Forests and the carbon cycle: *up and down the scales we go.*

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Background to my talk

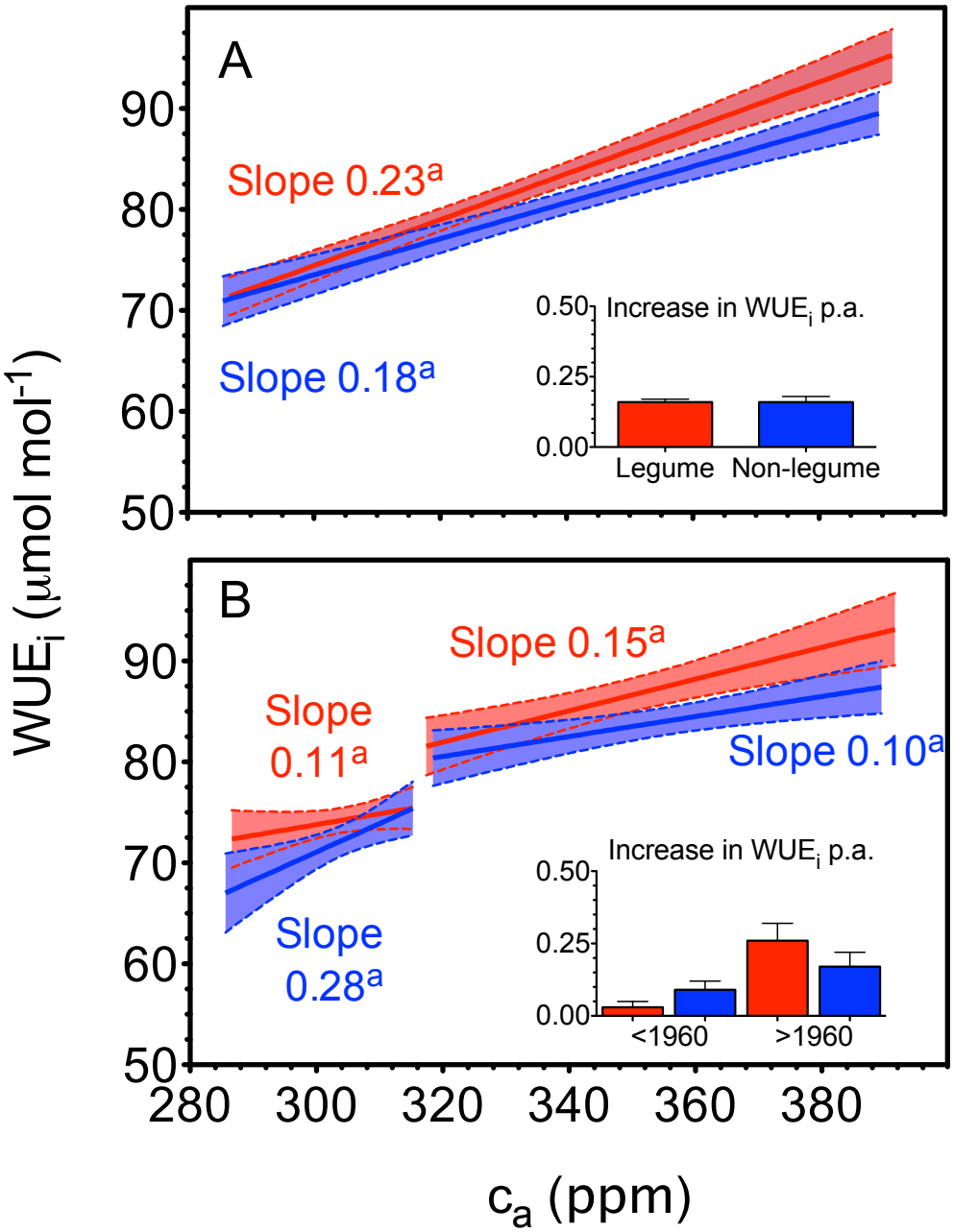
- Rising atmospheric [CO_2] seems sure, for at least the next decade or three…
- Changes in hydrological cycle are much less certain – amplitude and direction of change are hard to predict
- Nitrogen cycle – is it really coupled to the carbon cycle and (how) does it serve to limit the C cycle?
- Driving question: will forests save us?
  - A.k.a. a miner looking for a speck of gold

Carbon and forests

- The past 20 years has seen extraordinary growth in carbon models at all scales, but especially the global scale. These in turn draw upon (but are not limited to):
  - Climate models, at a range of scales;
  - DEMs, digital soil models, hydrological models, etc
  - Eddy flux data from stations within multiple continental networks;
  - Remote sensing capabilities (LAI, many attributes of leaf and land surfaces)

Example 1. Tropical forests

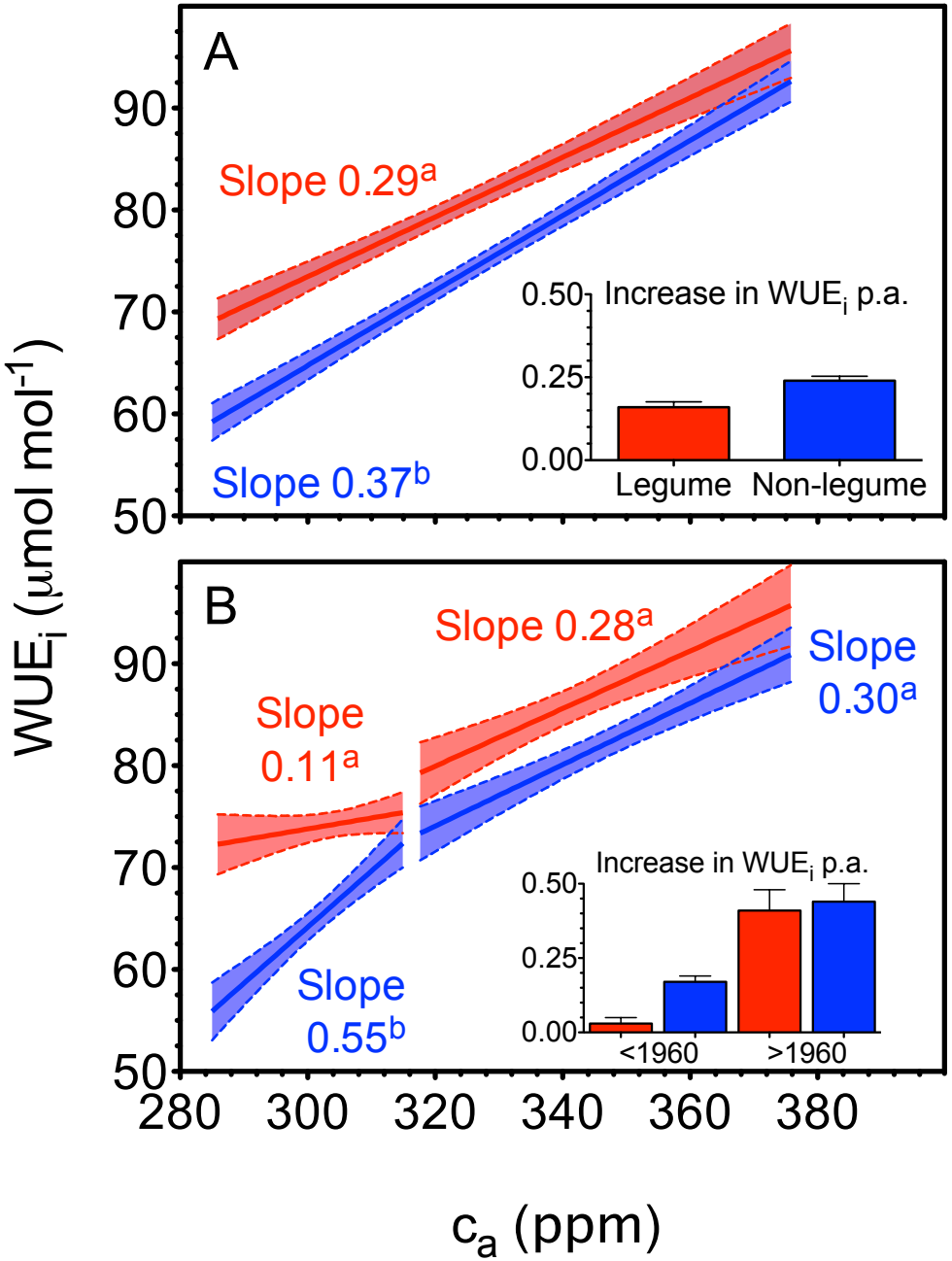
- Tree ring (Battipaglia *et al. PLoS ONE* 10: e0120962, 2015) and plot-based growth data (Brienen *et al. Nature* 519: 345 – 348, 2015) show that rates of growth of tropical forests are slowing (global models predict increasing growth).
- Numerous papers published in last few years support a hypothesis that wet tropical forests are NOT accumulating carbon faster as a result of rising atmospheric [CO_2].
- But there is good evidence that water use efficiency (WUE) is increasing with atmospheric [CO_2] at the stand and ecosystem scale in temperate and continental climate forests.
- We have evidence fron leaf-scale analysis that WUE depends on nitrogen. (Adams *et al. PNAS* 113: 4098 – 4013, 2016)
- Does this apply at the tree and forest scale in the tropics?



Original data from:
van der Sleen *et al.* *Nature Geosci* 8: 24 – 28, 2014

1100+ trees in Cameroon, Bolivia, Thailand

Adams and Turnbull, unpublished data



All available tree ring data from wet tropical forests.
van der Sleen data (less suppressed trees) + Indonesia, Brazil, Borneo, Peru.

- Our synthesis, and numerous other studies, suggest increasing WUE is a consistent response of forests to rising atmospheric [CO_2], not just in the wet tropics, but across temperate, arid/semi-arid, and continental forests.
- Legumes (and seemingly nitrogen), play a role in that increased WUE.

Example 2. Temperate forests

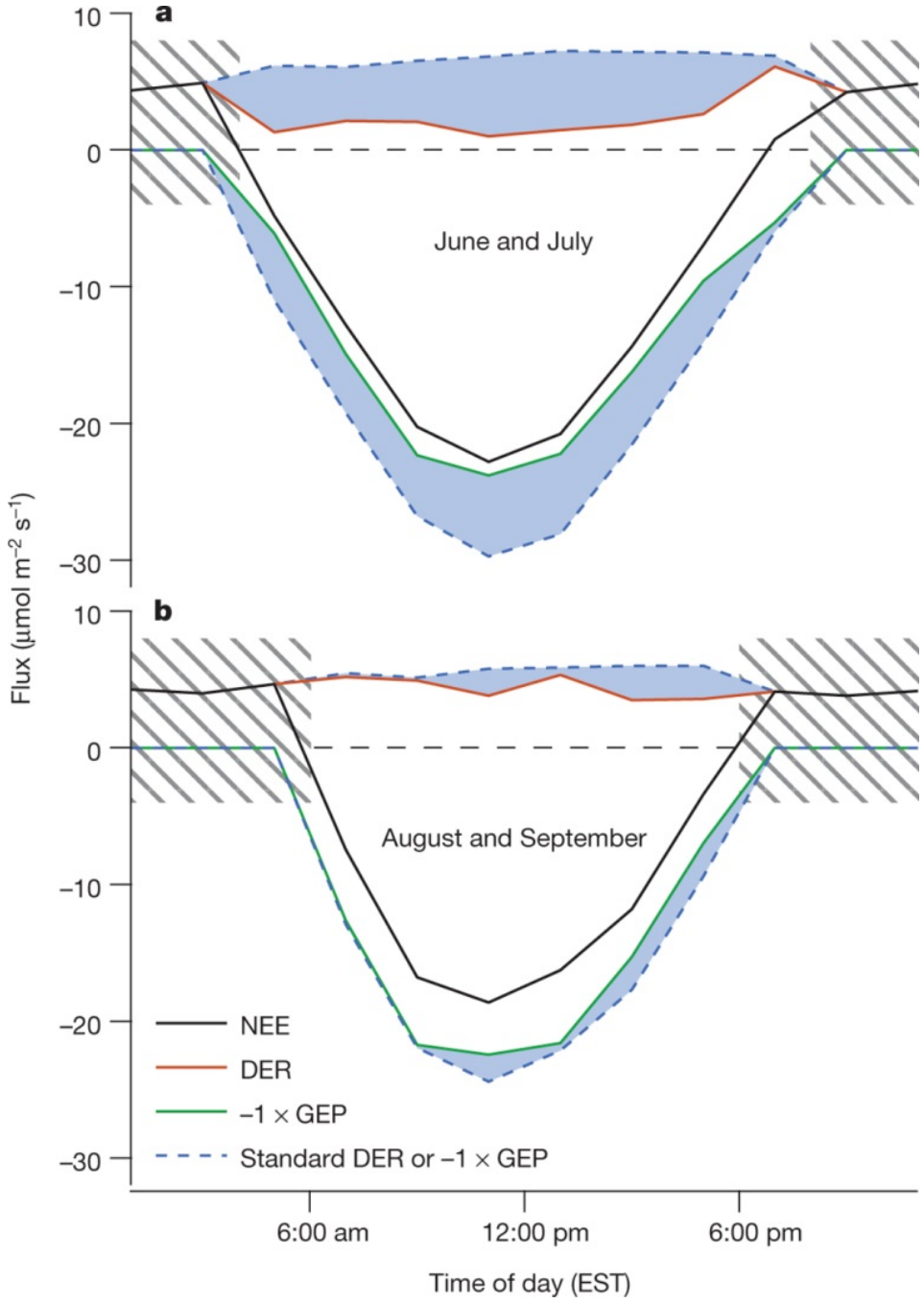
From Wehr *et al.* Nature 534: 680 – 683, 2016.

"The consequent view of temperate deciduous forests (an important CO_2 sink) is that, first, ecosystem respiration is greater during the day than at night; and second, ecosystem photosynthetic light-use efficiency peaks after leaf expansion in spring and then declines, presumably because of leaf ageing or water stress. This view has underlain the development of terrestrial biosphere models used in climate prediction and of remote sensing indices of global biosphere productivity."

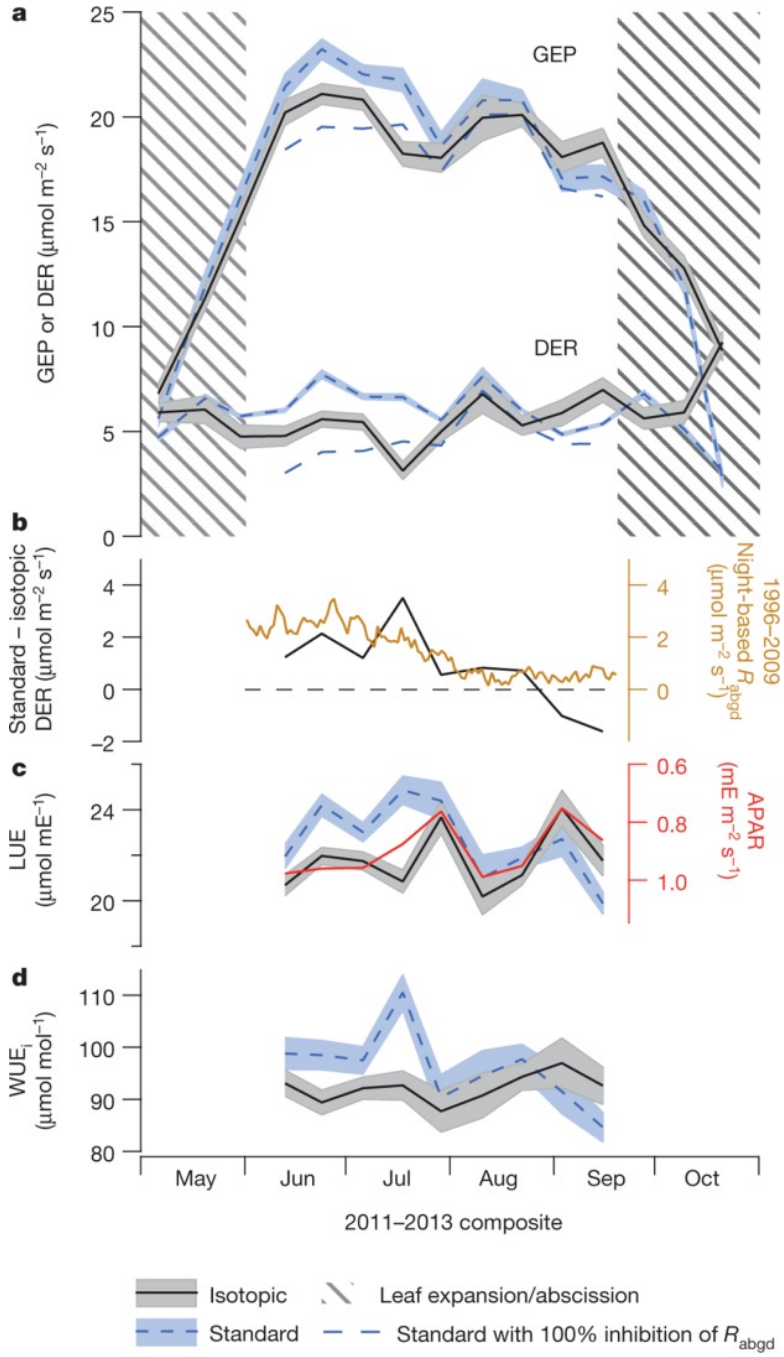
Also from Wehr *et al.*

- *For example, the oldest, simplest, and still most commonly adopted hypothesis is that DER follows the same function of air or soil temperature as does night-time ecosystem respiration, which is directly observable as night-time NEE*
- *Another common partitioning hypothesis is that DER follows a function of air temperature of the same form found to apply to night-time NEE (but not necessarily with the same parameter values), while GEP follows a saturating function of photosynthetically active radiation (PAR) of the same form found to apply to individual leaves*

R Wehr *et al. Nature* **534,** 680–683 (2016) doi:10.1038/nature17966



Using a novel isotope approach, Wehr *et al*. showed that photosynthesis and daytime respiration at the Harvard Forest are less than predicted in the first half of the growing season



Also, composite seasonal cycles of GEP and DER indicate strong inhibition of aboveground respiration by light and sustained photosynthetic efficiency

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Wehr *et al.* study:

- Provides ecosystem scale support for the many leaf-scale studies of the Kok effect – inhibition of respiration in the light.
- Provides some support that rates of respiration (dark/light) are mostly temperature-driven at a global scale (see also Heskel *et al. PNAS* 113: 3832 - 3837, 2016; Adams *et al. PNAS*, in press).
- Argues that for deciduous trees, photosynthetic LUE changes little within the growing season.

Example 3. Arid woodlands and shrublands

I recently posed a question to Professor Dan Binkley:

How do those woody plants, that we see throughout arid and semi-arid Australia, cope with radiation loads (365 days a year) that would (and do) kill people within days?

He replied:

- The background (null) thinking might be:
- Dissipate the radiation energy with xanthophylls, carotenoids, anthocyanins (the heat release might not be pleasant in a desert…)
- Fix energy with the light reaction chlorophyll, but send it to photorespiration rather than C fixation
- Send it to C fixation, but then simply oxidize the sugar rather than store the excess C – and the CO2 released could be refixed within the leaf, giving a nice, regenerating substrate for more C fixation…
- Alternative pathway respiration (cyanide-resistant) – the heat generated might be a disadvantage in the desert, I realize (some on-going work in Sweden may indicate this pathway is used to warm rhizospheres and foster water uptake (and nutrient) by lowering water viscosity – a cool idea)
- Accumulate high-energy C compounds (oils, etc.)

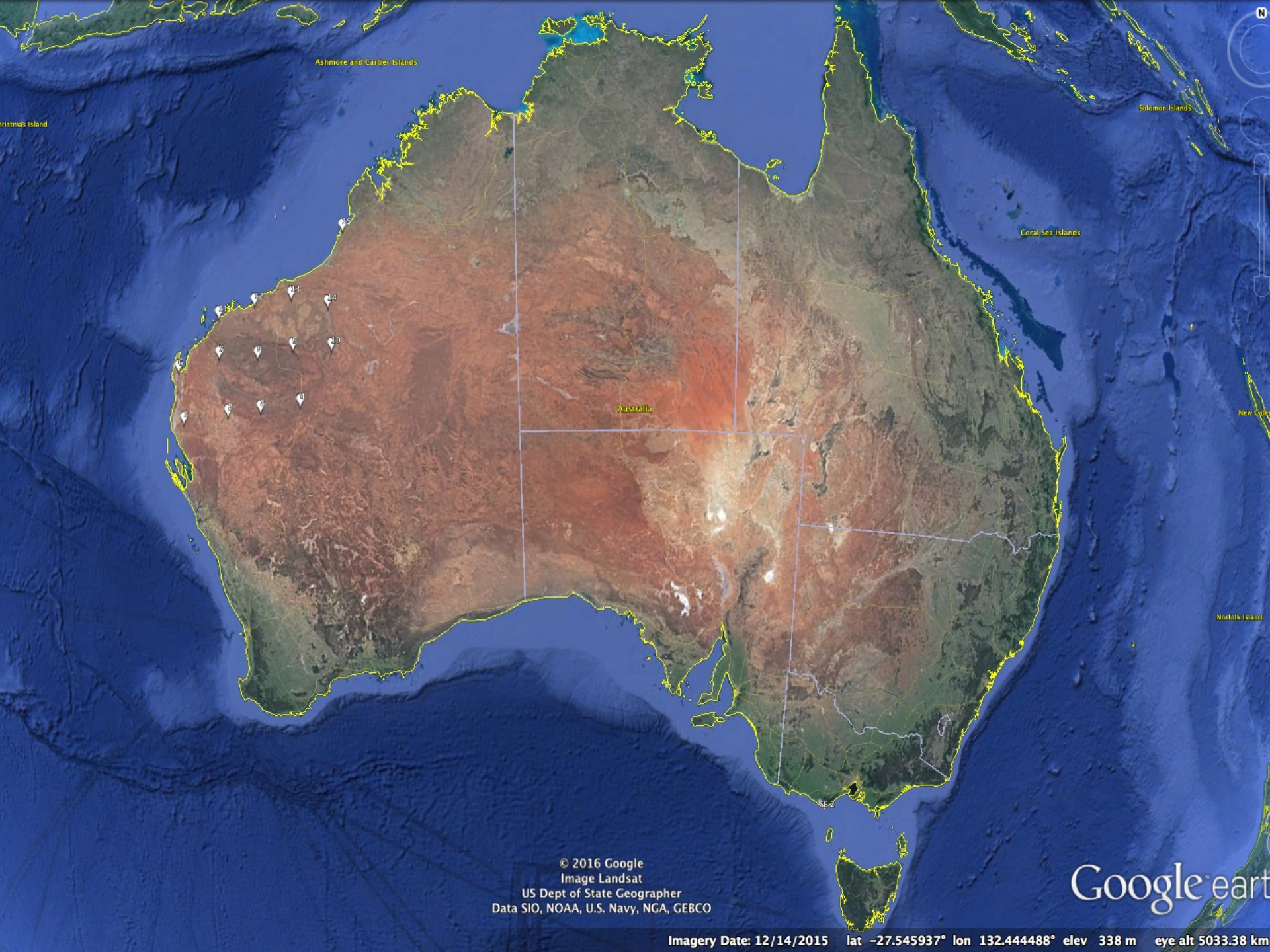
Ashmore and Cartier Islands
Solomon Islands
Coral Sea Islands
Australia
Norfolk Island
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Image Landsat
US Dept of State Geographer
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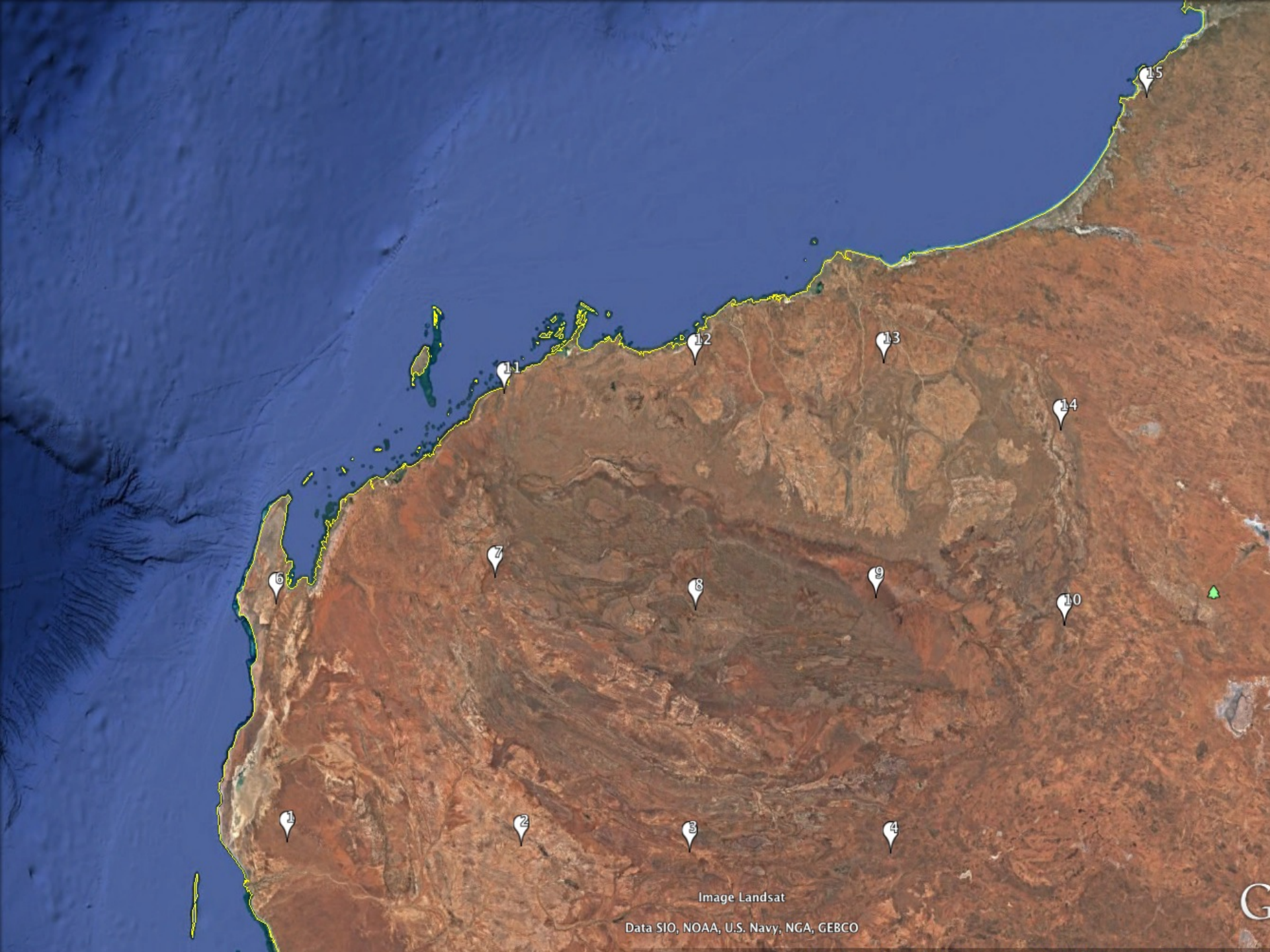
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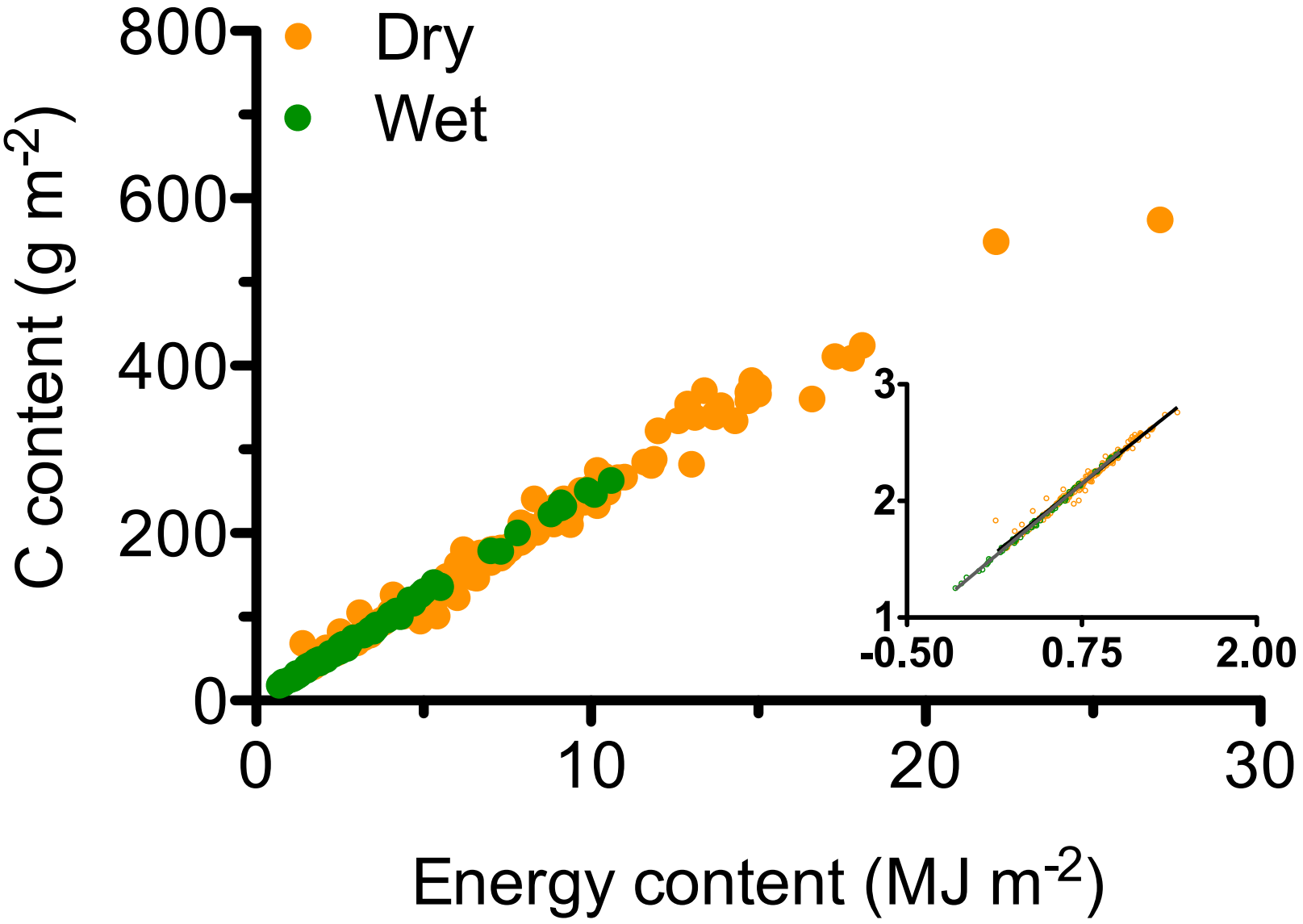
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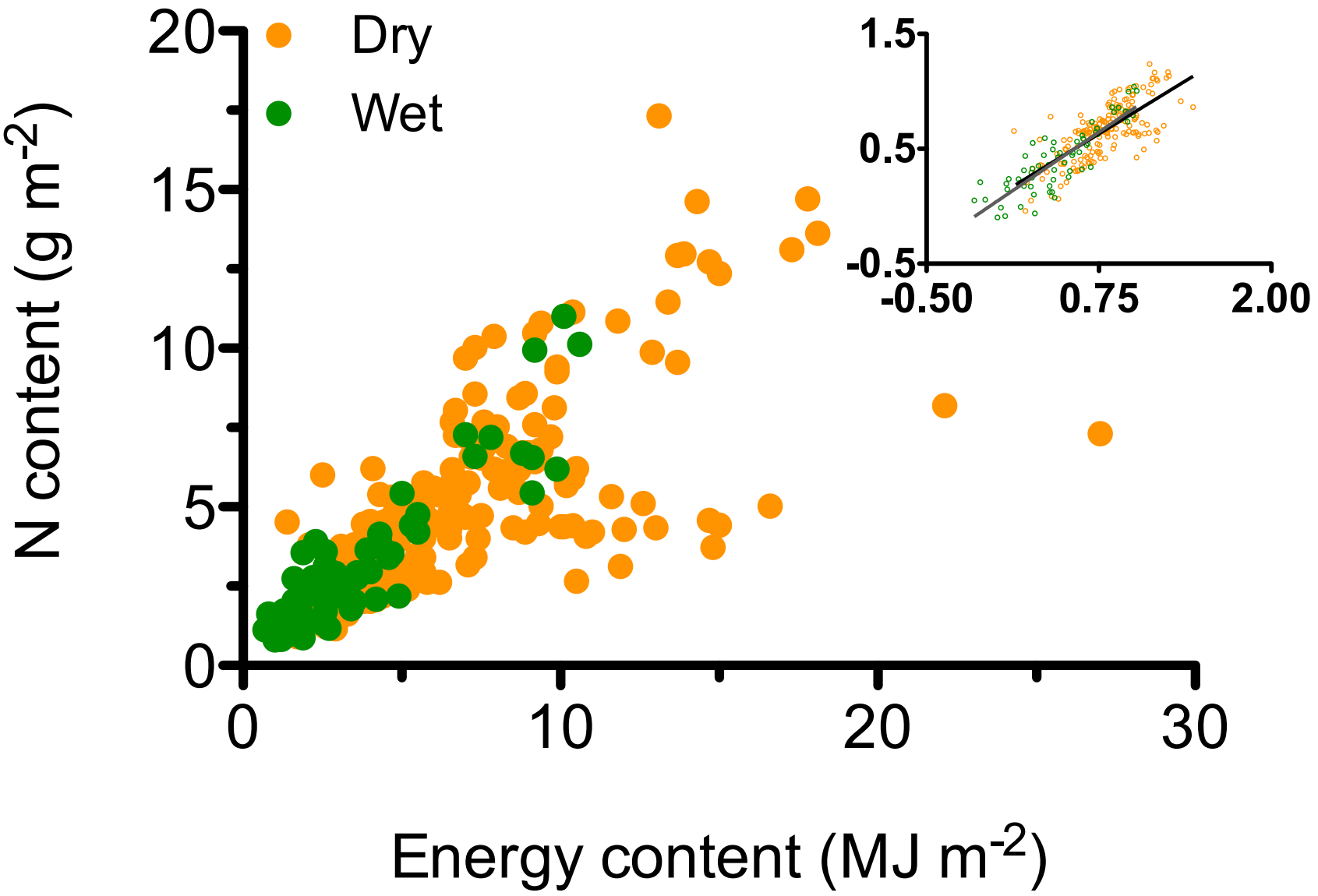
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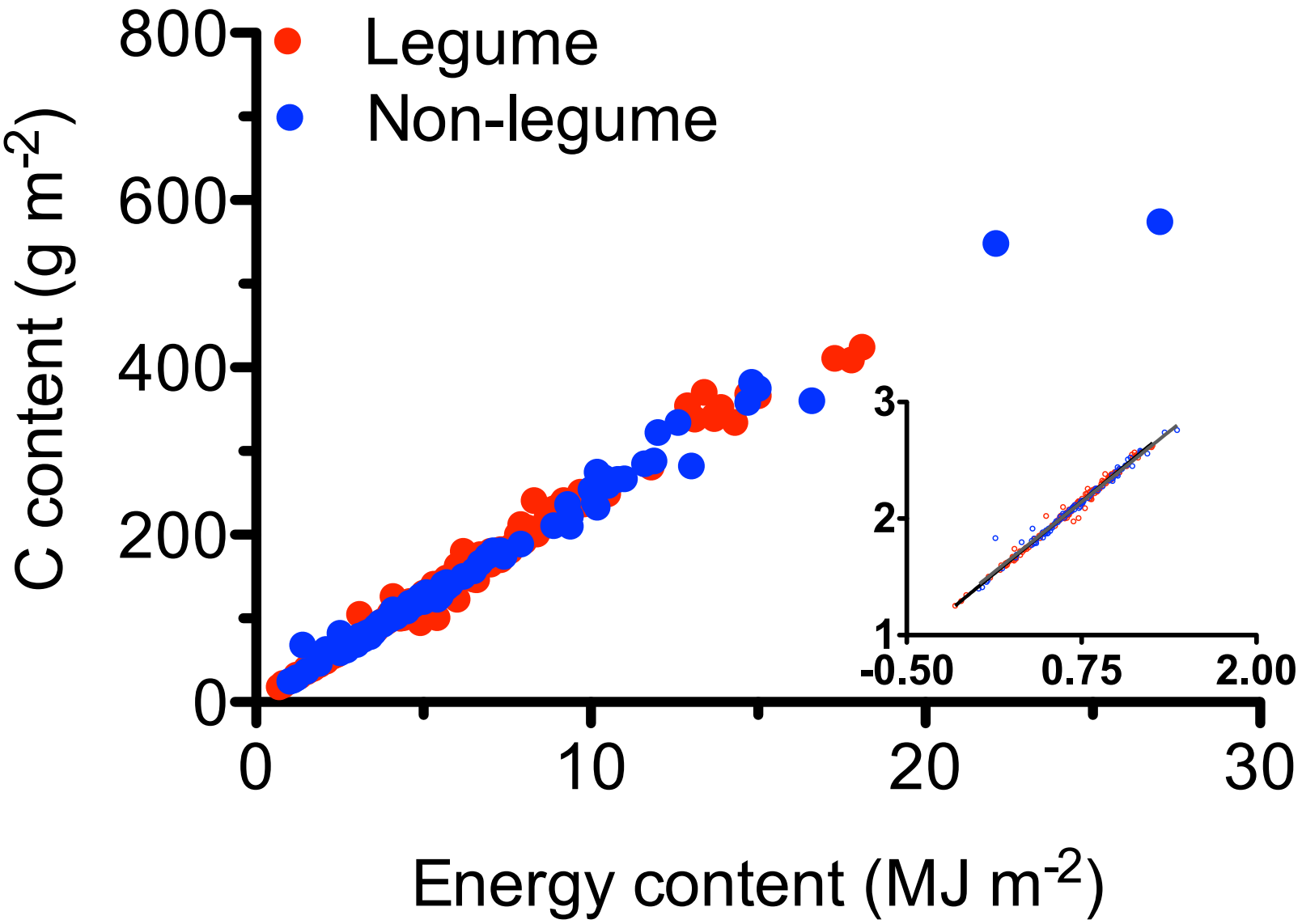
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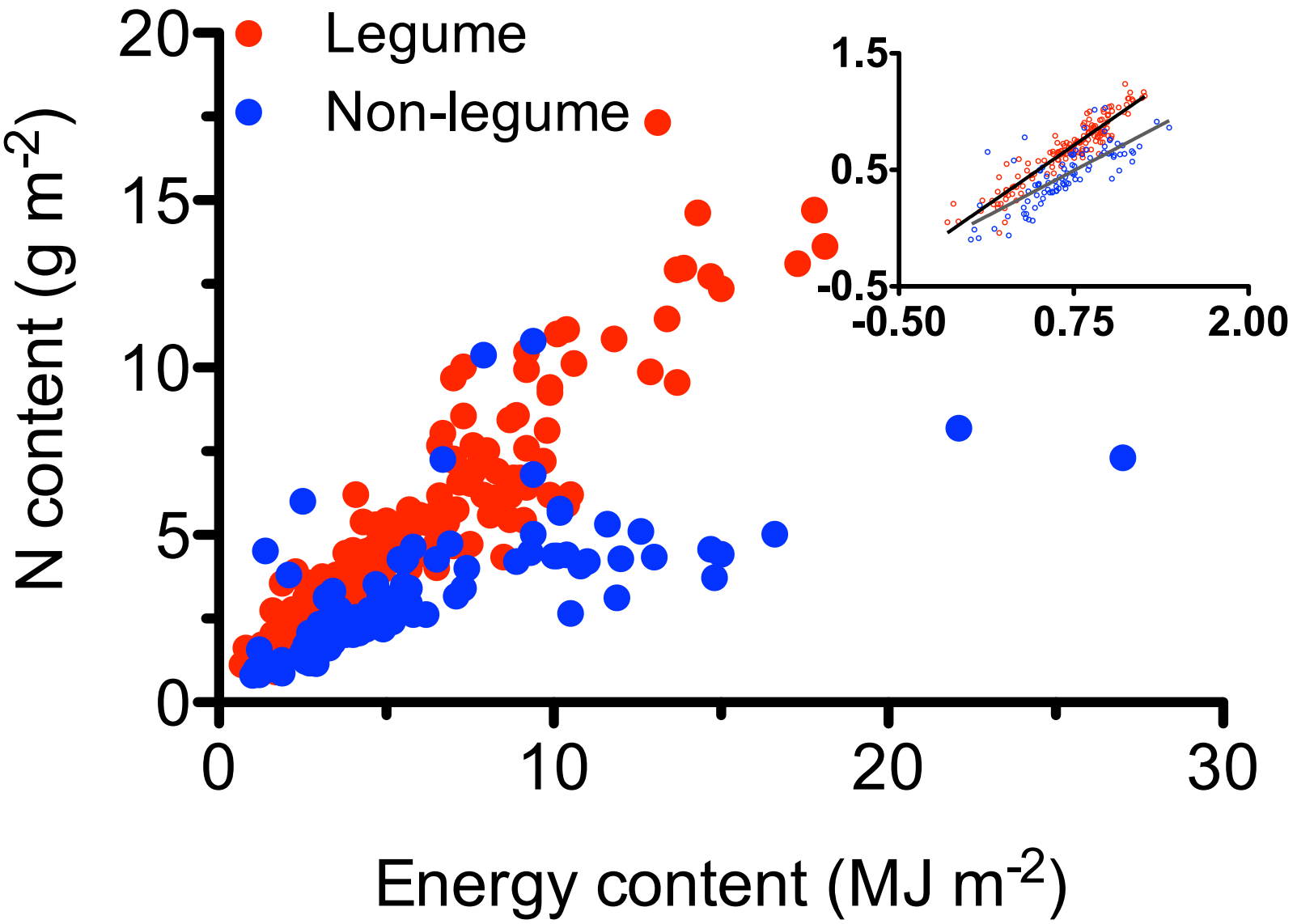
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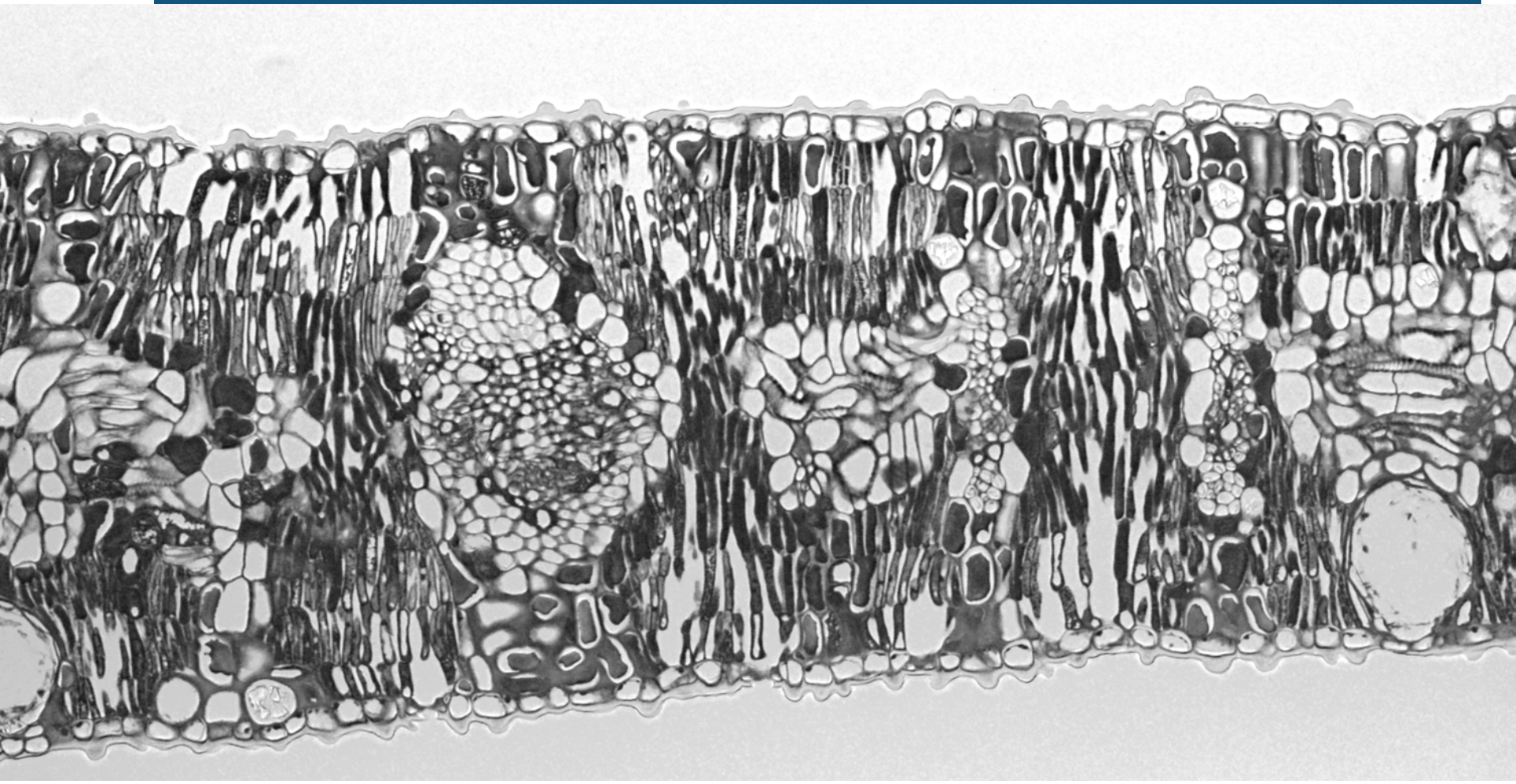
Eucalyptus leucophloia



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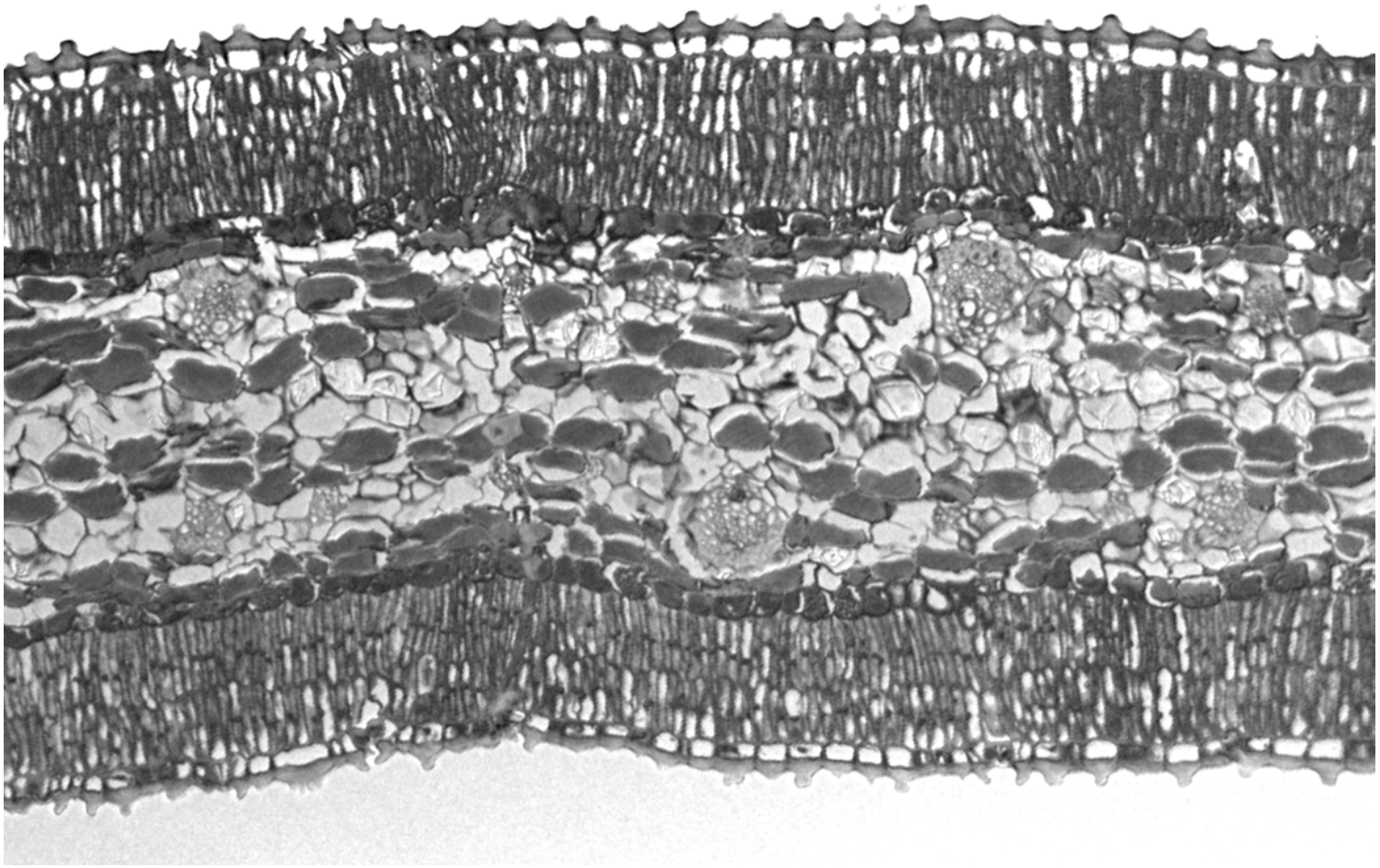
Acacia pruinocarpa



Commentary

- Foliage/leaves of woody plants in arid and semi-arid ecosystems are long-lived.
- New leaves are produced after significant rainfall events, but then 'accumulate' carbon and energy, sometimes for many years.
- Remote-sensing and model approaches to carbon fluxes in these systems are thus highly problematic:
  - Leaf N (mass or area based) may vary 2-3 fold for a given species depending on leaf age
  - SLA (or carbon density per unit leaf area) may vary 2-3 fold for a given species depending on leaf age
  - Light use efficiency varies >10 fold, PNUE >20 fold as leaves age
  - Leaf N / stored energy relationships are very different between legumes and non-legumes

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From Poulter *et al. Nature* 509: 600 – 603, 2014

Here we show that our three terrestrial carbon sink estimates are in good agreement and support the finding of a 2011 record land carbon sink. Surprisingly, we find that the global carbon sink anomaly was driven by growth of semi-arid vegetation in the Southern Hemisphere, with almost 60 per cent of carbon uptake attributed to Australian ecosystems, where prevalent La Nina conditions caused up to six consecutive seasons of increased precipitation. In addition, since 1981, a six per cent expansion of vegetation cover over Australia was associated with a fourfold increase in the sensitivity of continental net carbon uptake to precipitation.

General observations

- The “gold rush” of carbon modeling has helped stimulate research at a range of scales.
- As in all (good) models, assumptions are often “opportunities for research”.
- Wrong assumptions in models are mostly due to deeply imperfect knowledge of processes at stand tree, leaf, cellular and molecular scales (enhancing employment opportunities for empiricists).
- Greater recognition that without a much enhanced effort in “old fashioned” research, more models are not going to help. (i.e. we need research that ‘yields’ knowledge of tree and forest growth; knowledge of leaf, root and stem physiology, etc).
- We (forest scientists) need to present findings in ways that are understandable, coherent, and useful. We should also resist some of the irresponsible reporting of forest science – such as that we see now in Australia.

Yes, I feel like a miner looking for a speck of gold!

Acknowledgements

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