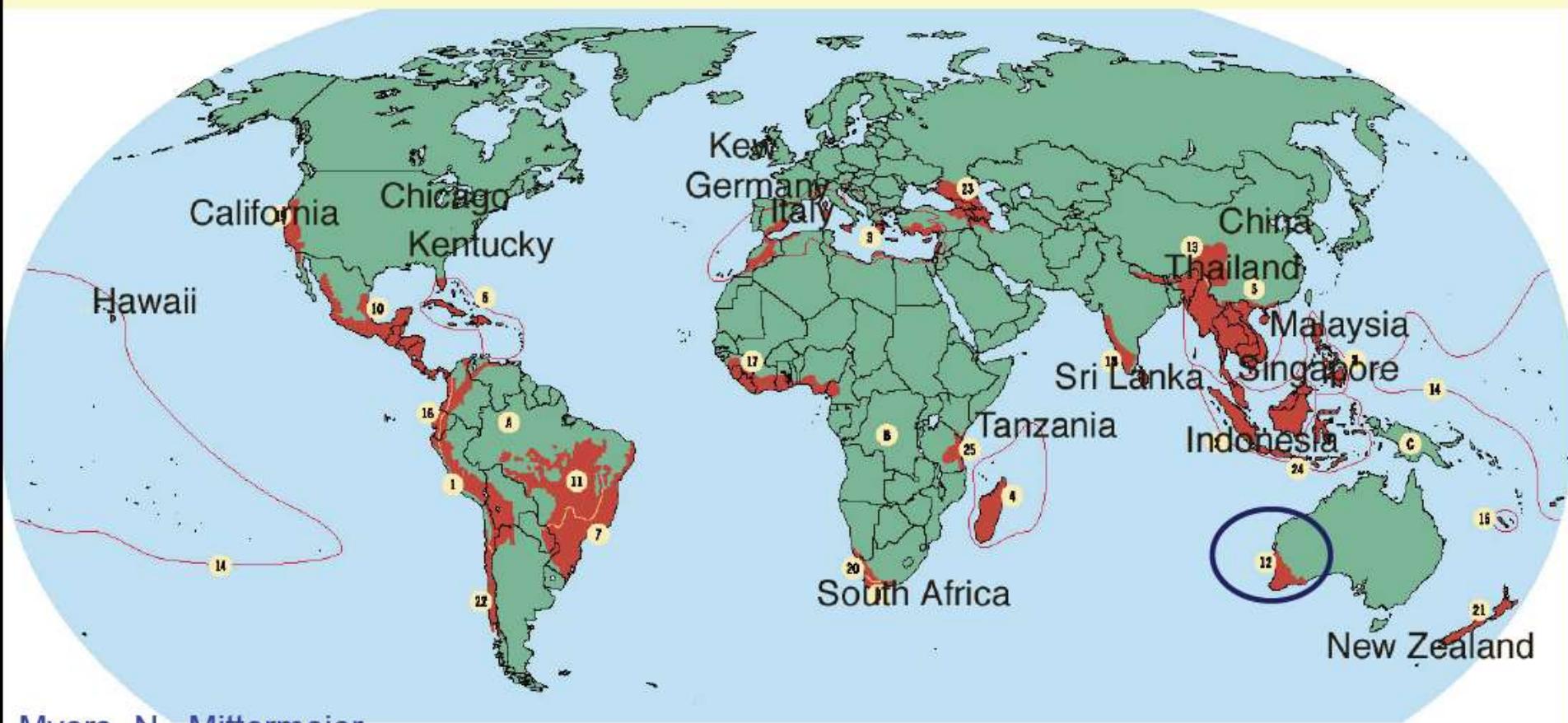


Mineral nutrition of native plants on the Swan Coastal Plain

Hans Lambers
School of Plant Biology
The University of Western Australia

The southwest corner of Western Australia is one of the 25 hotspots of biodiversity in the world



Myers, N., Mittermeier,
R.A., Mittermeier, C.G., da
Fonseca, G.A.B. & Kent, J.
2000. Biodiversity hotspots
for conservation priorities.
Nature 403: 853-858.

BIODIVERSITY HOTSPOTS

- 1 Tropical Andes
- 2 Sundaland
- 3 Mediterranean Basin
- 4 Madagascar & Indian Ocean Islands
- 5 Indo-Burma
- 6 Caribbean
- 7 Atlantic Forest Region
- 8 Philippines
- 9 Cape Floristic Region
- 10 Mesoamerica
- 11 Brazilian Cerrado
- 12 Southwest Australia
- 13 Mountains of Southwest China
- 14 Papua/Micronesia
- 15 New Caledonia
- 16 Chocó-Durán-Western Ecuador
- 17 Gulfian Forests of West Africa
- 18 Western Ghats & Sri Lanka
- 19 California Floristic Provinces
- 20 Succulent Karoo
- 21 New Zealand
- 22 Central Chile
- 23 Caucasus
- 24 Wallacea
- 25 Eastern Arc Mountains & Coastal Forests of Tanzania & Kenya

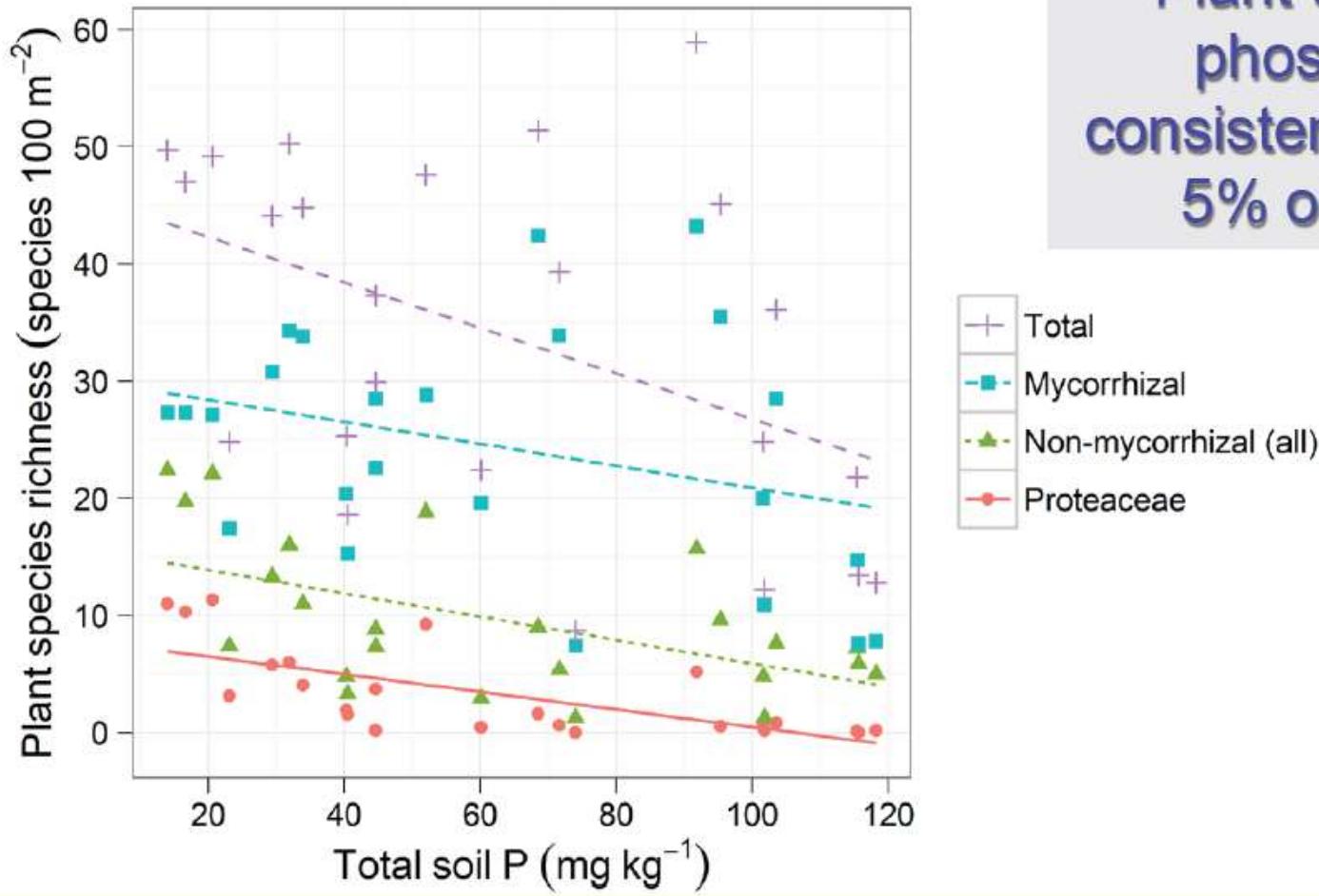


**Biodiversity is
more than 'lots of
species'**

**It is also about
'patterns and
processes'**

Lambers, H., Ahmed, I., Berkowitz, O., Dunne, C., Finnegan, P.M., Hardy, G.E.St.J., Jost, R., Laliberté, R., Pearse, S.J. & and Teste, F.P. 2013. Phosphorus nutrition of phosphorus-sensitive Australian native plants: Threats to a global biodiversity hotspot. *Conserv. Physiol.* 1: in press.

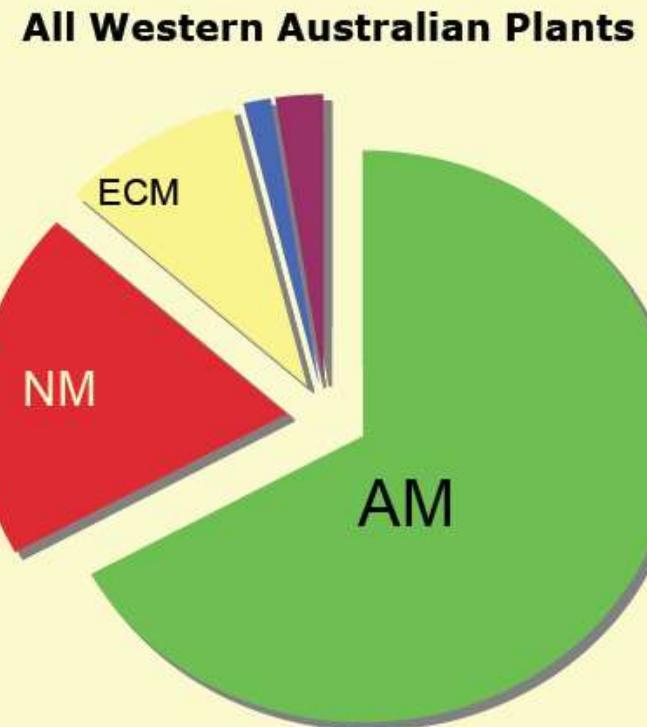
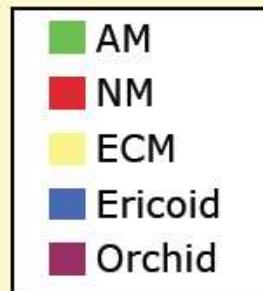
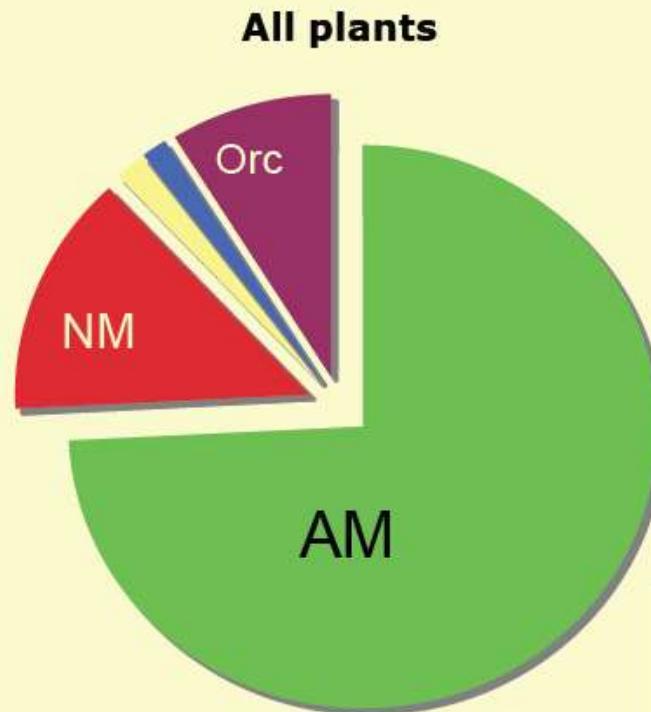
Pattern: plant species diversity increases with decreasing soil phosphorus (P)



Plant-available phosphorus consistently approx. 5% of total P

Lambers, H., Ahmed, I., Berkowitz, O., Dunne, C., Finnegan, P.M., Hardy, G.E.St.J., Jost, R., Laliberté, R., Pearse, S.J. & and Teste, F.P. 2013. Phosphorus nutrition of P-sensitive Australian native plants: Threats to a global biodiversity hotspot. *Conserv. Physiol.* 1: in press.

Process: proportions of species with different nutrient-acquisition strategies



Brundrett, M.C. 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.

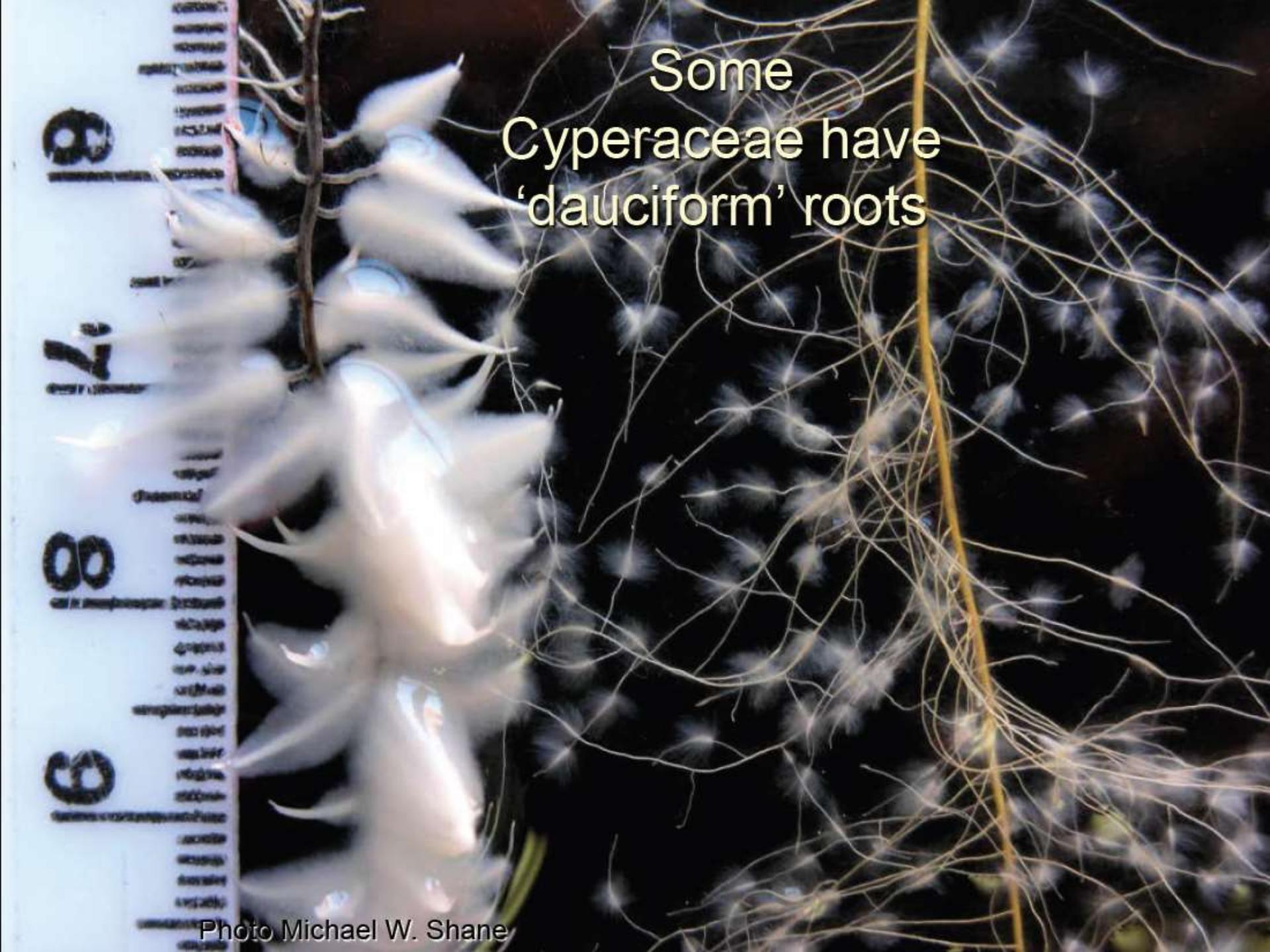
In the rest of the world, plants on nutrient-poor soils tend to live symbiotically with mycorrhizal fungi

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

A close-up photograph of a plant, likely a non-mycorrhizal species, showing its root system at the base. The roots are thick, white, and appear to be clustered around the stem, which is a characteristic adaptation for nutrient acquisition in poor soils.

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

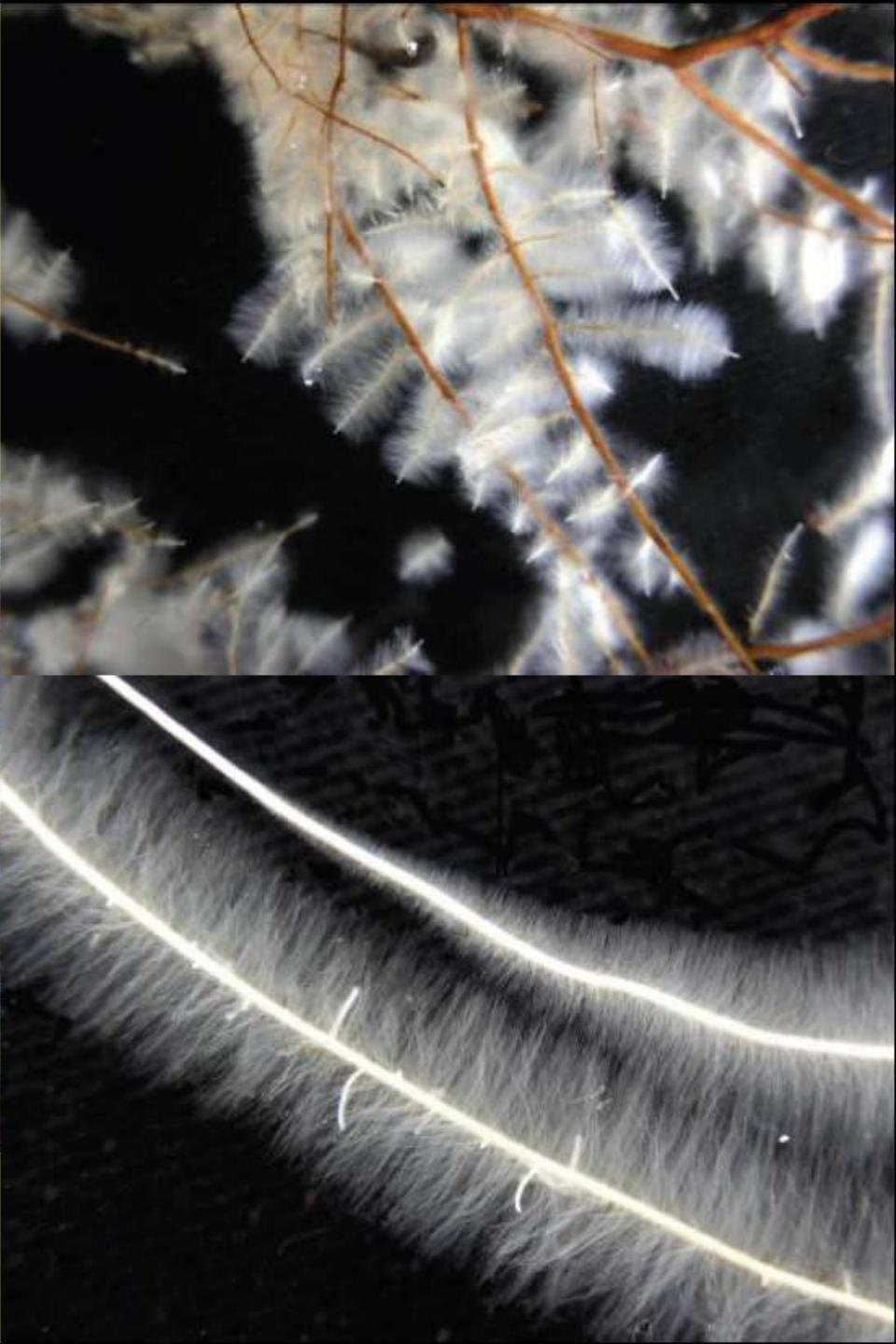
Many have **cluster roots**, as illustrated here



Some
Cyperaceae have
'dauciform' roots

Photo Michael W. Shane

**Other root clusters
include 'capillaroid
roots' in some
Restionaceae**



Photos Dr Michael Shane

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



Shane, M.W., McCully, M.E., Canny, M.J., Pate, J.S. & Lambers, H. 2011. Development and persistence of sandsheaths of *Lyginia barbata* (Restionaceae): Relation to root structural development and longevity. *Ann. Bot.* **108**: 1307-1322.

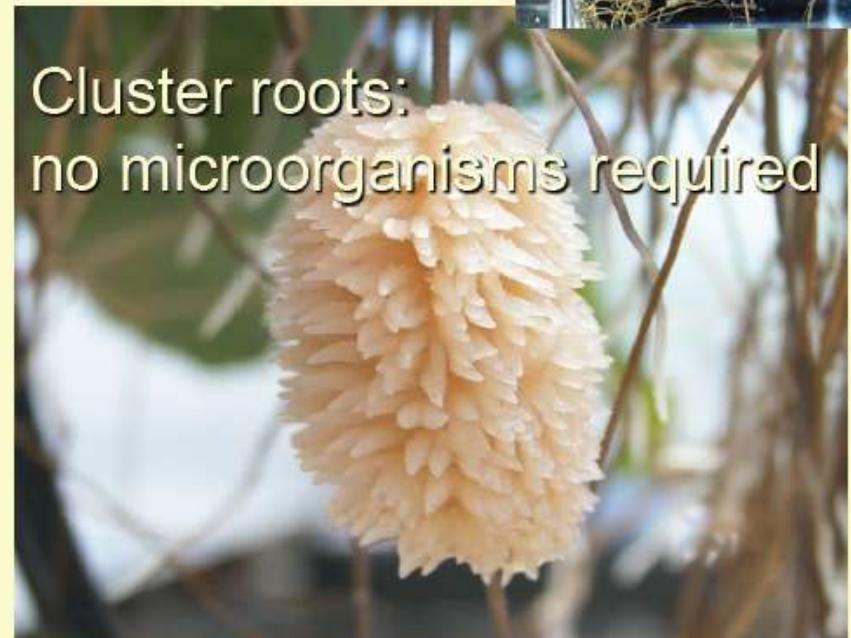
The difference between root nodules (symbiotic) and cluster roots (non-symbiotic)



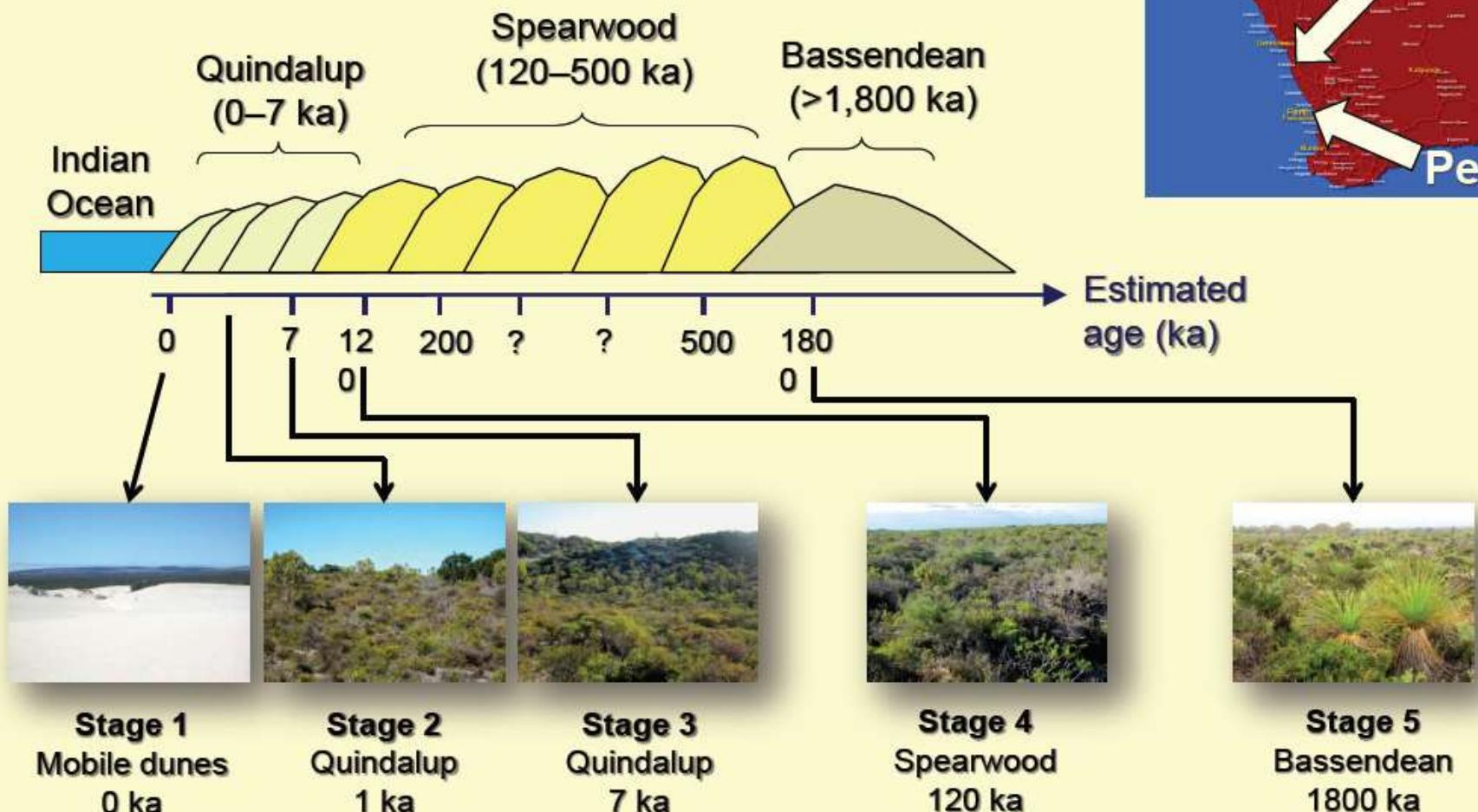
Nodules:
bacteria involved



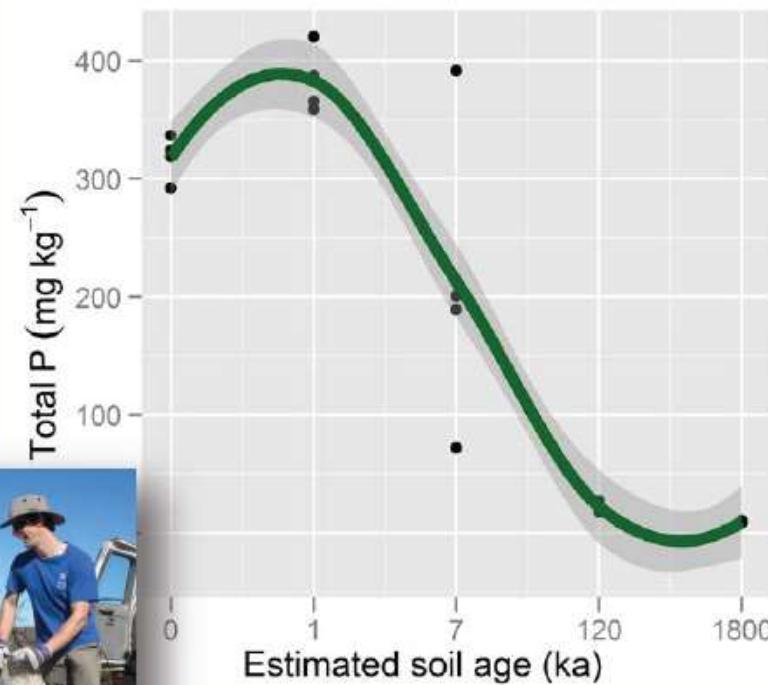
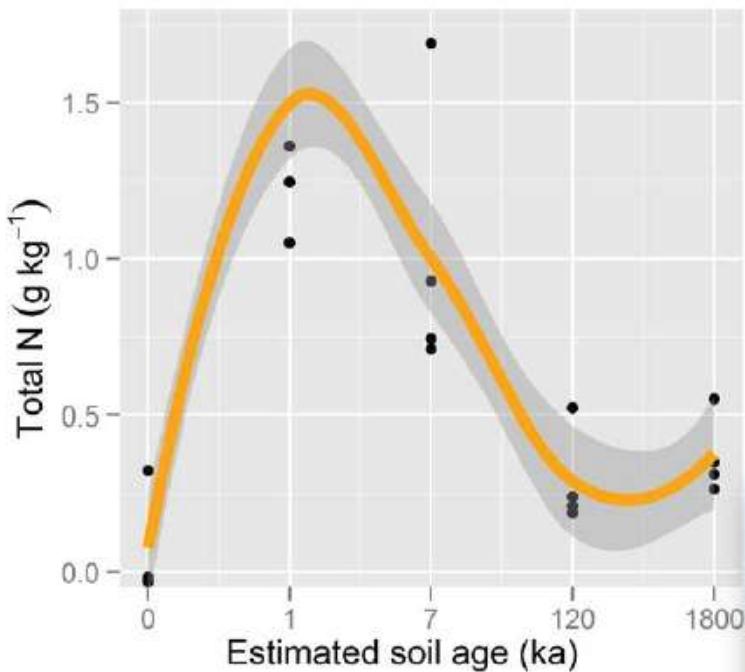
Cluster roots:
no microorganisms required



We work on the Jurien Bay dunes on the Swan Coastal Plane, increasing in age from west to east

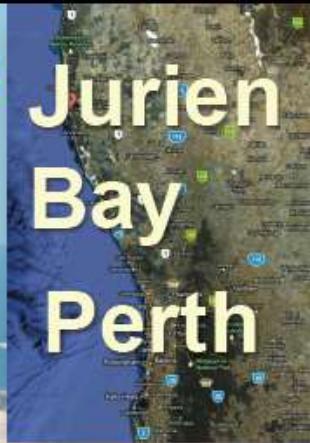


Pattern: nitrogen (N) limits plant growth on very young dunes; phosphorus (P) does on older ones



Laliberté, E., Turner, B.L., Costes, T., Pearse, S.J., Wyrwoll, K.-H., Zemunik, G. & Lambers, H. 2012. Experimental assessment of nutrient limitation along a 2-million year dune chronosequence in the south-western Australia biodiversity hotspot. *J. Ecol.* **100**: 631-642.

Jurien Bay >2-million-year dune chronosequence

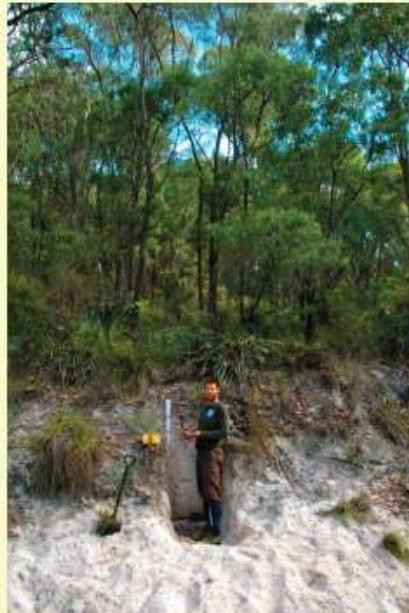


0-7 ky {

120-500 ky {

>2000 ky {

Collaboration with Smithsonian (Ben Turner)

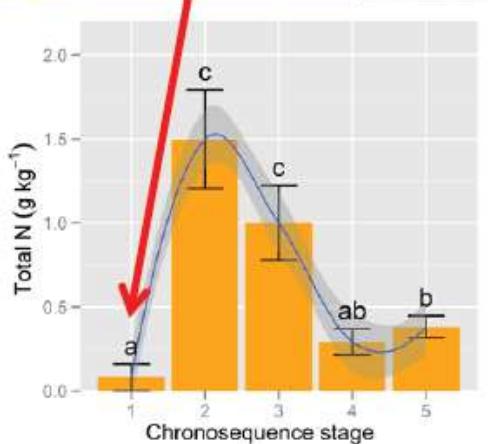


Stage 1: very young dunes (10's—100 years)

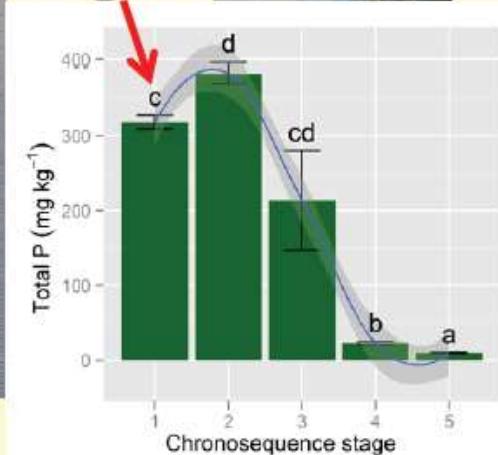
Photo: Graham Zemunik



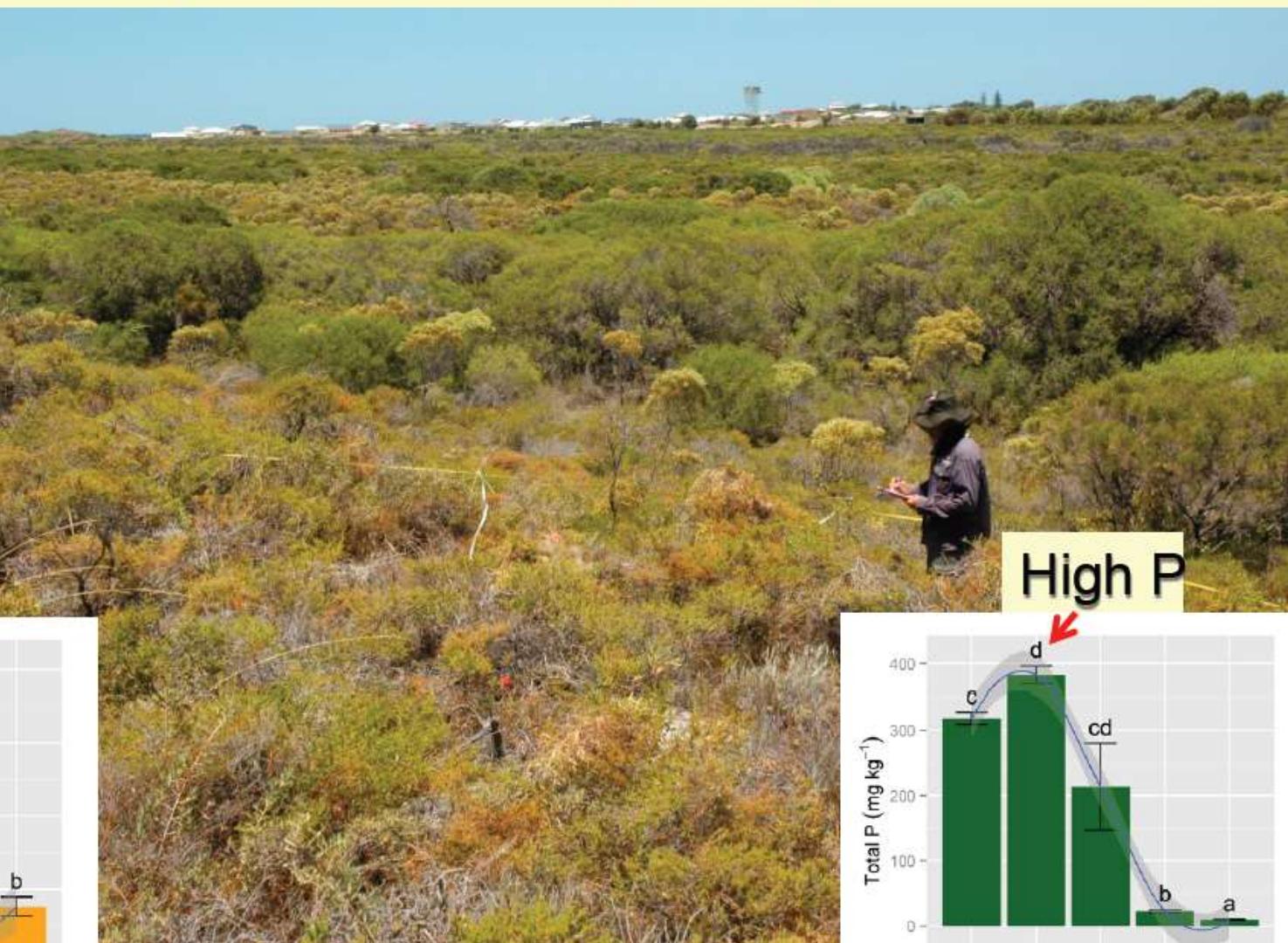
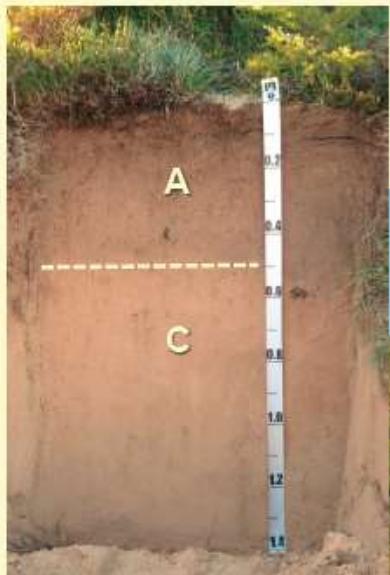
Very low N



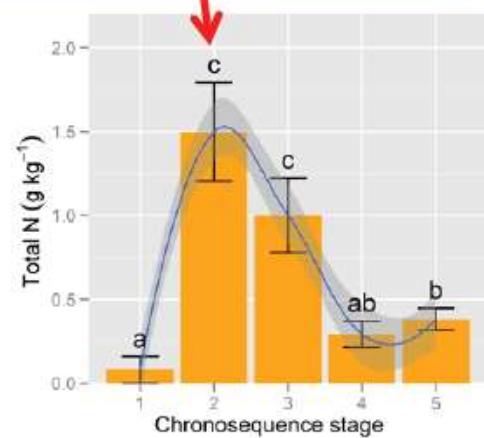
High P



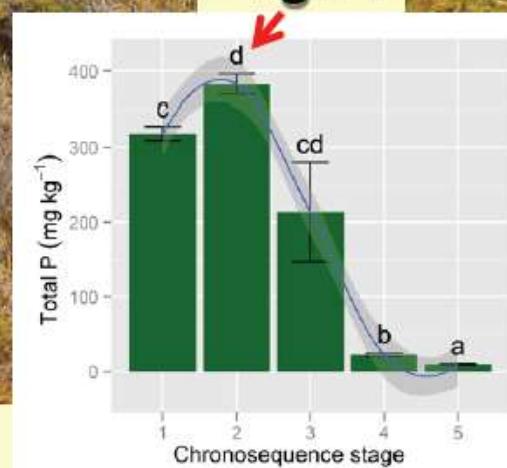
Stage 2: young dunes (100's-1000's years)



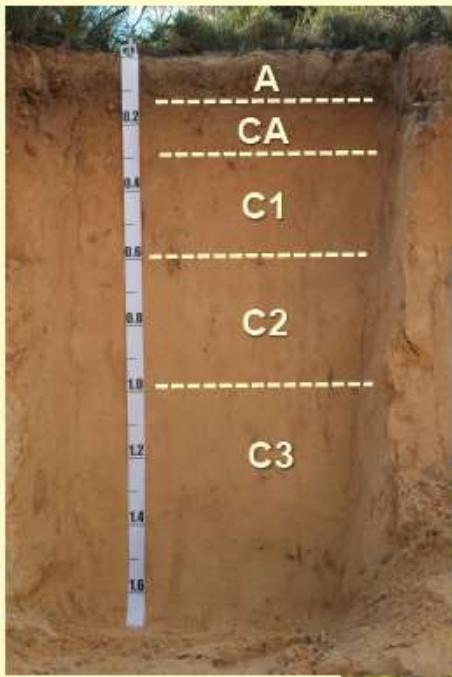
Highest N



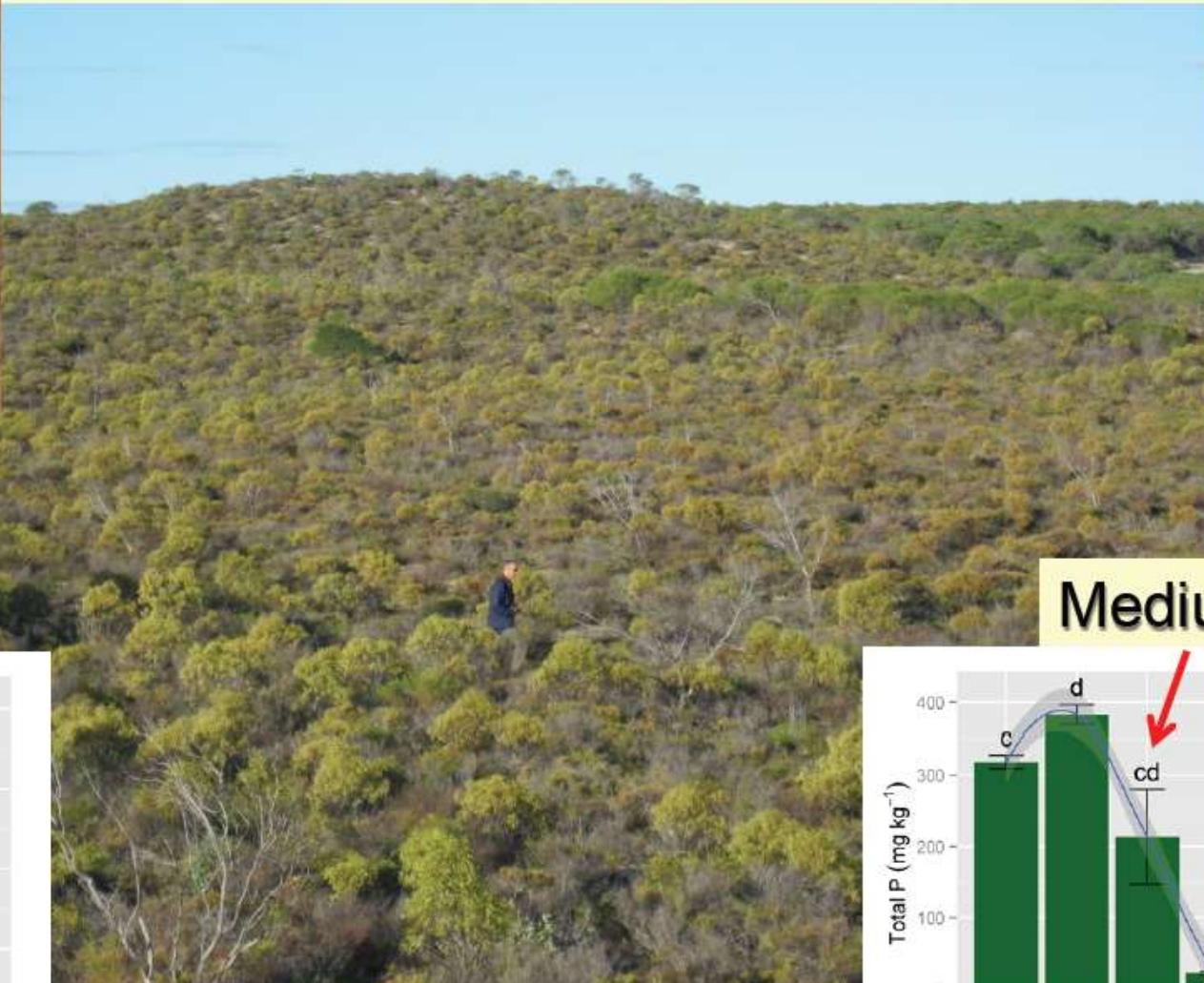
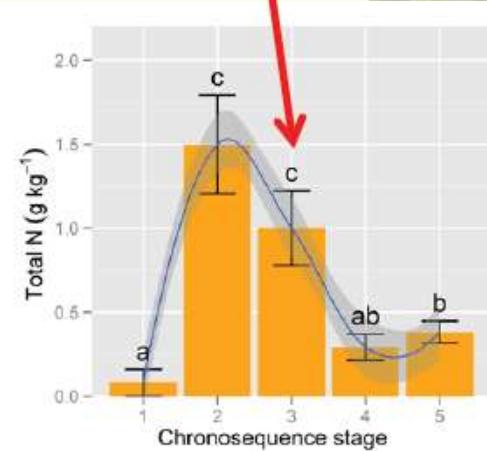
High P



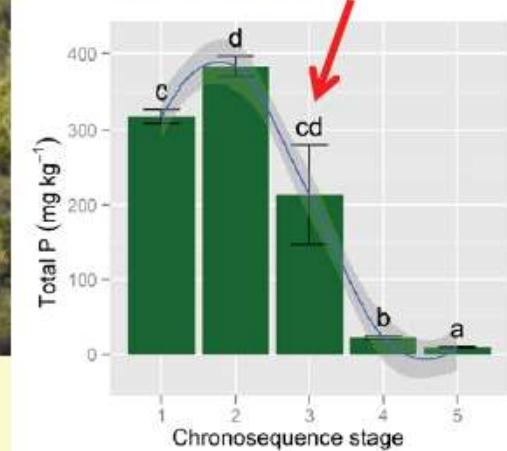
Stage 3: young dunes (~7000 years)



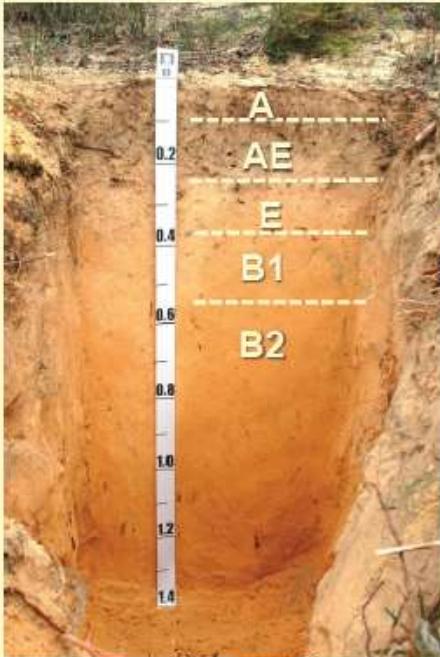
Medium N



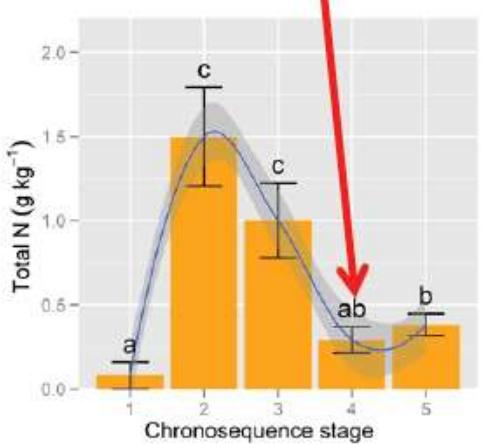
Medium P



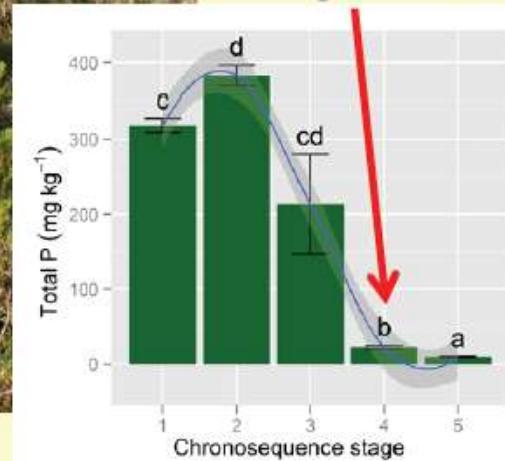
Stage 4: old dunes (~120,000 years)



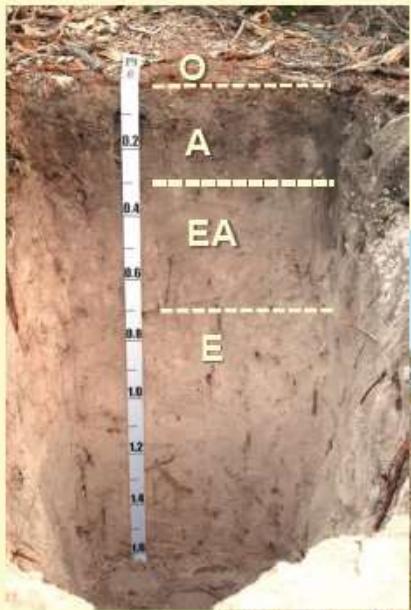
Low N



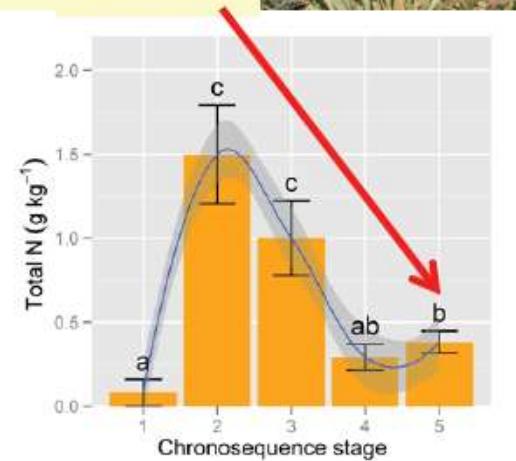
Very low P



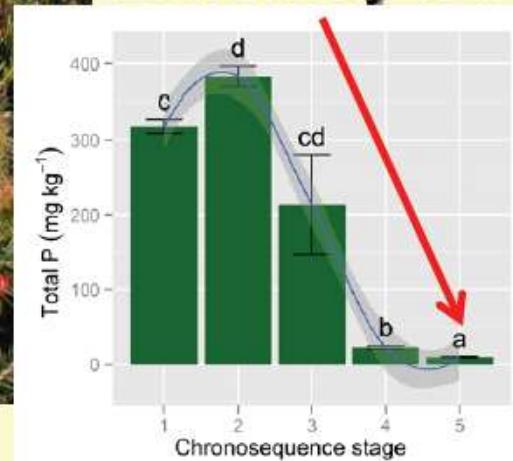
Stage 5: very old dunes (>2,000,000 years)



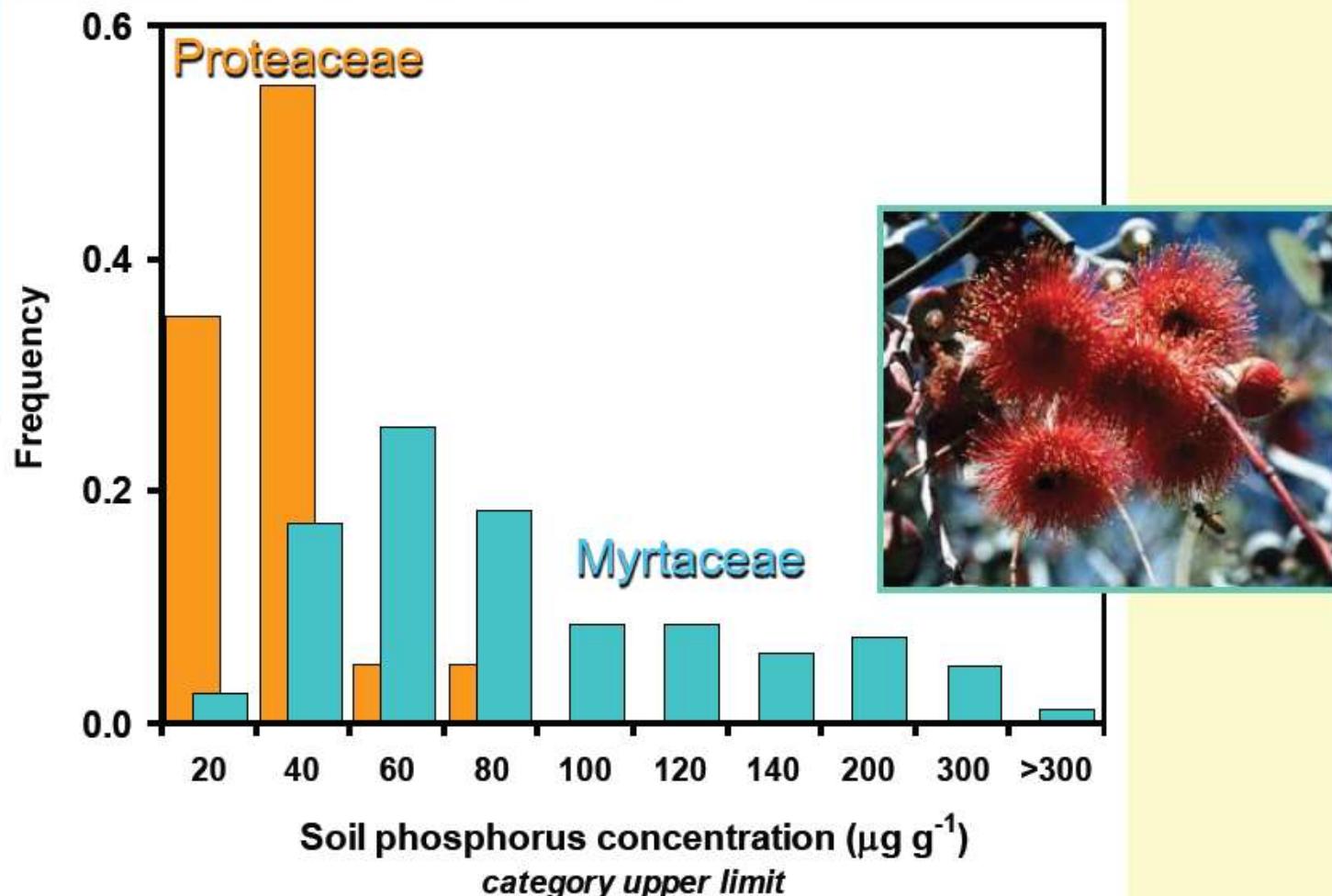
Low N



Extremely low P



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

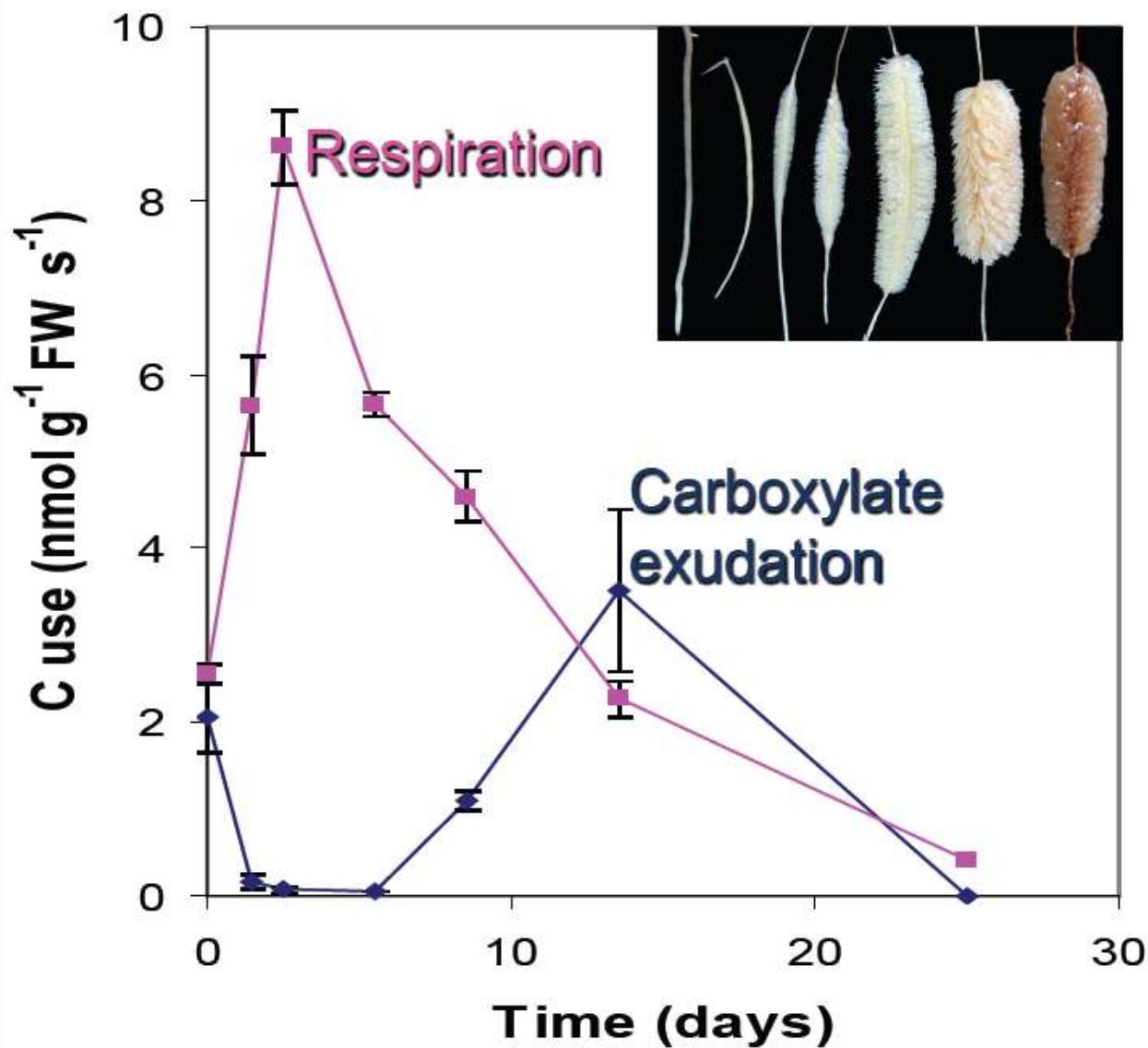


Process: developmental aspects of cluster roots



Shane, M.W., Cramer, M.D., Funayama-Noguchi, S., Cawthray, G.R., Millar, A.H., Day, D.A. & Lambers, H. 2004. *Plant Physiol.* **135**: 549-560.

Respiration and carboxylate exudation in cluster roots of *Hakea prostrata*

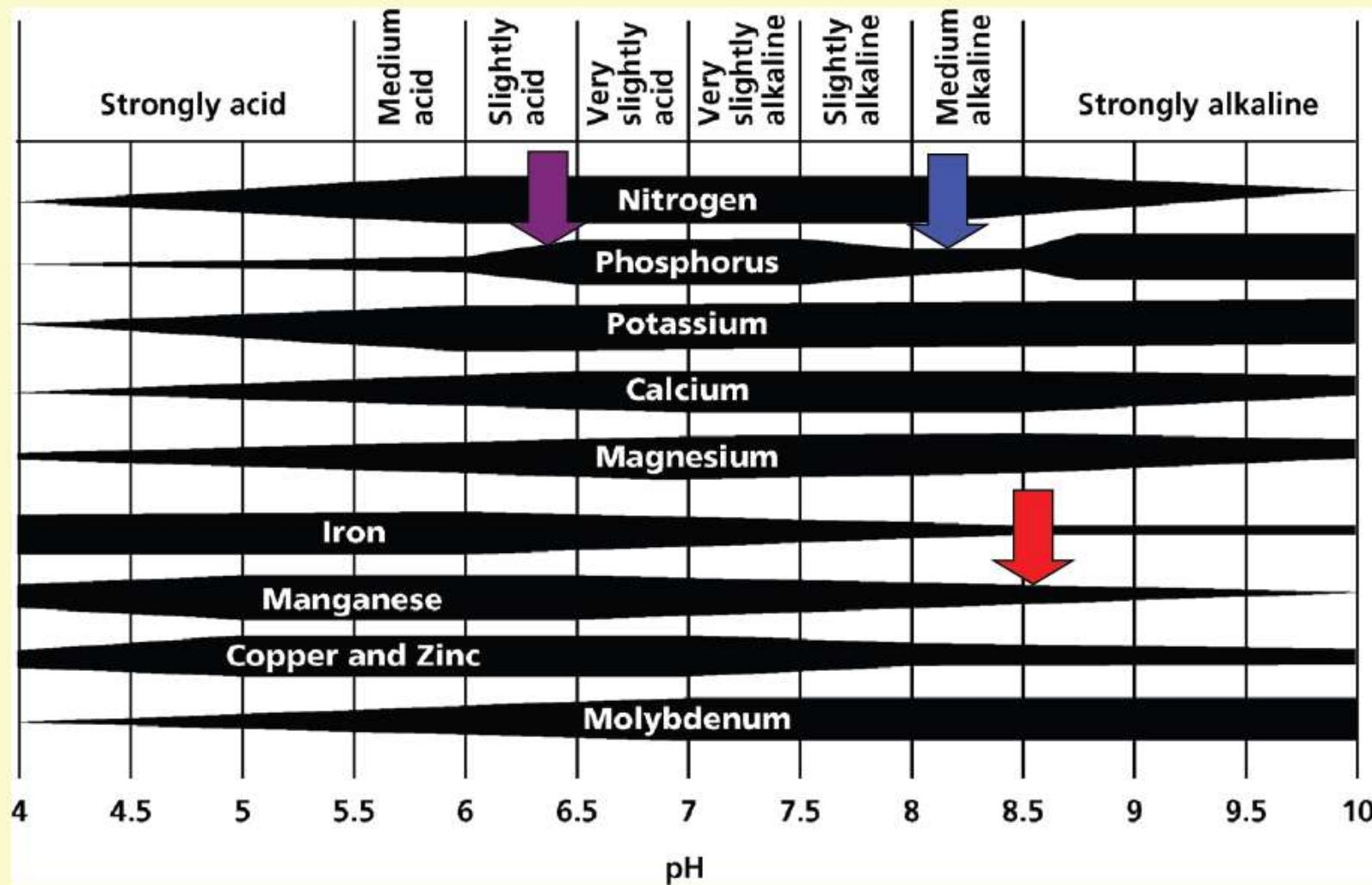


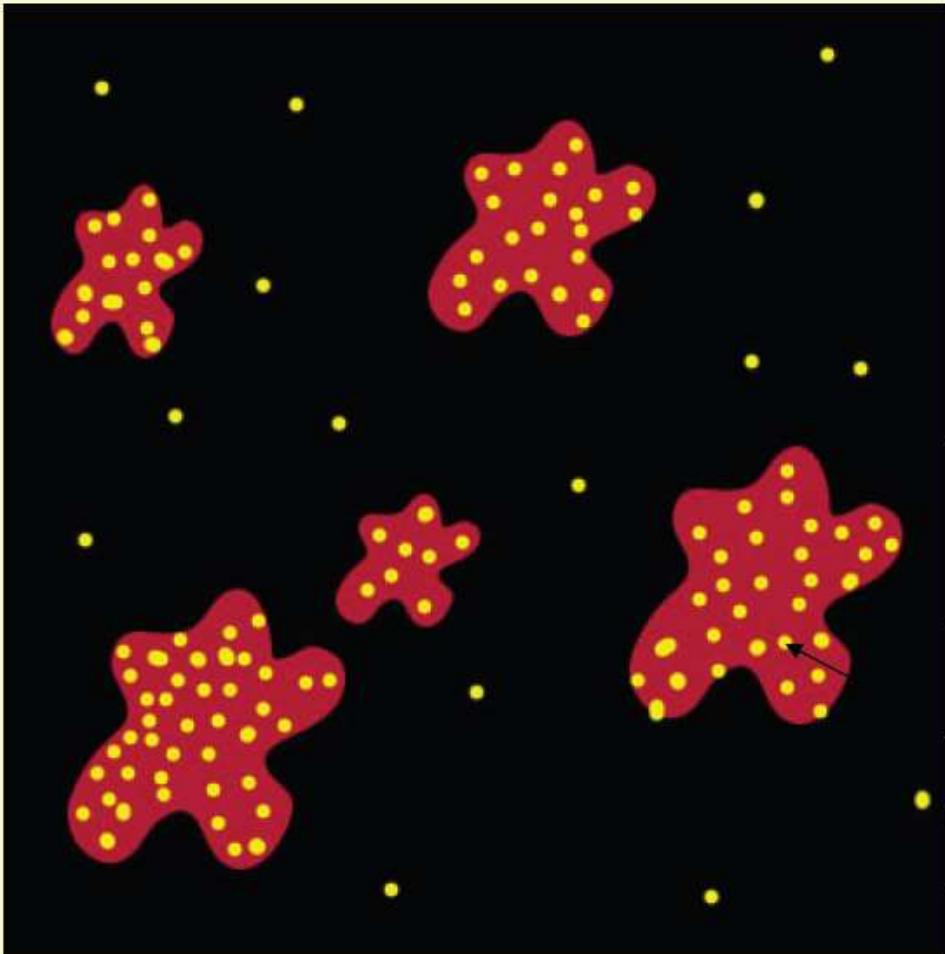
Shane et al. 2004.
Plant Physiol. 135:
549-560.

Carboxylates?

- Think of them as organic acids
- They are the anion component of the organic acids
- The main one that is released is citric acid
- Another one is malic acid
- It is not the “acid” that does the trick
- It is actually the anions (*i.e.* carboxylates)

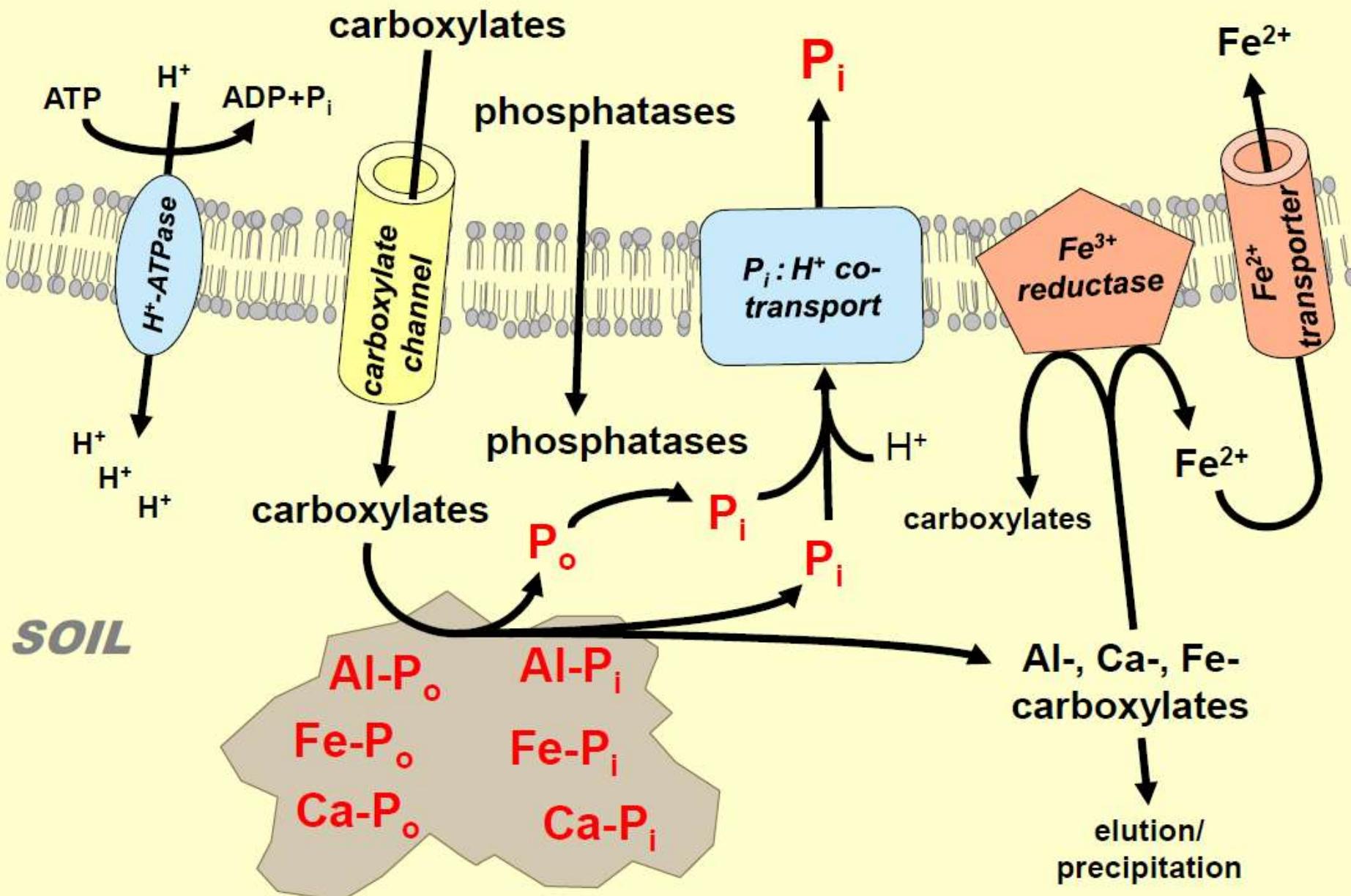
Nutrient availability as dependent on soil pH - note low availability of phosphorus and manganese at alkaline pH



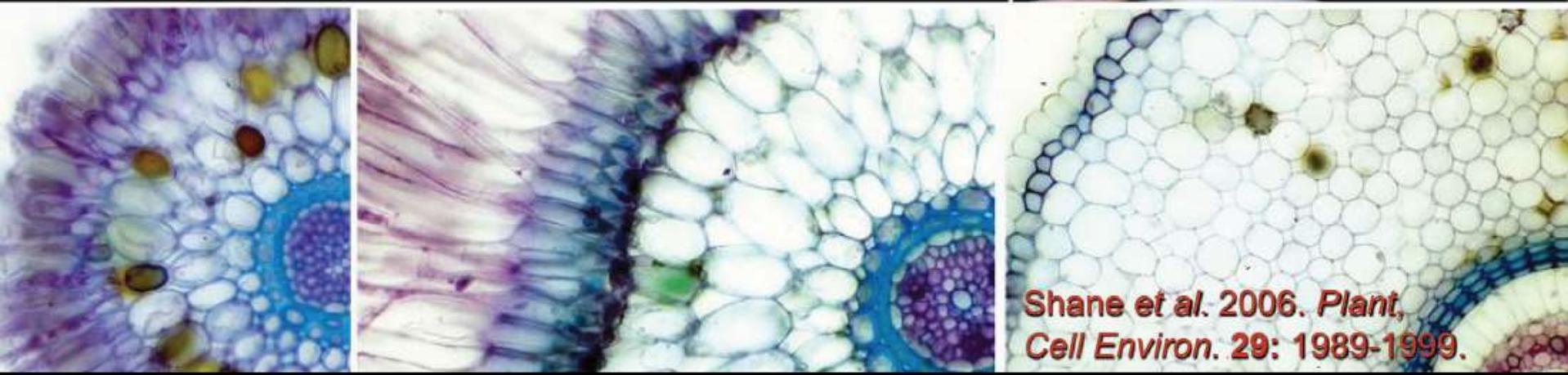
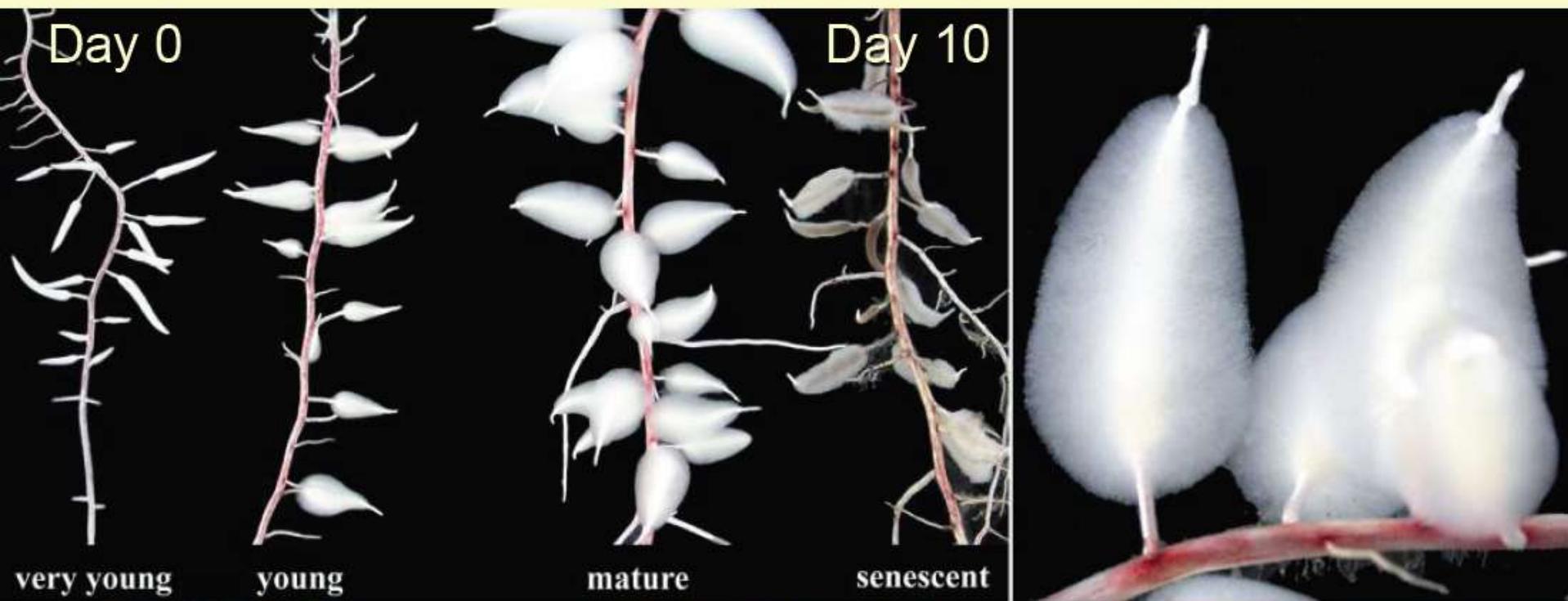


Soil looks a bit like this – with only a few phosphorus ions in solution

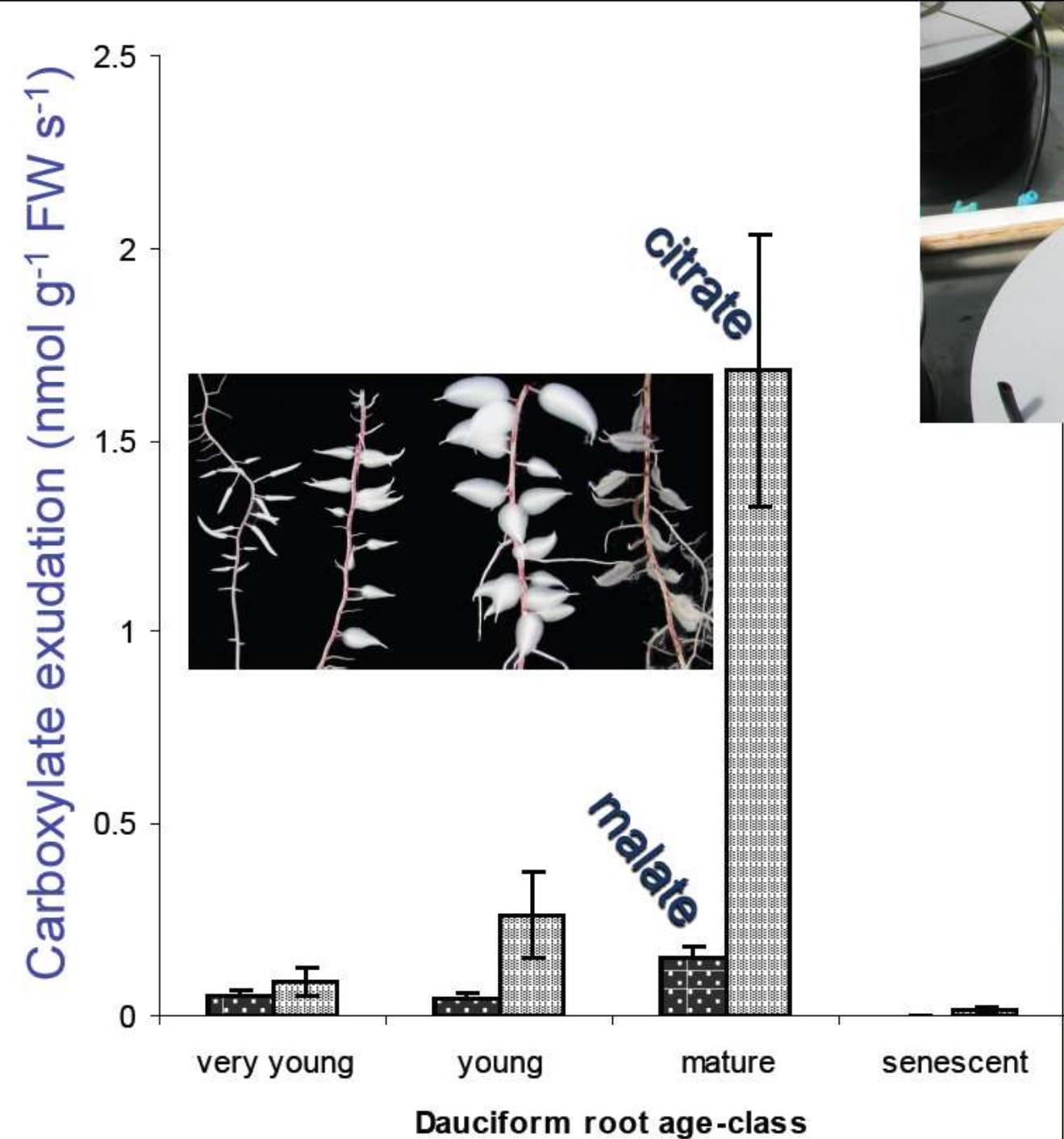
The dots on the oxide particles represent phosphorus on the soil surface



Dauciform root development in a Western Australian sedge, *Schoenus unispiculatus*



Shane et al. 2006. Plant,
Cell Environ. 29: 1989-1999.



Dauciform roots release exudates, in an exudative burst, just like cluster roots in Proteaceae

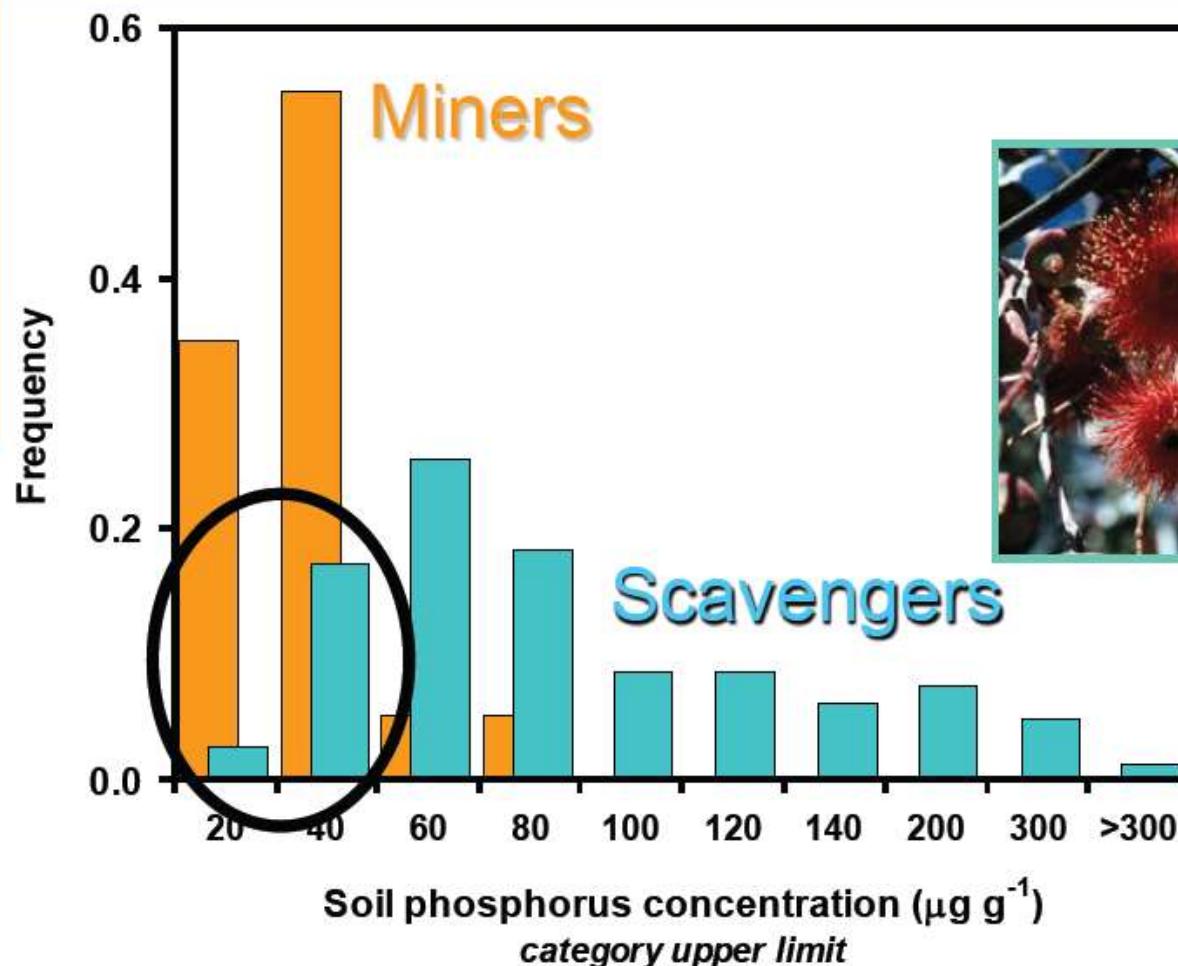
Shane et al. 2006. *Plant, Cell Environ.* 29: 1989-1999.

Conclusions re phosphorus acquisition in plants that release carboxylates

- Specialised roots
release vast amounts of
malate and citrate
- **Carboxylates mobilise
phosphorus**



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

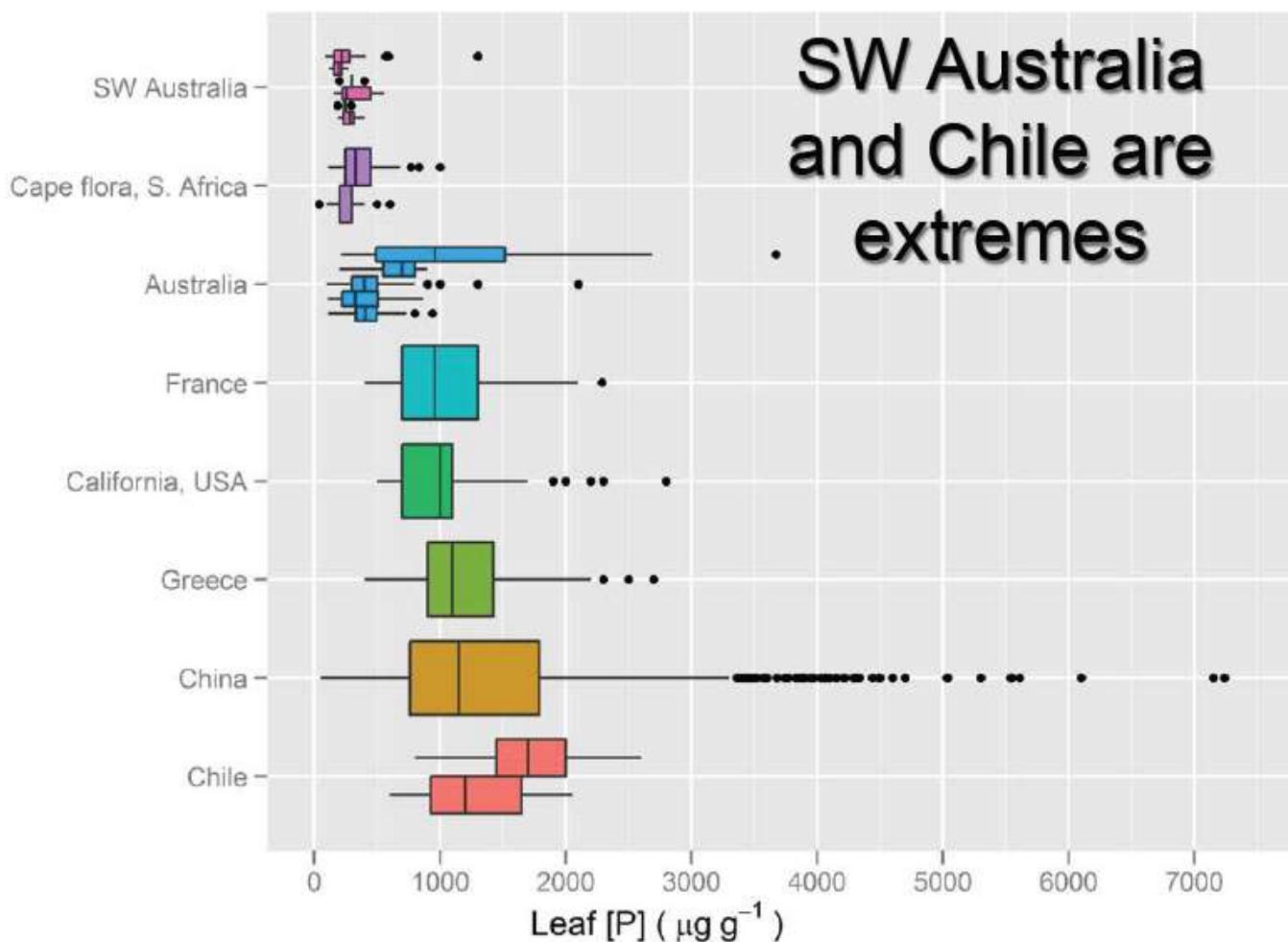




**Species in SW Australia
have very low leaf P
concentrations**



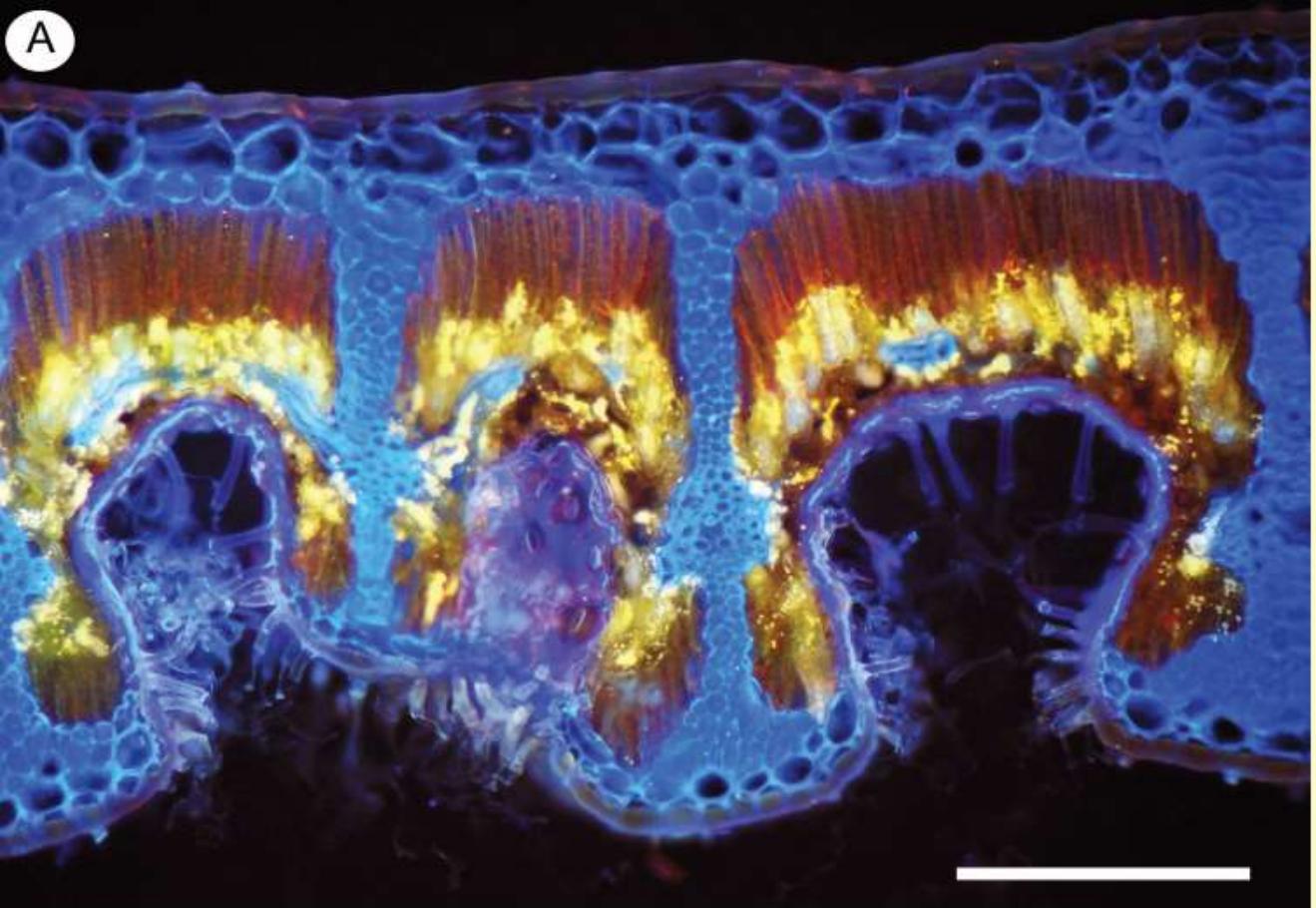
Pattern: phosphorus concentration in mature leaves



SW Australia
and Chile are
extremes

The central bar shows the median, the box represents the interquartile range (IQR), the whiskers show the location of the most extreme data points that are still within $1.5 \pm$ the upper or lower quartiles, and the black points are outliers that fall outside the values of the 'extreme limits' described above

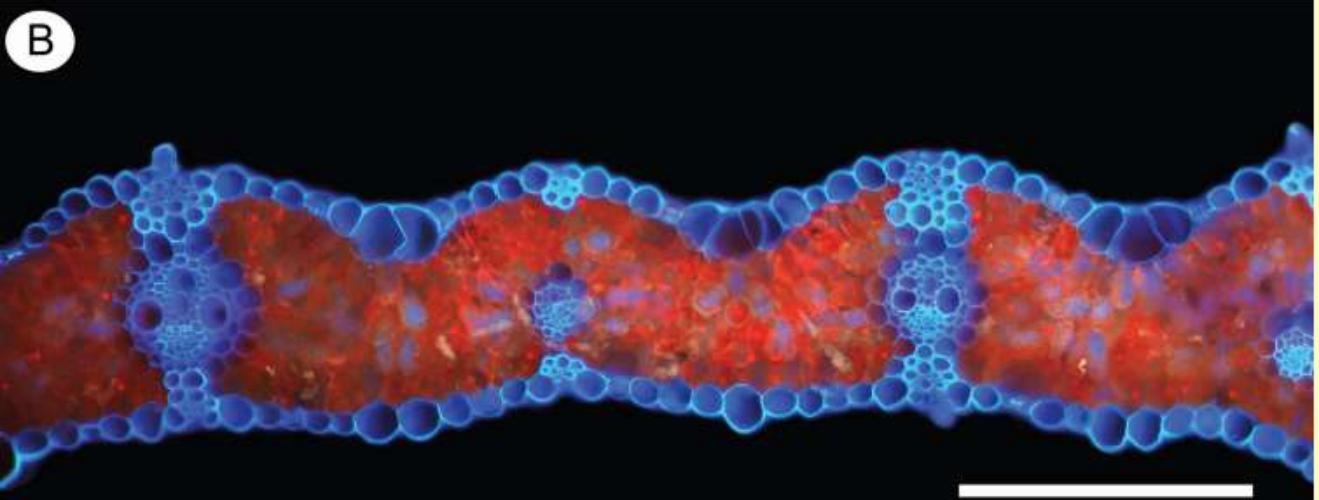
A



Cross section of a *Banksia* and a barley leaf

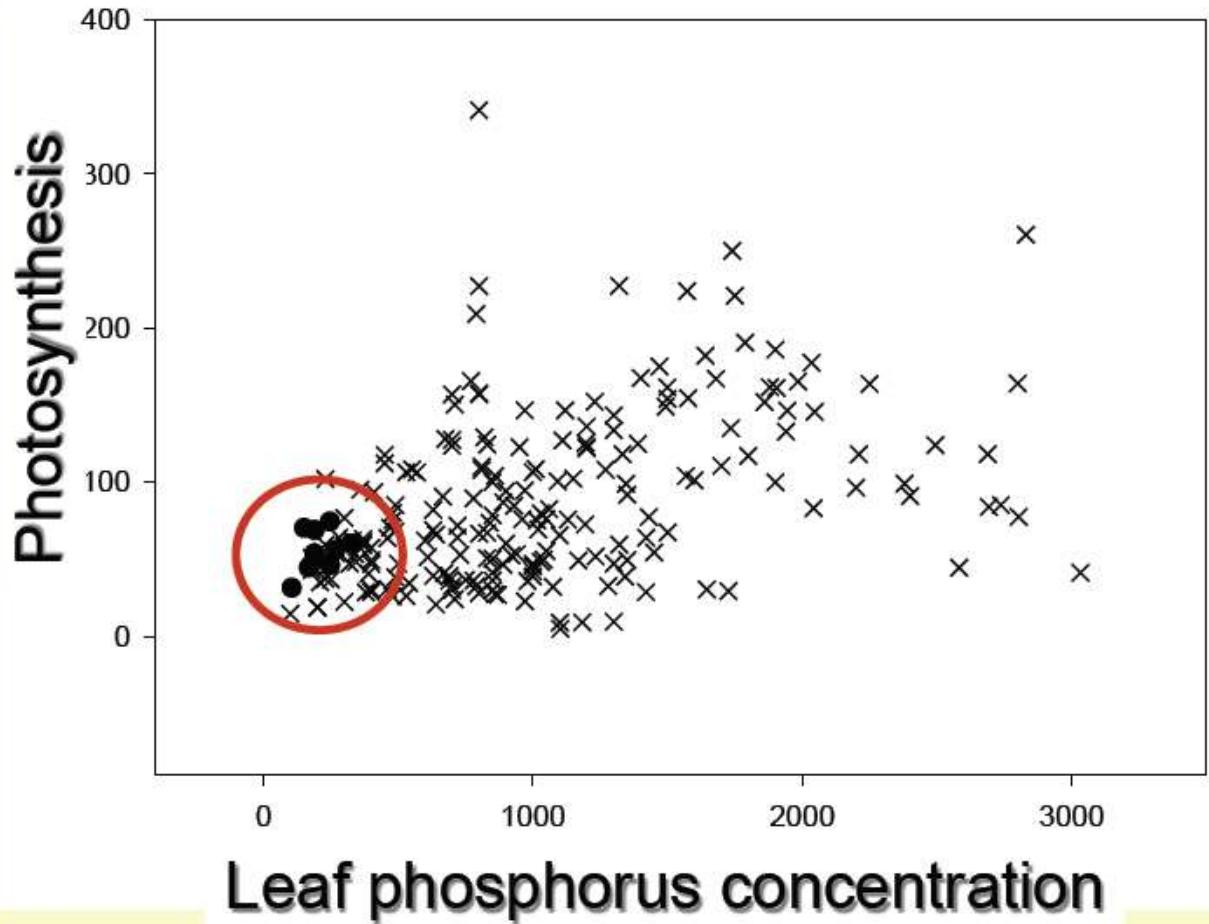
Note the **stomatal
crypts** and sunken
stomata in *Banksia
repens*

B



Lambers, H., Finnegan,
P.M., Laliberté, E., Pearse,
S.J., Ryan, M.H., Shane,
M.W. & Veneklaas, E.J.
2011. Phosphorus
nutrition of Proteaceae in
severely phosphorus-
impoverished soils: are
there lessons for future
crops? *Plant Physiol.* **156**:
1058-1066.

Process: photosynthesis of a range of Banksia species



Leaf phosphorus concentration



Wright et al. 2004. *Nature* **428**: 821-827;
Denton, M.D., Veneklaas, E.J., Freimoser, F.M. & Lambers, H.
2007. *Plant Cell Environ.* **30**: 1557-1565.

Conclusions re phosphorus concentrations in leaf tissues

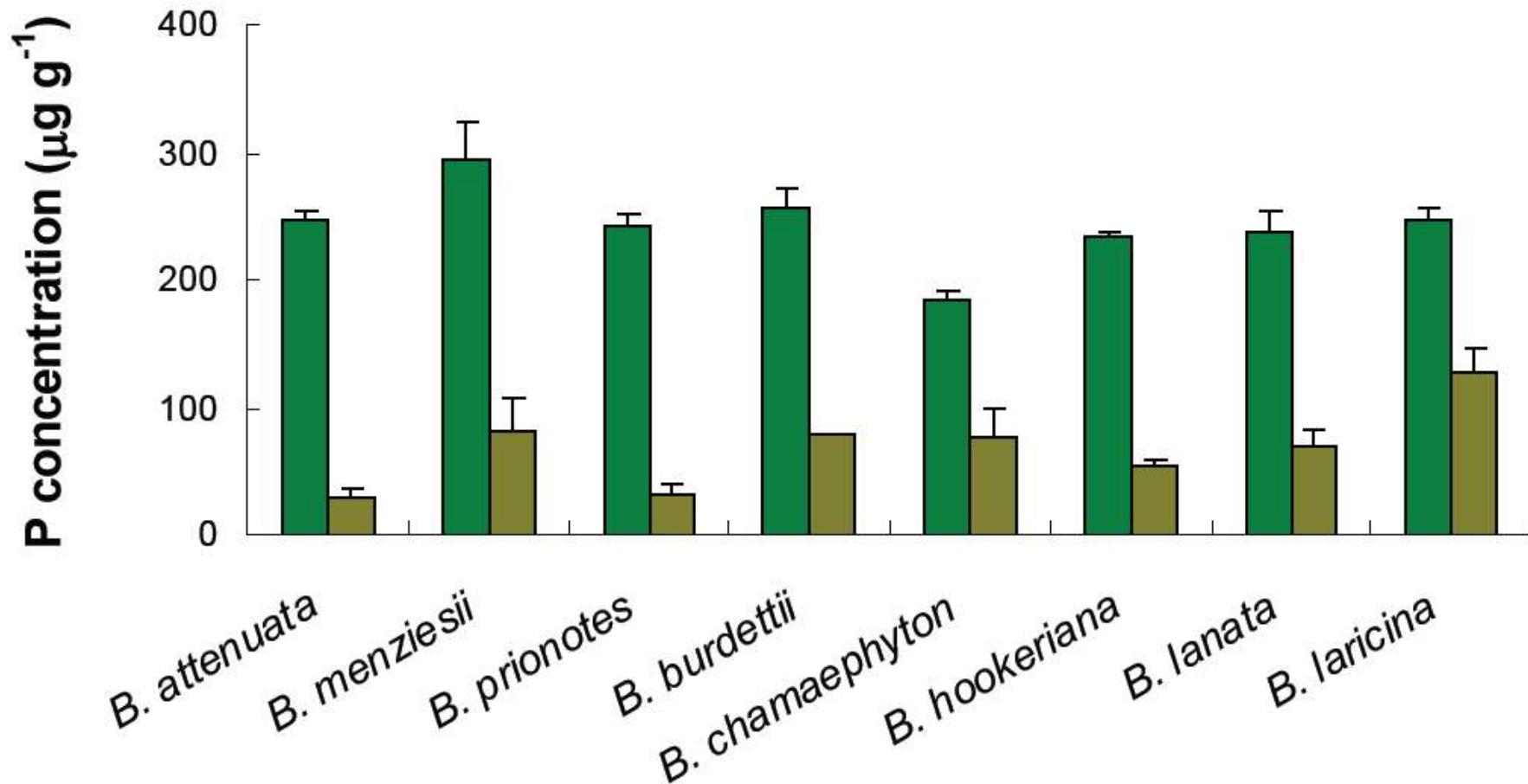
- Many SW Australian Proteaceae species function at **extremely low leaf P** concentrations
- Many SW Australian Proteaceae species have very **high rates of photosynthesis** per unit of **leaf P**



A close-up photograph of a Banksia shrub. The image shows several clusters of bright yellow, spiky flower structures (inflorescences) and some orange, textured seed pods (capsules). The shrub has many thin, greyish-brown branches with small, green, needle-like leaves.

Banksias have a tremendous capacity to remobilise phosphorus from old tissues before these are lost

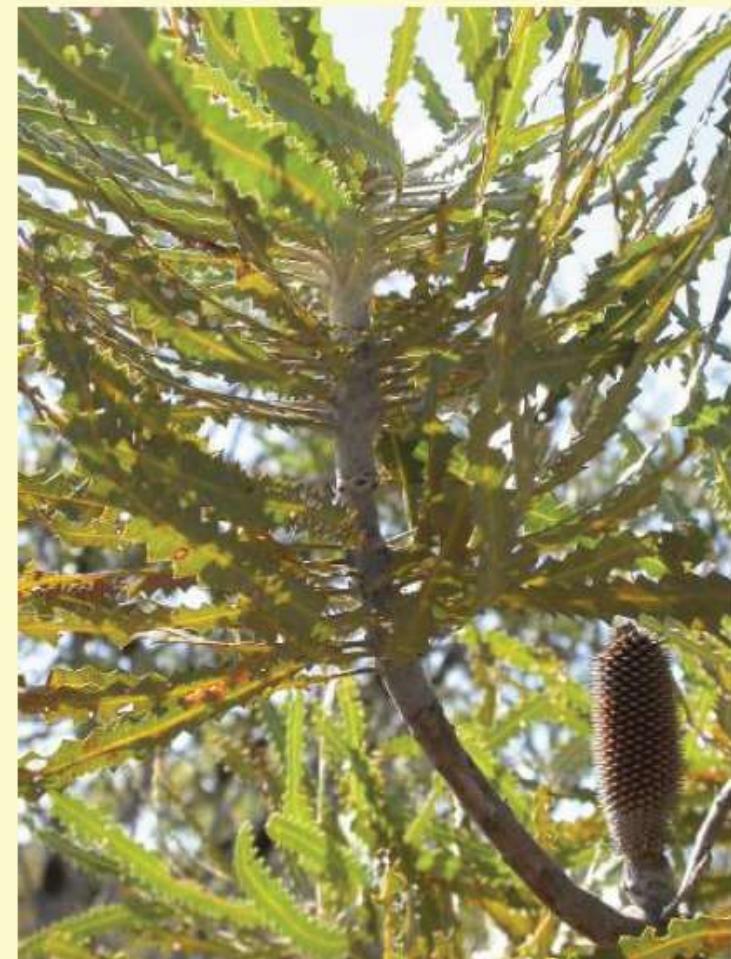
Phosphorus concentrations in young and senesced leaves of a range of *Banksia* species (Proteaceae)



Denton, M.D., Veneklaas, E.J., Freimoser, F.M. & Lambers, H. 2007. *Plant Cell environ.* **30**: 1557-1565.

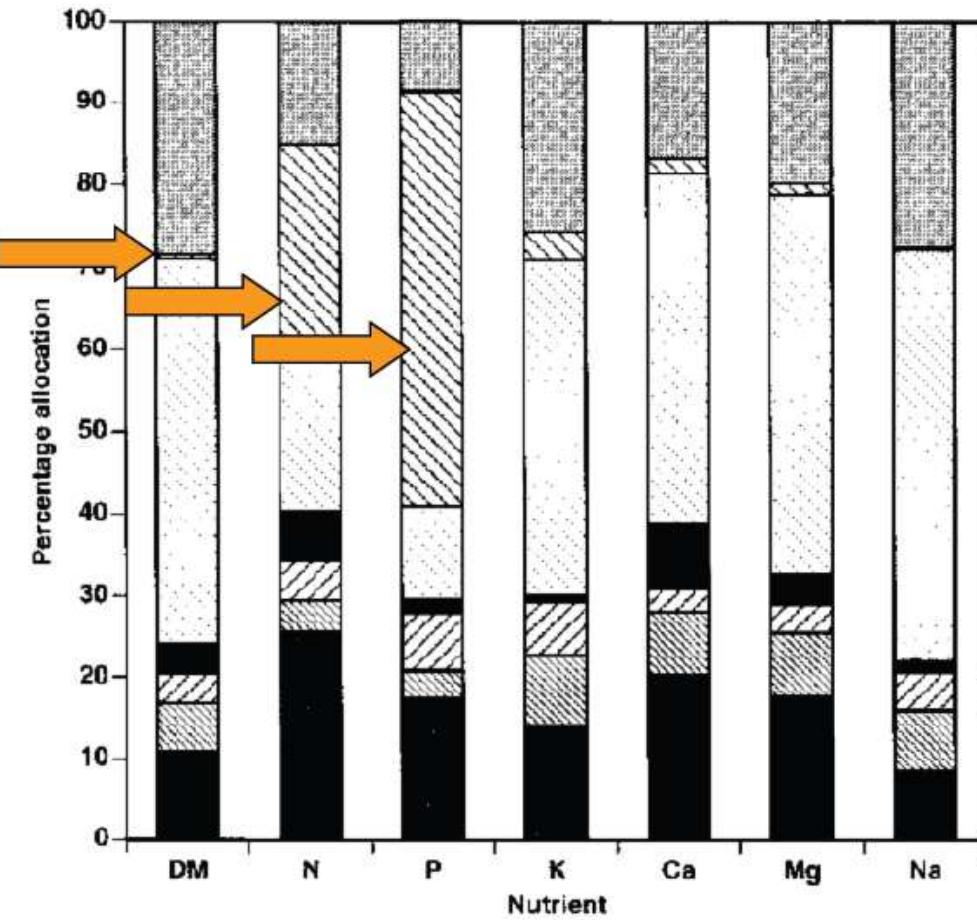
Conclusions re phosphorus remobilisation from senescing leaves and roots

- Banksia species in south-western Australia are extremely efficient at remobilising phosphorus from their senescing leaves
- They reduce the phosphorus concentration in senescing leaves further than any other species does





Proteaceae have
very high seed P
concentrations



Witkowski, E.T.F.
& Lamont, B.B.
1996. *Oecologia*
105: 38-42.

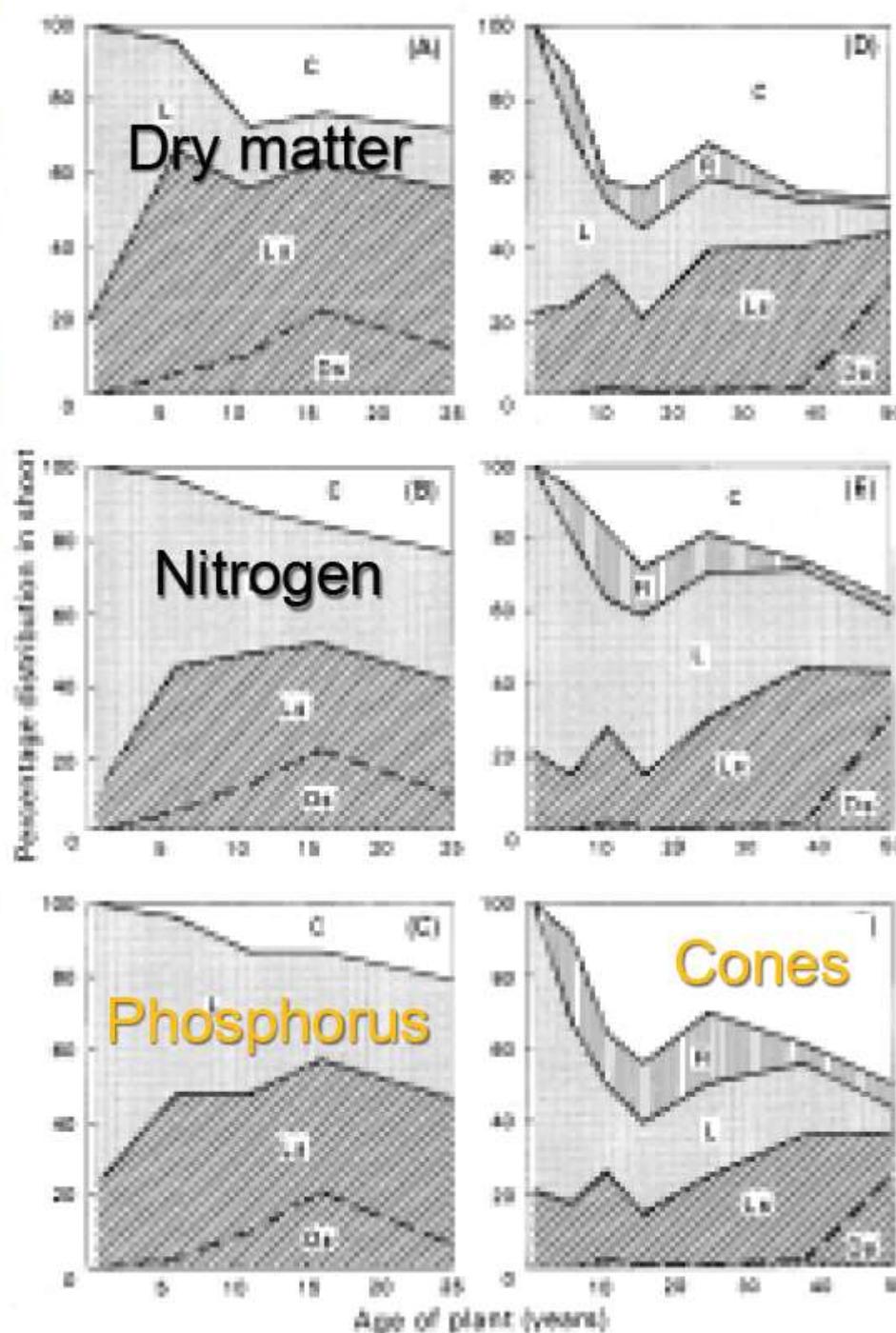
Percentage allocation of dry mass and nutrients to various above-ground components of *Banksia hookeriana*





resprouter

Groves, R.H., Hocking, P.J. & McMahon, A. 1986. Distribution of biomass, nitrogen, phosphorus and other nutrients in *Banksia marginata* and *B. ornata* shoots of different ages after fire. *Aust. J. Bot.* 34: 709-725.



seeder

Average phosphorus concentrations (mg g⁻¹ dry weight) in seeds of Western Australian Proteaceae and of a wide range of crop species



Proteaceae look after their offspring!

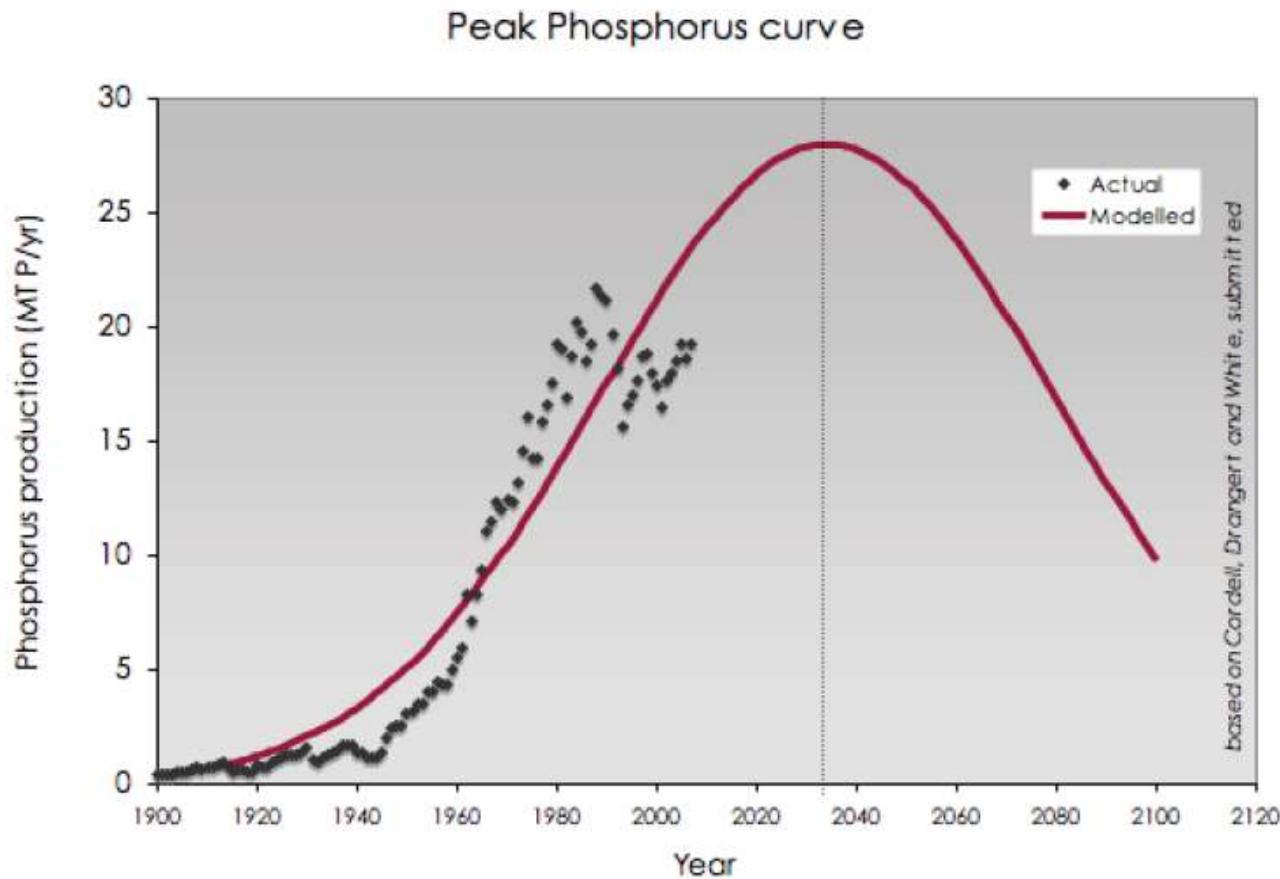
Denton, M.D., Veneklaas, E.J., Freimoser, F.M. & Lambers, H. 2007. *Plant Cell Environ.* **30**: 1557-1565.

Marschner, H. 1995. In: *Mineral Nutrition of Higher Plants*.

What traits do species need to be successful in severely P-impoverished landscapes?

- Efficient acquisition to ‘mine’ P that is ‘sorbed’ to soil particles, e.g., cluster roots
 - Efficient use of P in leaf metabolism
 - High P-remobilisation efficiency
 - High seed P content
-
- Proteaceae in south-western Australia have ***all*** these traits

Lifetime of phosphorus reserves



Cordell, D., Drangert, J.-O. & White, S. 2009. The story of phosphorus: Global food security and food for thought. *Glob. Environ. Change* **16**: 292-305.

Concluding remarks

- P-efficient native plants can teach us important lessons for sustainable agriculture
- Species with cluster roots are not only P-efficient on P-impoverished soils, but also on soils where most P is sorbed
- Enhancing P-acquisition efficiency is a good strategy when a large fraction of soil P is sorbed
- Enhancing P-use efficiency is a good way forward for crops in general

Acknowledgements

- **Mark Brundrett, Greg Cawthray, Matt Denton
Pat Finnegan, Etienne Laliberté, Stuart Pearse,
Michael Shane, Erik Veneklaas, Karl-Heinz
Wyrwoll**
- **Mariana Cruz Campo, Graham Zemunik, Martin
de Vos (UWA/Utrecht University)**
 - Margaret McCully,
- **Michael Cramer, Patrick Giavalisco, Steve
Hopper, Rafael Oliveira, Wolf Scheible, Mark
Stitt, Ronan Sulpice, Ben Turner**
- **Ian Wright & Peter Reich for permission to
access the glopnet database**
 - Australian Research Council