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Linking fine root diversity to ecosystem processes in models and the real world: Allocation of NPP belowground and fine root phenology

M. Luke McCormack & Dali Guo

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National Natural Science Foundation of China

国家自然科学基金委员会

Chinese Academy of Sciences

中国科学院

China Postdoctoral Science Foundation

中国博士后科学基金会

US DOE and US NSF

Colleen, Anthony, David, and Jeff

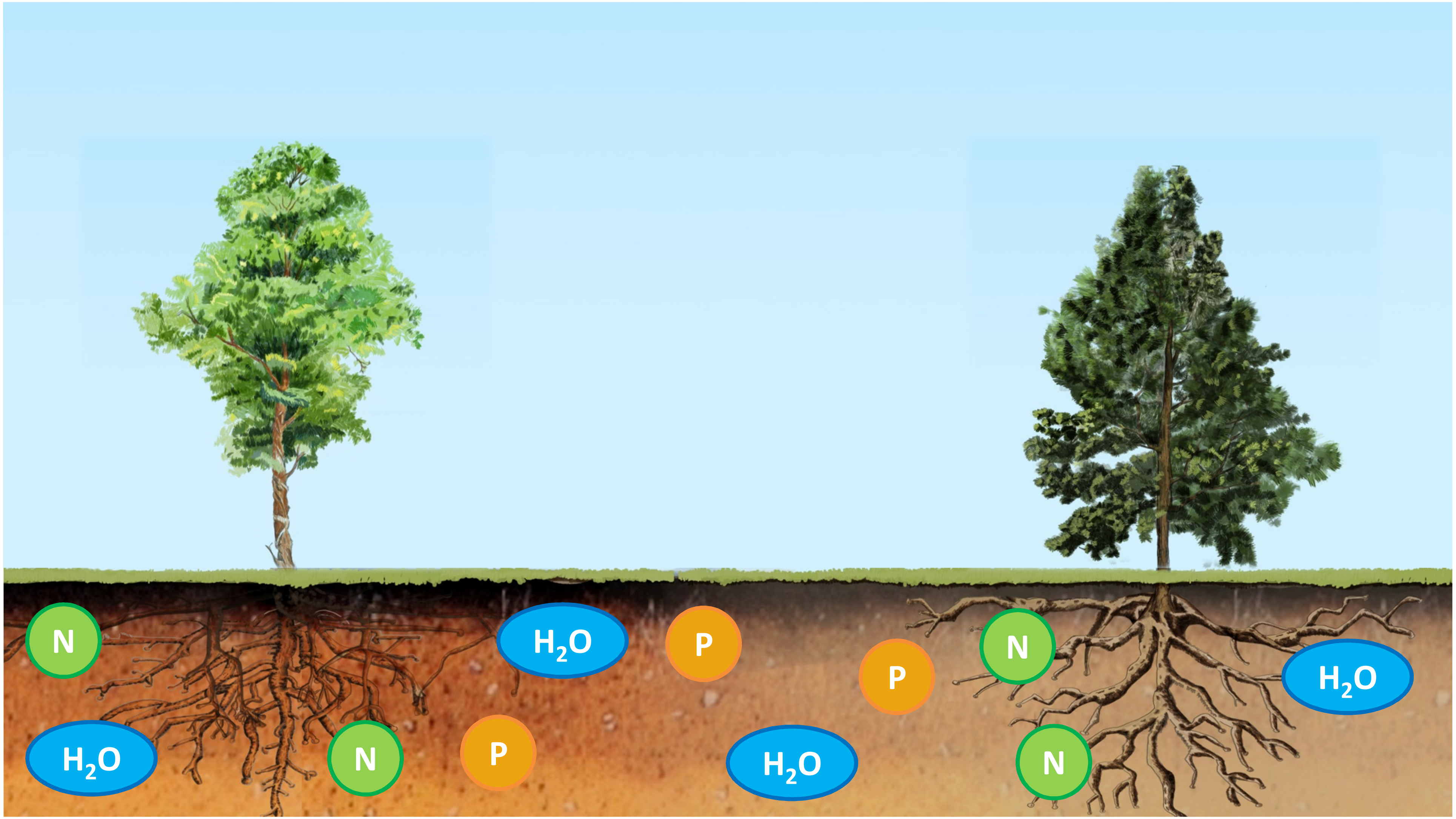
David Eissenstat, Erica Smithwick, Seth Pritchard, and many others

Summary Points

"Fine roots" should no longer be considered as a single, homogeneous pool in empirical studies or models

Phenology of *absorptive* fine roots is largely unknown and links to ecosystem processes not well-established

Fine roots and mycorrhizal fungi responsible for **uptake** as well as **transport** of resources



- Empirical estimates range from 10% to >50% percent of ecosystem NPP allocated to *fine roots* alone → **33% globally** (Jackson et al. 1997)

- Future improvements in models are limited by representation of belowground processes

Ciais et al., *Nat* Geosci, 2008; Ostle et al., *J of Ecol,* 2009;
Iversen et al., *New Phyt,* 2010; Malhi et al., *Phil Trans R Soc B,* 2011;
Wullschleger et al., *Ann Botany,* 2014; Smithwick et al., *Ecol Mod,* accepted

Grand challenge

Find the processes that can be improved in models to **provide the greatest gains** in model skill yet **remain analytically tractable**.

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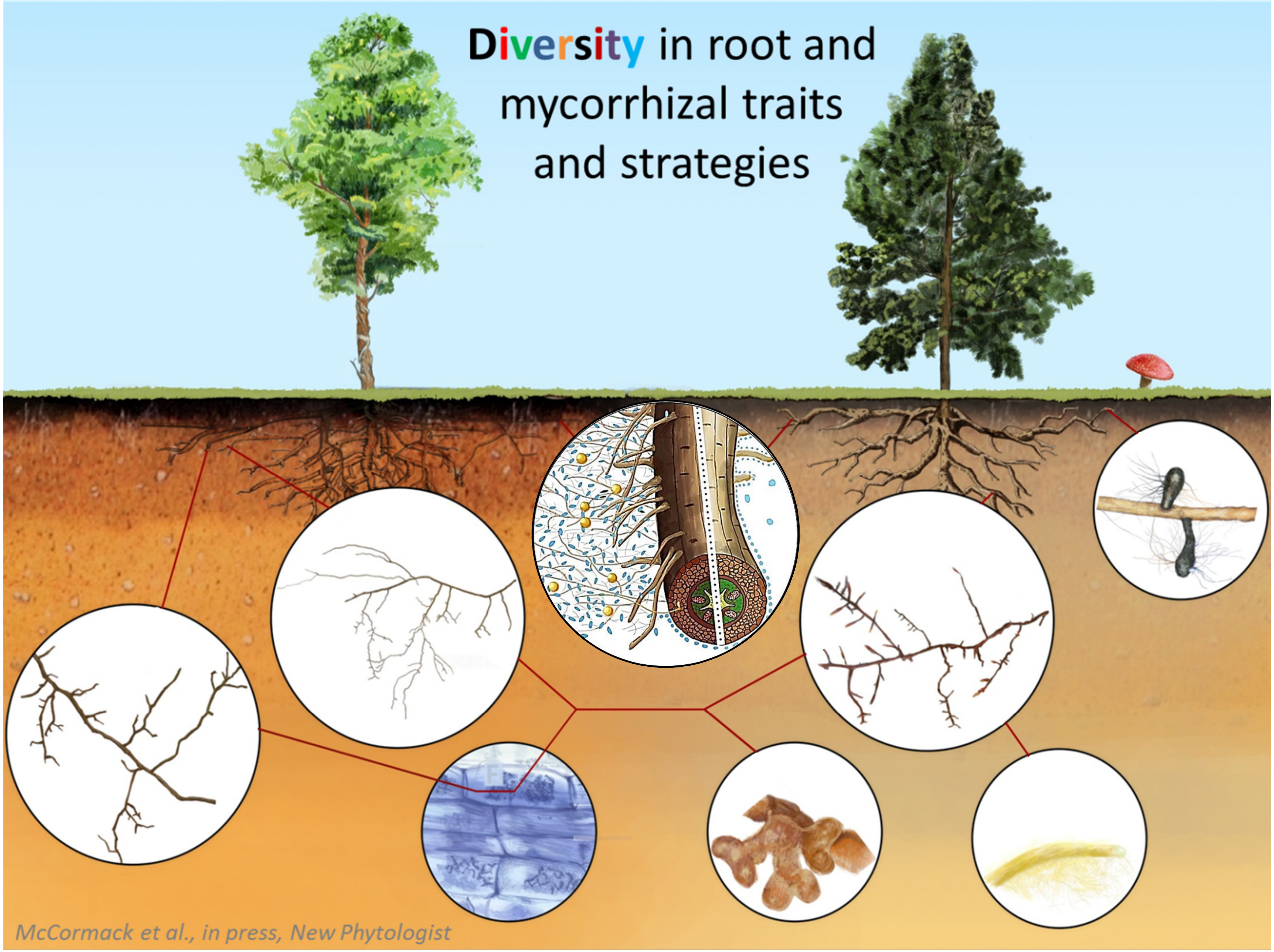
Find the processes that can be improved in models to **provide the greatest gains** in model skill yet **remain analytically tractable**.

- Empirical understanding must be sufficient to parameterize model in a meaningful way
- Model results must be understandable in light of the new process descriptions


Diversity in root and mycorrhizal traits and strategies
McCormack et al., in press, New Phytologist

Diversity within root branch

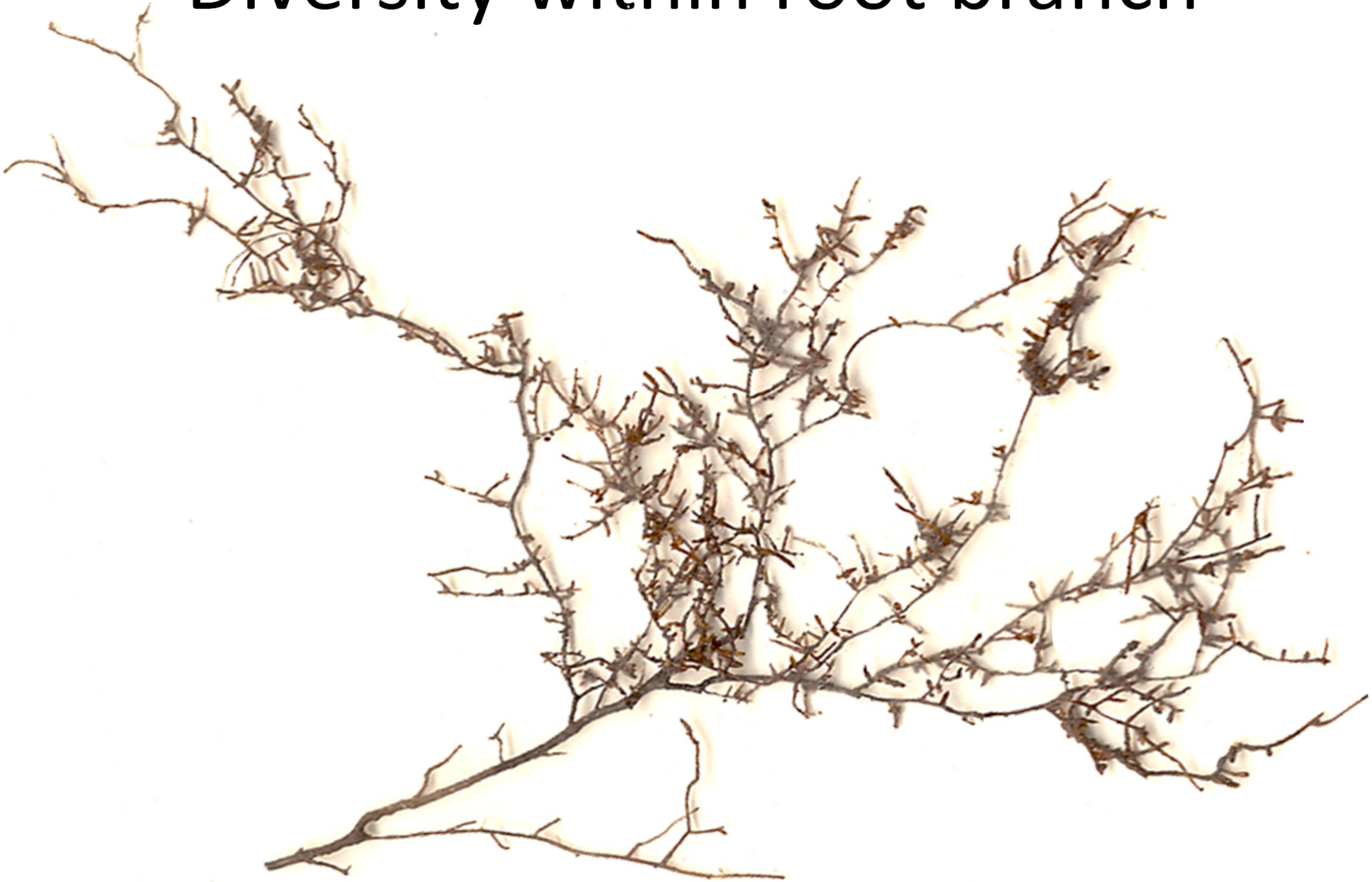


Photo by Sarah Kulpa

What are fine roots?

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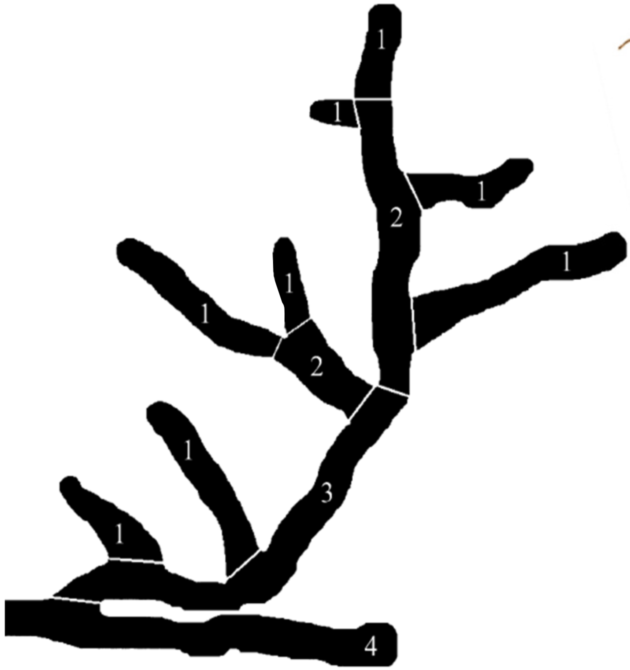

Pregitzer et al., *Ecol Mon*, 2002

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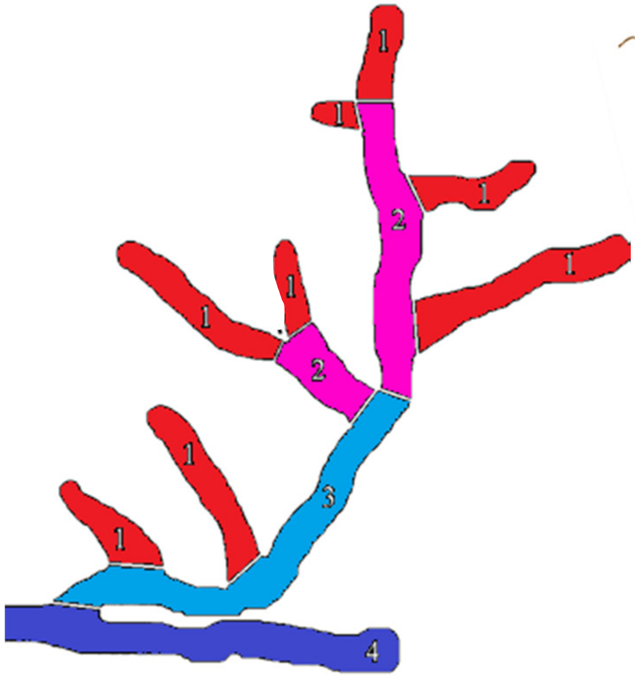

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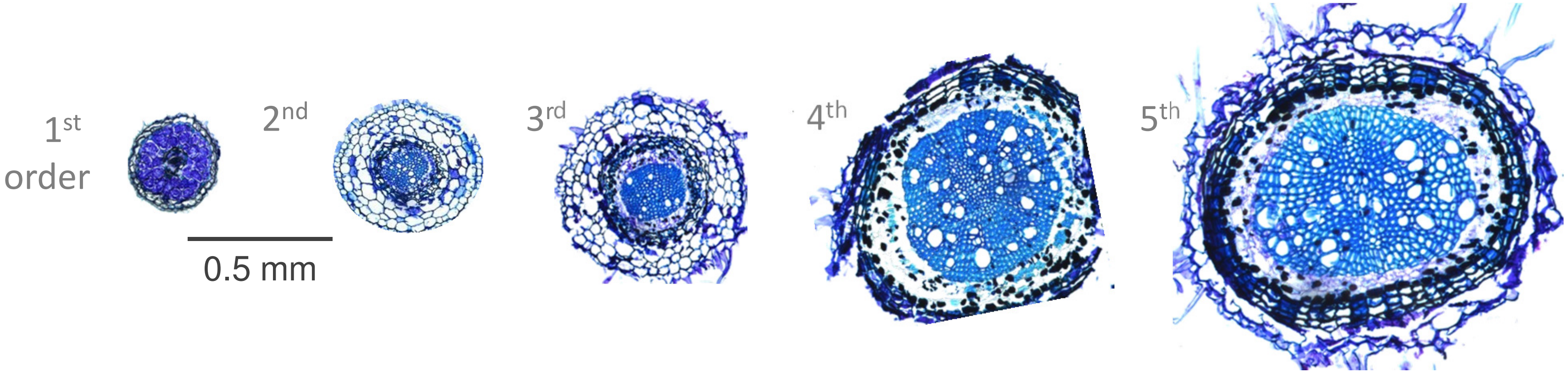
Diversity below 2 mm



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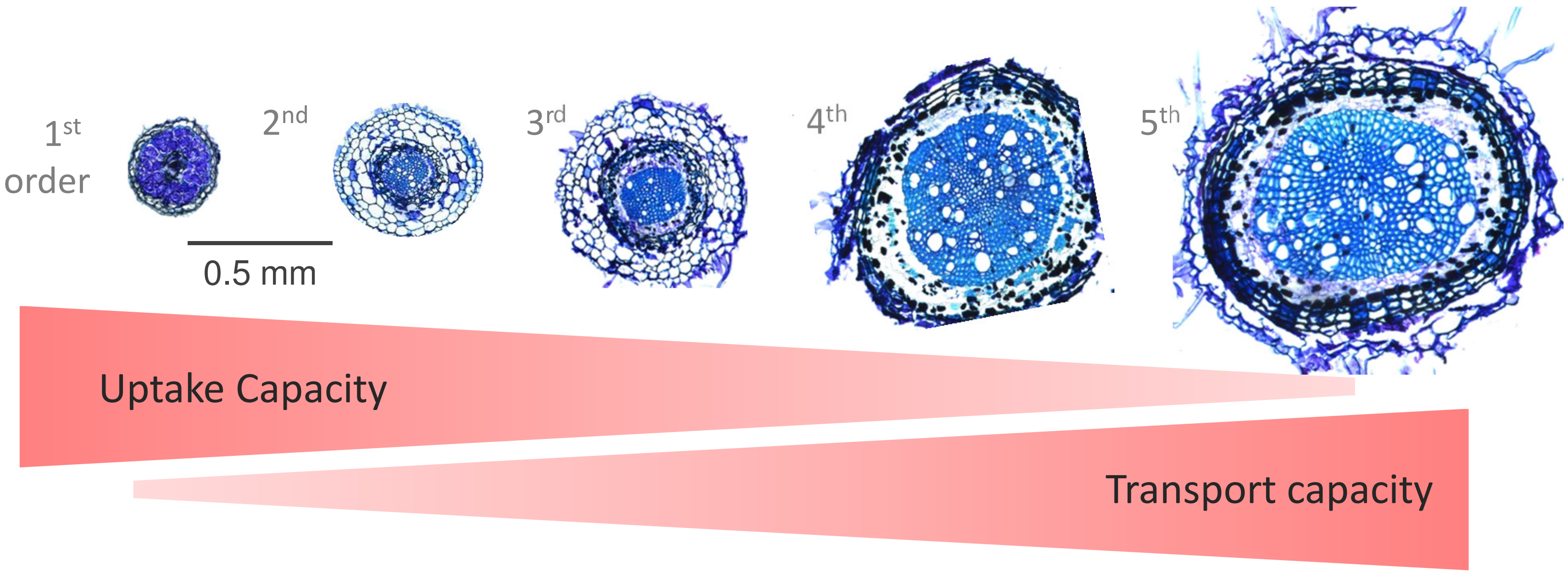

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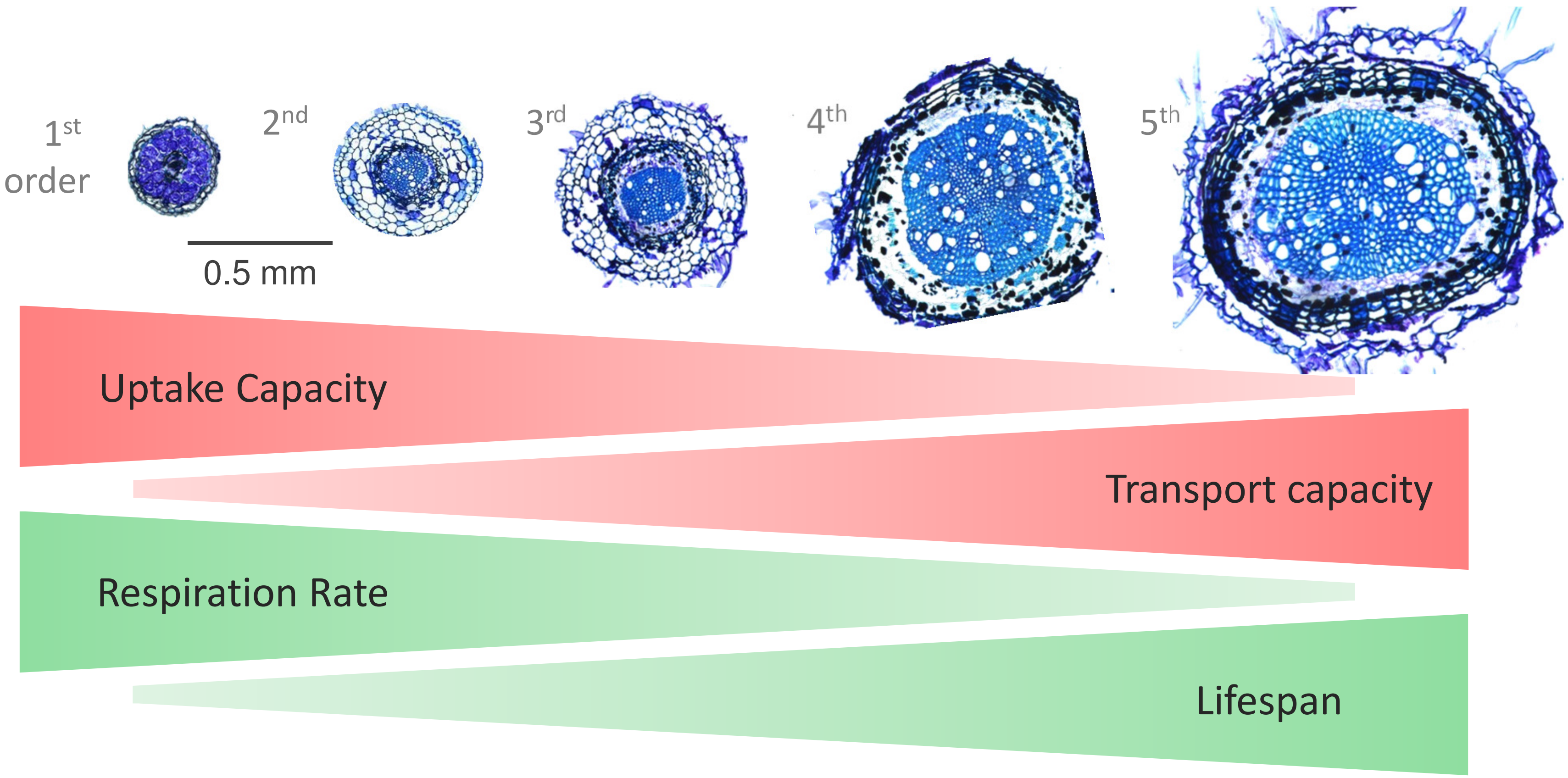

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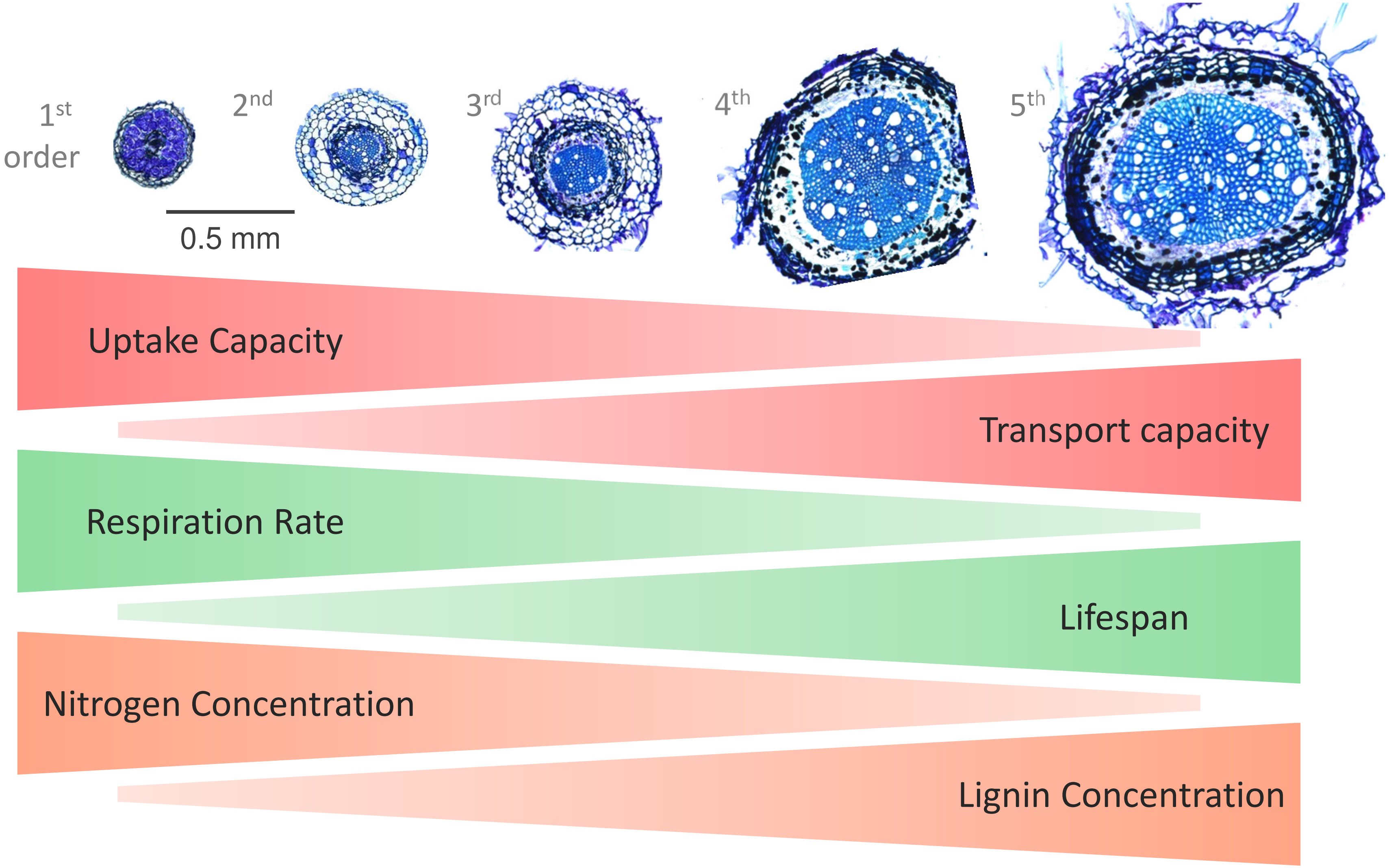
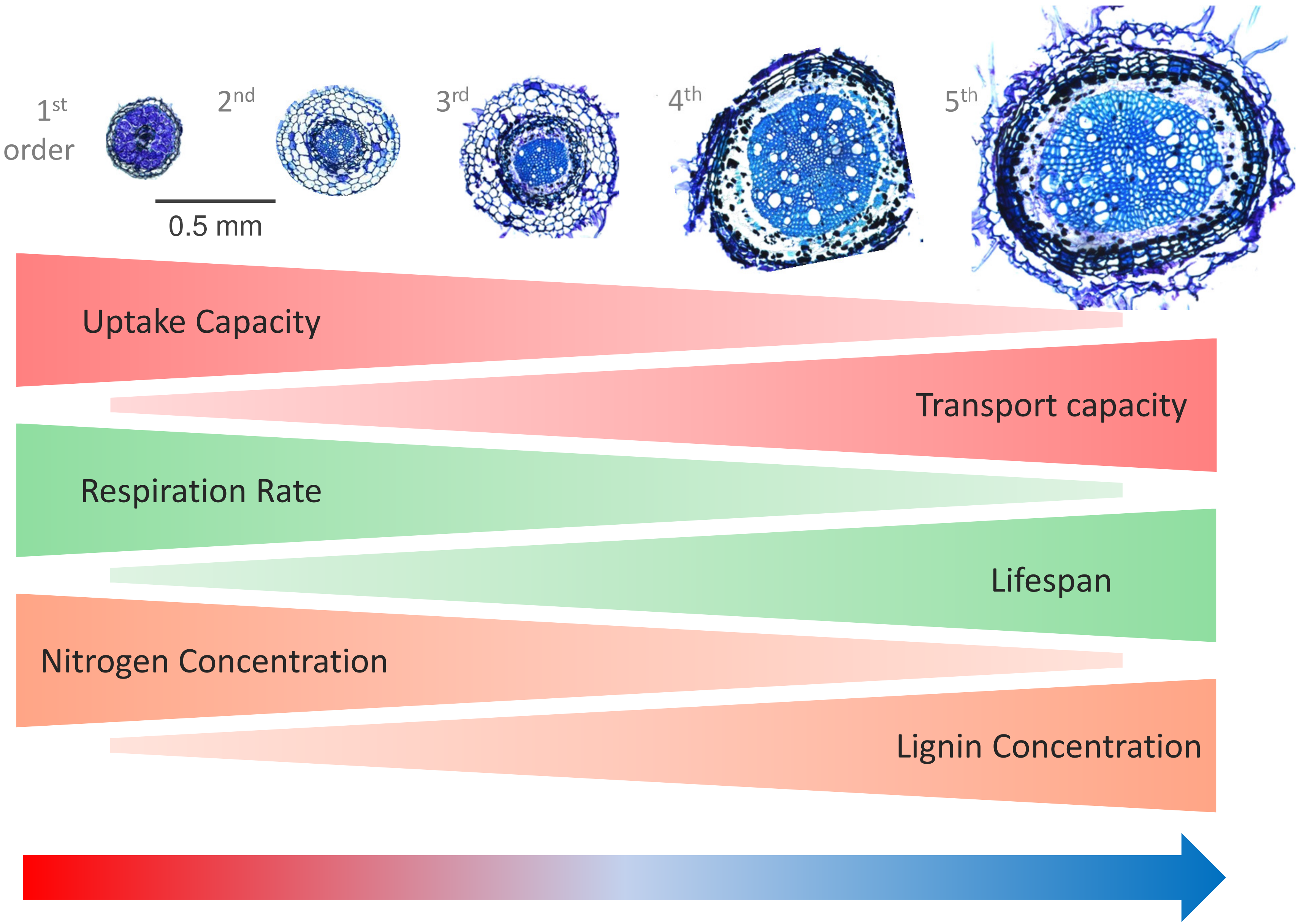
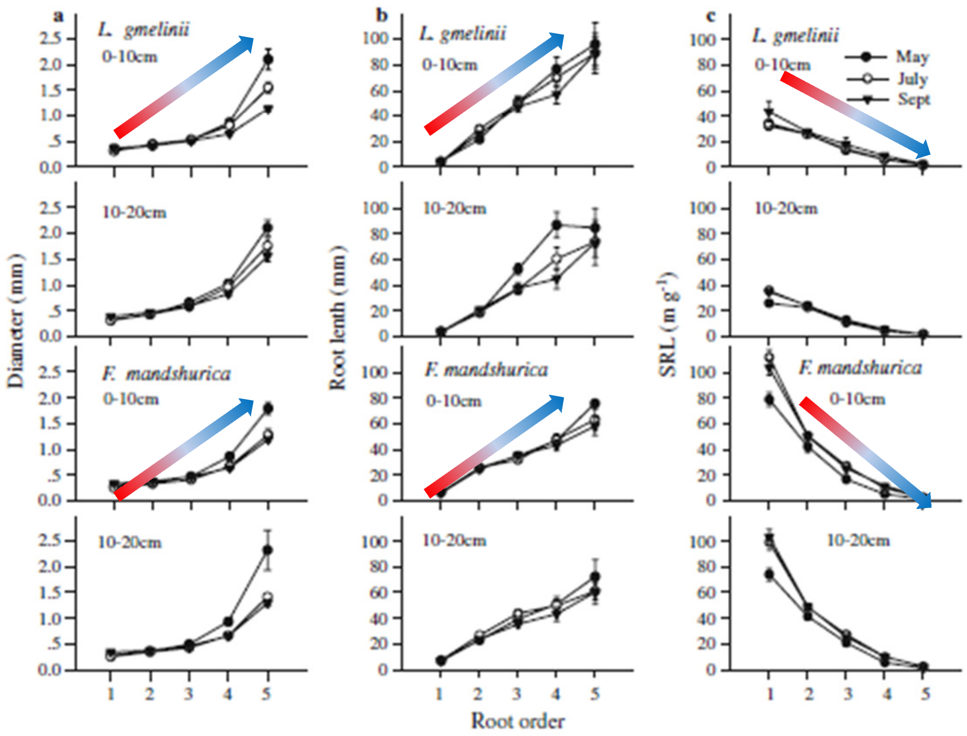
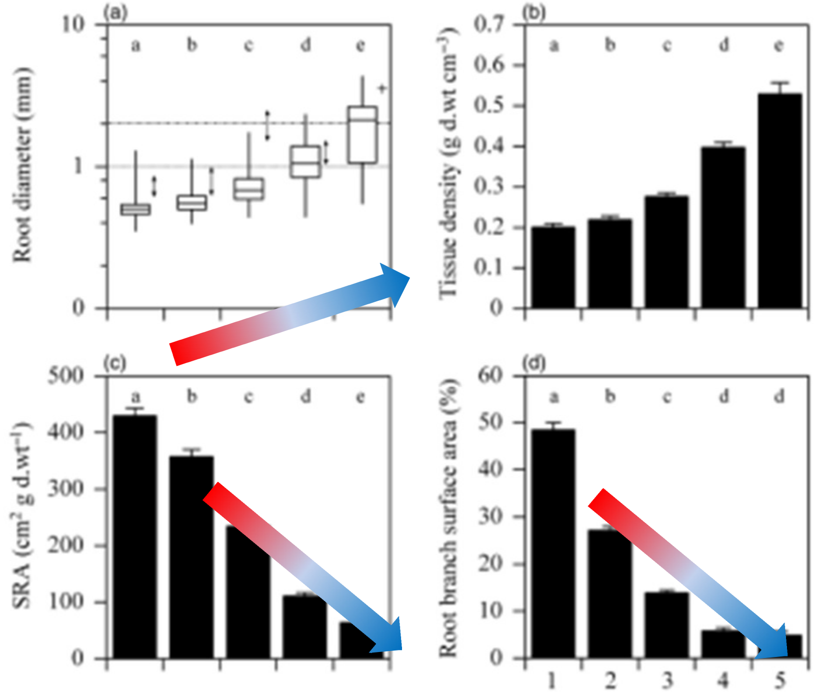


Diversity below 2 mm



Consistent patters from lower to higher order fine roots



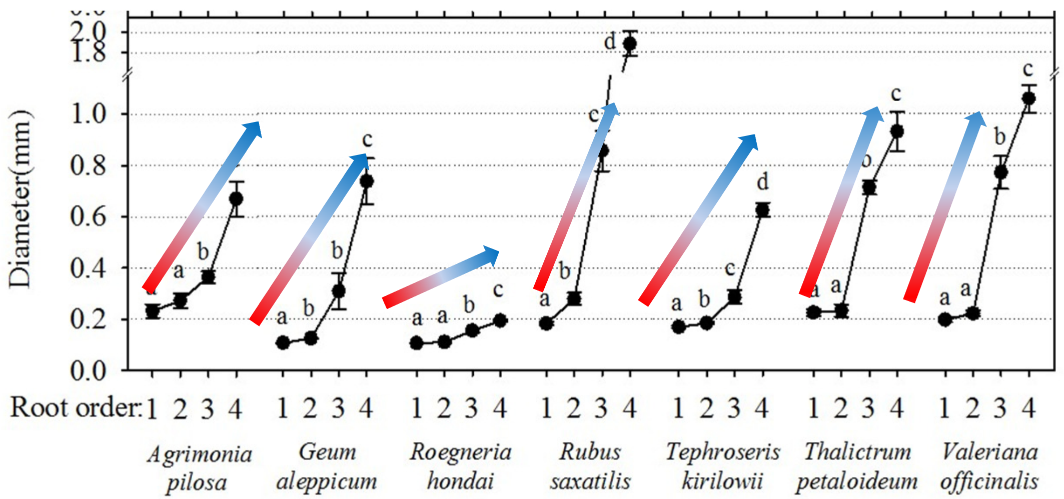


Plant, Cell & Environment

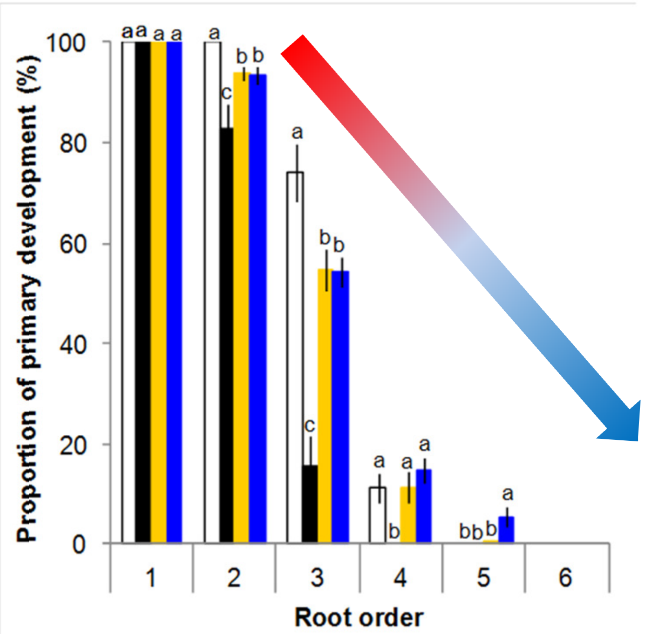
Plant, Cell and Environment (2011) 34, 33–42 doi: 10.1111/j.1365-3040.2010.02223.x

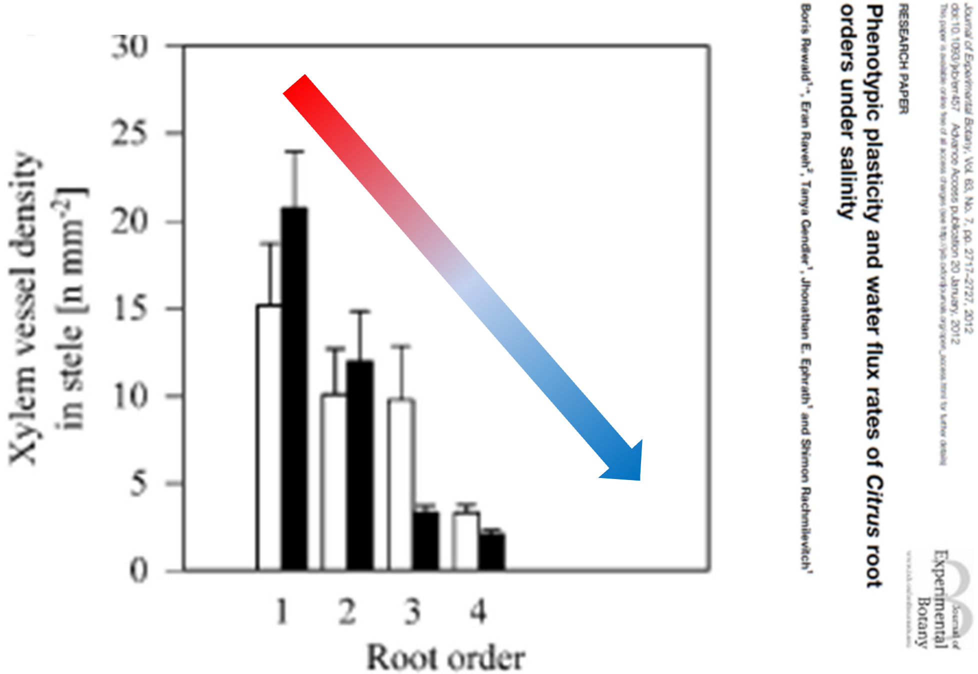
A root is a root is a root? Water uptake rates of *Citrus* root orders

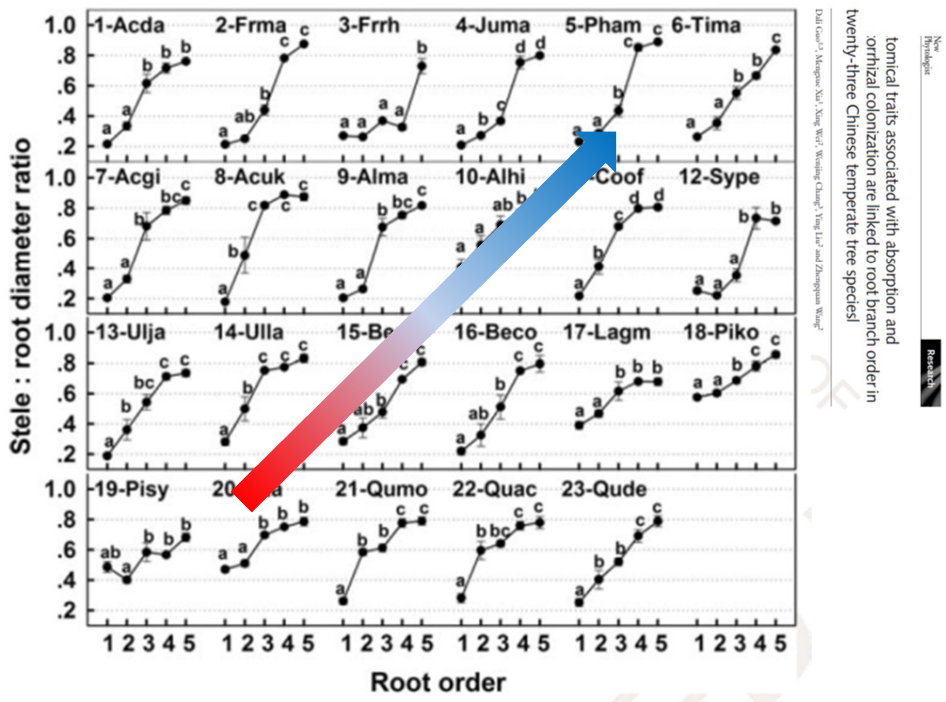
BORIS REWALD, JHONATHAN E. EPHRATH & SHIMON RACHMILEVITCH

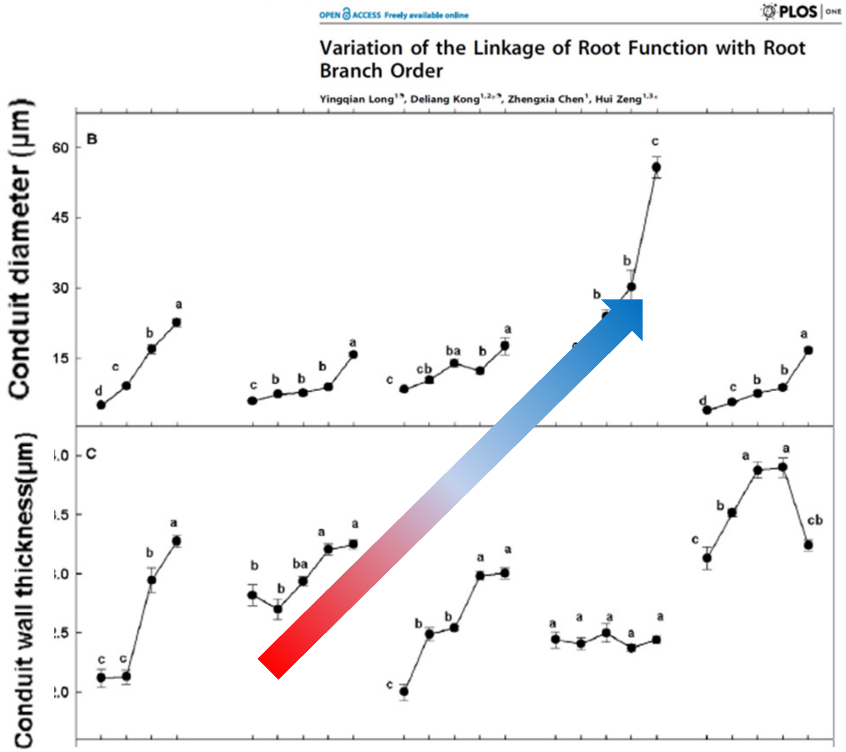


Morphology

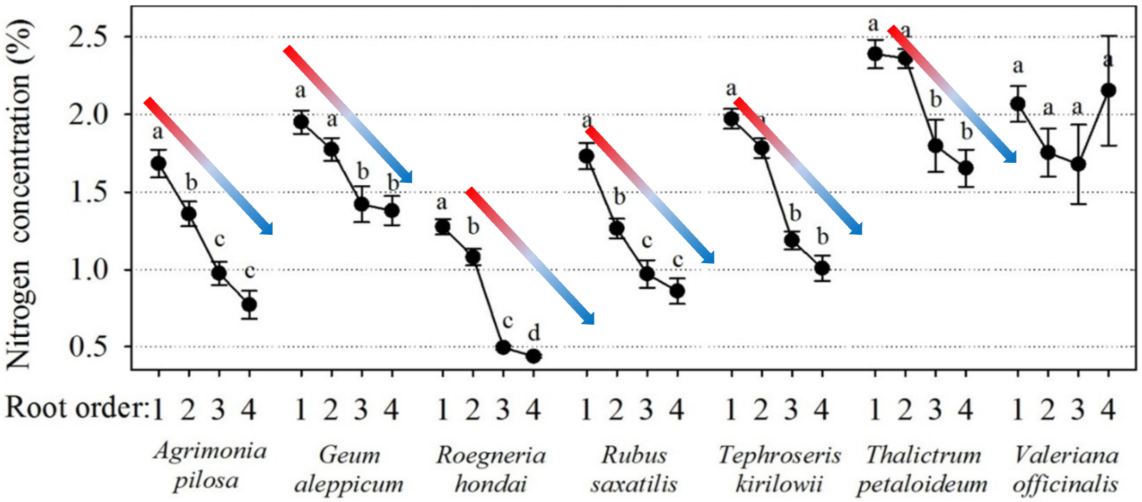








Secondary development and transport function



Plant Soil
DOI 10.1007/s11104-012-1464-4

REGULAR ARTICLE

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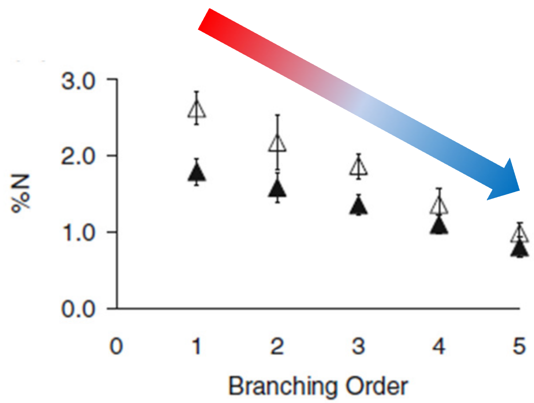
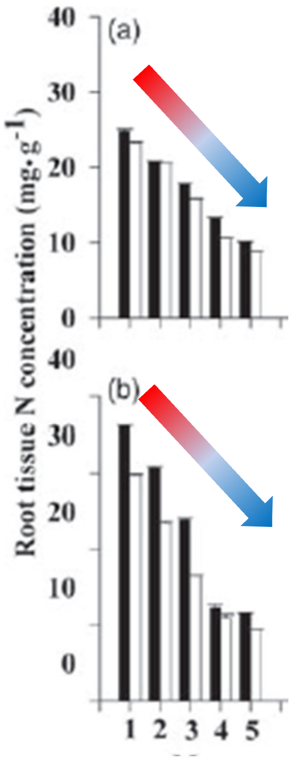
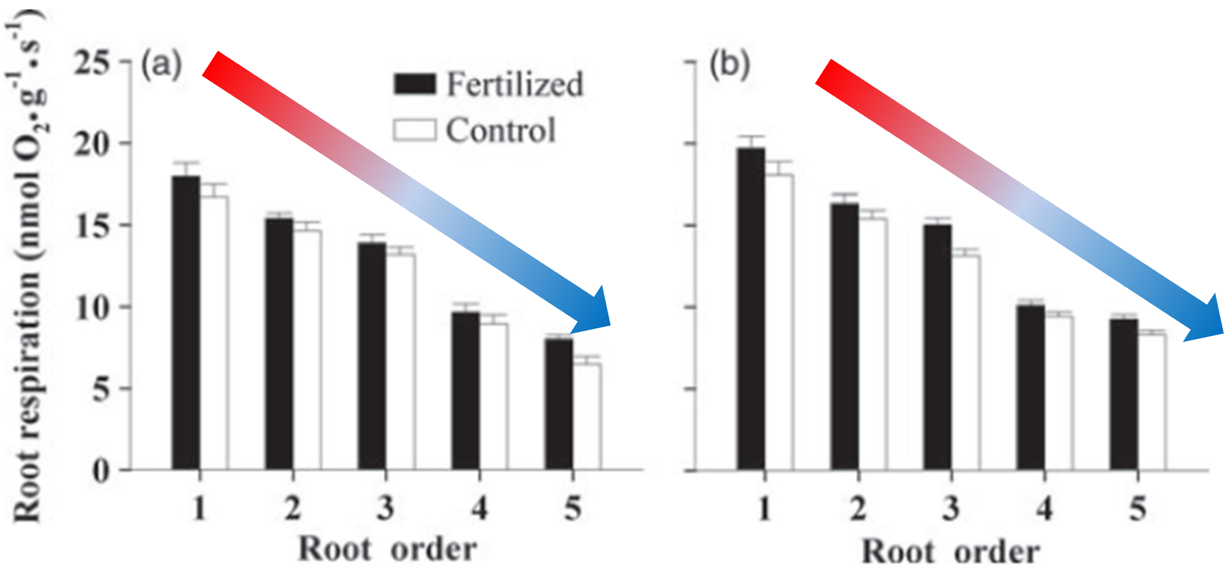
Andrew Ouimette · Dali Guo · Erik Hobbie · Jiacun Gu





N concentration




Tree Physiology 31, 718–726
doi:10.1093/treephys/tpr057

Original Article

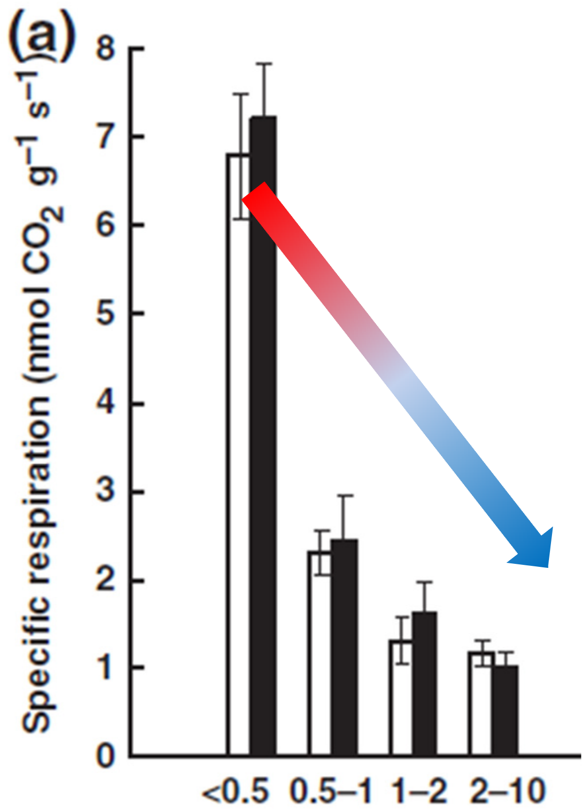
Effect of nitrogen fertilizer, root branch order and temperature on respiration and tissue N concentration of fine roots in *Larix gmelinii* and *Fraxinus mandshurica*

Shuxia Jia[1,2], Zhengquan Wang[2,5], Xingpeng Li[3], Xiaoping Zhang[1] and Neil B. Mclaughlin[4]

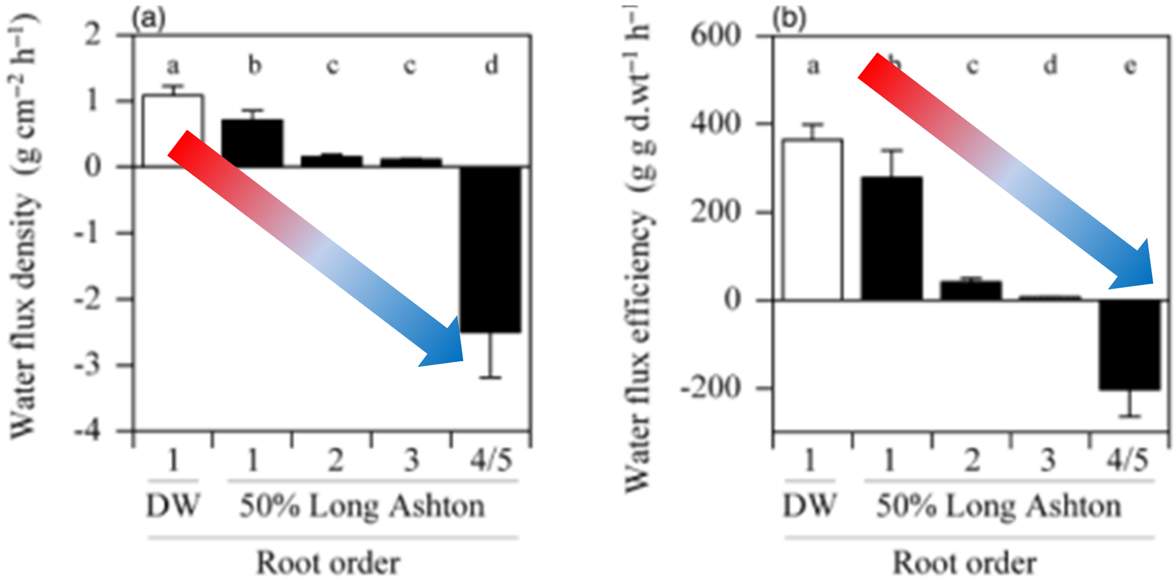
Global Change Biology (2012) 18, 258–266, doi: 10.1111/j.1365-2486.2011.02527.x

Chronic N deposition alters root respiration-tissue N relationship in northern hardwood forests

ANDREW J. BURTON*†, JULIE C. JARVEY*, MICKEY P. JARVI*, DONALD R. ZAK‡§ and KURT S. PREGITZER¶



Root respiration



Plant, Cell & Environment

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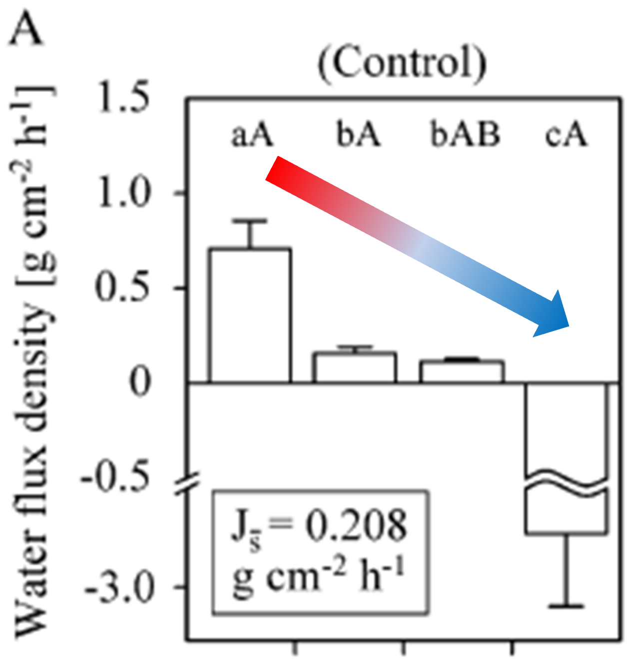


Journal of Experimental Botany, Vol. 63, No. 7, pp. 2717–2727, 2012
doi:10.1093/jxb/err457 Advance Access publication 20 January, 2012
This paper is available online free of all access charges (see http://jxb.oxfordjournals.org/open_access.html for further details)

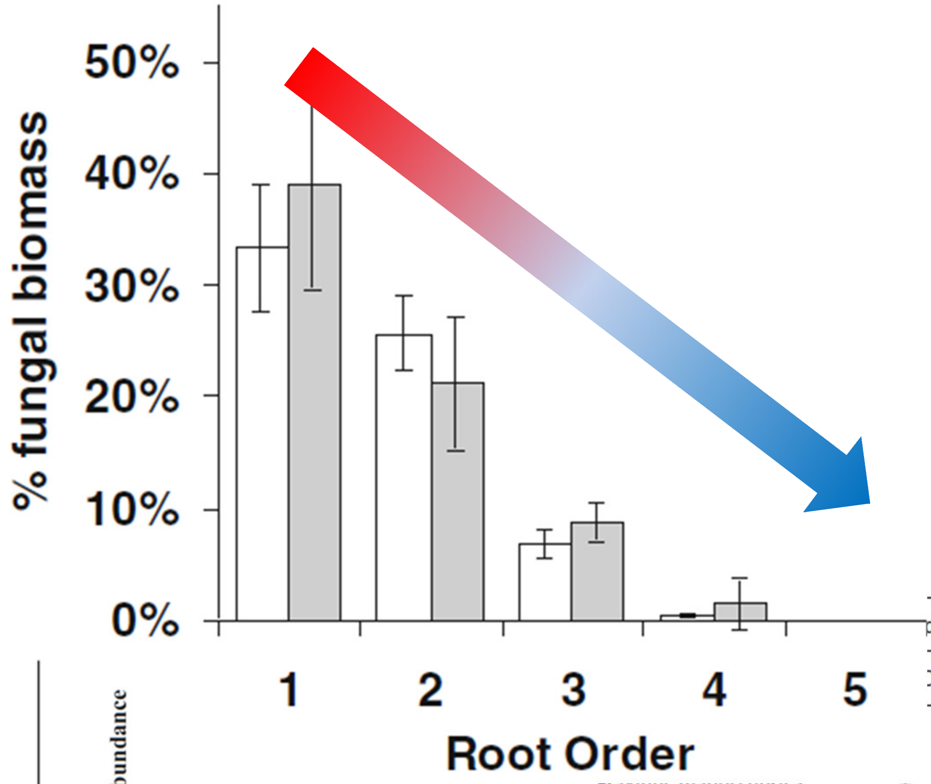
Journal of Experimental Botany
www.jxb.oxfordjournals.org

RESEARCH PAPER

Phenotypic plasticity and water flux rates of *Citrus* root orders under salinity

Boris Rewald[1,*], Eran Raveh[2], Tanya Gendler[1], Jhonathan E. Ephrath[1] and Shimon Rachmilevitch[1]

Uptake Rates



New Phytologist
Research

Anatomical traits associated with absorption and mycorrhizal colonization are linked to root branch order in twenty-three Chinese temperate tree speciesl

Dali Guo[1,3], Mengxue Xia[1], Xing Wei[2], Wenjing Chang[3], Ying Liu[2] and Zhengquan Wang[2]

Plant Soil
DOI 10.1007/s11104-012-1464-4
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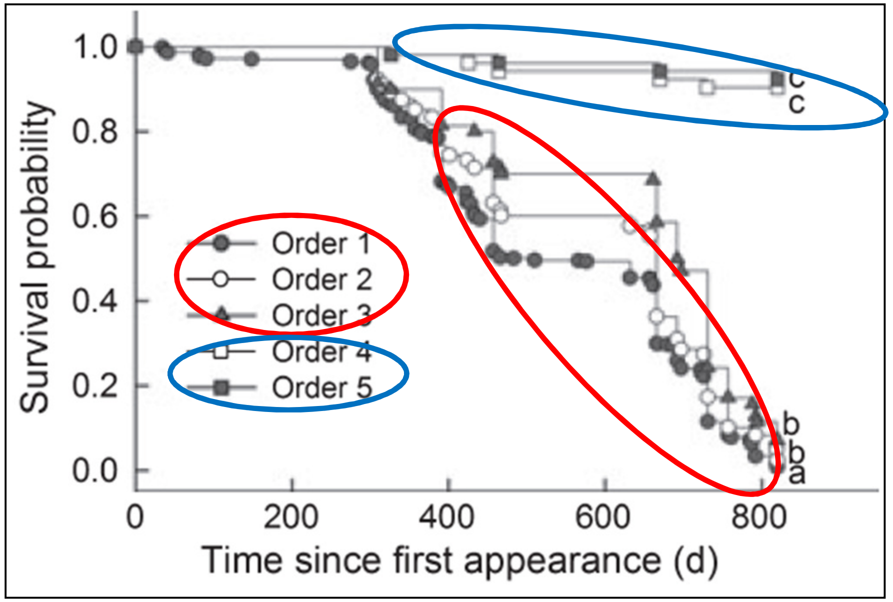
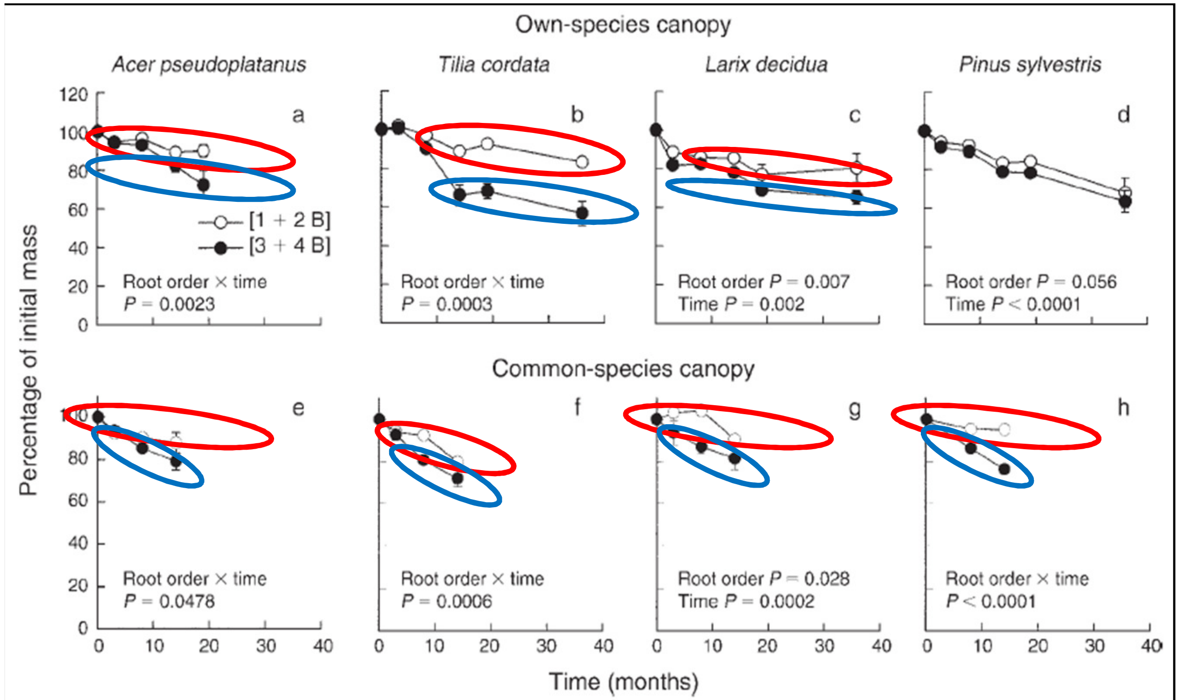
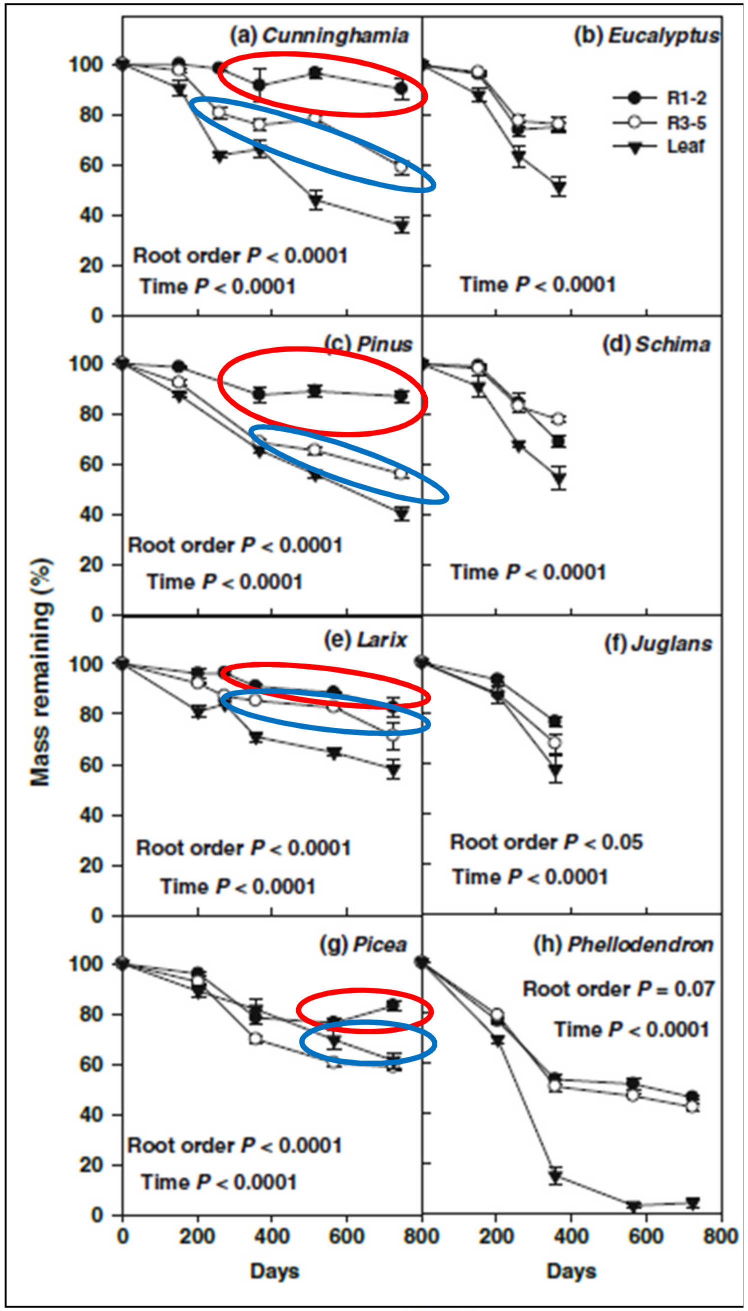
	der 1			Order 2			Order 3			Order 4			Order 5		
	C	SX	CCL	MC	SX	CCL	MC	SX	CCL	MC	SX	CCL	MC	SX	CCL
[illegible]				++++			+	■	○		■	●		■	●
Fraxinus mandschurica	+			++			+	□	○		■	●		■	●
Fraxinus rhynchophylla	++++			++++			++++			++++				■	●
Juglans Mandshurica	+			+			+	□			■	●		■	●
Phellodendron amurense	+++			++++			+++	□	○		■	●		■	●
Tilia mandshurica	++++			[illegible]				■	●		■	●		■	●
AM and EM															
Acer ginnala	++++			[illegible]			+	□	○		■	●		■	●
Acer ukurunduense	++++			+	[illegible]			■	●		■	●		■	●
Alnus mandshurica	++++			++++			+	□	○		■	●		■	●
Alnus hirsuta	+++	□	○	+	□	○	[illegible]	□	○		■	●		■	●
Cornus officinalis	++++			++	□	○	[illegible]	■	●		■	●		■	●
Ulmus laciniata	++++			+	□	○	[illegible]	[illegible]	●		■	●		■	●
Ulmus japonica	++++			+++	□	○	+	[illegible]	[illegible]		■	●		■	●
Syringa pekinensis	+++			++++			++	□			■	●		■	●
EM															
Betula costata	++++			+++	□	○	+	□	○		■	●		■	●
Betula platyphylla	++++			++	□	○	++	■	○		[illegible]	●		■	●
Larix gmelinii	++++			++++			+	□	○		[illegible]	[illegible]		■	●
Pinus koraiensis	++++			++++			++++				■	[illegible]		■	●
Pinus sylvestris var. mongolica	++++			++++			++	□	○		■	●		■	●
Pinus tabulaeformis	++++			++++			+++	□	○		■	●		■	●
Quercus acutissima	+++			++	□	○	+	□	○		■	●		■	●
Quercus dentata	++++			++++			+++	□	○		■	●		■	●
Quercus mongolica	++++			+++				■	●		■	●		■	●

Mycorrhizal colonization



Ephemeral root modules in *Fraxinus mandshurica*





Decomposition of the finest root branching orders: linking belowground dynamics to fine-root function and structure

Slow decomposition and limited nitrogen release by lower order roots in eight Chinese temperate and subtropical trees

Yanmei Xiong · Pingping Fan · Shenglei Fu · Hui Zeng · Dali Guo

Lifespan and decomposition

New Phytologist
Research

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Mengxue Xia[1], Dali Guo[1,2] and Kurt S. Pregitzer[3]

Ecological Monographs, 81(1), 2011, pp. 89–102

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Plant Soil (2013) 363:19–31
DOI 10.1007/s11104-012-1290-8

REGULAR ARTICLE

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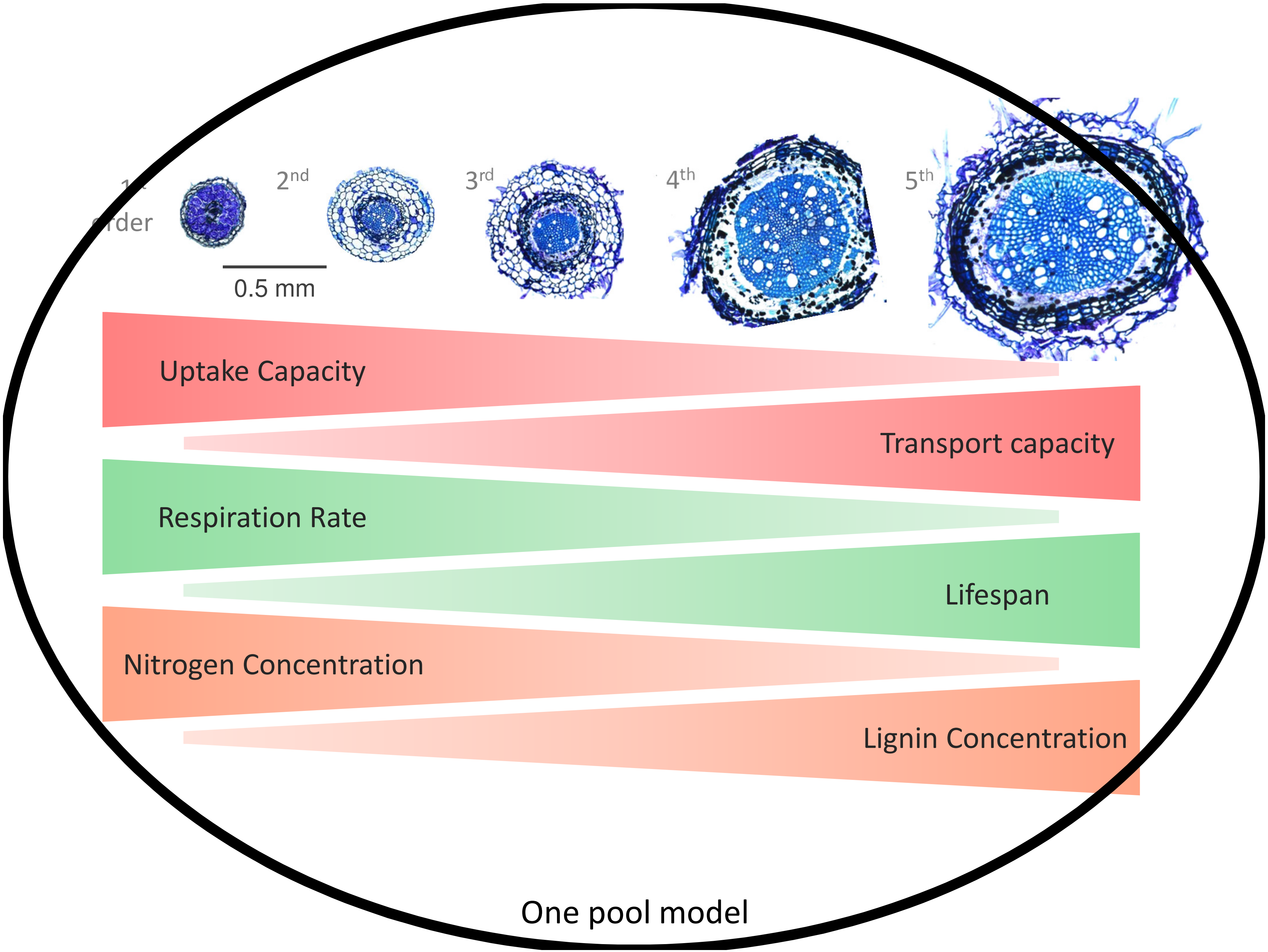
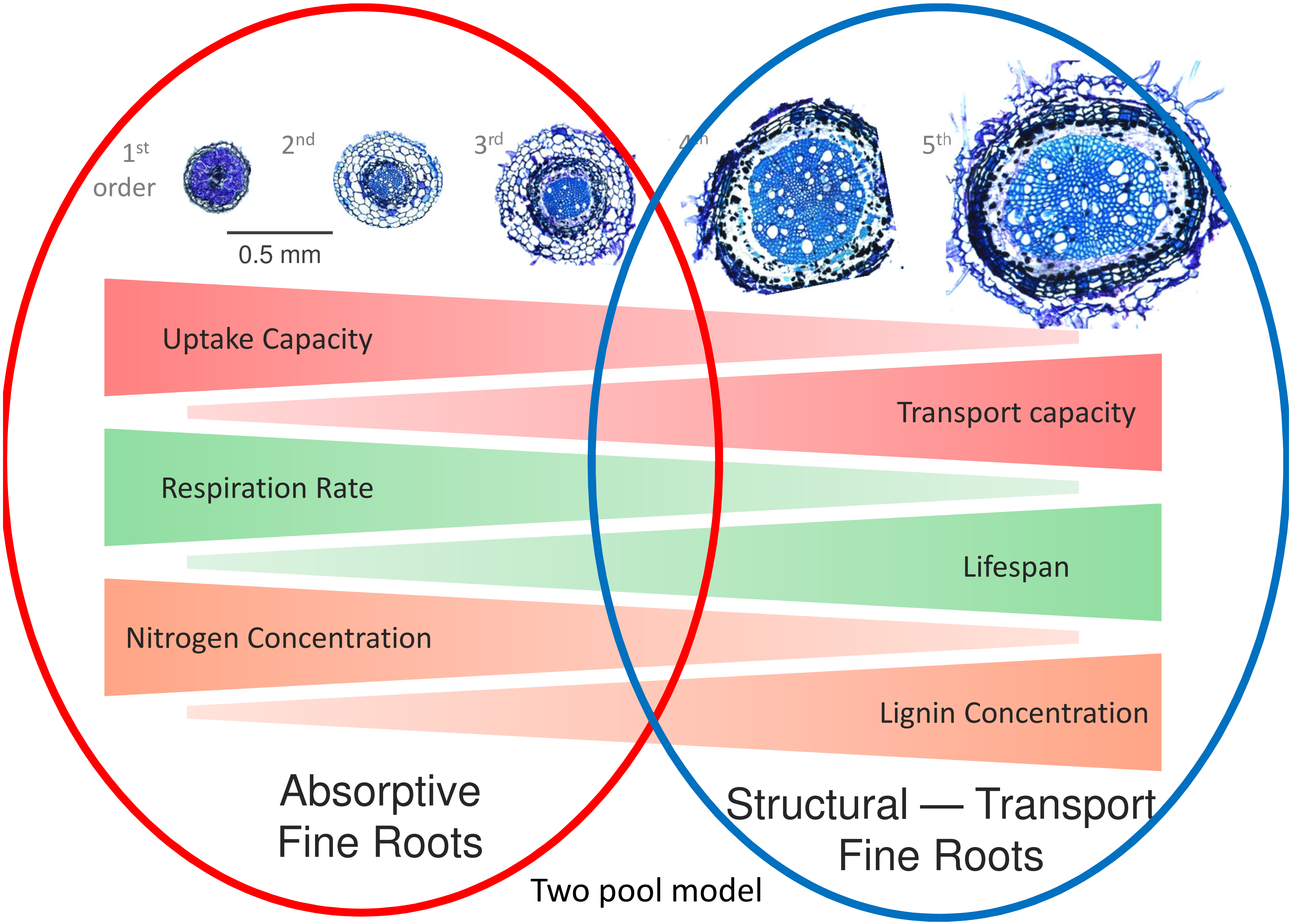
Lifespan and decomposition

Can we update models to better reflect diversity in fine root form and function?

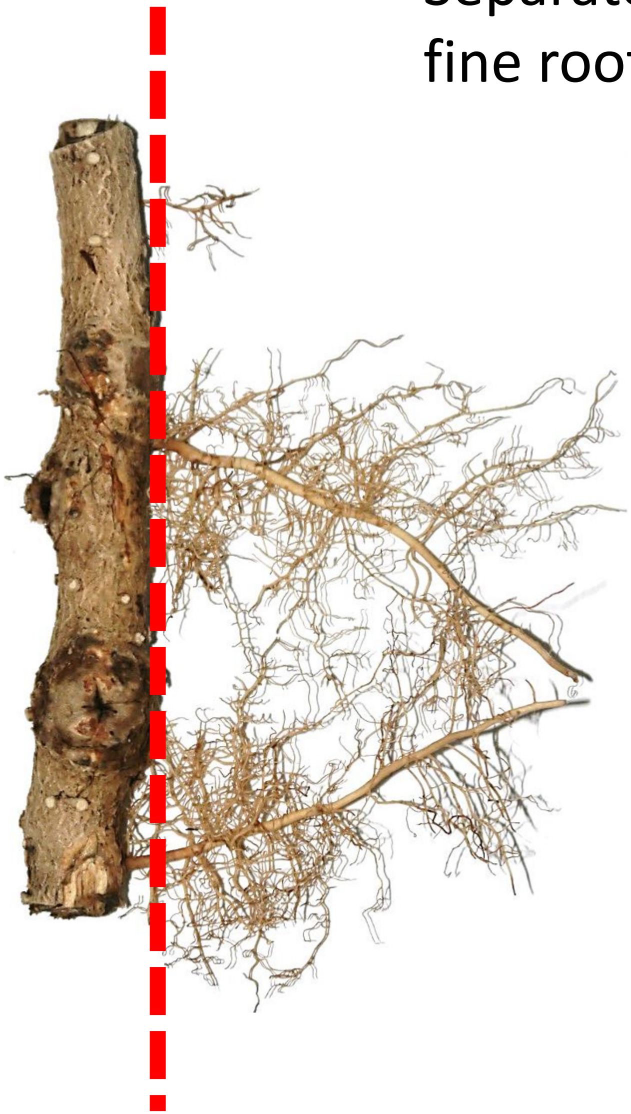


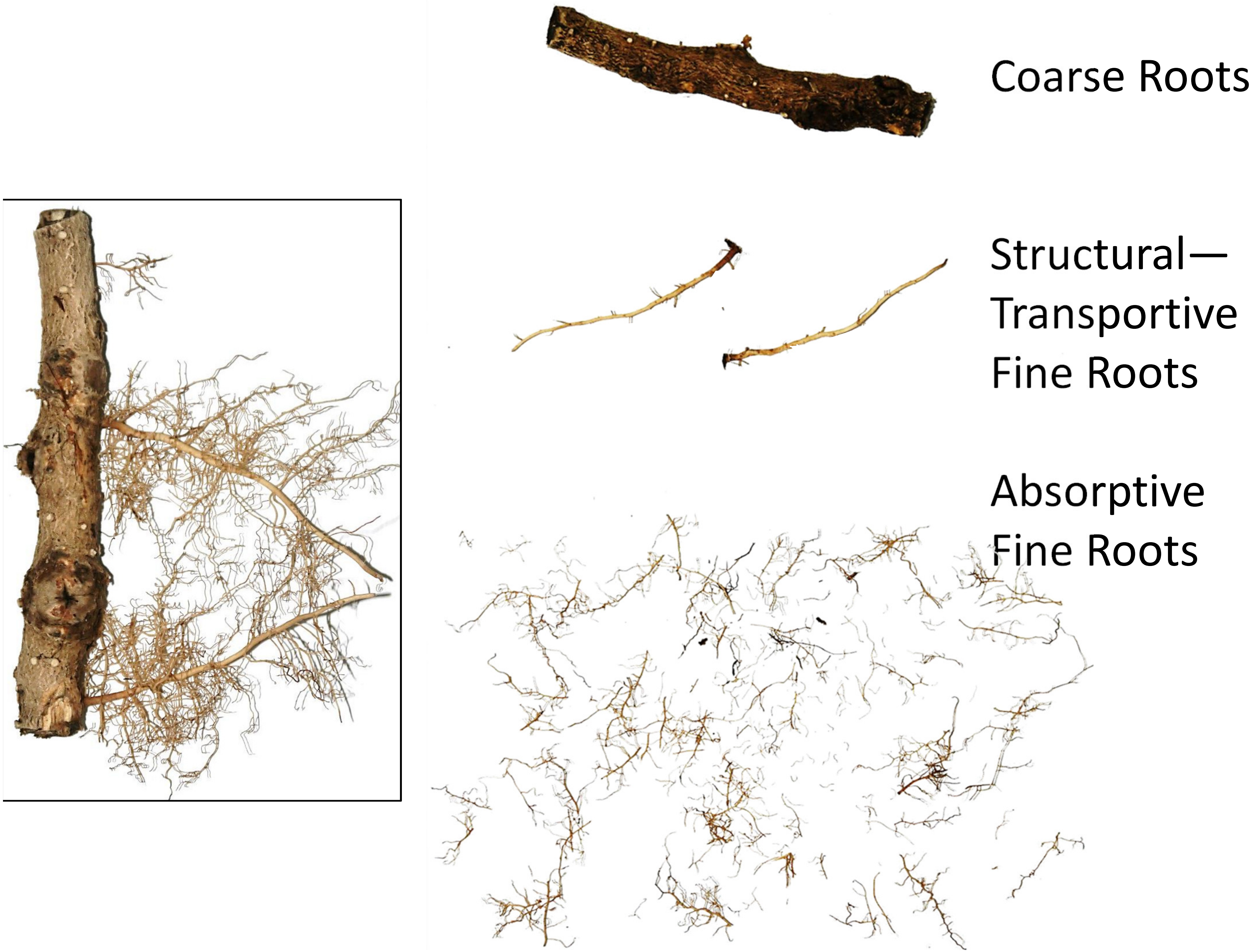
2nd
3rd
4th
5th
0.5 mm
Uptake Capacity
Transport capacity
Respiration Rate
Lifespan
Nitrogen Concentration
Lignin Concentration
One pool model

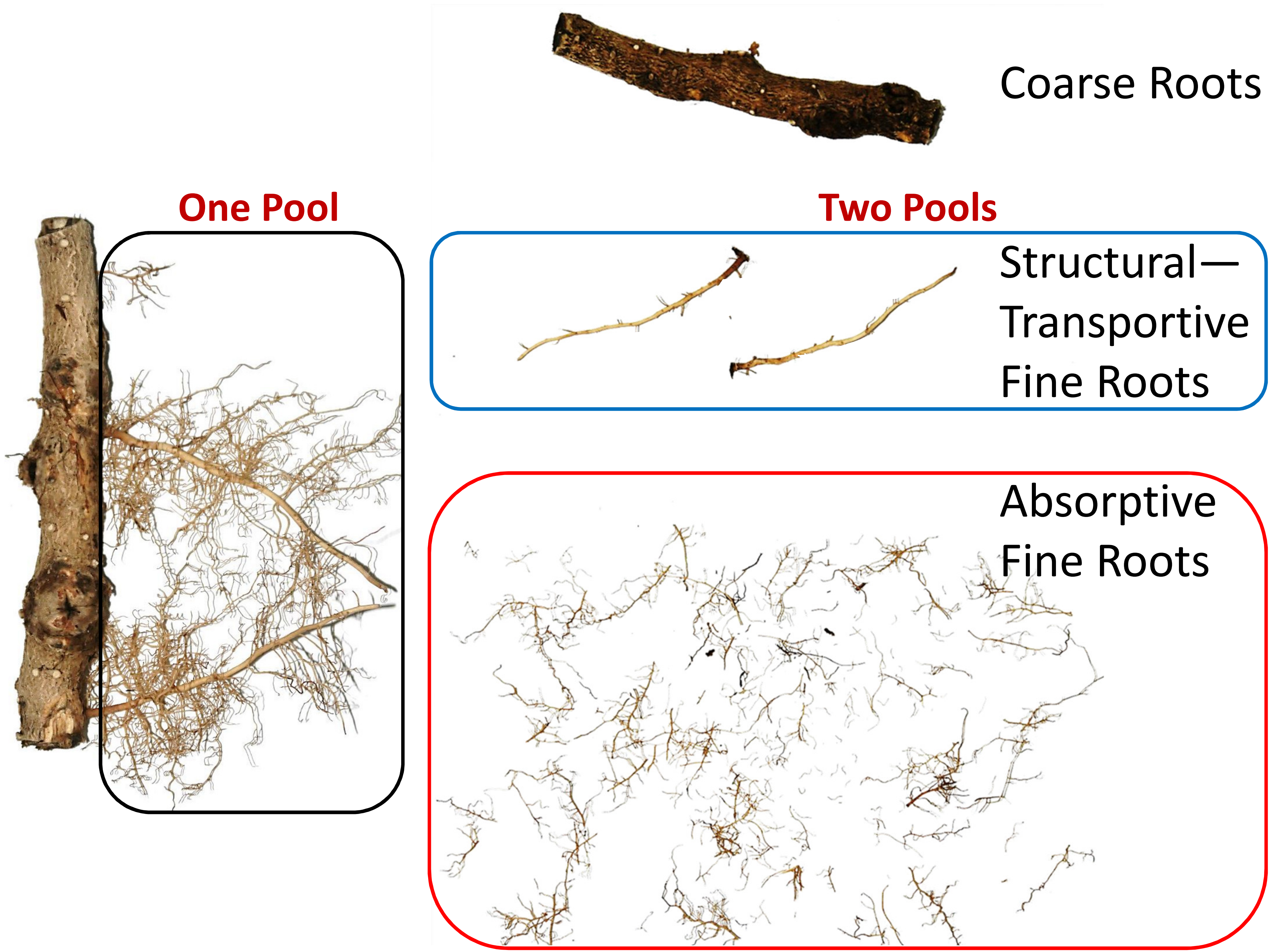


Two pool model

Separate roots into functional classes of *absorptive* fine roots vs. *structural—transportive* fine roots




Coarse Roots
Structural—
Transportive
Fine Roots
Absorptive
Fine Roots


Coarse Roots
One Pool
Two Pools
Structural—
Transportive
Fine Roots
Absorptive
Fine Roots

Does changing from a one-pool model of fine roots to a two-pool model of fine roots matter?

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Case Study: Compare global allocation estimates of NPP to fine root production based on one- vs. two-pool approach.

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Case Study: Compare global allocation estimates of NPP to fine root production based on one- vs. two-pool approach.

1. Standing fine root biomass
2. Turnover rates for each fine root pool
3. Partitioning among fine root pools

1. Global estimates of fine root biomass from Jackson et al. 1997

Biome	Land area (10^6 km^2)	Total fine root biomass (10^9 Mg)
Tropical rainforest	17.0	9.7
Tropical seasonal forest	7.5	4.3
Temperate evergreen forest	5.0	4.1
Temperate deciduous forest	7.0	5.6
Boreal forest	12.0	7.2
Woodland and shrubland	8.5	4.4
Savanna	15.0	14.9
Temperate grassland	9.0	13.6
Tundra/alpine	8.0	7.7
Desert	18.0	4.9
Cultivated	14.0	2.1
Totals	121	78.2

Jackson, Mooney, and Schulze, *PNAS* 94: 7362-7366, 1997.

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33%

Jackson, Mooney, and Schulze, *PNAS* 94: 7362-7366, 1997.

2. Root turnover rates

- *Absorptive* fine roots: used a standard turnover rate based on direct observations

  1.0 yr^{-1}

- *Structural* fine roots: two scenarios based on studies using isotopic methods to estimate longevity

  0.1 yr^{-1}

3. Biomass partitioning among absorptive and structural fine roots

- Based on studies reporting fine root biomass of individual root orders for all orders up to 1 or 2 mm
- Included 20 different species/sites from different plant functional types (trees, shrubs, forbs, and grasses

3. Biomass partitioning among absorptive and structural fine roots

Biome	**Proportion Absorptive / Structural Fine Roots** *-Scenario 2-* *Average*
Woody Dominated Biomes	35 / 65
Herbaceous Dominated Biomes	81 / 19
Cultivated Lands	100 / 0

3. Biomass partitioning among absorptive and structural fine roots

Biome	**Proportion Absorptive / Structural Fine Roots** *-Scenario 1-* *Minimum Absorptive*	*-Scenario 2-* *Average*	*-Scenario 3-* *Maximum Absorptive*
Woody Dominated Biomes	10 / 90	35 / 65	75 / 25
Herbaceous Dominated Biomes	50 / 50	81 / 19	90 / 10
Cultivated Lands	100 / 0	100 / 0	100 / 0

3. Biomass partitioning among absorptive and structural fine roots

Biome	**Proportion Absorptive / Structural Fine Roots** *-Scenario 1- Minimum Absorptive*	*-Scenario 2- Average*	*-Scenario 3- Maximum Absorptive*
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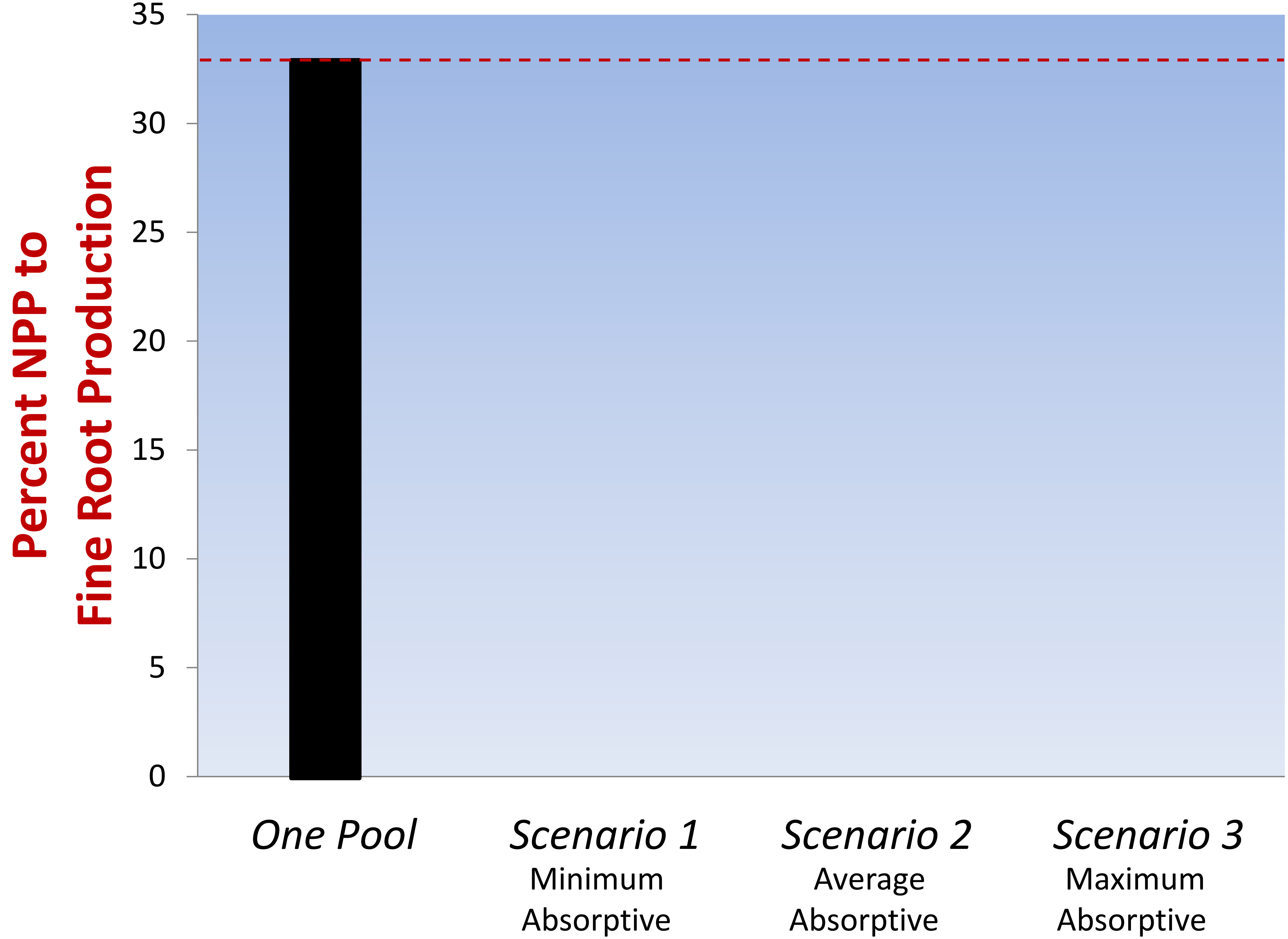
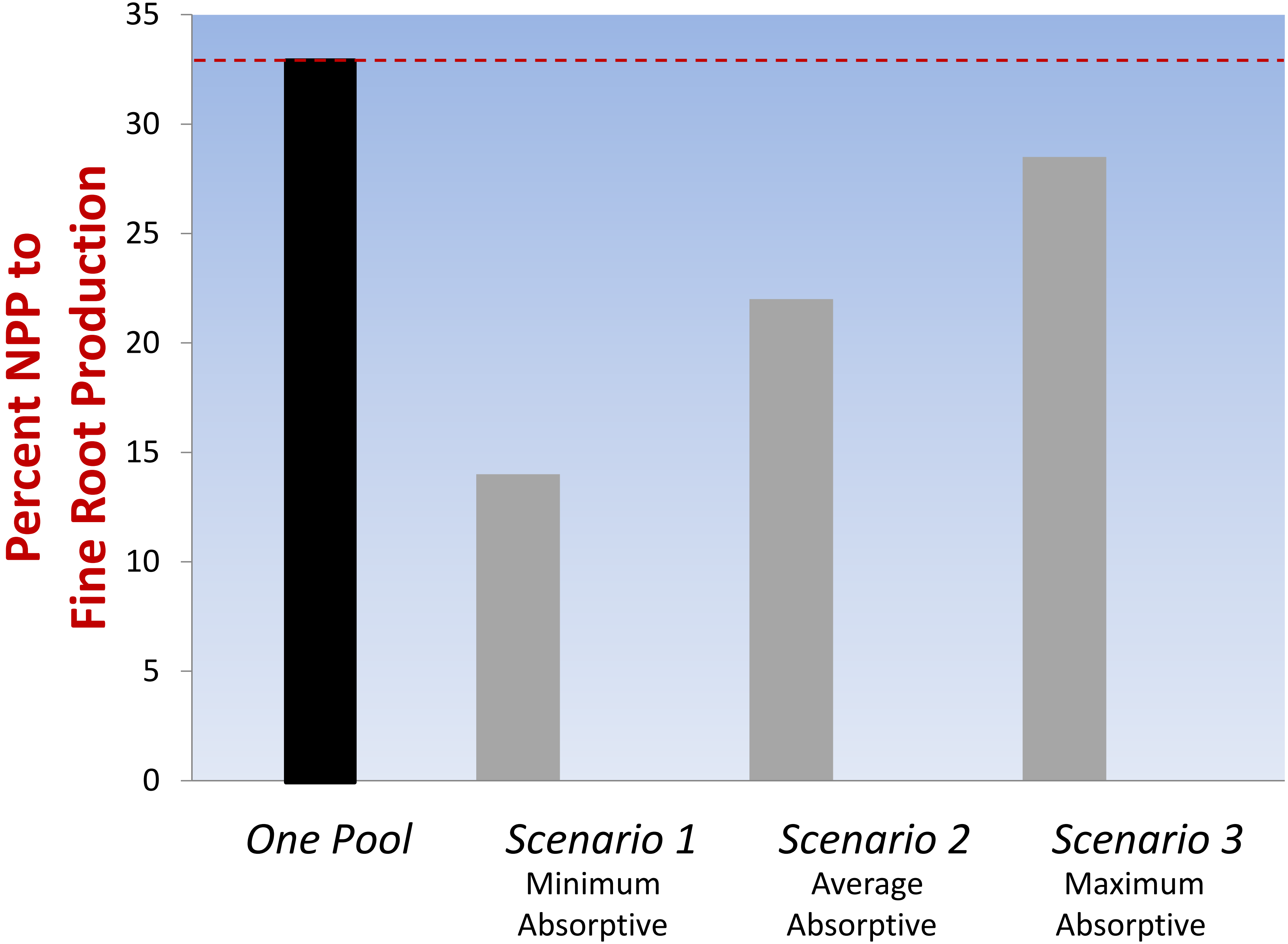
Herbaceous Dominated Biomes	50 / 50	81 / 19	90 / 10
Cultivated Lands	100 / 0	100 / 0	100 / 0

Results



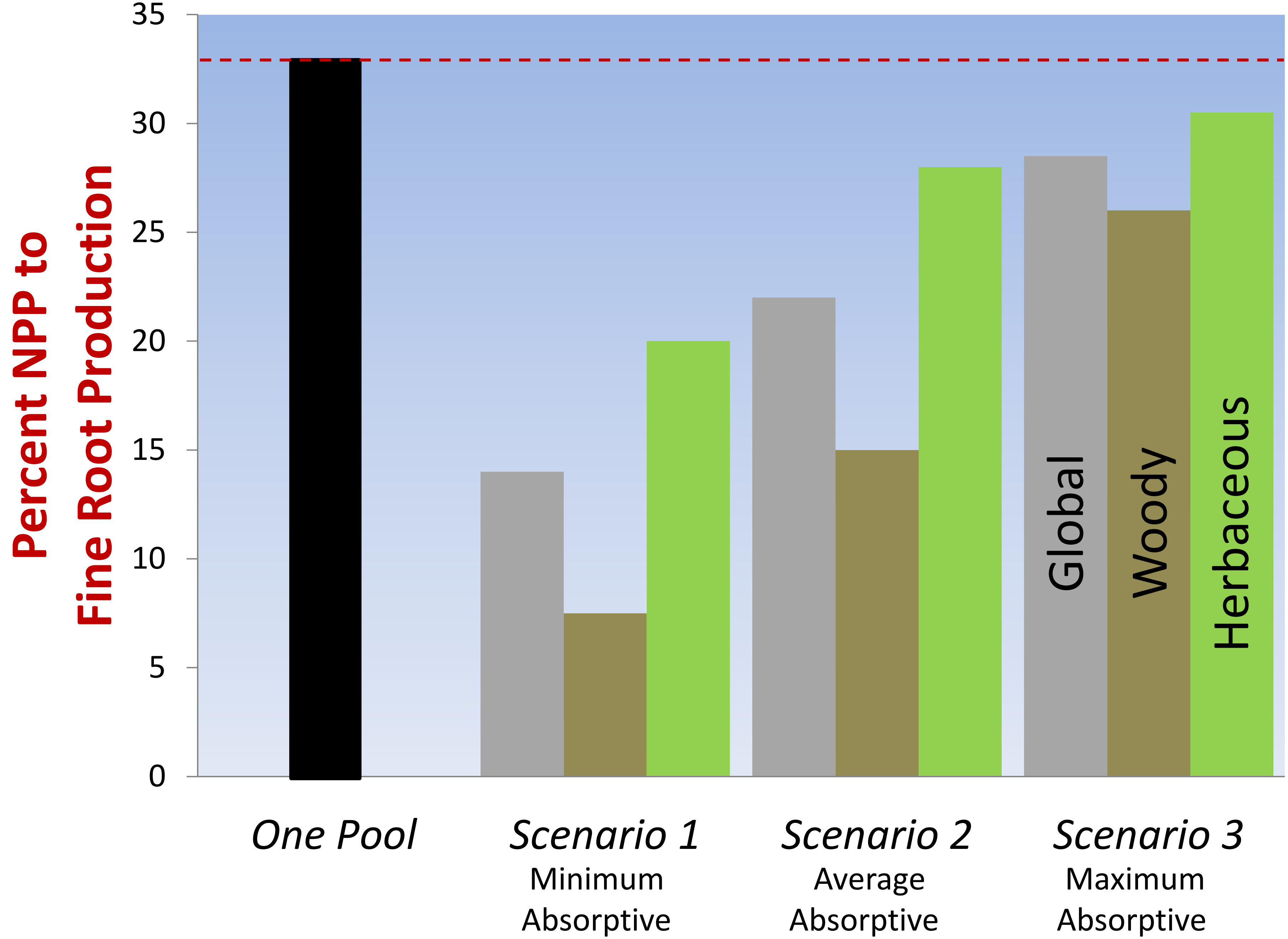
Percent NPP to Fine Root Production
35
30
25
20
15
10
5
0
One Pool
Scenario 1
Minimum Absorptive
Scenario 2
Average Absorptive
Scenario 3
Maximum Absorptive

Results



35
30
25
20
15
10
5
0
Percent NPP to
Fine Root Production
One Pool
Scenario 1
Minimum
Absorptive
Scenario 2
Average
Absorptive
Scenario 3
Maximum
Absorptive

Results



Percent NPP to
Fine Root Production
35
30
25
20
15
10
5
0
Global
Woody
Herbaceous
One Pool
Scenario 1
Minimum
Absorptive
Scenario 2
Average
Absorptive
Scenario 3
Maximum
Absorptive

Results: Summary

- Using 2-pool model substantially reduces estimates of NPP allocation to fine roots

Results: Summary

- Using 2-pool model substantially reduces estimates of NPP allocation to fine roots
- Changes more dramatic in woody biomes than herbaceous biomes
- Where is the rest of NPP going???

Results: Summary

- Using 2-pool model substantially reduces estimates of NPP allocation to fine roots
- Changes more dramatic in woody biomes than herbaceous biomes
- Where is the rest of NPP going???
  - Exudates, mycorrhizal fungi, respiration, etc.

Grand challenge—Summary

Find the processes that can be improved in models to **provide the greatest gains** in model skill yet **remain analytically tractable**.

- **Empirical understanding must be sufficient to parameterize model in a meaningful way** ✓
- **Model results must be understandable in light of the new process descriptions** ✓

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- **Model results must be understandable in light of the new process descriptions**
- **Future work needed to define biomass partitioning across more species and along environmental gradients**

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