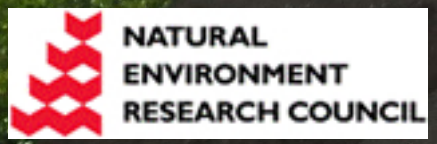
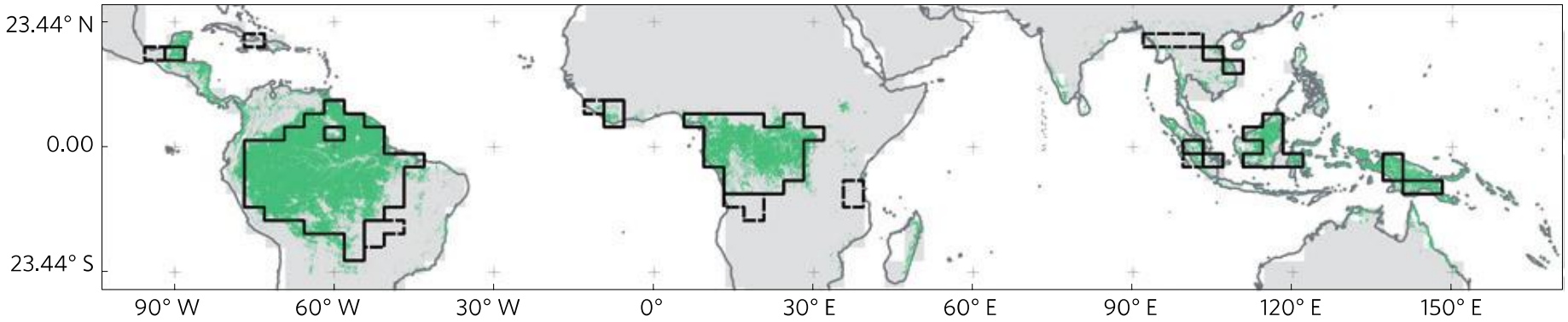
Modeling tropical forest dynamics using an individual-based forest simulator

Sophie Fauset

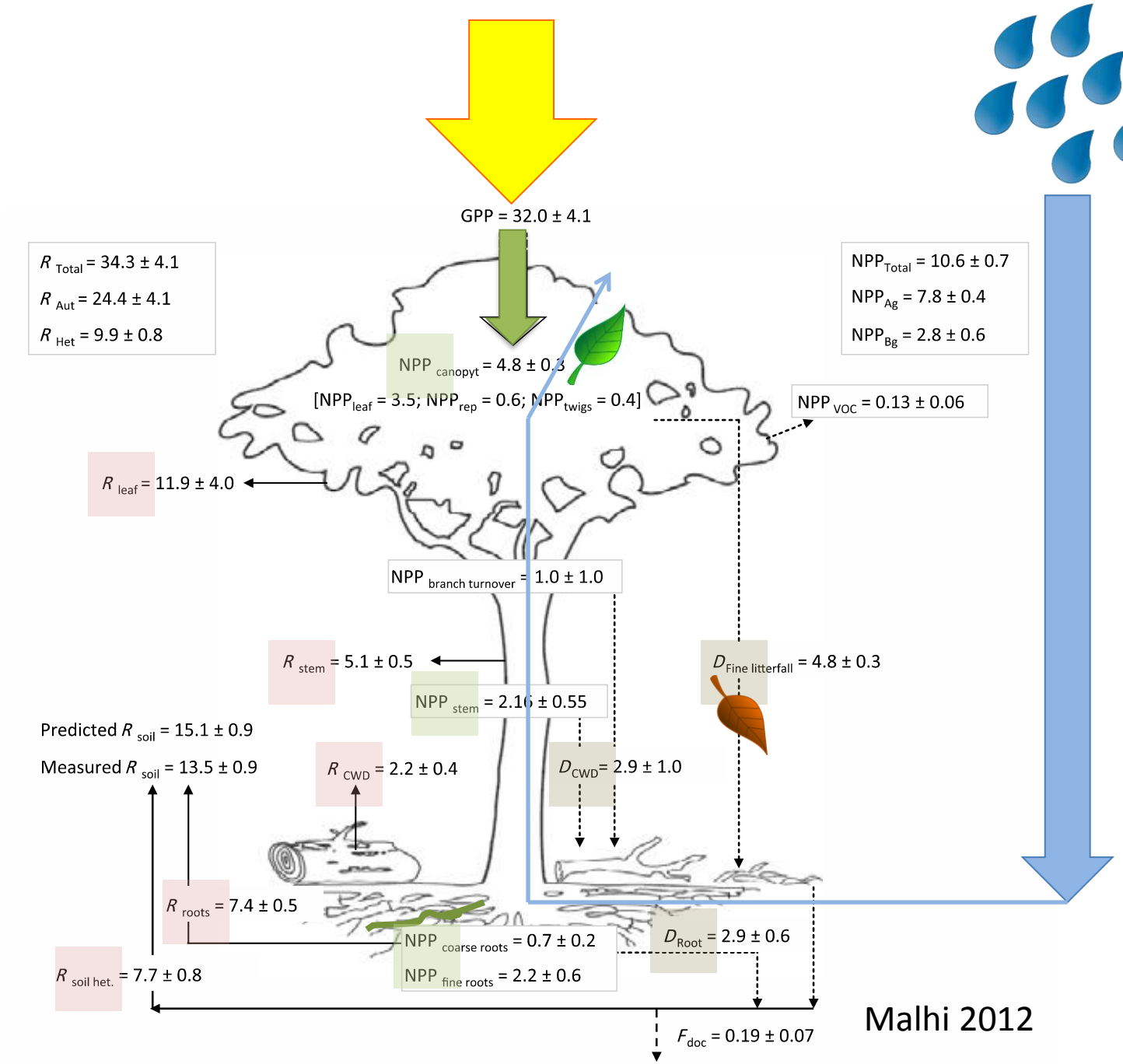
Tim Baker, Bradley Christoffersen, Nikos Fyllas, David Galbraith, Manuel Gloor, Michelle Johnson





- Contain 50 % of the Earth's plant and animal species.
- Provide income and commodities.
- House many species used in medicine.
- Used for climate change mitigation.

- Gas exchange – water, CO_2, O_2.
- Estimated intact forest sink – 1.19 Pg C yr^{-1}.
- An important unknown in global climate models.


GPP = 32.0 ± 4.1
R_{Total} = 34.3 ± 4.1
R_{Aut} = 24.4 ± 4.1
R_{Het} = 9.9 ± 0.8
NPP_{Total} = 10.6 ± 0.7
NPP_{Ag} = 7.8 ± 0.4
NPP_{Bg} = 2.8 ± 0.6
$NPP_{canopyt}$ = 4.8 ± 0.3
[NPP_{leaf} = 3.5; NPP_{rep} = 0.6; NPP_{twigs} = 0.4]
NPP_{VOC} = 0.13 ± 0.06
R_{leaf} = 11.9 ± 4.0
$NPP_{branch\ turnover}$ = 1.0 ± 1.0
R_{stem} = 5.1 ± 0.5
$D_{Fine\ litterfall}$ = 4.8 ± 0.3
NPP_{stem} = 2.16 ± 0.55
Predicted R_{soil} = 15.1 ± 0.9
Measured R_{soil} = 13.5 ± 0.9
R_{CWD} = 2.2 ± 0.4
D_{CWD} = 2.9 ± 1.0
R_{roots} = 7.4 ± 0.5
$NPP_{coarse\ roots}$ = 0.7 ± 0.2
$NPP_{fine\ roots}$ = 2.2 ± 0.6
D_{Root} = 2.9 ± 0.6
$R_{soil\ het.}$ = 7.7 ± 0.8
F_{doc} = 0.19 ± 0.07
Malhi 2012

PERGAMON

Global Environmental Change 9 (1999) S21} S30

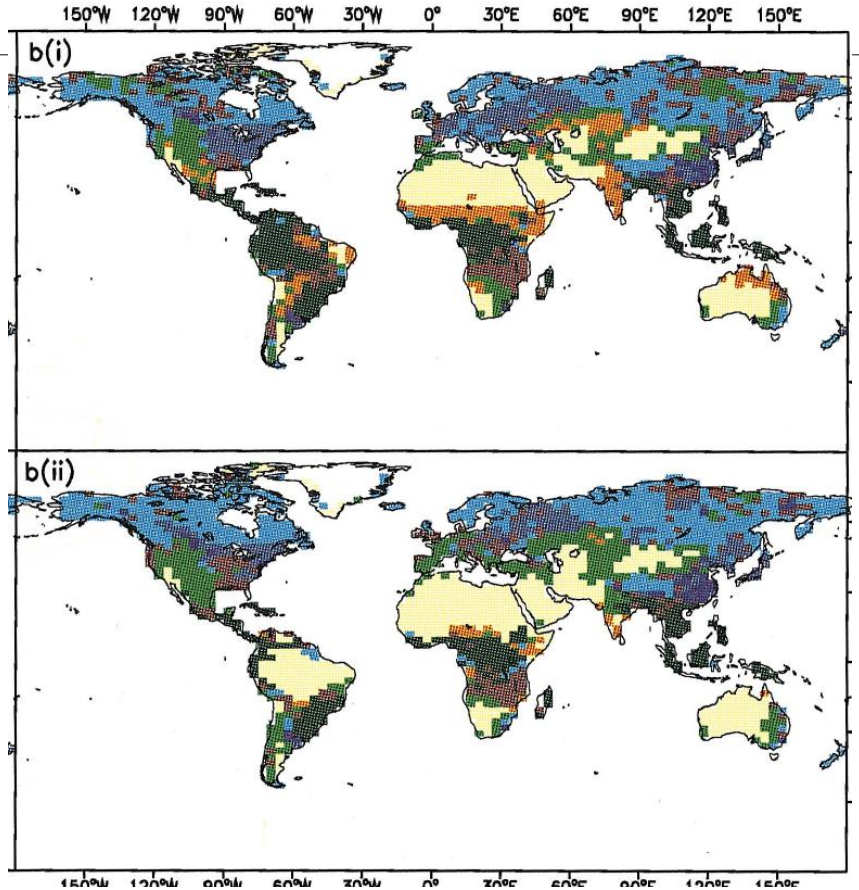
GLOBAL ENVIRONMENTAL CHANGE

www.elsevier.com/locate/gloenvcha

Climate change impacts on ecosystems and the terrestrial carbon sink: a new assessment

Andrew White*, Melvin G.R. Cannell, Andrew D. Friend[1]

Institute of Terrestrial Ecology, Bush Estate, Penicuik, Midlothian EH26 0QB, UK



Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model

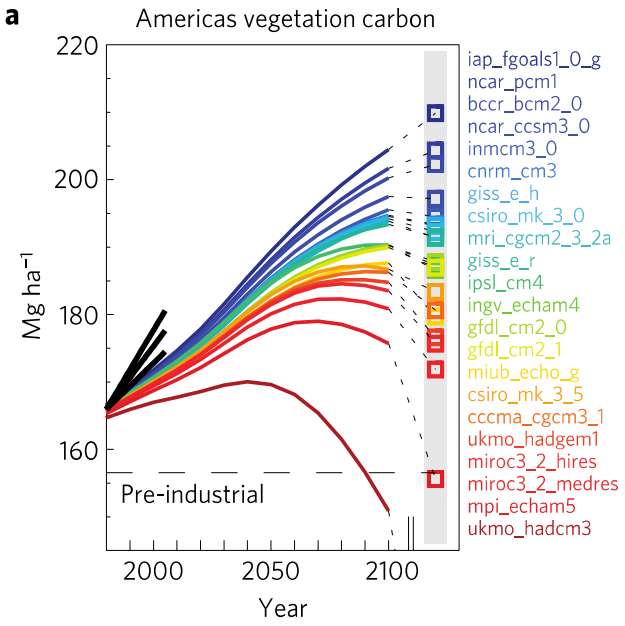
Peter M. Cox*, Richard A. Betts*, Chris D. Jones*, Steven A. Spall* & Ian J. Totterdell†

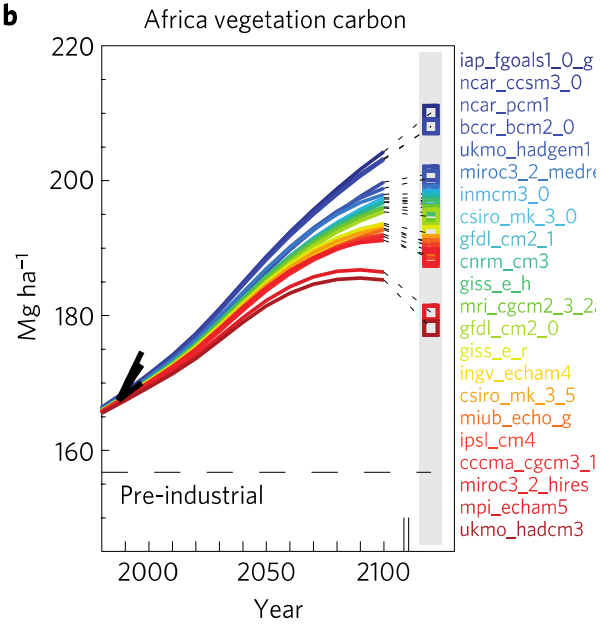
* *Hadley Centre, The Met Office, Bracknell, Berkshire RG12 2SY, UK*
† *Southampton Oceanography Centre, European Way, Southampton SO14 3ZH, UK*

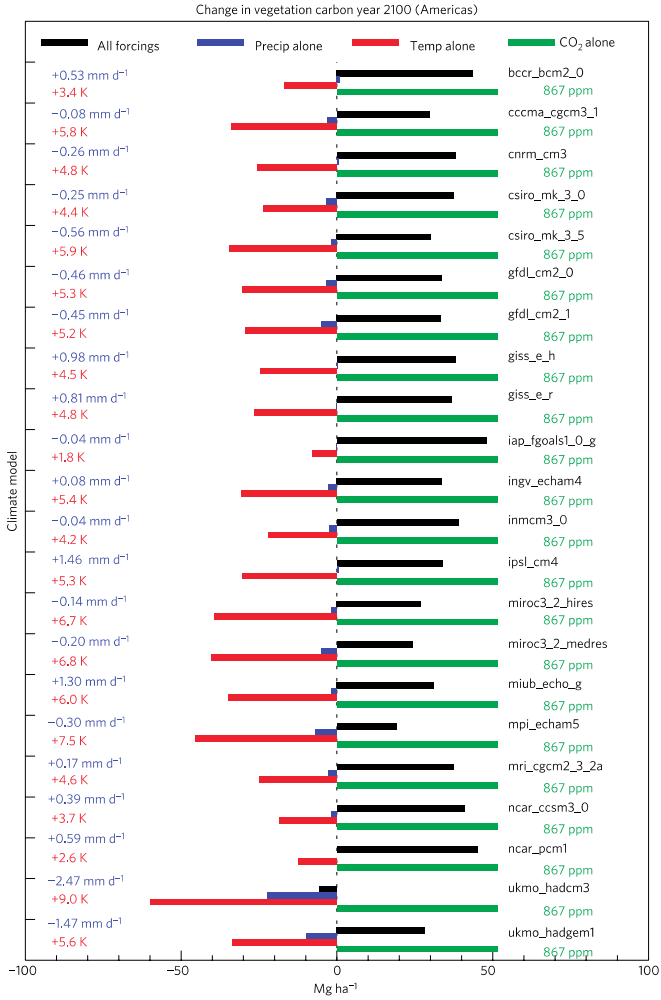
LETTERS
PUBLISHED ONLINE: 10 MARCH 2013 | DOI: 10.1038/NGEO1741
nature geoscience

Simulated resilience of tropical rainforests to CO_2-induced climate change

Chris Huntingford[1]*, Przemyslaw Zelazowski[2], David Galbraith[2,3], Lina M. Mercado[1,4], Stephen Sitch[3,4], Rosie Fisher[5], Mark Lomas[6], Anthony P. Walker[6], Chris D. Jones[7], Ben B. B. Booth[7], Yadvinder Malhi[2], Debbie Hemming[7], Gillian Kay[7], Peter Good[7], Simon L. Lewis[3,8], Oliver L. Phillips[3], Owen K. Atkin[9], Jon Lloyd[3,10], Emanuel Gloor[3], Joana Zaragoza-Castells[11], Patrick Meir[9,11], Richard Betts[7], Phil P. Harris[1], Carlos Nobre[12], Jose Marengo[12] and Peter M. Cox[13]







Physiological responses to global change

- CO_2
- Temperature
- Precipitation

- Acclimatization of physiological rates
- Shifting species composition in response to changes in environment
- Nutrient limitation
- Are the assumptions correct?
- Do the models simulate the tropics well?

Gridcells vs trees – the Amazon

- Datasets

rainfor

GEM
Global Ecosystems Monitoring Network

FORESTPLOTS.NET

Spatial patterns in the Amazon

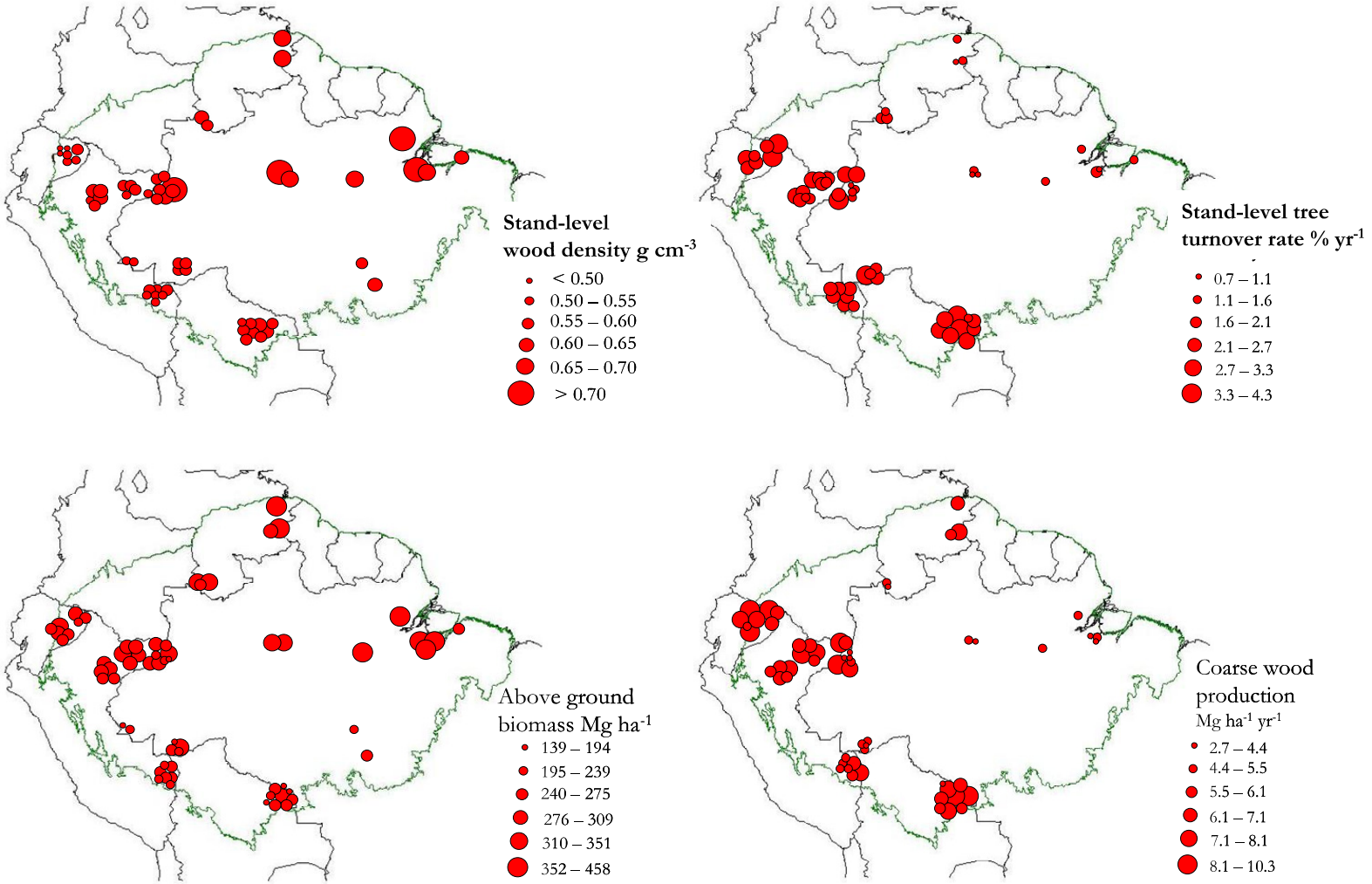
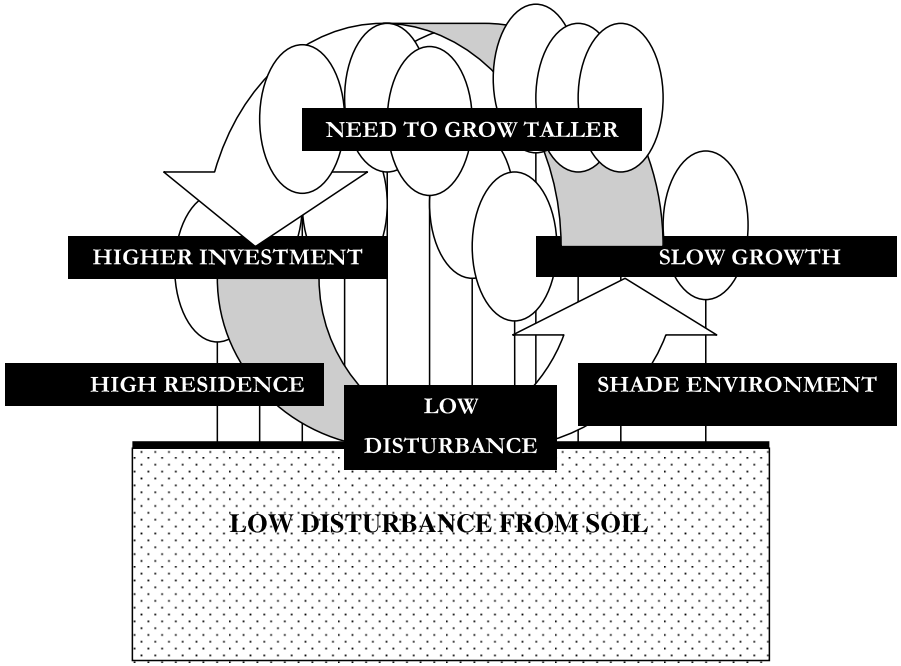
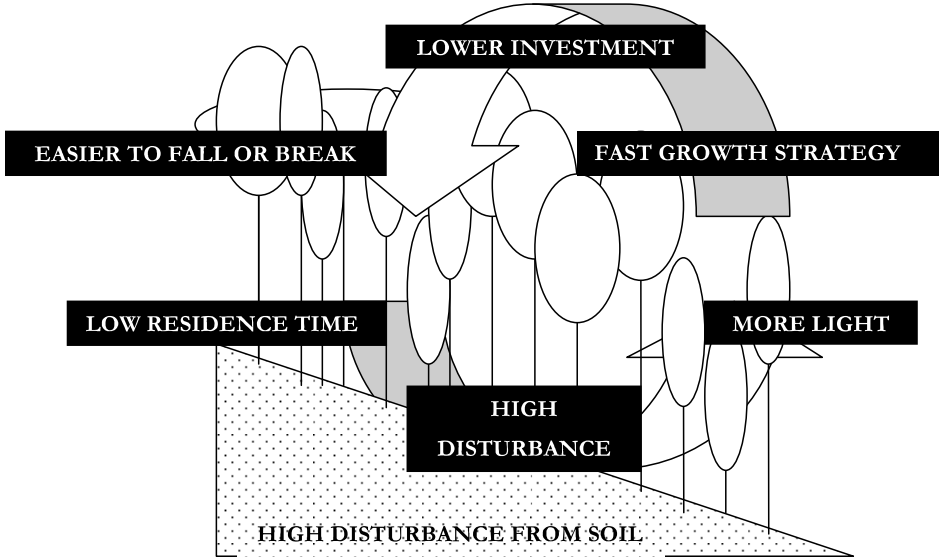


Fig. 1. Geographical distribution of stand-level wood density (ϱ_W), stand-level tree turnover rates (φ), above-ground biomass (B) and above-ground coarse wood production (W_P) across the Amazon Basin. Size of circles represents relative magnitudes.

Quesada et al. 2012



- Older soils – nutrient poor, more developed structure.
- Trees well anchored in ground, low disturbance.
- Shaded, low resource environment.
- Slow growth of trees, high investment, long residence times.

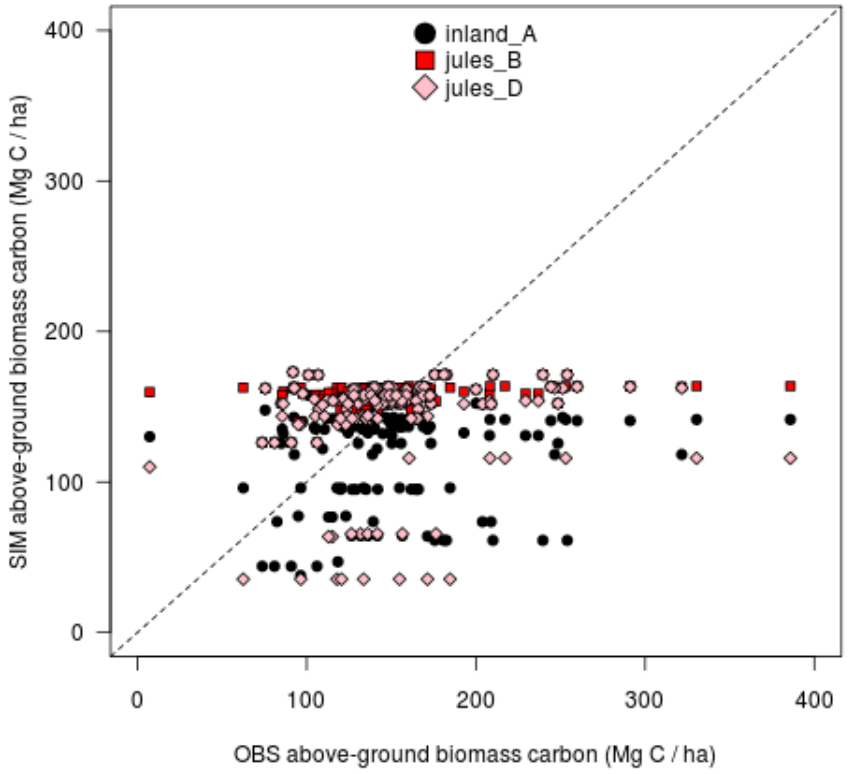


- Younger soils – nutrient rich, poor soil structure.
- Trees not well anchored in ground, high disturbance.
- Light, high resource environment.
- Fast growth of trees, low investment, short residence times.

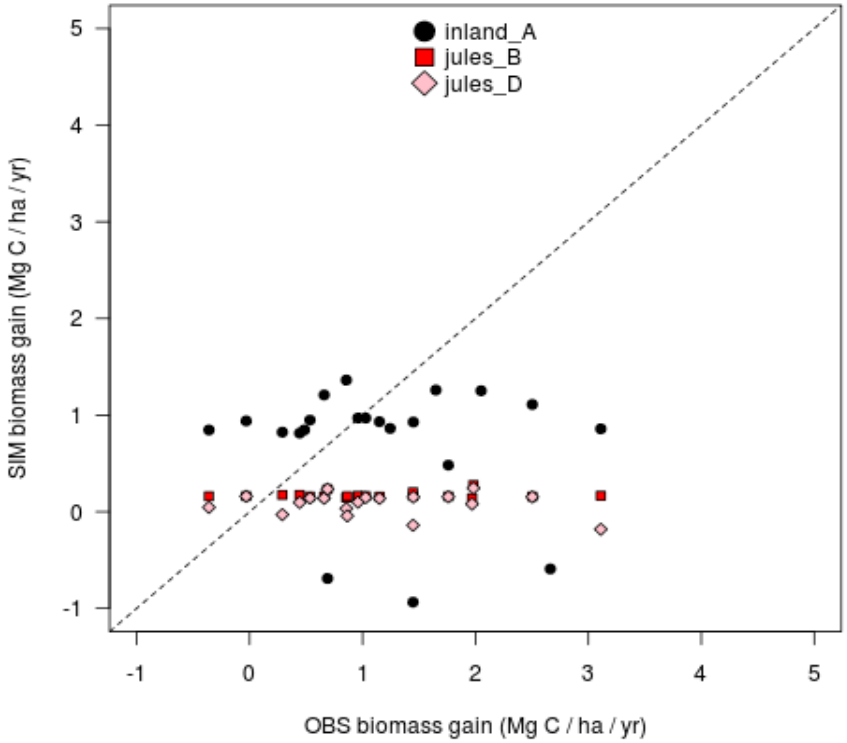
Quesada et al. 2012

Obs v Models for RAINFOR plots

Above ground biomass C



Above ground biomass gain

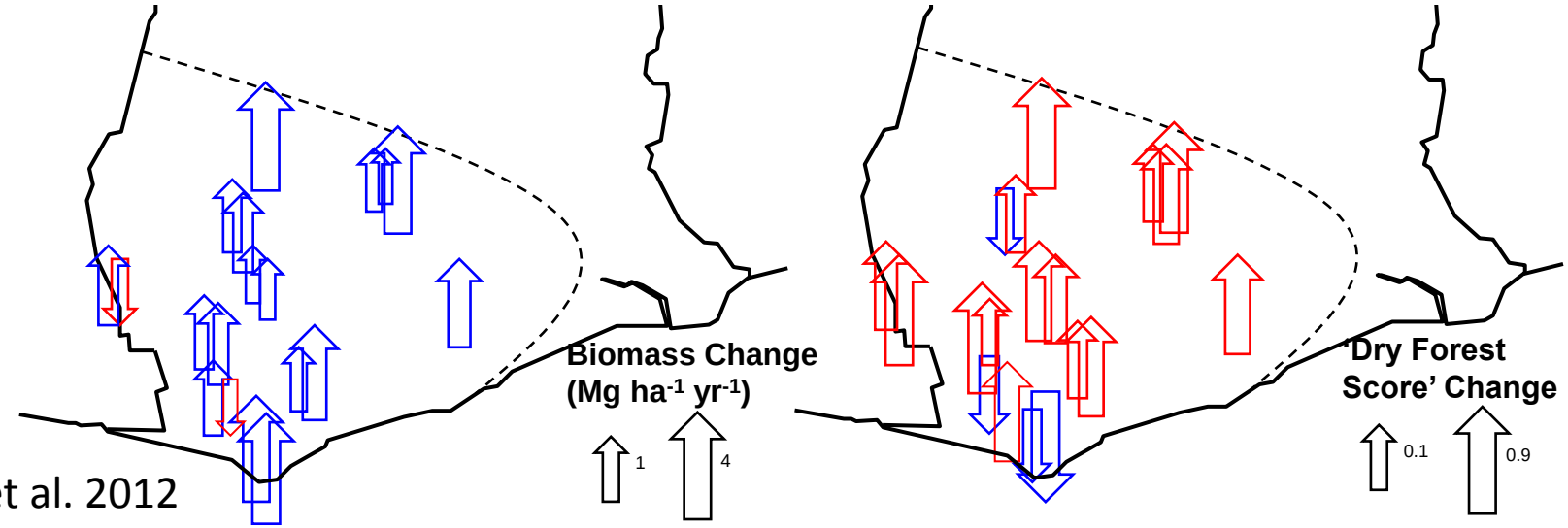


Individuals and traits

- Tropical forests are incredibly species rich.
- Different species have different characteristics and habitat associations.
- Phenotypic expression of traits is dependent on species and modulated by the environment (Fyllas et al. 2009).
- Representing the variation in life strategies present at a single site may be important…

Example: response to long-term drought

- 20 year study during a 40 year drought (11 % reduction in precipitation since 1970).
- Forest structure remained intact, but species composition shifted throughout the region.
- Species adapted to the new conditions increased.
- A species rich ecosystem may contain individuals with traits suited to altered conditions.



Fauset et al. 2012

TFS: Trait-based Forest Simulator

- We need to account for variation in species/traits within and between sites.
- Can we predict the spatial variation in Amazon forest functioning by accounting for trait variation?
- Does the outcome of simulations under different scenarios vary if we allow shifts in species/traits?
- Hopefully a more realistic model will give us more realistic results.

TFS: Trait-based Forest Simulator

- Steady state model developed by Nikos Fyllas, further development to produce a fully dynamic model.
- Designed to utilise the large forest plots database.
- Current version is initialised from data to give the between and within site variation in traits and forest structure.

Trait-Based Forest Simulator (TFS)

Inputs

Size class distribution
Traits distribution
Climate
Soil

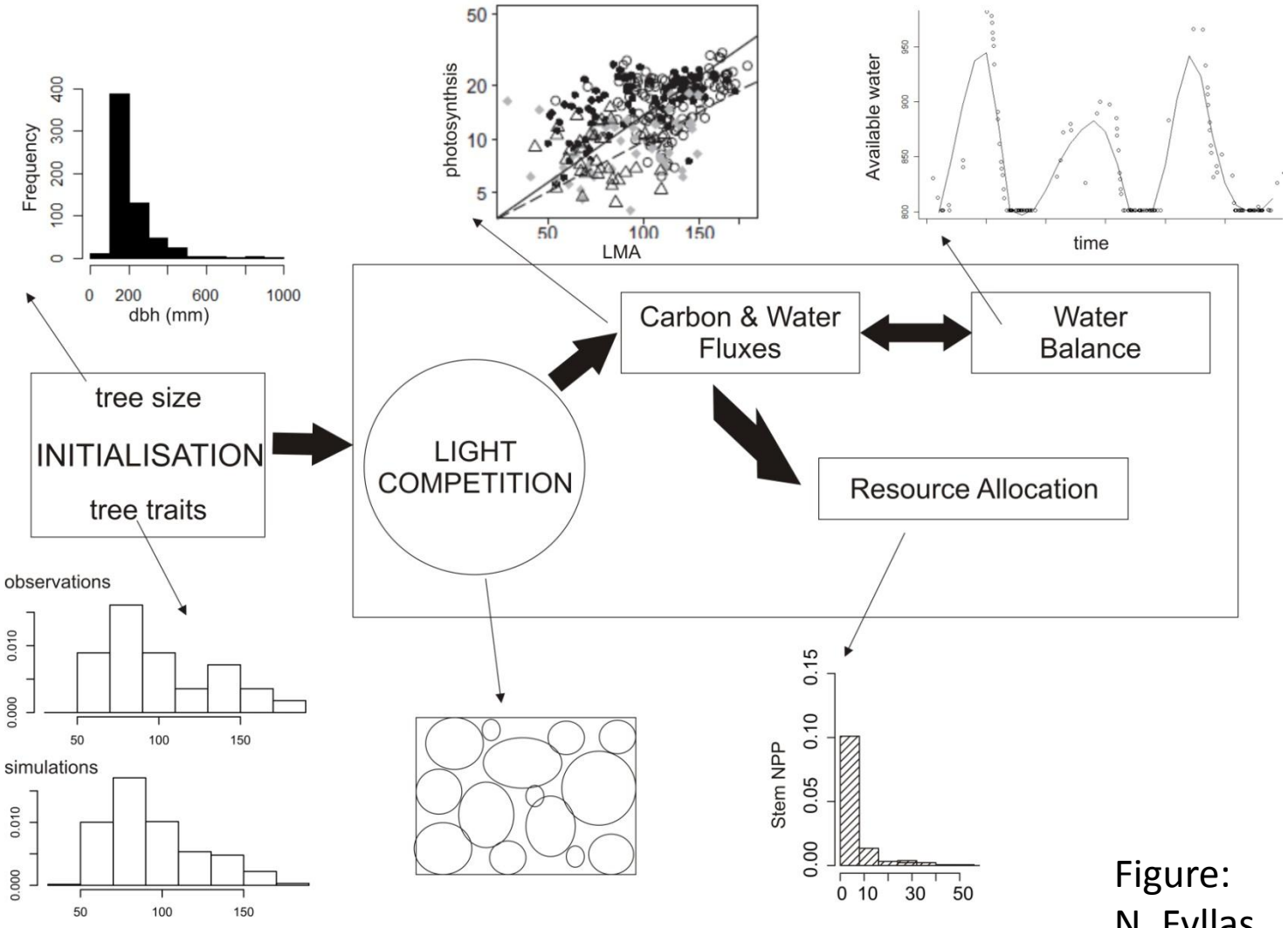
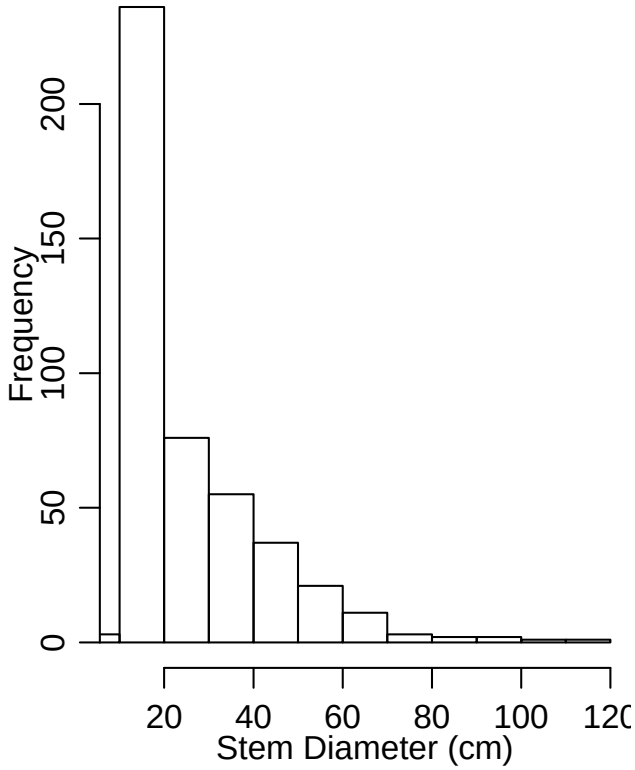


Figure:
N. Fyllas

Initialisation: Individuals

- Input:

  Size class distribution.



- Input:

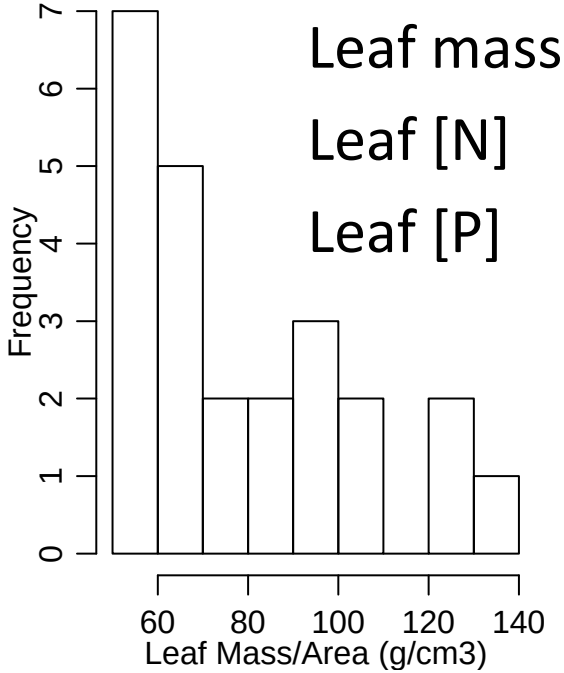
  Traits distribution.

  Wood density

  Leaf mass per area

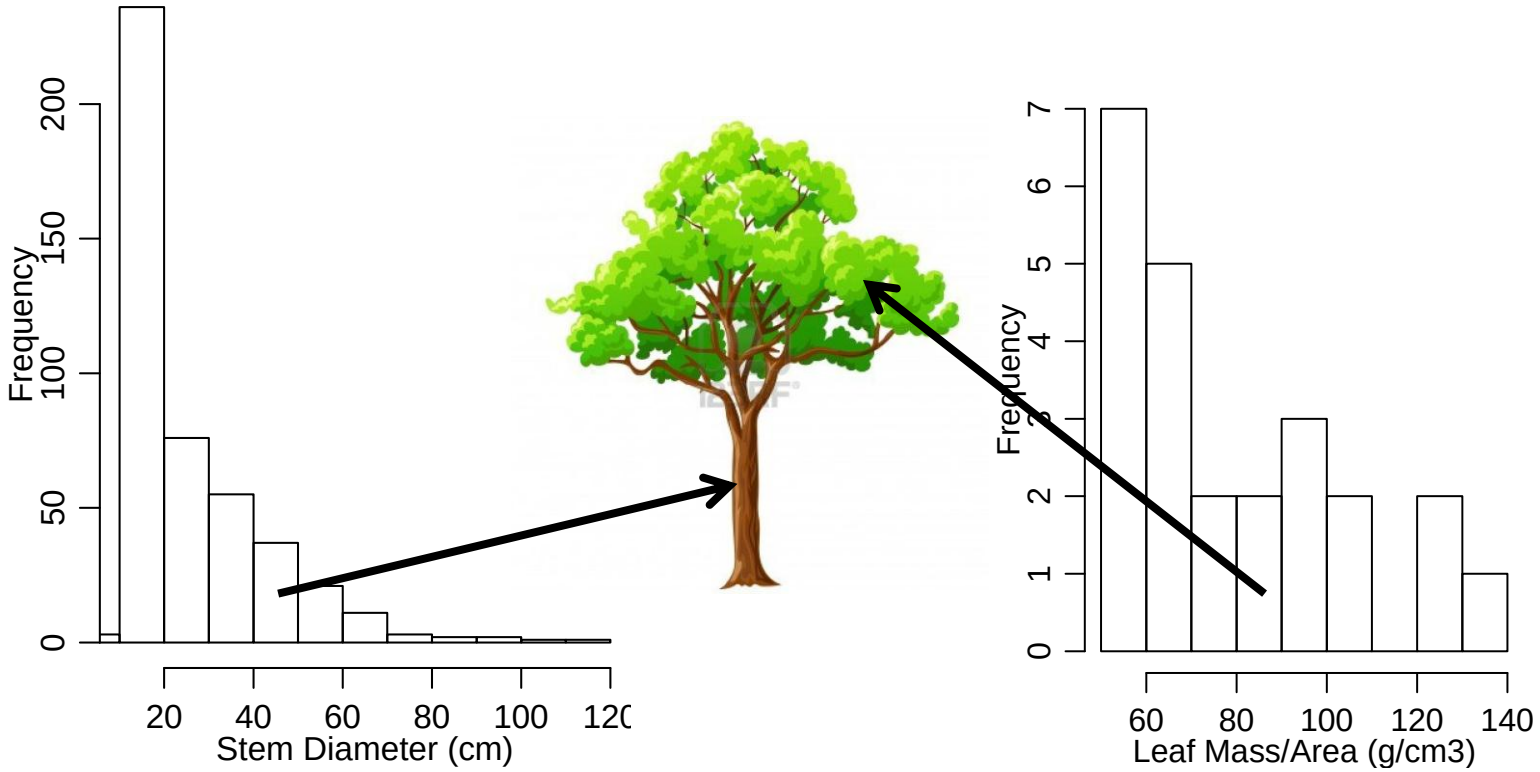
  Leaf [N]

  Leaf [P]



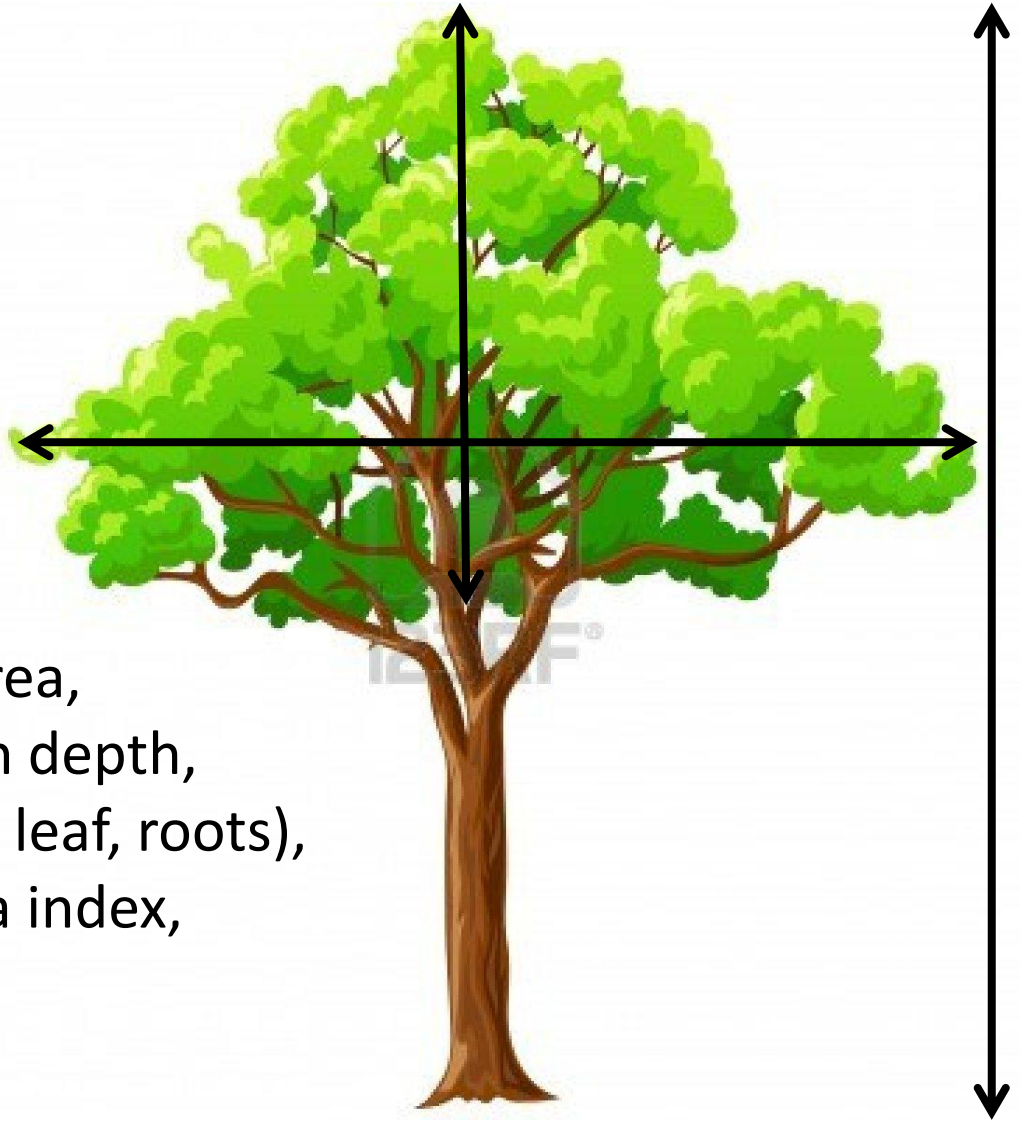
Initialisation: Individuals

- Each diameter becomes an individual.
- A value for each trait (conserving the co-variation between traits) is applied from the measured distribution.



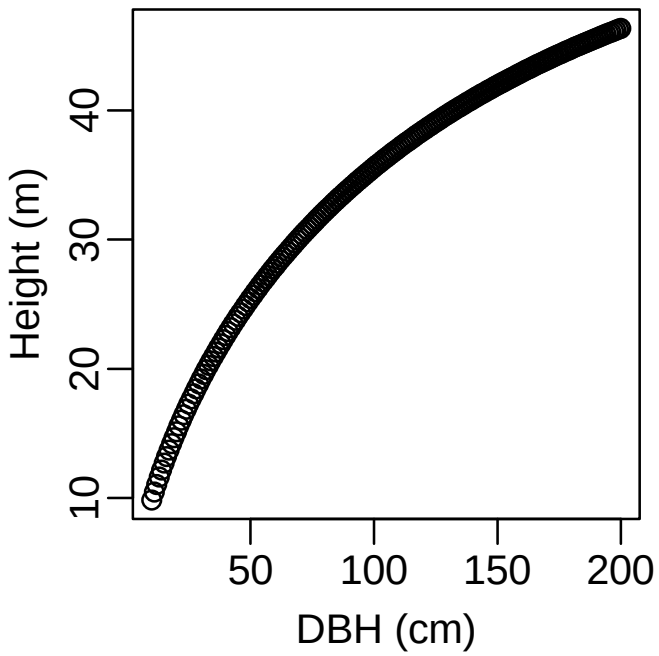
Initialisation: Individuals

From diameter and traits we use allometry to further describe the tree structure.

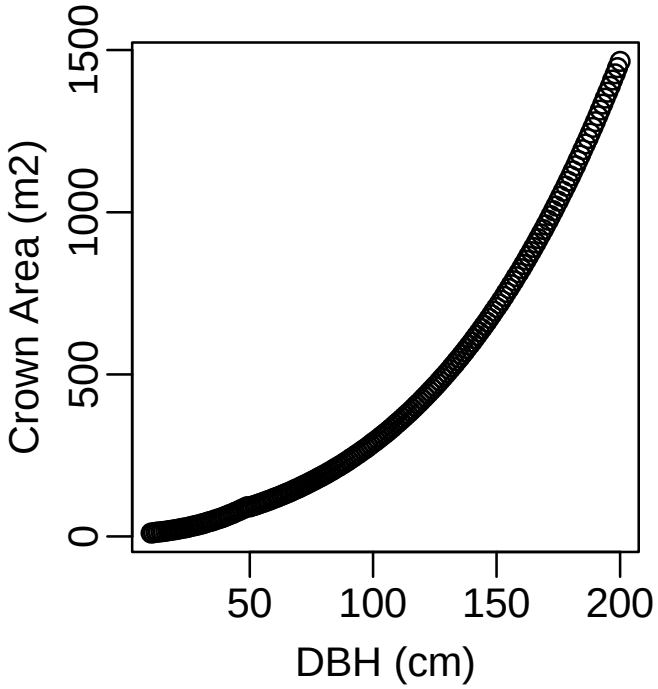


Tree height, crown area, crown volume, crown depth, biomass pools (stem, leaf, roots), foliage area, leaf area index, rooting depth.

Example allometries



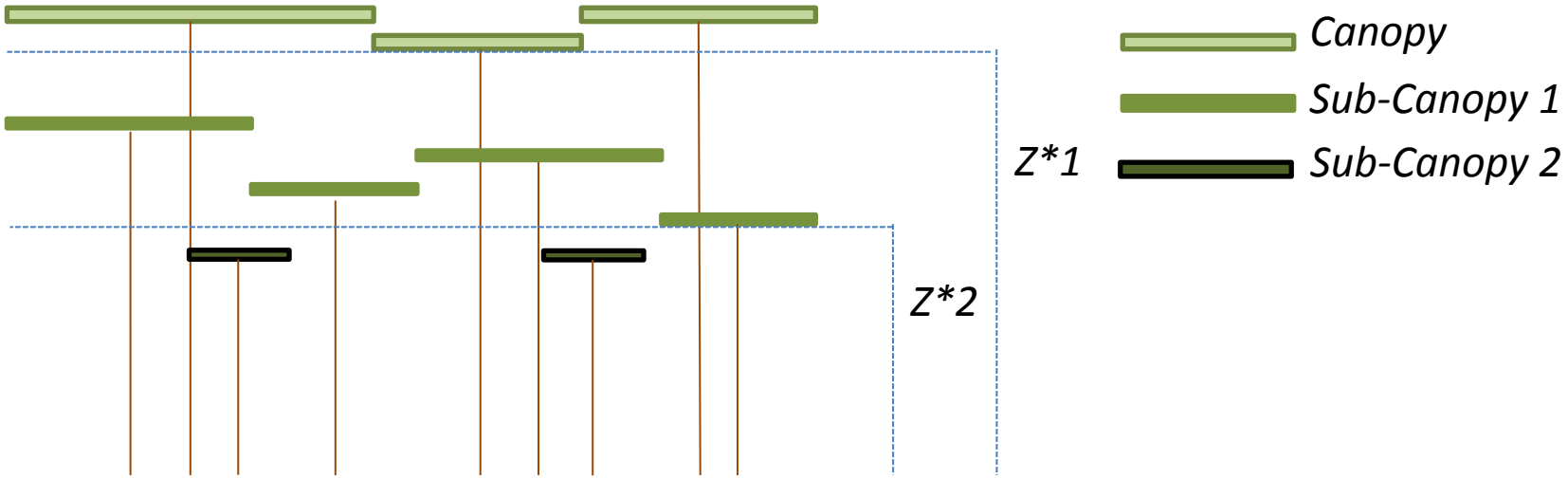
Using Bongers, Bongers & Poorter 2006



Using equation from Rosie Goodman

Initialisation: Light competition

- Tropical canopies are arranged in multiple layers, determining how much light is received by an individual.
- Perfect plasticity approximation, Purves et al. 2007, Bohlman & Pacala 2012.
  - 1. Sort trees from tallest to shortest
  - 2. Cumulatively sum crown area
  - 3. Once cumulative crown area = plot area, one layer of canopy is full, and continue on to second, third, or fourth layer.



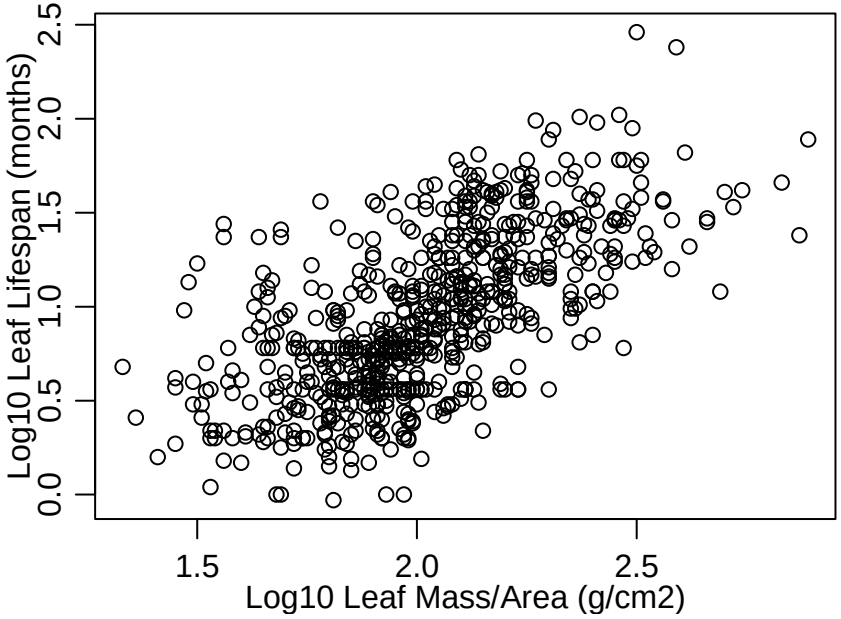
Model Processes – Individual, diurnal

- Soil moisture and available water
  - Rooting depth, soil depth, rainfall and evaporation
- Photosynthesis and stomatal conductance
  - Photosynthetic rates limited by [N] or [P]
  - Requires LMA, LAI, climate
  - Light absorbtion and energy balance based on Wang & Leuning 1998.
  - Stomatal conductance follows Medlyn et al. 2011.
- Respiration – stem, leaf, fine & coarse roots
  - Temperature dependent
  - Requires sapwood biomass, [N], crown area, Vcmax

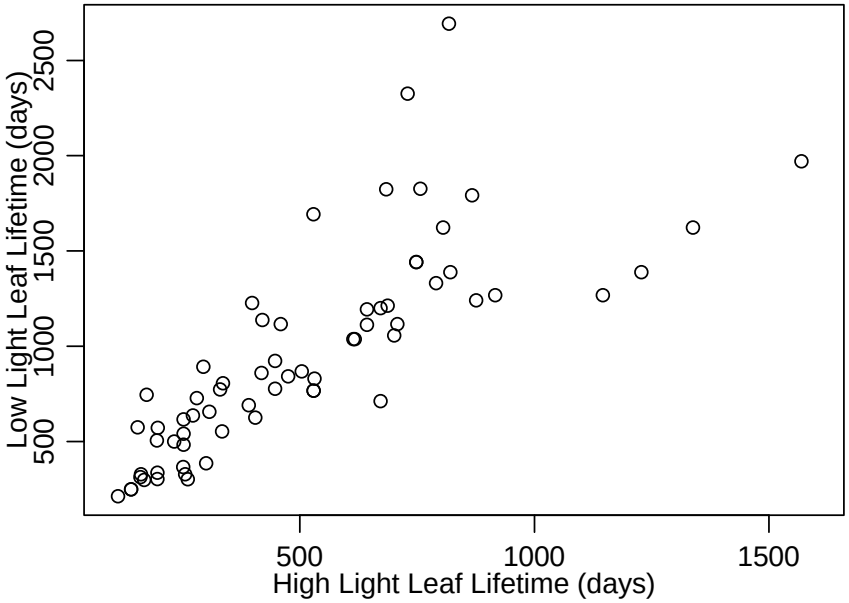
- Produces GPP, NPP, Rm, evaporation.

Litterfall

- All carbon pools (stem, roots, leaves) loose biomass through litterfall.
- Leaf lifespan is related to leaf mass per area (return on investment).
- Shaded leaves have a longer leaf life span.



Wright et al. 2004; GLOPNET data



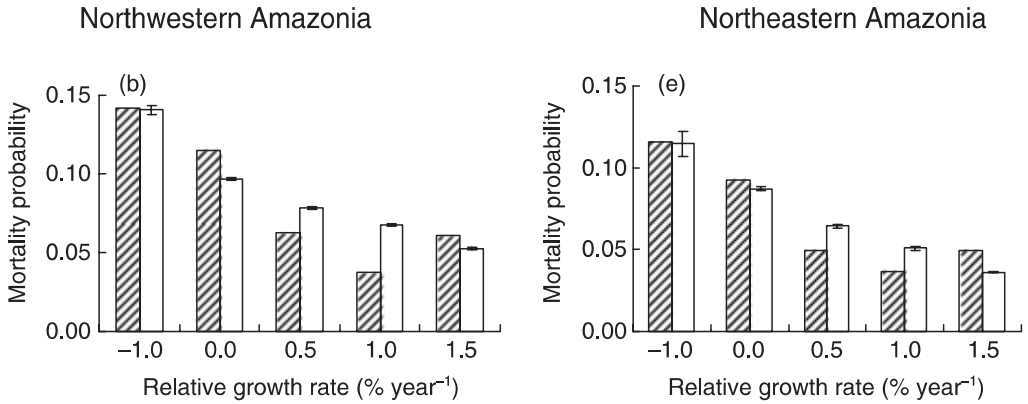
Data from: Lowman 1992, Miyaji 1997, Sterck 1999, Reich 2004, Kitajima 2013.

Allocation

- Each day NPP is allocated to biomass pools.
- First, if there is sufficient NPP, litterfall from all compartments is replaced.
- Leaf litter gets highest priority for replacement under low NPP.
- Left over NPP also assigned to pools, primarily stem and leaves.
- Update allometry from new pool sizes.

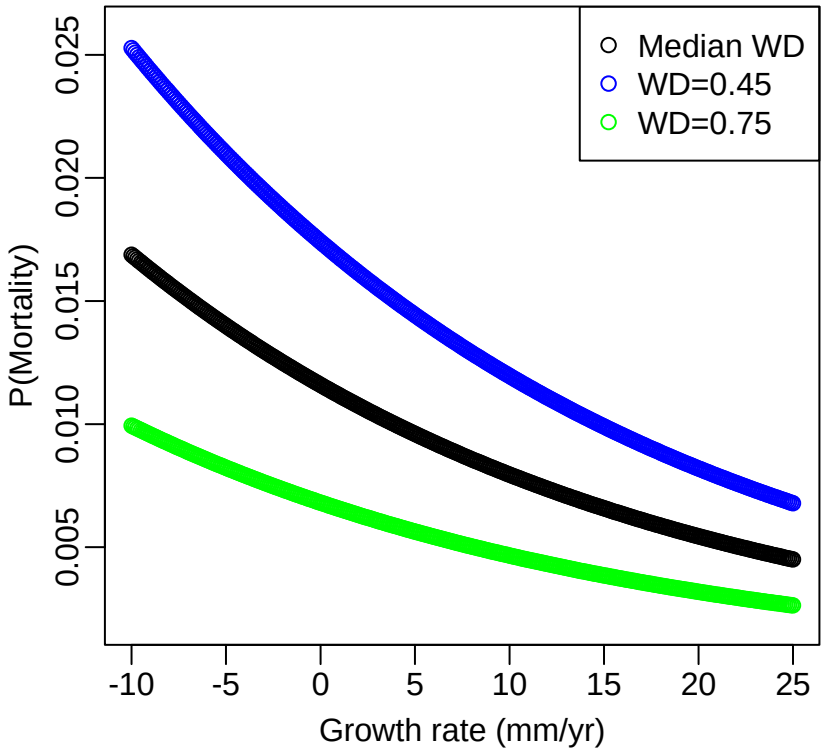
Population Dynamics - Mortality

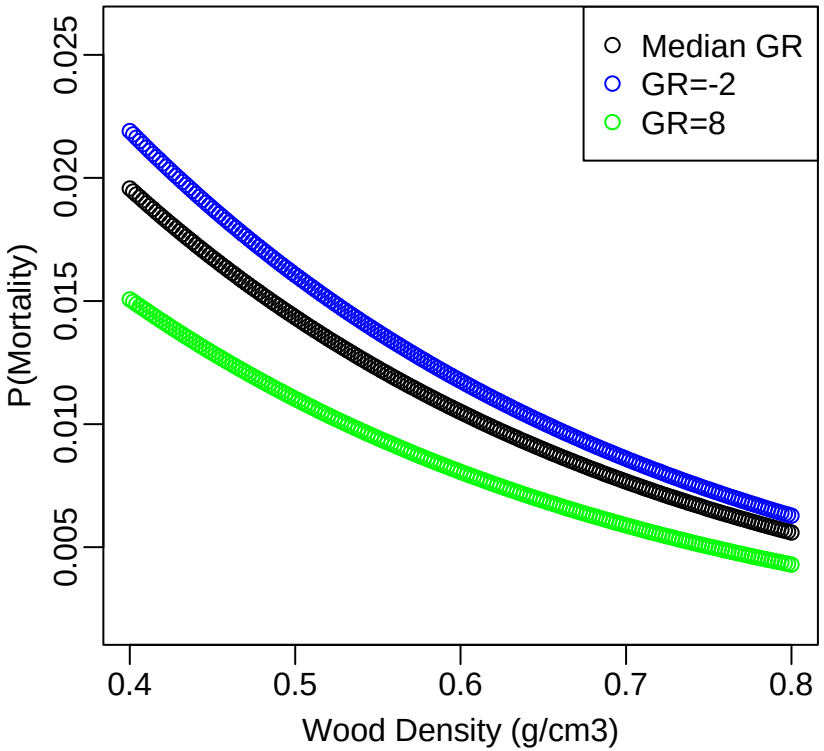
- Probability of mortality for each tree based on growth and wood density.
- Used RAINFOR plot data to come up with an equation – ML logistic regression based on Lines et al. 2010 and Chao et al. 2008.



- Growth rates based on penultimate census period.

Mortality

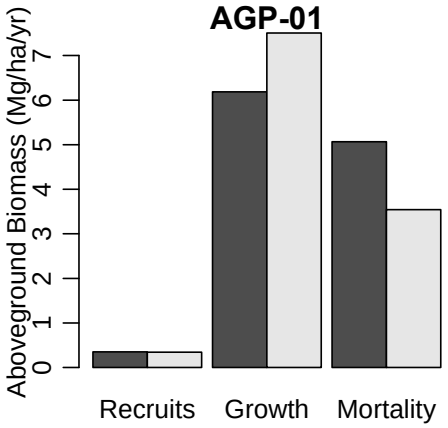

Median WD
WD=0.45
WD=0.75
P(Mortality)
0.005
0.010
0.015
0.020
0.025
-10
-5
0
5
10
15
20
25
Growth rate (mm/yr)

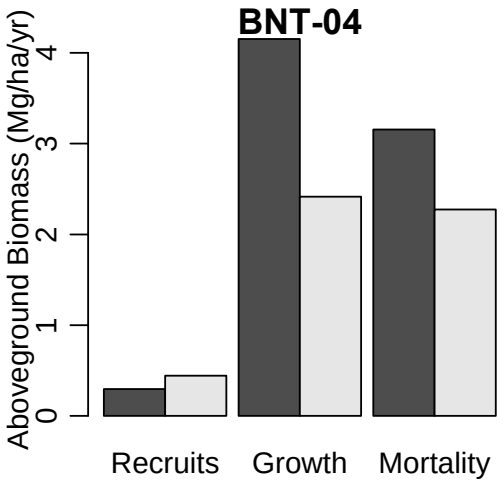

Median GR
GR=-2
GR=8
P(Mortality)
0.005
0.010
0.015
0.020
0.025
0.4
0.5
0.6
0.7
0.8
Wood Density (g/cm3)

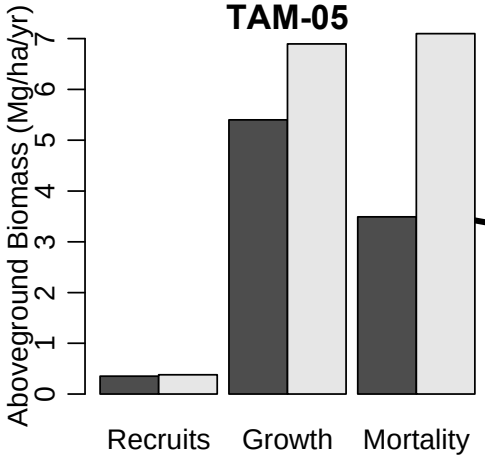
Population Dynamics - Recruitment

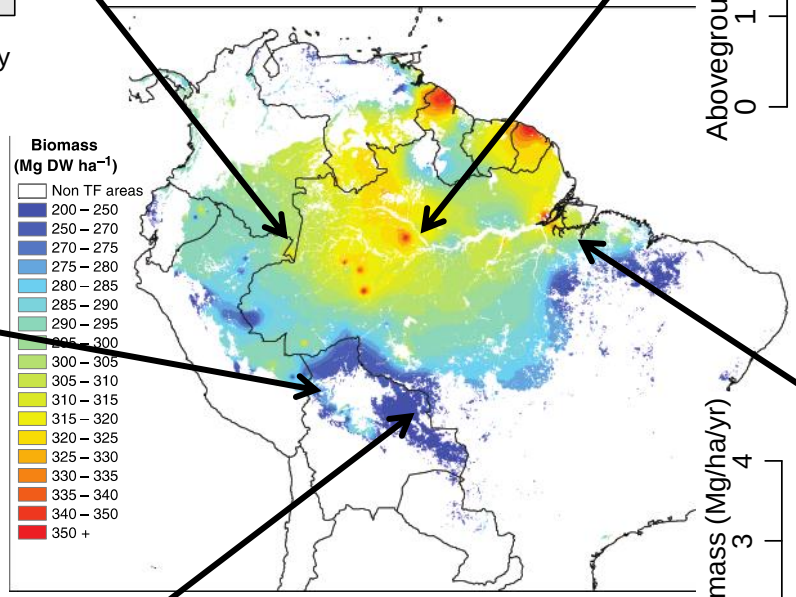
- At present set to 2 % per year.
- To be developed
  - create ‘seeds’ from the current tree population
  - ‘plant’ a subsample at random locations
  - calculate photosynthesis (considering shading)
  - only those with highest photosynthesis survive

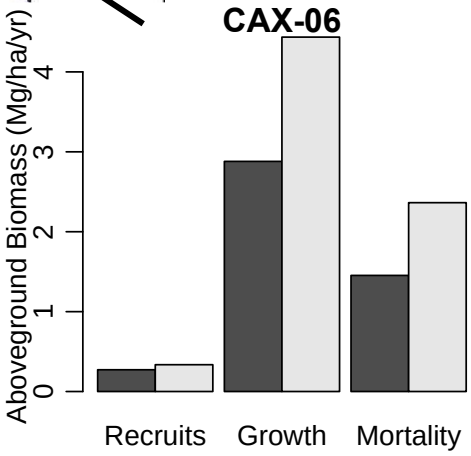
Simulated vs observed AGB dynamics (preliminary)

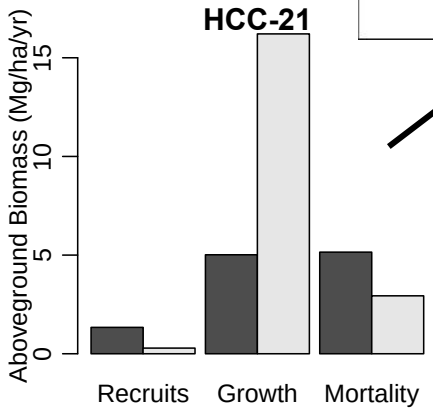


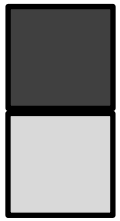










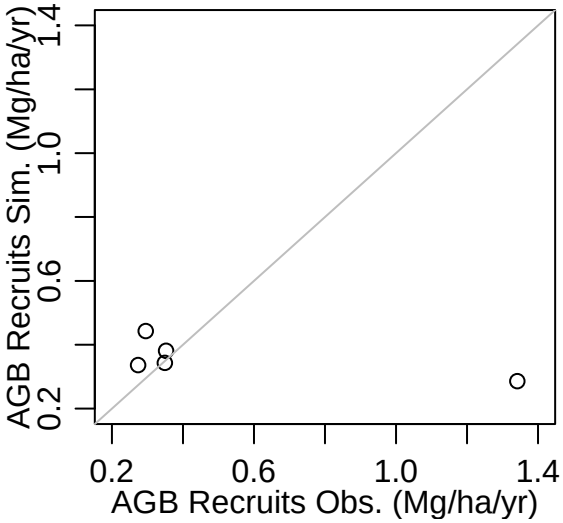


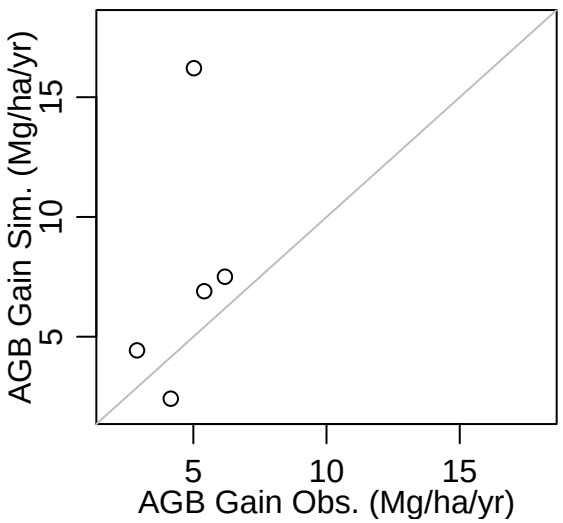
Observed

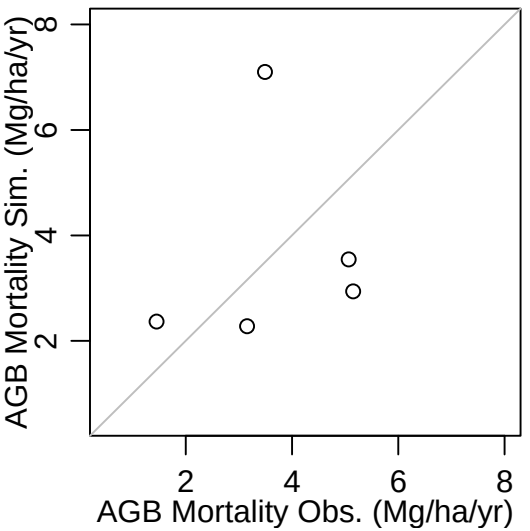
Simulated

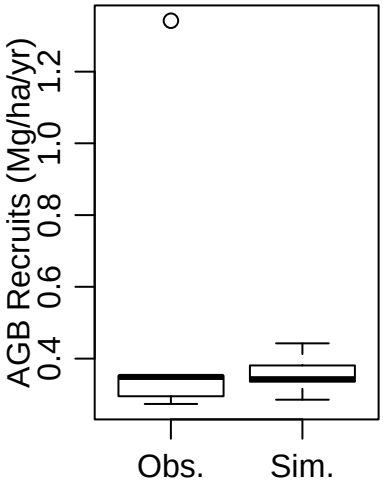
Biomass map, Malhi et al. 2006

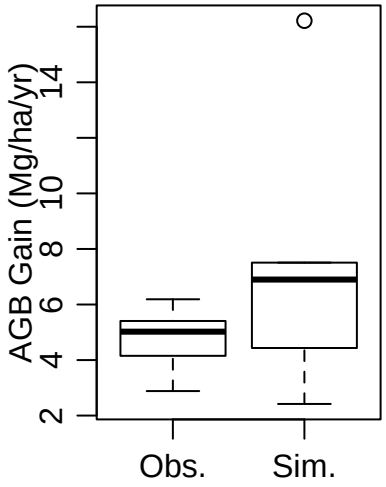
Simulated vs observed AGB dynamics (preliminary)

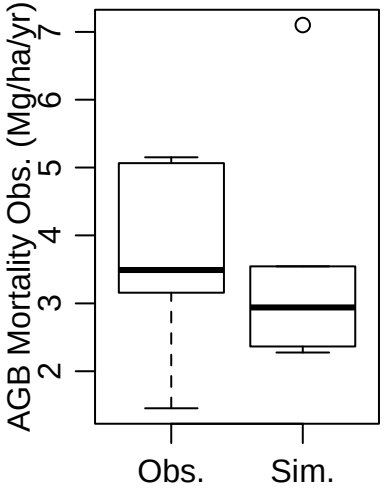




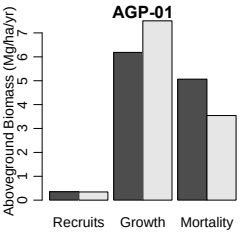






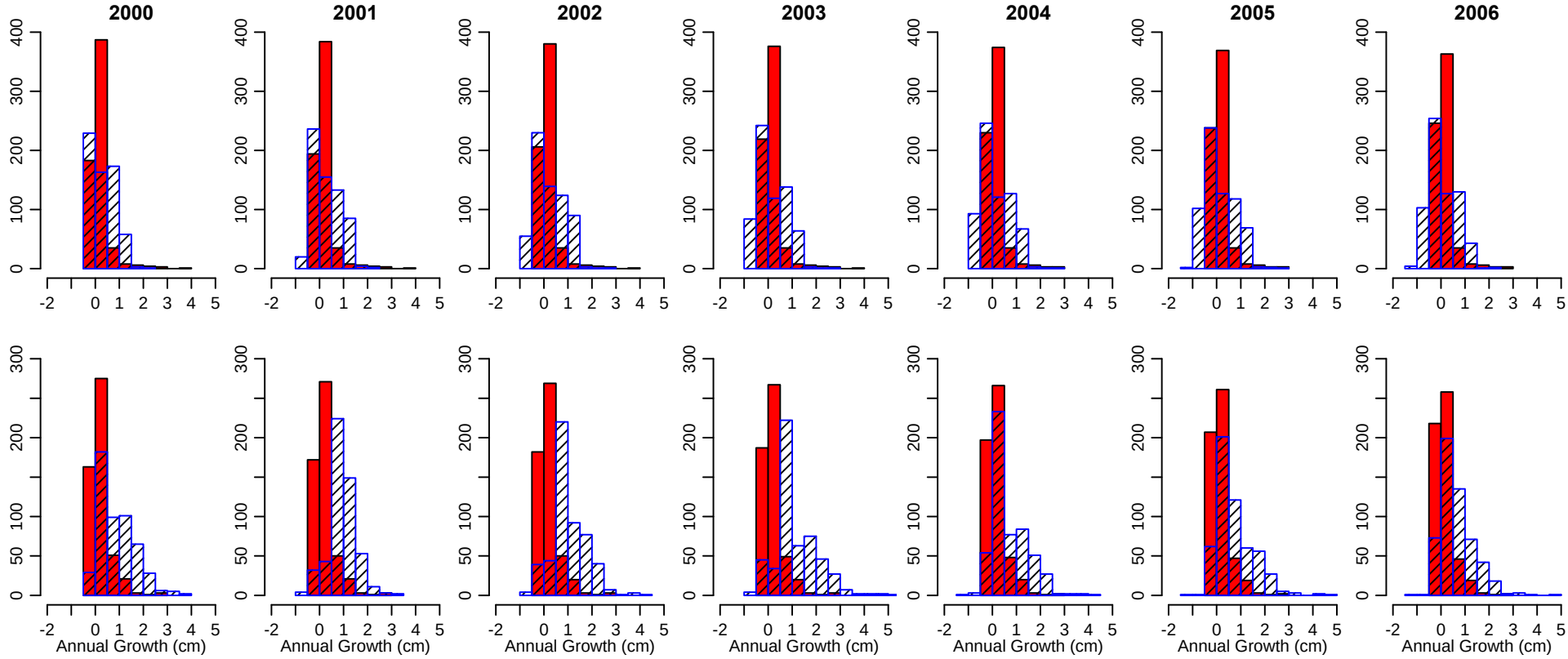


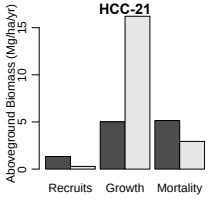
Tree by tree growth



Observations
Simultations

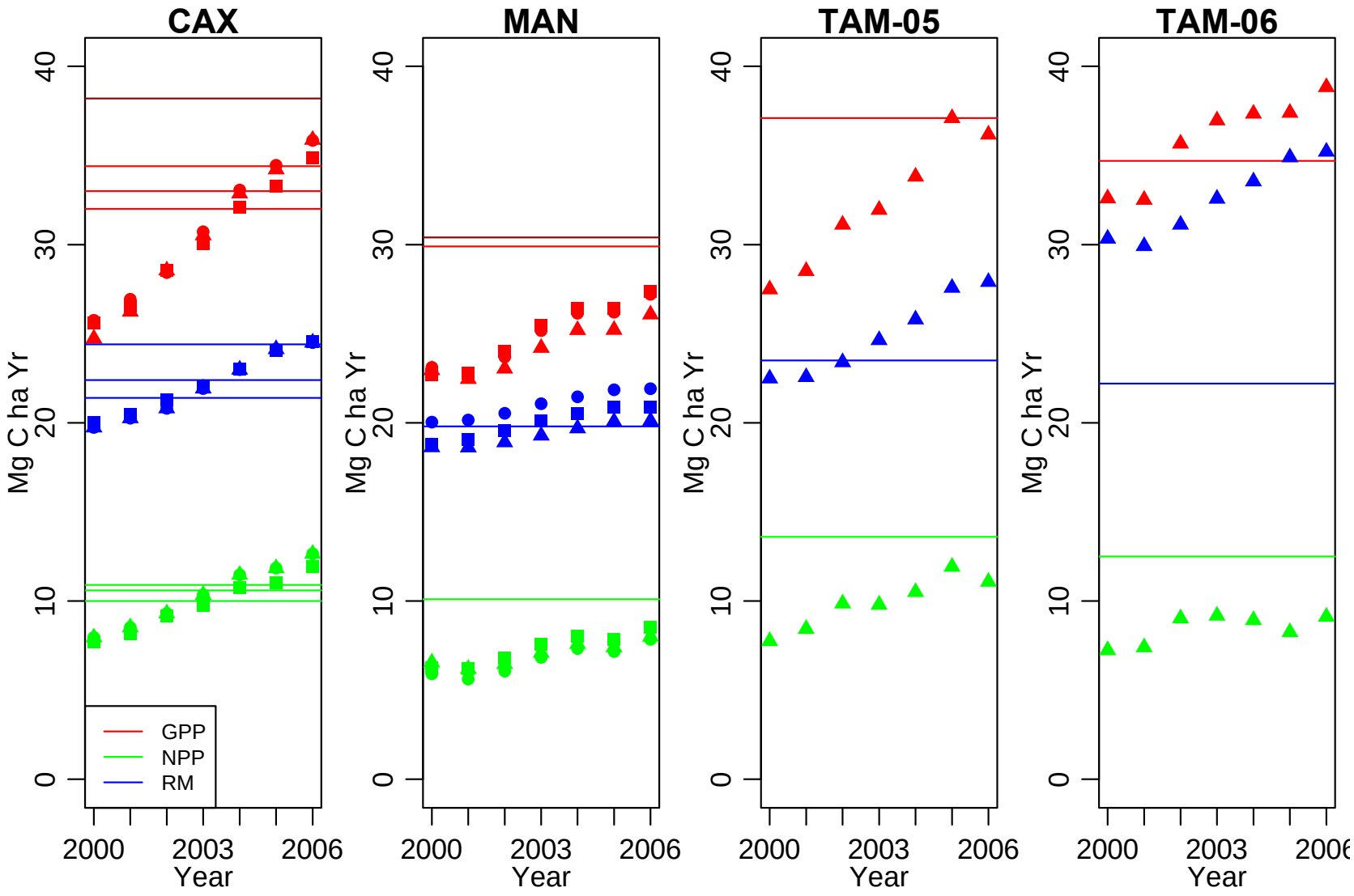
AGP-01





HCC-21

GPP, NPP, RM


CAX
MAN
TAM-05
TAM-06
Mg C ha Yr
0
10
20
30
40
2000
2003
2006
Year
GPP
NPP
RM

Summary

- Sensitivity of tropical forest ecosystems to global change still unclear.
- Currently used models to not perform well in replicating spatial patterns in the Amazon.
- Models incorporating the variation in plant traits within and between communities may improve realism and accuracy.
- Using individual based models has some additional challenges and may highlight key ecological tradeoffs, eg. LMA-leaf lifespan

Acknowledgements

Model Development
Nikos Fyllas
Manuel Gloor
Tim Baker
Michelle Johnson
Bradley Christoffersen
David Galbraith

Datasets
All RAINFOR and GEM collaborators and field participants
Oliver Phillips
Gabriela Lopez Gonzalez