
Why do we have the greatest plant diversity on our poorest sandy soils in south-western Australia?
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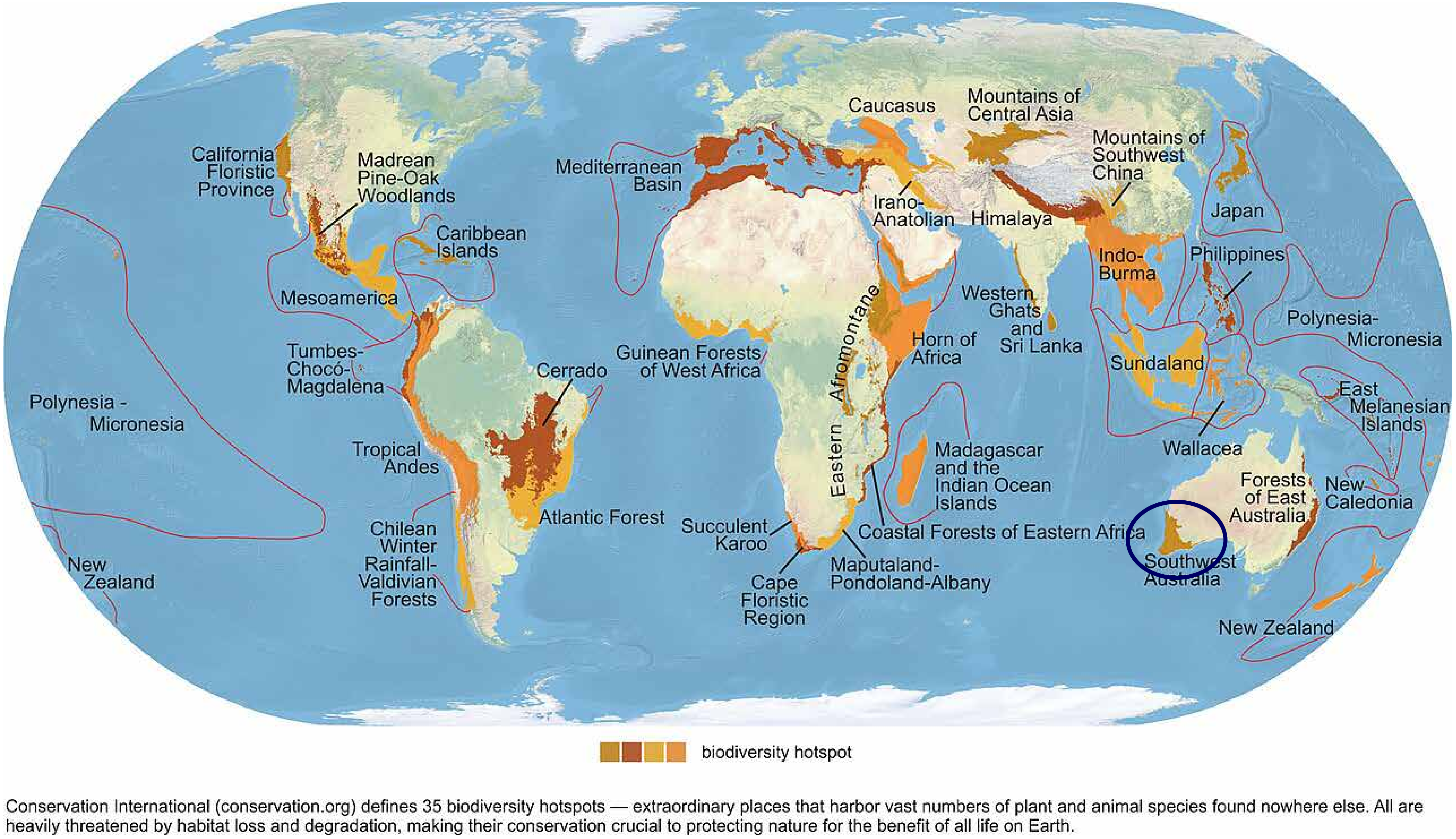
SW Australia is a global biodiversity hotspot: one of only 36 in the world



https://en.wikipedia.org/wiki/Biodiversity_hotspot#/media/File:Biodiversity_Hotspots_Map.jpg

What exactly is a biodiversity hotspot?

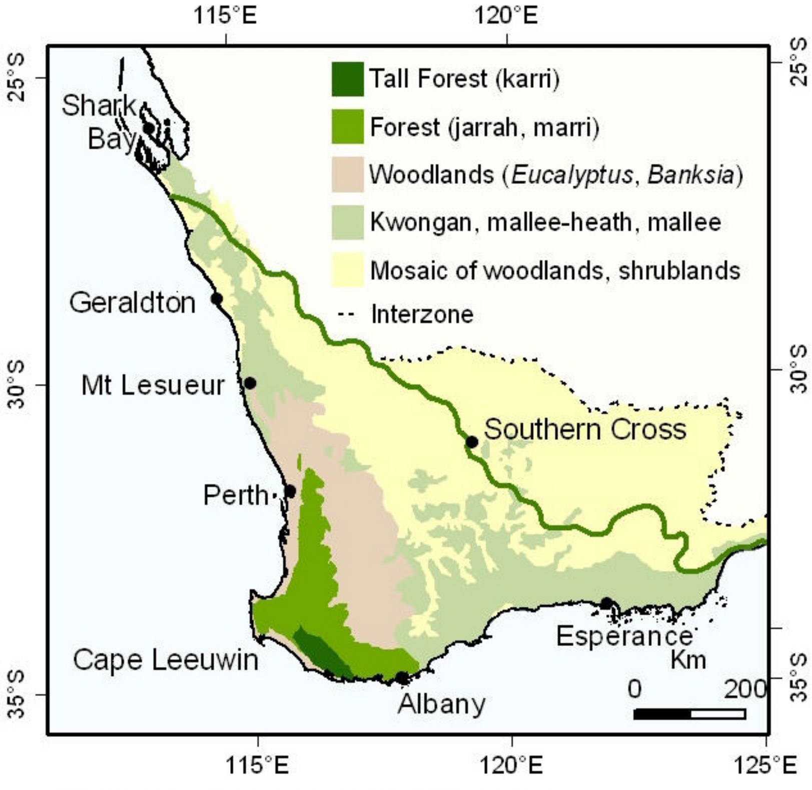
To qualify, an area must:

1. contain at least 1,500 of the world's plant species as endemics 😇

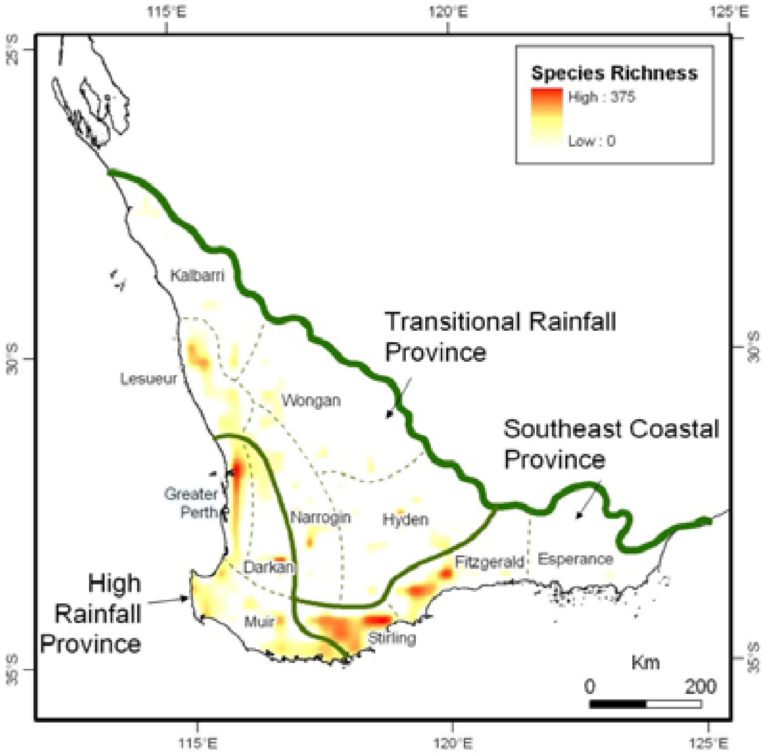
2. have lost 70% or more of its primary vegetation 😠

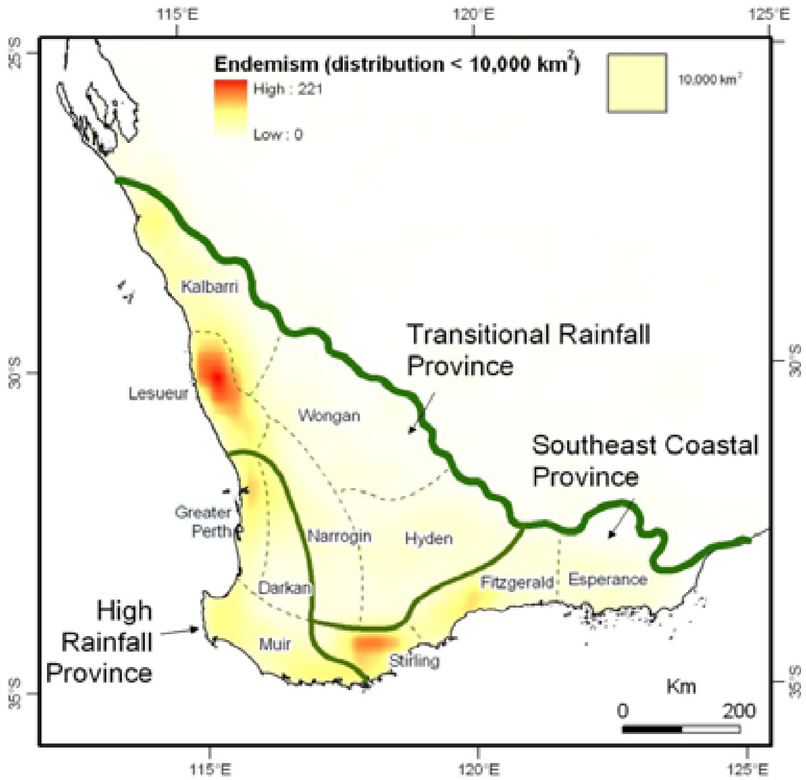
Myers N, Mittermeier RA, Mittermeier CG, Da Fonseca GaB, Kent J. 2000. Biodiversity hotspots for conservation priorities. *Nature* **403:** 853-858.

‘Isoflors’ for biodiversity of the southwest of WA, home for 8,000 plant species (a third of Australia’s flora)



(d) Vegetation mosaic after Beard (1975)





Hopper SD, Gioia P. 2004. The Southwest Australian Floristic Region: evolution and conservation of a global hotspot of biodiversity. *Annu. Rev. Ecol. Evol. Syst.* **35:** 623-650.

Factors determining plant species richness

Mother Nature

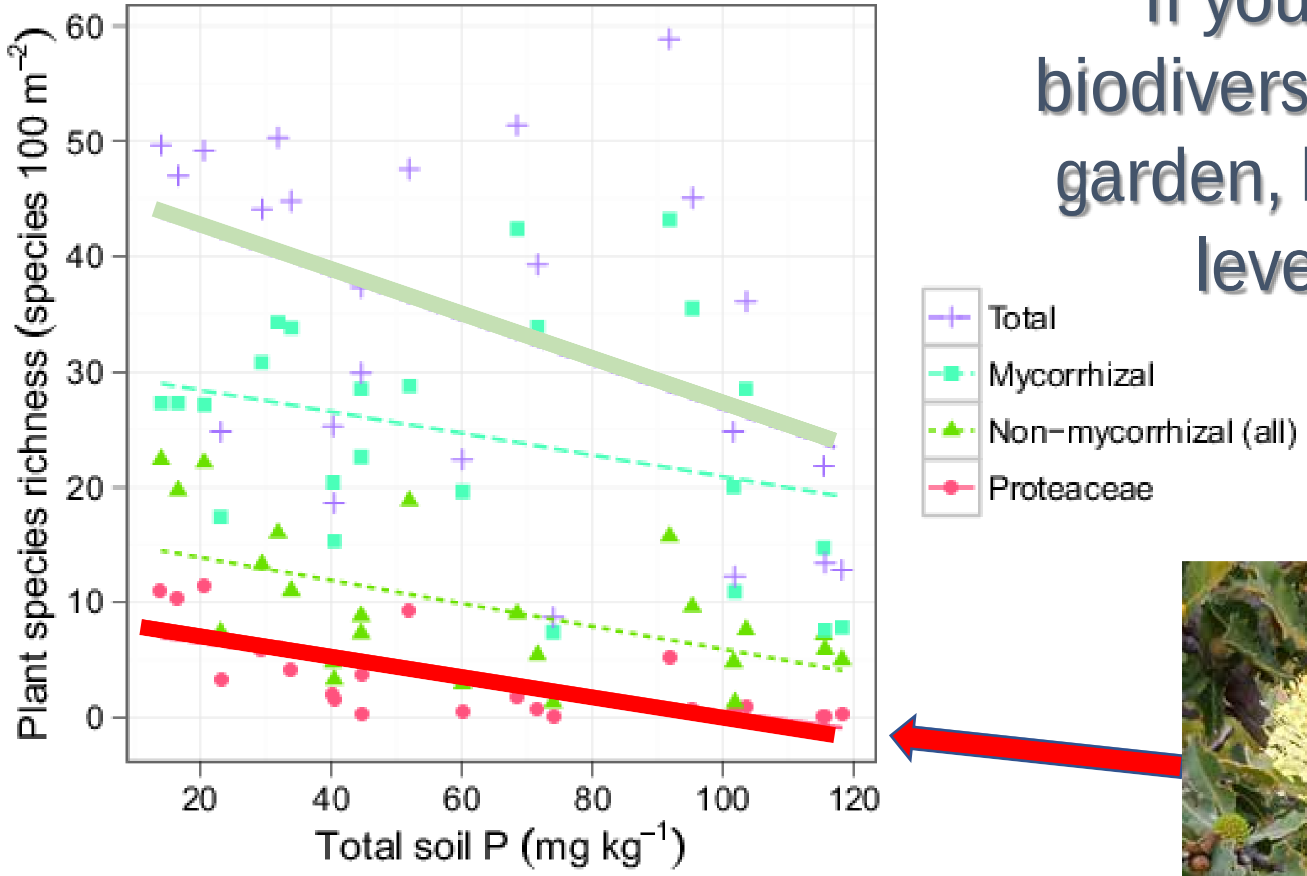
- Geological stability: variation in habitats

- Climatic stability: no mass extinctions

Father Time

- Soil infertility: phosphorus

Pattern: plant species diversity increases with decreasing soil phosphorus (P)



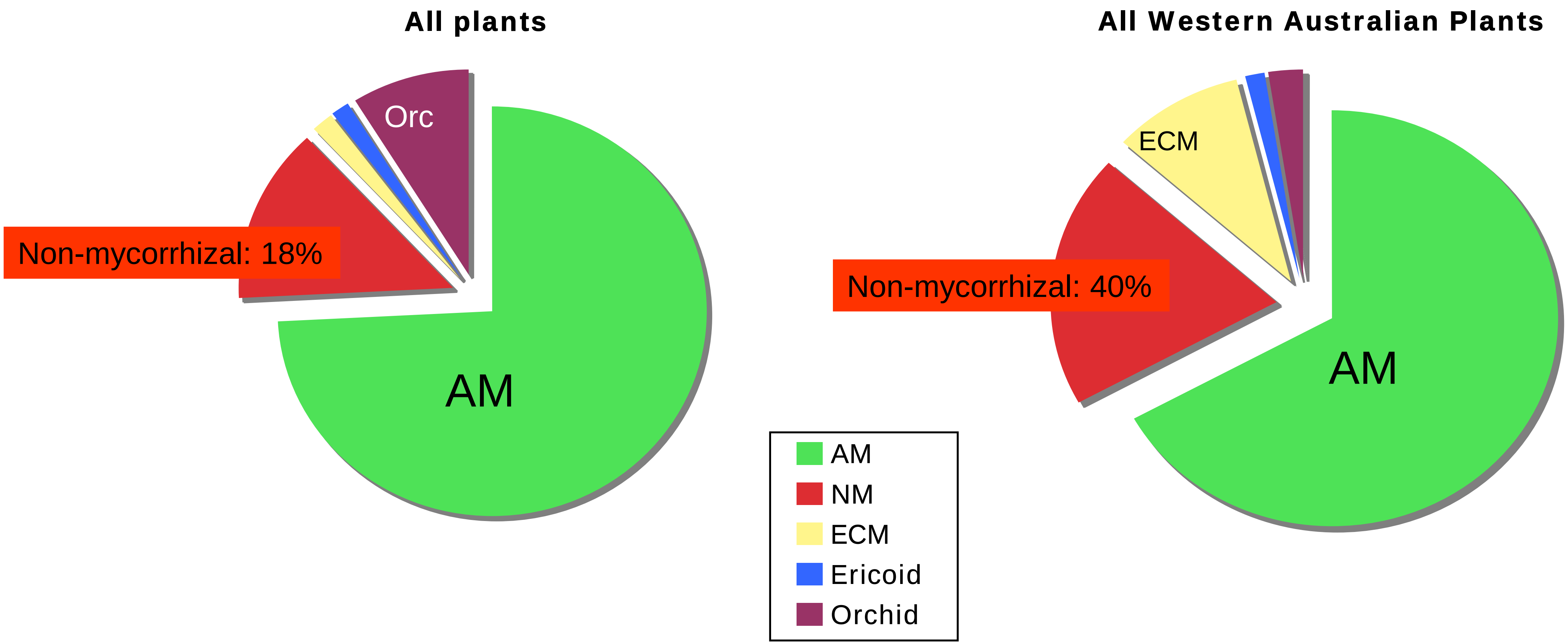
If you want to conserve biodiversity or create it in your garden, keep soil phosphorus levels at a minimum

Lambers H, Shane MW, Laliberté E, Swarts ND, Teste FP, Zemunik G. 2014. Plant mineral nutrition. In Plant Life on the Sandplains in Southwest Australia, a Global Biodiversity Hotspot. Ed. H Lambers. pp 101-127. UWA Publishing, Crawley.

In the rest of the world, plants on nutrient-poor soils tend to live symbiotically with mycorrhizal fungi

- The mycorrhizal fungi acquire phosphorus for the plants, in exchange for sugars and fatty acids
- Mycorrhizas also occur in Western Australia, but this symbiosis is relatively less common

Process: proportions of species with different nutrient-acquisition strategies



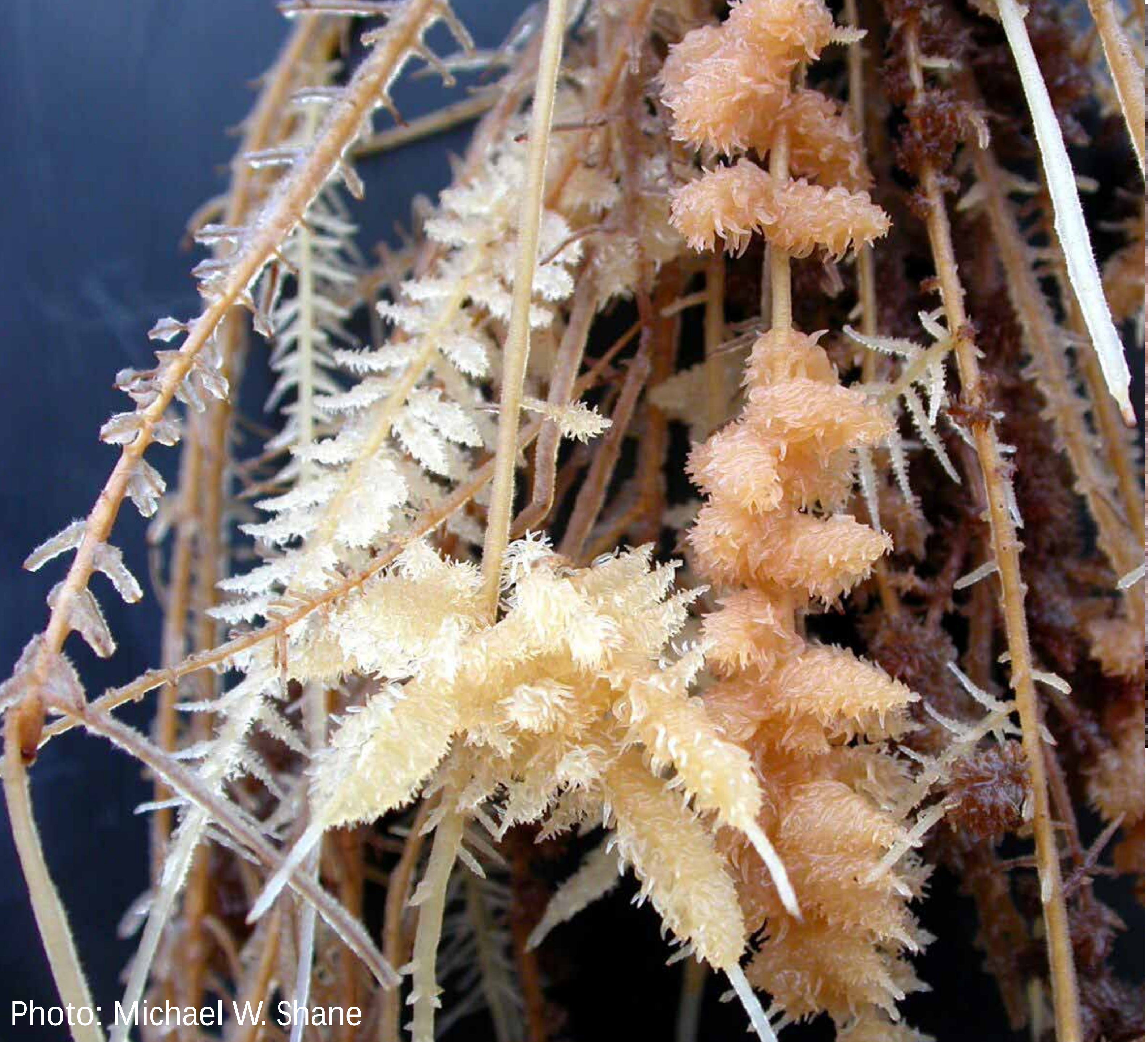
Brundrett MC. 2009. Mycorrhizal associations and other means of nutrition of vascular plants: Understanding the global diversity of host plants by resolving conflicting information and developing reliable means of diagnosis *Plant Soil* **320:** 37-77.

What special features allow the non-mycorrhizal plants in Western Australia to acquire nutrients from very poor soils?

Photo Michael W. Shane

Photo: Marion Cambridge

Many have simple cluster roots, as illustrated here for *Hakea prostrata* (Proteaceae)



Banksia species (Proteaceae) have compound cluster roots

Some Cyperaceae have ‘dauciform’ roots

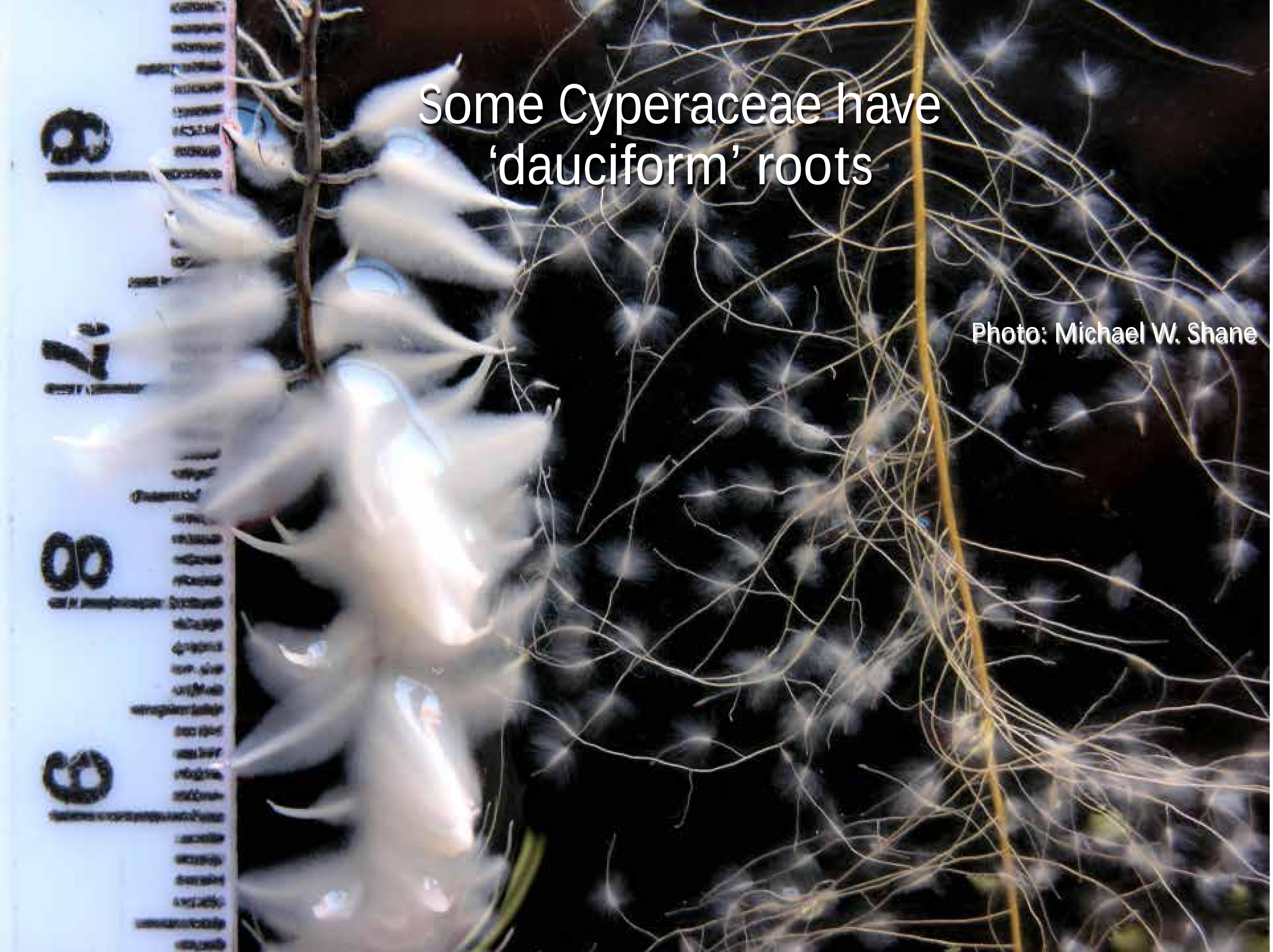
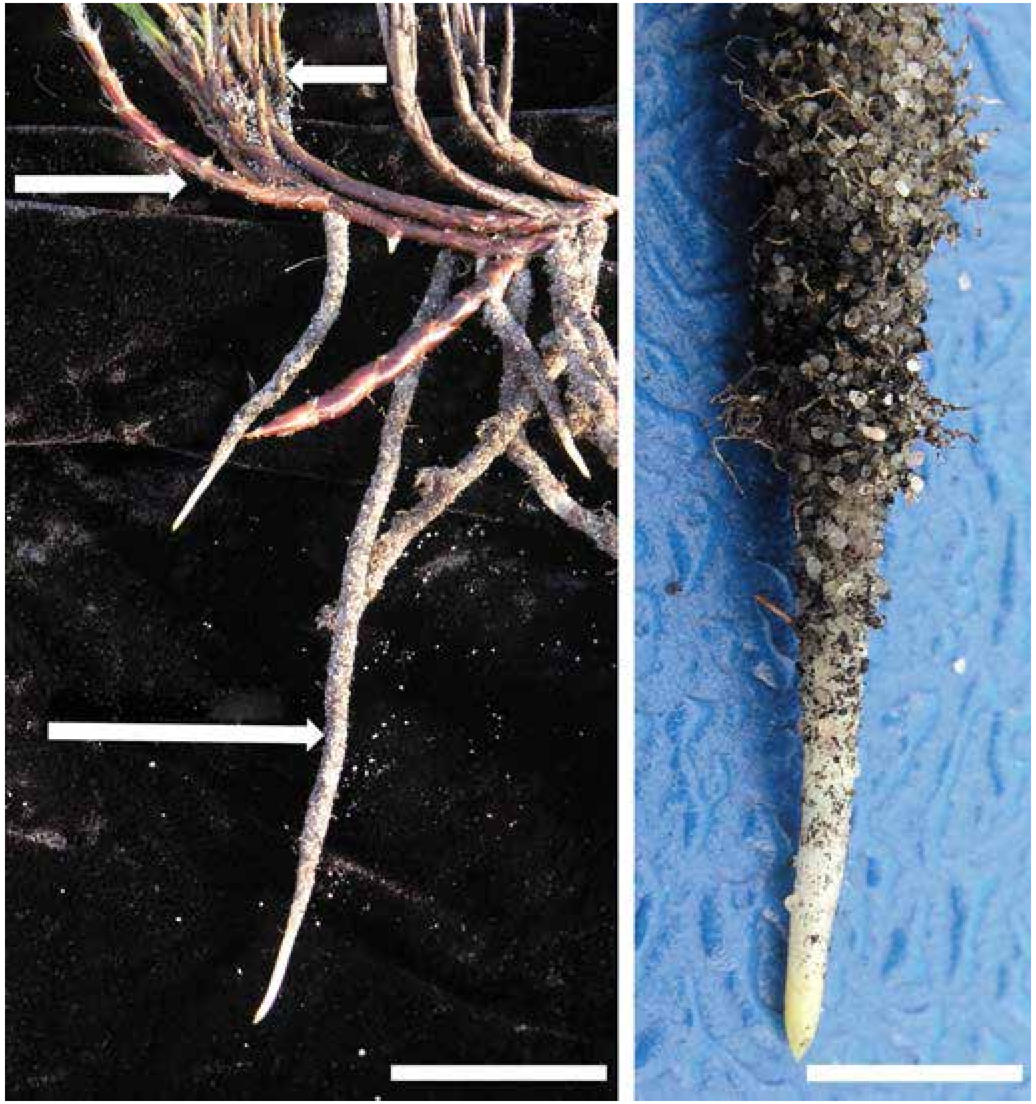


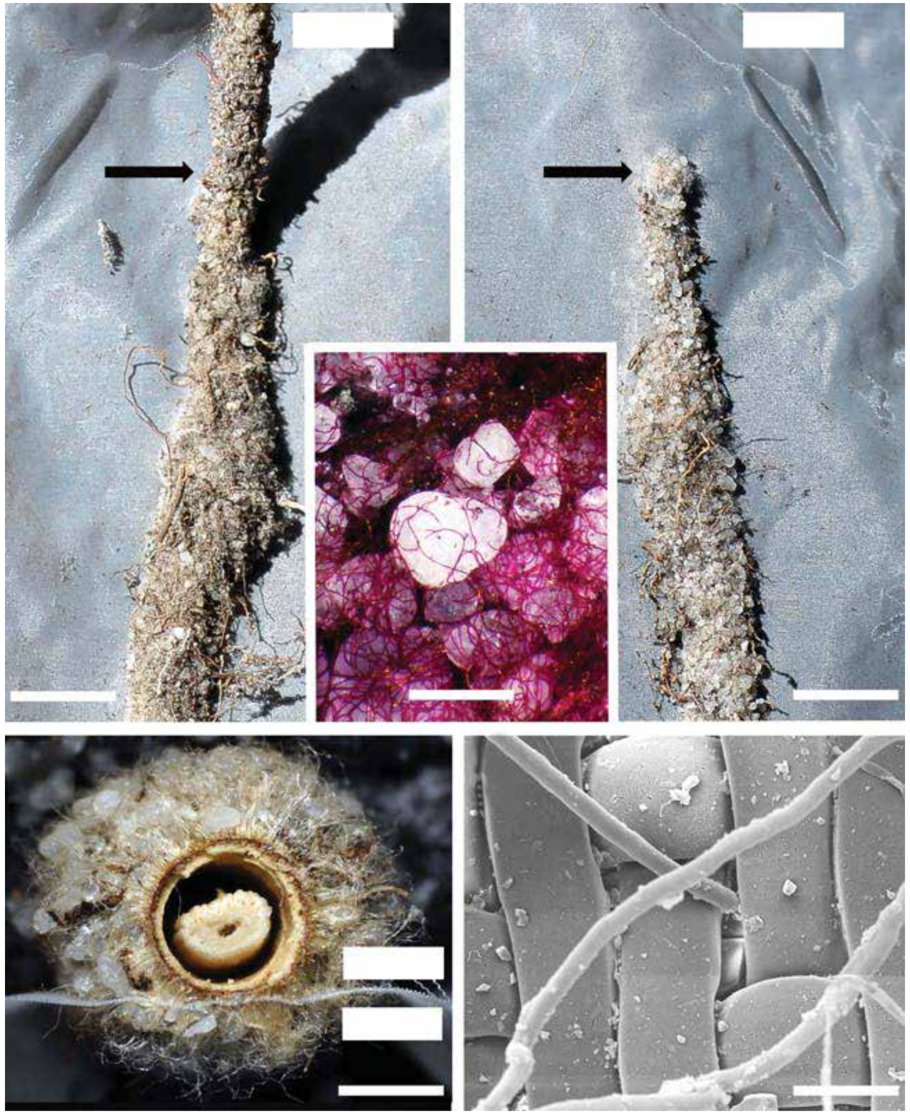
Photo: Michael W. Shane

Some Restionaceae have capillaroid roots

Photos: Michael W. Shane

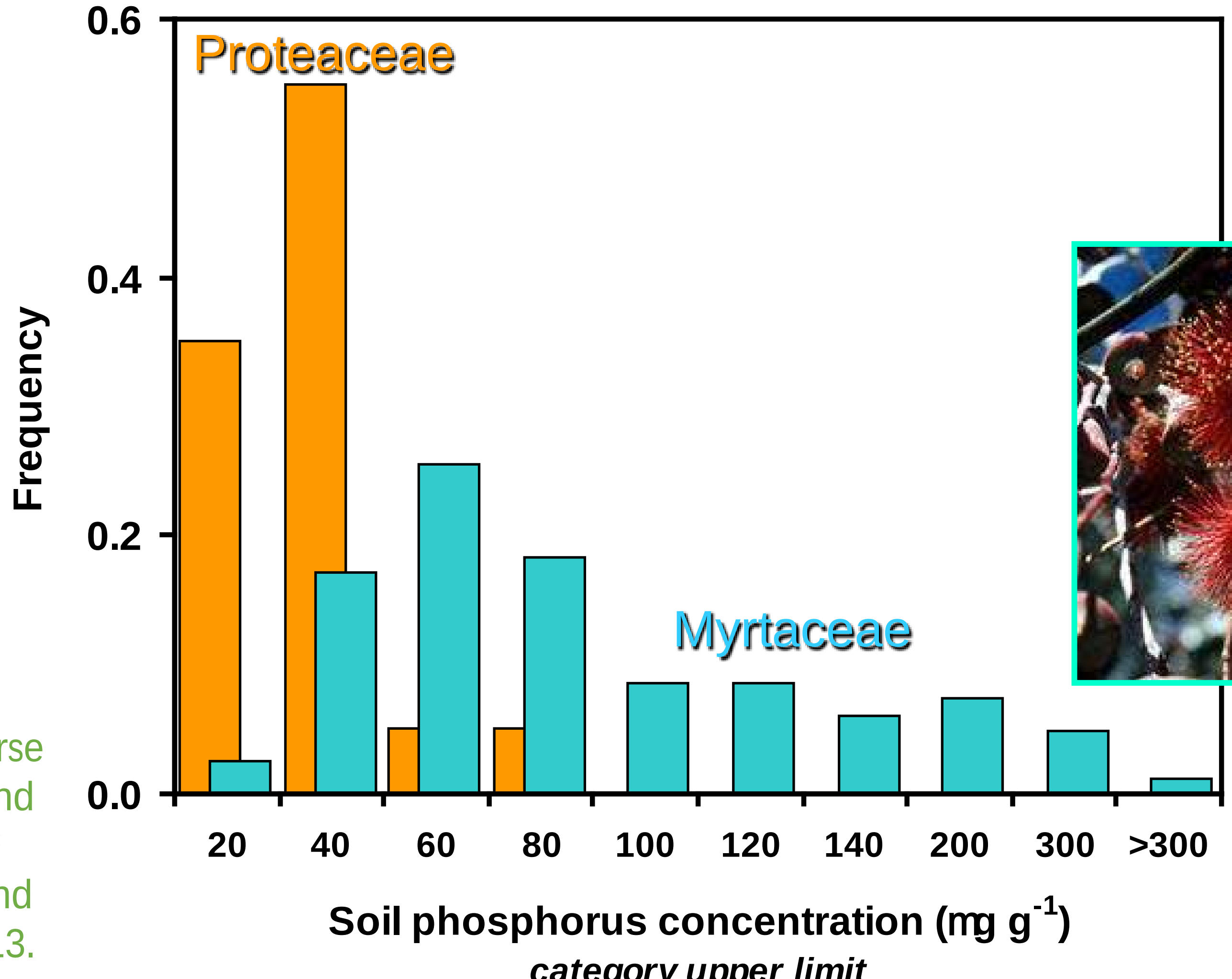
Sand-binding roots of *Lyginia barbata* (Anarthriaceae)





Shane MW, McCully ME, Canny MJ, Pate JS Lambers H. 2011. Development and persistence of sandsheaths of *Lyginia barbata* (Restionaceae): Relation to root structural development and longevity. *Ann. Bot.* **108:** 1307-1322.

Phosphorus status of the soil supporting non-mycorrhizal Proteaceae (with cluster roots) and mycorrhizal Myrtaceae in Western Australia

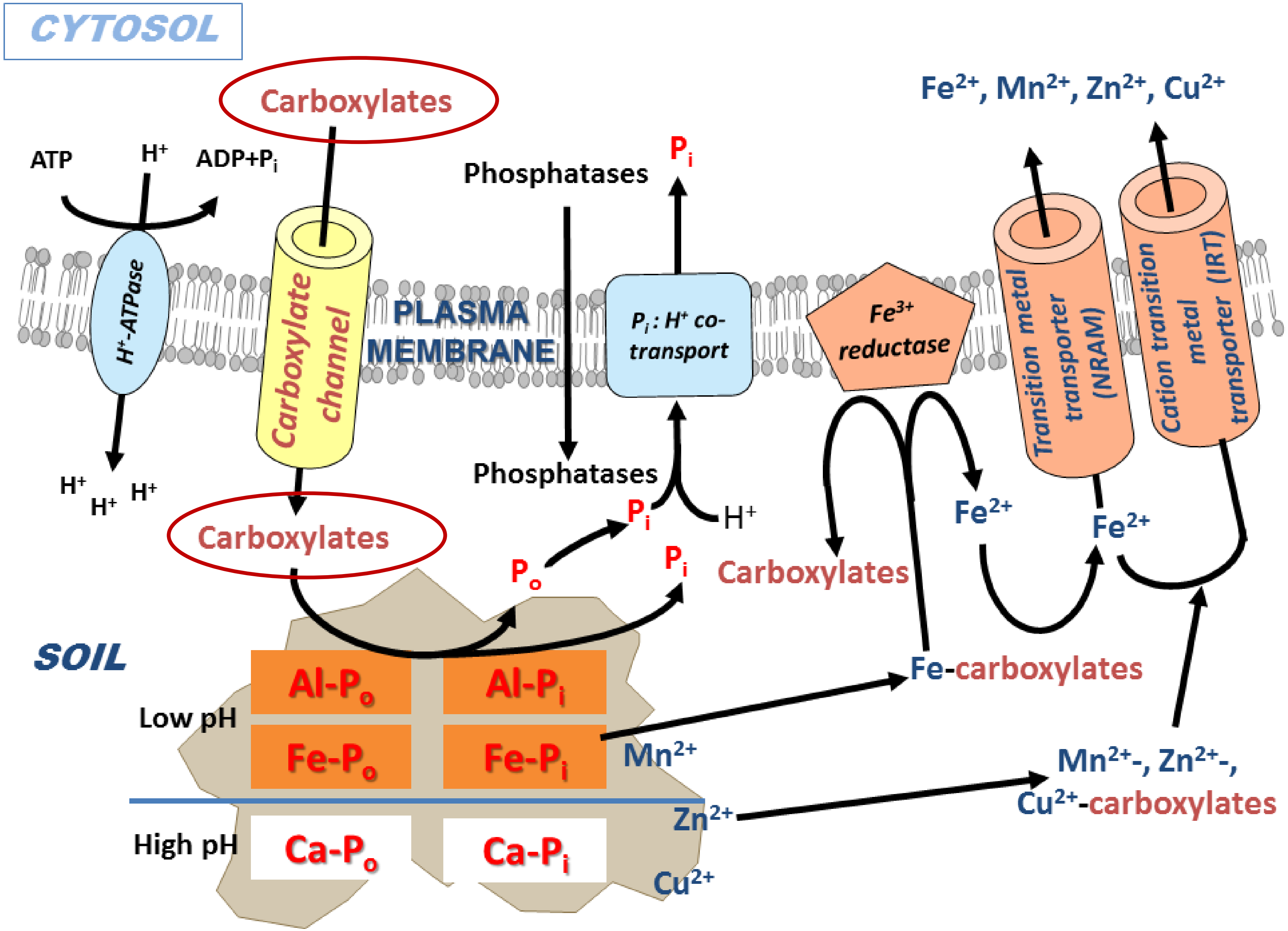


Lambers H, Shane MW, Cramer MD, Pearse SJ, Veneklaas EJ. 2006. Root structure and functioning for efficient acquisition of phosphorus: matching morphological and physiological traits *Ann. Bot.* **98:** 693-713.

Developmental aspects of cluster roots: very short-lived

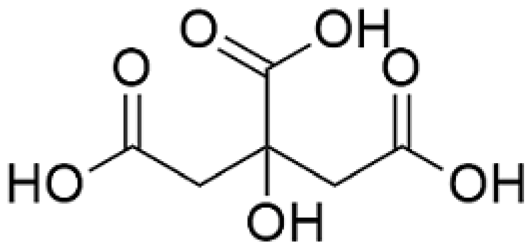
Shane MW, Cramer MD, Funayama-Noguchi S, Cawthray GR, Millar AH, Day DA, Lambers H. 2004. Developmental physiology of cluster-root carboxylate synthesis and exudation in harsh hakea. Expression of phosphoenolpyruvate carboxylase and the alternative oxidase *Plant Physiol.* **135:** 549-560.

Photo: Jianmin Shi

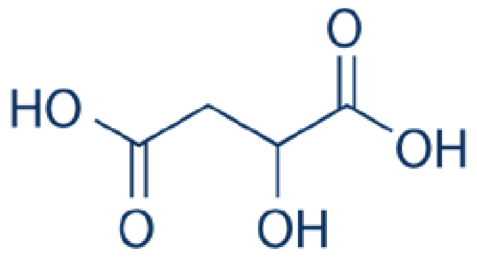


Lambers H, Hayes PE, Laliberté E, Oliveira RS, Turner BL. 2015. Leaf manganese accumulation and phosphorus-acquisition efficiency. *Trends Plant Sci*. **20:** 83-90.

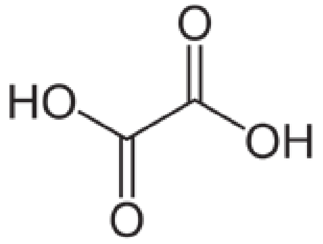
What are carboxylates (+organic anions)?



Citric acid



Malic acid



Oxalic acid

- Think of them as organic acids
- They are the anion component of the organic acids
- The main one that is released is citrate acid
- Others are malate and oxalate
- It is not the ‘acid’ that does the trick
- It is actually the anion (*i.e.* carboxylate)
- Protons may play an additional role in alkaline soils

Conclusions *re* phosphorus acquisition in plants that release carboxylates

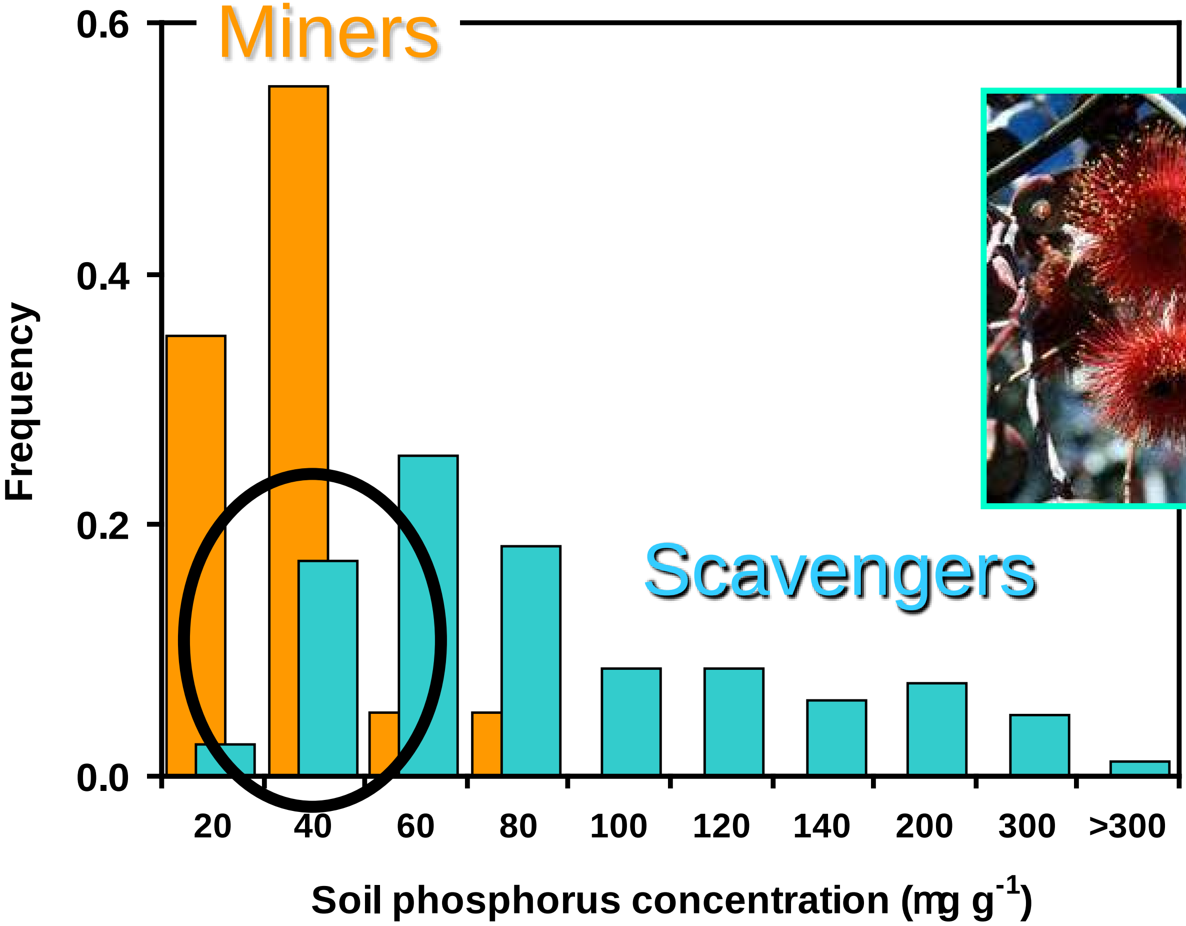
- Specialised roots release vast amounts of citrate and malate

- Citrate and malate mobilise phosphorus

- This is a 'mining strategy'

Phosphorus status of the soil supporting non-mycorrhizal Proteaceae (with cluster roots) and mycorrhizal Myrtaceae in Western Australia

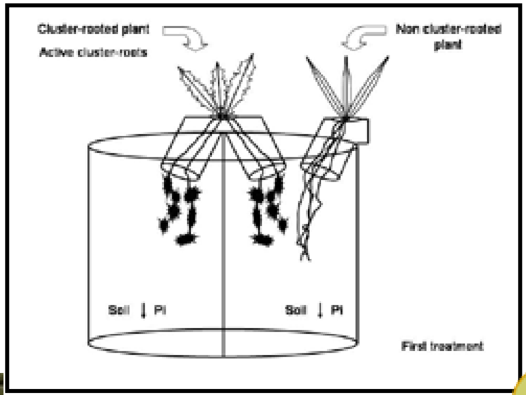
Photo: Jianmin Shi



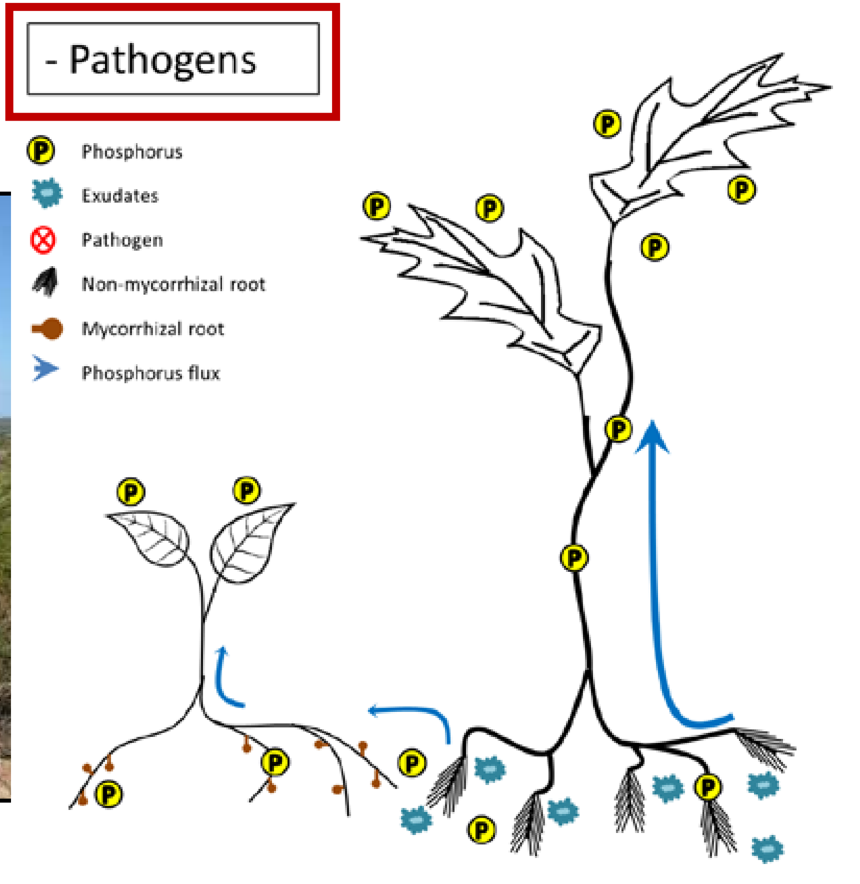
Lambers H, Shane MW, Cramer MD, Pearse SJ, Veneklaas EJ. 2006. Root structure and functioning for efficient acquisition of phosphorus: matching morphological and physiological traits *Ann. Bot.* **98:** 693-713.

Facilitative interactions between a species with cluster roots and a mycorrhizal species

Banksia attenuata
(Proteaceae)



Scholzia involucrata
(Myrtaceae)

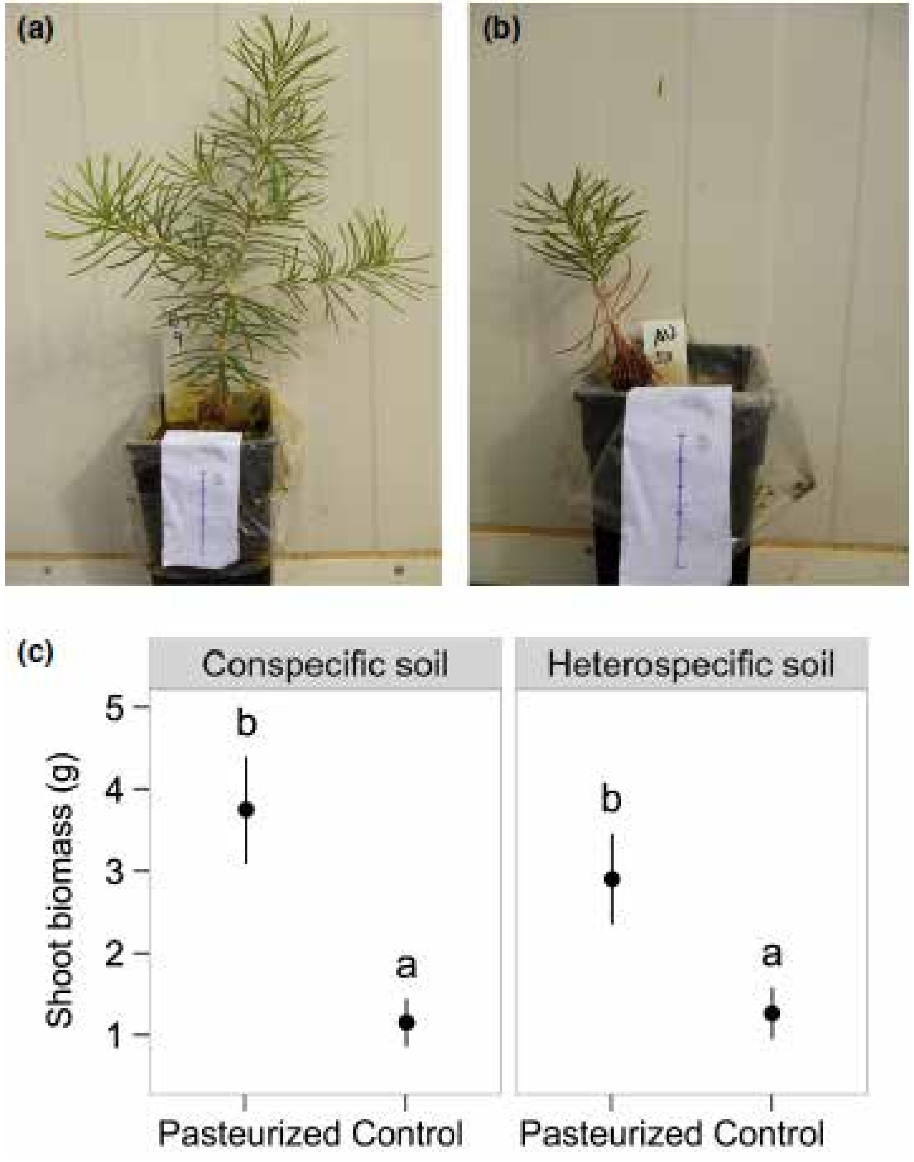


Some facilitation, strong competition

Muler AL, Oliveira RS, Lambers H & Veneklaas EJ. 2014. Does cluster-root activity of *Banksia attenuata* (Proteaceae) benefit phosphorus or micronutrient uptake and growth of neighbouring shrubs? *Oecologia* **174**: 23-31.

Albornoz FE. 2016. Changes in root symbionts during long-term soil and ecosystem development and their ecological role for the maintenance of plant diversity. PhD Thesis.

Growth of *Banksia leptophylla* is impaired by soil pathogens in species-rich kwongan

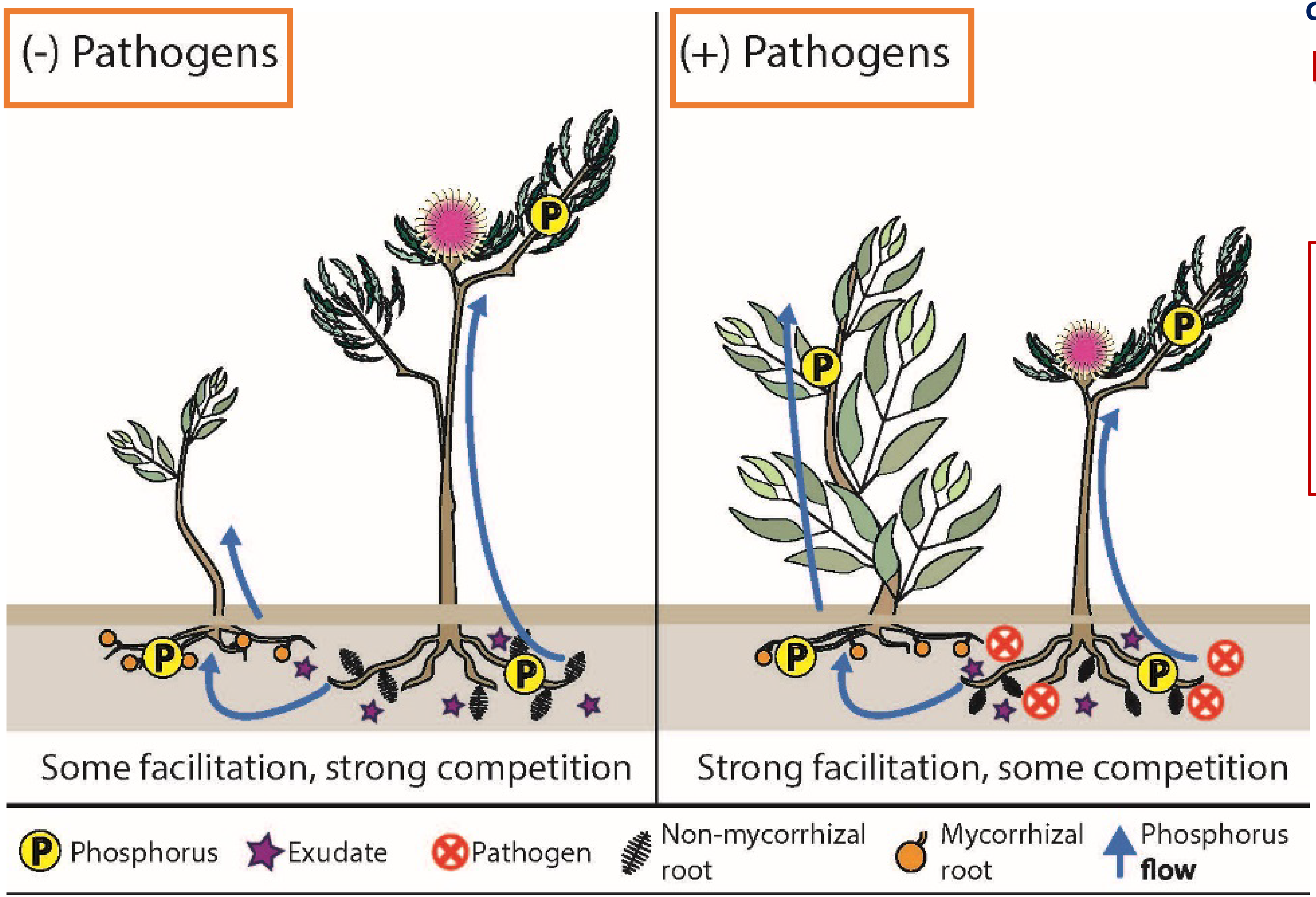


- Seedlings grown in soil collected under conspecific mature shrubs or under co-occurring *Acacia spathulifolia*; soils were either pasteurised or not

- Seedlings grown in (a) pasteurised or (b) unpasteurised soil
- (c) Shoot biomass in the different soil treatments
- The damping-off pathogen *Pythium irregulare* was isolated from > 60% of root or soil samples from the control soils, but never recovered in samples from the pasteurised soils

Laliberté E, Lambers H, Burgess TI, Wright SJ. 2015 Phosphorus limitation, soil-borne pathogens and the coexistence of plant species in hyperdiverse forests and shrublands. *New Phytol.* **206,** 507-521.

Why do we have the greatest plant diversity on the poorest soils?



Trade-off: efficient P acquisition by short-lived roots vs. defence against pathogens

The friendly mycorrhizal fungi protect their mycorrhizal host against pesky oomycete pathogens

Lambers H, Albornoz F, Kotula L, Laliberté E, Ranathunge K, Teste FP, Zemunik G. 2018. How belowground interactions contribute to the coexistence of mycorrhizal and non-mycorrhizal species in severely phosphorus-impoverished hyperdiverse ecosystems. *Plant Soil* **424:** 11-34.

Why do we have such an incredible plant diversity on the sandplains in the southwest of WA?

- The greatest biodiversity occurs on our poorest soils
- Facilitation among plants in nutrient-poor habitats is more important than competition
- Proteaceae that are efficient at getting phosphorus are susceptible to pathogens
- Mycorrhizal plants are less effective at getting phosphorus but cope better with pathogens
- Interactions among the four players account for our megadiversity in the southwest

Photo: Hazel Dempster

Acknowledgements

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