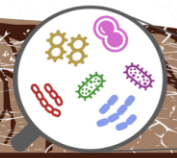
Leipzig – Germany *03.12.2021*

Ph.D. defense

From tree to soil: microbial and spatial mediation of tree diversity effects on carbon cycling in subtropical Chinese forests

Rémy Beugnon



SUMMARY

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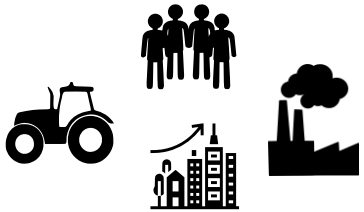
HUMAN ACTIVITIES CHANGE OUR WORLD

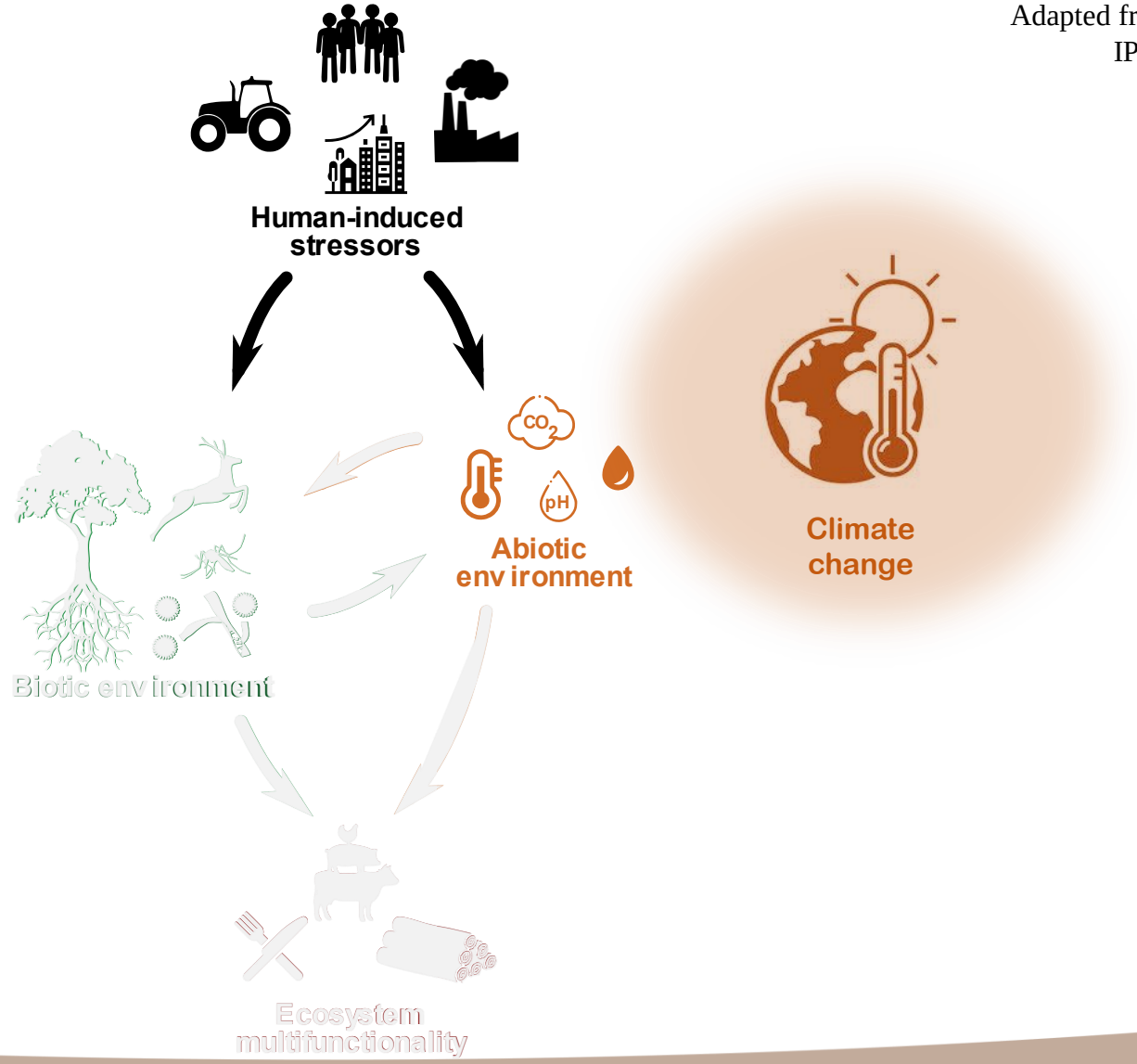
Adapted from Giling *et al.* 2019



Human-induced stressors

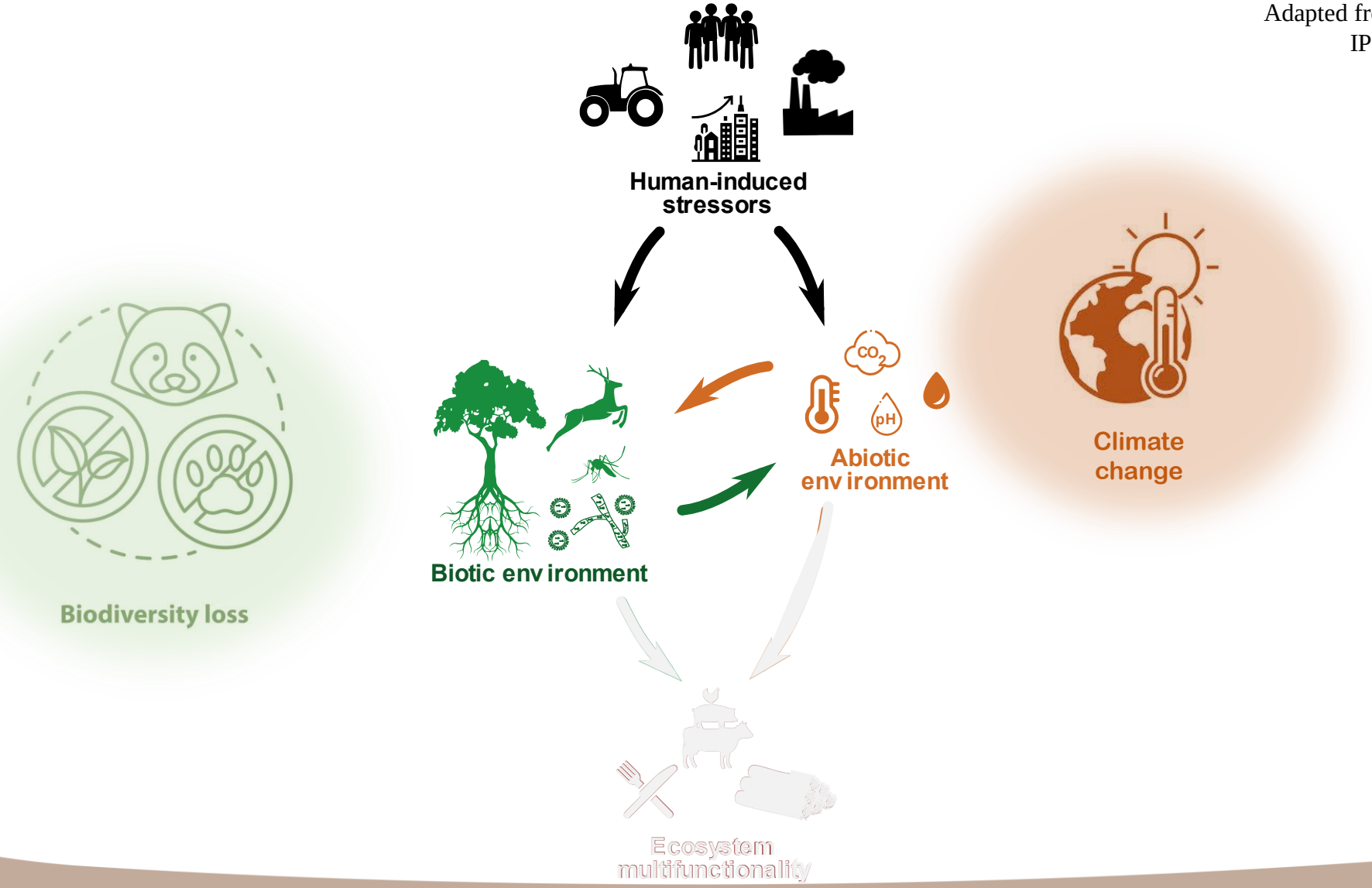
HUMAN ACTIVITIES CHANGE OUR WORLD

Adapted from Giling *et al.* 2019
IPCC 2019, IPCC 2021



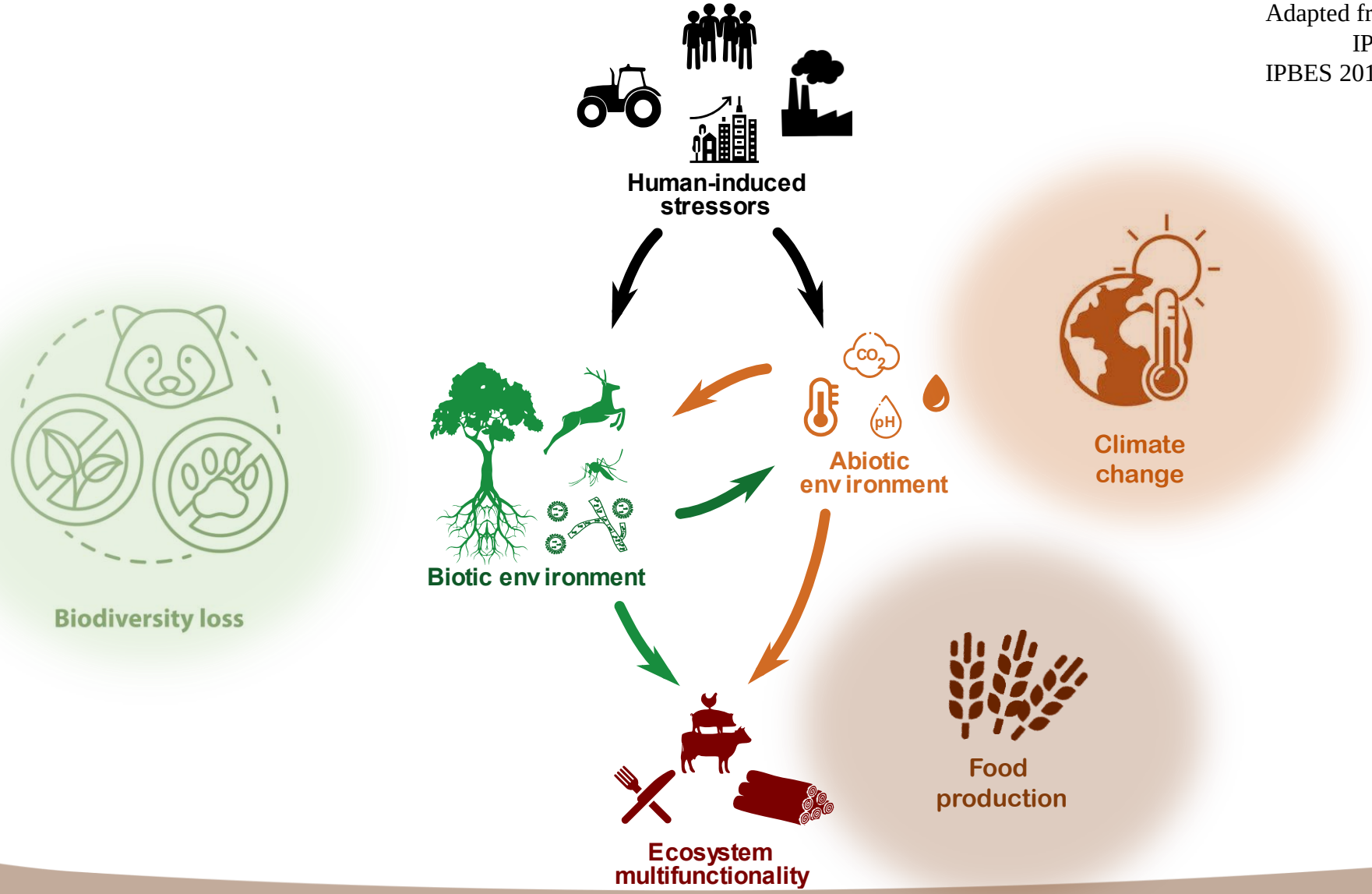
HUMAN ACTIVITIES CHANGE OUR WORLD

Adapted from Giling *et al.* 2019
IPCC 2019, IPCC 2021
IPBES 2019



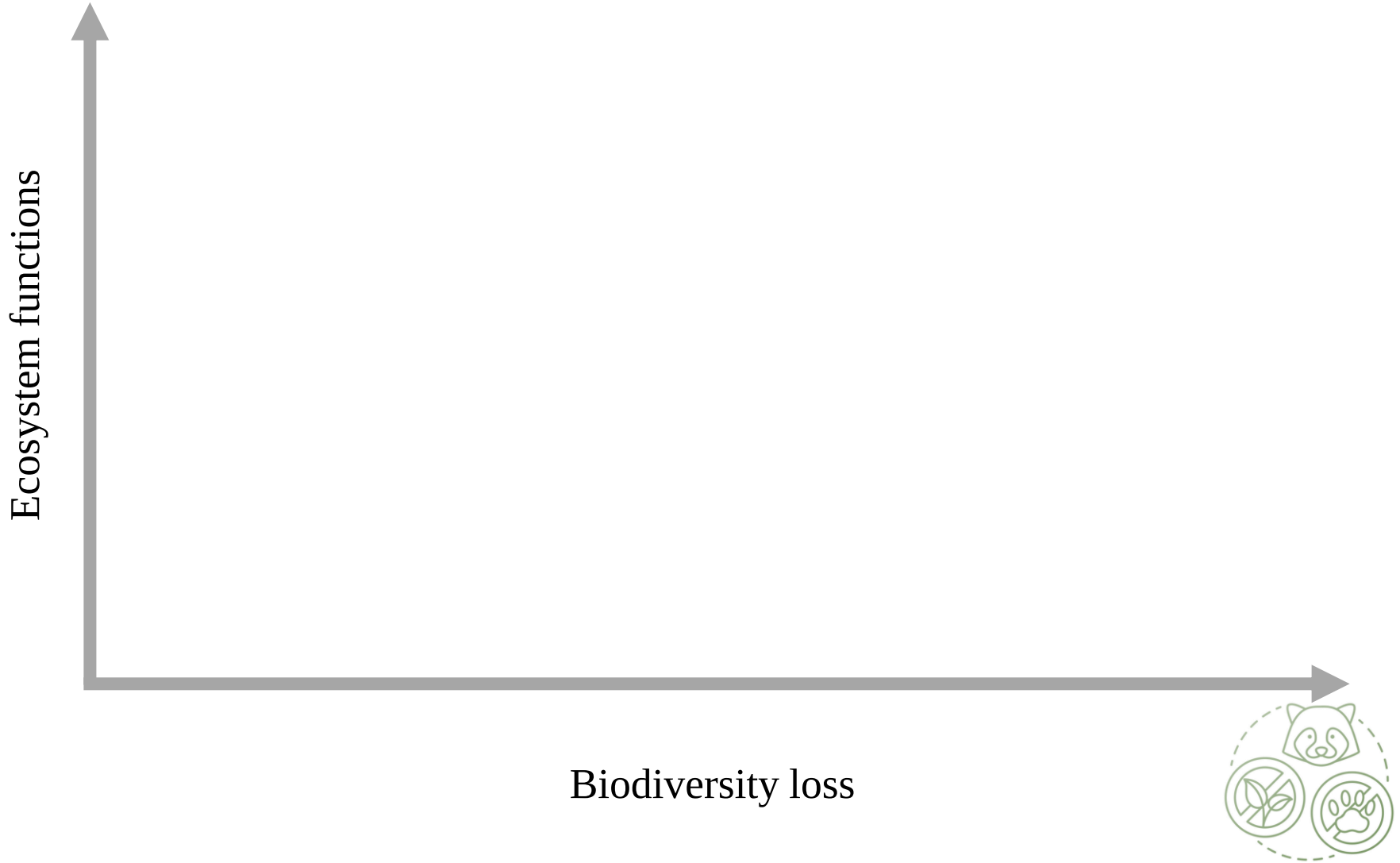
HUMAN ACTIVITIES CHANGE OUR WORLD

Adapted from Giling *et al.* 2019
IPCC 2019, IPCC 2021
IPBES 2019, Pörtner *et al.* 2021



BIODIVERSITY AND ECOSYSTEM FUNCTIONING

IPBES report 2019



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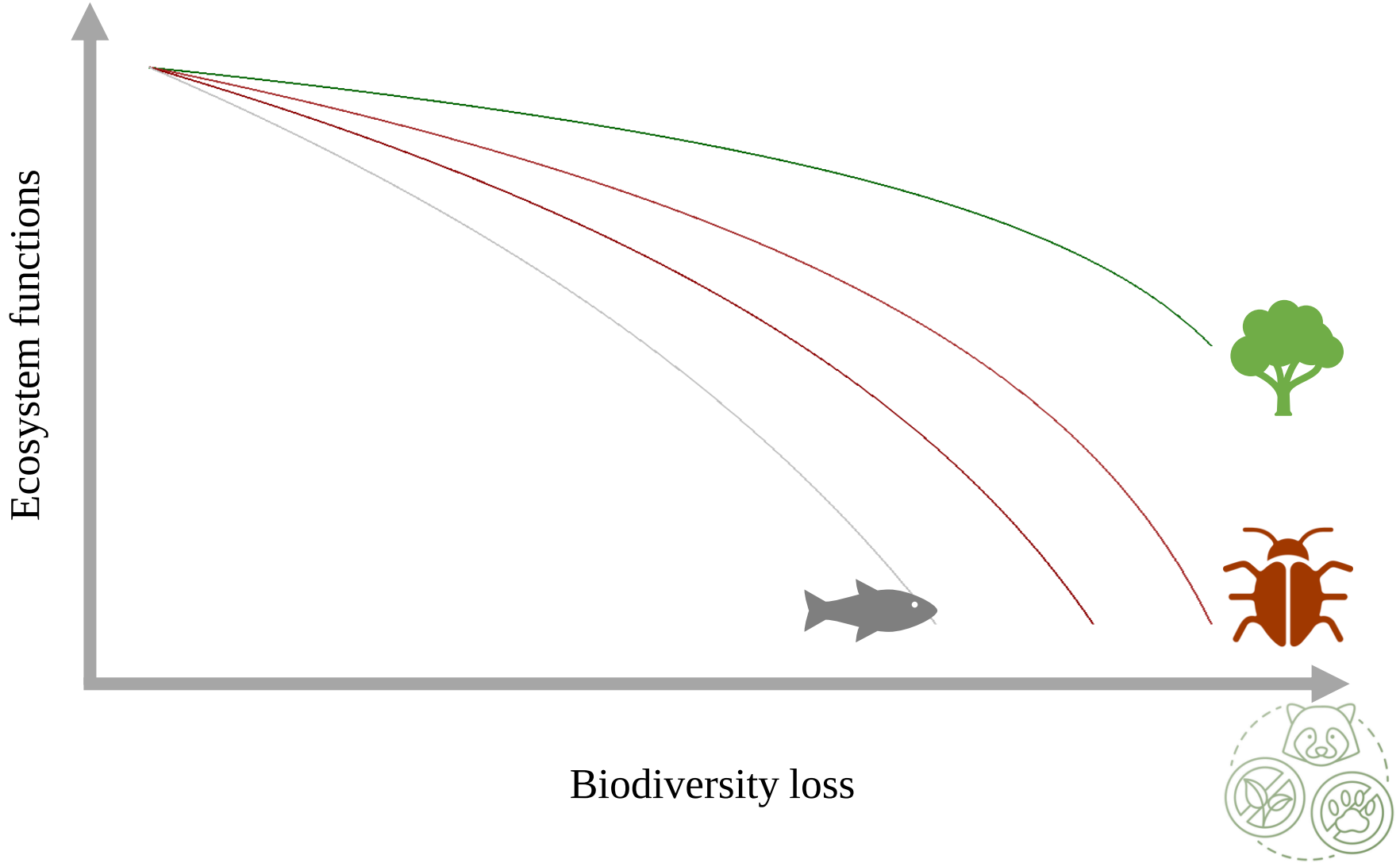
IPBES report 2019



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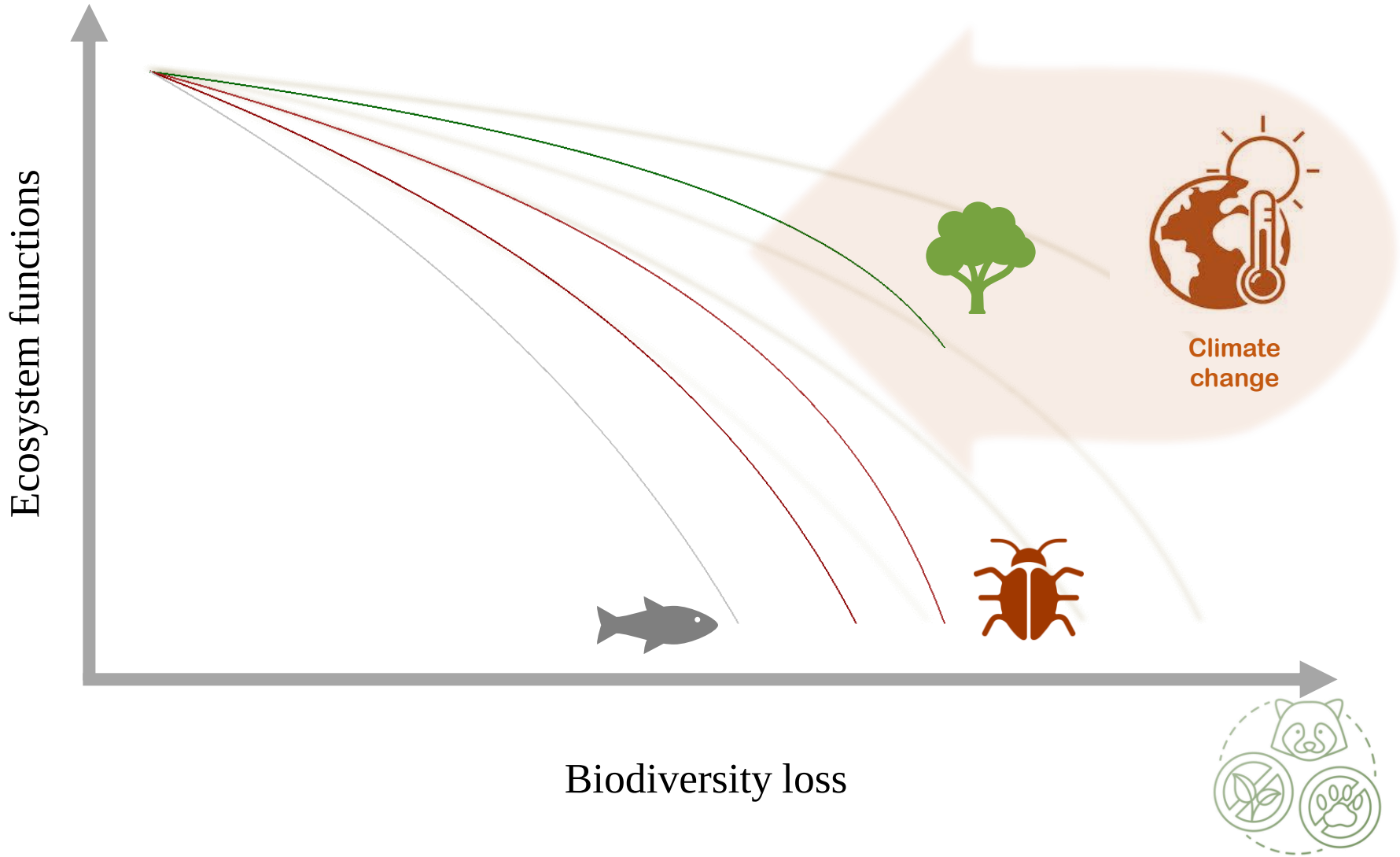
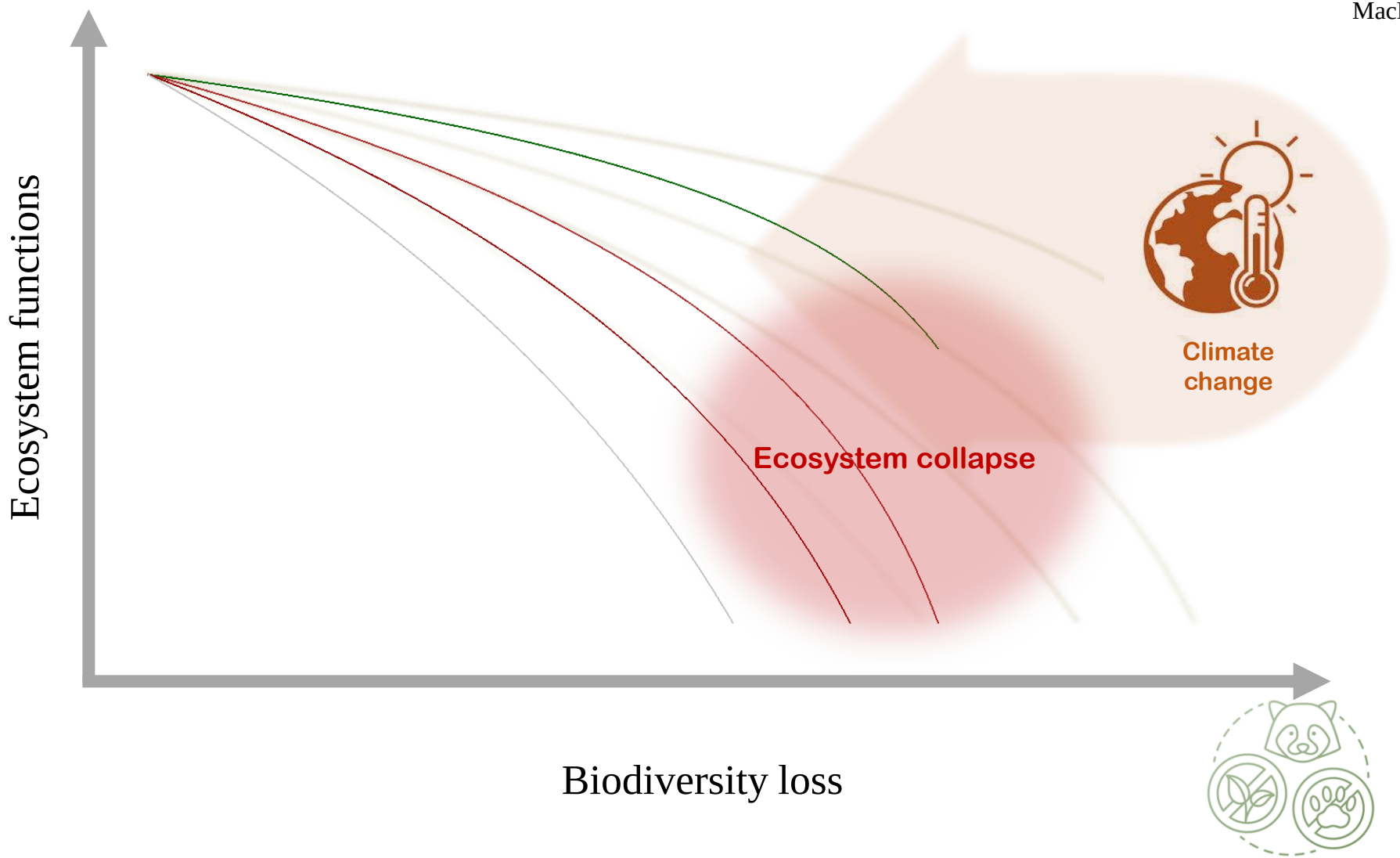


BIODIVERSITY AND ECOSYSTEM FUNCTIONING

MacDougall *et al.* 2013



NATURE-MITIGATION OF CLIMATE CHANGE

Bastin *et al.* 2019, Lewis *et al*. 2019

FROM TREE TO SOIL CARBON STORAGE

CO_2

Photosynthesis

FROM TREE TO SOIL CARBON STORAGE

CO_2

Photosynthesis

Biomass production

FROM TREE TO SOIL CARBON STORAGE

CO_2

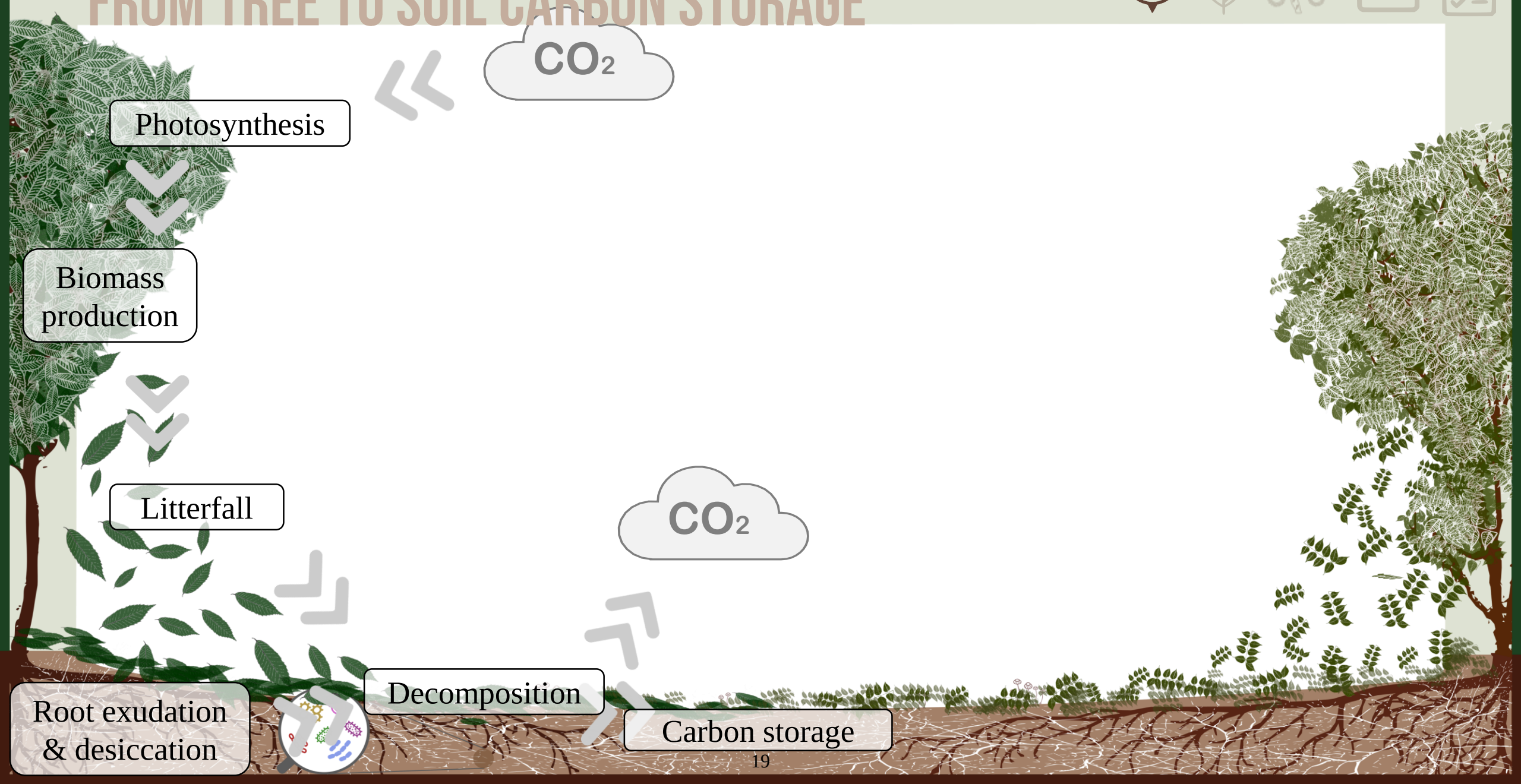
Photosynthesis

Biomass production

Litterfall

Root exudation & desiccation

FROM TREE TO SOIL CARBON STORAGE



FROM TREE TO SOIL CARBON STORAGE

CO_2

Photosynthesis

Biomass production

Litterfall

CO_2

Root exudation & desiccation

Decomposition

Carbon storage

Erosion

TREE DIVERSITY AND FOREST CARBON CYCLE

Huang *et al.* 2017, 2018

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Root exudation & desiccation

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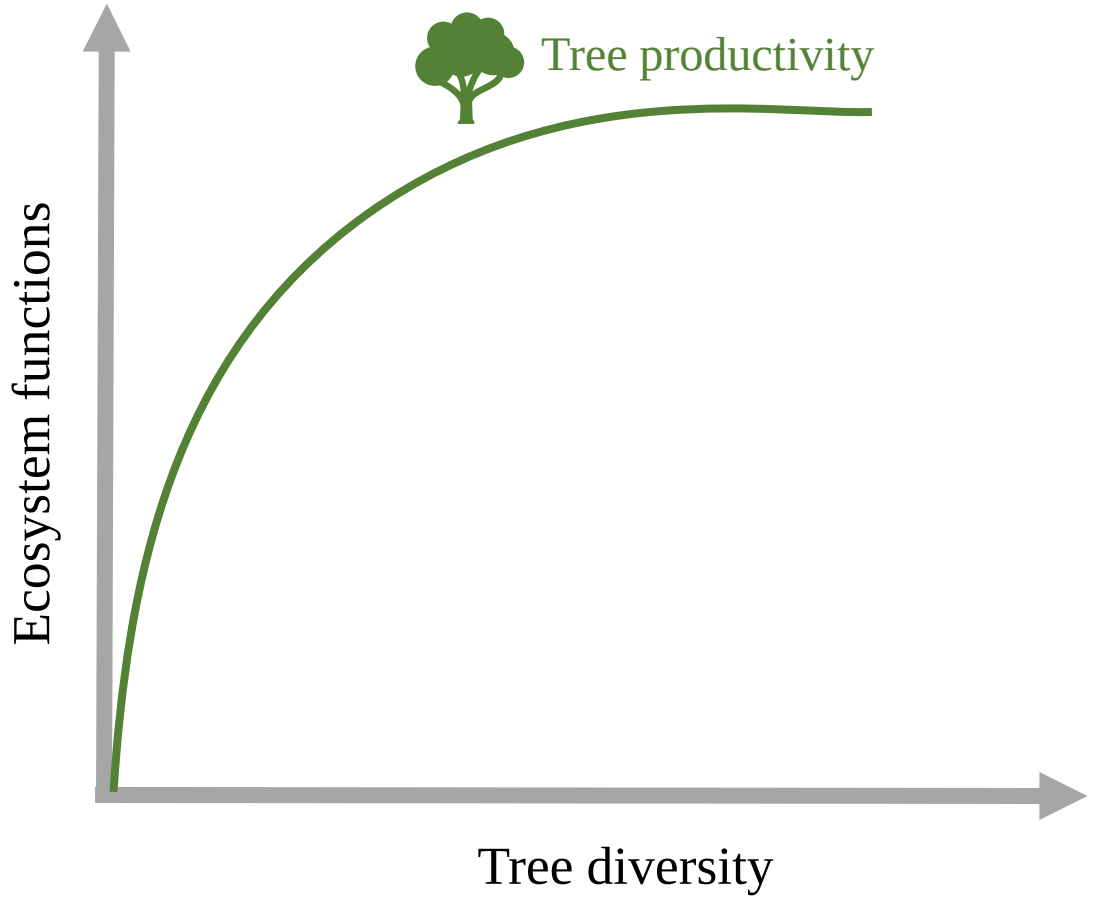

TREE DIVERSITY AND FOREST CARBON CYCLE

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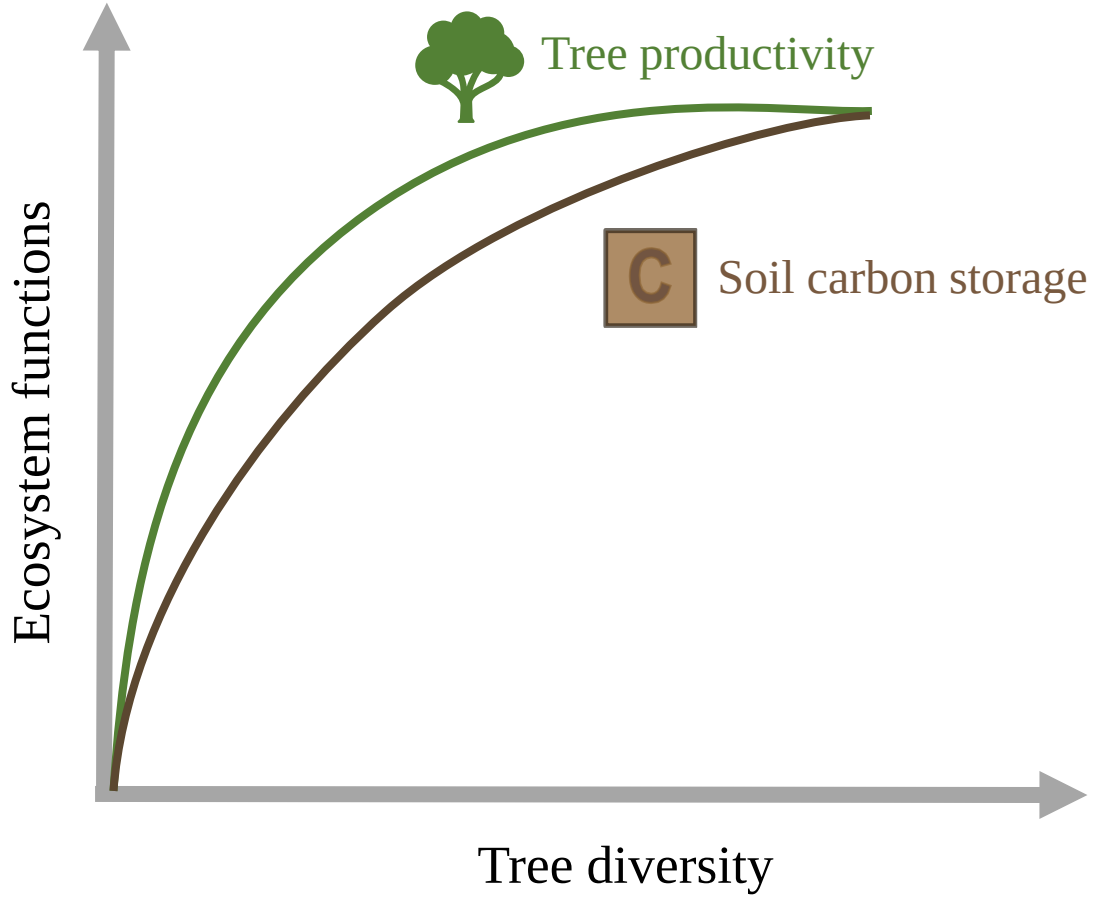

TREE DIVERSITY AND FOREST CARBON CYCLE

Huang *et al.* 2017, 2018, Seitz *et al.* 2015, Xu *et al.* 2020

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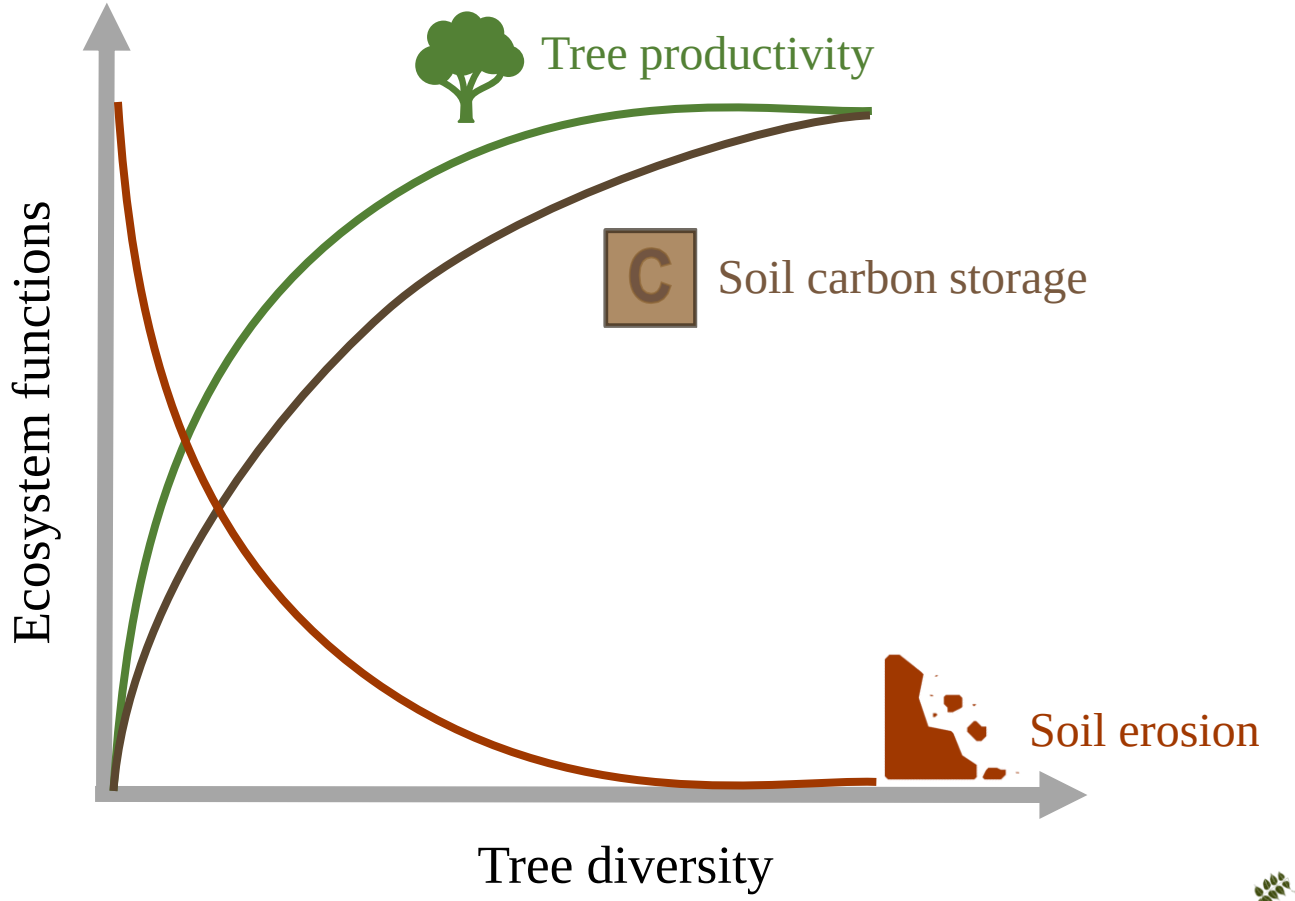
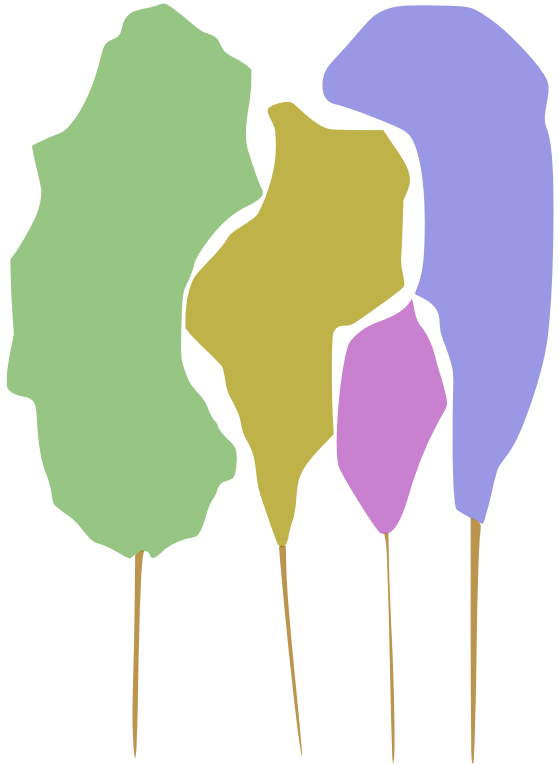


TREE DIVERSITY & RESOURCE PARTITIONING



Adapted from Hildebrand *et al.* 2021

TREE DIVERSITY & RESOURCE PARTITIONING

Barry *et al.* 2019, Huang *et al.* 2017, 2018, Poisot *et al.* 2013, Sapijanskas *et al.* 2014, Seitz *et al.* 2015, Williams *et al.* 2019, Xu *et al.* 2020

SUBSTRATE PARTITIONING

TREE DIVERSITY & RESOURCE PARTITIONING

Barry *et al.* 2019, Huang *et al.* 2017, 2018, Poisot *et al.* 2013, Sapijanskas *et al.* 2014, Seitz *et al.* 2015, Williams *et al.* 2019, Xu *et al.* 2020

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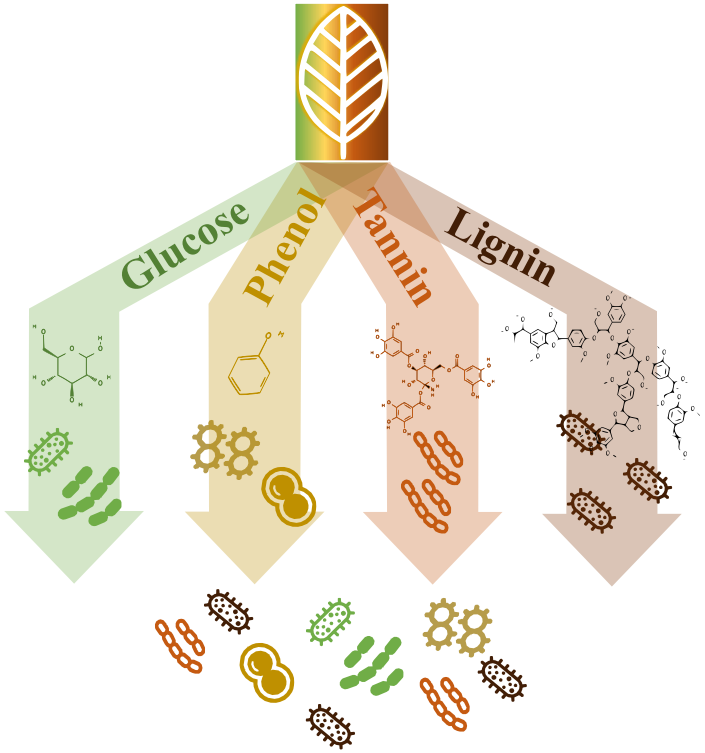

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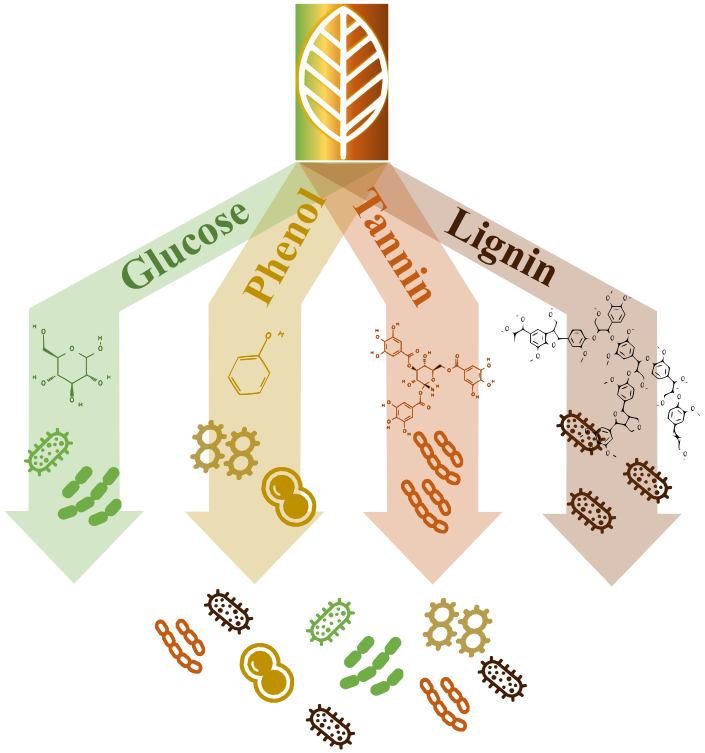

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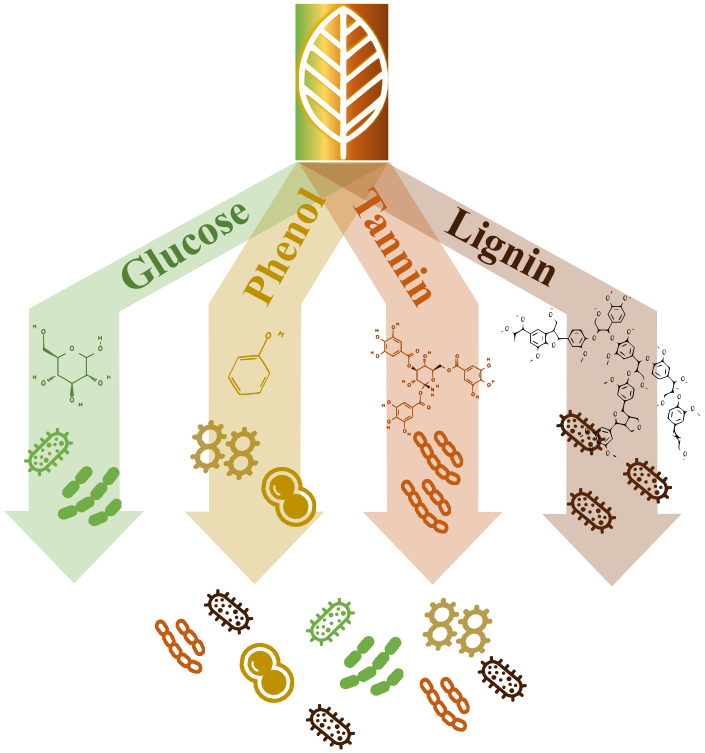

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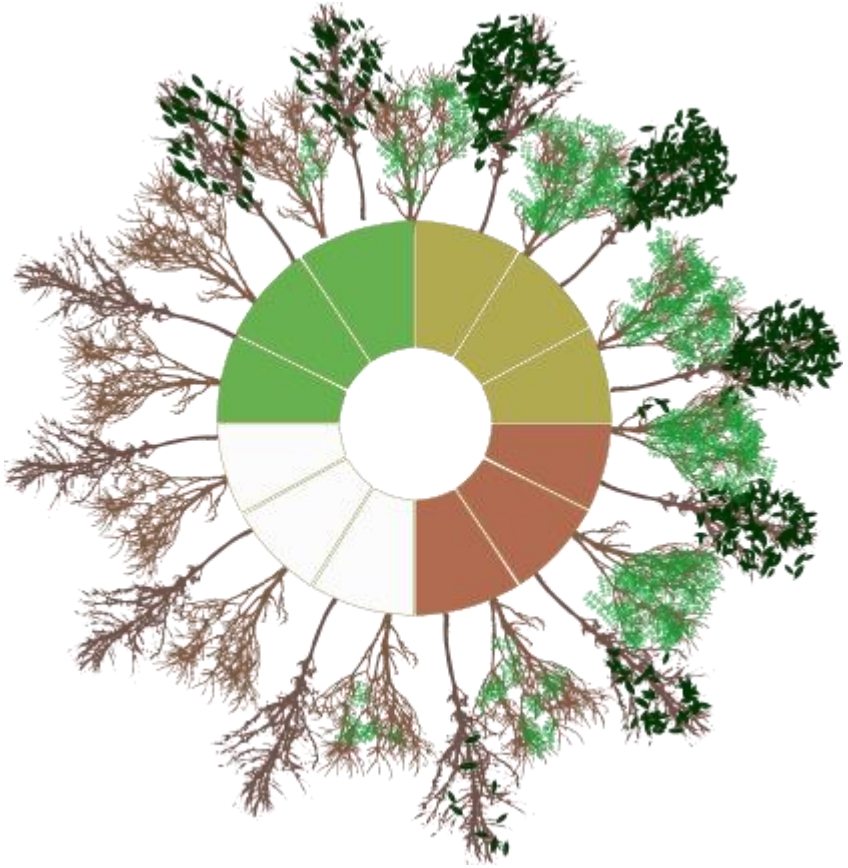

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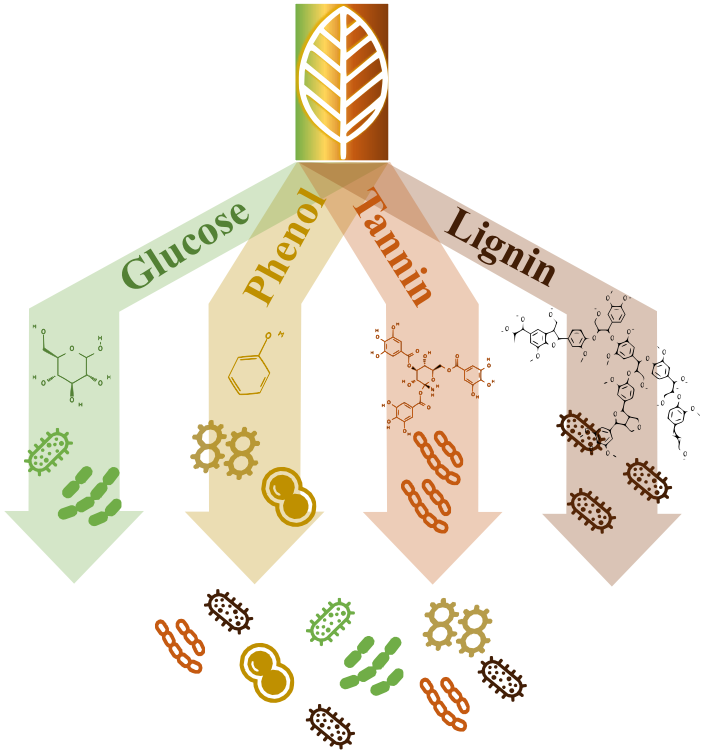

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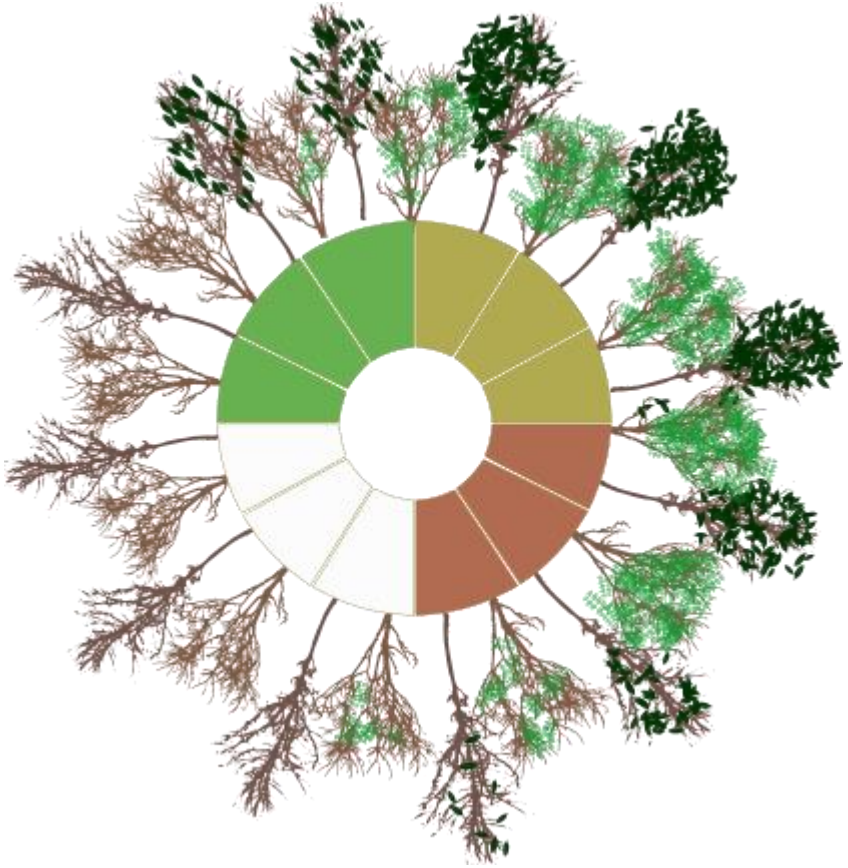
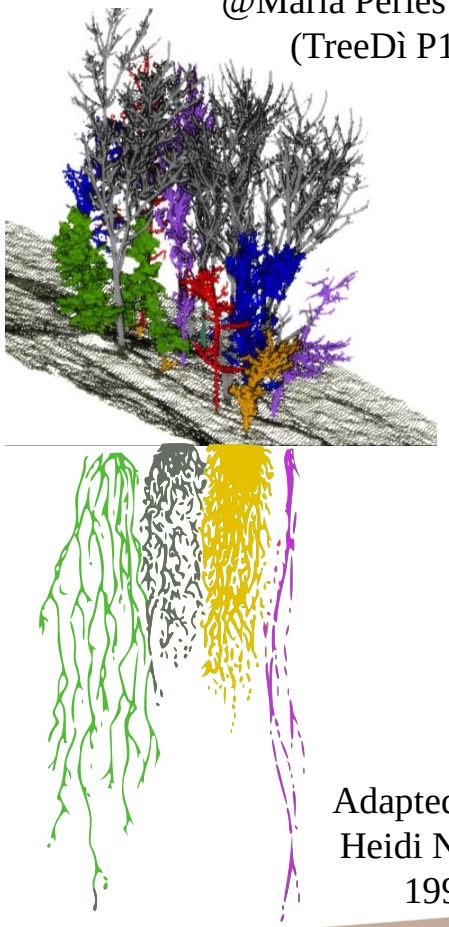


SPATIAL PARTITIONING

@Maria Perles Garcia
(TreeDì P1G)



Adapted from
Heidi Natura
1995

TREE DIVERSITY & RESOURCE PARTITIONING

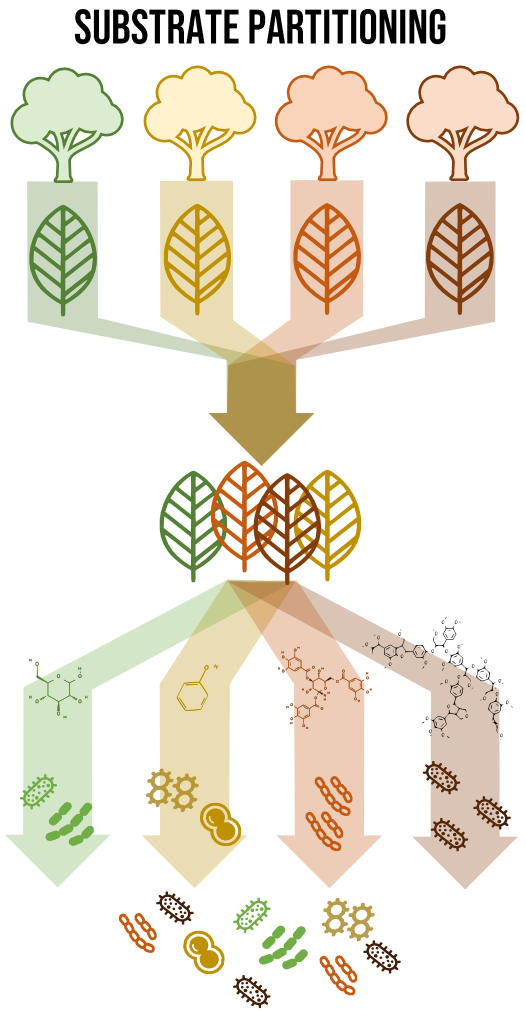
Barry *et al.* 2019, Huang *et al.* 2017, 2018, Poisot *et al.* 2013, Sapijanskas *et al.* 2014, Seitz *et al.* 2015, Williams *et al.* 2019, Xu *et al.* 2020

SPECIES DIVERSITY

PRODUCT DIVERSITY

CONSUMER DIVERSITY

ECOSYSTEM FUNCTIONS



TREE DIVERSITY & RESOURCE PARTITIONING

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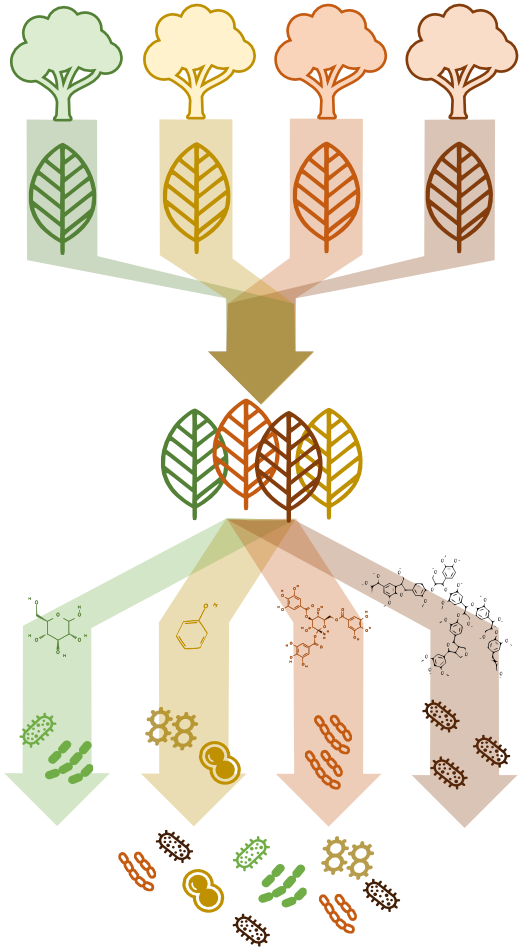

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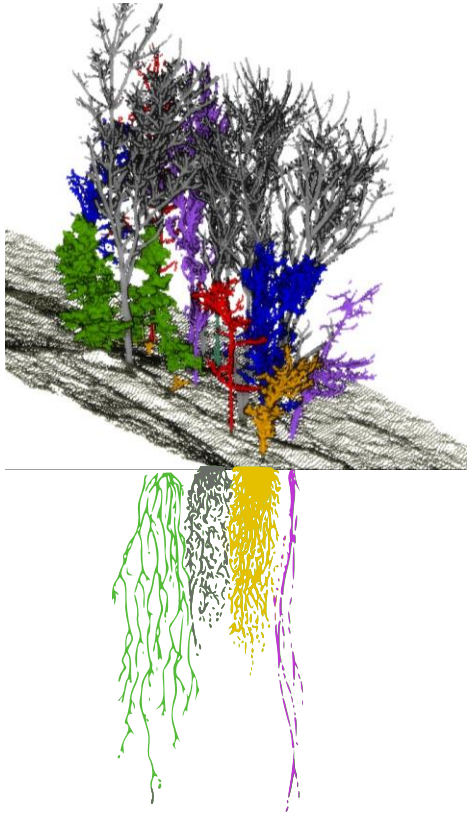

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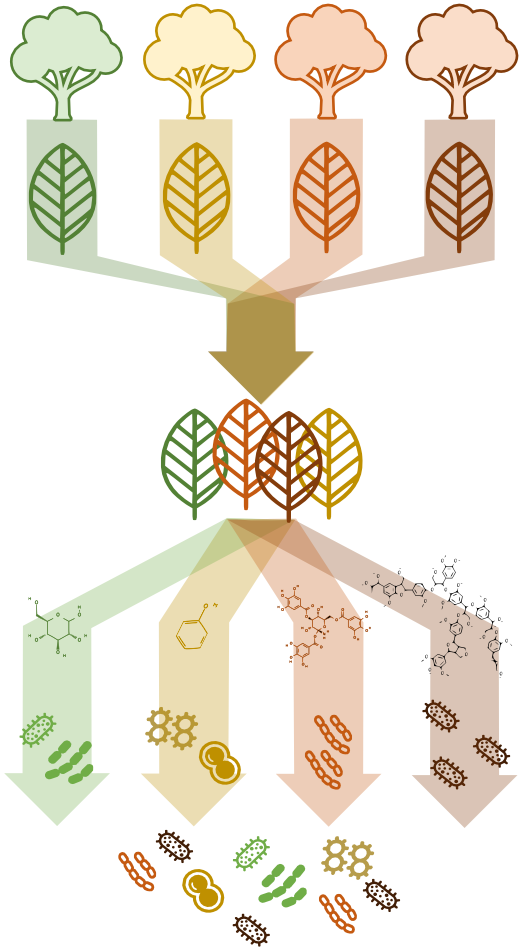

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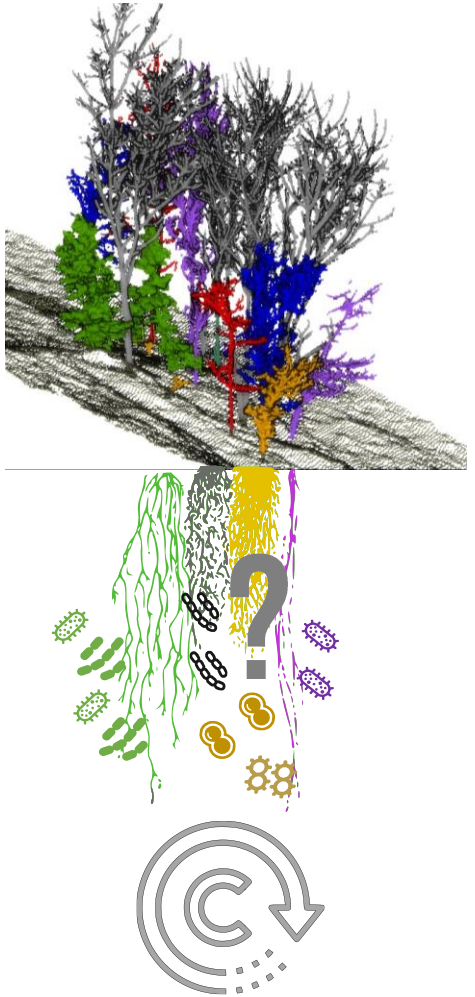
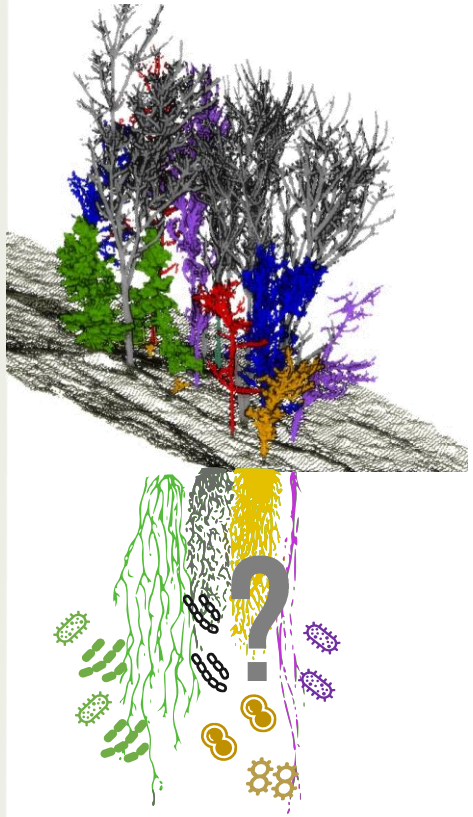


SPACE AND SPECIES INTERACTIONS

Trogisch *et al.* 2021, Williams *et al.* 2019

SPATIAL DISTRIBUTION



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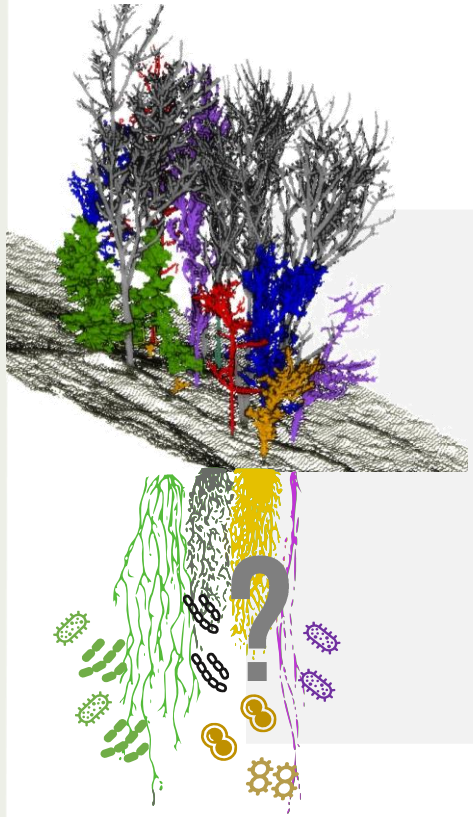
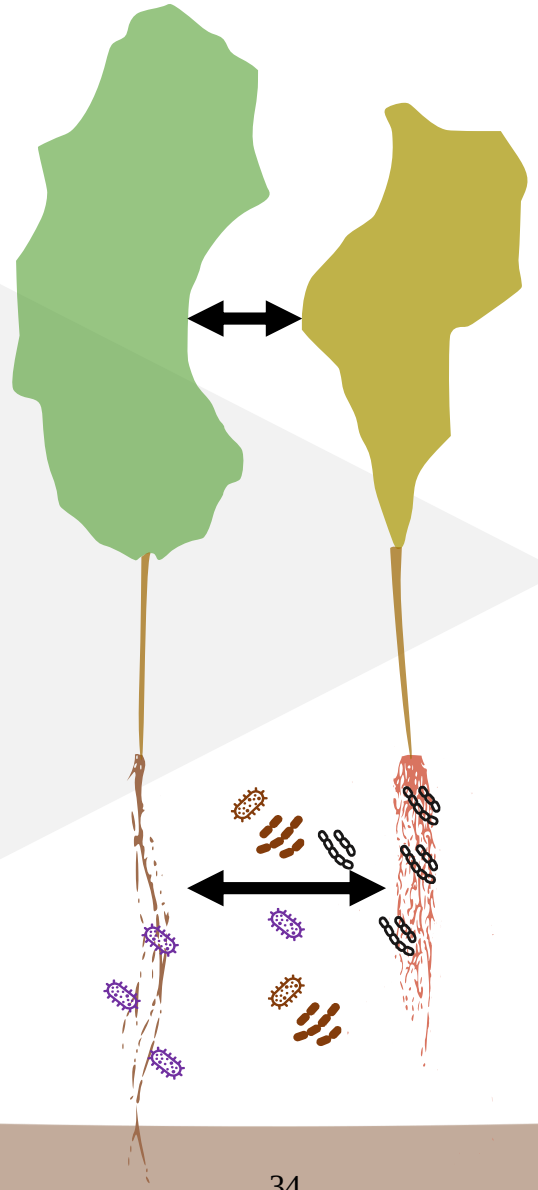


SPECIES INTERACTIONS



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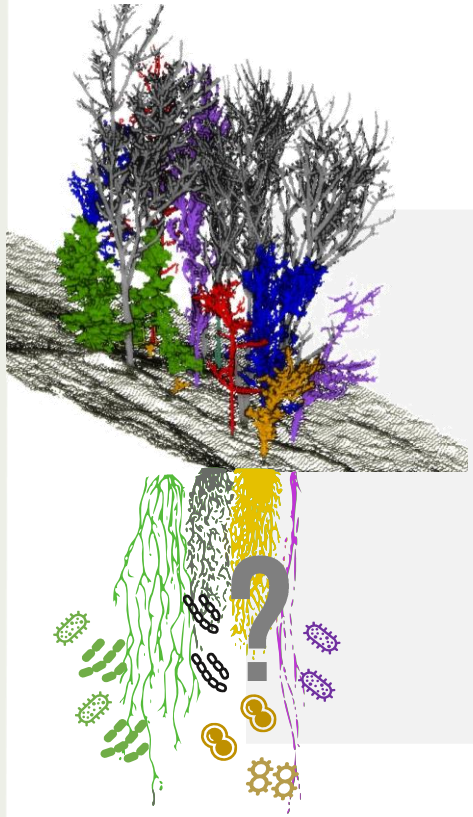

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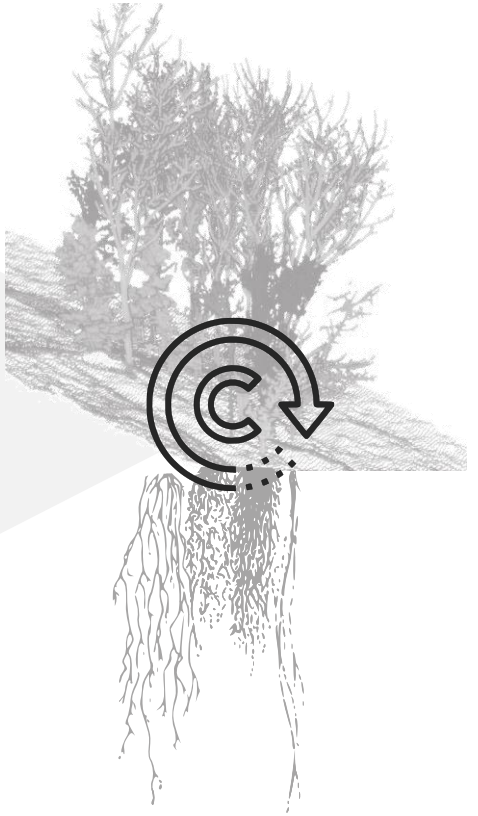
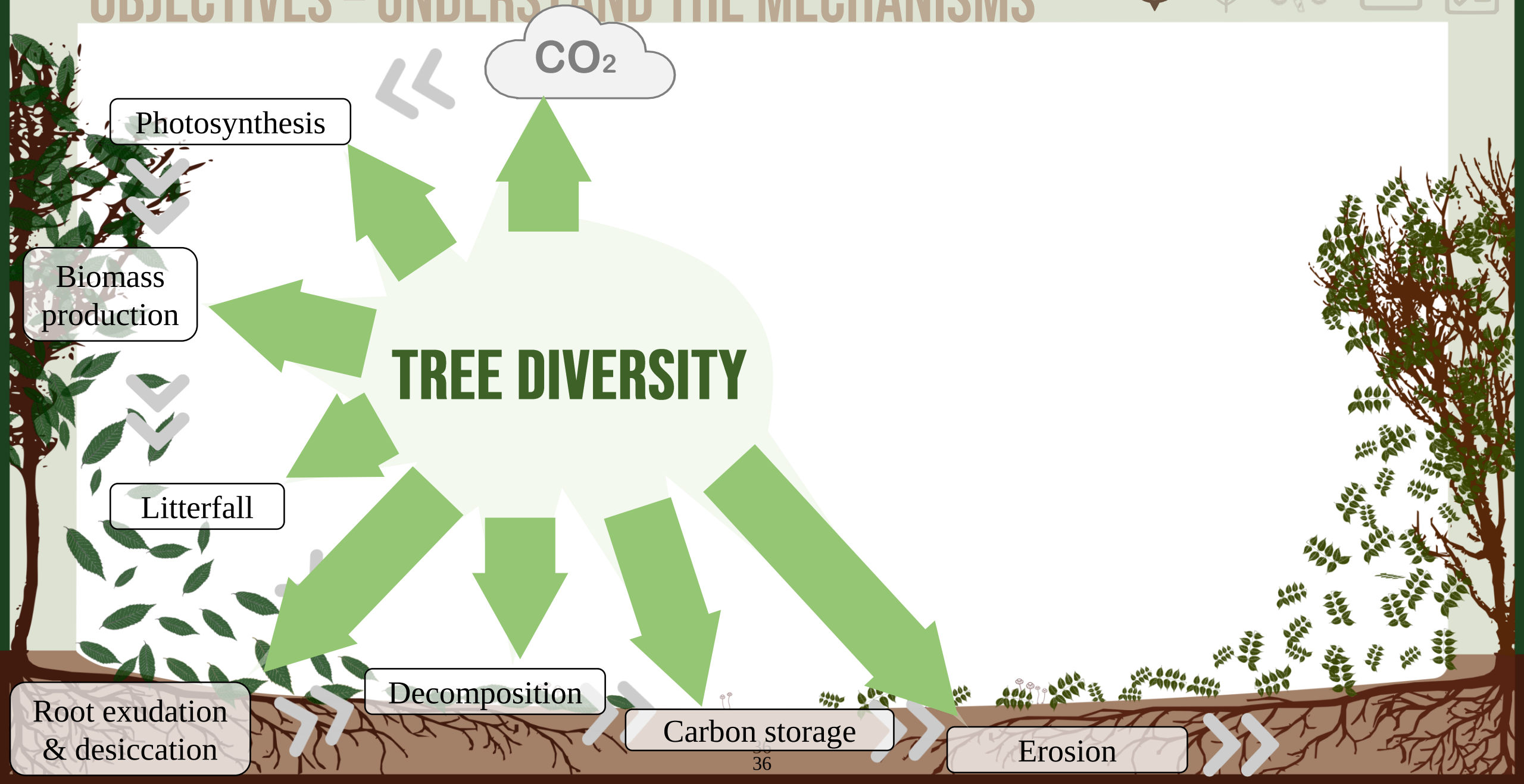


OBJECTIVES – UNDERSTAND THE MECHANISMS



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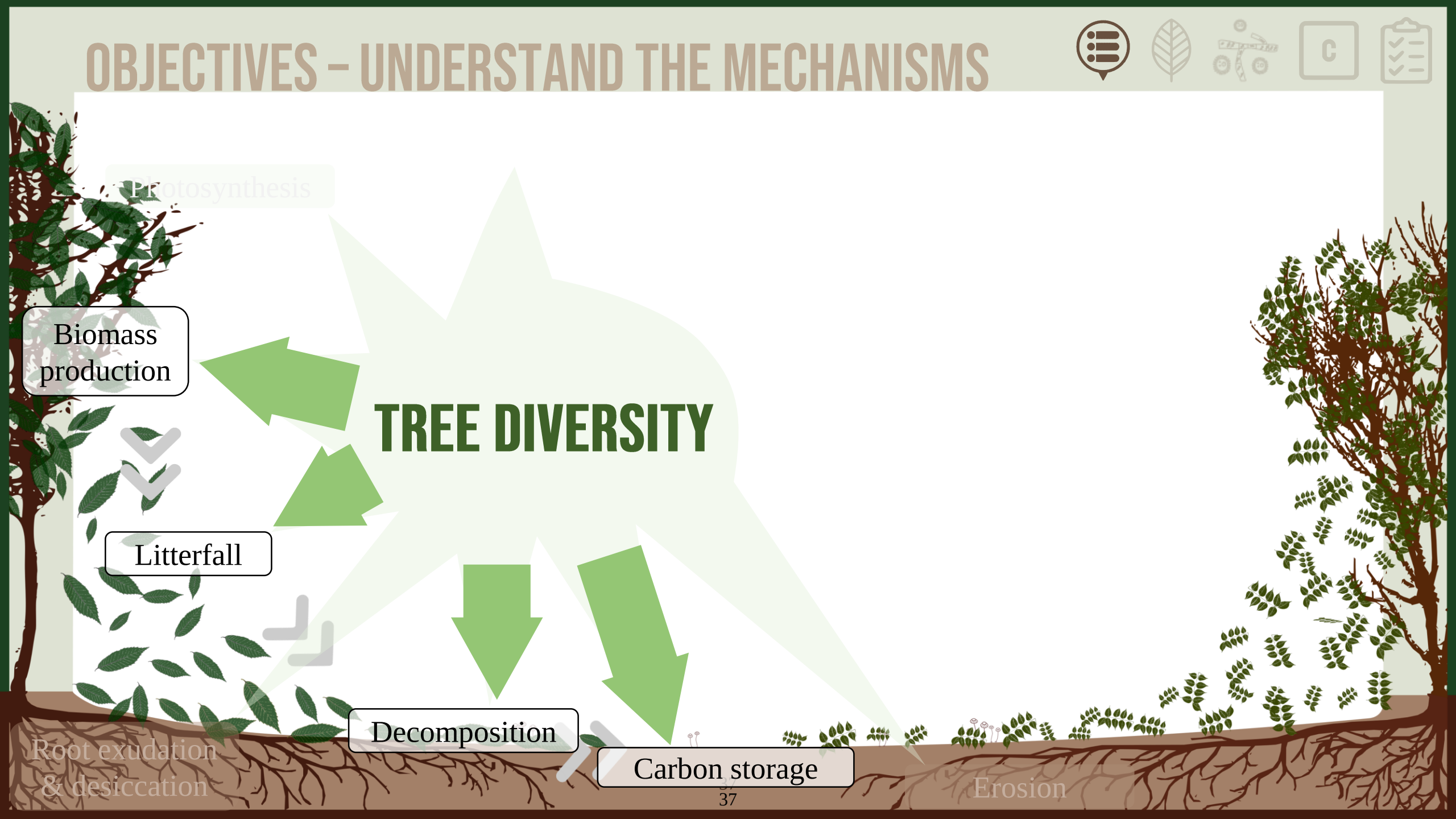

OBJECTIVES – UNDERSTAND THE MECHANISMS

Photosynthesis

Biomass production

TREE DIVERSITY

Litterfall

Decomposition

Root exudation & desiccation

Carbon storage

Erosion

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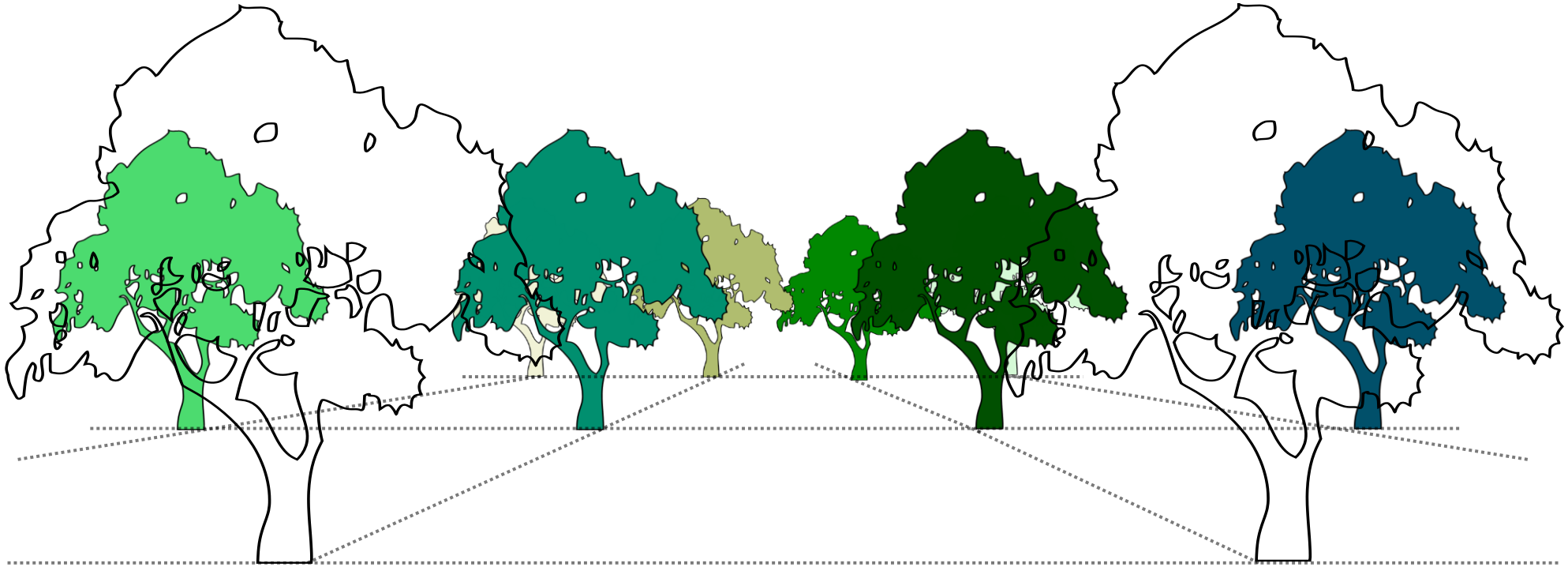
OBJECTIVES – WITH RESPECT FOR SPACE



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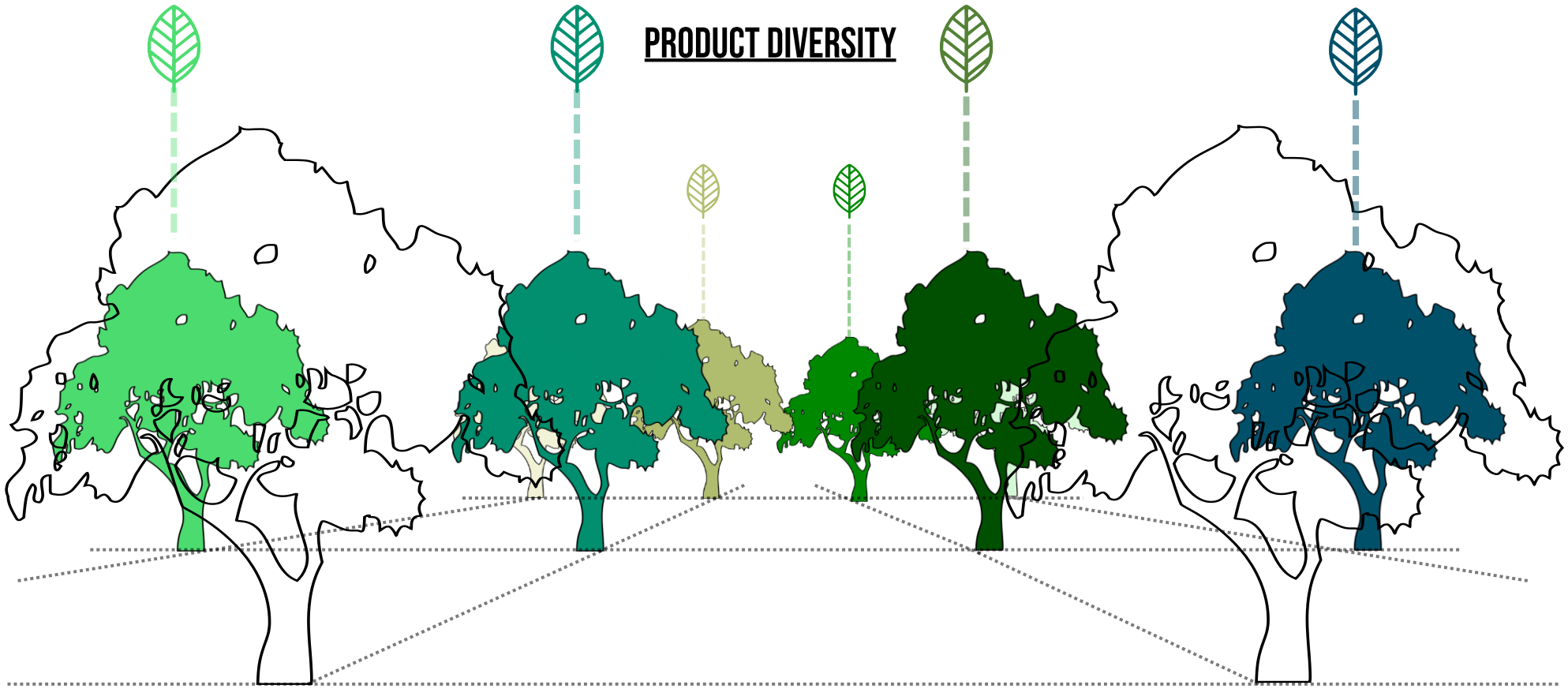

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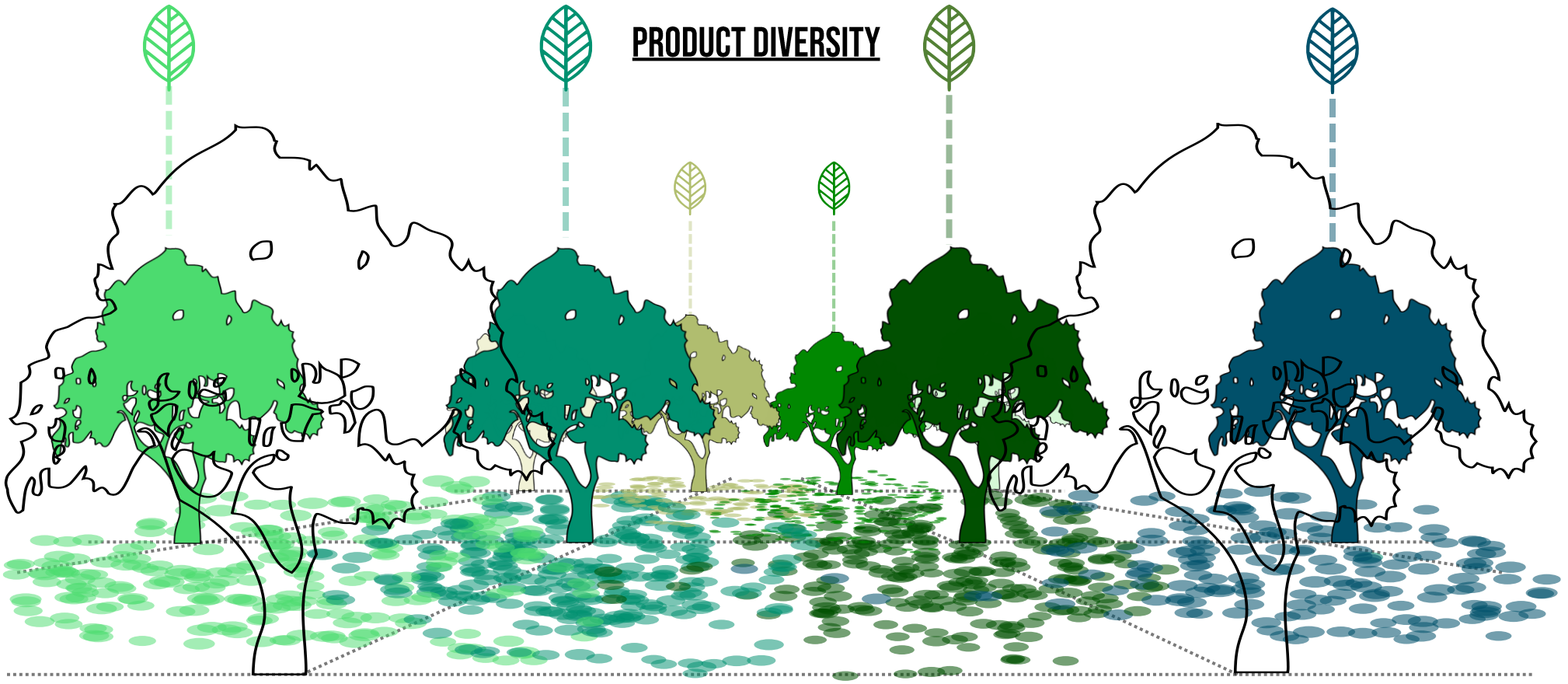


OUTLINE

Biomass production

Litterfall

Decomposition

Root exudation & desiccation

Soil microbial community

Soil microbial functions

Carbon storage

Erosion

OUTLINE

Biomass production

CHAPTER I

Litterfall

Environmental conditions

Soil microbial community

Soil microbial functions

Decomposition

Root exudation & desiccation

Carbon storage

Erosion

43

OUTLINE

Biomass production

CHAPTER I

Litterfall

Environmental conditions

Decomposition

Root exudation & desiccation

CHAPTER II

Soil microbial community

Soil microbial functions

Carbon storage

Erosion

OUTLINE

CHAPTER III

Biomass production

Litterfall

Environmental conditions

Soil microbial community

Soil microbial functions

Decomposition

Carbon storage

Root functional traits

Erosion

CHAPTER I

CHAPTER II

STUDY SITE

Belarus
Poland
Ukraine
Austria
Kazakhstan
Mongolia
Romania
Italy
Spain
Uzbekistan
Kyrgyzstan
Greece
Turkey
Türkmenistan
China
South Korea
East China Sea
Nepal
India
Myanmar


@Tobias Proβ

STUDY SITE

Subtropical Chinese forests: warm, rainy summers and cool, dry winters

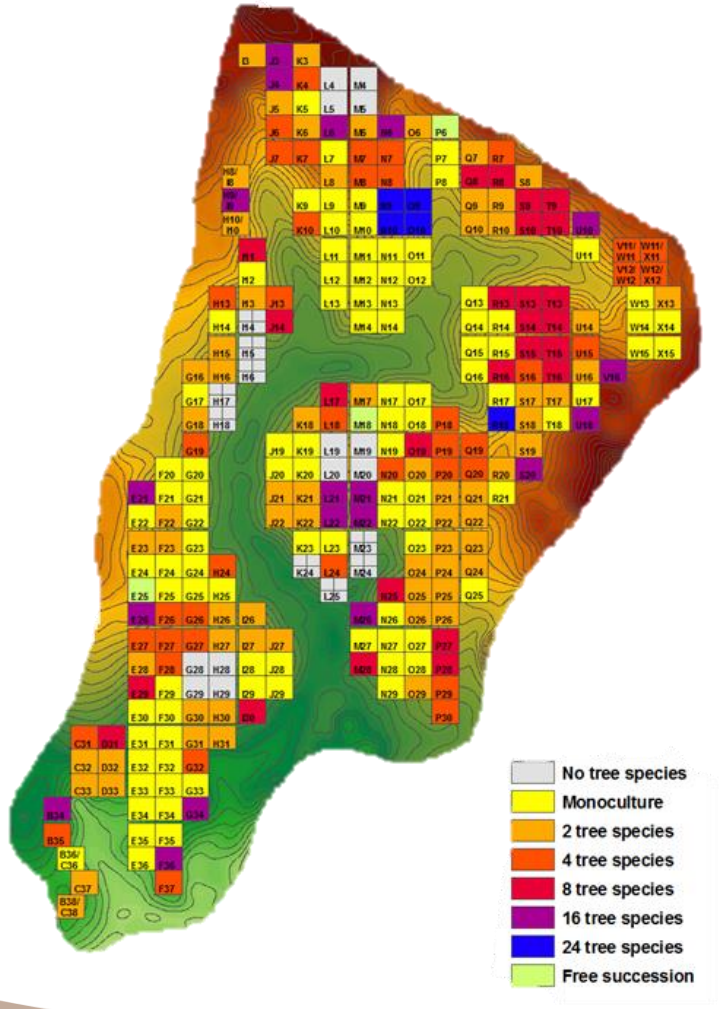
STUDY SITE

Biome with the highest average net ecosystem productivity among Asian forests, it is thus ideal for the study of carbon cycling and its determinants.

BEF CHINA DESIGN

Bruelheide *et al.* 2014, Scholten *et al.* 2017

29.08-29.11° N, 117.90–117.93° E



Mean annual temperature of 16.7 °C (*vs.* 10.2 °C in Leipzig)

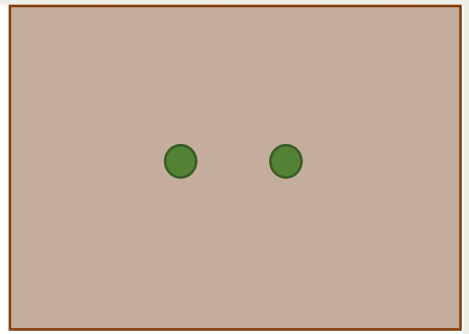
Mean annual rainfall of 1 821 mm (*vs.* 723 mm in Leipzig)

Soils are Cambisols and derivative, with Regosol on ridges

Natural vegetation: *Cyclobalanopsis glauca, Castanopsis eyrei, Daphniphyllum oldhamii, and Lithocarpus glaber*

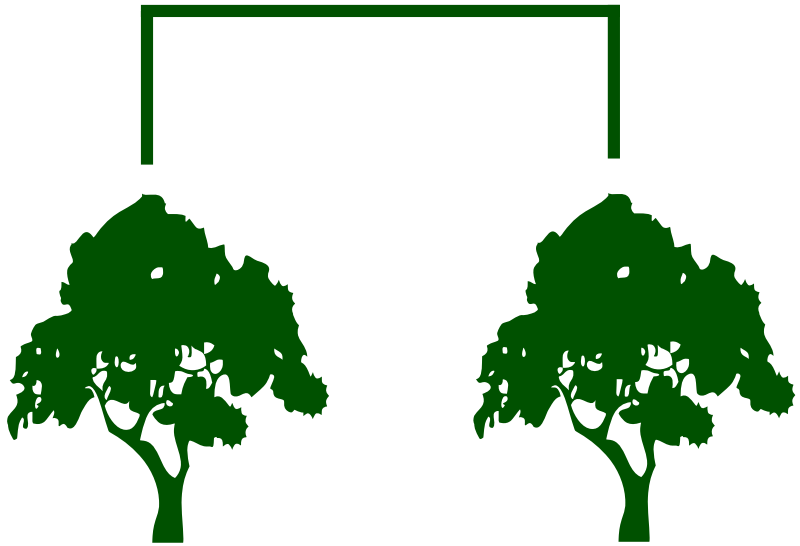
Planted in 2009 after a clear-cut of the previous commercial forests

TREEDÌ SAMPLING DESIGN

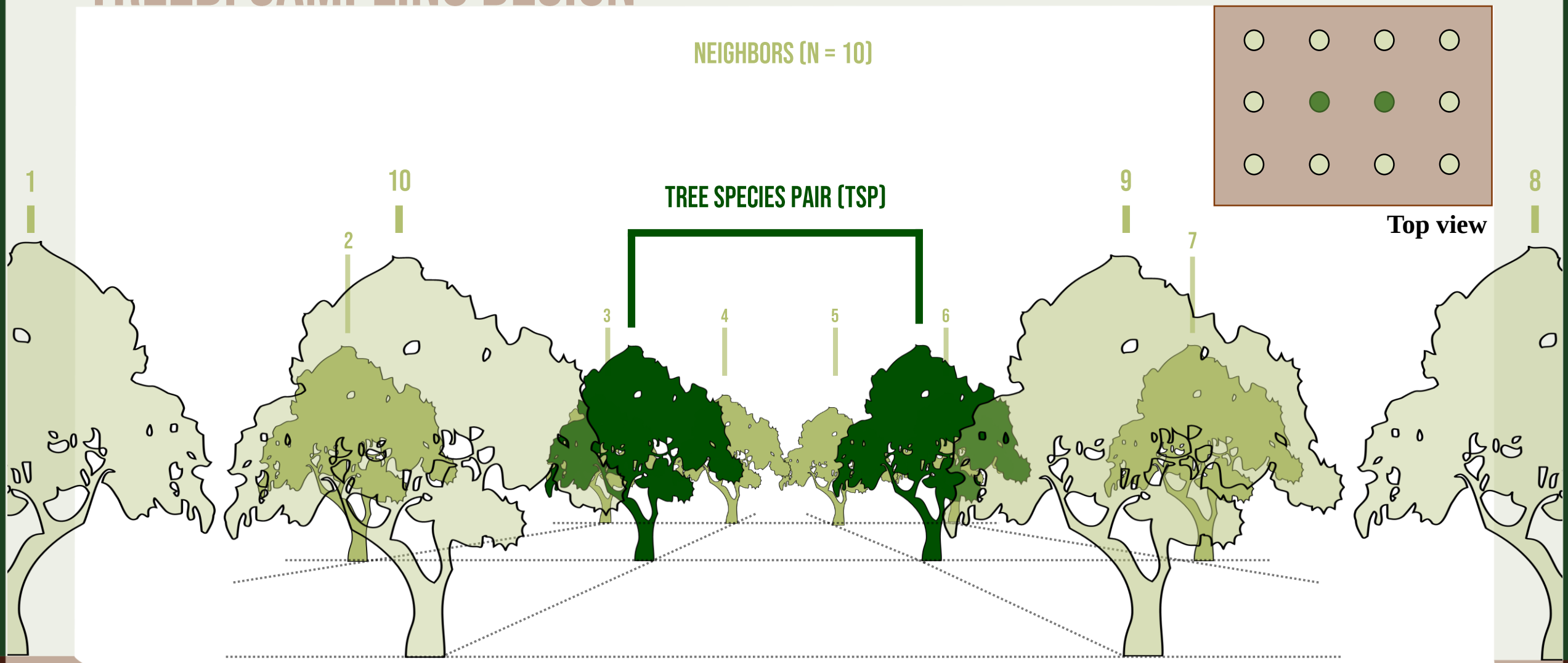


Top view

TREE SPECIES PAIR (TSP)

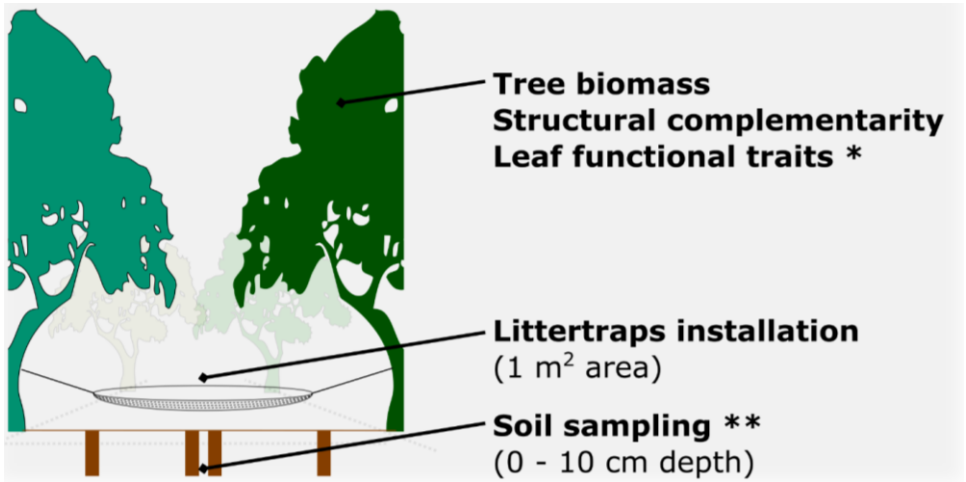


TREEDÌ SAMPLING DESIGN



MY SAMPLING DESIGN

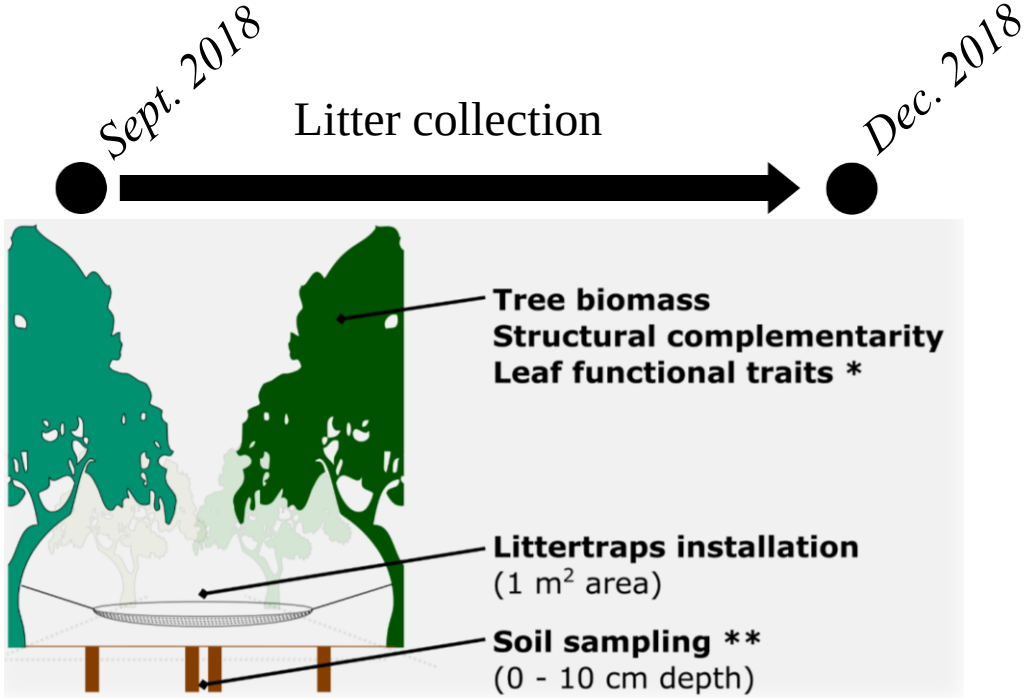
Sept. 2018



*: in collaboration with the TreeDì project P1G, P2G, P5G

**: in collaboration with the TreeDì project P7G and P8C

MY SAMPLING DESIGN

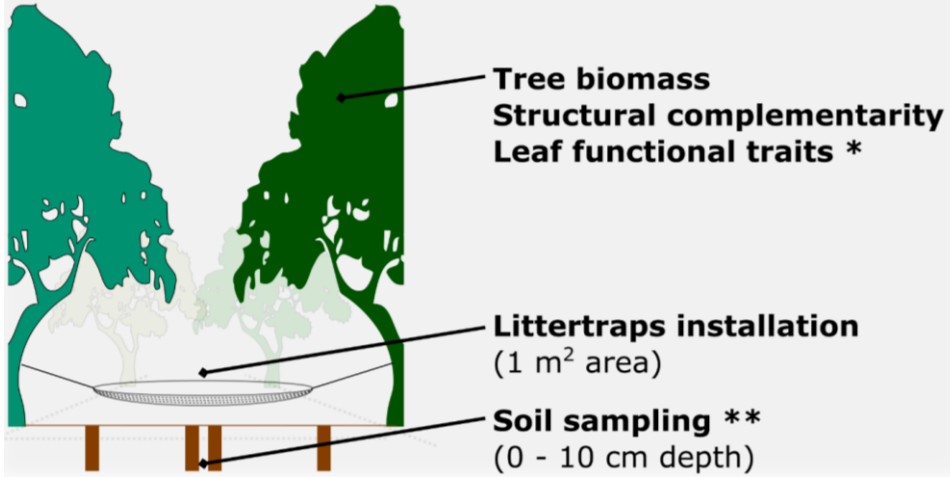


*: in collaboration with the TreeDì projects P1G, P2G, P5G

**: in collaboration with the TreeDì projects P7G and P8C

MY SAMPLING DESIGN

Sept. 2018 — Litter collection → Dec. 2018

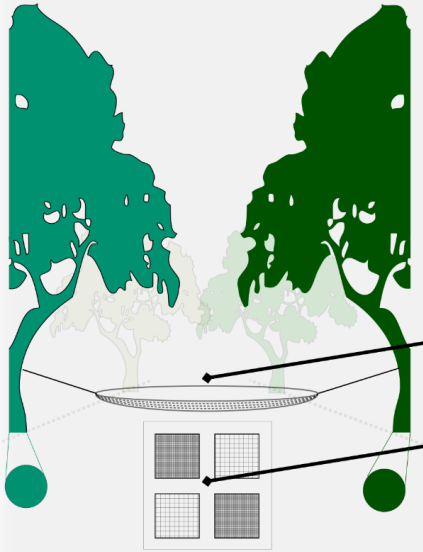


Tree biomass
Structural complementarity
Leaf functional traits *

Littertraps installation
(1 m^2 area)

Soil sampling **
(0 - 10 cm depth)

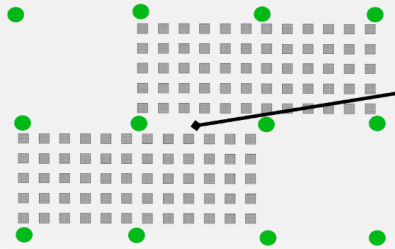
Between TSPs



Litter sampling

Litterbags installation
(4 bags:
- 2 x 0.054 mm mesh
- 2 x 5 mm mesh)

In the Common Garden experiment



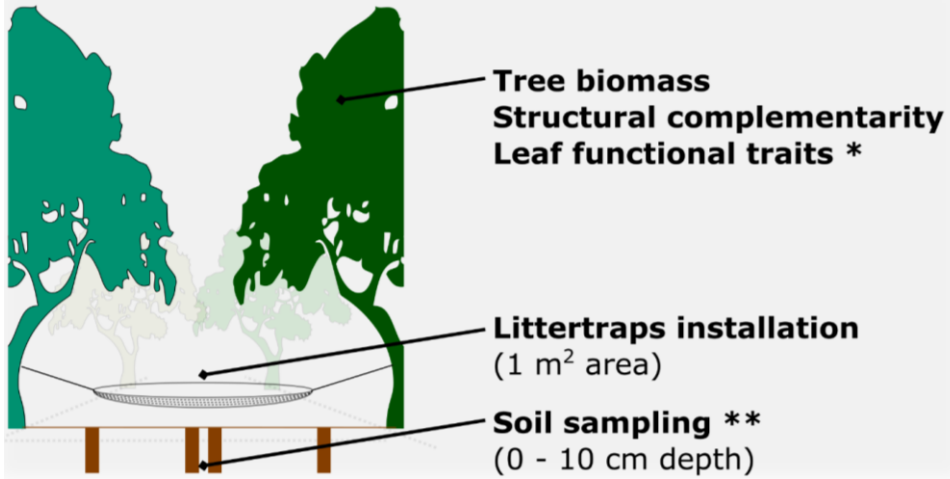
Litterbags installation
(2 x 0.054 mm mesh per TSP)

(in *Shima Superba* monoculture)

*: in collaboration with the TreeDì projects P1G, P2G, P5G
**: in collaboration with the TreeDì projects P7G and P8C

MY SAMPLING DESIGN

Sept. 2018 — Litter collection → Dec. 2018 — Decomposition incubation → Sept. 2019

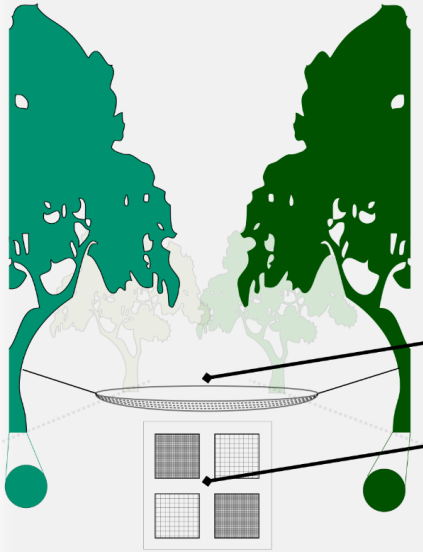


Tree biomass
Structural complementarity
Leaf functional traits *

Littertraps installation
(1 m^2 area)

Soil sampling **
(0 - 10 cm depth)

Between TSPs



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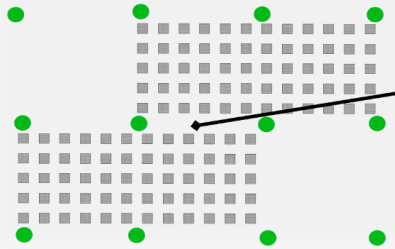

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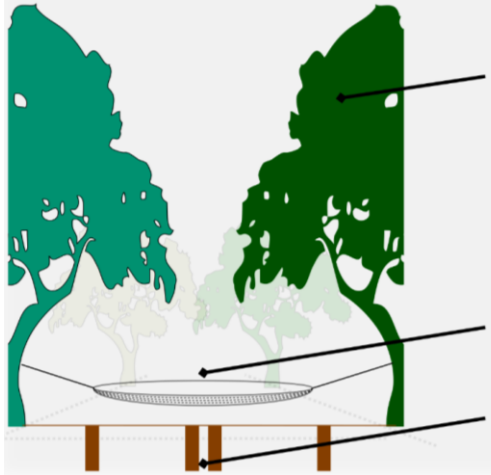
MY SAMPLING DESIGN

Sept. 2018 — Litter collection — Dec. 2018 — Decomposition incubation — Sept. 2019 — **Litterbag sampling**



Tree biomass
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Littertraps installation
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Soil sampling **
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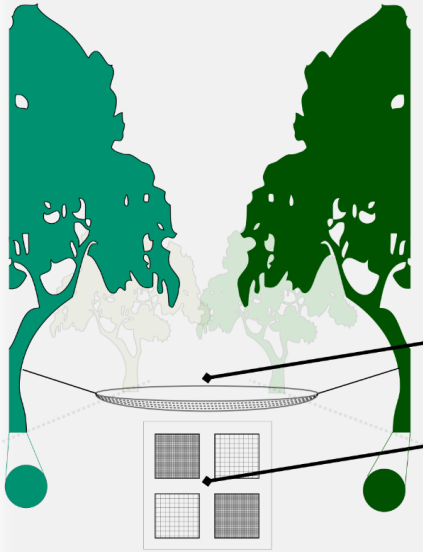
Between TSPs



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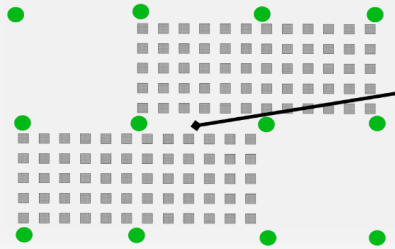

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*: in collaboration with the TreeDì projects P1G, P2G, P5G
**: in collaboration with the TreeDì projects P7G and P8C

CHAPTER I – DIVERSITY, LITTERFALL AND DECOMPOSITION

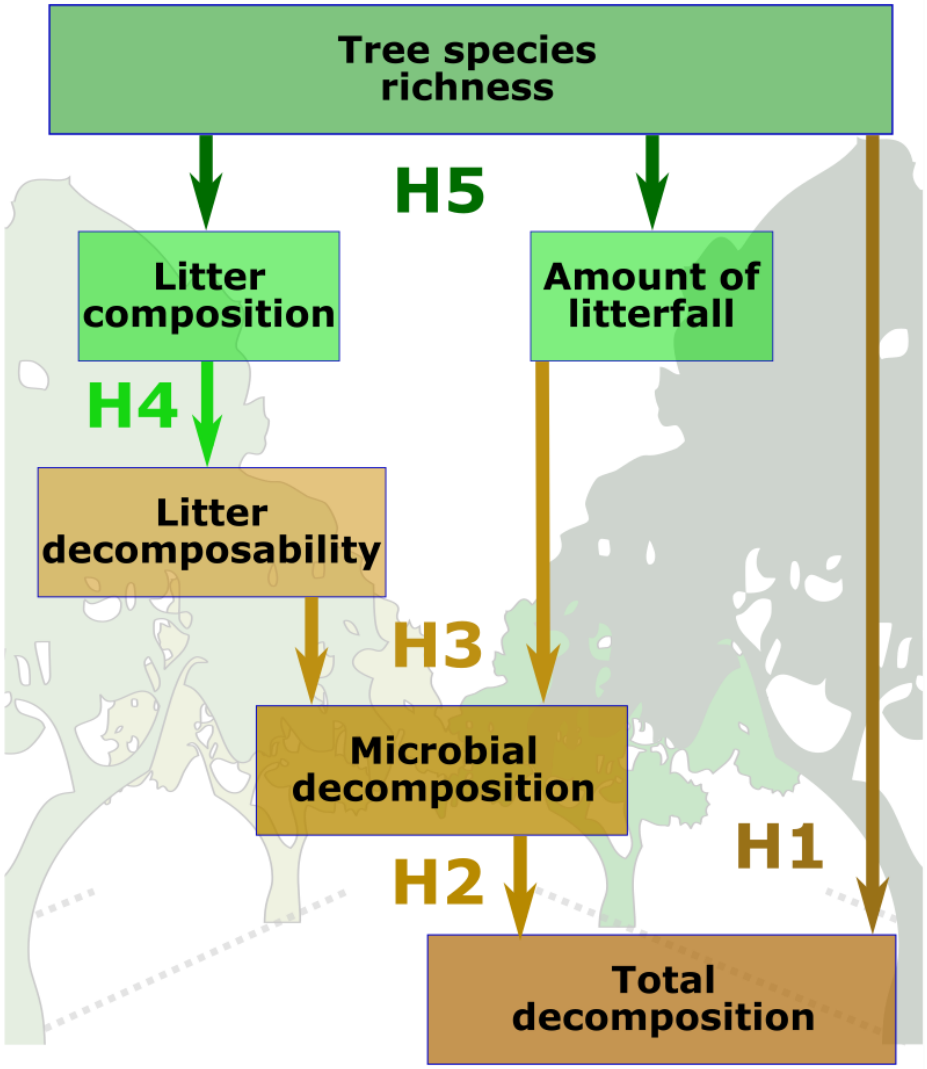
ARTICLE

Tree diversity effects on litter decomposition are mediated by litterfall and microbial processes

Rémy Beugnon[1,2], Nico Eisenhauer[1,2], Helge Bruelheide[3,1], Andréa Davrinche[3,1], Jianqing Du[4,5], Sylvia Haider[3,1], Georg Haehn[3,1], Mariem Saadani[3,1], Bala Singavarapu[6,1,3], Marie Sünnemann[1,2], Lise Thouvenot[1,2], Yanfen Wang[4,5], Tesfaye Wubet[6,1], Kai Xue[4,5] & Simone Cesarz[1,2]

Submitted to Functional Ecology

HYPOTHESES


Tree species richness
H5
Litter composition
Amount of litterfall
H4
Litter decomposability
H3
Microbial decomposition
H1
H2
Total decomposition

MY SAMPLING DESIGN

Sept. 2018 — Litter collection → Dec. 2018 — Decomposition incubation → Sept. 2019

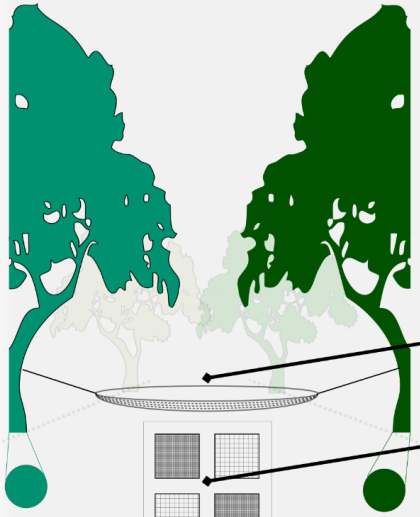
Litterbag sampling

Tree biomass
Structural complementarity
Leaf functional traits *

Littertraps installation
(1 m^2 area)

Soil sampling **
(0 - 10 cm depth)

Between TSPs



Litter sampling

Litterbags installation
(4 bags:
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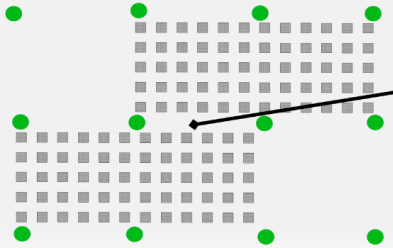
In the Common Garden experiment



Litterbags installation
(2 x 0.054 mm mesh per TSP)

(in *Shima Superba* monoculture)

*: in collaboration with the TreeDì projects P1G, P2G, P5G
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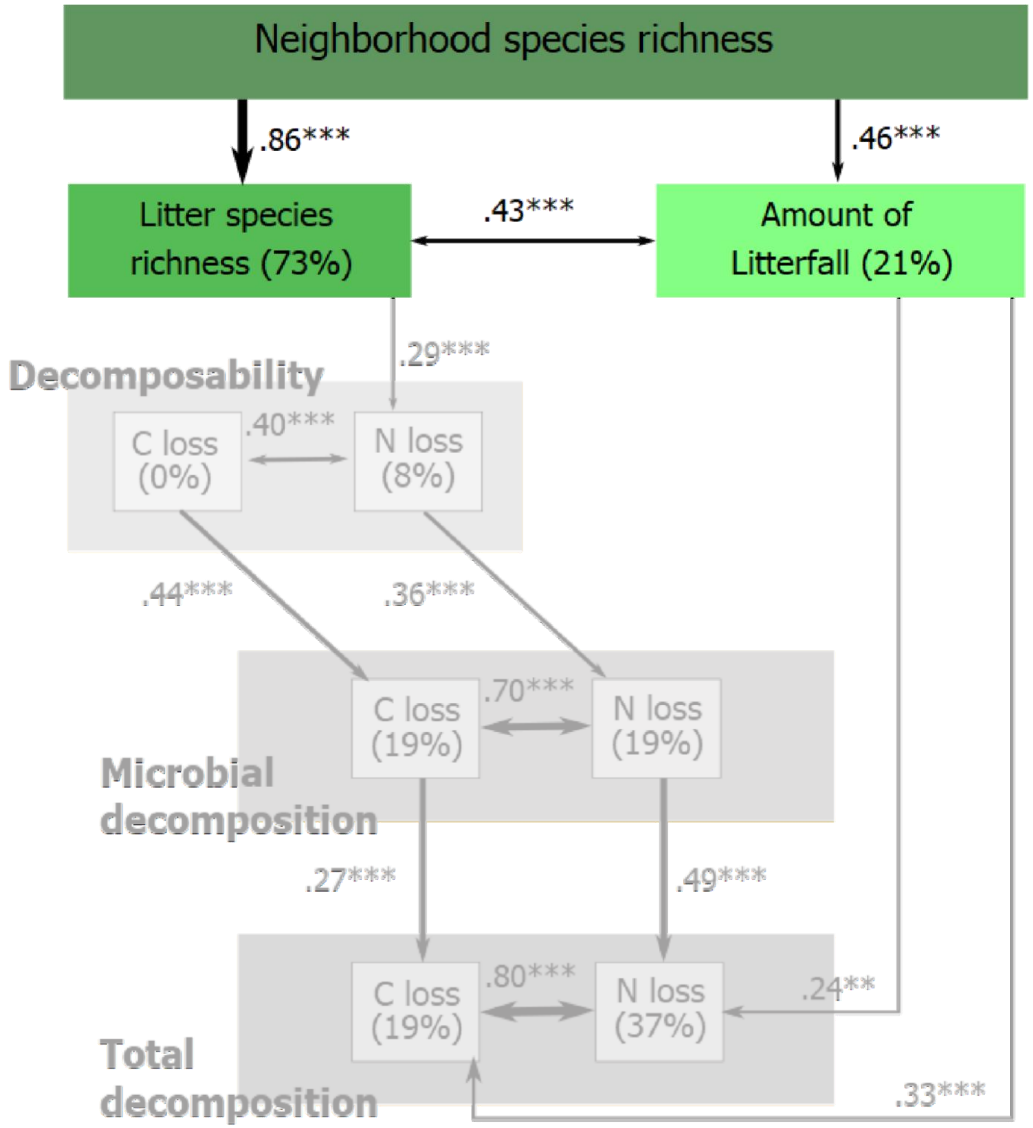
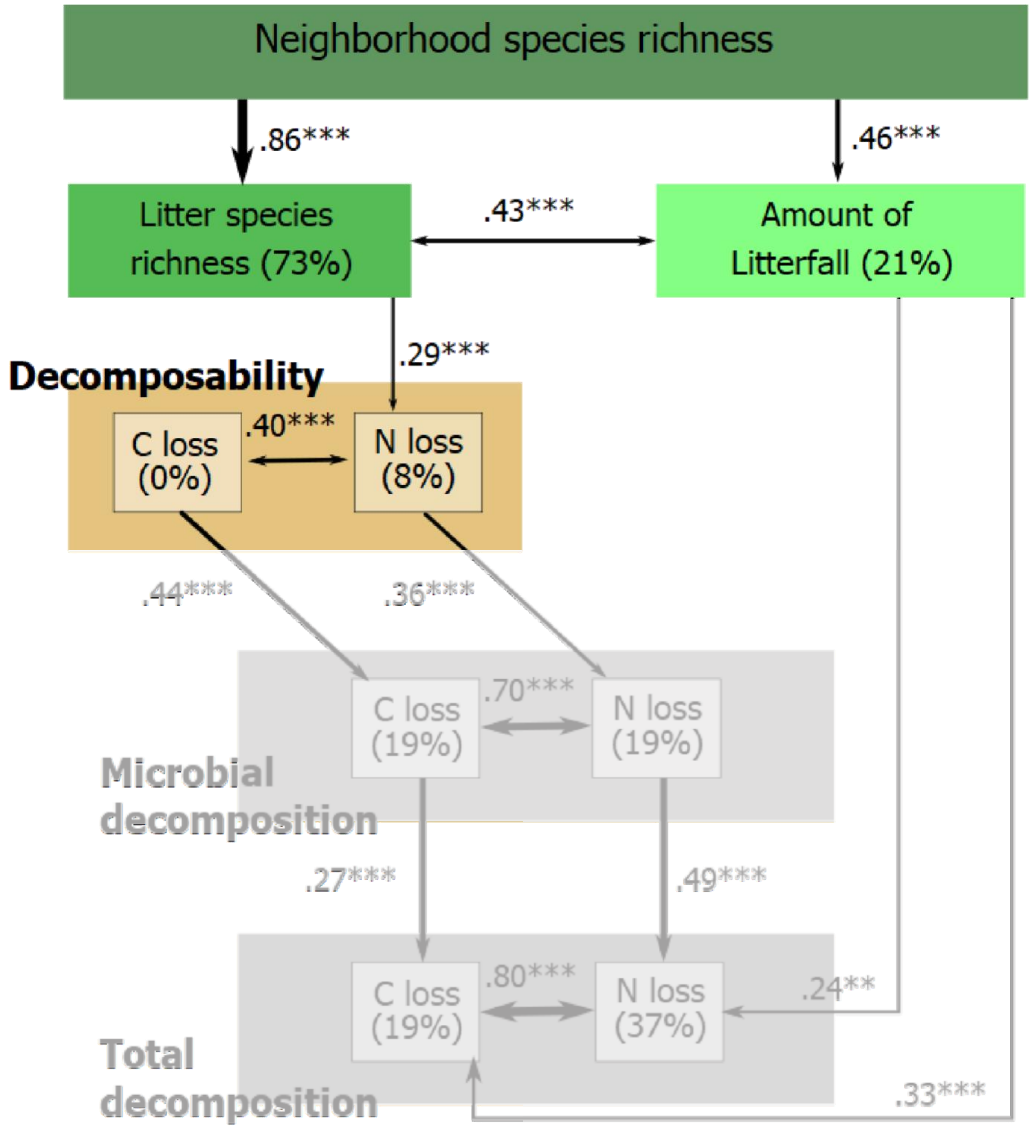
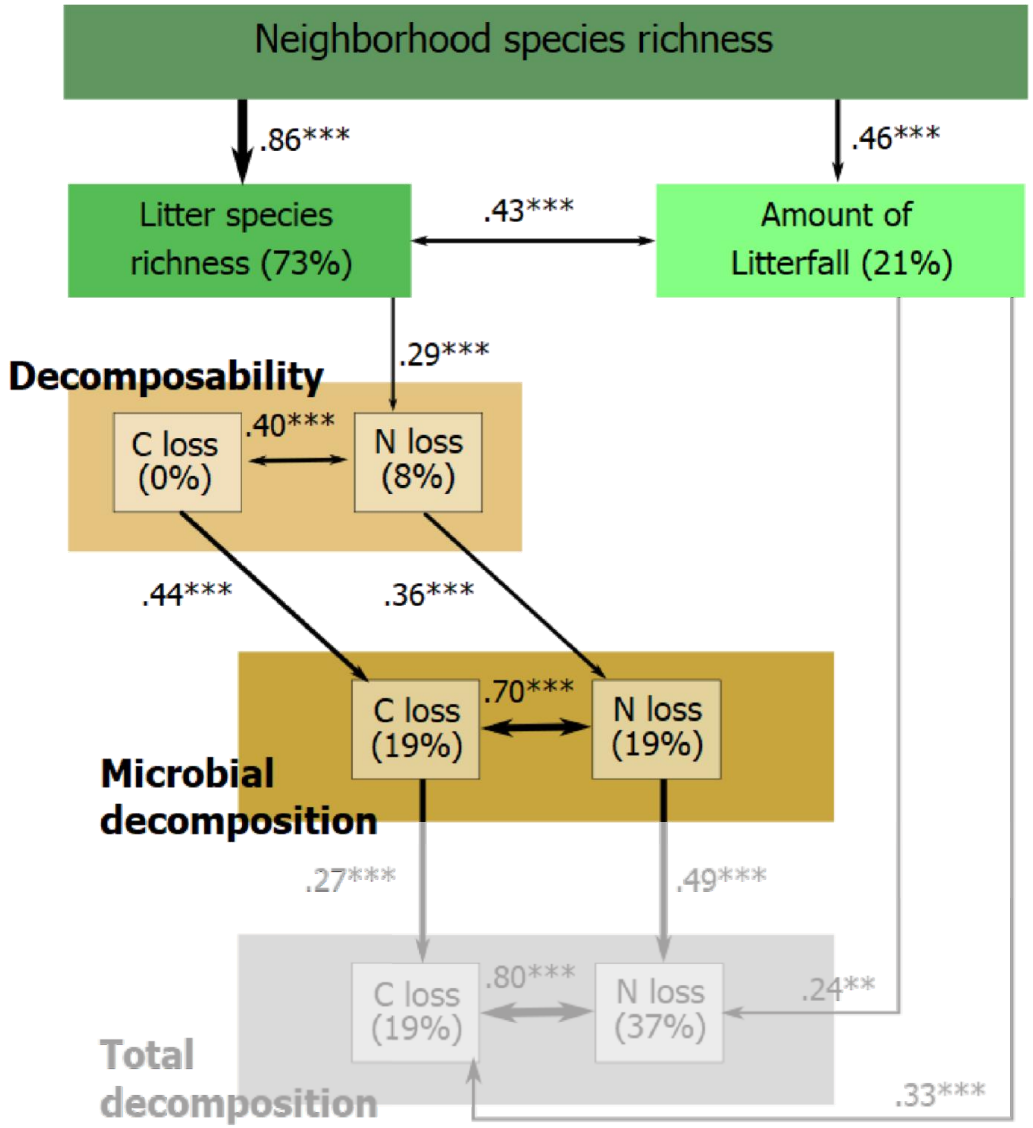
MASS AND DIVERSITY EFFECTS



MASS AND DIVERSITY EFFECTS



MASS AND DIVERSITY EFFECTS



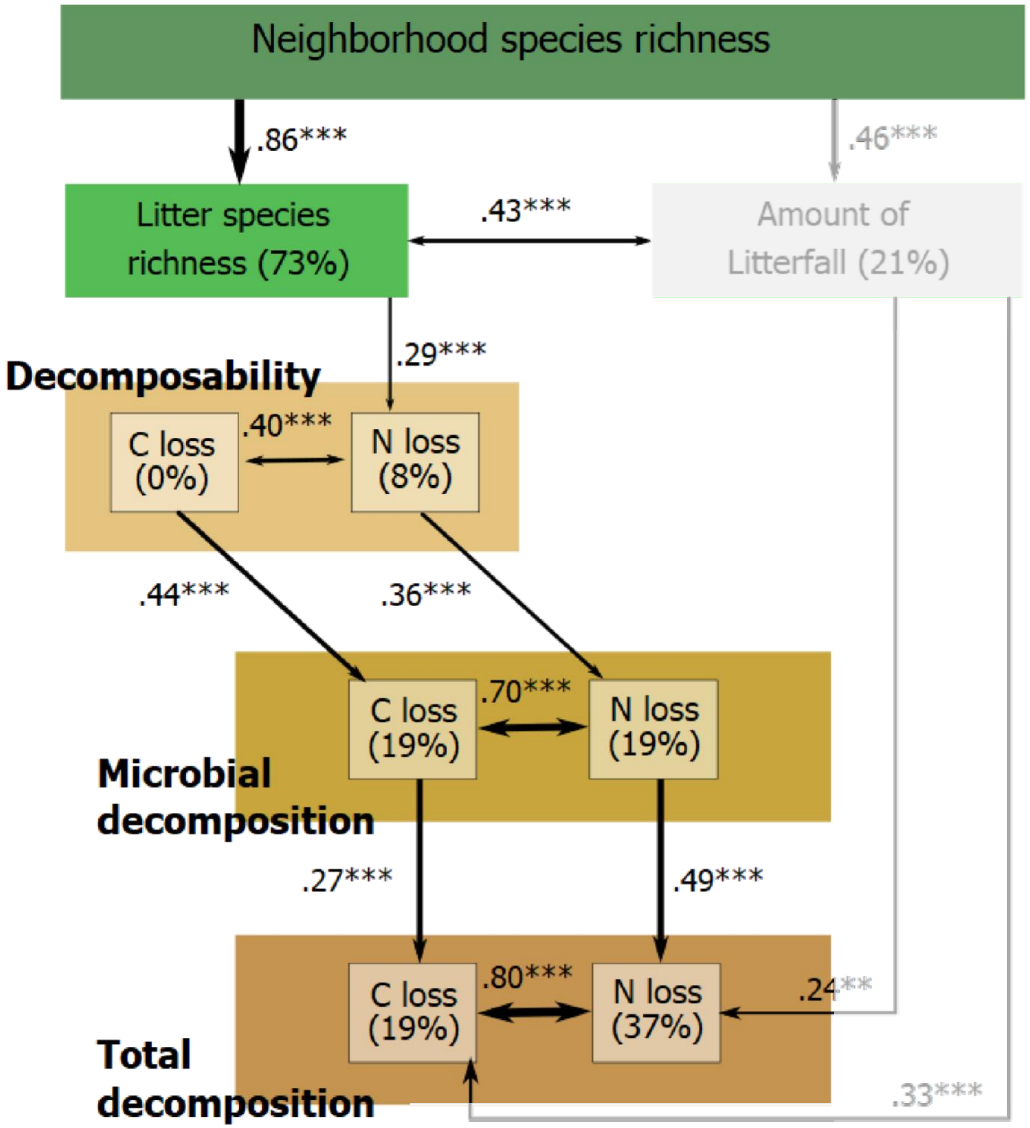
MASS AND DIVERSITY EFFECTS

DIVERSITY EFFECT

SPECIES RICHNESS

LITTER SPECIES RICHNESS

DECOMPOSITION



MASS AND DIVERSITY EFFECTS

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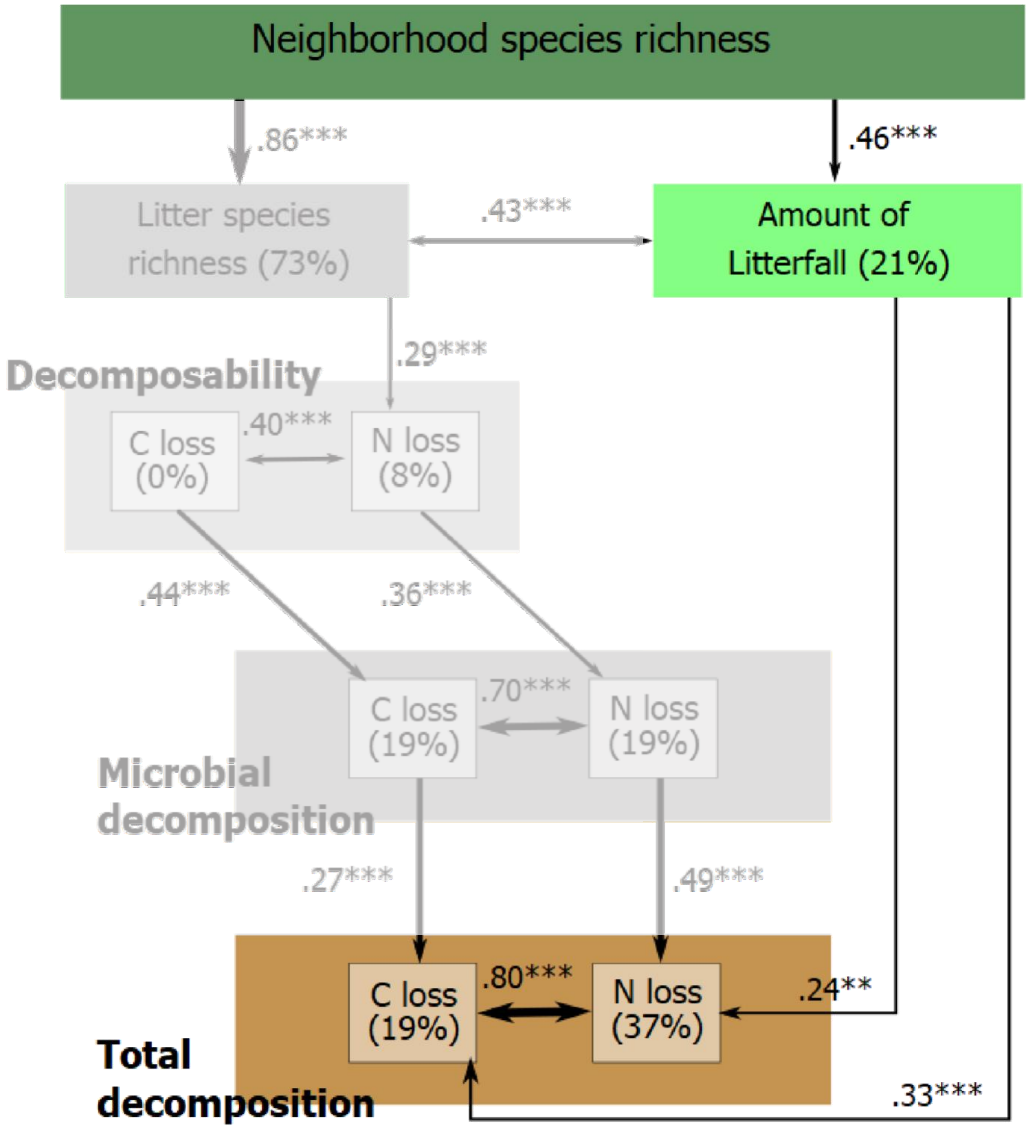


MASS EFFECT

SPECIES RICHNESS

AMOUNT OF LITTERFALL

DECOMPOSITION

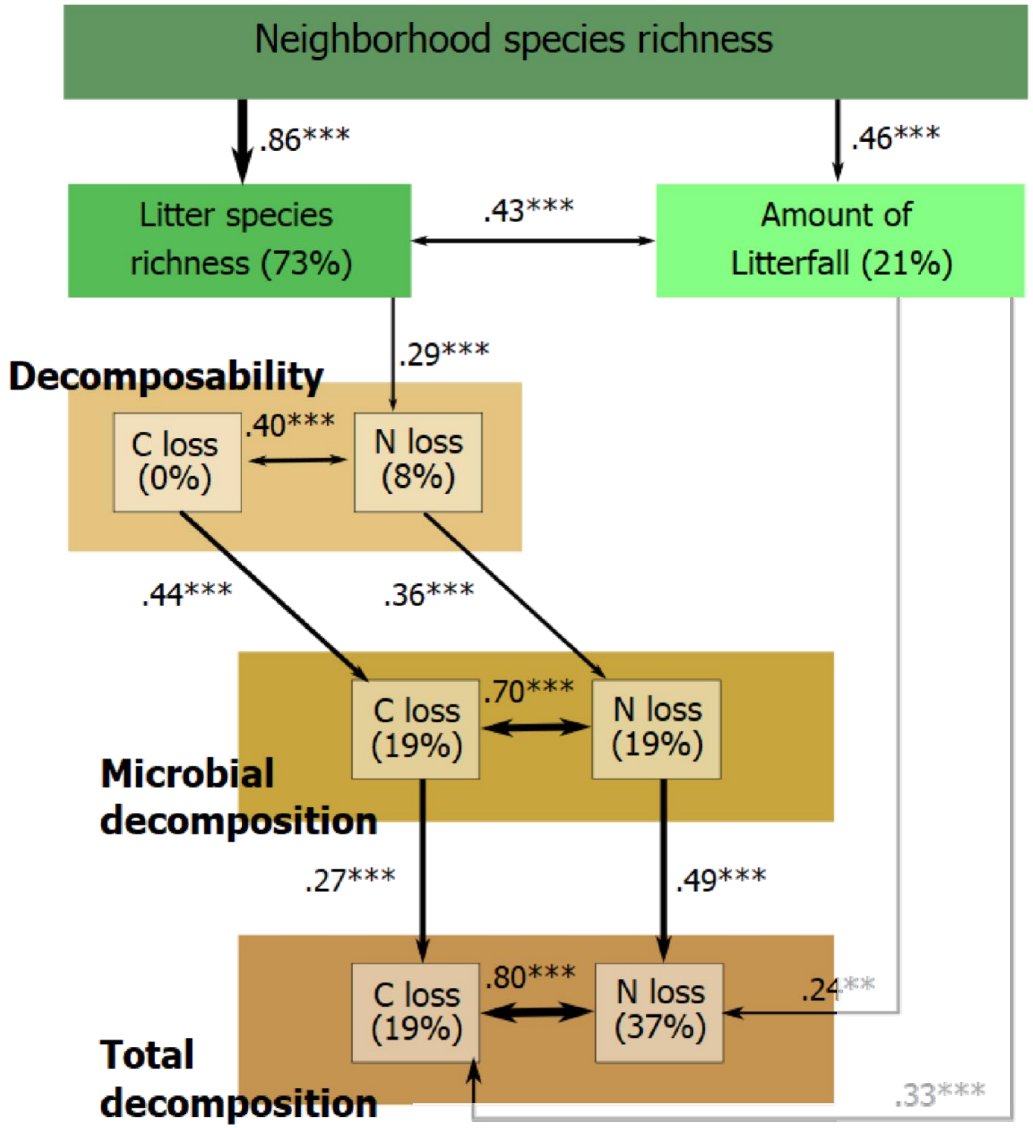
MASS AND DIVERSITY EFFECTS

DIVERSITY EFFECT

SPECIES RICHNESS

LITTER SPECIES RICHNESS

DECOMPOSITION



MASS EFFECT

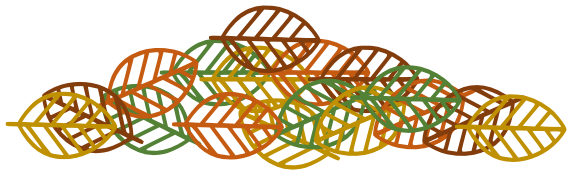
SPECIES RICHNESS

AMOUNT OF LITTERFALL

DECOMPOSITION

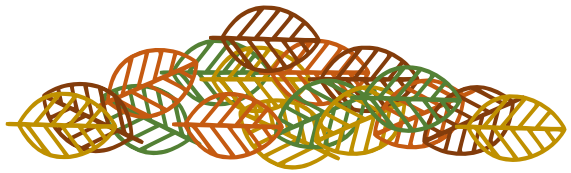
About 84 – 87% (± 30%) of total decomposition was covered by the microbial community alone

MAIN RESULTS



Tree species richness increased **the amount of litterfall** and **litter diversity**

MAIN RESULTS



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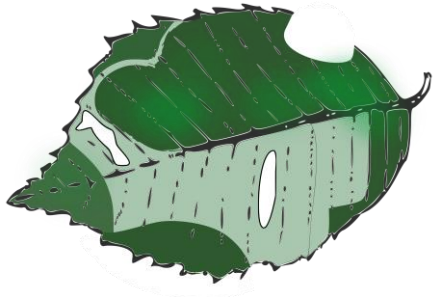
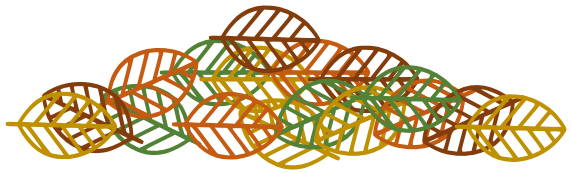


Tree species richness promoted decomposition via **biomass effect and diversification of the products**

MAIN RESULTS



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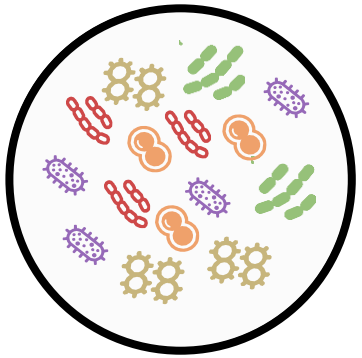


Litter decomposition was mostly **carried out by microbial communities** in subtropical Chinese forests

CHAPTER II – SOIL MICROBIAL COMMUNITY FACETS

ISME Communications
New Developments in Microbial Ecology

ARTICLE

Tree diversity and soil chemical properties drive the linkages between soil microbial community and ecosystem functioning

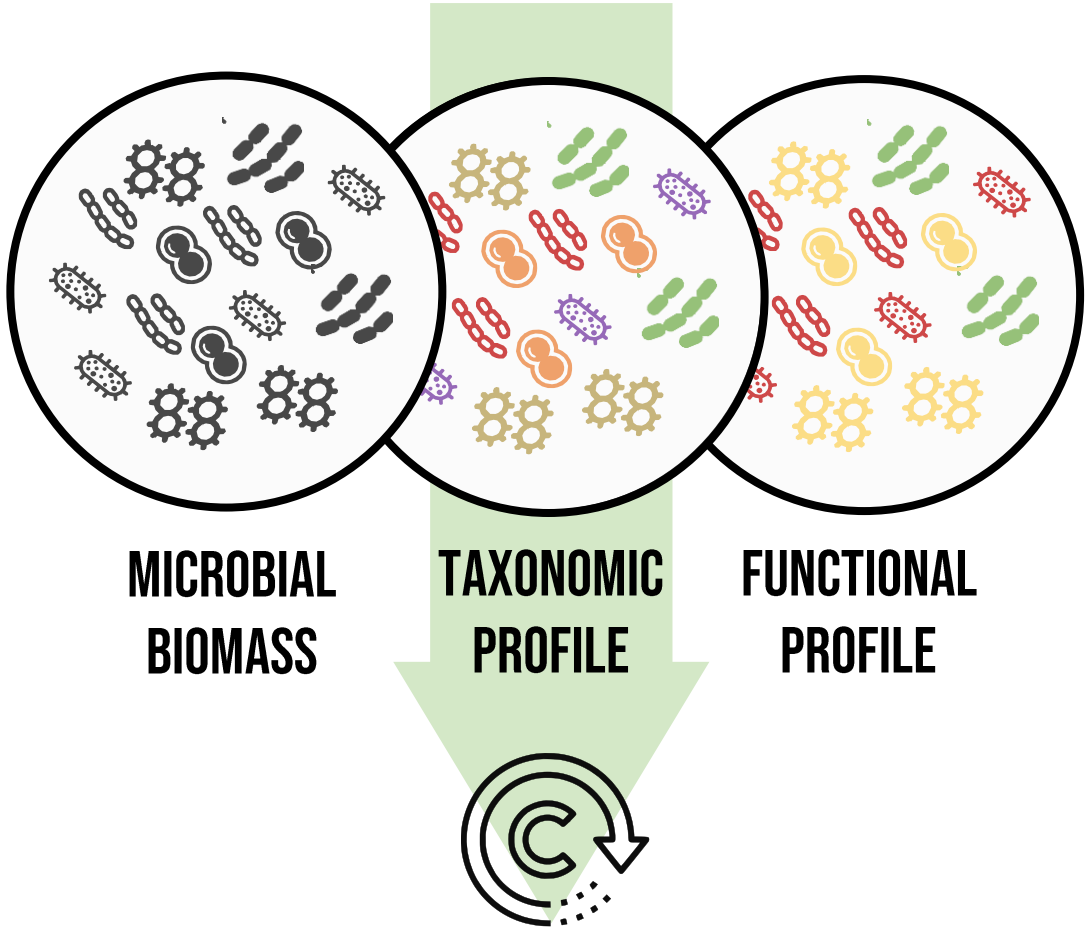
Rémy Beugnon[C,1,2], Jianqing Du[3], Simone Cesarz[1,2], Stephanie D. Jurburg[1,2], Zhe Pang[3], Bala Singavarapu[1,4,5], Tesfaye Wubet[1,4], Kai Xu[C,3,6], Yanfen Wang[3,6,S] & Nico Eisenhauer[1,2,S]

@ Jianqing Du

HYPOTHESES

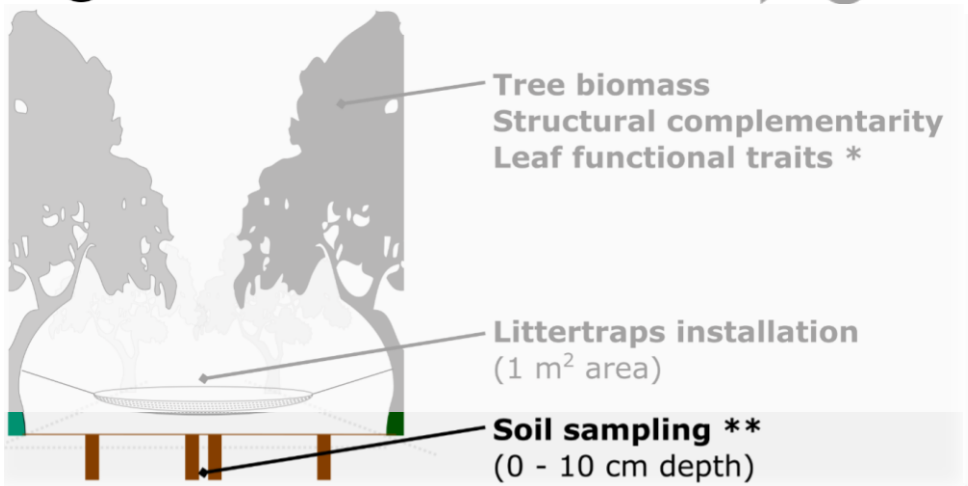
TREE DIVERSITY

MICROBIAL FACETS



MY SAMPLING DESIGN

Sept. 2018 — Litter collection — Dec. 2018 — Decomposition incubation — Sept. 2019

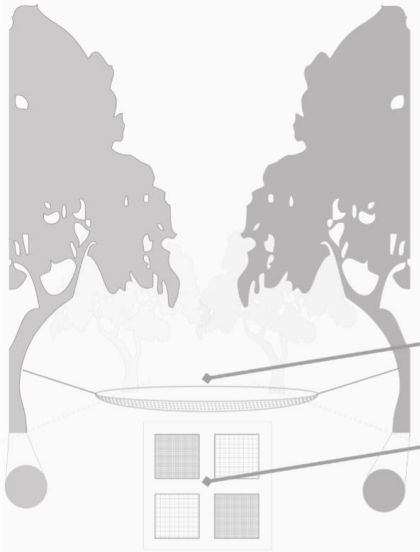


Tree biomass
Structural complementarity
Leaf functional traits *

Littertraps installation
(1 m² area)

Soil sampling **
(0 - 10 cm depth)

Between TSPs



Litter sampling

Litterbags installation
(4 bags:
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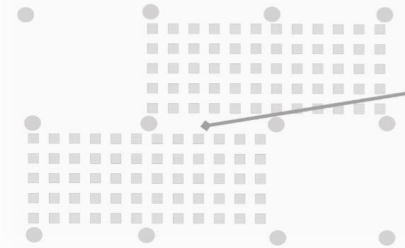
In the Common Garden experiment



Litterbags installation
(2 x 0.054 mm mesh per TSP)

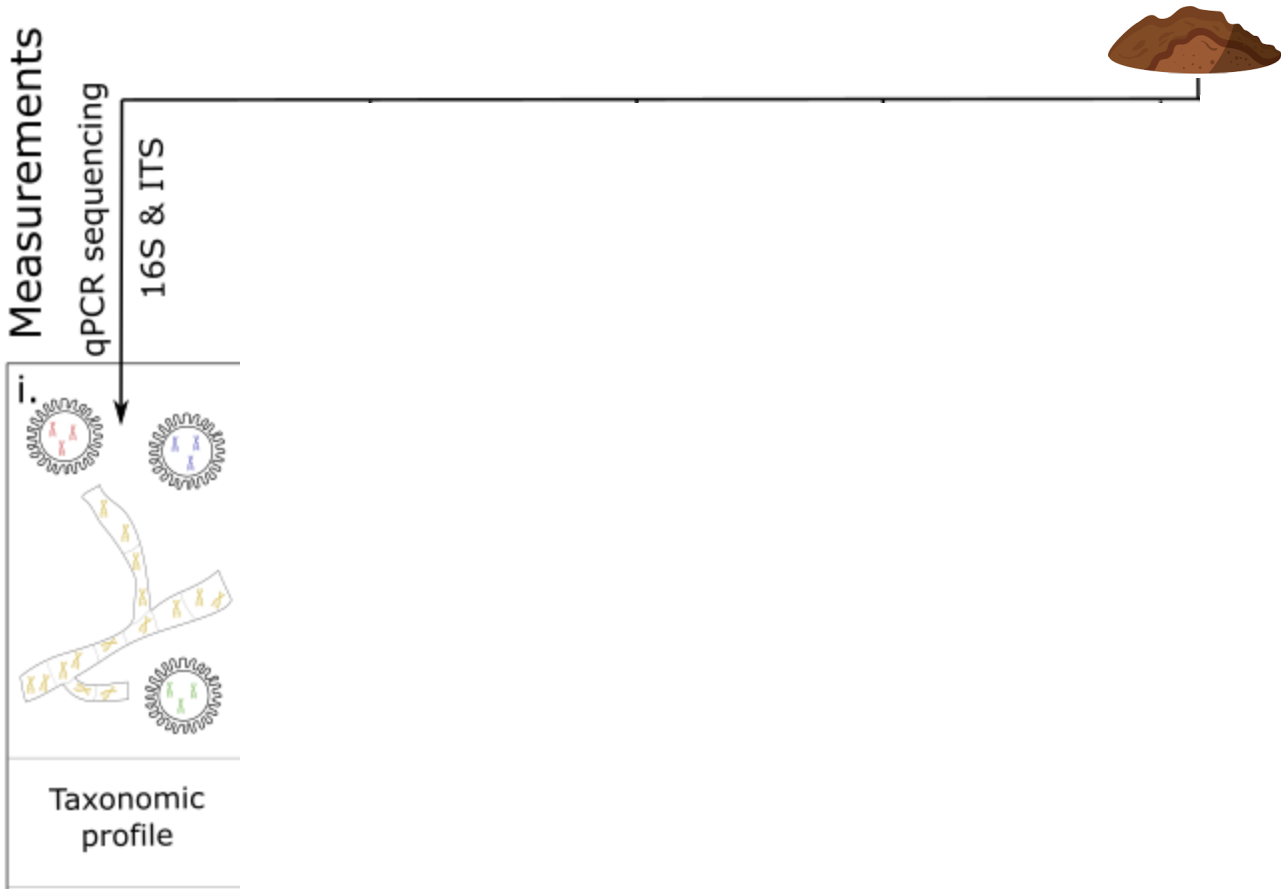
Litterbag sampling

**: in collaboration with the TreeDì projects P7G and P8C

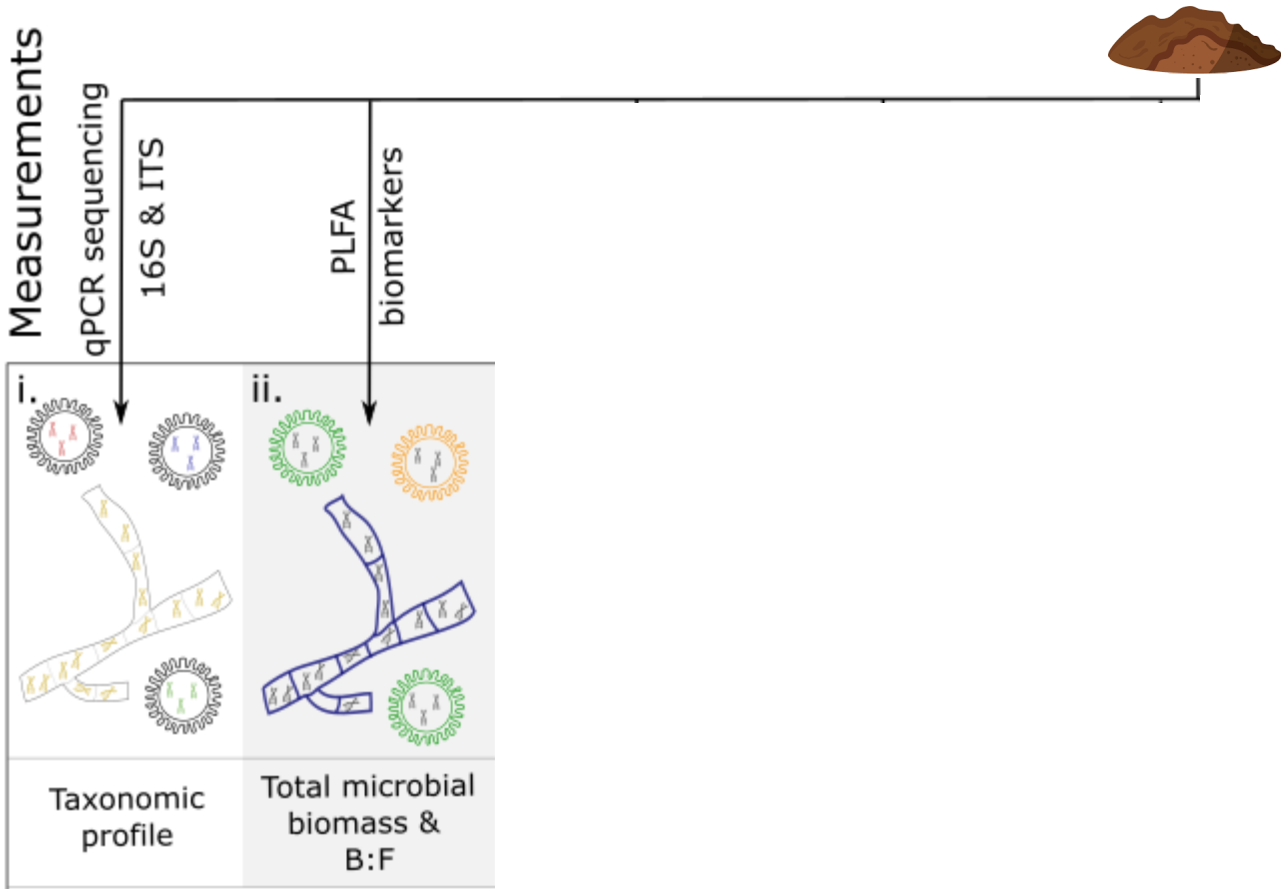
METHOD

Soil sample

METHOD

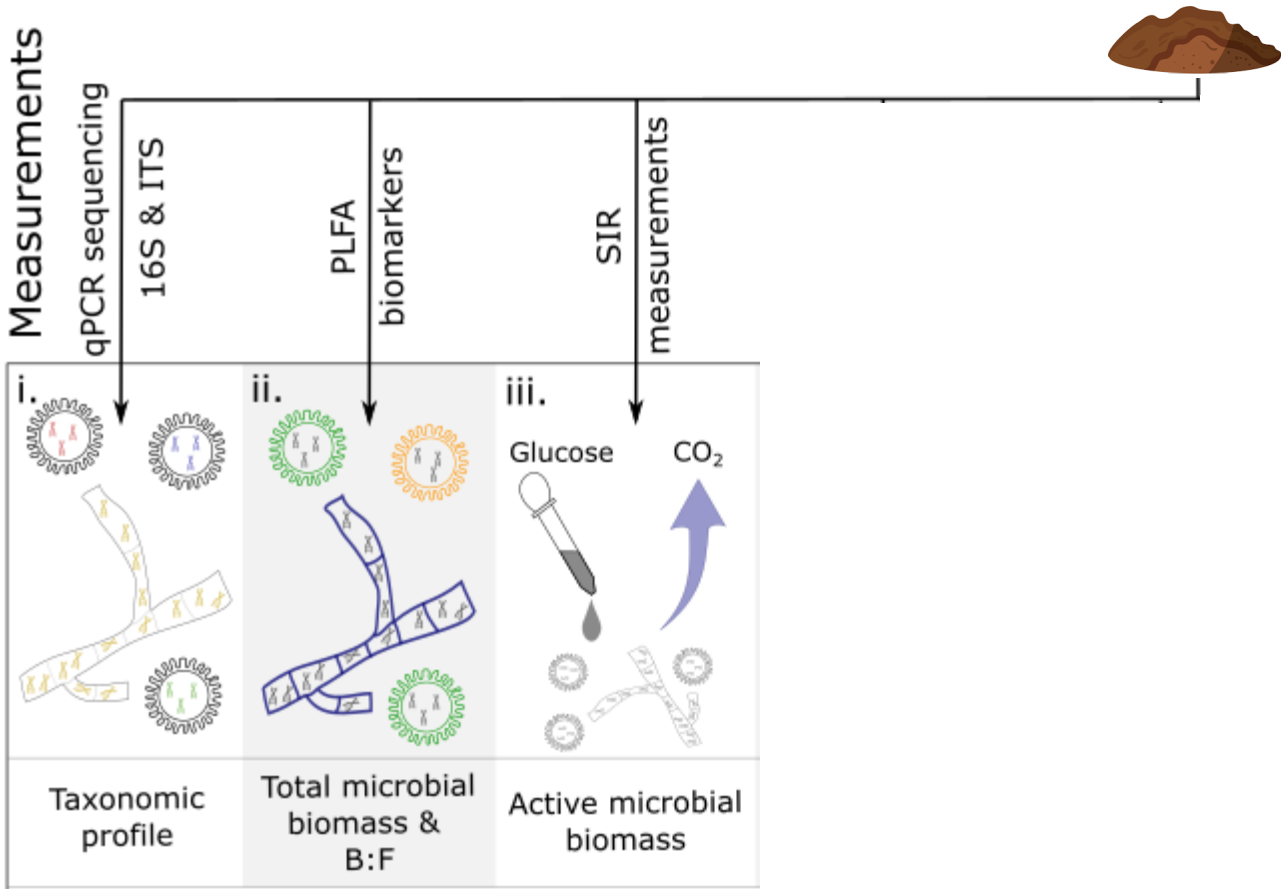


METHOD



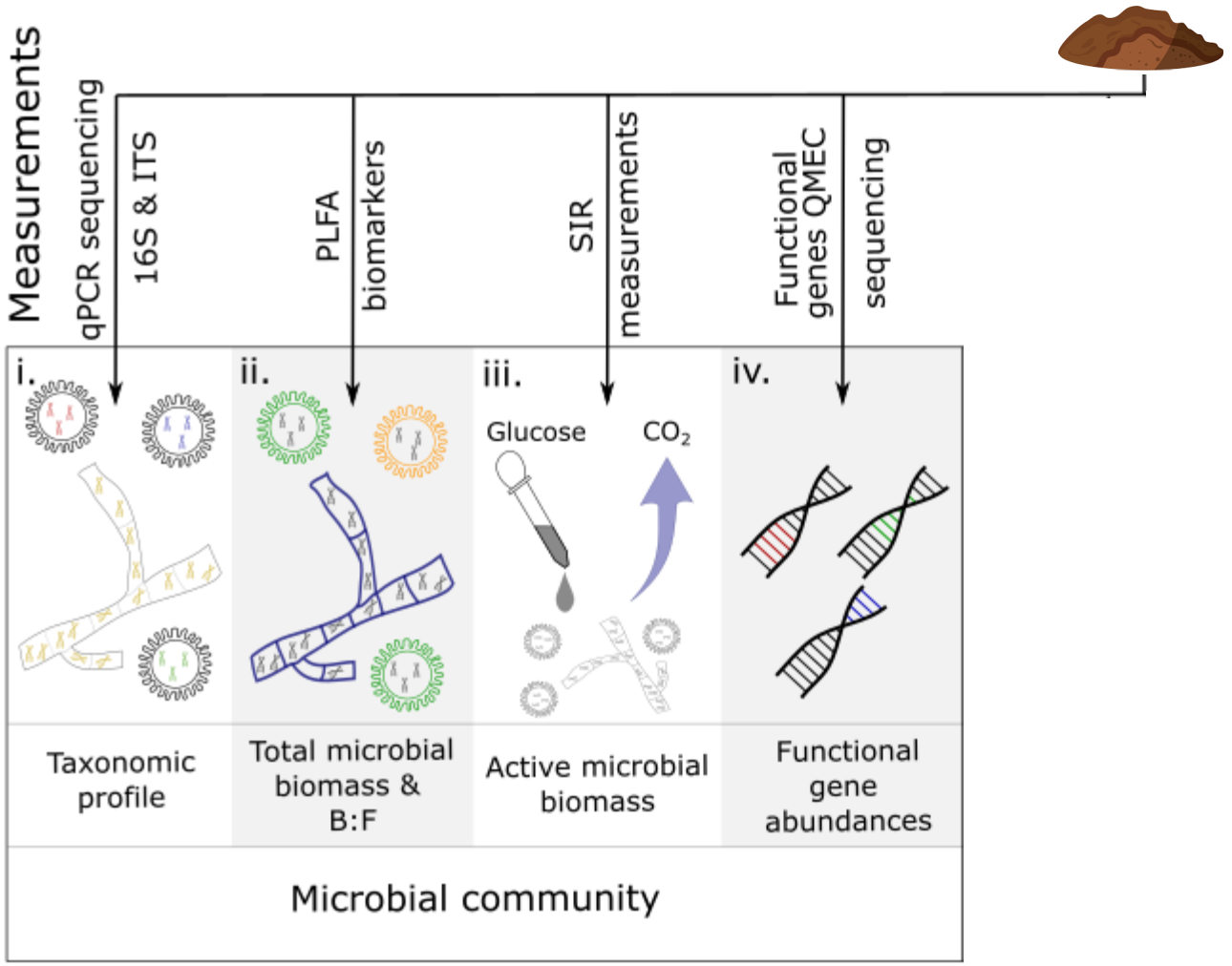
PLFA: Phospholipid Fatty Acid
B:F: bacterial to fungal ratio

METHOD



PLFA: Phospholipid Fatty Acid SIR: Substrate induced respiration
B:F: bacterial to fungal ratio

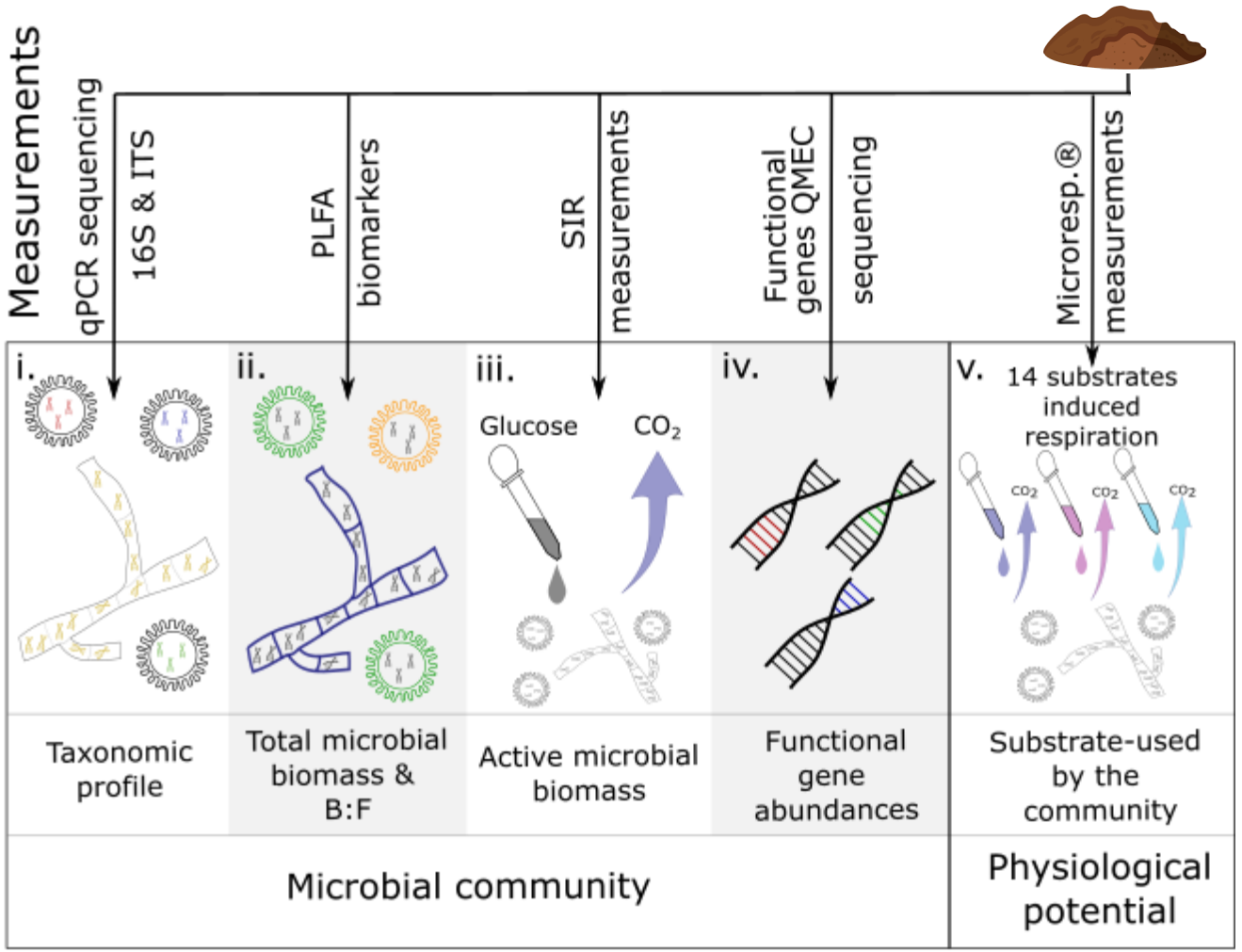
METHOD



PLFA: Phospholipid Fatty Acid
B:F: bacterial to fungal ratio

SIR: Substrate induced respiration
QMEC: Quantitative Microbial Element Cycling

METHOD



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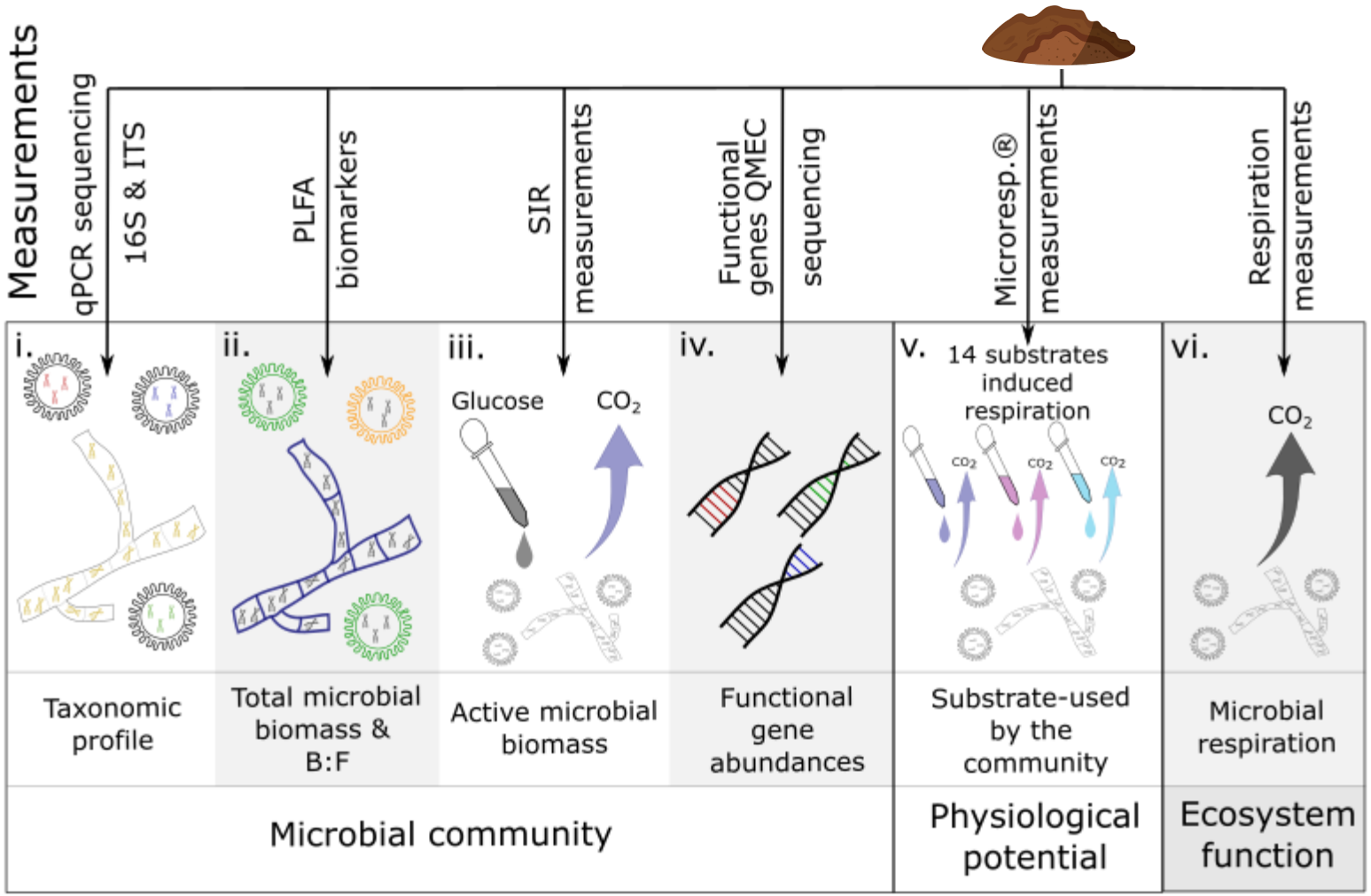

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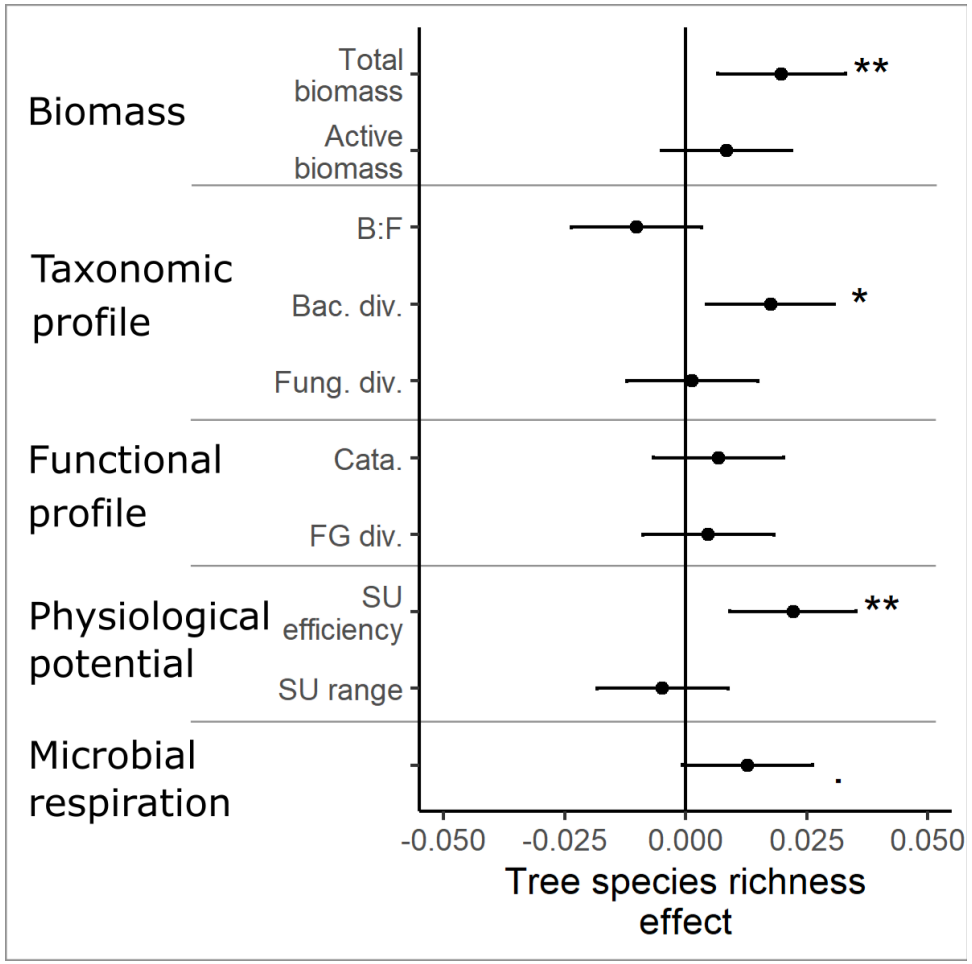
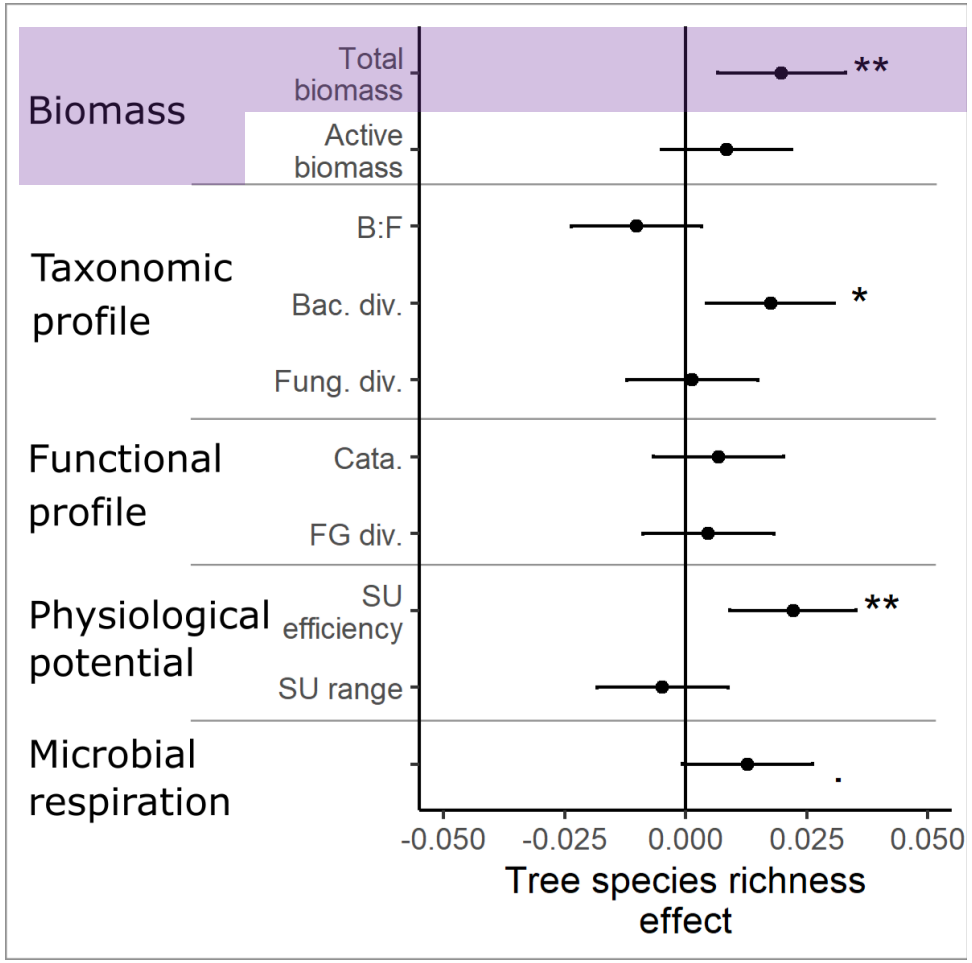
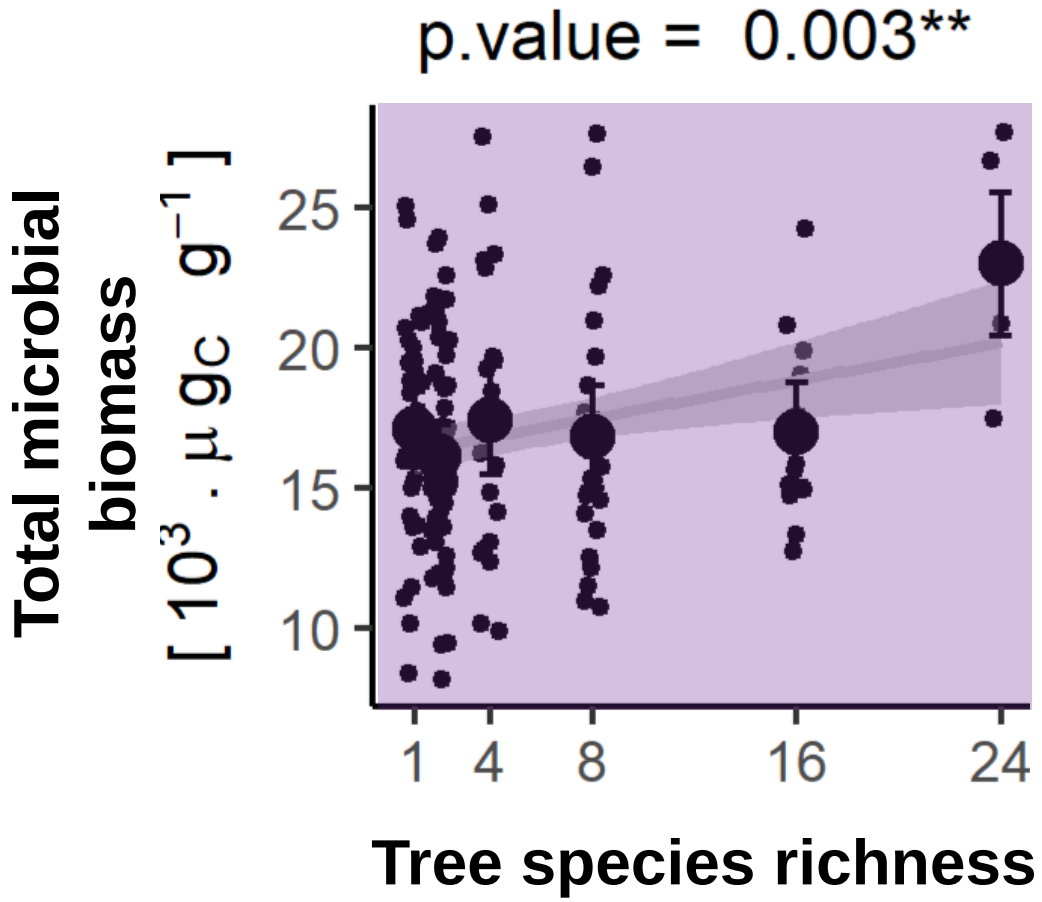
TREE DIVERSITY & SOIL MICROBES



TREE DIVERSITY & SOIL MICROBES





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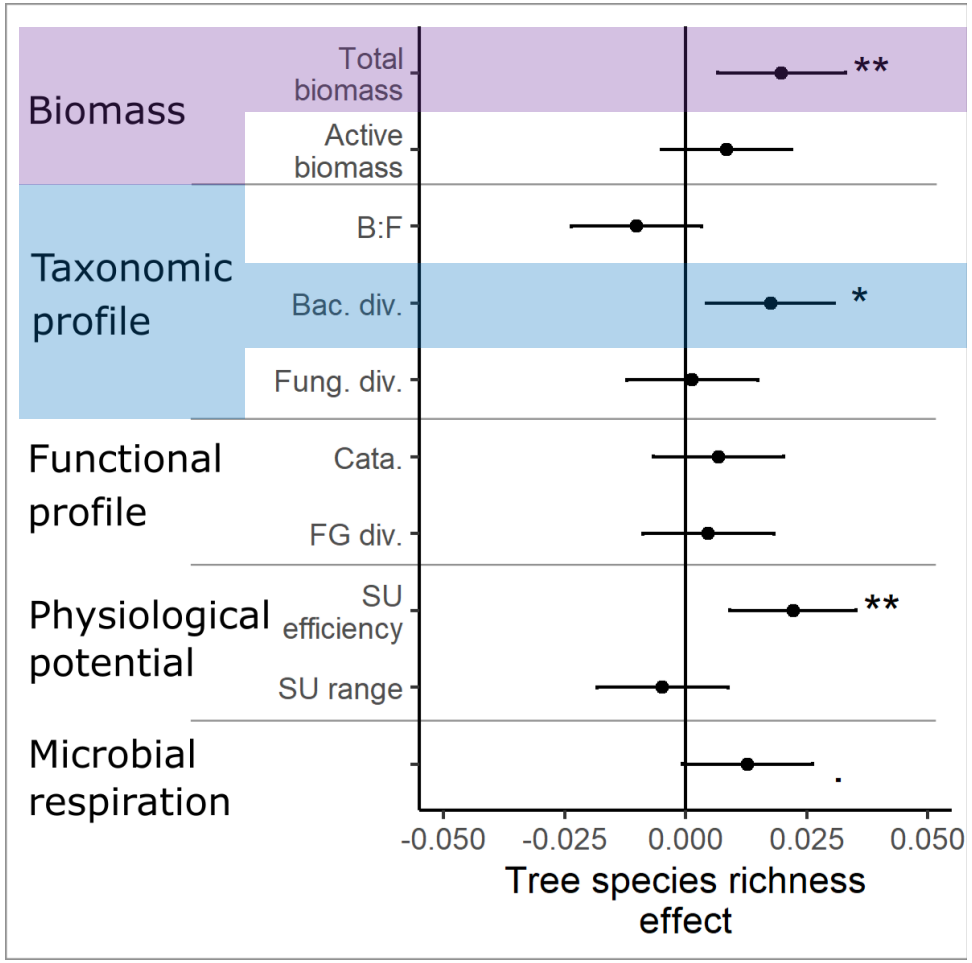

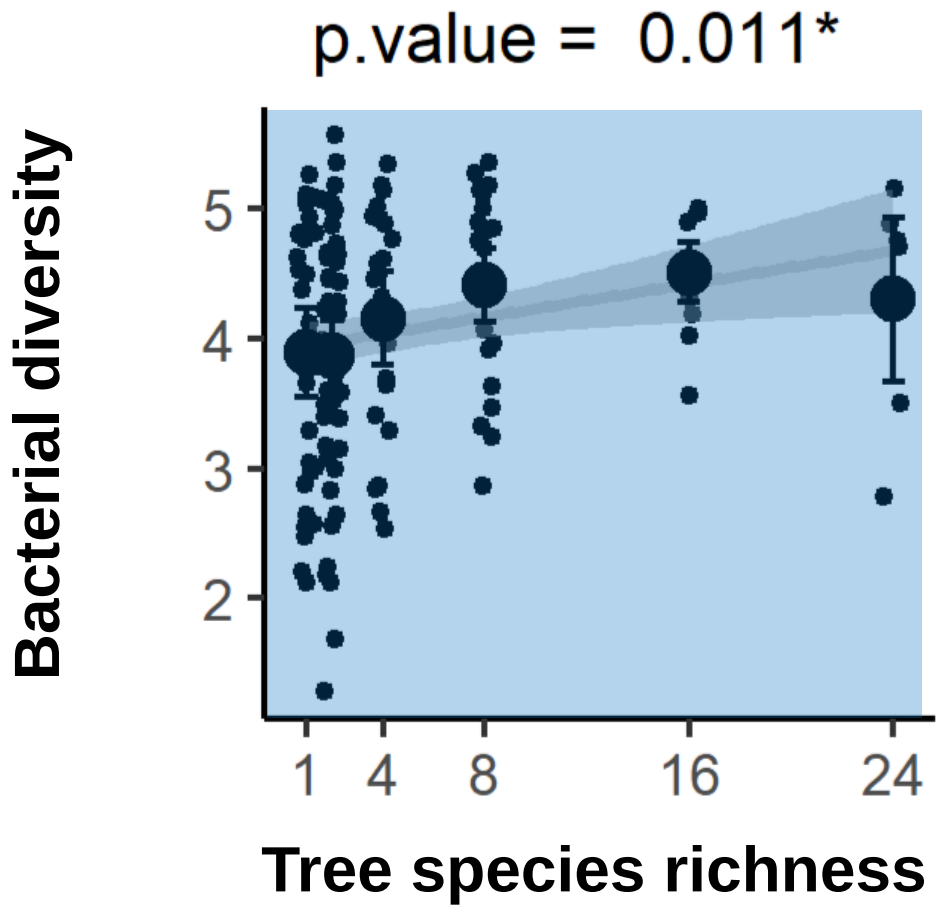

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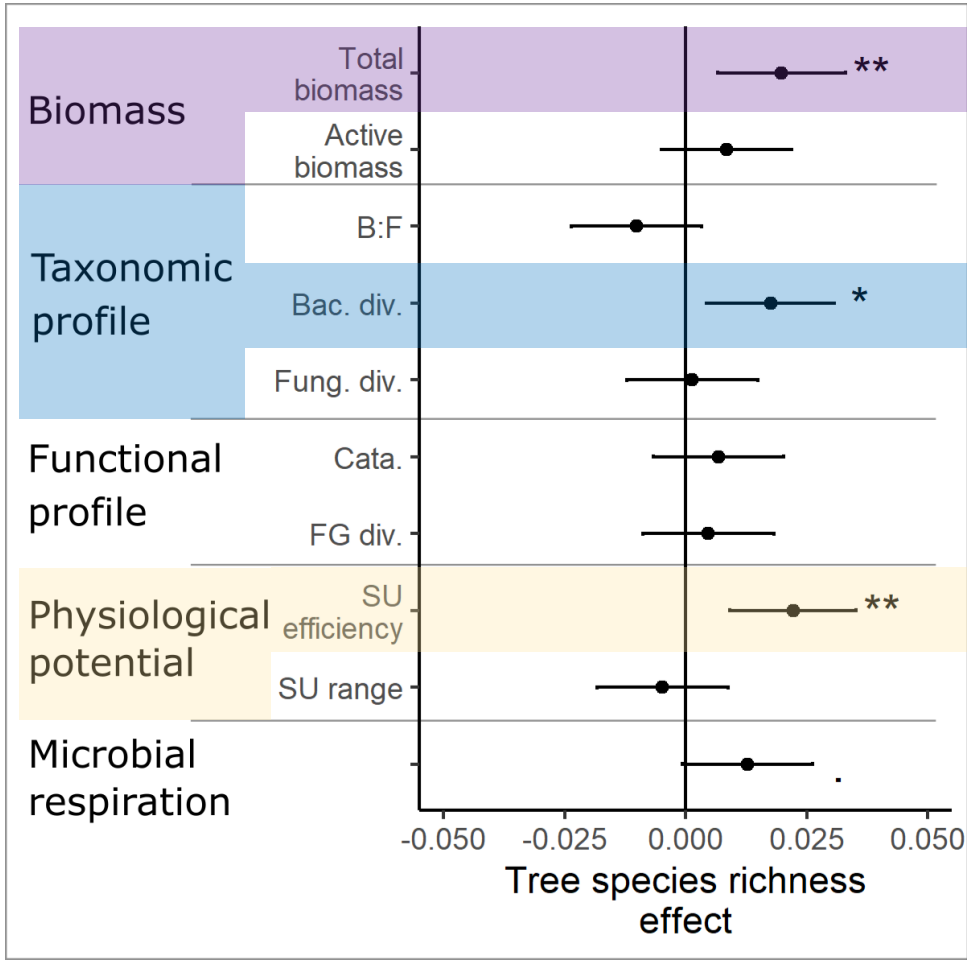

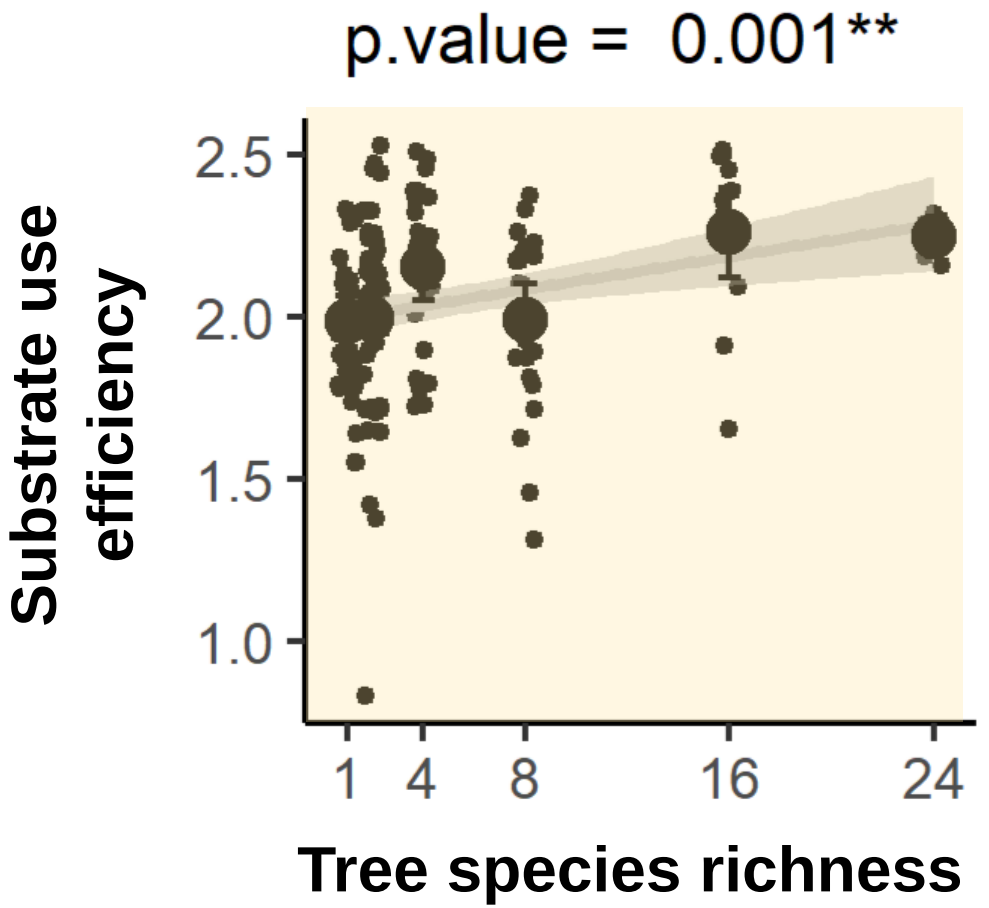

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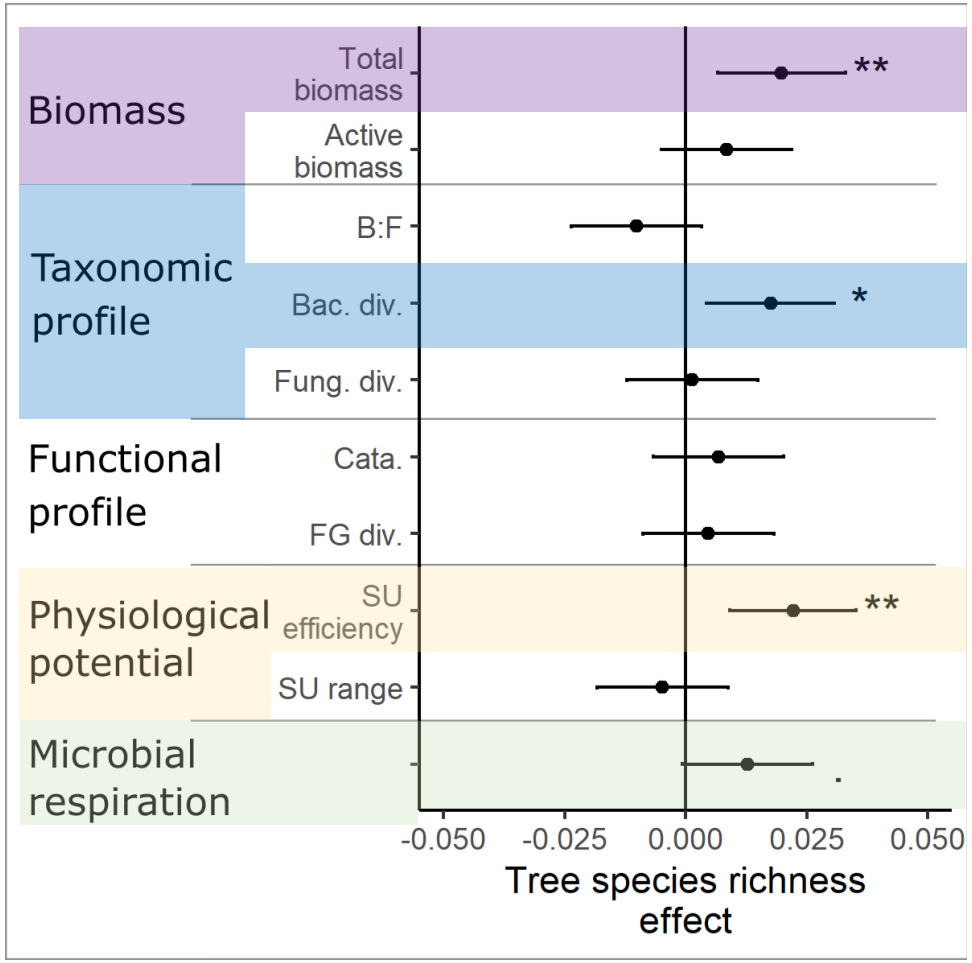
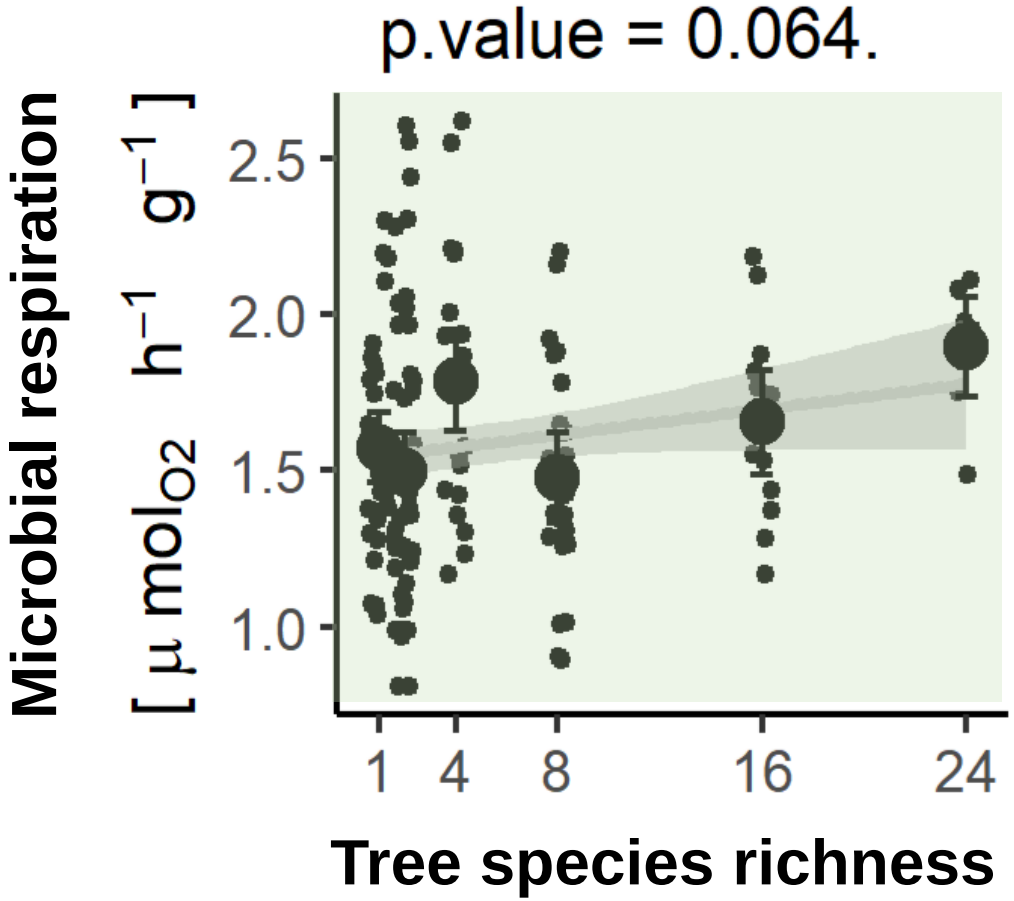
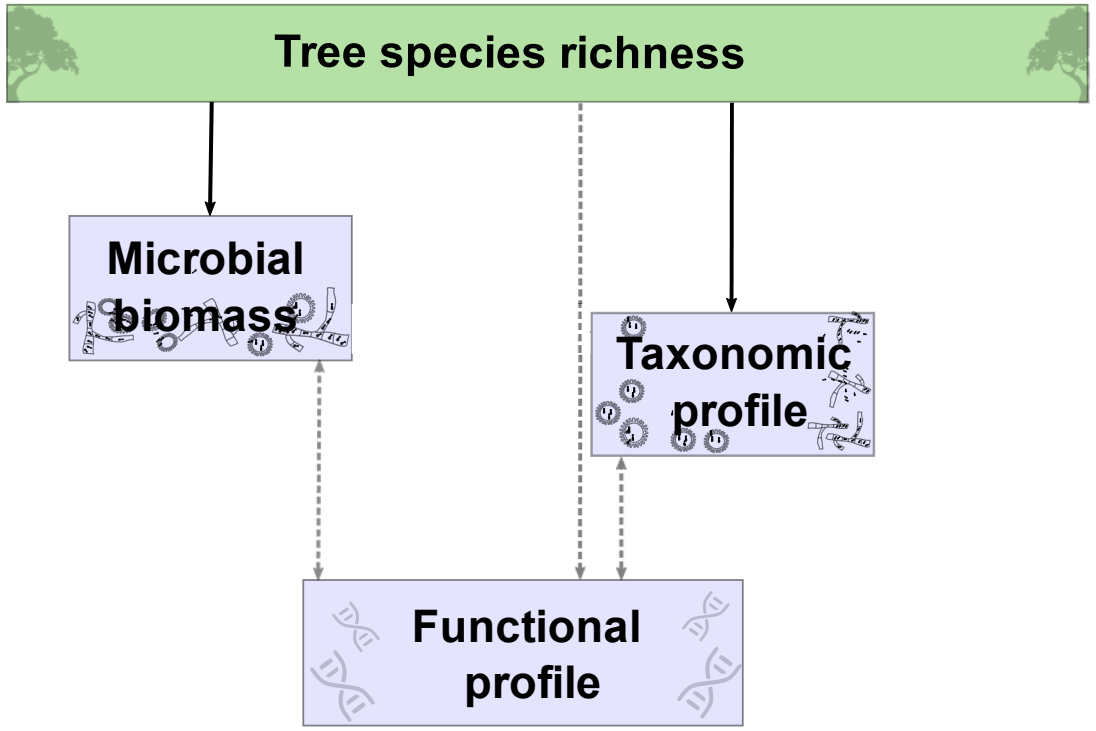




RELATIONSHIPS BETWEEN MICROBIAL FACETS



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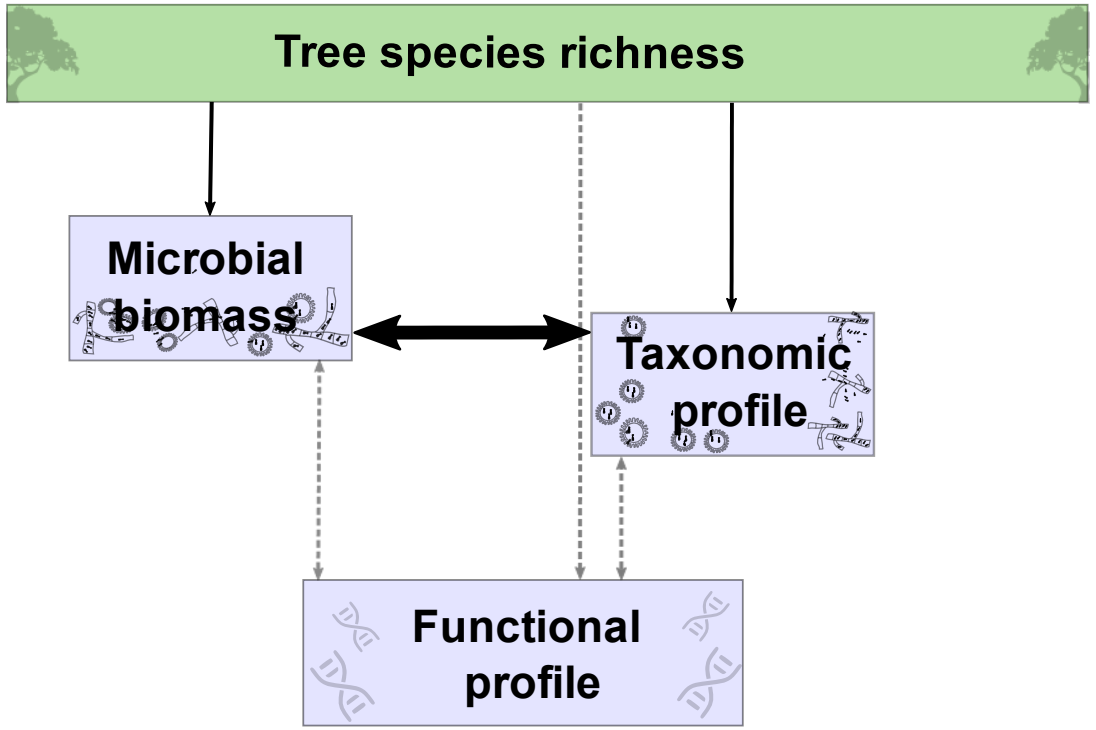
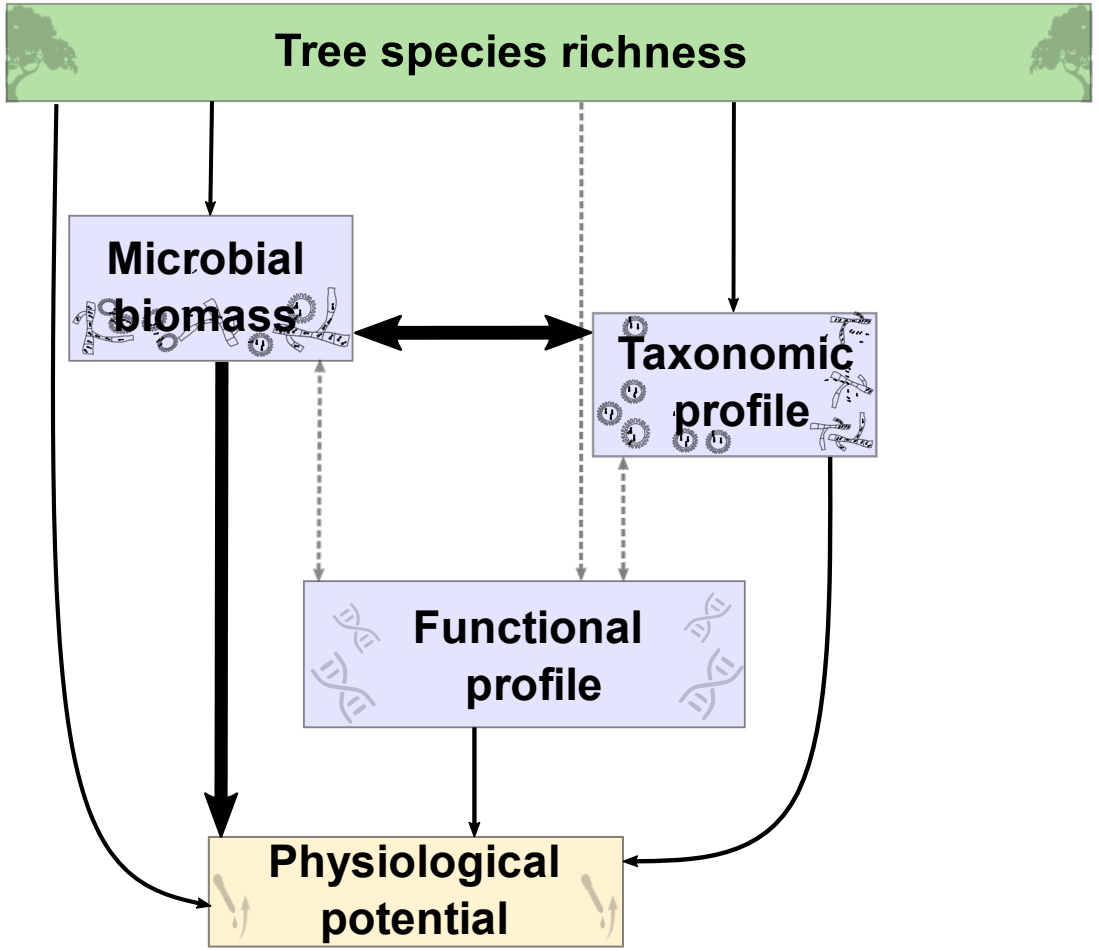


CASCADING EFFECTS ON MICROBIAL FUNCTIONS



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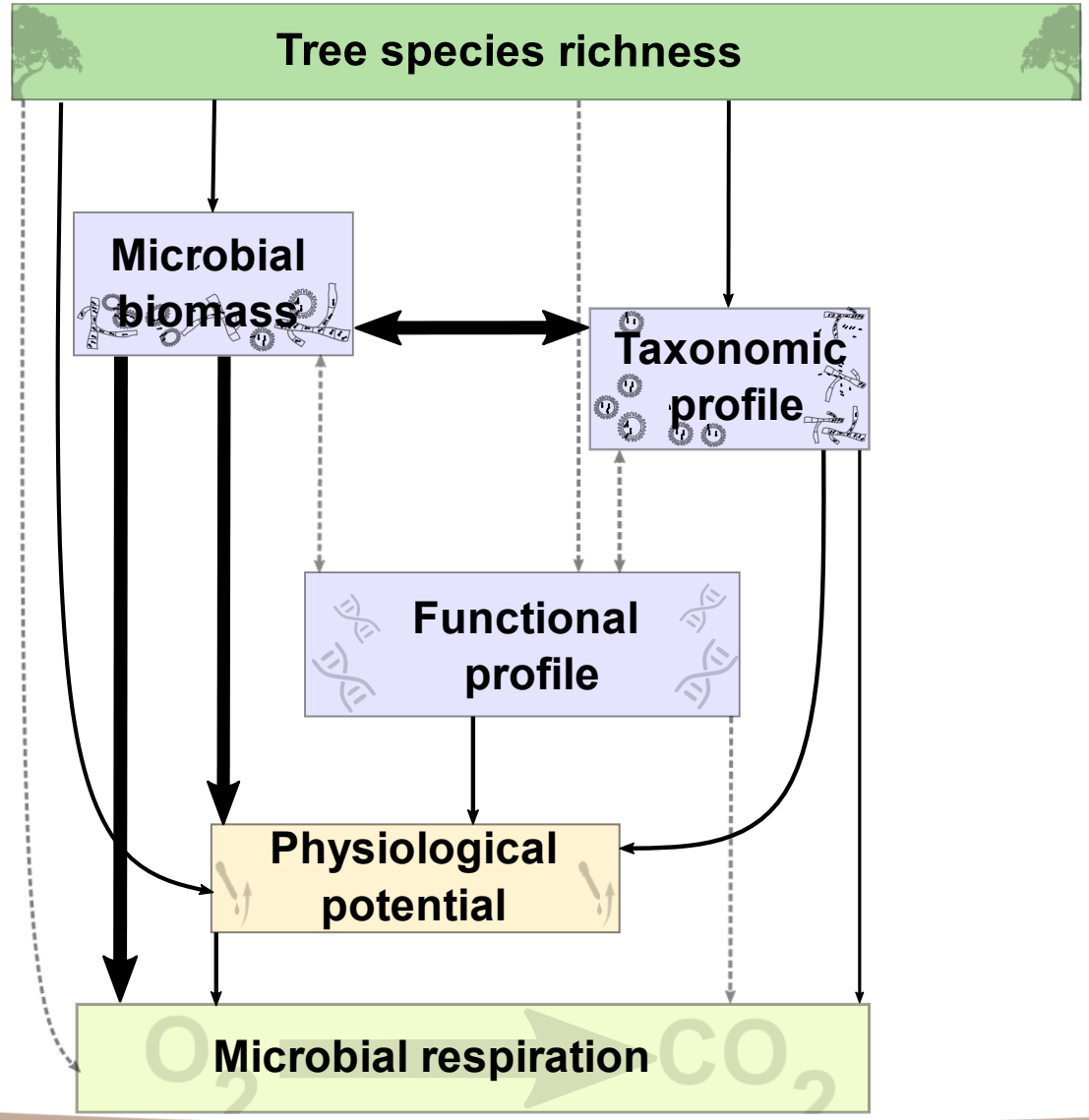
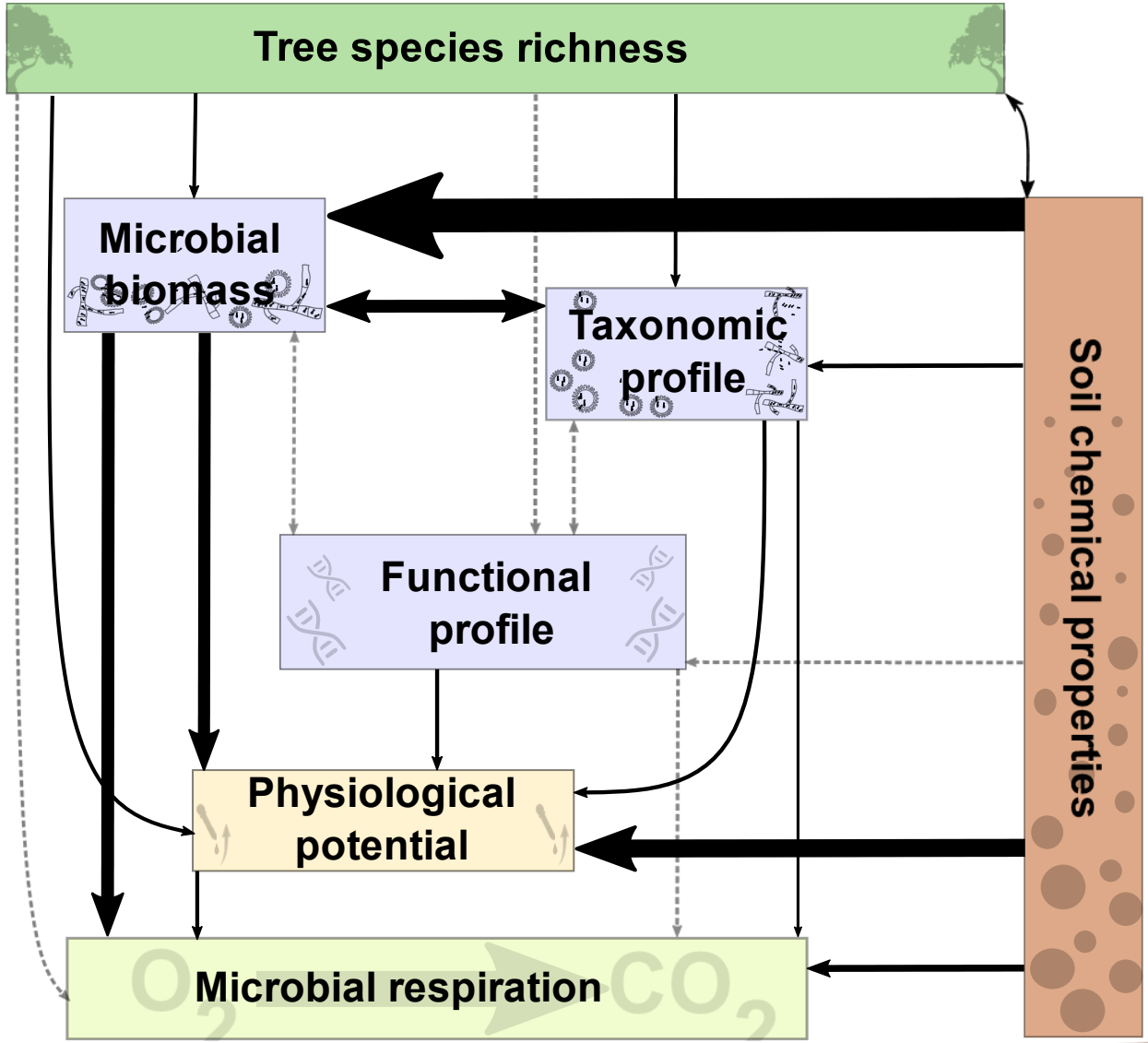
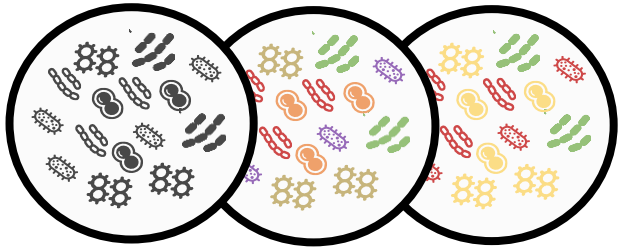


SOIL CHEMICAL PROPERTIES DEPENDENCE

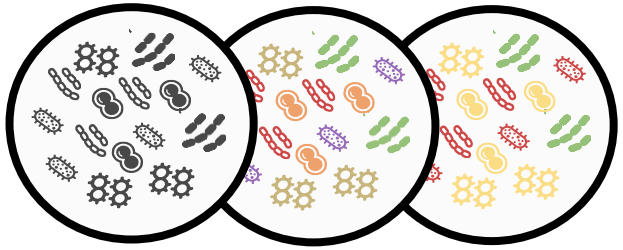


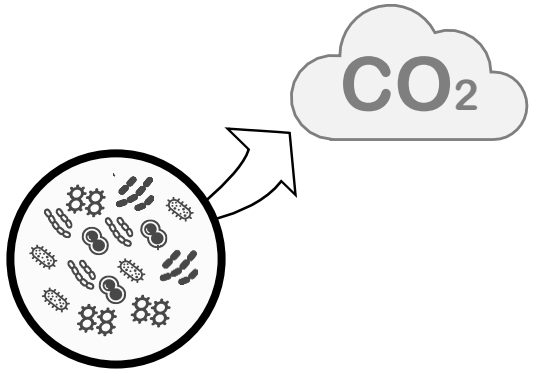
MAIN RESULTS



Tree species richness increased **soil microbial biomass, bacterial diversity and soil microbial respiration**

MAIN RESULTS

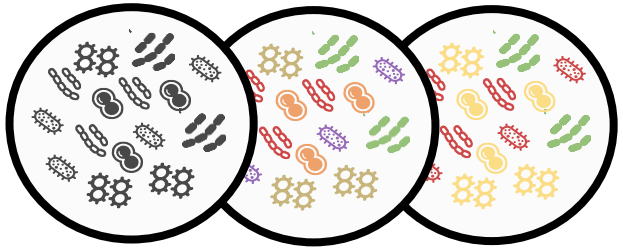




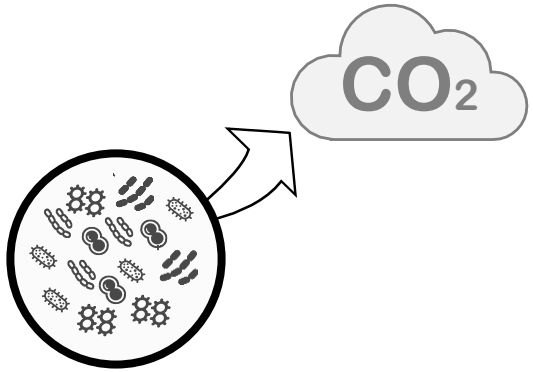
Tree species richness increased **soil microbial biomass, bacterial diversity and soil microbial respiration**

Tree species richness effects on soil microbial functions are mediated by **soil microbial biomass**

MAIN RESULTS



Tree species richness increased **soil microbial biomass, bacterial diversity and soil microbial respiration**



Tree species richness effects on soil microbial functions are mediated by **soil microbial biomass**

Soil microbial communities and functions **highly depended on soil chemical properties**, especially, soil carbon content

CHAPTER III – CARBON CYCLE IN DIVERSE FORESTS

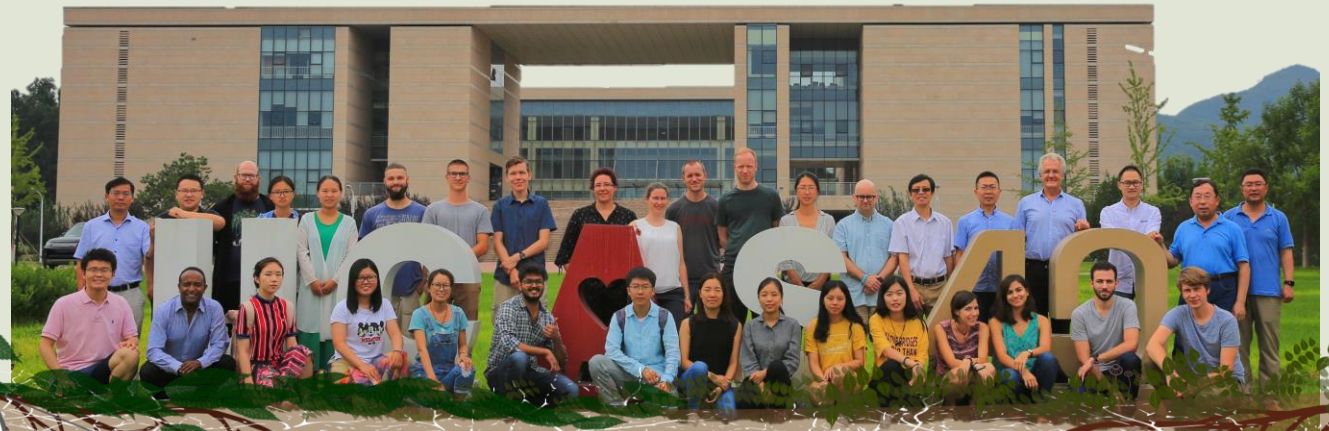
C

ARTICLE

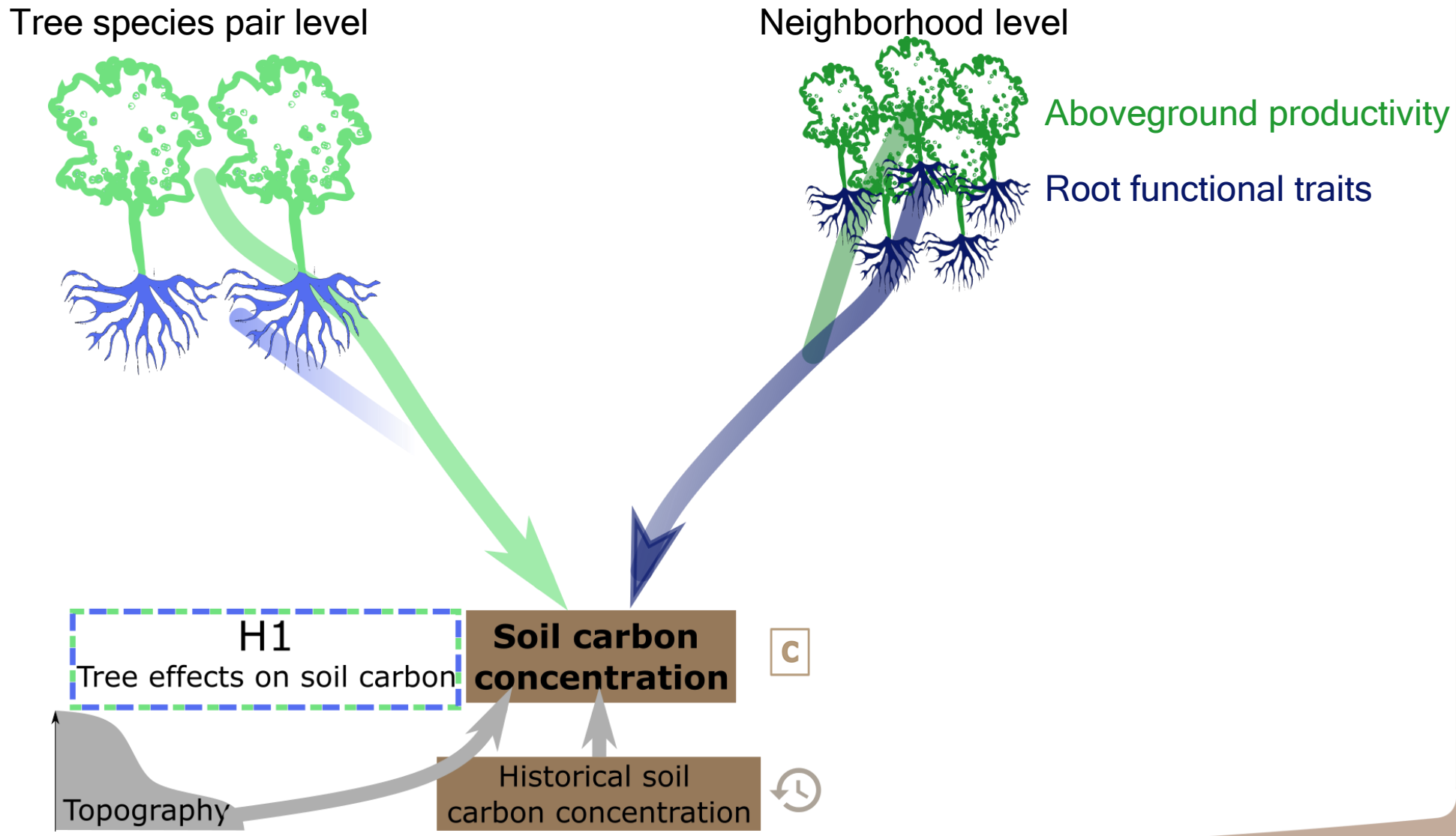
Abiotic and biotic drivers of scale-dependent tree trait effects on soil microbial biomass and soil carbon concentration

Rémy Beugnon[C,1,2], Wensheng Bu[3], Helge Bruelheide[4,1], Andréa Davrinche[4,1], Jianqing Du[5], Sylvia Haider[4,1], Matthias Kunz[6], Goddert von Oheimb[6], Maria D. Perles-Garcia[6,1,4], Mariem Saadani[4,1], Thomas Scholten[7], Steffen Seitz[7], Bala Singavarapu[8,1,4], Stefan Trogisch[4,1], Yanfen Wang[5,9], Tesfaye Wubet[8,1], Kai Xue[5,9], Bo Yang[10], Simone Cesarz[1,2,S] & Nico Eisenhauer[1,2,S]

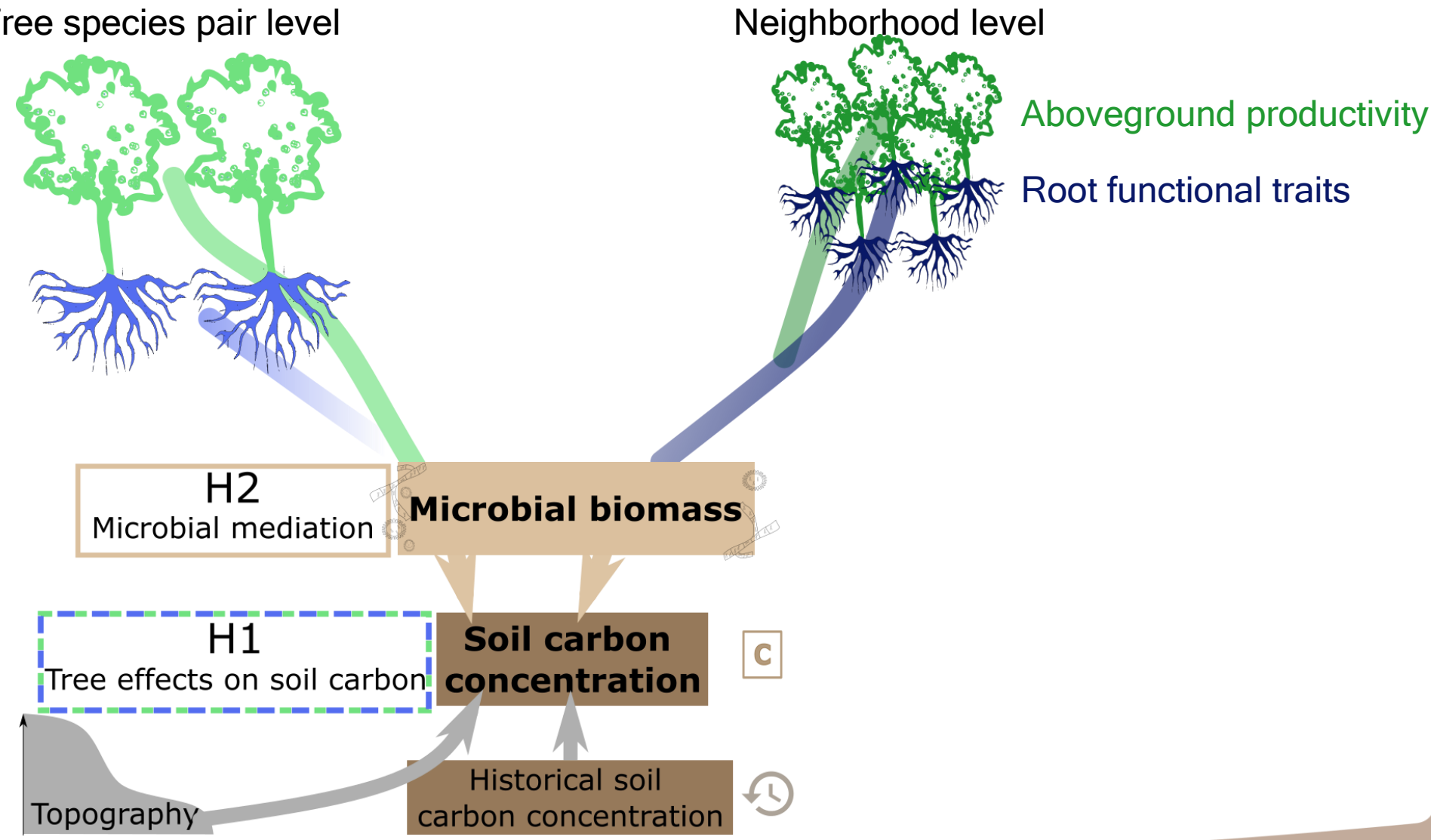
Under review in Ecological Monographs



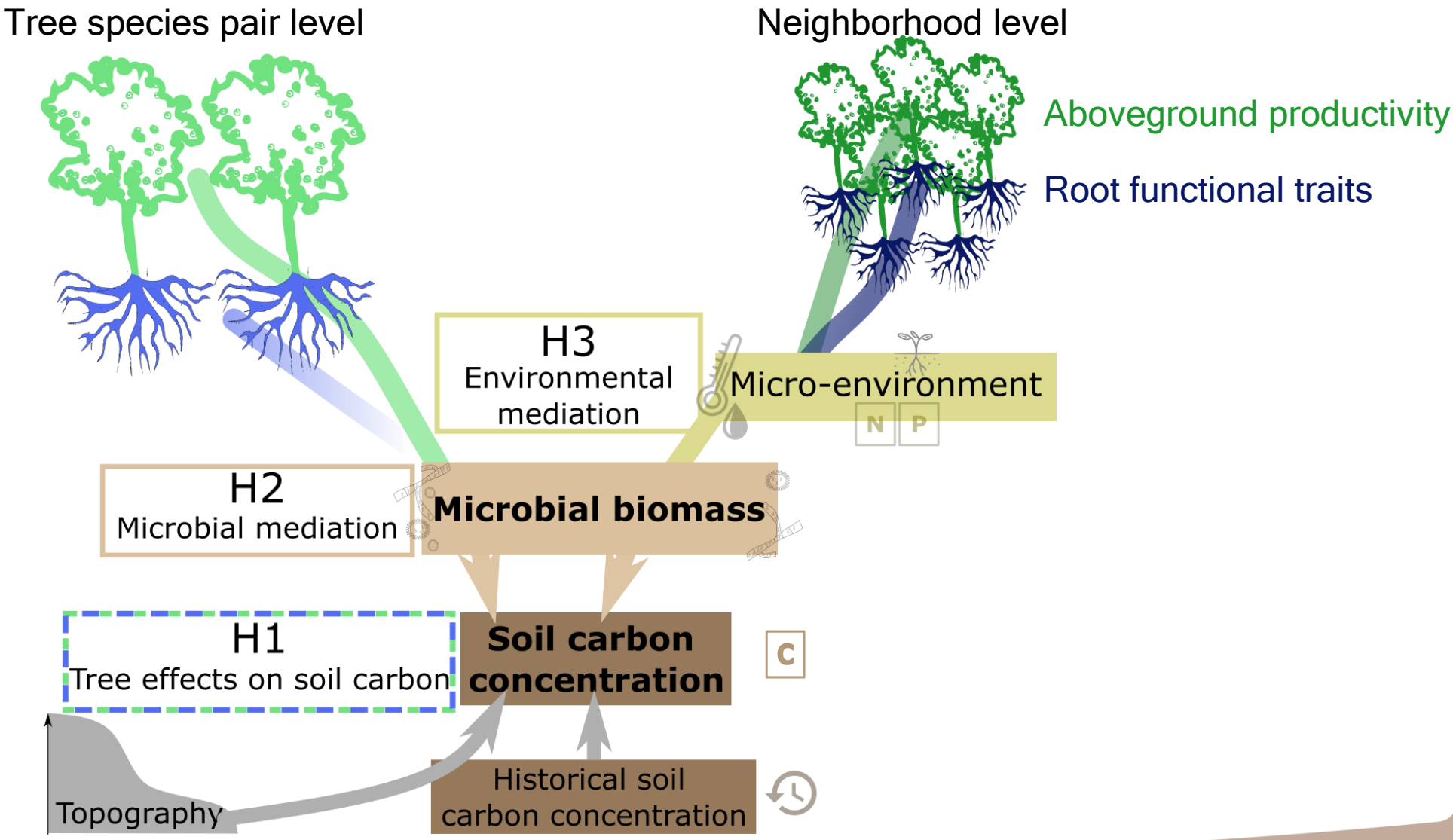
HYPOTHESES


Tree species pair level
Neighborhood level
Aboveground productivity
Root functional traits
H1
Tree effects on soil carbon
Soil carbon concentration
C
Topography
Historical soil carbon concentration

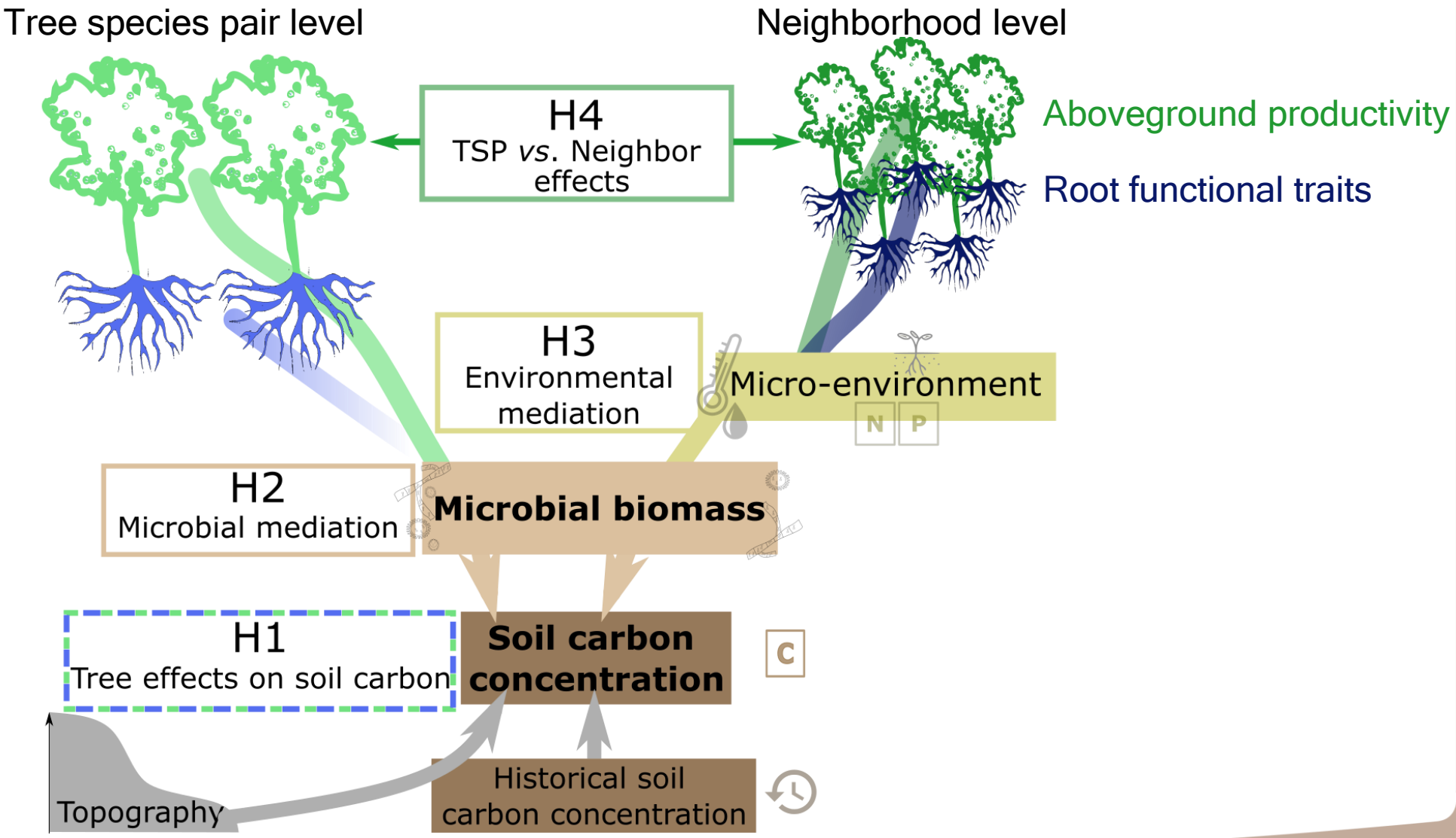
HYPOTHESES


Tree species pair level
Neighborhood level
Aboveground productivity
Root functional traits
H2
Microbial mediation
Microbial biomass
H1
Tree effects on soil carbon
Soil carbon concentration
C
Topography
Historical soil carbon concentration

HYPOTHESES

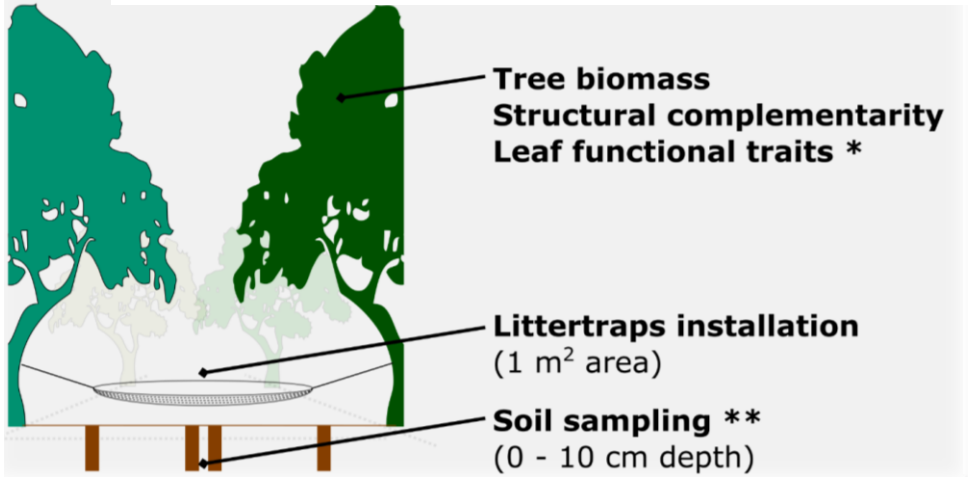

Tree species pair level
Neighborhood level
Aboveground productivity
Root functional traits
H3
Environmental mediation
Micro-environment
N
P
H2
Microbial mediation
Microbial biomass
H1
Tree effects on soil carbon
Soil carbon concentration
C
Topography
Historical soil carbon concentration

HYPOTHESES


Tree species pair level
Neighborhood level
H4
TSP *vs*. Neighbor effects
Aboveground productivity
Root functional traits
H3
Environmental mediation
Micro-environment
N
P
H2
Microbial mediation
Microbial biomass
H1
Tree effects on soil carbon
Soil carbon concentration
C
Topography
Historical soil carbon concentration

MY DESIGN SAMPLING

Sept. 2018 — Litter collection — Dec. 2018 — Decomposition incubation — Sept. 2019



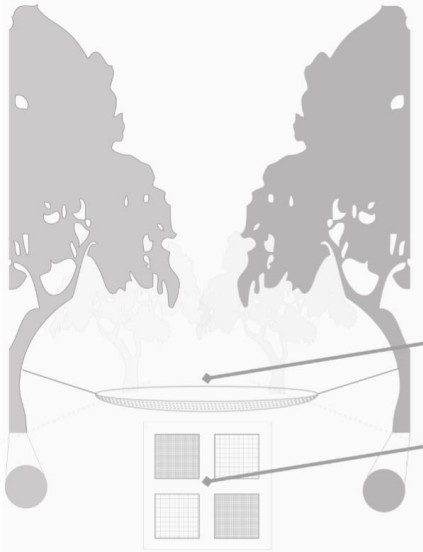
Tree biomass
Structural complementarity
Leaf functional traits *

Littertraps installation
(1 m^2 area)

Soil sampling **
(0 - 10 cm depth)

Litterbag sampling

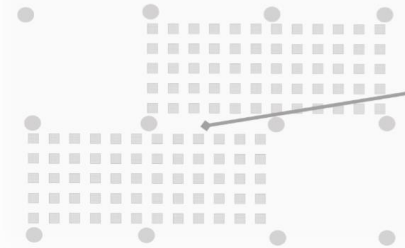
Between TSPs



Litter sampling

Litterbags installation
(4 bags:
- 2 x 0.054 mm mesh
- 2 x 5 mm mesh)

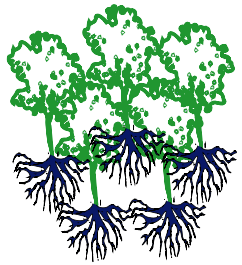
In the Common Garden experiment

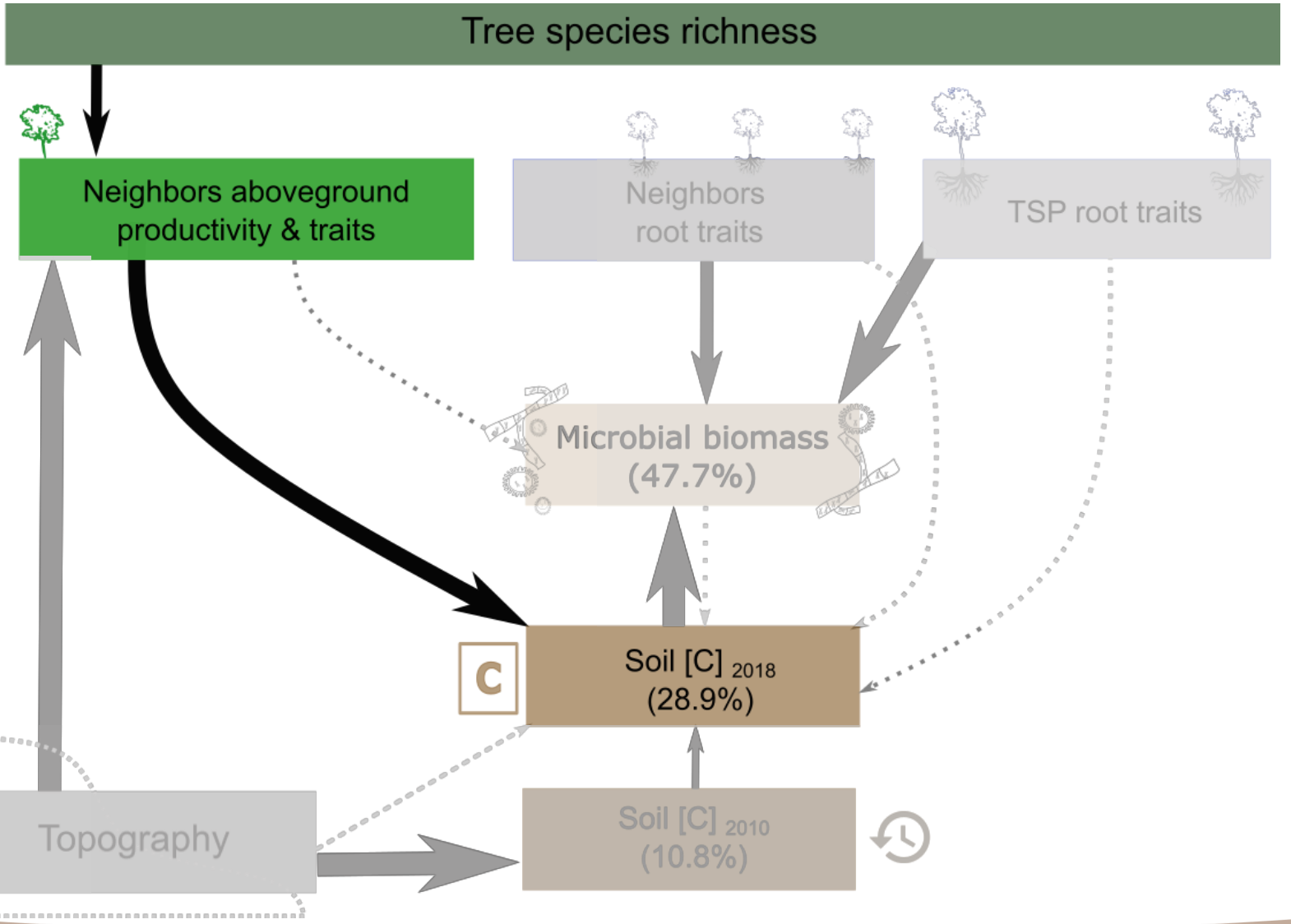


Litterbags installation
(2 x 0.054 mm mesh per TSP)

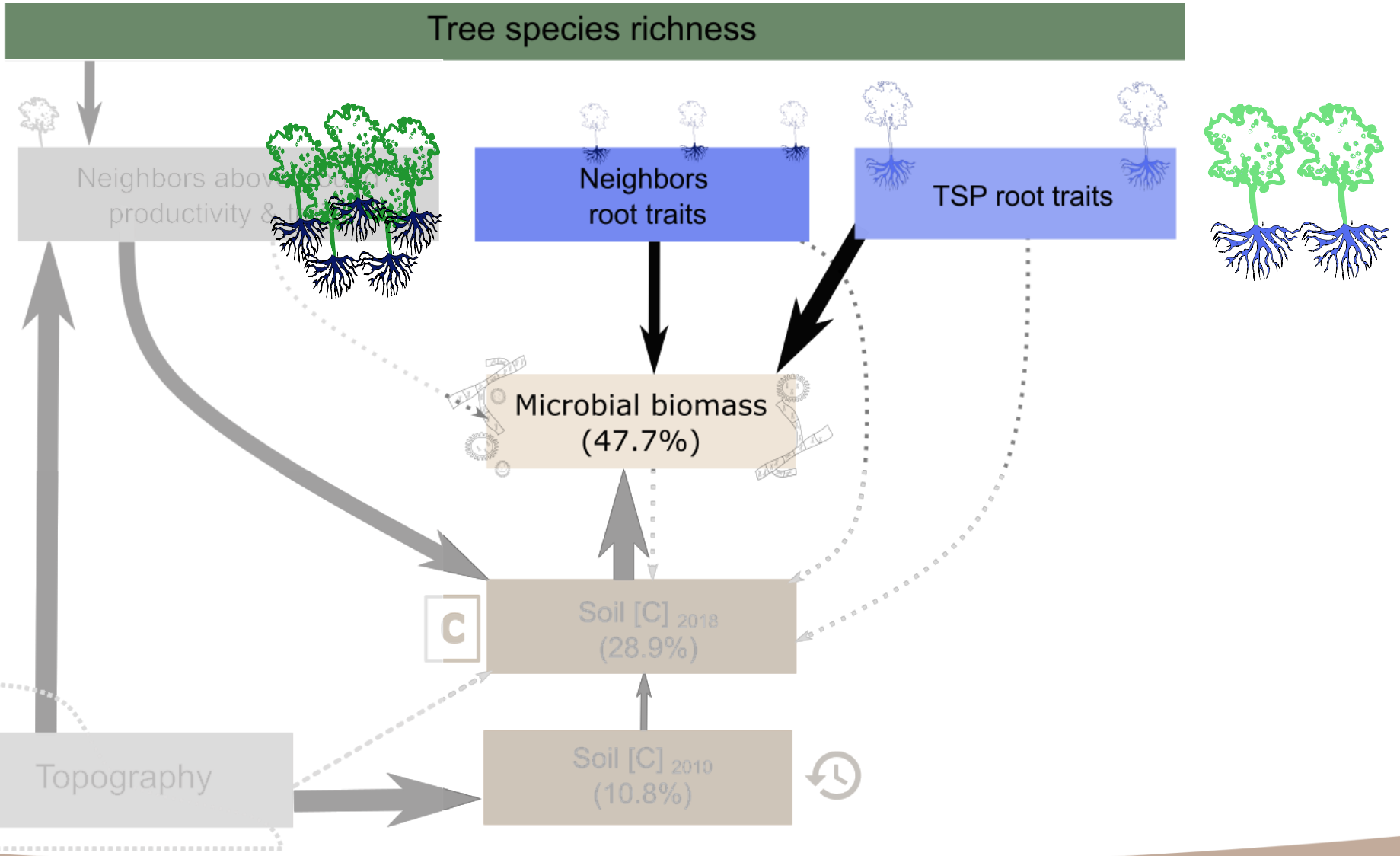
*: in collaboration with the TreeDì projects P1G, P2G, P5G
**: in collaboration with the TreeDì projects P7G and P8C

SCALE-DEPENDENCY OF TREE DIVERSITY

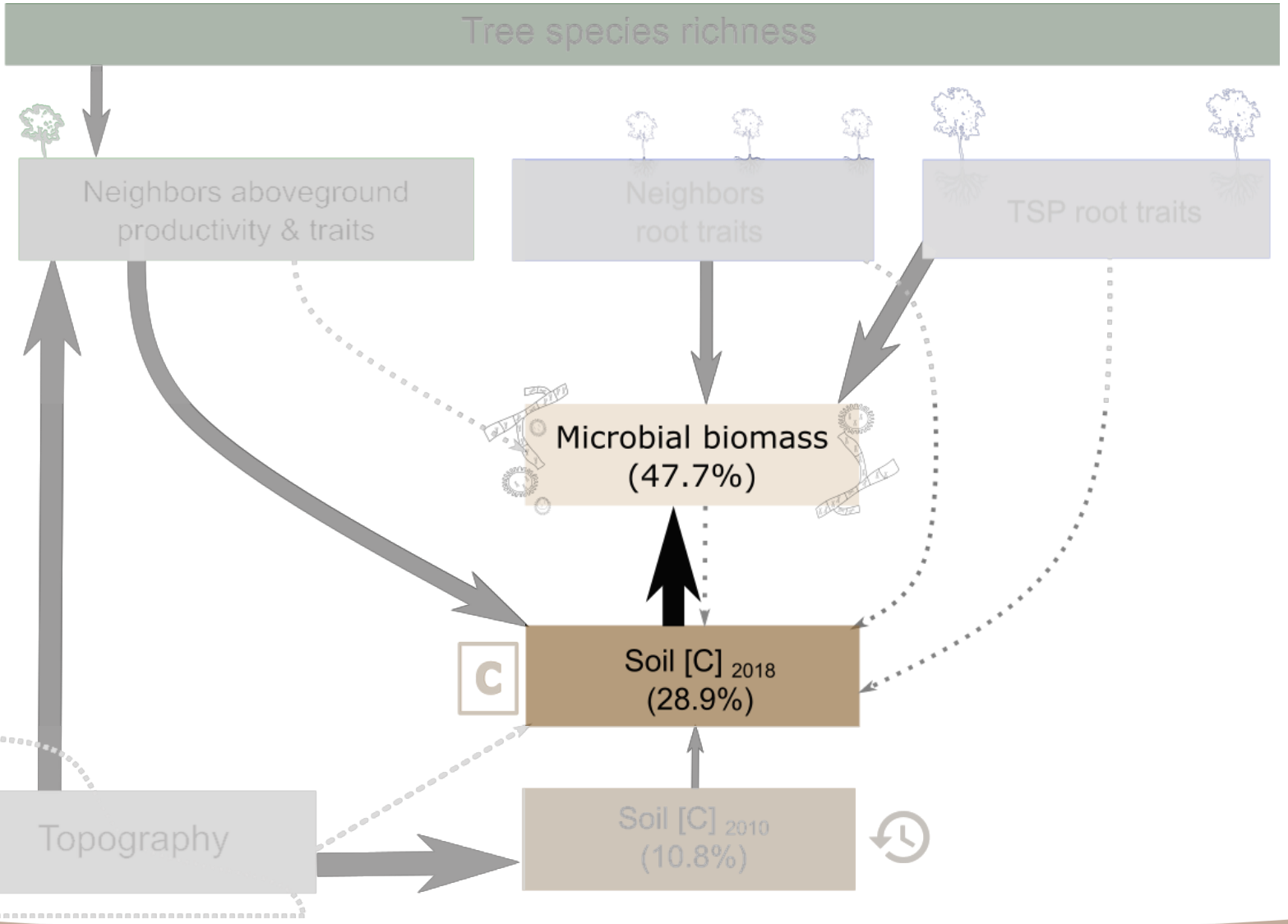




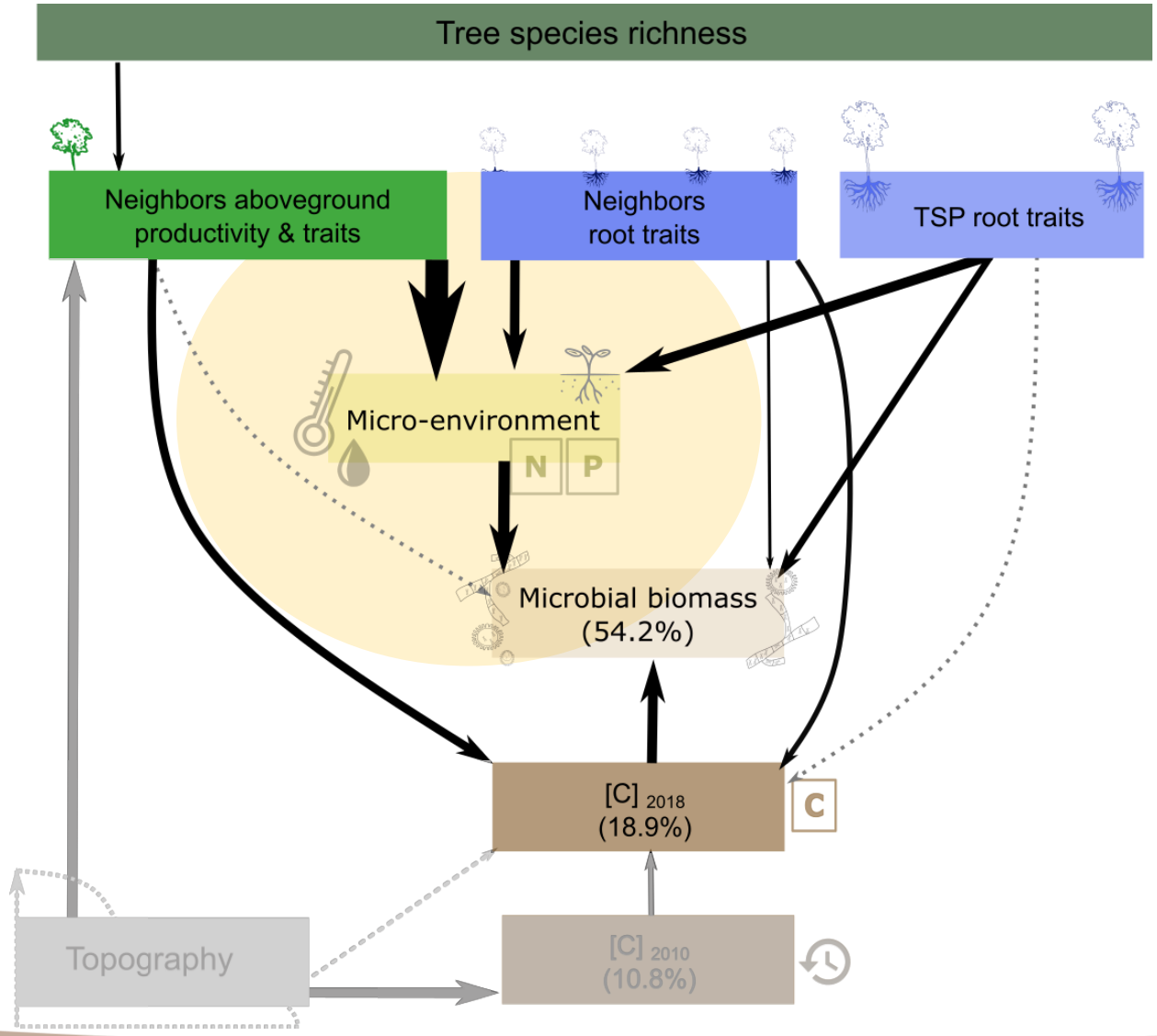
SCALE-DEPENDENCY OF TREE DIVERSITY



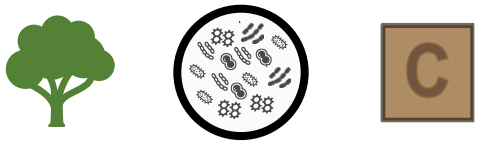
SCALE-DEPENDENCY OF TREE DIVERSITY



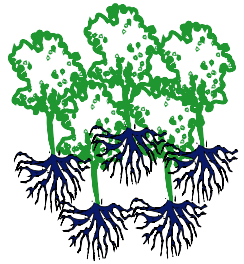
ENVIRONMENTAL CONDITIONS MEDIATION



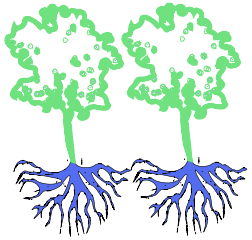
MAIN RESULTS



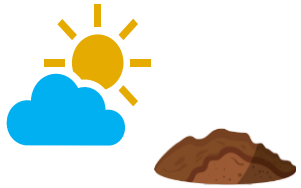
Tree species richness increased **tree productivity, microbial biomass, soil carbon concentration**



Soil carbon concentrations are driven at **neighborhood level**



Soil microbial biomass is driven at **tree species pair level**



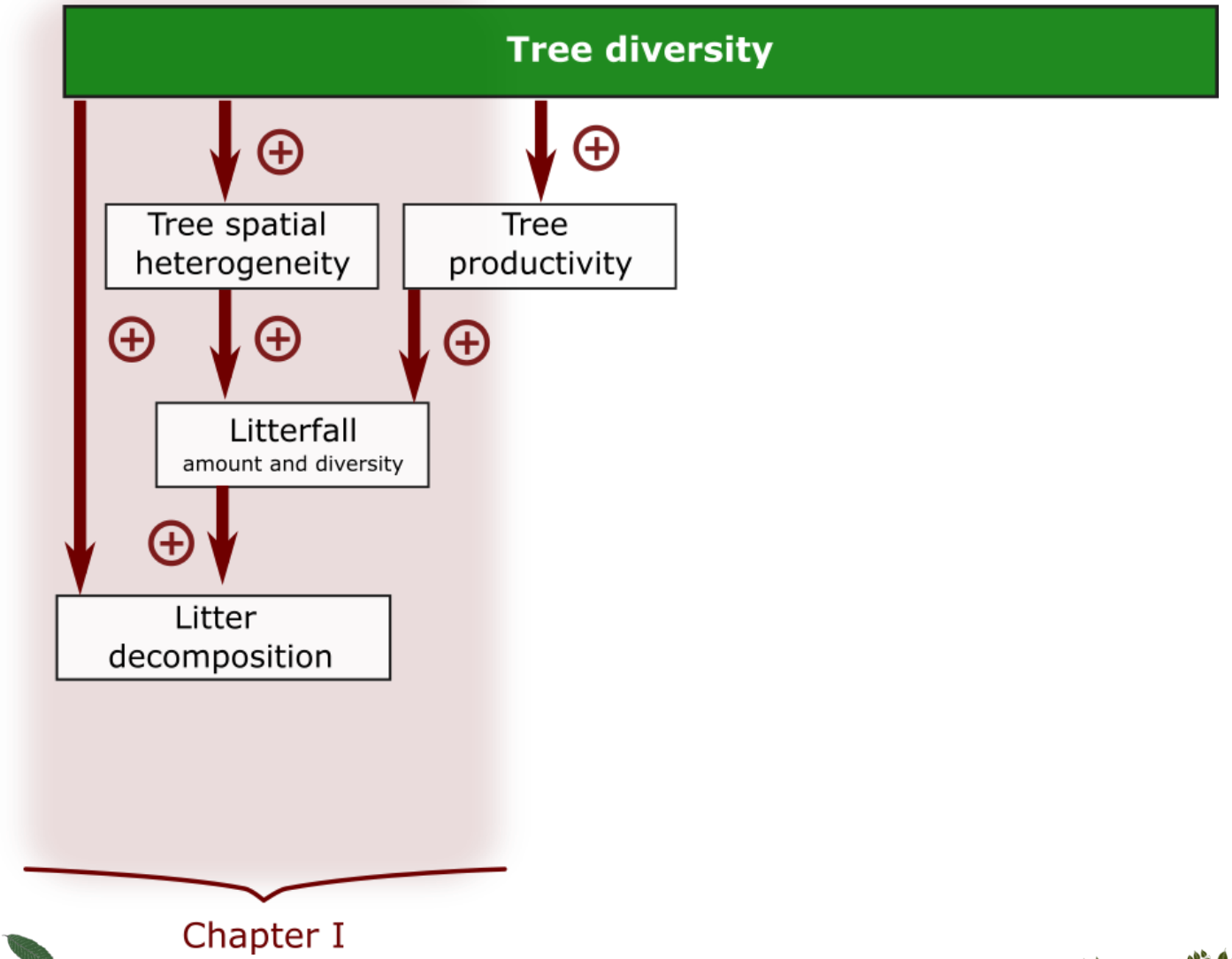
Environmental conditions mediate tree species richness effects on soil microbial biomass.

CONCLUSION AND PERSPECTIVES

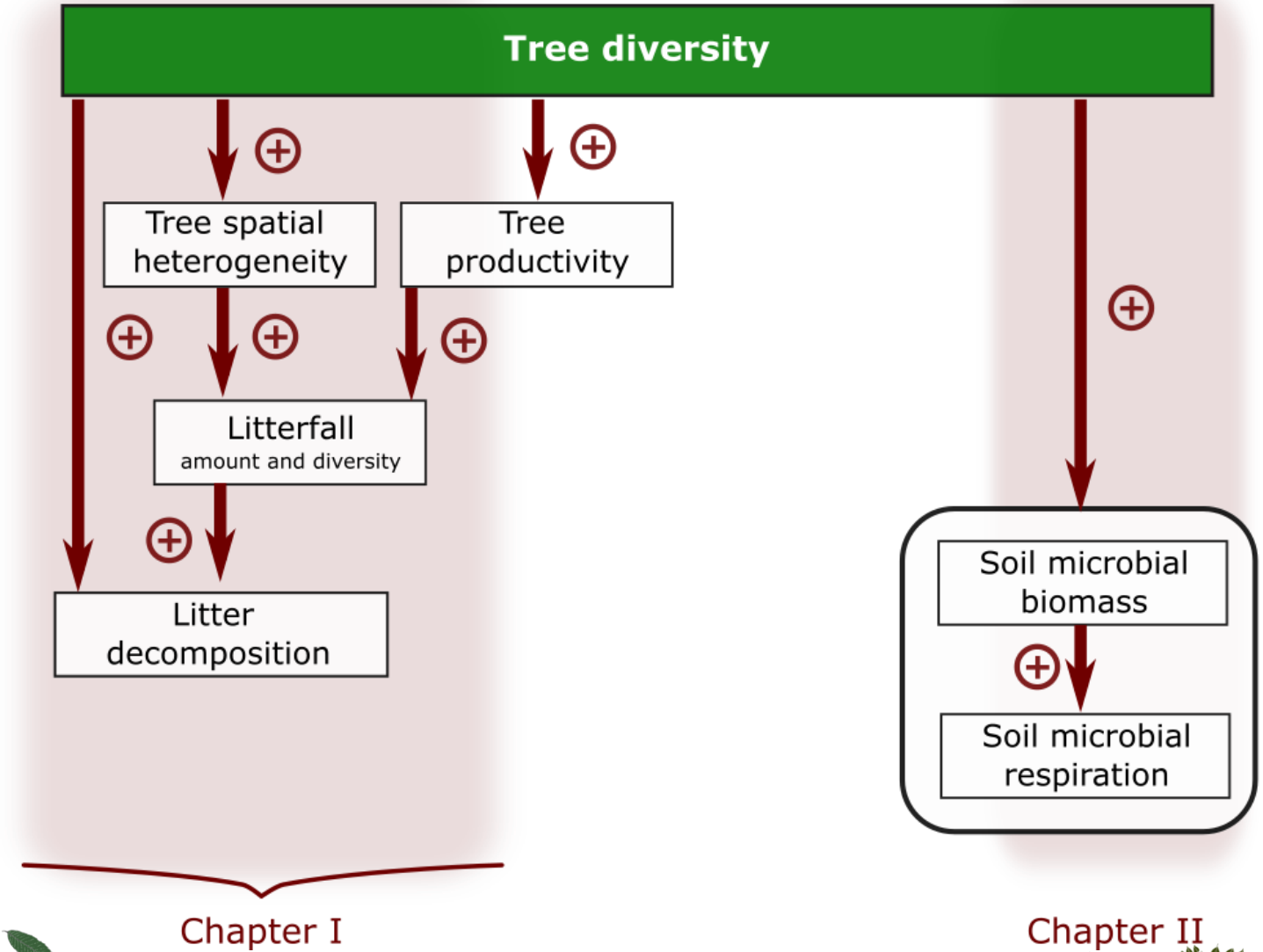
TREE DIVERSITY

MAIN RESULTS

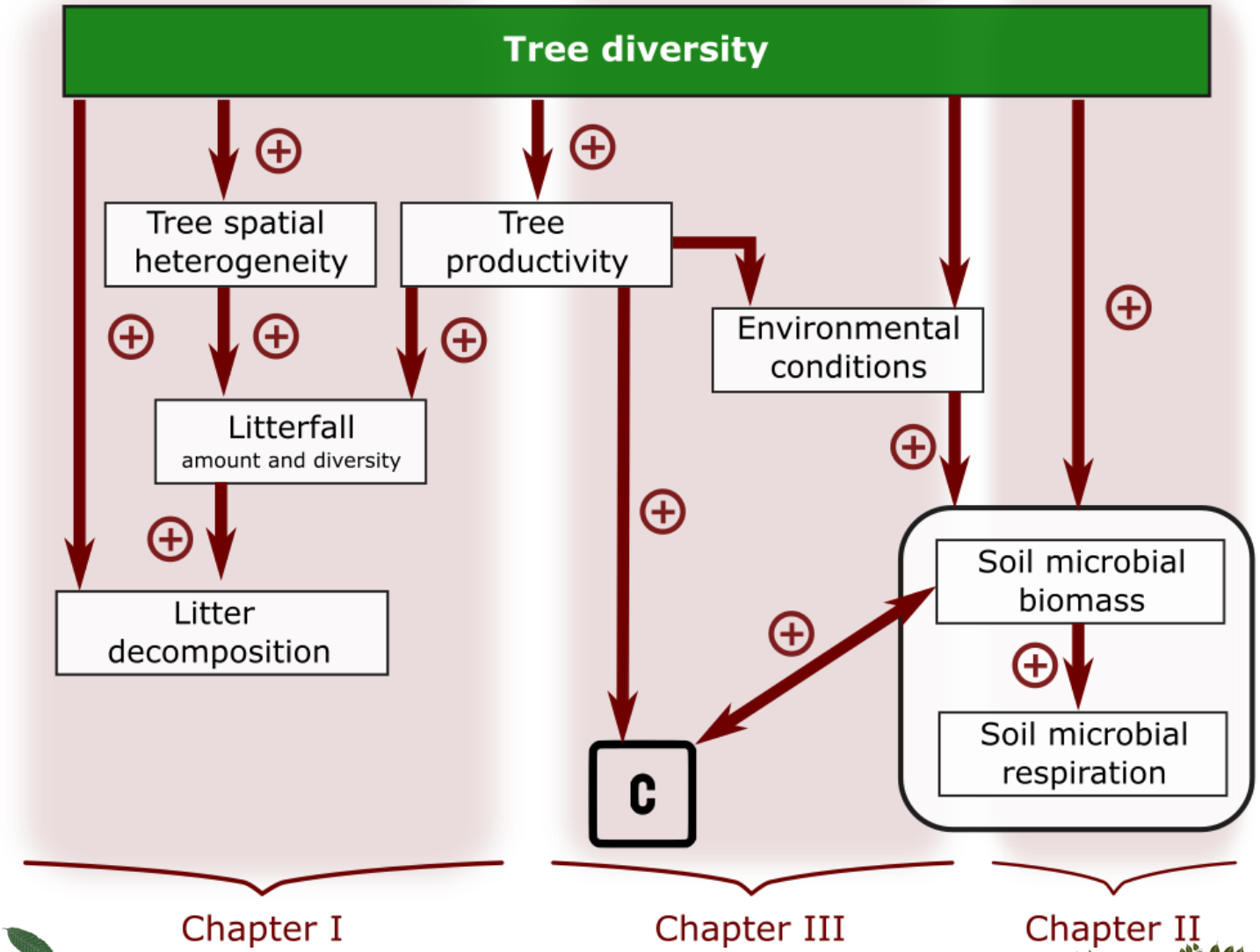
MAIN RESULTS



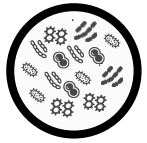
MAIN RESULTS



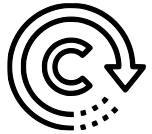
MAIN RESULTS



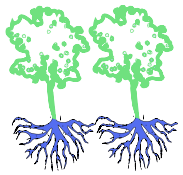
MAIN CONCLUSIONS



Carbon cycle in subtropical forests are **under microbial control**

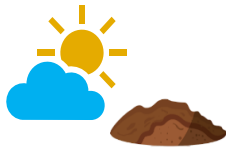


Tree diversity controls forest carbon cycle at every step (Huang *et al*, 2017, 2018, Xu *et al*. 2020)



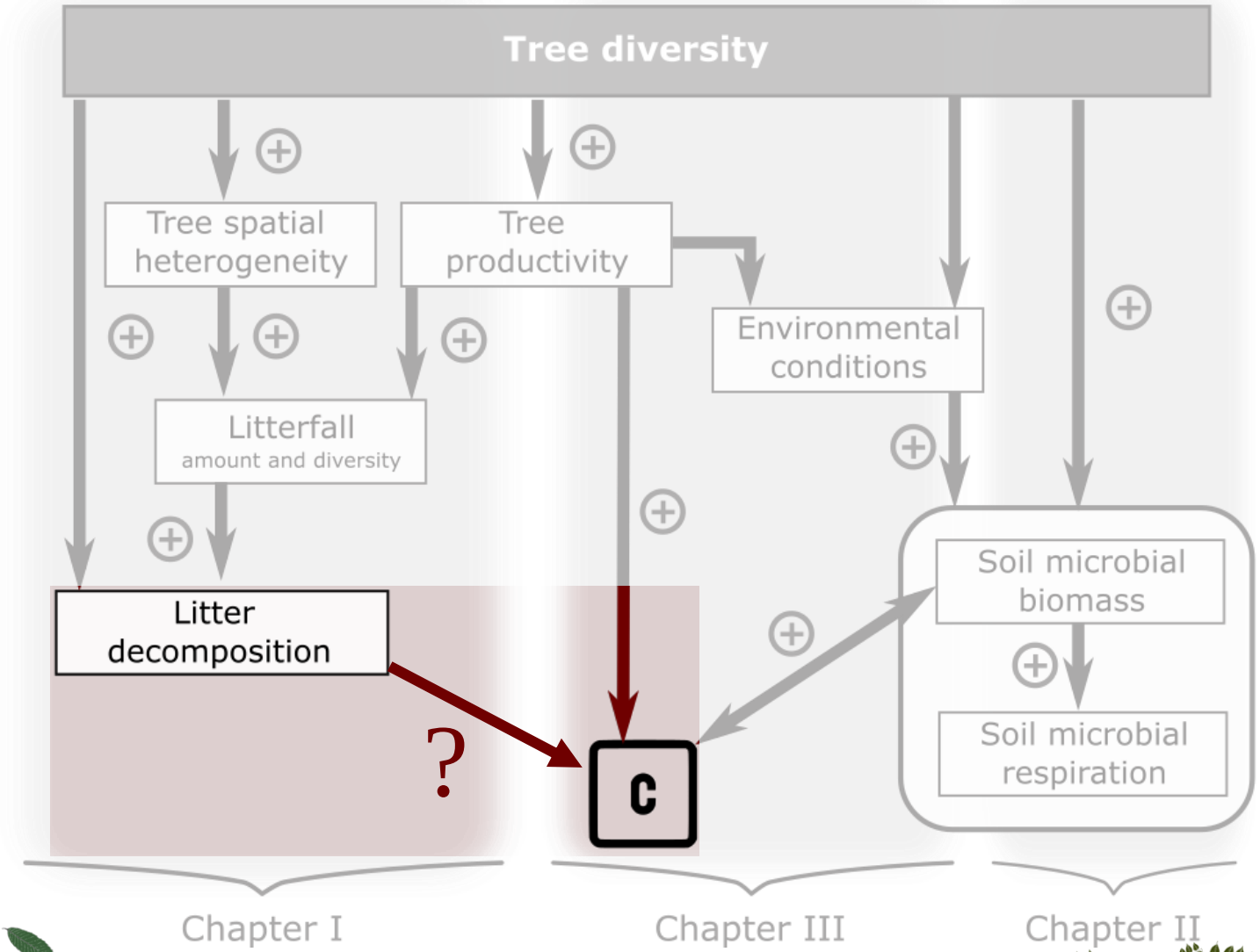
Tree-tree interactions and tree spatial complementarity effects on ecosystem functions are key to understand forest ecosystems (Trogisch *et al*. 2021, Williams *et al*. 2017)

Small scale heterogeneity matters and it is induced by tree diversity



Tree diversity effects on ecosystem function are **mediated by environmental modifications** (Cesarz *et al*. 2021, Joly *et al*. 2017, Gottschall *et al*. 2019)

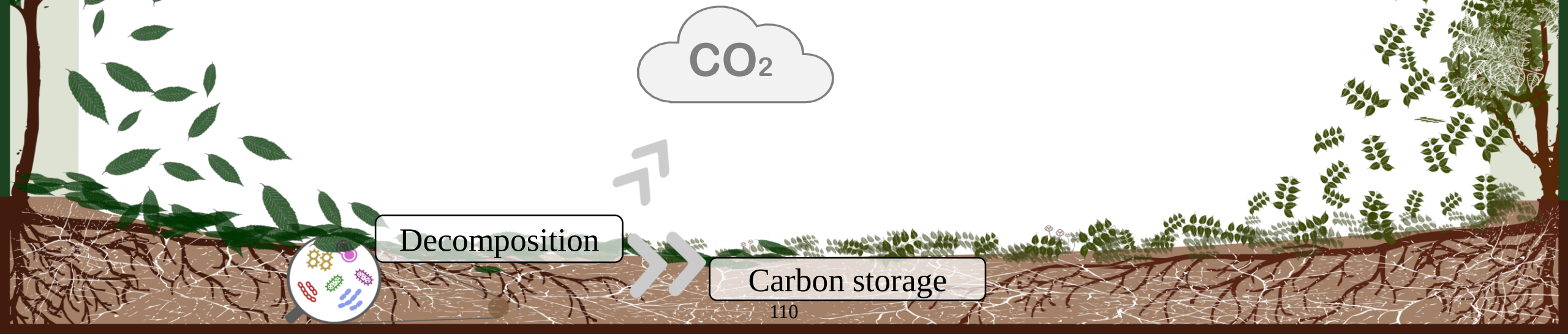
THE MISSING LINK



THE MISSING LINK

Need to better **quantify decomposition dynamics:**

CO_2 **mineralization *vs.* stabilization in soils** C



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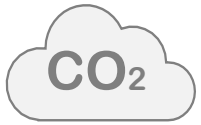
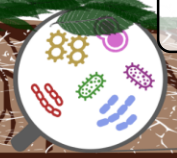


mineralization *vs.* stabilization in soils

Need to understand **carbon dynamics in soil** (Käsner and Miltner 2018)



Decomposition

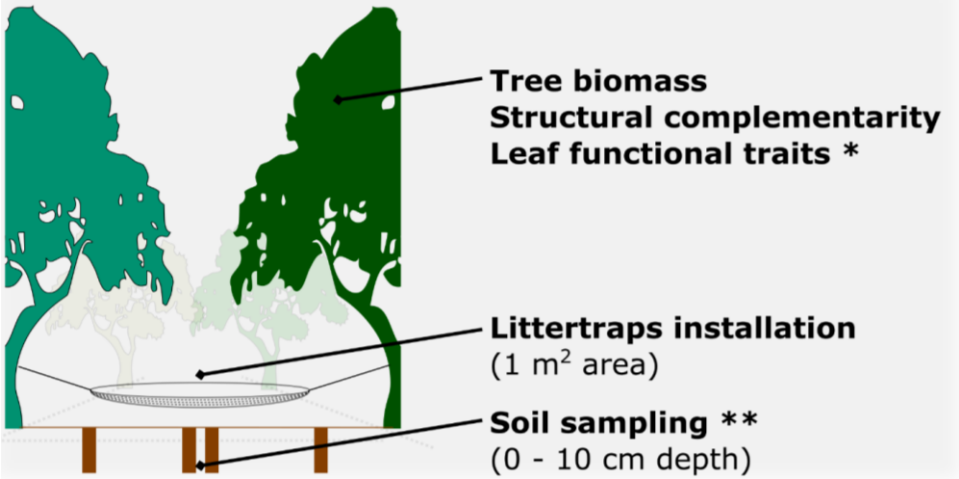
Carbon storage

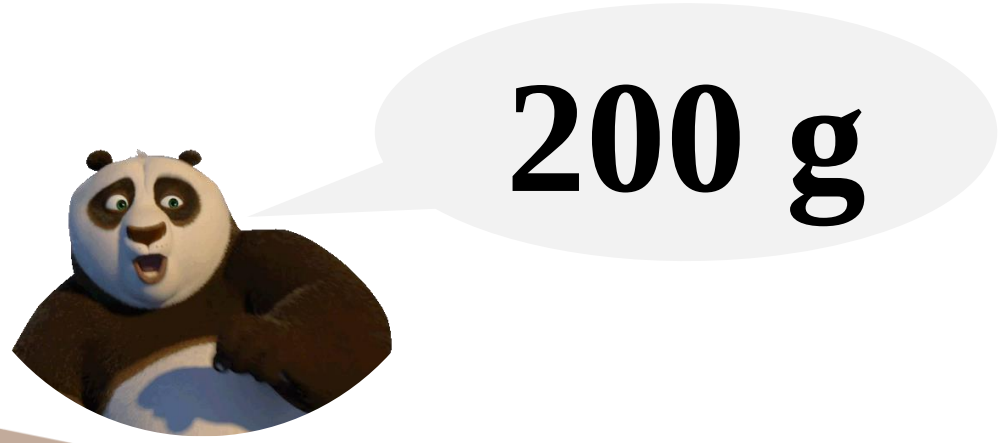
INCREASING SPATIO-TEMPORAL RESOLUTIONS

Need for **high spatio-temporal resolution** of the measurements

INCREASING SPATIO-TEMPORAL RESOLUTIONS

Need for **high-resolution and non-invasive measurements**

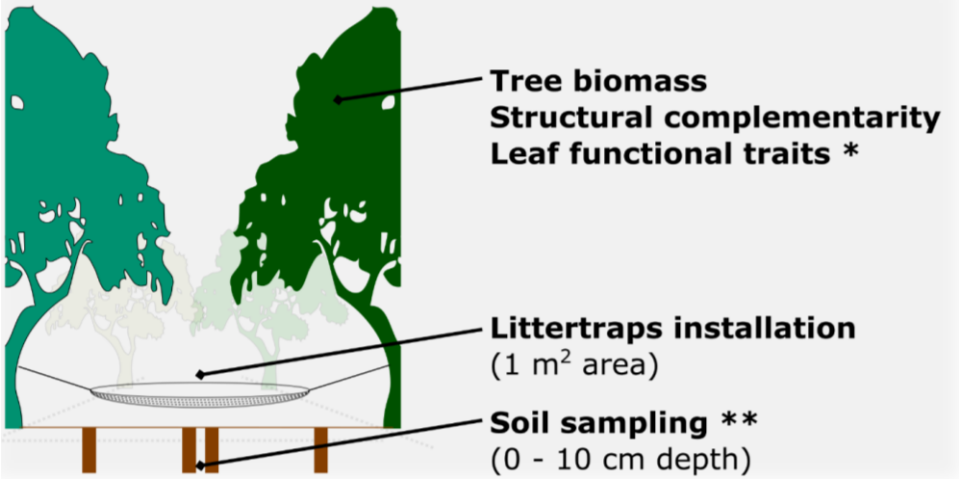


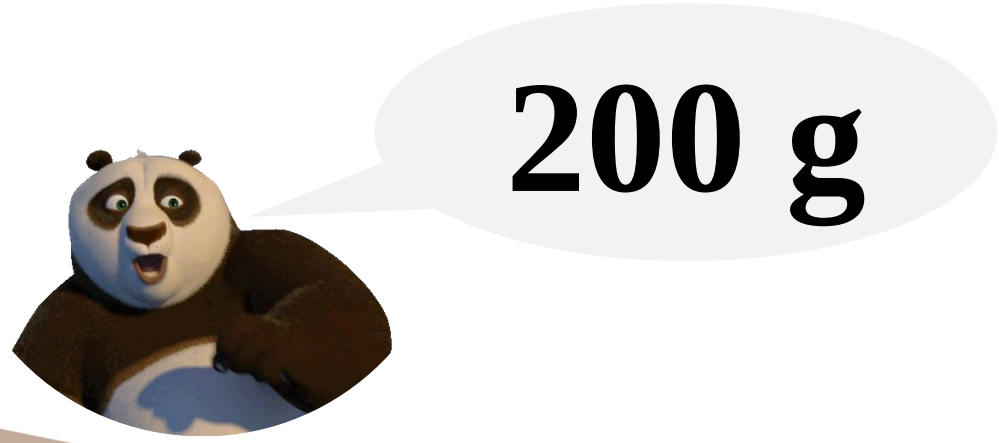


*: in collaboration with the TreeDì project P1G, P2G, P5G
**: in collaboration with the TreeDì project P7G and P8C

INCREASING SPATIO-TEMPORAL RESOLUTIONS

Need for **high-resolution and non-invasive measurements**





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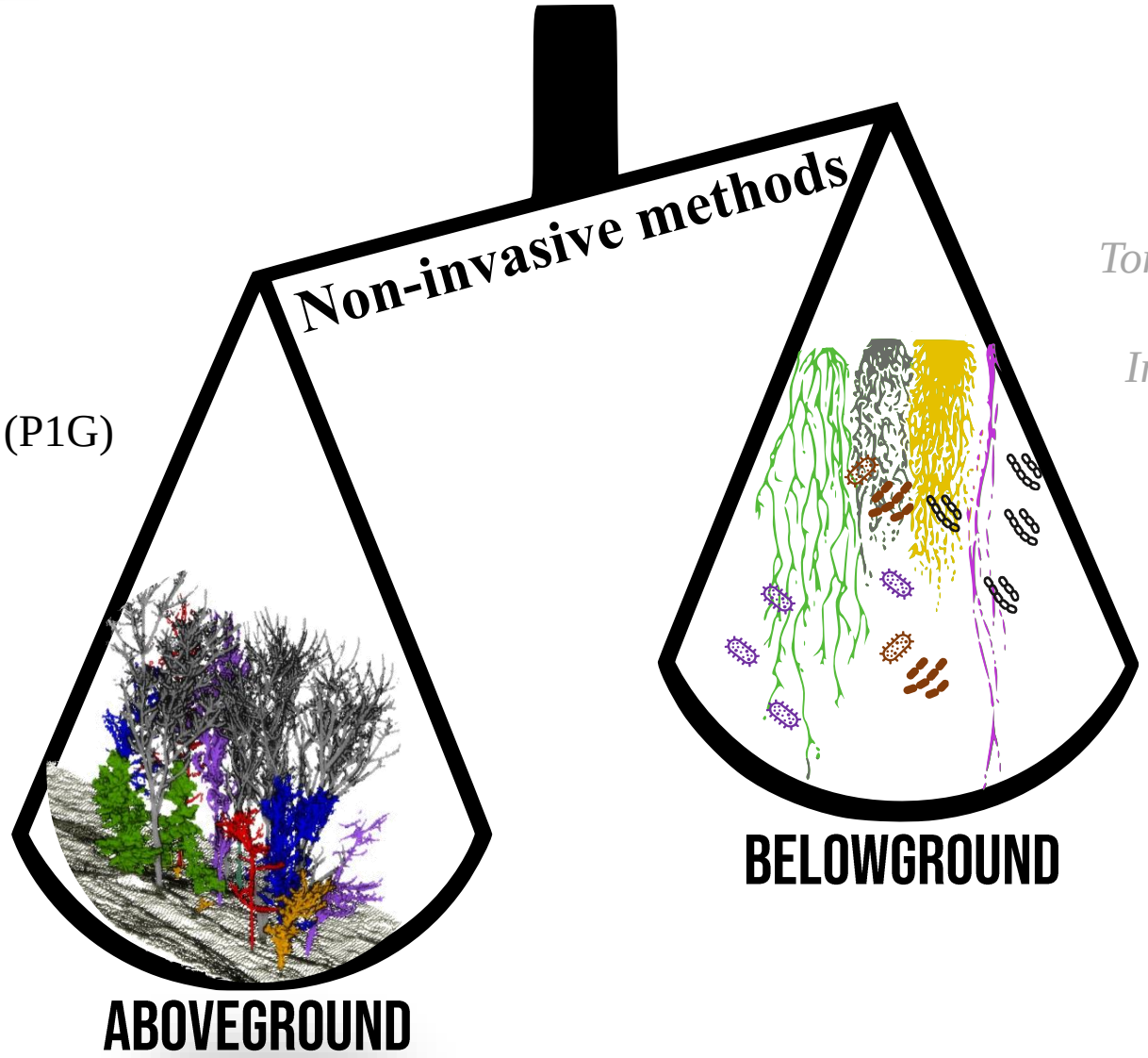
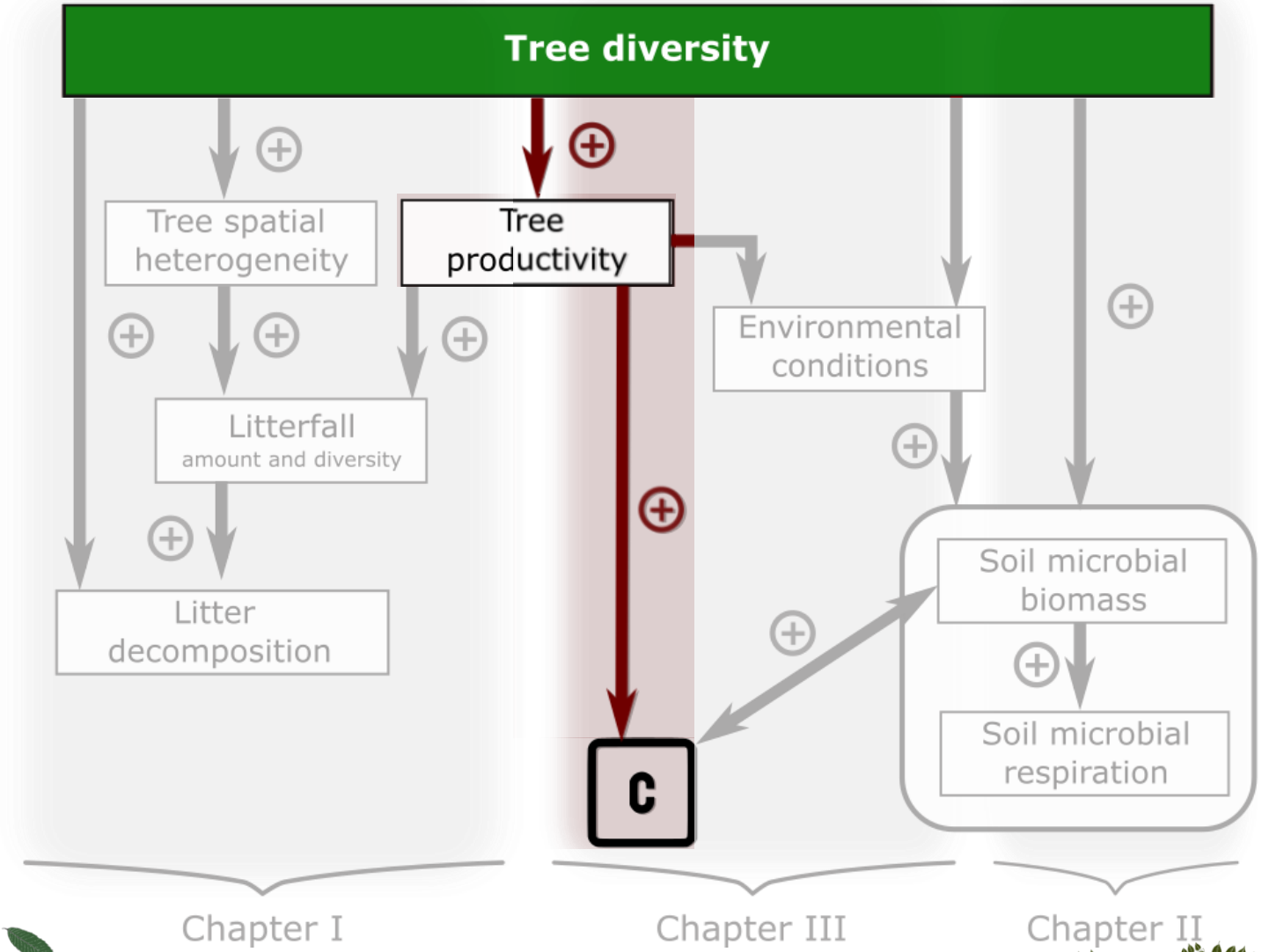
INCREASING SPATIO-TEMPORAL RESOLUTIONS

Terrestrial Laser Scanning (P1G)
Thermal imagery
Remote sensing
Inventories
Leaf spectrometry (P2G)
Air quality sensors
Camera trapping
Dummy caterpillars (P4G)
AMMOD project
Soundscape
Smellscape (VOC)

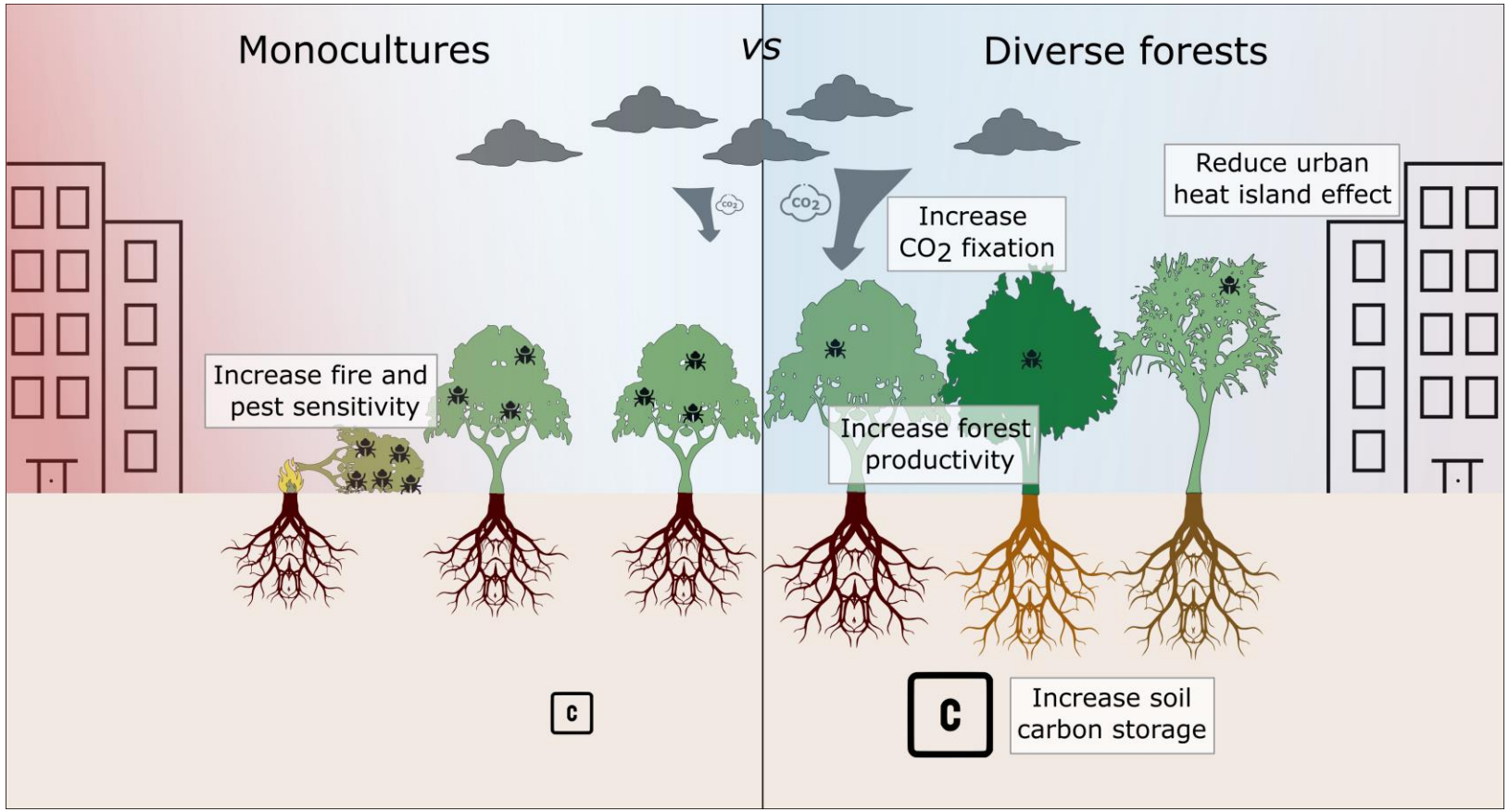


Minirhizotron
pH & chemical sensors
EDAPHOLOG
Bait-lamina strips
Tomography (X-ray, acoustic)
In situ soil spectrometry
In situ enzyme measurements
Microfluidic chips

MAIN RESULTS



DIVERSITY TO MITIGATE CLIMATE CHANGE



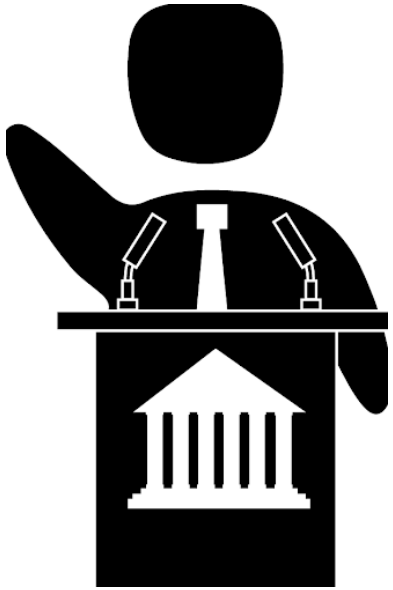
Beugnon *et al.* 2022
Messier *et al.* 2019

The high potential of tree diversity to mitigate climate change and buffer its effects on ecosystems

OUR RESEARCH FOR OUR SOCIETIES

Beugnon *et al.* 2022
Messier *et al.* 2019

Need to **get involved and build with policy makers** to push forward biodiversity research and actions



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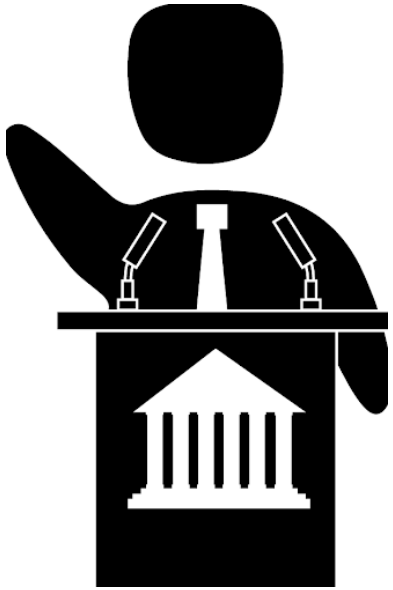
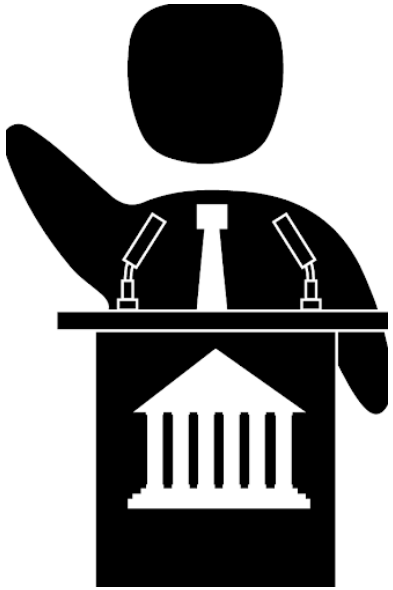


- **Provide accurate** and **personalized action** (what should we plant where?)

OUR RESEARCH FOR OUR SOCIETIES

Beugnon *et al.* 2022
Messier *et al.* 2019

Need to **get involved and build with policy makers** to push forward biodiversity research and actions



- **Provide accurate** and **personalized action** (what should we plant where?)
- Open a **new area for BEF research**

Beugnon *et al.* 2022
Messier *et al.* 2019

Involve the public and young minds:

Soil biodiversity collection

Helen Phillips

Malte Jochum

frontiers FOR YOUNG MINDS

ACKNOWLEDGMENTS

The DFG for funding my research

iDiv members and services for the constant support

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EIE colleagues and friends for their constant assistance

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Nico and Simone for their constant trust and guidance

My co-authors for their numerous insights and help

My Chinese counterpart Jianqing Du for our collab.

My collaborators and mentors for their support

My students for teaching me how to supervise

My office mate for always cheering me up

My friends for their constant presence

My family for this chance

Célia for being here