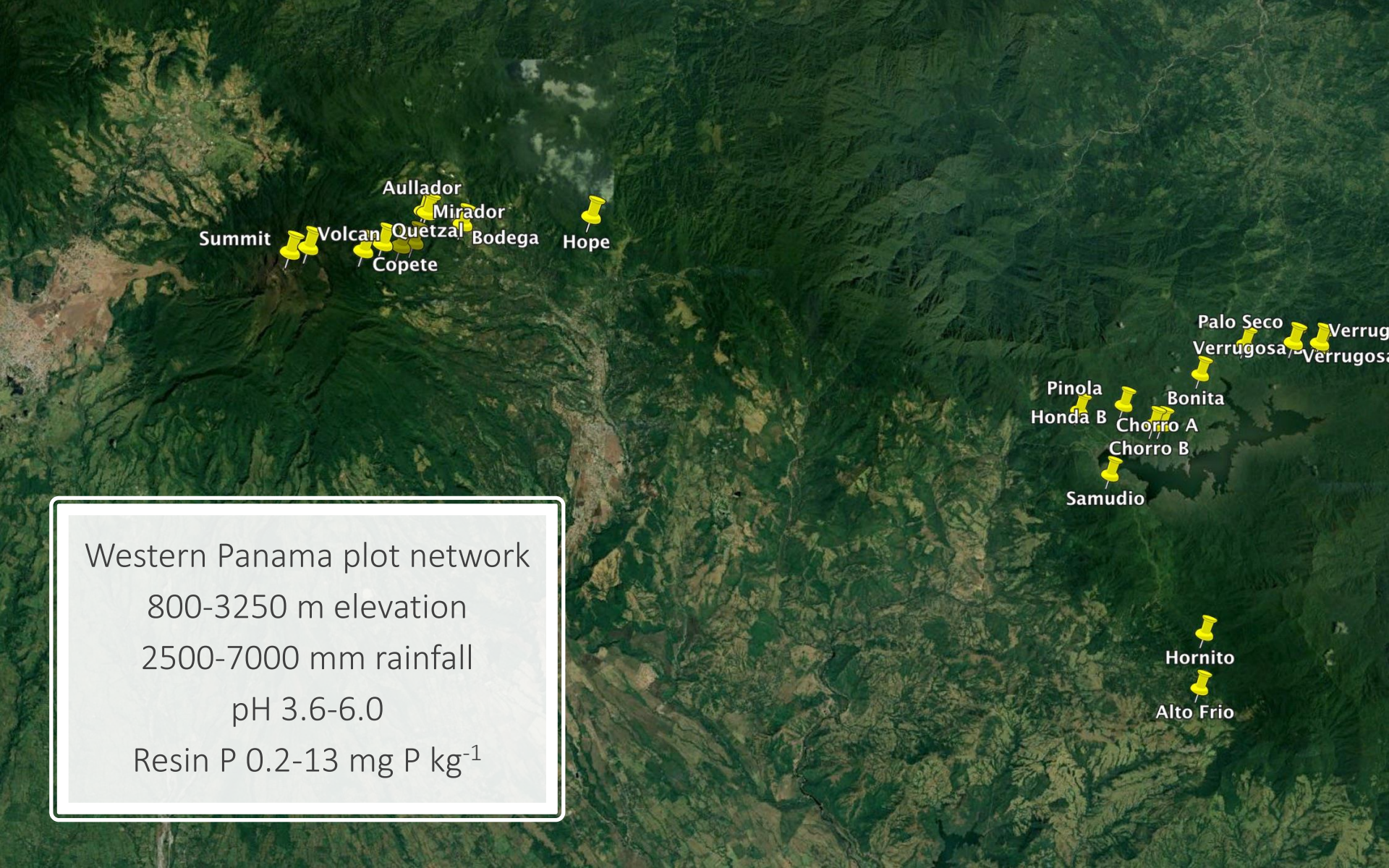
Nutrient limitation in tropical forests

Jim Dalling, University of Illinois at Urbana-Champaign
and Smithsonian Tropical Research Institute, Panama

Jamaica: Grand Ridge of the Blue Mountains

Panama: Barro Colorado Island

http://biogeodb.stri.si.edu/bioinformatics/maps.php



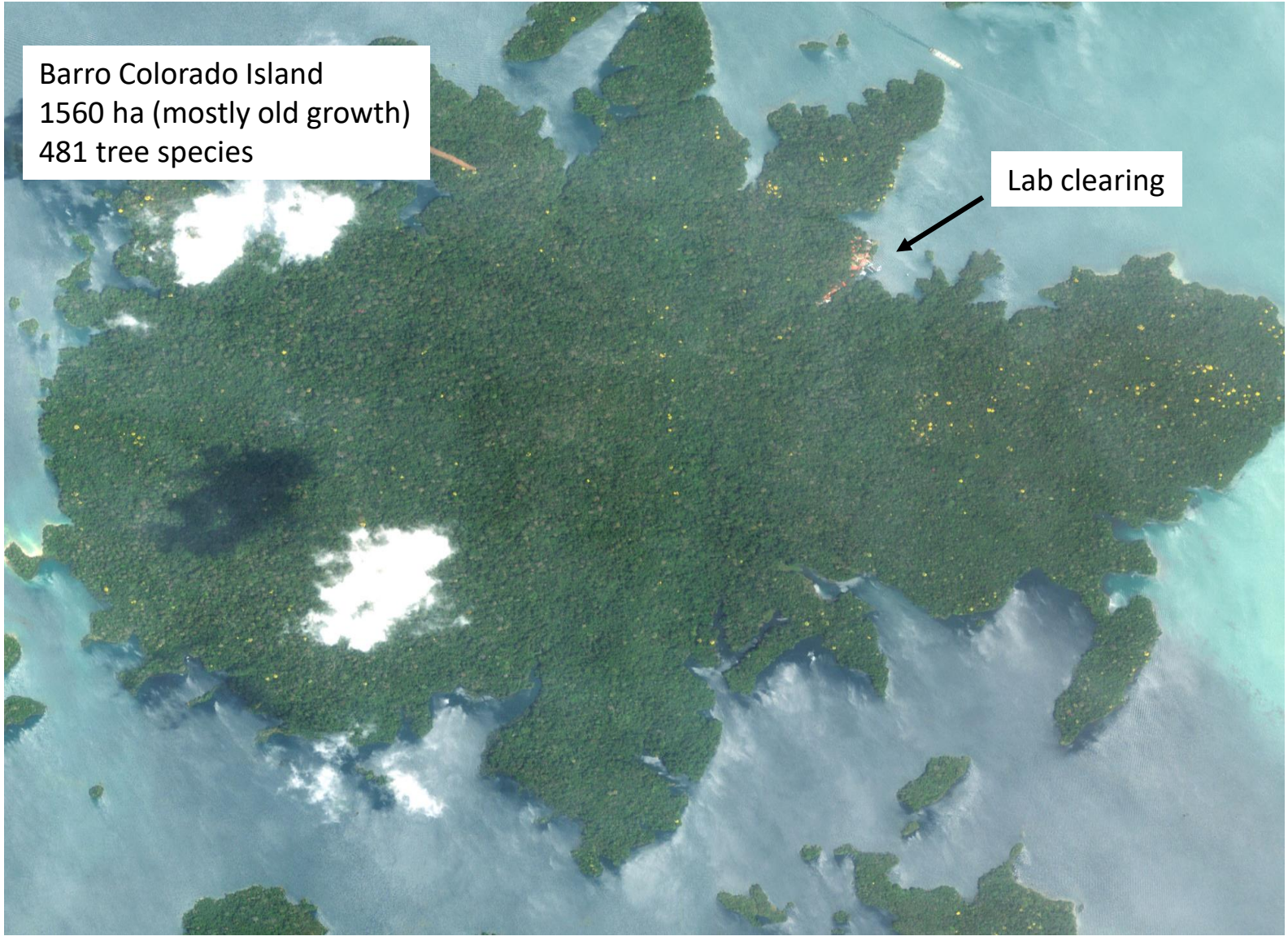
Western Panama plot network

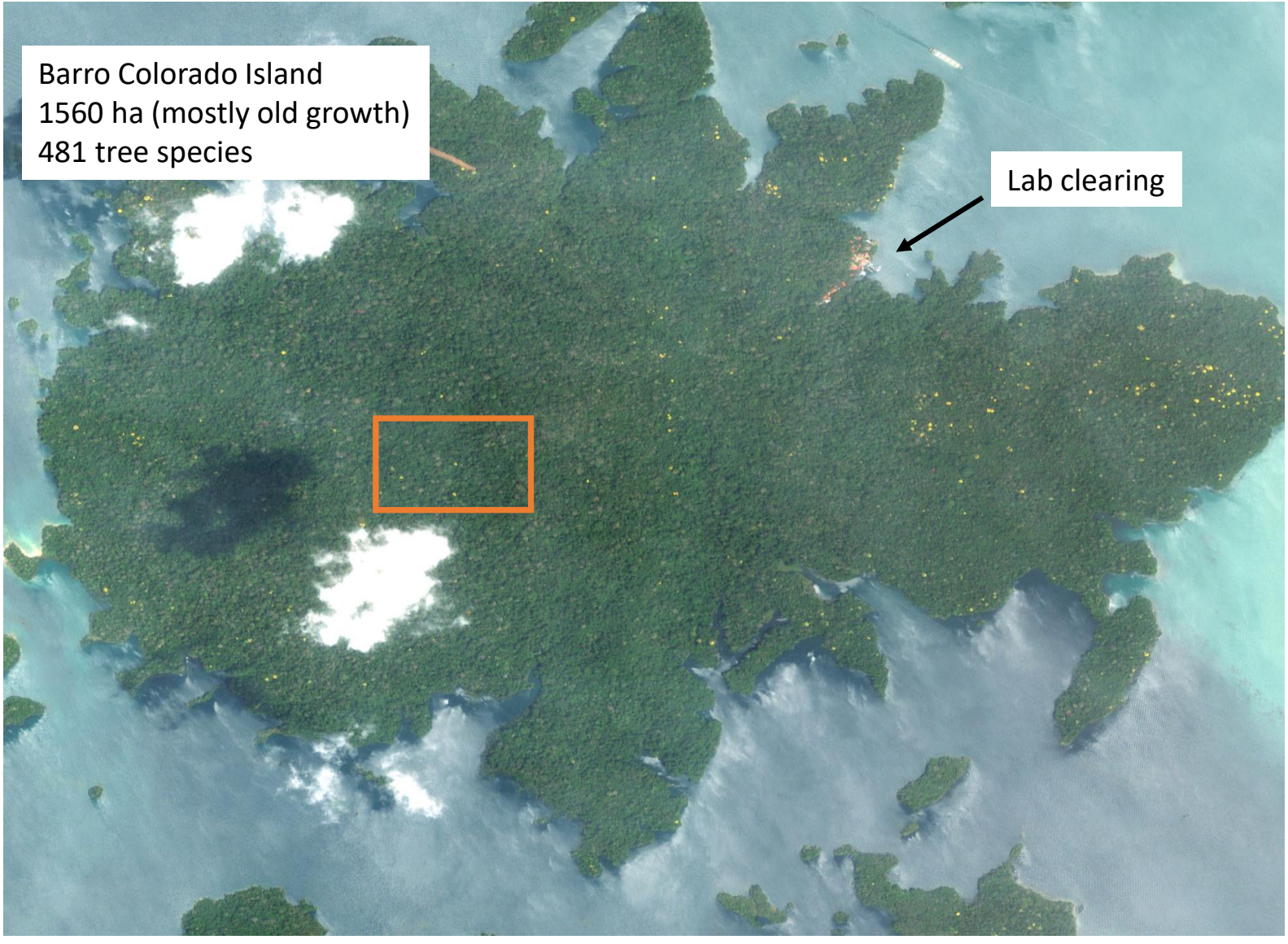
800-3250 m elevation

2500-7000 mm rainfall

pH 3.6-6.0

Resin P 0.2-13 mg P kg^{-1}


Barro Colorado Island
1560 ha (mostly old growth)
481 tree species
Lab clearing

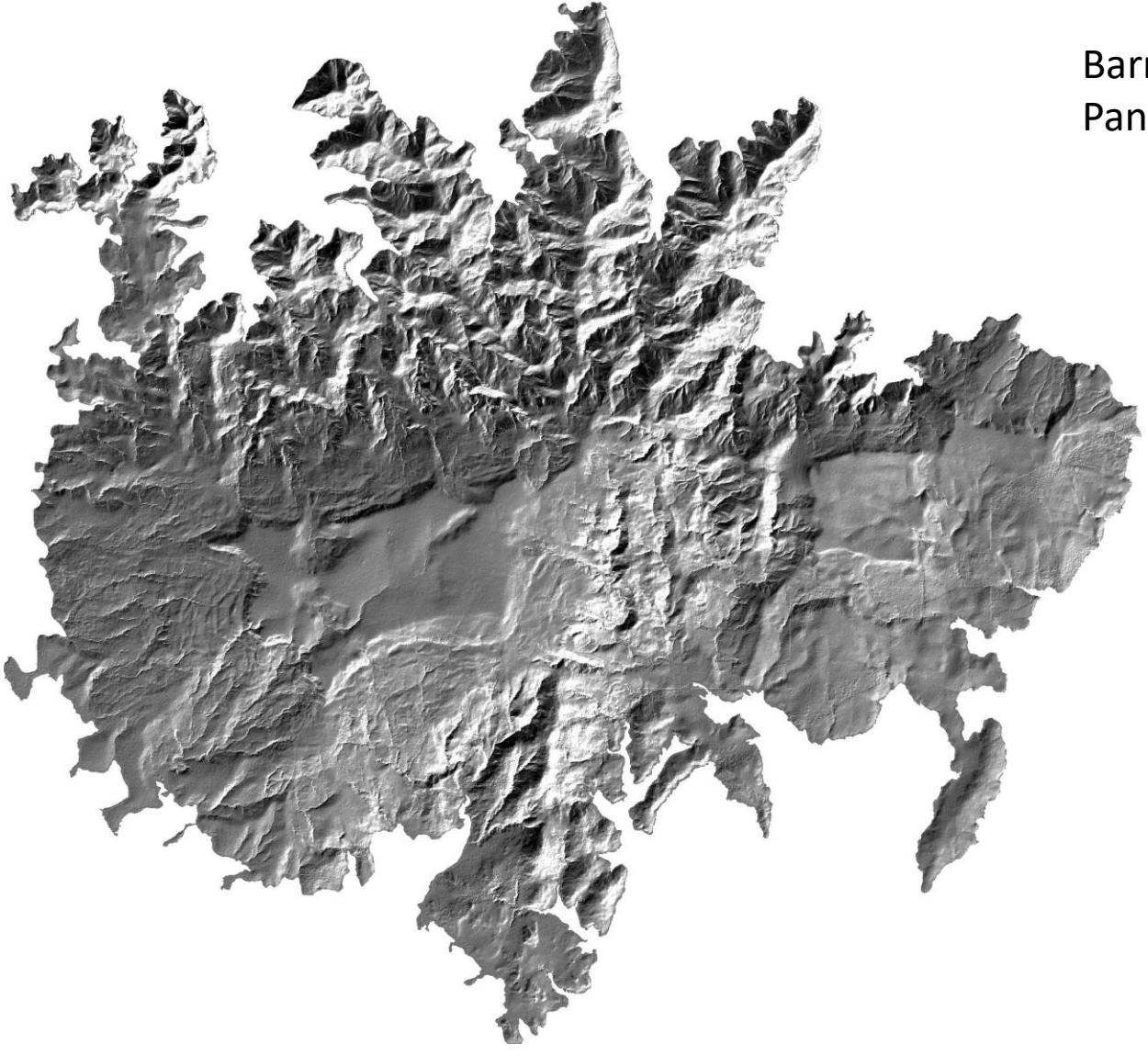

Barro Colorado Island
1560 ha (mostly old growth)
481 tree species
Lab clearing

A typical tropical forest soil?

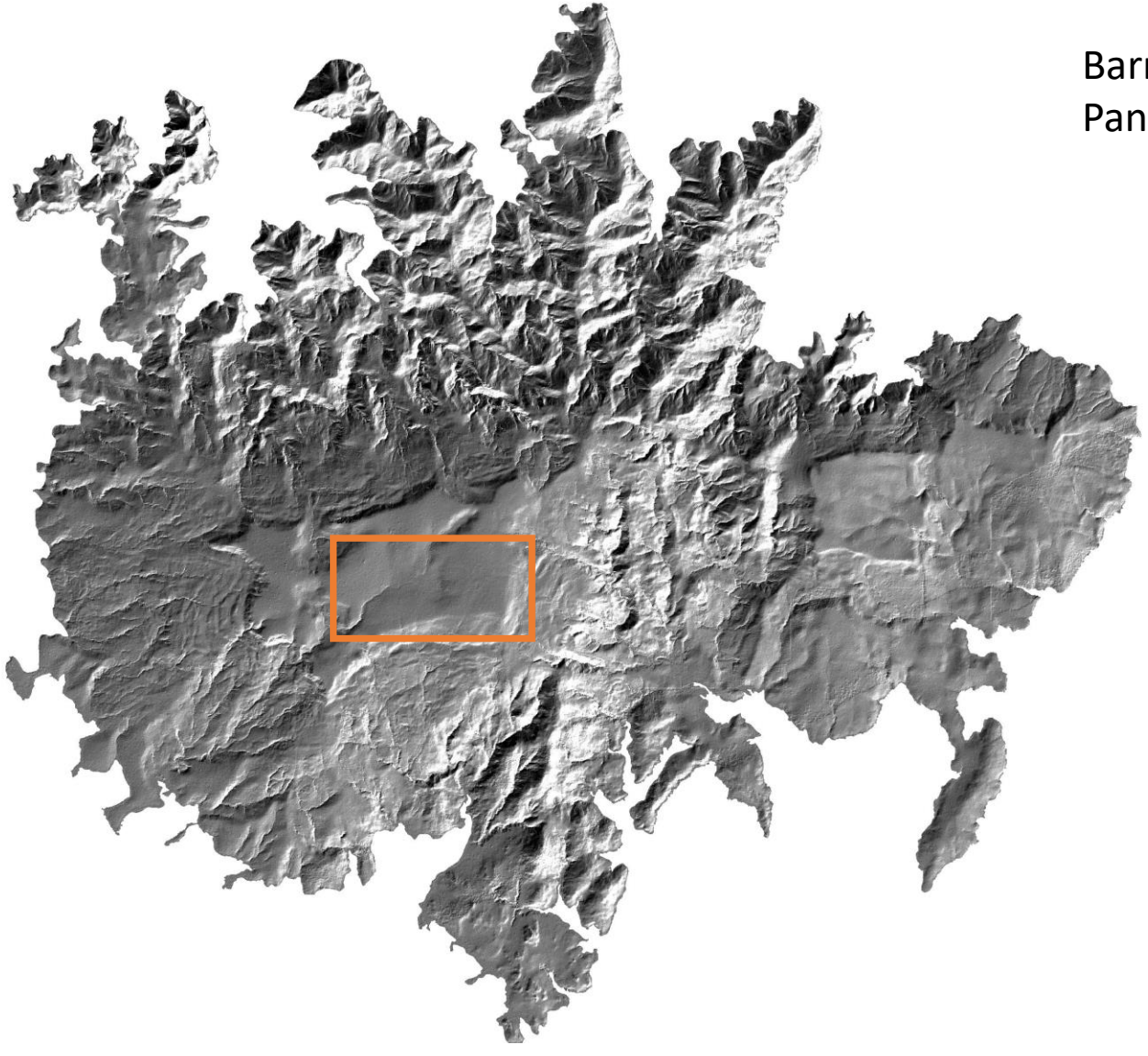
An oxisol soil from Barro Colorado Island, Panama

~1 ppm extractable P

- Organically enriched surface horizon
- Uniform yellow-red subsoil
- Weathering of clay minerals to ferric sesquioxides
- low pH, low CEC
- High Al saturation
- Strong P adsorption to Fe and Al oxides

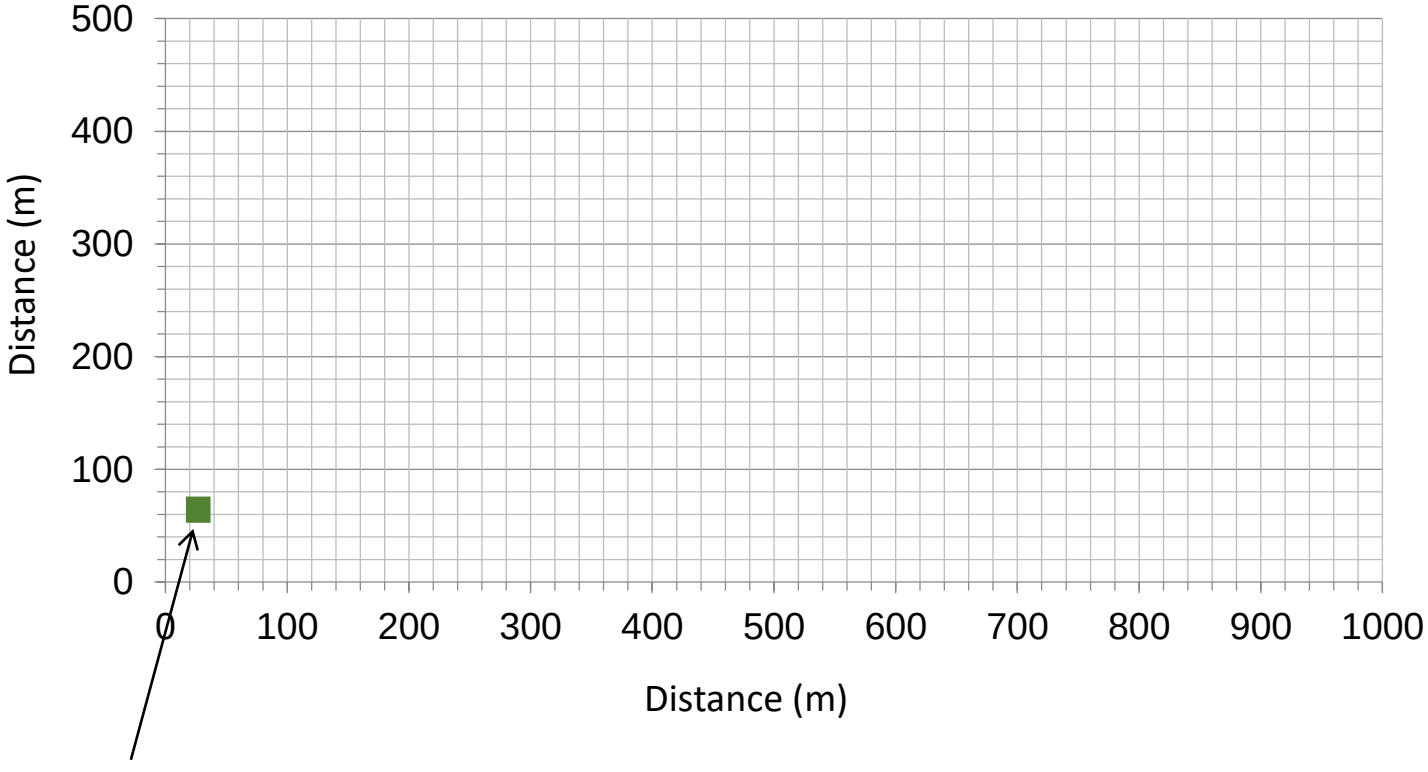


Barro Colorado Island
Panama



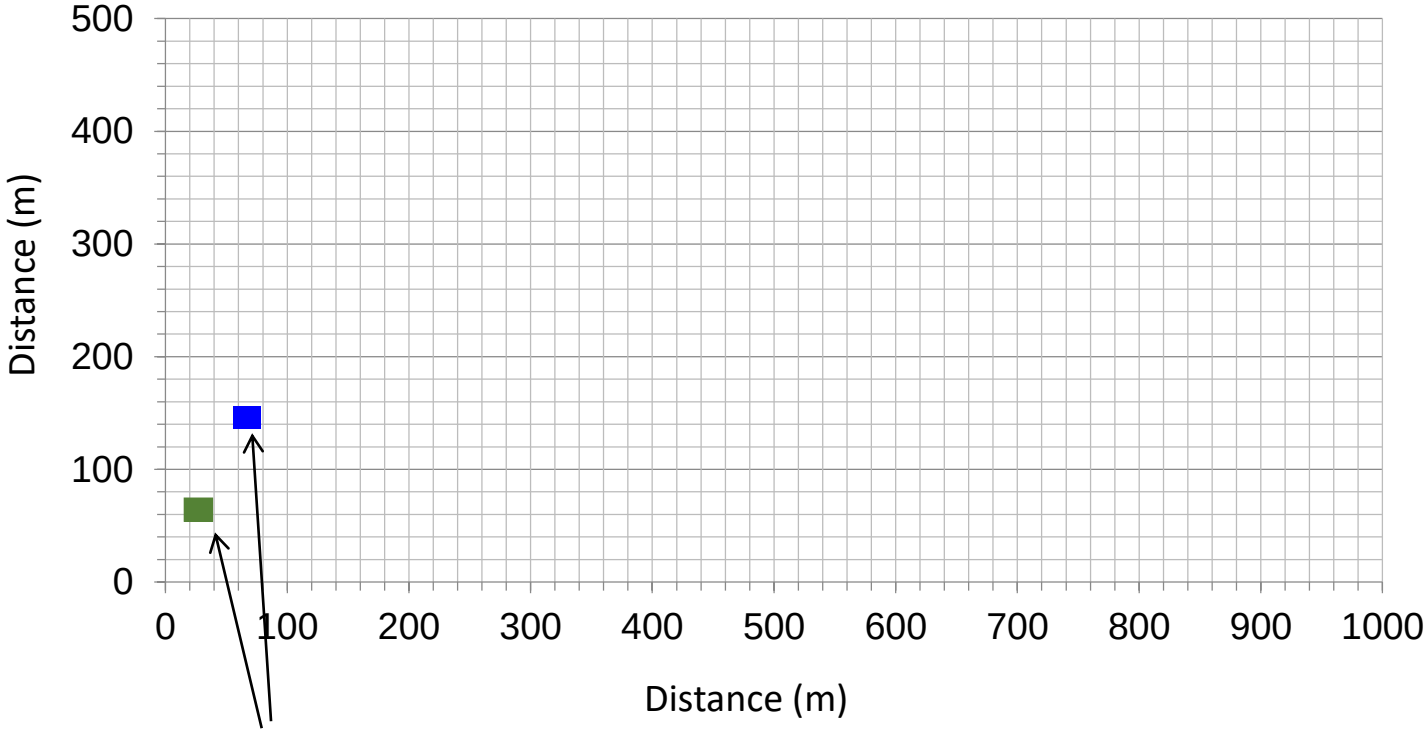
Barro Colorado Island
Panama

50 ha forest dynamics plots are gridded in 20 m x 20 m quadrats



~ 20-30 individual trees >10 cm diameter at breast height (DBH)
~ 5-10 canopy trees
~ 10-15 tree species >10 cm DBH

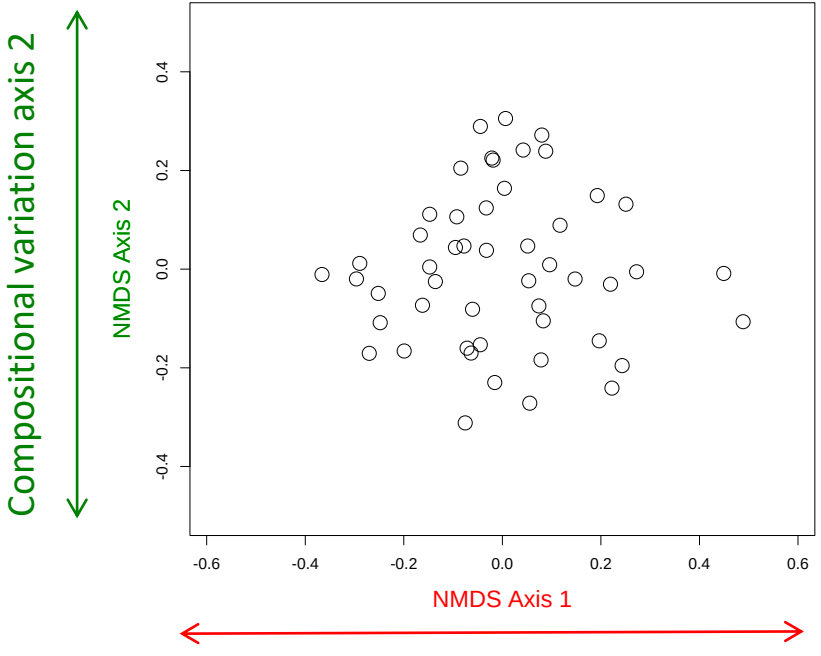
Compositional variation across a plot



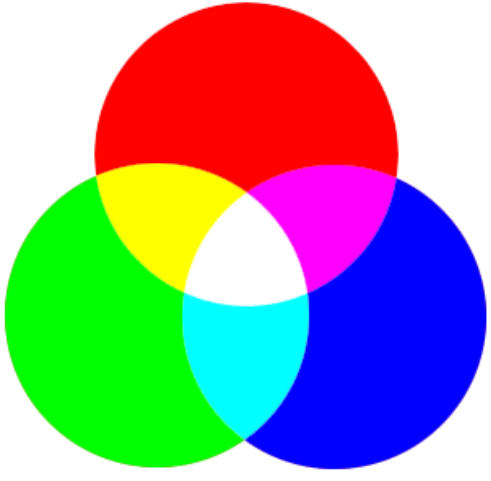
Two quadrats will differ in the composition of species – this is compositional turnover or *compositional beta diversity*.

We can also explore the phylogenetic relationships of species across quadrats – this is *phylogenetic beta diversity*.

How does species composition vary across a 50 ha plot?

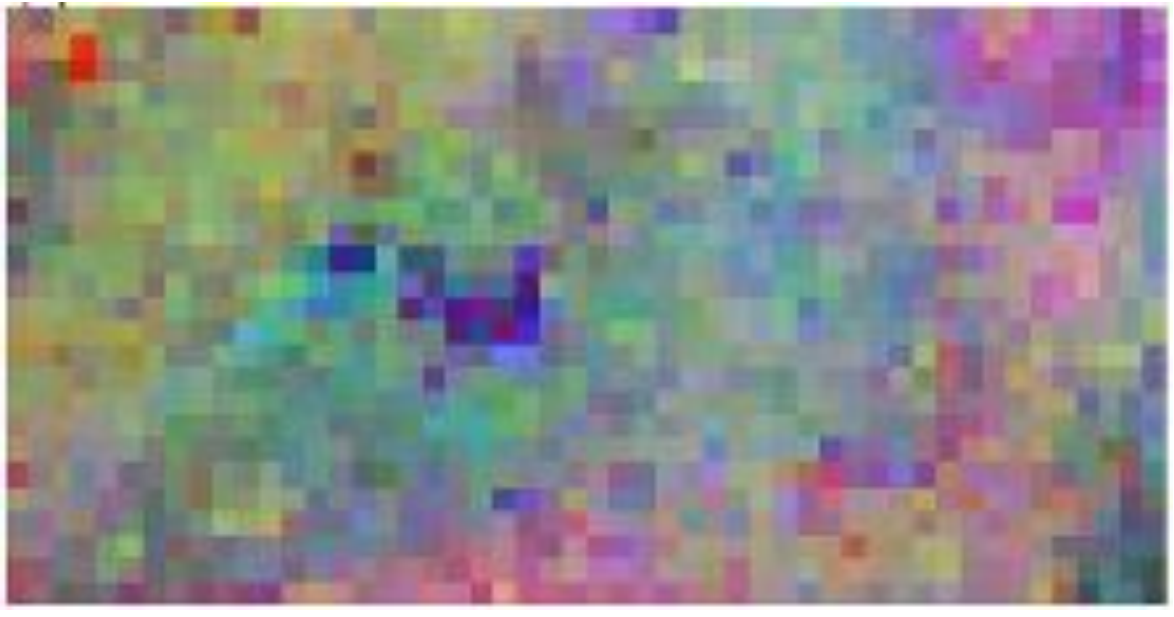


How do you *visualize* compositional variation across a plot?



RGB: Colors are an additive combination of red, green, blue

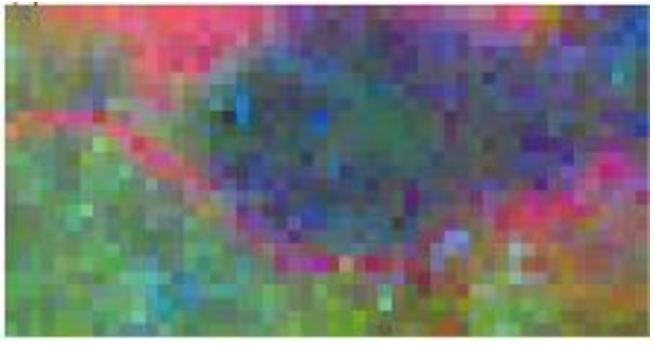
BCI compositional beta diversity



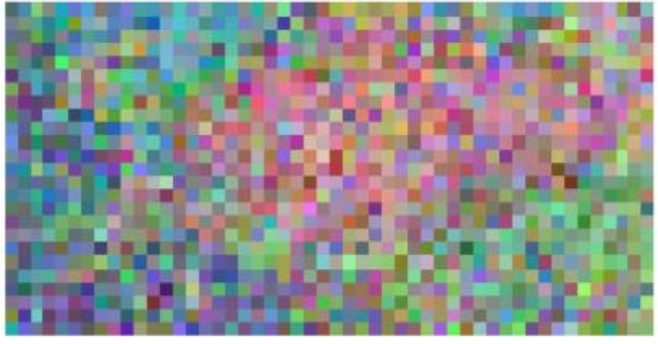
Baldeck *et al.*, 2013 Proc. Royal Soc.

We can also see *phylogenetic* beta diversity

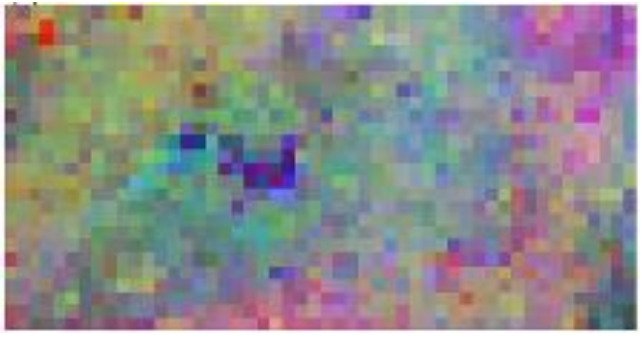
Pasoh compositional beta



Pasoh phylogenetic beta



BCI compositional beta

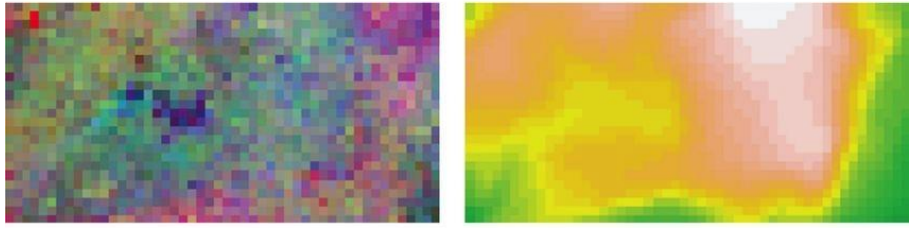


BCI phylogenetic beta

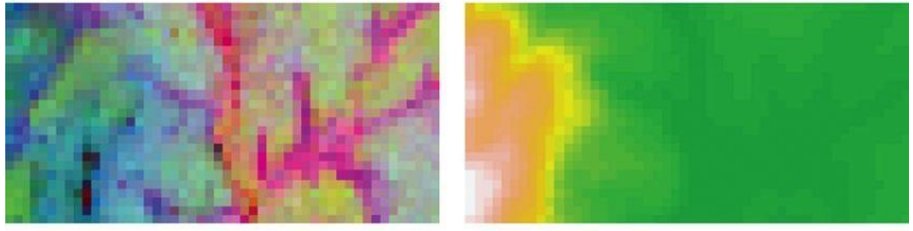
Baldeck et al., (2016) Oecologia

Tree Community Composition

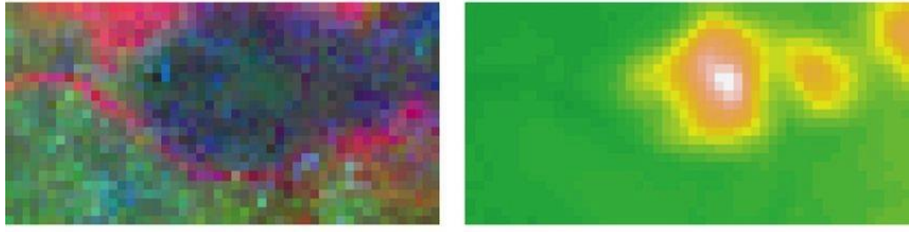
(*a*) Barro Colorado Island



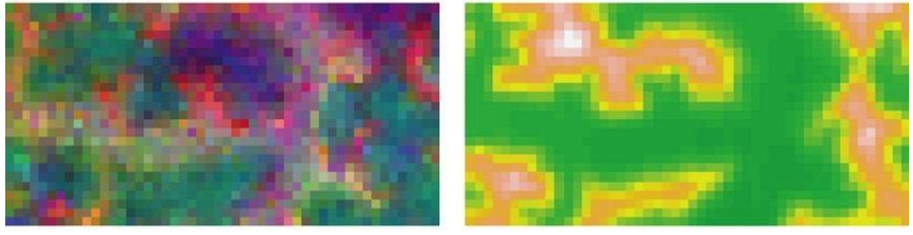
(*b*) Korup



(*c*) Pasoh

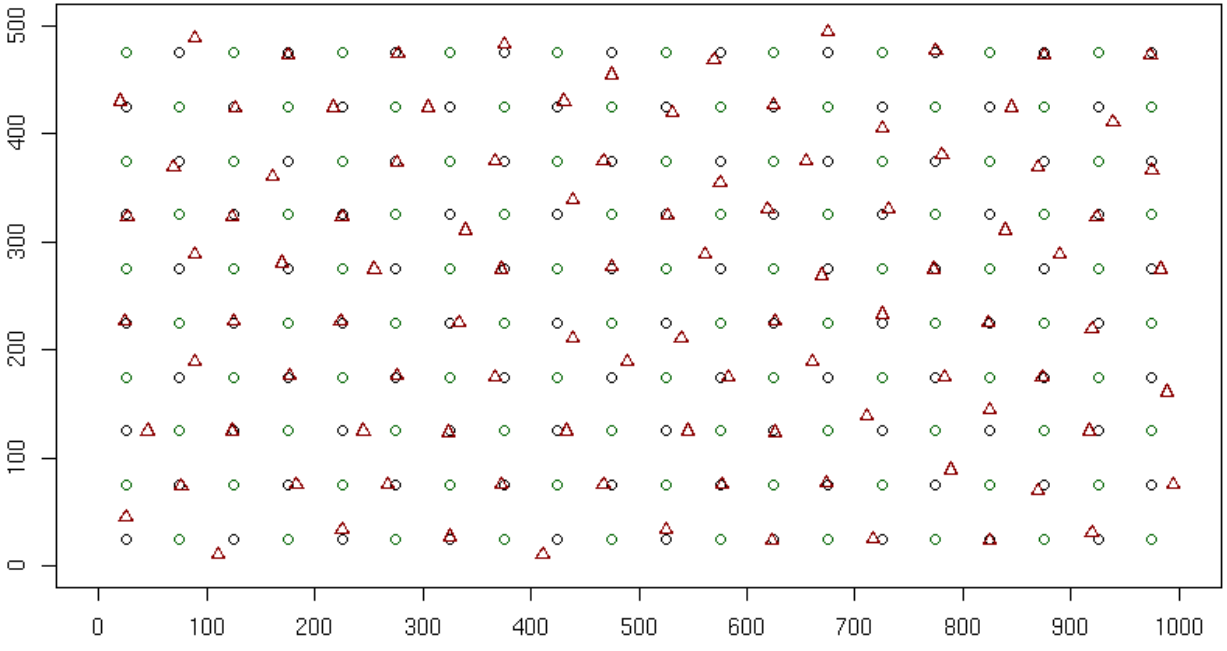


(*d*) Yasuni



Topography

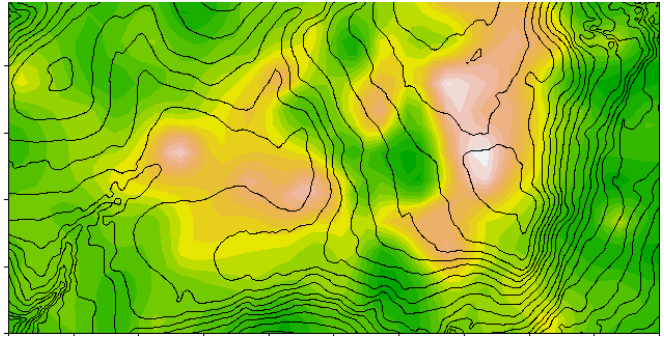
Mapping soil nutrients in a 50 ha plot



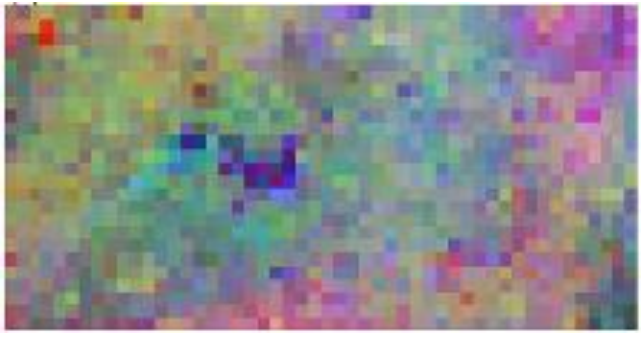
Stratified random sampling (6 samples/ha)
Grid sampling with ‘extra’ points at 2, 8 and 20 m

Compositional variation in tropical forests: seeing is believing!

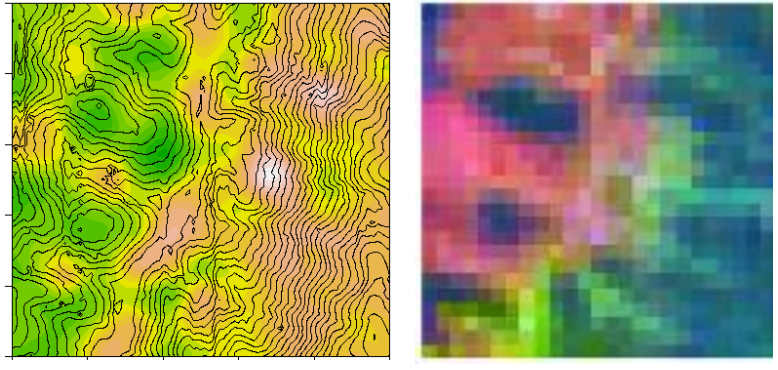
BCI phosphorus map



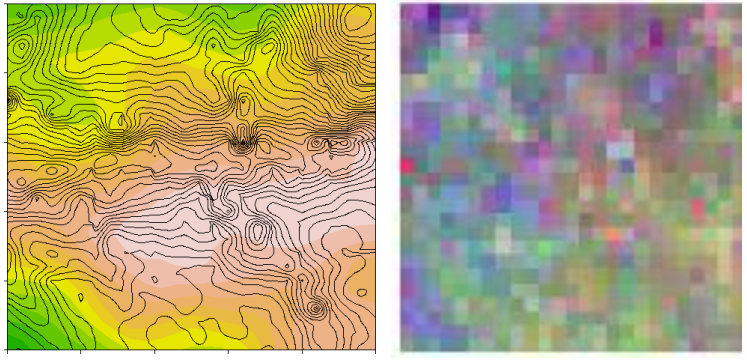
BCI composition map



Sinharaja pH map



La Planada Al sat map



30-50% of tree spp show significant associations with soil variables (John et al. 2007 PNAS)

Summary: what we know

- Even “homogeneous” forest plots like BCI have substantial compositional variation that relates to environmental factors
- Topography explains some compositional variation; soil nutrients explains another equal sized component
- Adding environmental variables reduces unexplained variation that ecologists attribute to ‘dispersal limitation’.

Caribbean coast – 4 m rain per year

What about larger spatial scales?

65 km Isthmus of Panama

550 common tree spp

10 km

Pacific coast – 2 m rain per year

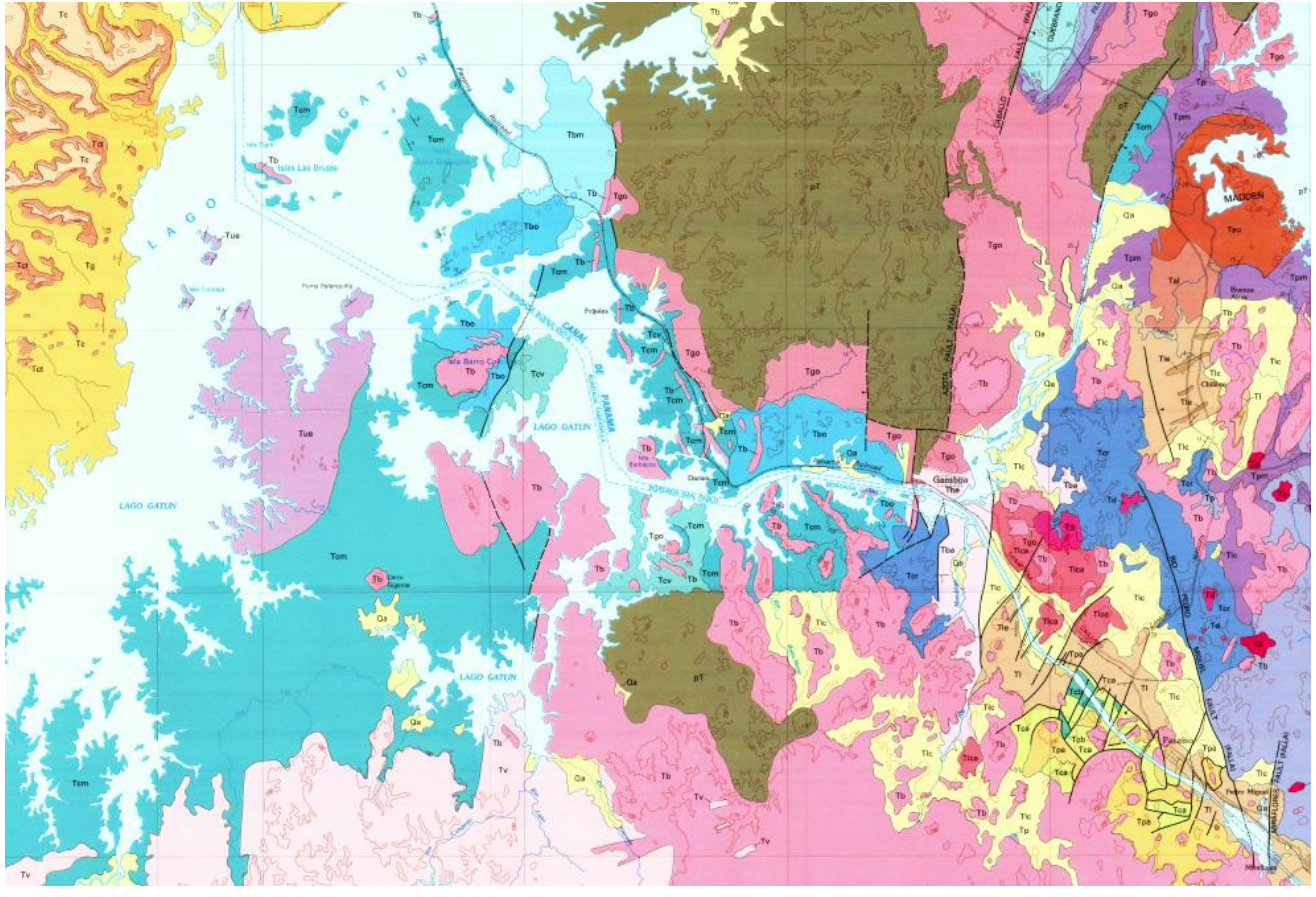
Caribbean coast – 4 m rain per year

Barro Colorado Island

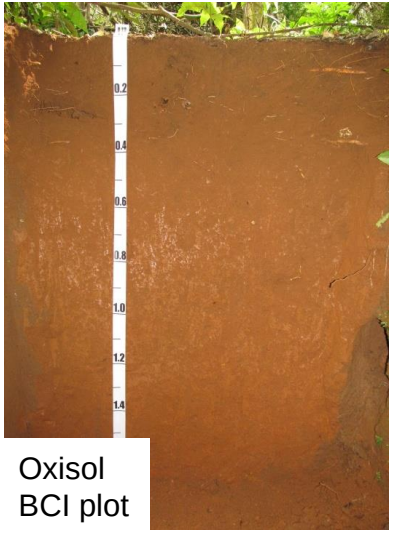
10 km

Pacific coast – 2 m rain per year

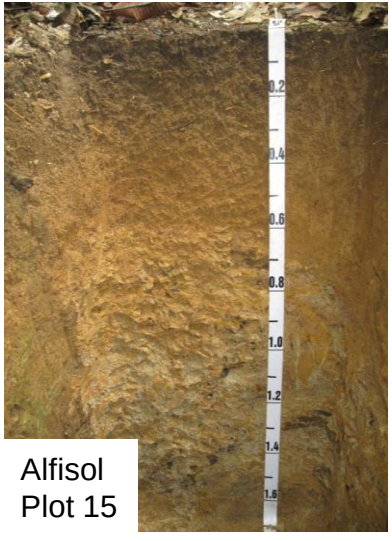
Panama Canal Area Geological Map



Soil variation in Canal Area forests

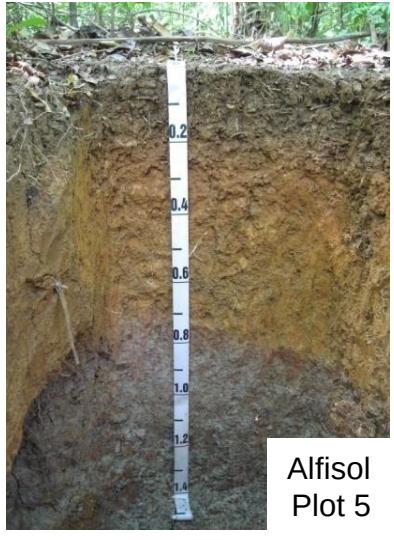


Oxisol
BCI plot



Alfisol
Plot 15

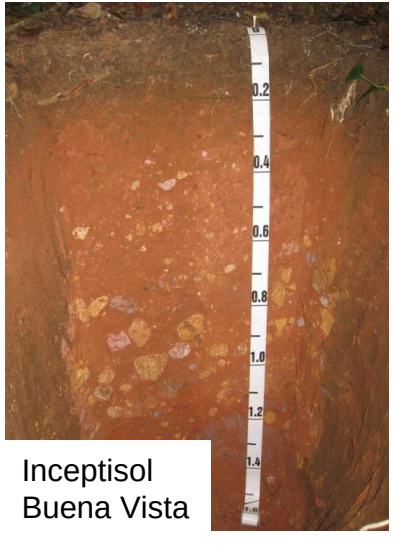
Ultisol
Plot 6



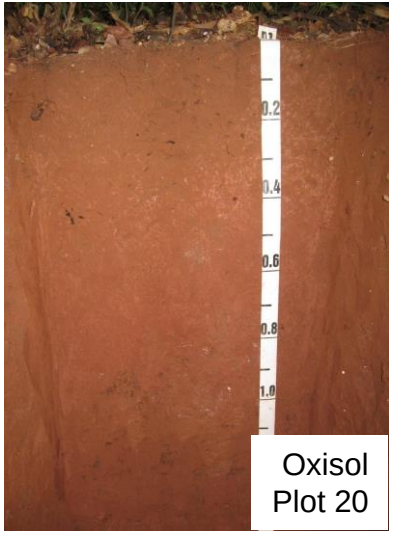
Alfisol
Plot 5

Mollisol
Madden Dam

Ultisol
Rio Paja



Inceptisol
Buena Vista



Oxisol
Plot 20

Caribbean coast – 4 m rain per year

pH 3.3–7.3

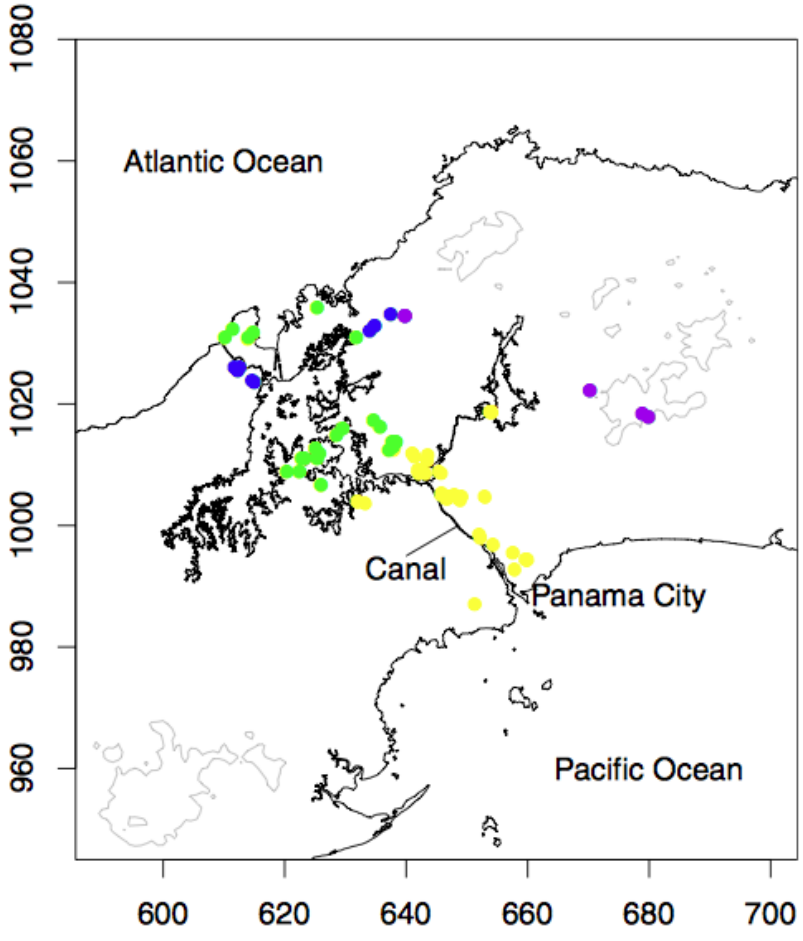
Total phosphorus 64–1553 mg P kg^{-1}

Available phosphate 0.04–23 mg P kg^{-1}

10 km

Pacific coast – 2 m rain per year

Canal Area permanent forest dynamics plots

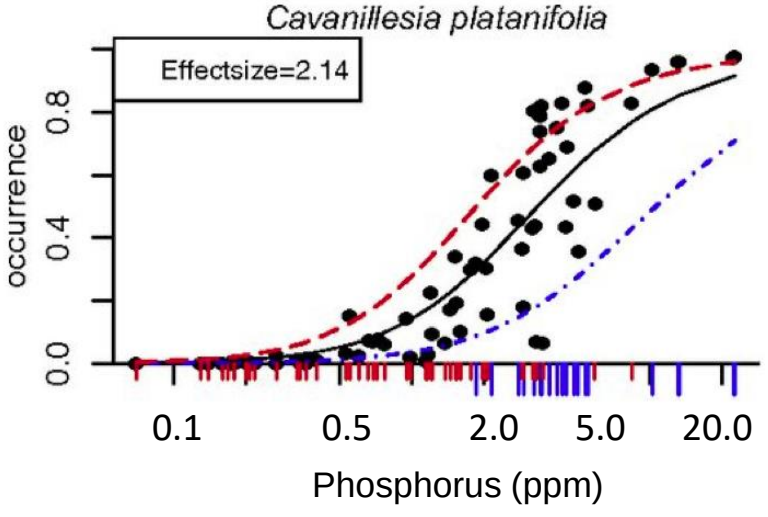


Plot inventories: Rick Condit

Soil surveys: Ben Turner

Condit et al. 2013
PNAS

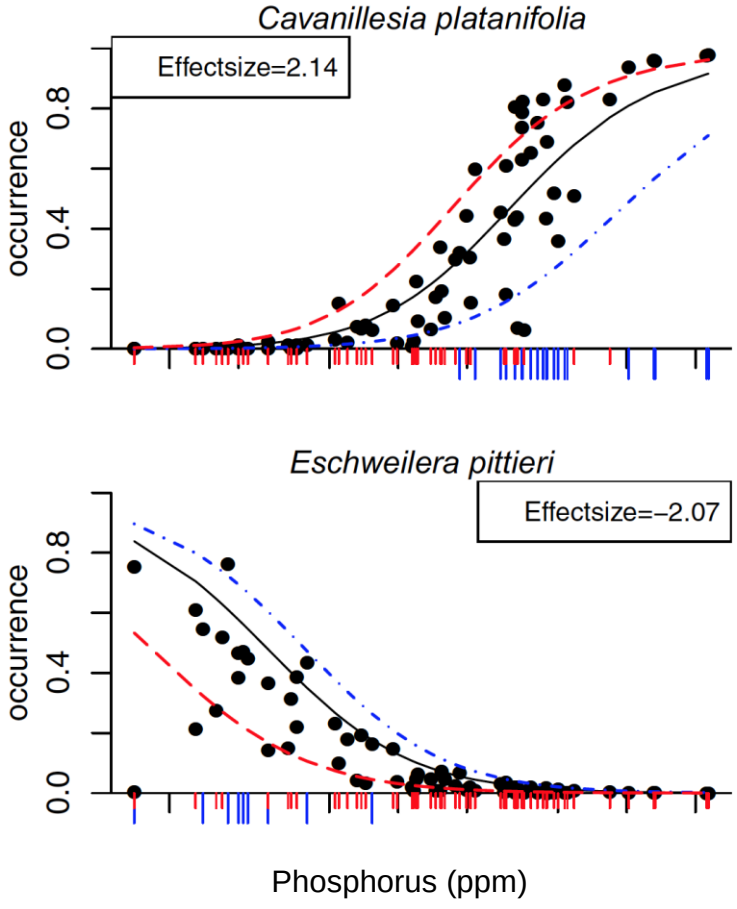
Species-specific responses to phosphorus

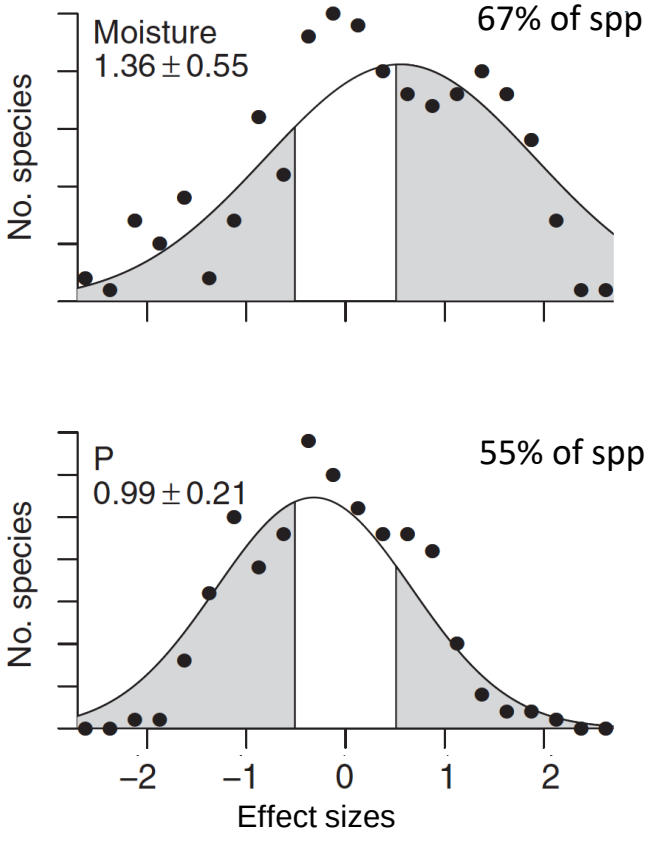


Condit et al. 2013 PNAS

Cavanillesia platanifolia
(Malvaceae)

Species-specific responses to phosphorus





Condit et al. 2013 PNAS

Do species distributions reflect growth performance?

Zalamea et al. (2016) New Phytologist

If species distributional patterns reflect differences in P requirements

- Growth responses to P addition will correlate with species P affinity (Condit's effect size)

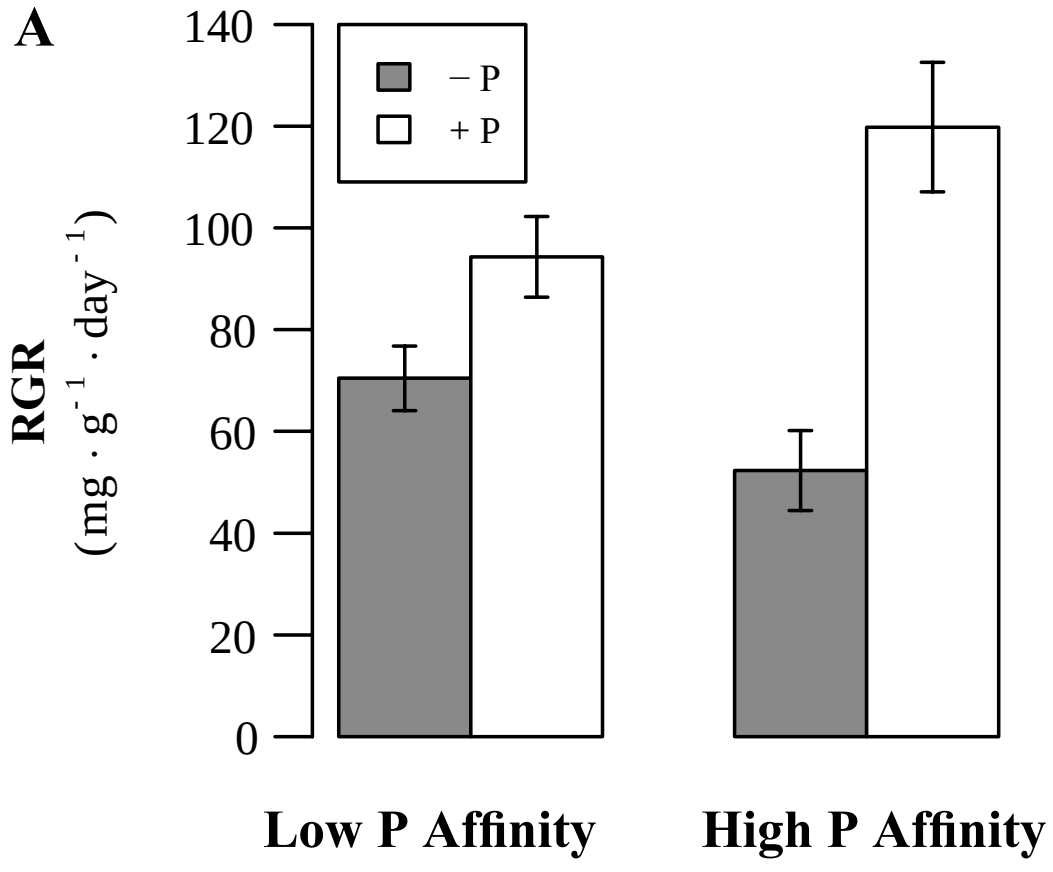
- Species with affinity to low P sites will have:
  - higher P use efficiency,
  - higher root biomass allocation,
  - higher phosphatase enzyme activity

15 fast-growing tree species with varying effect sizes for P in a phosphorus-poor soil

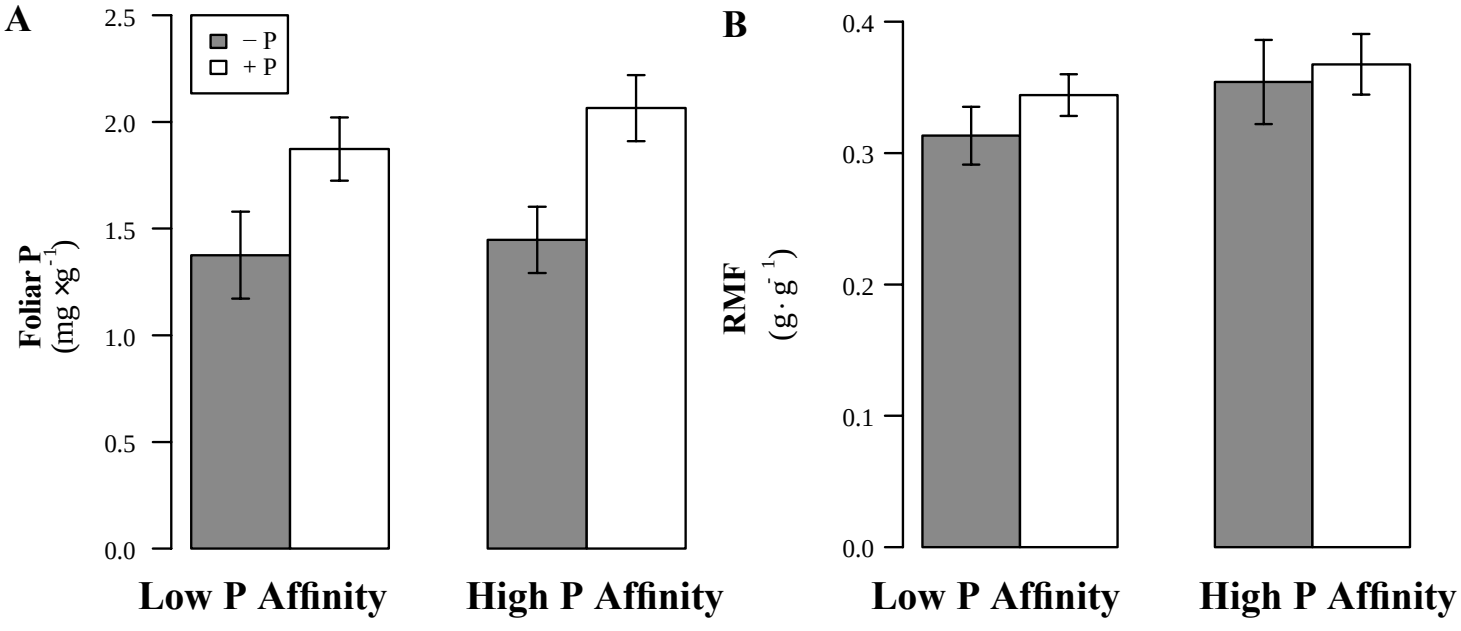
Full nutrient solution + Two treatments: –P and +P

Measure growth rate (RGR), allocation, foliar [P], phosphatase activity

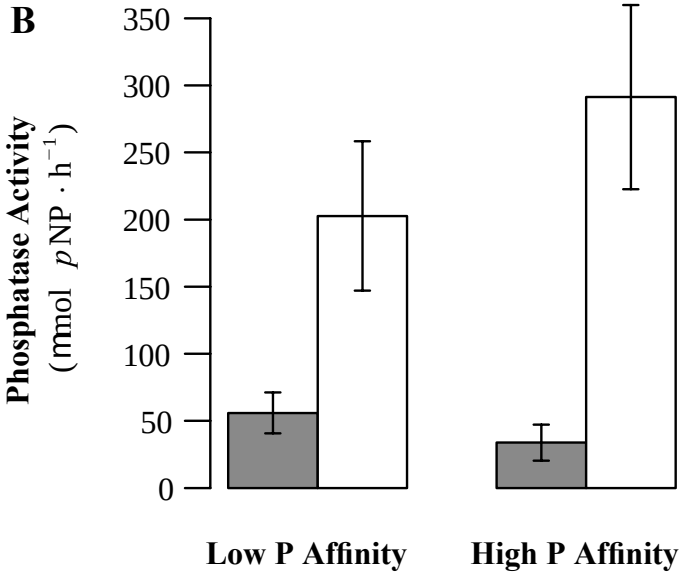
Growth response to P addition: P limits growth



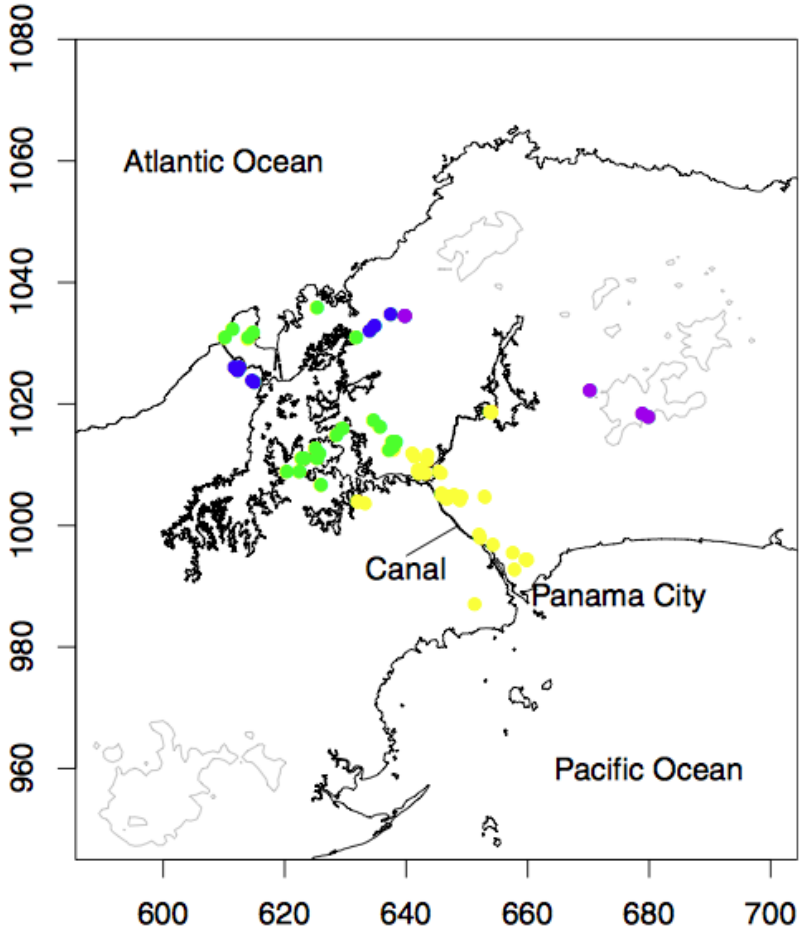
Foliar [P] and root mass fraction (RMF) doesn't explain growth differences



Production of phosphatase enzymes doesn't explain growth differences



Canal Area permanent forest dynamics plots

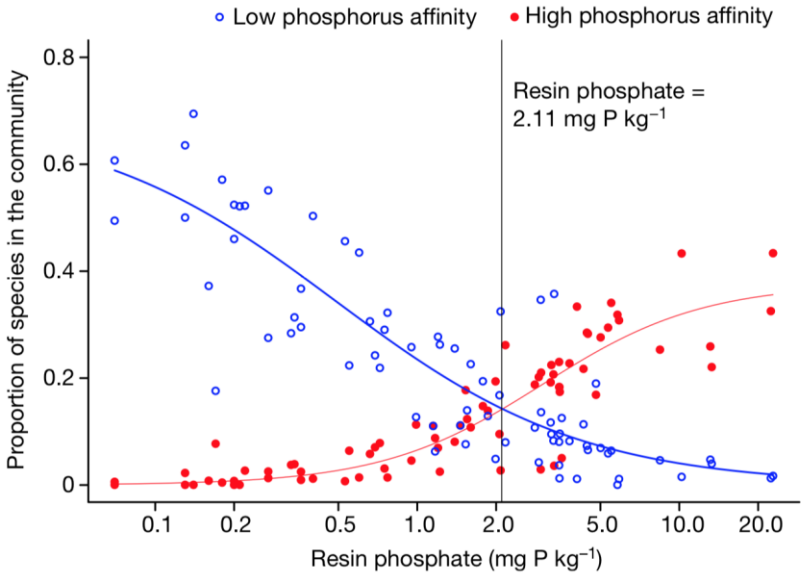


Plot inventories: Rick Condit

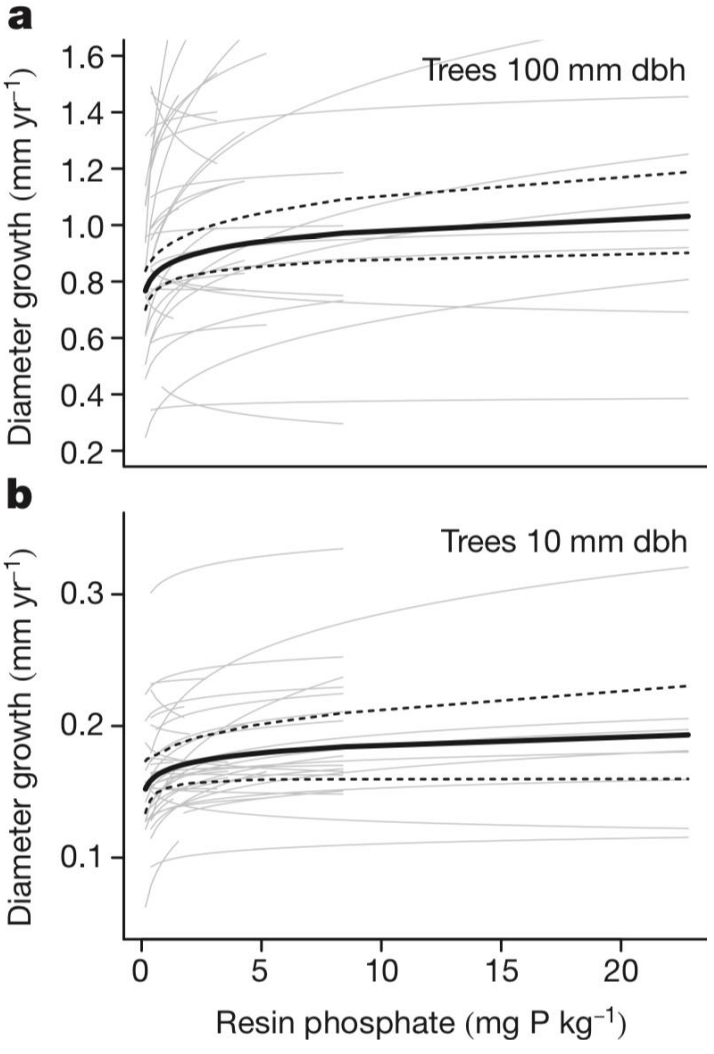
Soil surveys: Ben Turner

Condit et al. 2013
PNAS

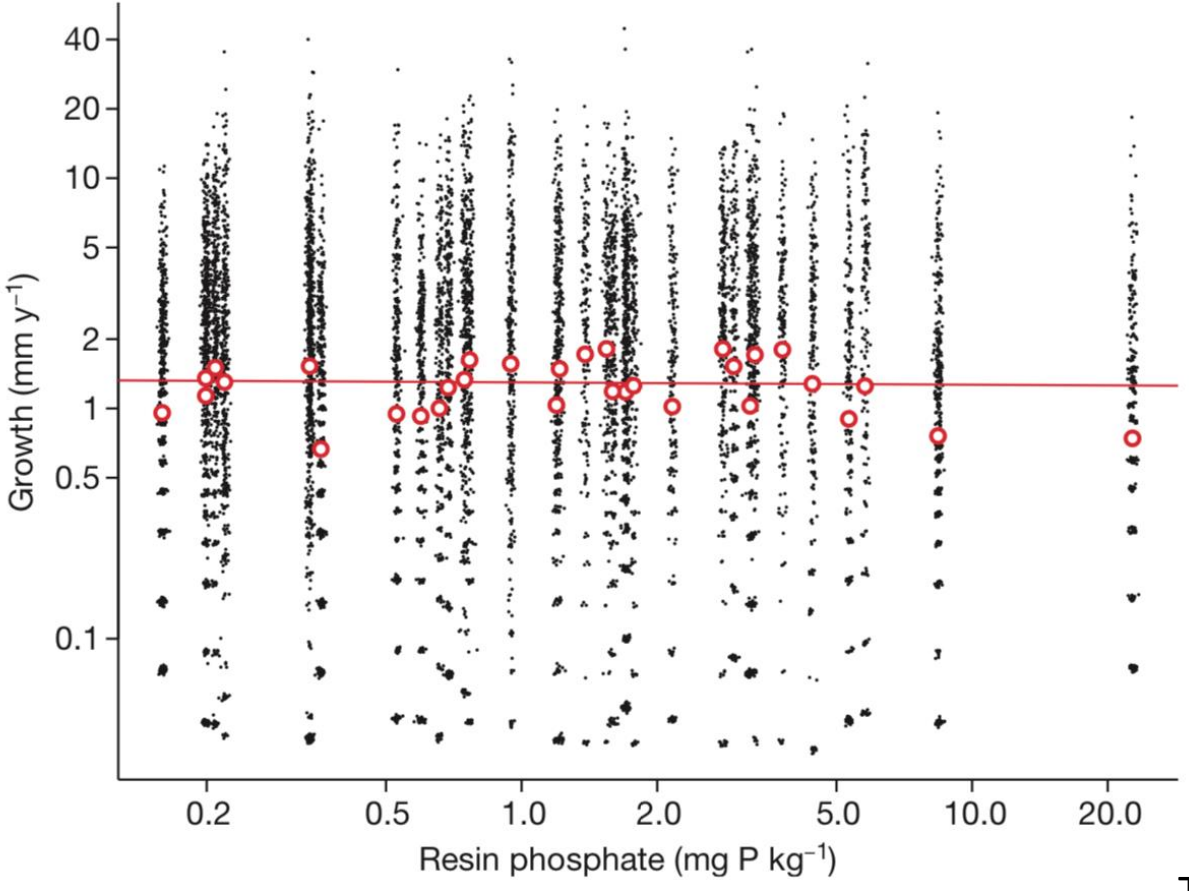
Growth responses to P in the field



Turner et al. 2018 Nature



Despite individual positive responses to P plot-level growth rates across Panama are uncorrelated with P availability



Turner et al. 2018

Summary: what we don't know

1. What traits underpin species distributional affinities (and responses to) P availability?

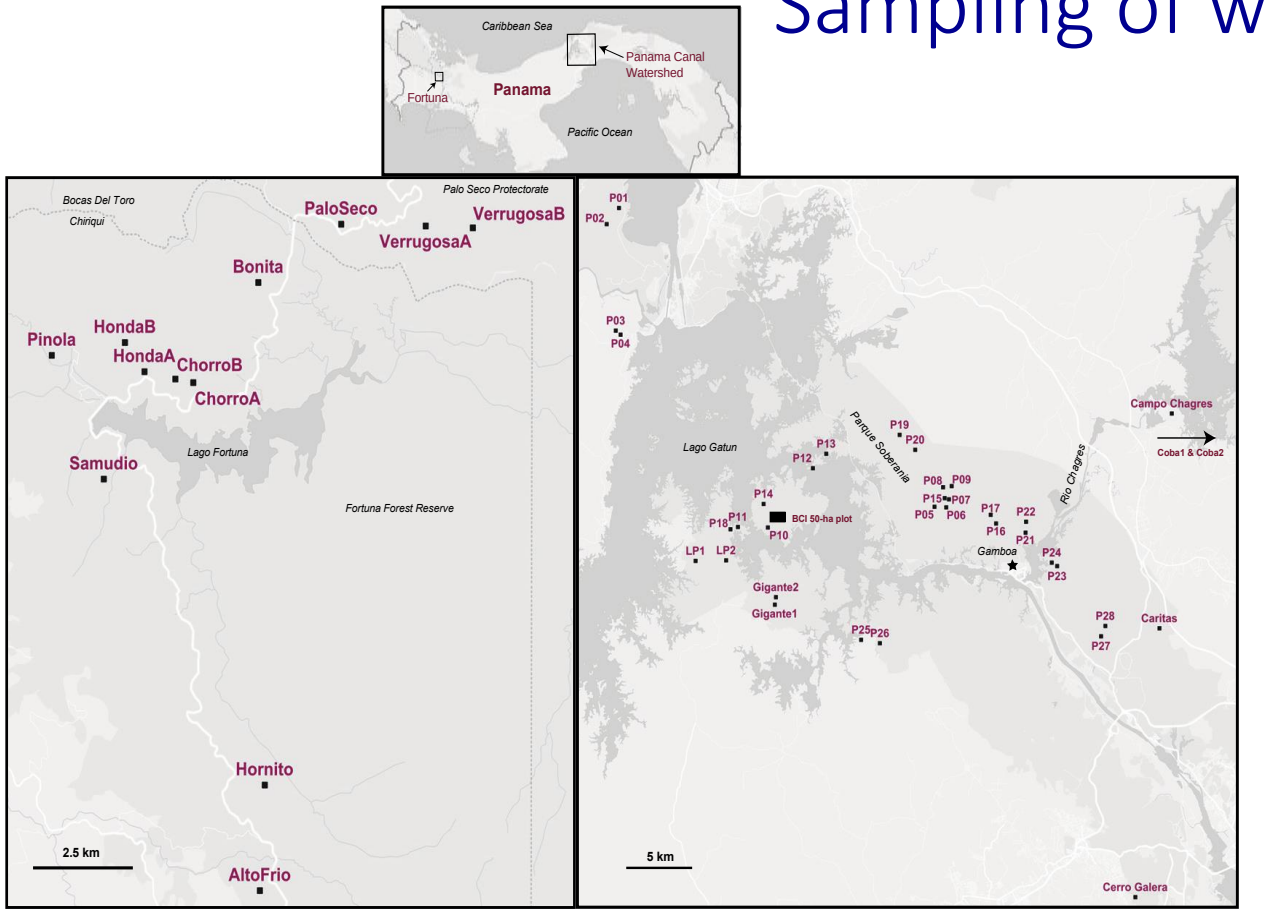
2. What allows a species to grow fast under low P conditions?

3. Why is there a trade-off between growth rate in high vs low P?

4. Why don't radial growth rates at the plot level increase as P availability increases?

How do tissue nutrient traits relate to variation in soil fertility?

Sampling of wood nutrients

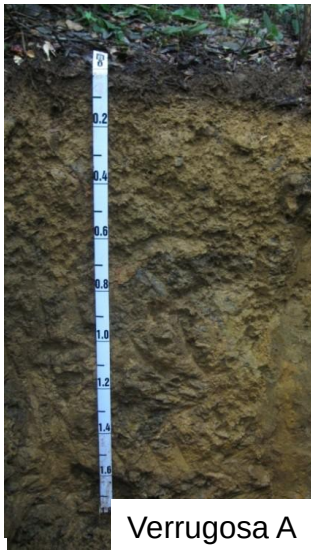


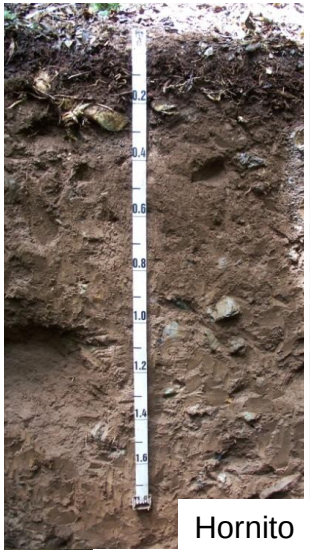
Soil variation across the Fortuna 1 ha plots

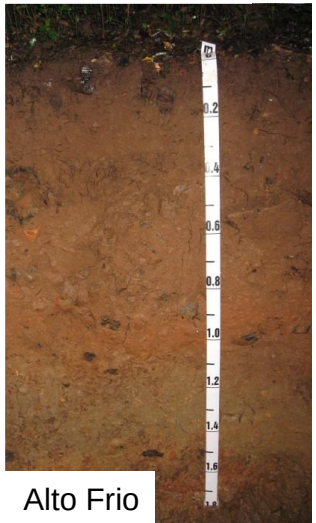
Chorro A

Honda A

Honda B


Verrugosa A


Hornito


Alto Frio

Bonita

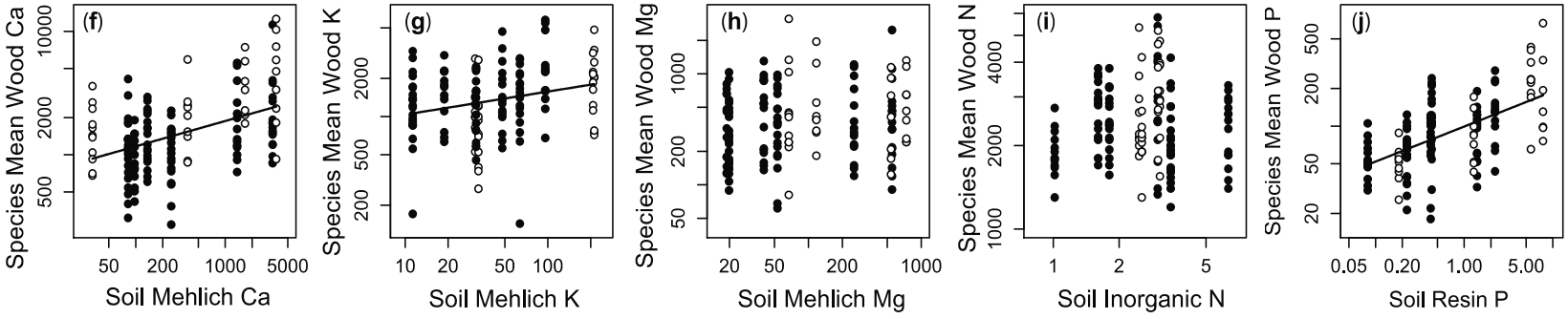
Pinola

Zarceadero

Chorro B

Species are highly variable in wood nutrients

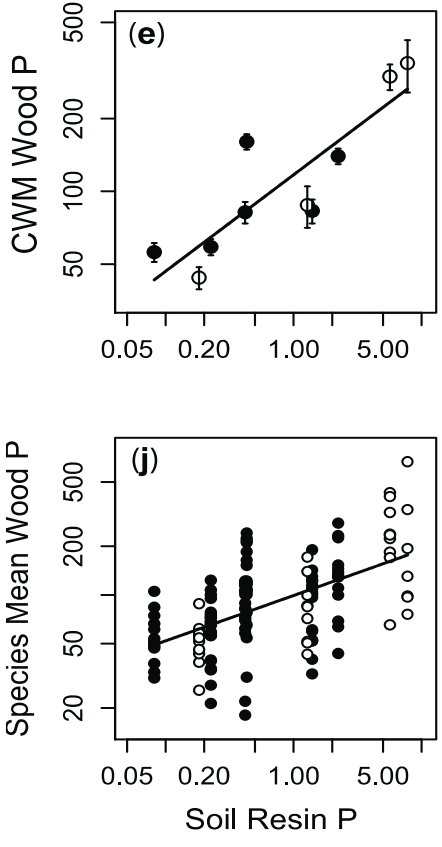
Data from ten 1 ha plots
Open symbols: Canal Watershed; Filled symbols: Fortuna



Ca – 45 fold variation
K – 36 fold variation
Mg – 51 fold variation
N – 4.5 fold variation
P – 35 fold variation

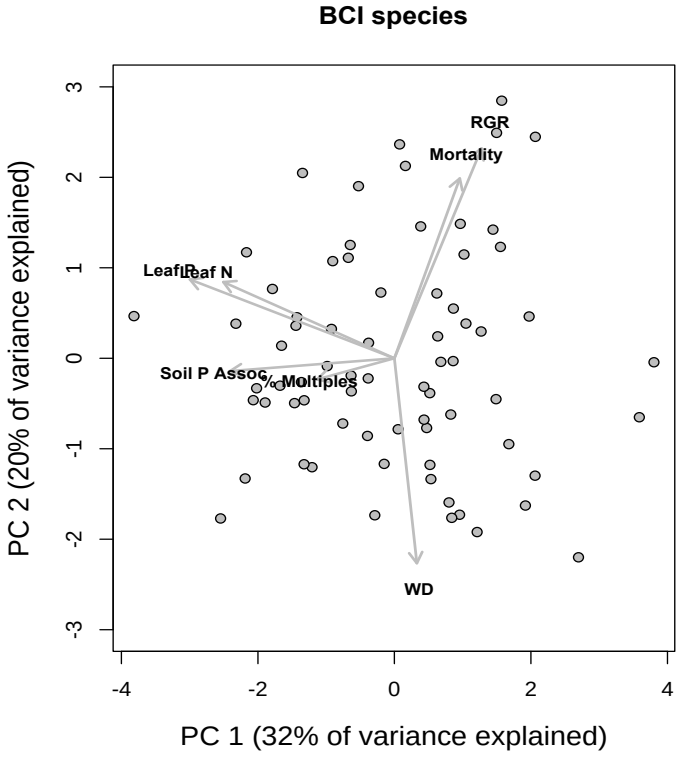
Heineman et al. (2016)
New Phytologist

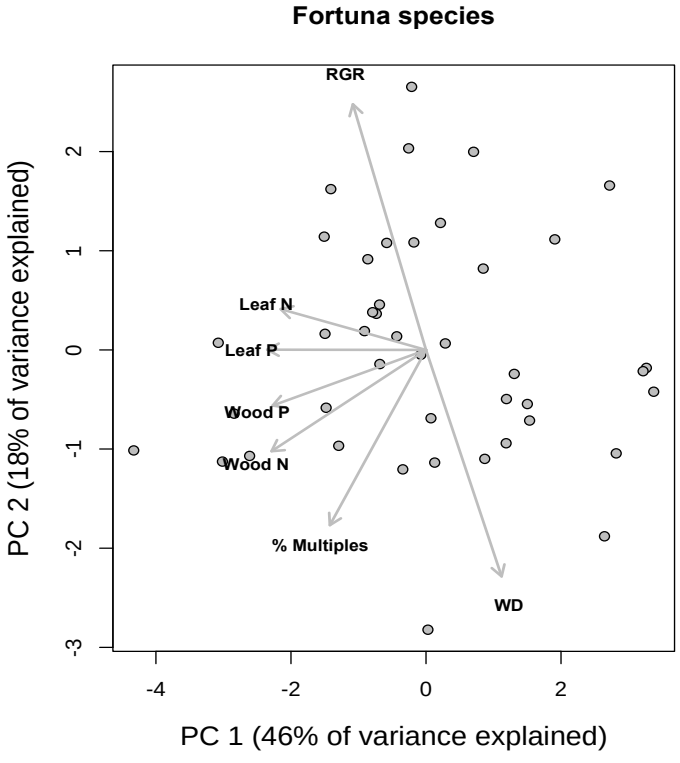
Community weighted mean (CWM) wood P is tightly correlated with soil nutrients



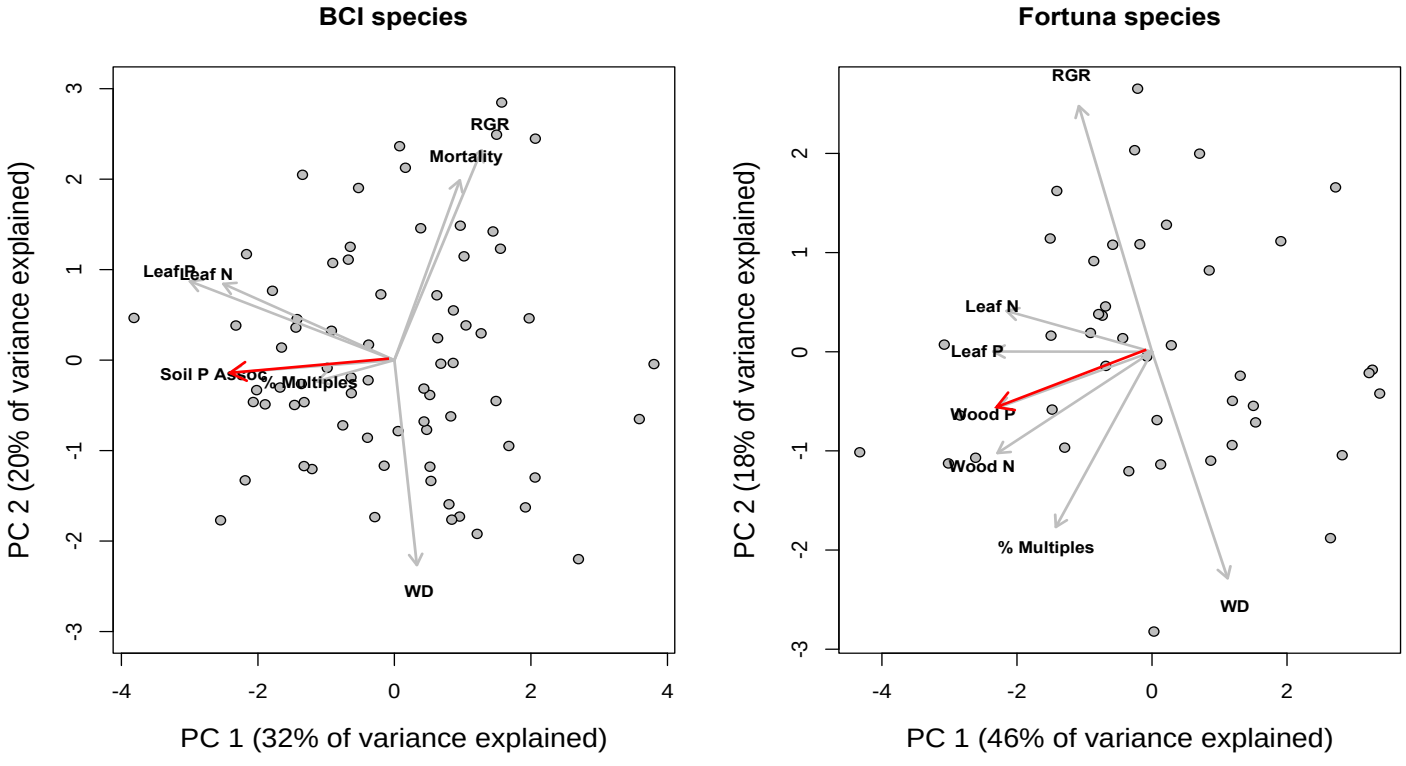
Are wood nutrients associated with the leaf or the wood economic spectrum?

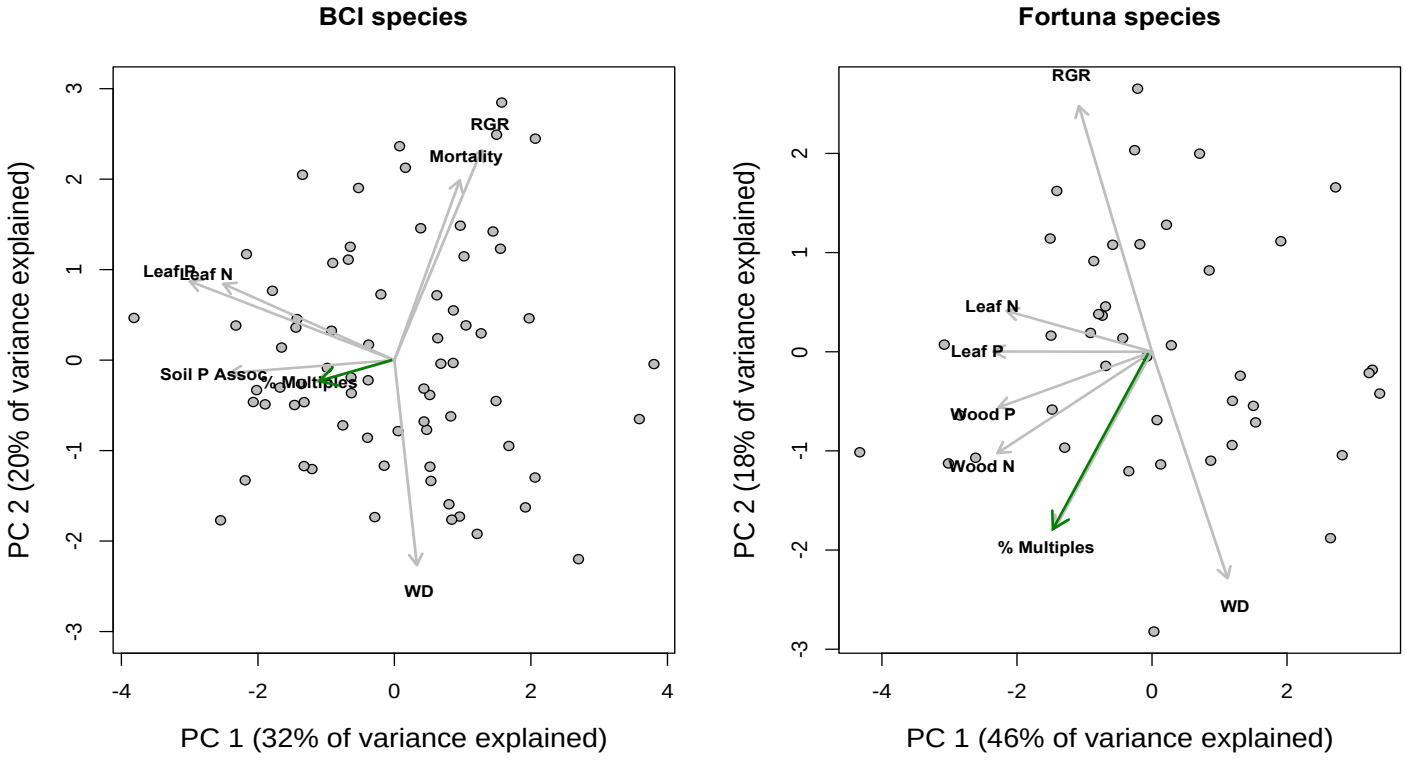
PCA of species wood and leaf traits





Heineman et al. unpublished


BCI species
RGR
Mortality
Leaf P
Leaf N
Soil P Assoc
% Multiples
WD
PC 2 (20% of variance explained)
PC 1 (32% of variance explained)
Fortuna species
RGR
Leaf N
Leaf P
Wood P
Wood N
% Multiples
WD
PC 2 (18% of variance explained)
PC 1 (46% of variance explained)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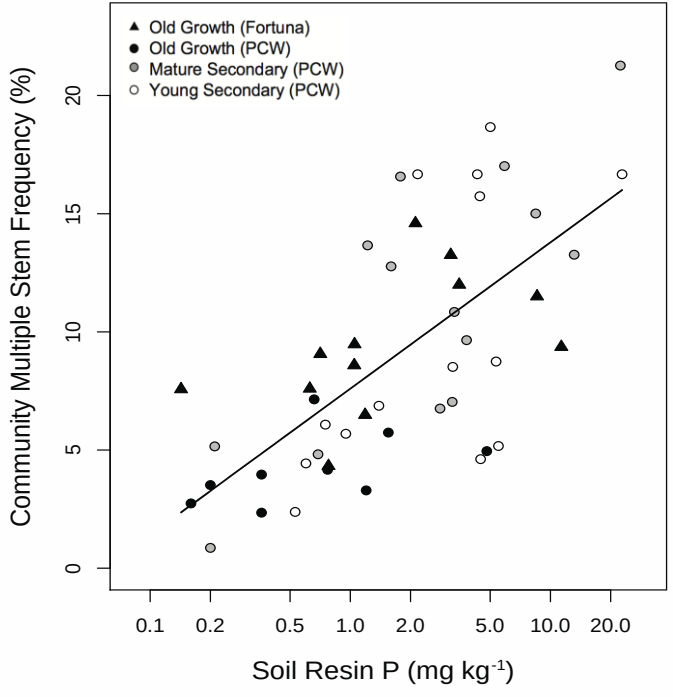
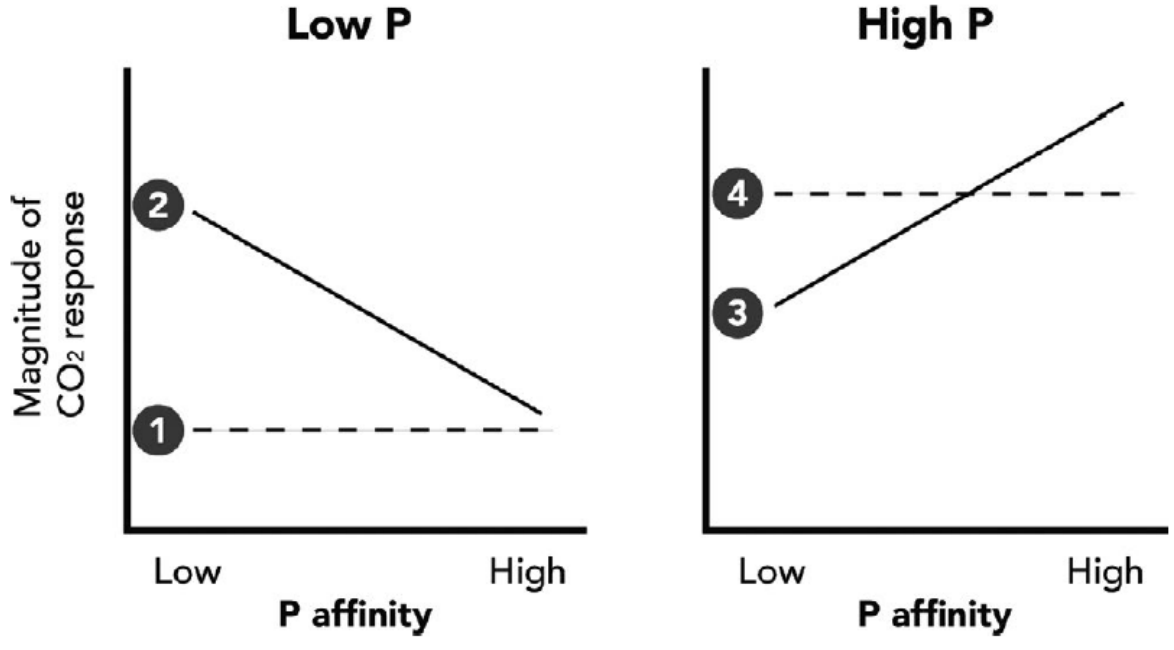
Leaf N
Leaf P
Wood P
Wood N
% Multiples
WD
PC 2 (18% of variance explained)
PC 1 (46% of variance explained)

Species associated to high P soils have a higher frequency of multiple stems and likely resprout more frequently

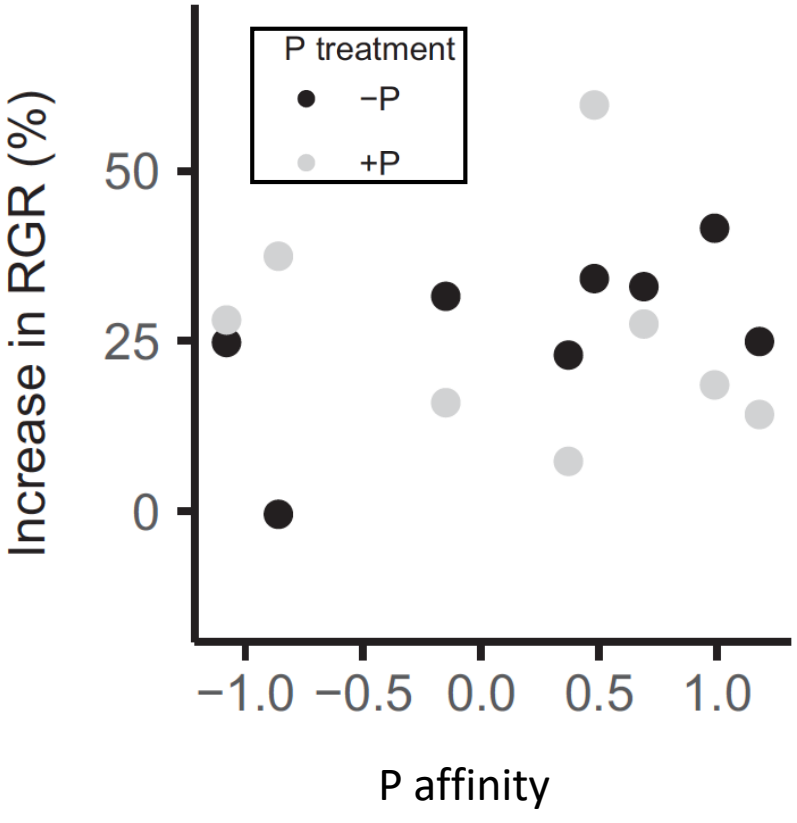


Heineman, unpublished data

Final thought: If P is important in structuring forest composition what will be the global change consequences?



Growth responses to elevated CO_2



RGR response to elevated CO_2 is uncorrelated with P affinity in either low P or High P conditions

= reordering of communities?

Thompson et al. (2019) Functional Ecology

Final summary

- We need to do a better job of integrating soil measurements into ecological studies and predictive modeling
- We have an incomplete understanding of the functional basis for plant responses to soil variables
- Phosphorus limitation is widespread – understanding how plants cope with low P has important implications for forests and agriculture
- Soil variation provides an additional little understood barrier to species migration patterns

Thanks!!

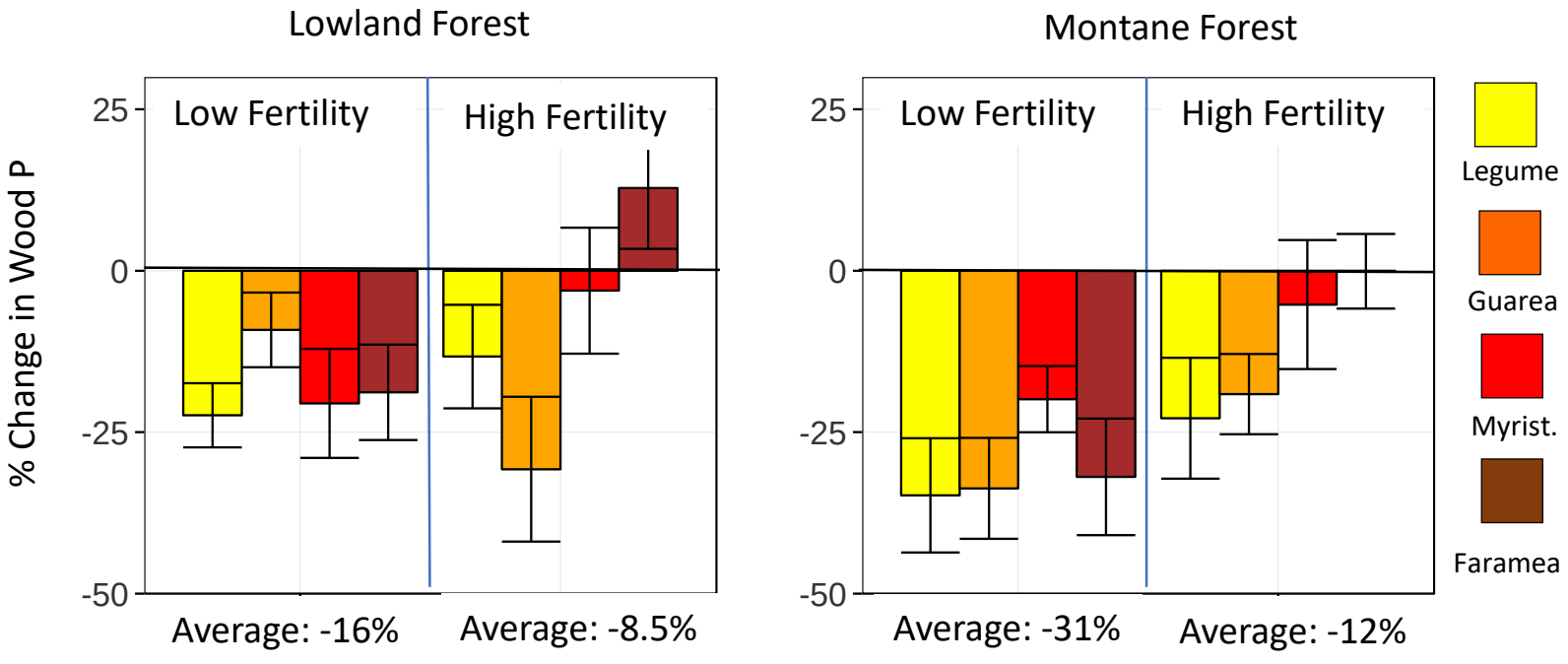
Experimental Design: Defoliation Procedure

Before

After

- 70% of leaves removed from defoliated trees after wet season leaf flush

Results: Phosphorus Remobilization



ANOVA Table

Variable	*F*	*P*
Elevation	5.39	**0.021**
Fertility	9.93	**0.002**
Taxa	2.52	0.060
Fertility x Taxa	3.62	**0.014**

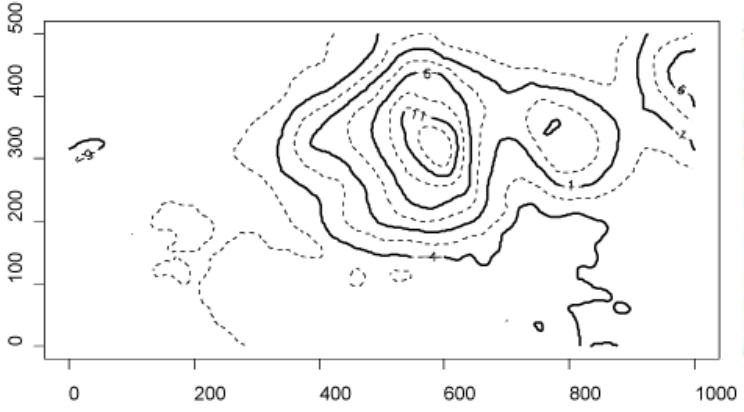
Western Panama: Volcan Baru and Fortuna

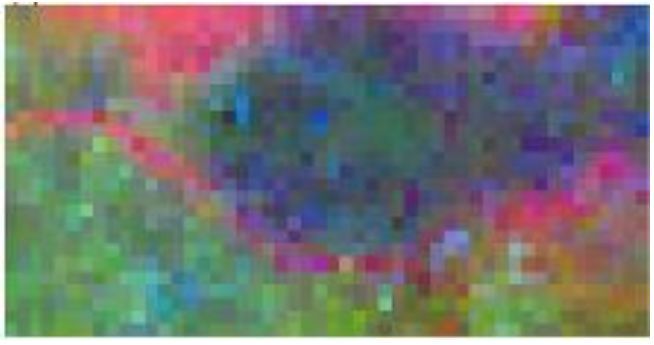
Oak forest 3000 m
Volcan Baru

Western Panama: Continental Divide

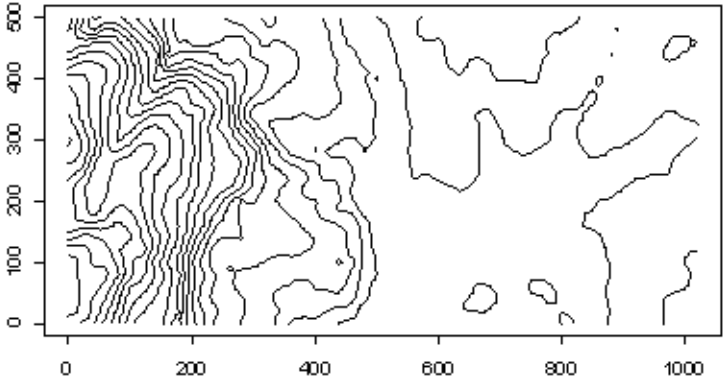
Compositional beta diversity in tropical forests: seeing is believing!

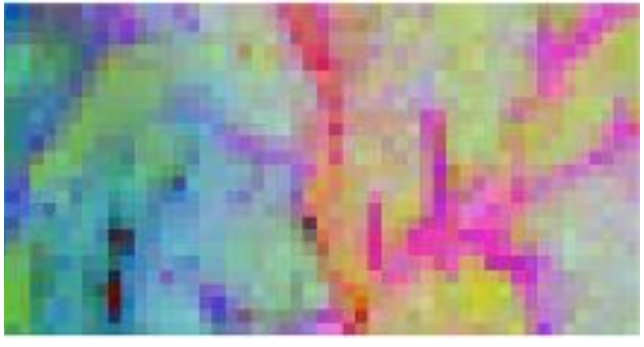
Pasoh, Malaysia



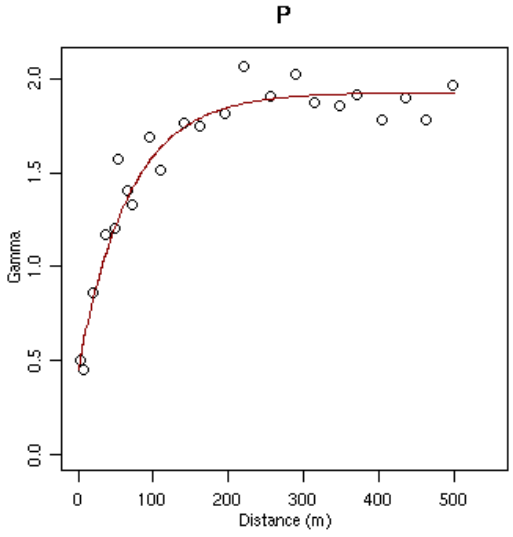


Korup, Cameroon

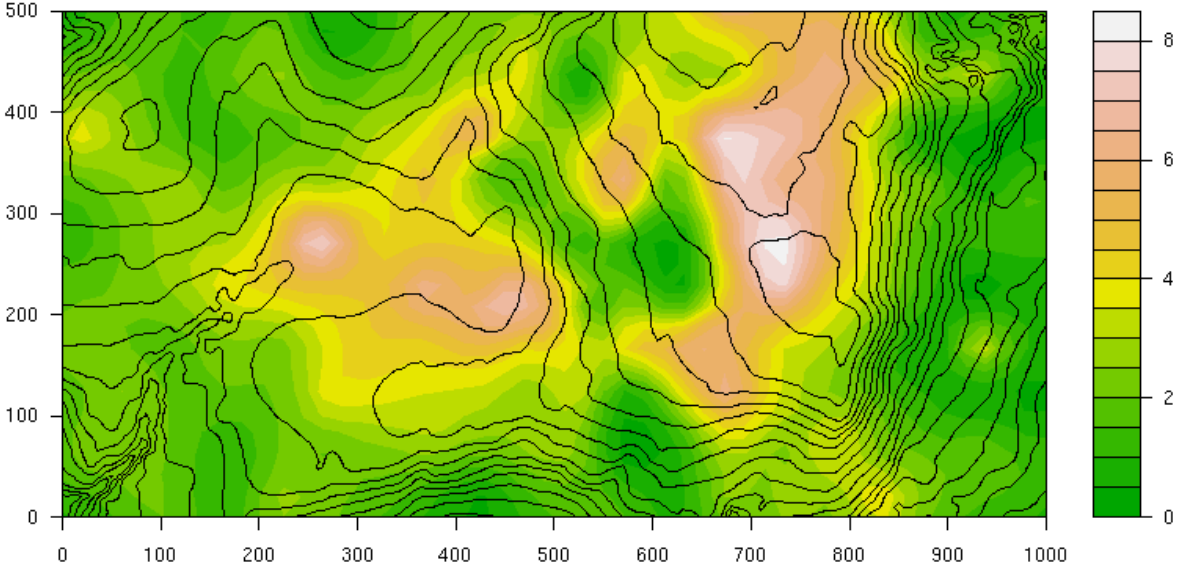




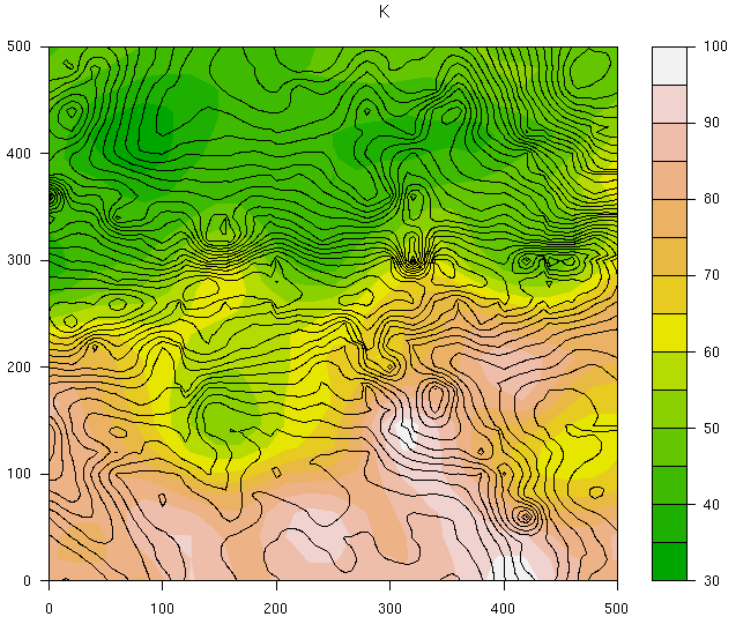
Baldeck et al. (2013) Proc. Royal Soc. B

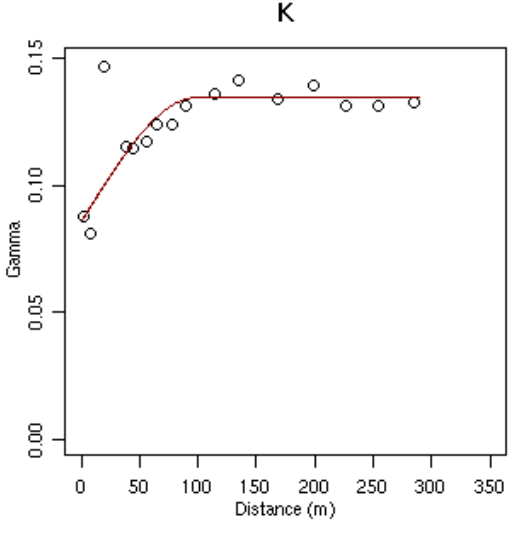


Barro Colorado Island, Panama

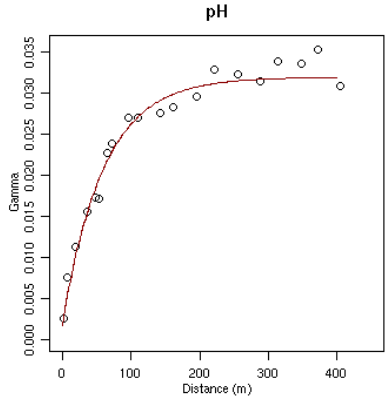


La Planada, Nariño, Colombia

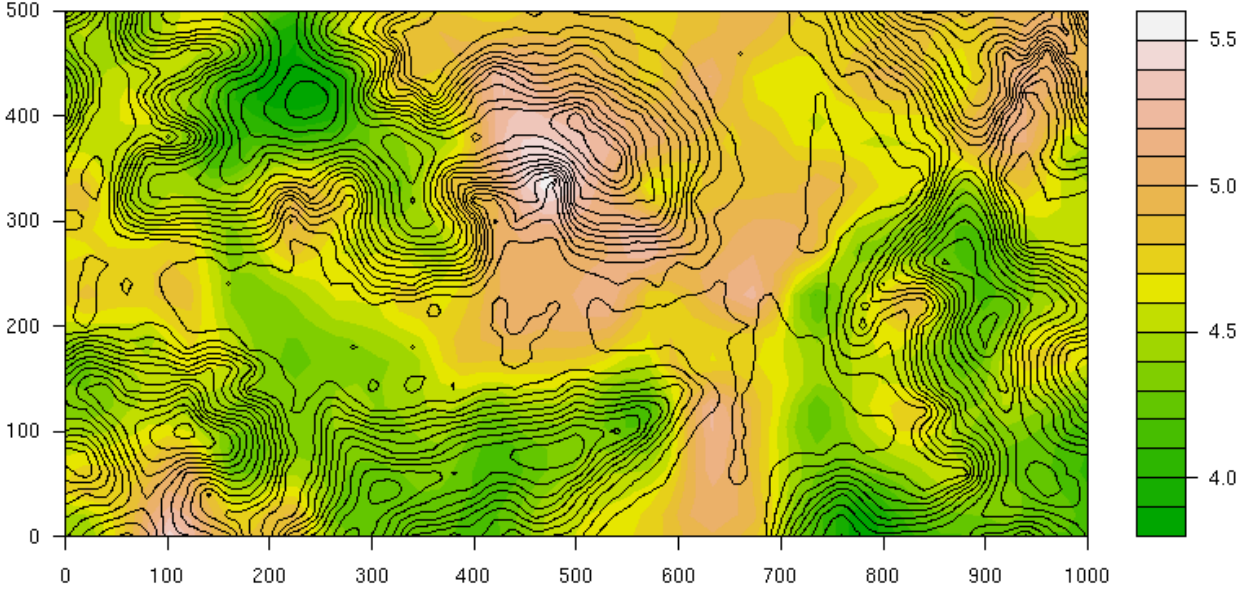




Yasuní National Park, Ecuador



pH

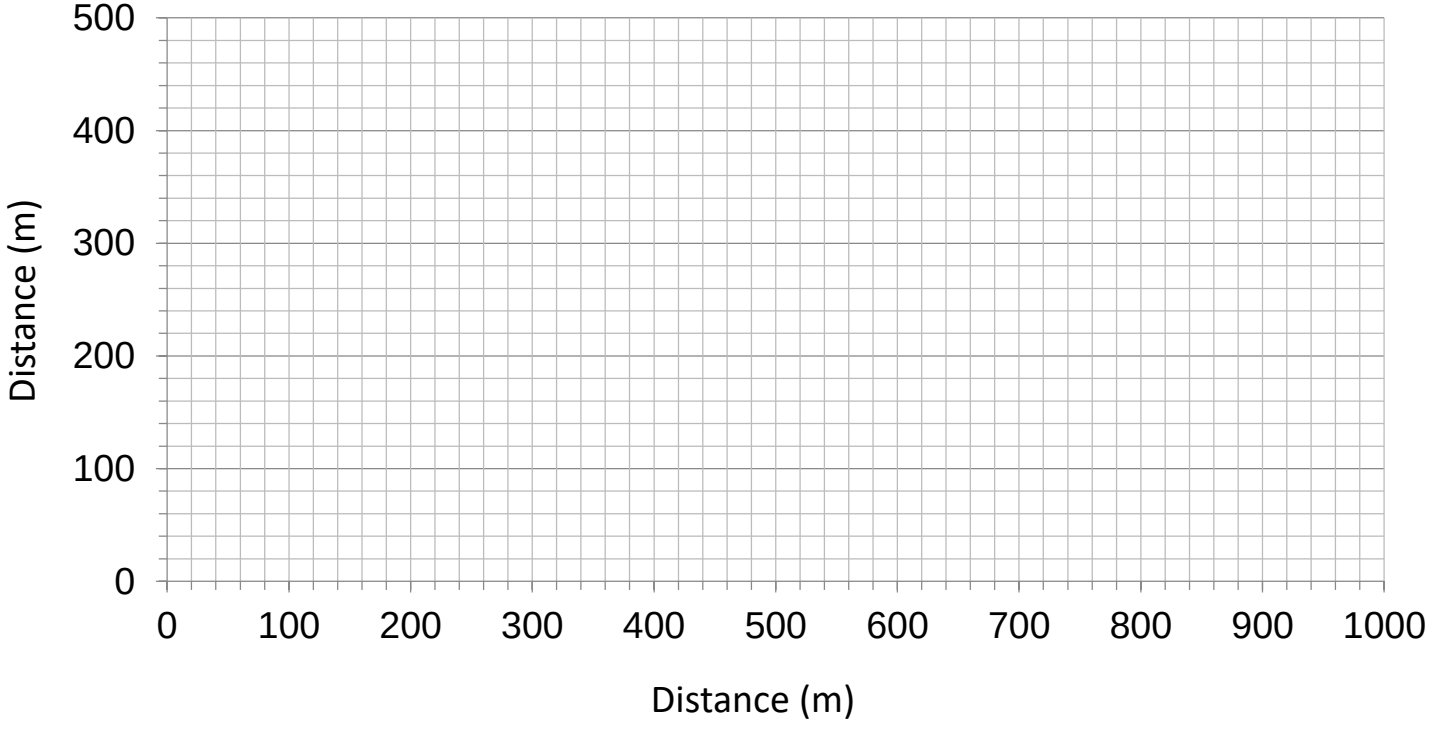


Across ForestGeo plots:

30-50% of tree species show significant distributional associations with soils variables

John et al. 2007 PNAS

50 ha forest dynamics plots are gridded in 20 m x 20 m quadrats



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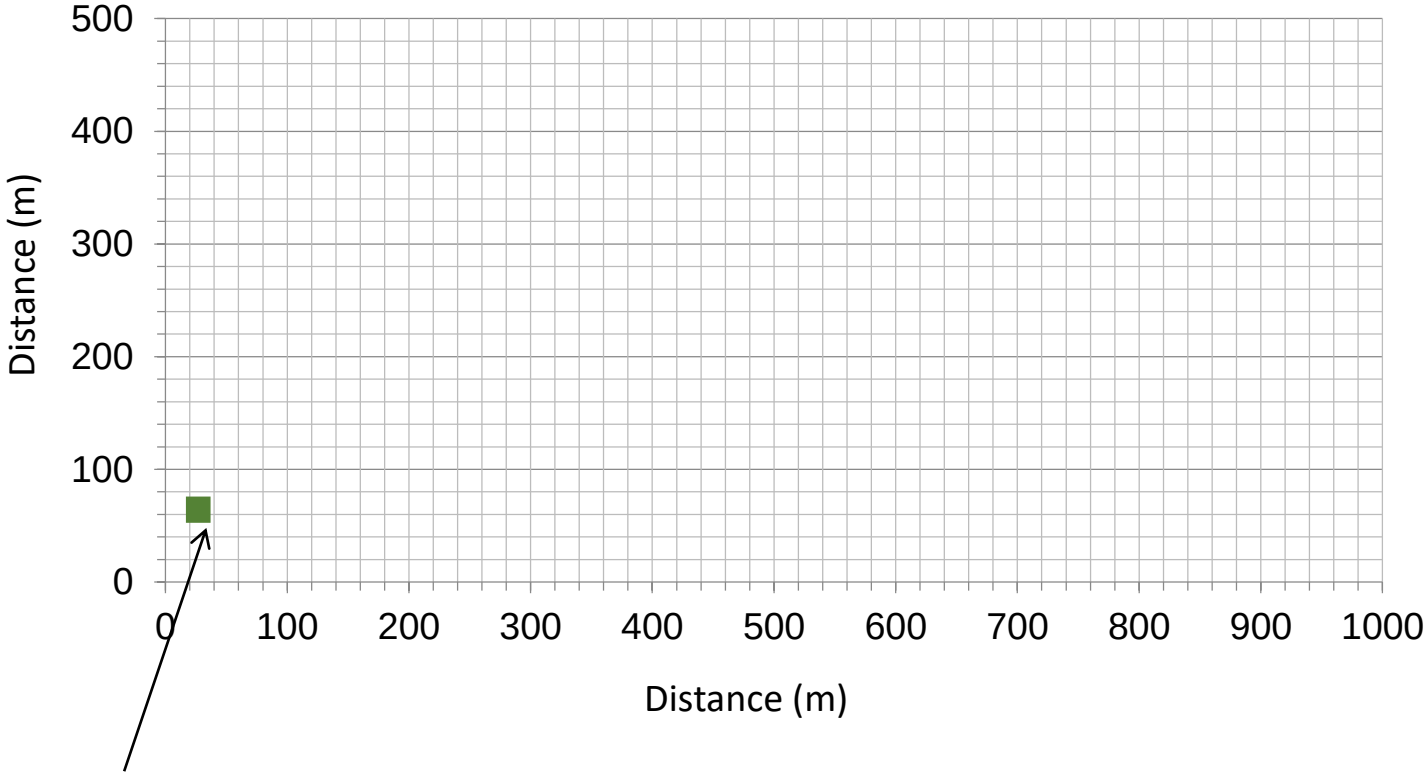
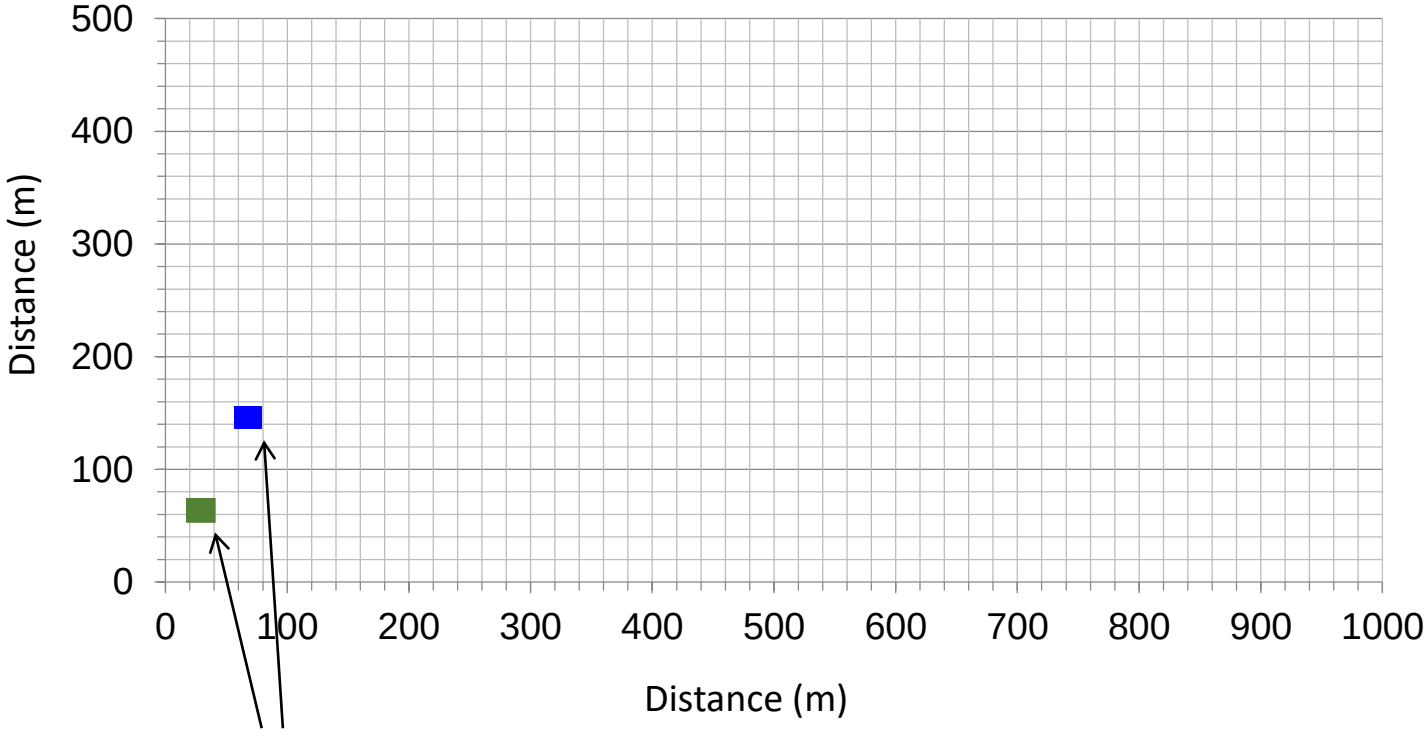


~ 20-30 individual trees >10 cm diameter at breast height (DBH)
~ 5-10 canopy trees
~ 10-15 tree species >10 cm DBH

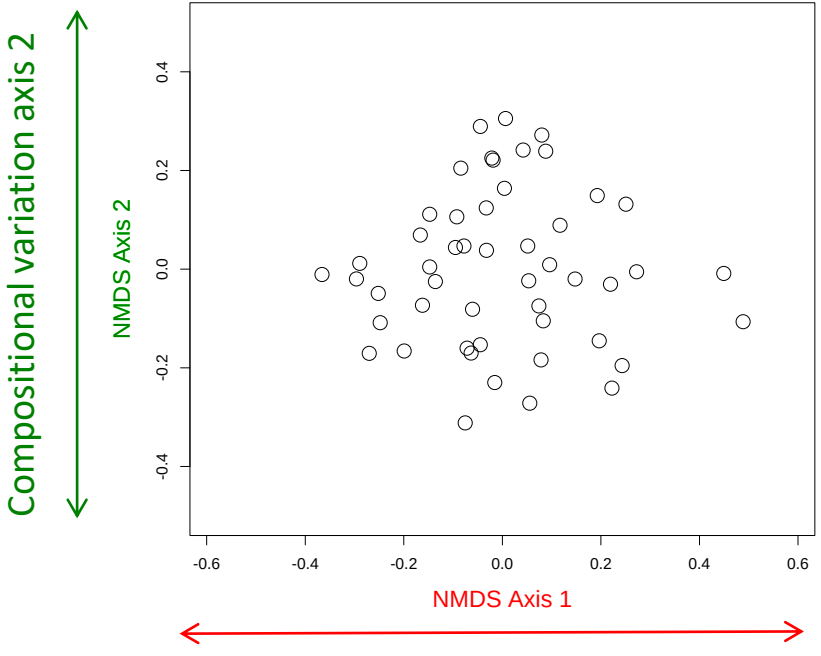
Compositional variation across a plot



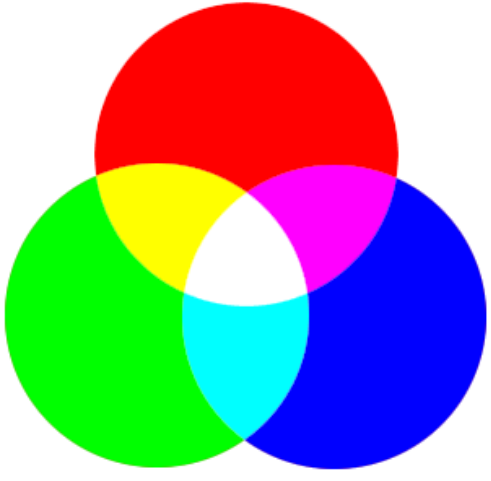
Two quadrats will differ in the composition of species – this is compositional turnover or *compositional beta diversity*.

We can also explore the phylogenetic relationships of species across quadrats – this is *phylogenetic beta diversity*.

How does species composition vary across a 50 ha plot?

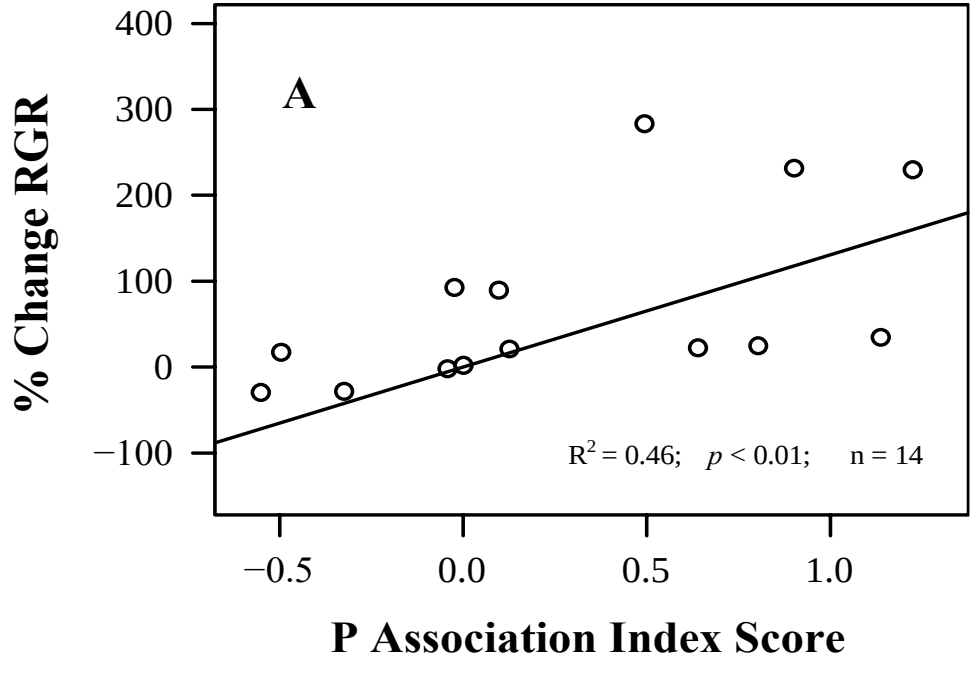


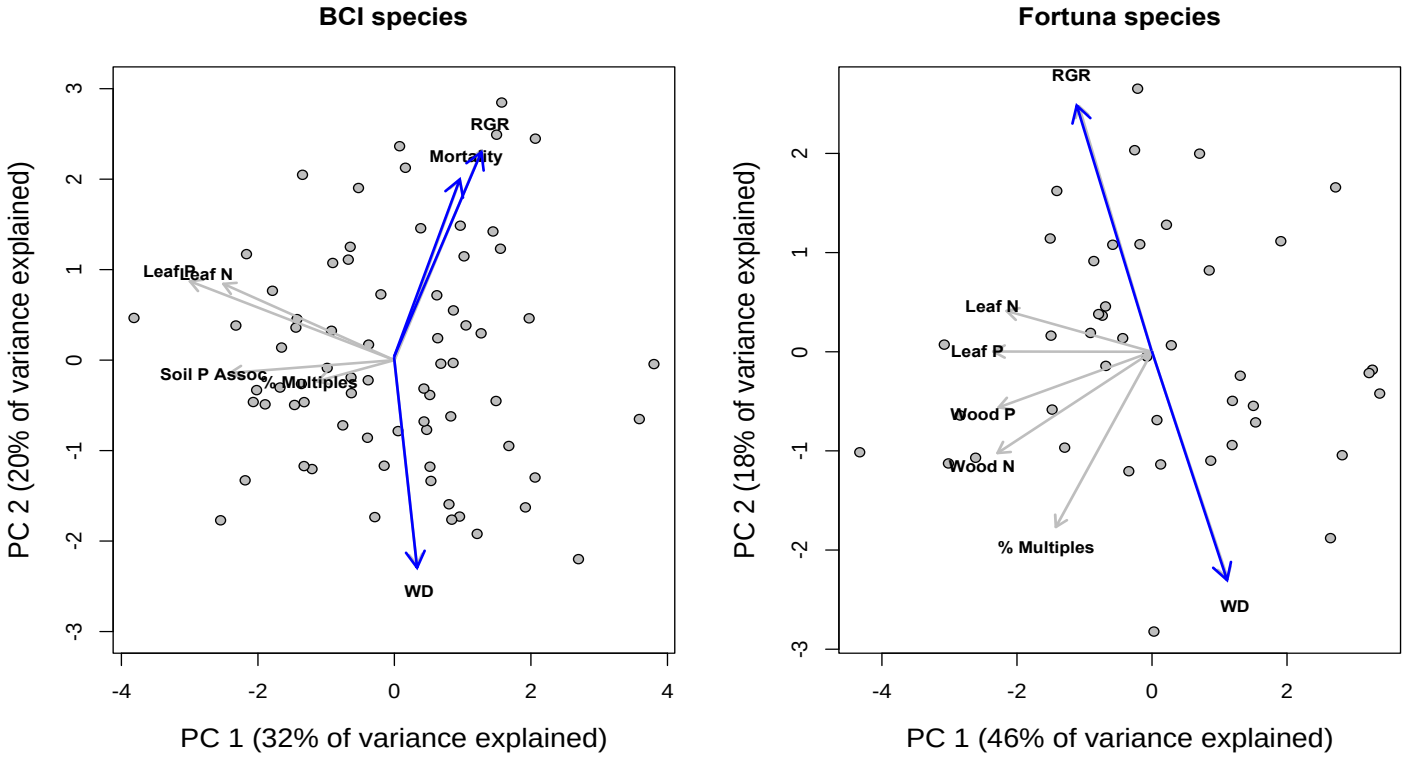
How do you *visualize* compositional variation across a plot?



RGB: Colors are an additive combination of red, green, blue

Magnitude of growth response to P correlates with species distributional association with P

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