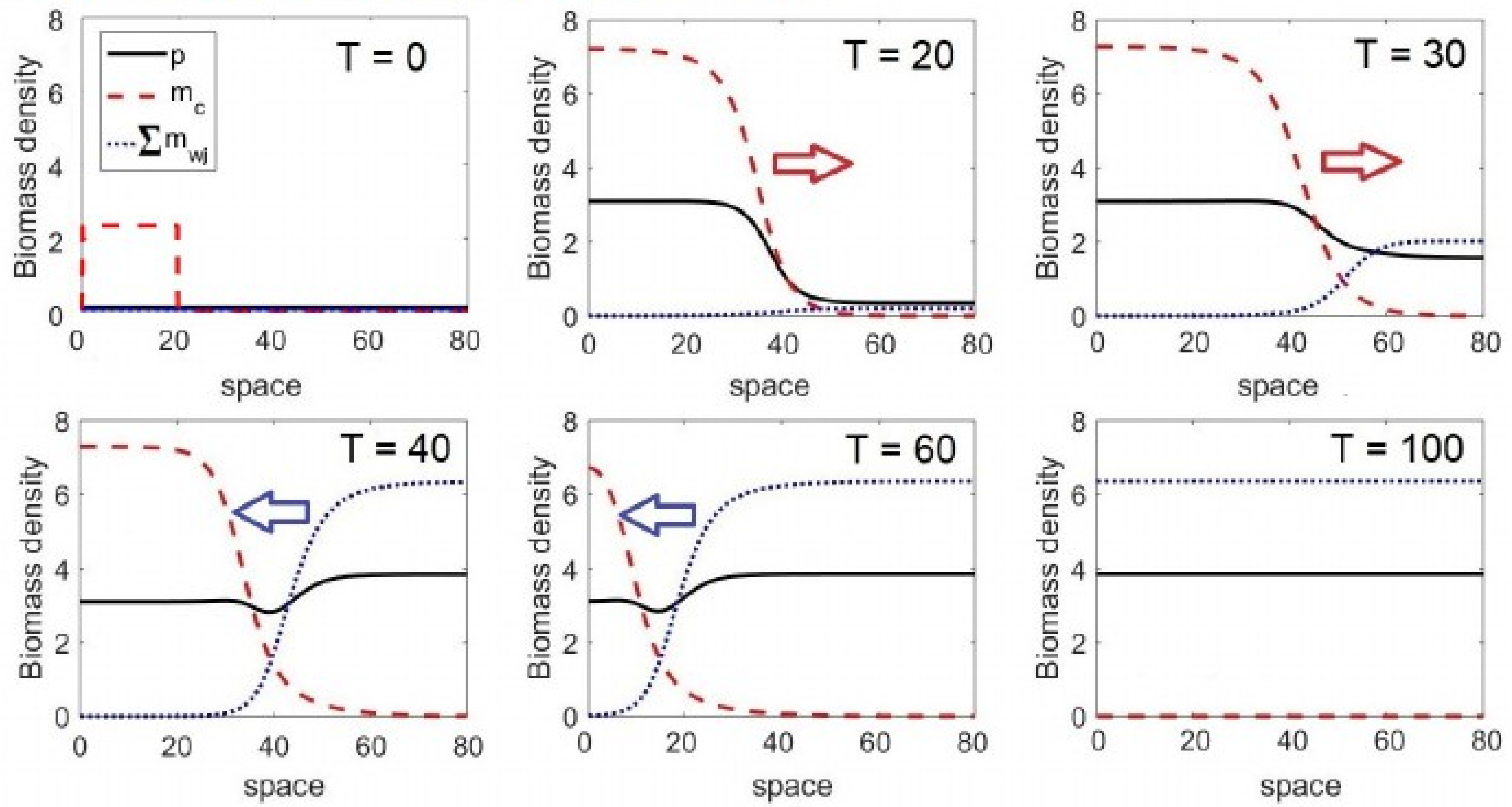
Mathematically interesting: The fungi compete between each others and interact with the medium in which they disperse (i.e., the plant)



Increase community diversity
Decrease mutualist quality of the inoculants
INOCULANT INVADES
COEXISTENCE
BISTABILITY
INOCULANT DOES NOT PERSIST
Depends on the inoculated area ...
m_c
m_{w1} ... m_{wN}
p
Σm_{wj}

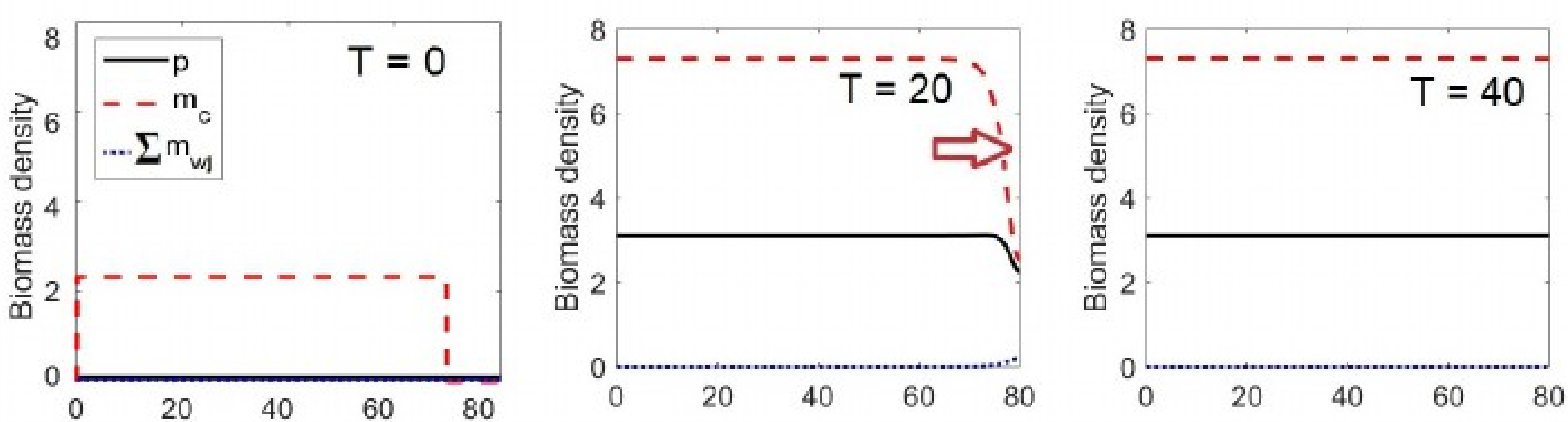
BISTABLE TRAVELING WAVE

INOCULANT DOES NOT PERSIST



Displacement of the inoculant occurs through improved mutualistic relationship with the plant

INOCULANT INVADES



Invasion of the inoculant occurs if inoculation occurs over a large area

Can the inoculated fungal species become invasive?

YES!

If the inoculated fungi:
- Are strong competitors
- Have low mutualist quality
- Are inoculated over a large area

High breeding pressure & large-scale fertilization

+

And if native fungi:
- Are weak competitors
- Present low diversity

Intense agricultural practises

Spread speed

$$c_c^* = 2\sqrt{D_c P_w^* \left(\frac{q_{cm}\beta_c a_{wc}}{a_{wc} + N M_w^*} - \frac{q_{hm}\alpha_c}{P_w^* + d} \right)}$$

Dispersal ability of the inoculants

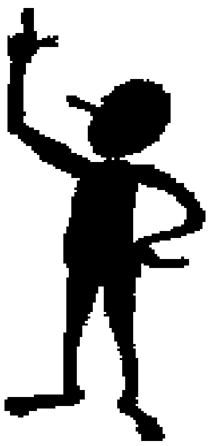
Mutualist quality of the inoculants

Native community diversity

Should we inoculate or not?

YES!

... But with weakly competing inoculants

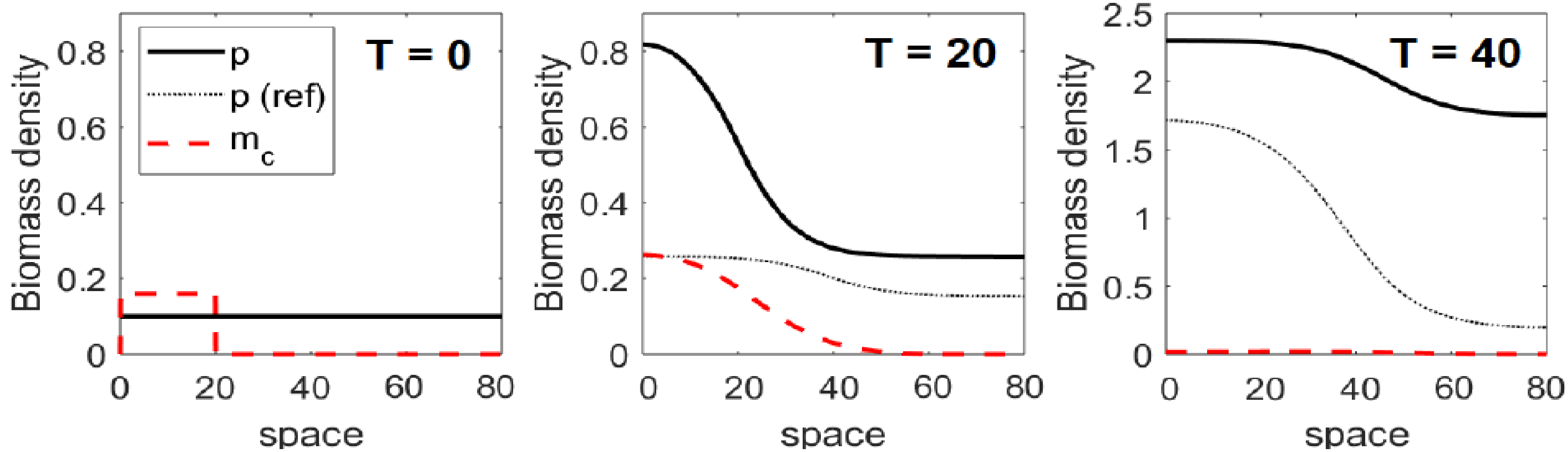


- No biodiversity risk!
- Boost in plant growth (due to an increase in fungal abundance)
- Restoration of a native community

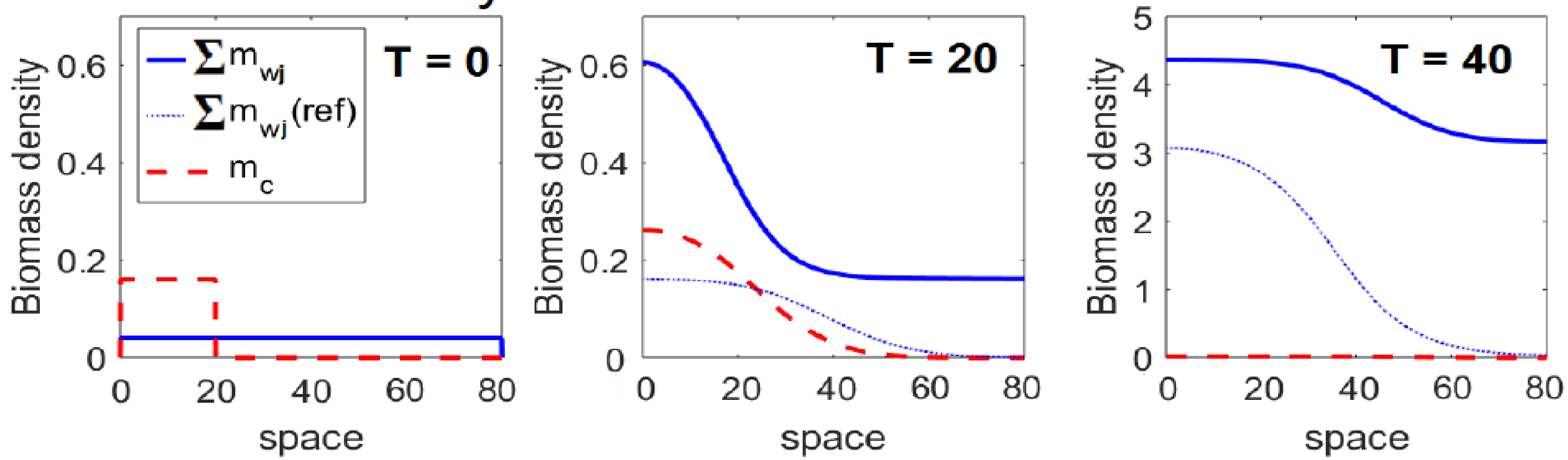
M.M. Martignoni, J. Garnier, M.M. Hart, R.C. Tyson (2020), Investigating the impact of the mycorrhiza inoculum on the resident fungal community and on plant growth, *Ecological Modelling*

Use weakly competing inoculants !

Boost plant productivity



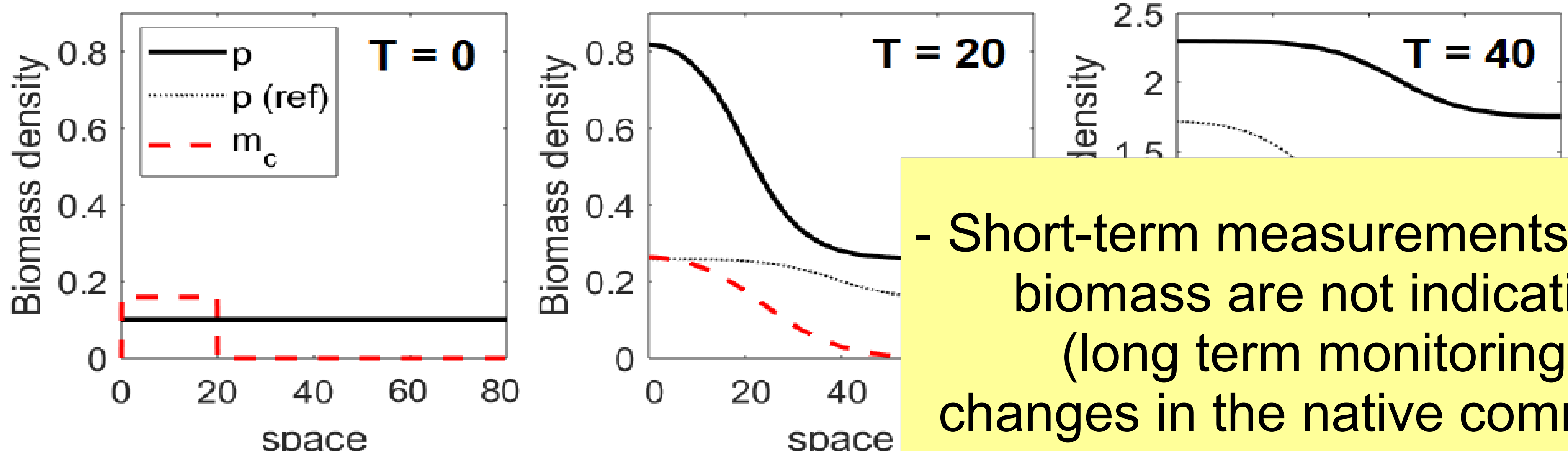
Native community restoration



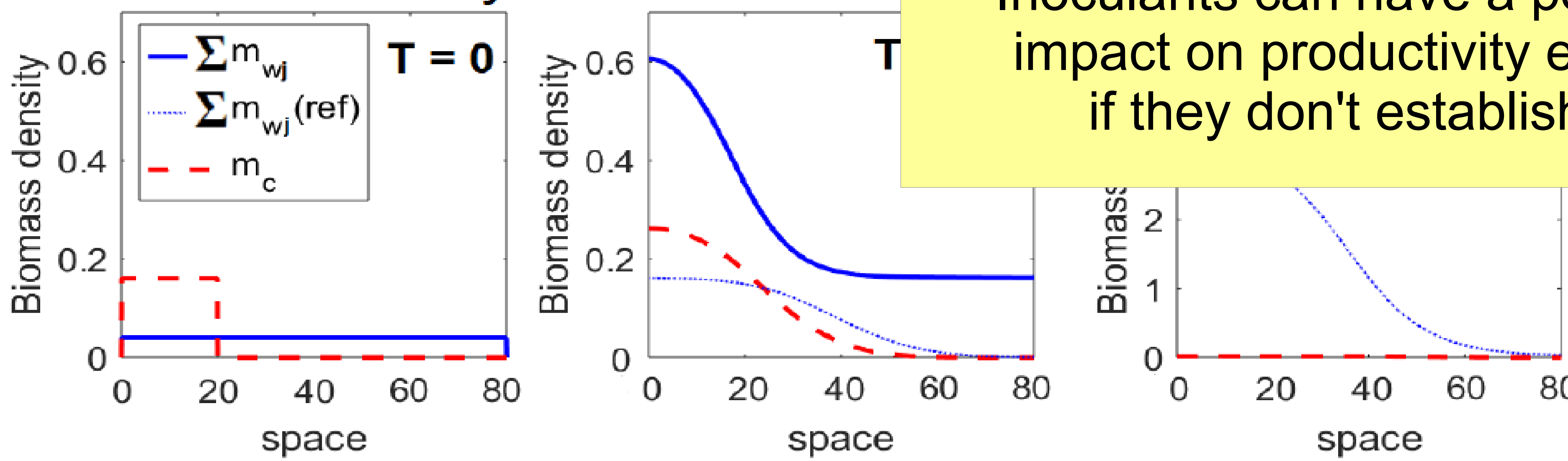
... even if the inoculated fungi do not establish !

Use weakly competing inoculants !

Boost plant productivity



Native community restoration



- Short-term measurements of plant biomass are not indicative!
(long term monitoring + changes in the native community)

- Inoculants can have a positive impact on productivity even if they don't establish

... even if the inoculated fungi do not establish !

CONCLUSION

- We do have a theoretical framework to help the management of communities of mutualists (e.g., AM fungi), and measurable quantitative criteria to predict resilience, invasibility, spread, and productivity of these communities.

- The models developed can be used as building blocks in larger community models (examples of future directions: include multiple partners/hosts, environmental limitations,...) .

- In our model growth rates are related to nutrients transfer, what leads to a possible interplay between theory and experiments.

M.M. Martignoni, J. Garnier, X. Zhang, D. Rosa, V. Kokkoris, R.C. Tyson, M.M. Hart (2021), Co-inoculation with arbuscular mycorrhizal fungi differing in carbon sink strength induces a synergistic effect in plant growth, *Journal of Theoretical Biology*

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QUESTIONS ?