Carbon allocation and partitioning

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Ecosystem Ecology

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Confusion

- Carbon allocation from Dickson & Isenbrands (1993):
  - “Biomass not allocated,” but “accumulated the end result of the allocation process.”
  - Translocation and transport should be limited to metabolic process description
  - Carbon allocation: “distribution of carbon within the plant to different plant parts” where allocation is an adaptive response to resource stress
  - Carbon partitioning: division of carbon into metabolic, structural or storage pools

More confusion:

- Carbon allocation (review by Litton et al 2007):
  - Patterns in live biomass (Enquist & Niklas 2002)

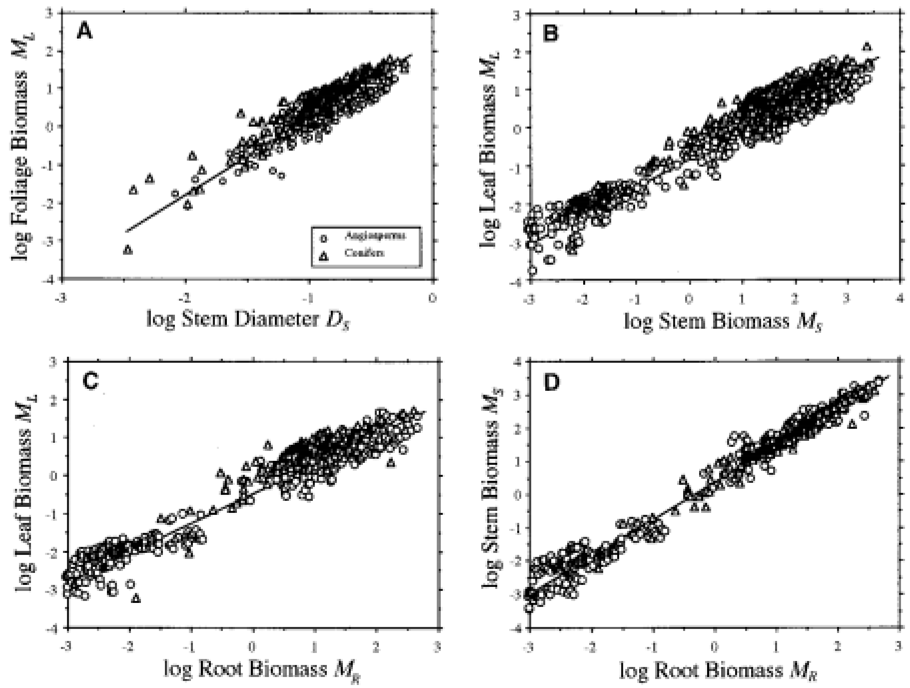


Fig. 1. D_S and M_L, M_S, and M_R relations for average plants from worldwide data sets. Solid lines are reduced major axis regression curves of log-transformed data. Angiosperm and conifer species are denoted by circles and triangles, respectively. **(A)** M_L versus D_S (trunk diameter at breast height). **(B)** M_L versus M_S. **(C)** M_L versus M_R ($r^2 = 0.861$, $n = 338$, $F = 2439$, $P < 0.0001$). **(D)** M_S versus M_R. See Table 1 for additional statistics. Note, the relatively larger spread in (B) and (C) is due to differences between Angiosperms and Gymnosperms.

More confusion:

- Carbon allocation (review by Litton (2007)):
  - Patterns in live biomass (Enquist & Niklas (2002)
  - Flux (Keith et al (1997)): Both pools and fluxes

Table 4. Components of annual belowground carbon allocation (tC ha^{-1})

	Unfertilized	P-fertilized	SED*	P
1. Soil CO_2 efflux	7.11	6.55	0.137	<0.001
2. Litterfall	2.46	2.77	0.294	n.s.
3. Coarse root production	0.45	0.60	0.086	n.s.
4. Belowground carbon allocation $4 = [(1-2)+3]$	5.10	4.38	0.336	<0.01

* Standard Error of the Difference of the means.

More confusion:

- Carbon allocation (review by Litton et al 2007):
  - Patterns in live biomass (Enquist & Niklas 2002)
  - Flux (Keith et al (1997)): Both pools and fluxes
  - Distribution of flux (Giardina et al 2003):

$$\mathbf{TBCA = F_S + F_E - F_A + \Delta C_S + \Delta C_R + C_L}$$

where:

F_S = soil surface CO_2 efflux

F_E = leached C

F_A = litterfall

ΔC_S = change in C in mineral soil

ΔC_R = increment of C in root biomass

C_L = Litter layer mass

Terminology

- Biomass: amount of material present (eg. g, kg, etc.)
- Flux: Movement of carbon to specific component of the ecosystem per unit time (eg. g yr^{-1})
- Pools: amount of material in a component
- Partitioning: GPP/amount used by component (proportion or percentage)
- Allocation: general term for where and how much carbon is throughout the ecosystem (biomass) and where it is moving to/from (flux and partitioning)

From Litton et al (2007)

Estimation of components

- Mass Balance Approach
- Gross Primary Production (GPP)
  - GPP = total assimilated CO_2 – ($R_{leaf(day)}$ + photorespiration)
  - GPP = ANPP + APR + TBCF
- Annual Net Primary Production (ANPP)
- Above Ground Respiration (APR)
- Total Below Ground Carbon Flux (TBCF)

ANPP

- **ANPP = $F_A + F_W + \Delta C_C + \Delta C_W$**
  - where:
  - F_A = flux of C associated with litterfall
  - F_W = flux of C associated with mortality
  - ΔC_C = increment of C associated with C content in live leaves
  - ΔC_W = increment of C associated with aboveground biomass

Simplified as:

$$ANPP_{total} = ANPP_{foliage} + ANPP_{wood}$$

- Where:
  - $ANPP_{foliage} = F_A + \Delta C_C$
  - $ANPP_{wood} = F_W + \Delta C_W$

from Giardina et al (2003)

Litterfall

http://www.crestmonsoon.org/maemoh/Photo/Litter.JPG

Litterfall

- Annual (or other time scale) C inputs to forest floor
- Estimate LAI_{max} (corrected for herbivory losses)
- Can be broken up into components
- Rule of thumb: detect 20% difference in litterfall at a site
  - For example, 15-20 for deciduous forest type

Bernier et al (2008)

Litterfall

- Processing
  - Subsample for LA if desired (Leaf Mass per Area)
  - Dried 24-48 hours at 70°C
  - Sort (plant part, species, etc.)

$$P_c = (M_c\ (1\text{-}H)\ C_c\ (P_{L,f}/P_{L,I})/A)$$

where:

- P_c = Annual production of canopy components
- M_c = annual dry mass of litter
- H = fraction of leaf area lost to herbivory
- C_c = Carbon fraction (typically 50%)
- $P_{L,f}$ = average leaf mass per area of fresh leaves
- $P_{L,I}$ = average leaf mass per area of leaves in the litter
- A = total basket area

Bernier et al (2008)

Litterfall

- Complications:
  - System (e.g. deciduous broadleaf vs. coniferous)
  - No measurement of pollen or VOCs
  - Timing (Northern vs. Southern Hemisphere)
  - Decomposition in basket
  - Climate
  - Diameter of twigs (<1 cm typical)
  - Labor

Bernier et al (2008)

ANPP

- **ANPP = $F_A + F_W + \Delta C_C + \Delta C_W$**
  - where:
  - F_A = flux of C associated with litterfall
  - F_W = flux of C associated with mortality
    - Added back into estimates
    - Can account for 1-2% per year (Kloeppel et al 2007)
    - Think about length of study

from Giardina et al (2003)

ANPP

- **ANPP = $F_A + F_W + \Delta C_C + \Delta C_W$**
  - where:
  - F_A = flux of C associated with litterfall
  - F_W = flux of C associated with mortality
  - ΔC_C = increment of C associated with C content in live leaves
    - Monthly measurements of LAI with LAI-2000 Plant Canopy Analyzers (Li-COR)
    - During overcast, calm conditions
    - Linear interpolation for months that were missed because of climate conditions
    - Overlap and clumping corrected using allometric relationship between DBH and LAI

from Giardina et al (2003)

Leaf Area Direct Measure

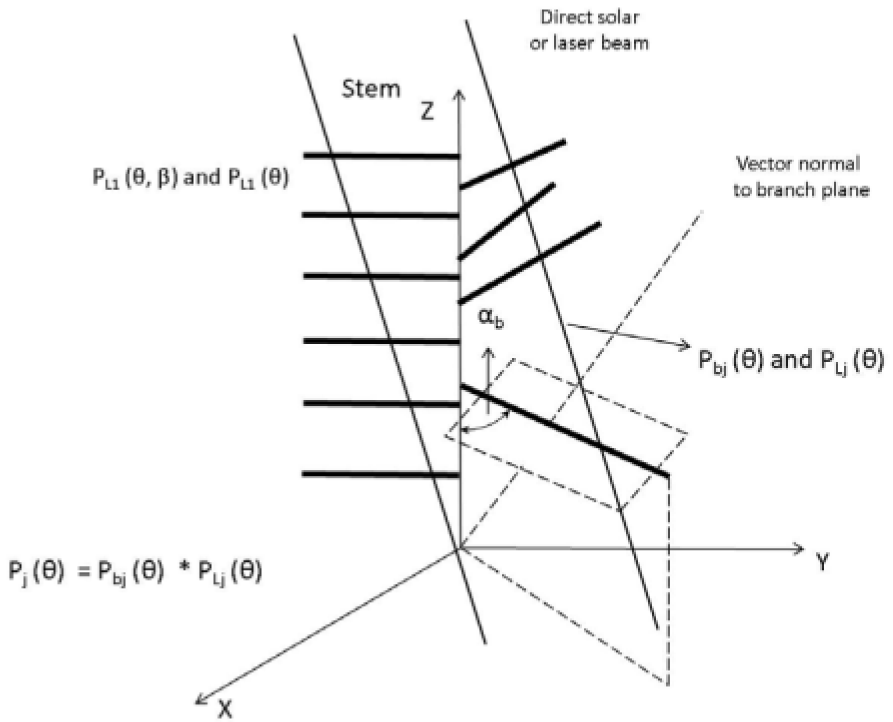
- Direct Measure (Litterfall and destructive harvest)
- Used for development of indirect measures
- Most accurate
- Total mass/area = LAI x LMA (for each species)???
- Allometric relationships, such as LAI and DBH
- Complications:
  - Species
  - Forest composition
  - Canopy position
  - Climate
  - Weather

from Smith et al 2008

Leaf Area Indirect Measure

- Effective LAI (L_e) – assume random distribution of foliage

Figure 3. Schematic diagram illustrating the multi-layer theoretical model to calculate the gap fraction.



from Zhang and Moskal 2009

Leaf Area Indirect Measure

- Effective LAI (L_e) – assume random distribution of foliage
  - Canopy gap fraction
  - Includes woody components
  - Can convert for non-random distributions (see Kucharik et al (1999) and Gower et al (1999))
  - Often 30-70% of true LAI
  - Without conversion, Plant Area Index (PAI)
  - Can subtract Wood Area Index from PAI to get LAI
- Complications:
  - Forest type (boreal forests have high proportions of wood area to total plant area)
  - Overcompensation (LAI $\neq$ PAI -WAI)
  - Weather
  - Upper limit (about 5-6)

from Smith et al 2008

LA Indirect Measure

- Digital Camera – Hemispherical
  - Assumes random distribution
  - Diffuse sky conditions
  - Correction factors (L_e -> PAI) unless light environment is only goal
  - Software (eg. CIMES: http://jmnw.free.fr/)
  - Key concepts:
    - Consistent exposure
    - Correct for camera and lens
    - Correct for clumping
- LAI 2000 plant canopy gap analyzer (Li-COR)
  - Instantaneous processing
  - Above canopy reference required
  - Underestimation in heterogeneous canopies

from Smith et al 2008

LAI 2000 Plant Canopy Analyzer

http://envsupport.licor.com/images/env/product_list_photos/LAI-2000_lg.jpg

ANPP

- **ANPP = $F_A + F_W + \Delta C_C + \Delta C_W$**
  - where:
  - F_A = flux of C associated with litterfall
  - F_W = flux of C associated with mortality
  - ΔC_C = increment of C associated with C content in live leaves
  - ΔC_W = increment of C associated with aboveground biomass
    - Monthly measurement of DBH, input into site specific allometric equation for DBH and woody biomass

from Giardina et al (2003)

APR

- **APR = L_{RC} + L_{RM} + W_R**
  - where:
  - L_{RC} = sum of construction
  - L_{RM} = sum maintenance respiration
  - W_R = respiration of aboveground wood

APR

- **APR = L_{RC} + L_{RM} + W_R**
  - where:
  - L_{RC} = sum of construction
    - How much energy is expelled in the formation of structural and metabolic compounds (Baruch & Goldstein 1999)
    - Assumed cost to be 25% of leaf NPP, from other research. Leaf NPP = $F_A + \Delta C_C$ (Giardina et al 2003)

APR

- **APR = L_{RC} + L_{RM} + W_R**
  - where:
  - L_{RC} = sum of construction
  - L_{RM} = sum maintenance respiration
    - Estimated by 'periodically' (4 times) measuring CO_2 efflux at night from intact leaves
    - Used towers
    - Plexiglass chambers with PPSystems CIRAS-1 in open system mode
    - Between 21:00 and 02:00
    - Four positions in the canopy
    - $L_{RM} = N_C \, x \, a$ x (seconds of darkness in 1 year) where N_c is annual average N content of forest canopy (mol N m^{-2}) and *a* is a dark respiration coefficient produced from CIRAS-1 measurements
    - N_c estimated from LAI and from measurement of SLA and Leaf N from harvested leaves

from Giardina et al (2003)

APR

- **$APR = L_{RC} + L_{RM} + W_R$**
  - where:
  - L_{RC} = sum of construction
  - L_{RM} = sum maintenance respiration

http://www.ppsystems.com/images/products/EGM-4_CPY-4_web.jpg

APR

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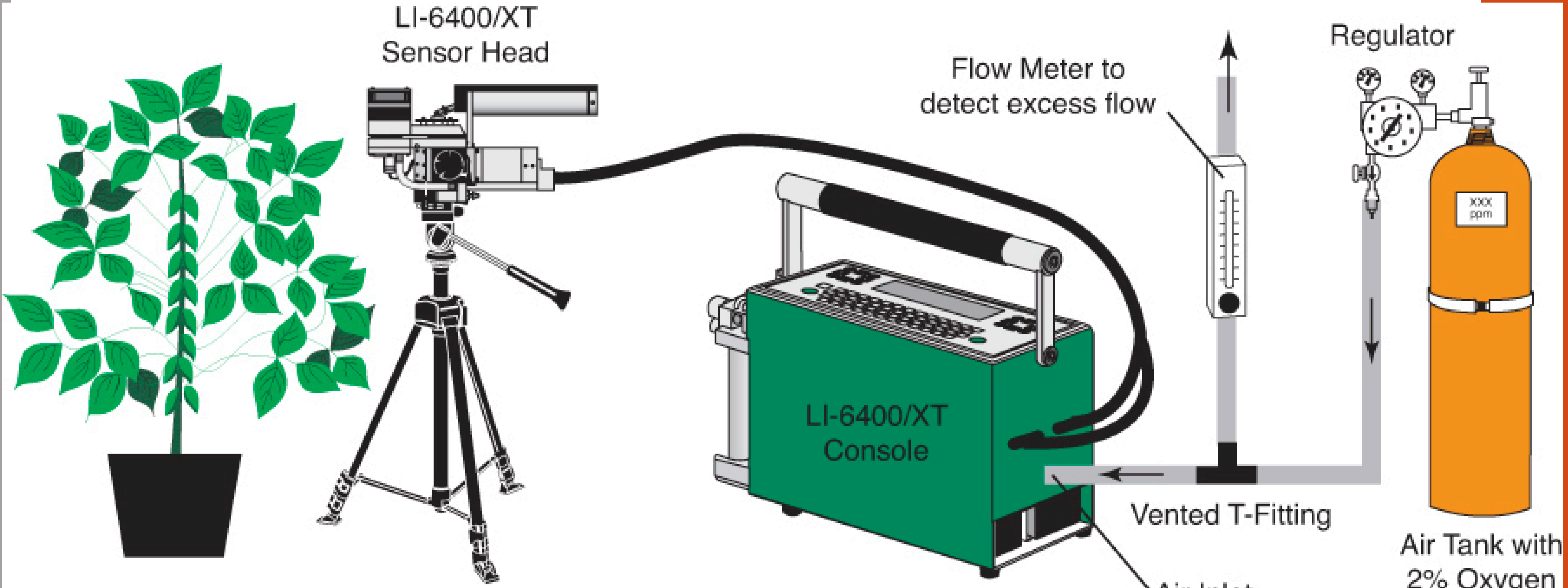


http://www.licor.com/env/newsline/wp-content/uploads/2011/01/TechTipDrawing2.jpg

APR

- **APR = L_{RC} + L_{RM} + W_R**
  - where:
  - L_{RC} = sum of construction
  - L_{RM} = sum maintenance respiration
  - W_R = respiration of aboveground wood
    - Same PPSystems CIRAS-1 system
    - Applied allometrically derived equation for woody biomass and multiplied by seconds in the year to get flux

from Giardina et al (2003)

APR

- **APR = L_{RC} + L_{RM} + W_R**
  - where:
  - L_{RC} = sum of construction
  - L_{RM} = sum maintenance respiration
  - W_R = respiration of aboveground wood

http://www.ese.u-psud.fr/IMG/jpg/Chambre-resp_site-4.jpg

APR

- **$APR = L_{RC} + L_{RM} + W_R$**
  - where:
  - L_{RC} = sum of construction
  - L_{RM} = sum maintenance respiration
  - W_R = respiration of aboveground wood
- Sources of error:
  - Assumed cost of construction, but differs and can be important (Baruch & Goldstein 1999)
  - Scaling based on allometric equations: importance of site specific equations
  - Operator
  - Planning
  - Leakage

from Giardina et al (2003)

TBCF

- **TBCF = F_S + F_E - F_A + ΔC_S + ΔC_R + C_L**
  - where:
  - F_S = soil surface CO_2 efflux
    - CIRAS-1 Soil Respiration Chamber
    - measured rate x seconds in a month

TBCF

- **TBCF = F_S + F_E - F_A + ΔC_S + ΔC_R + C_L**
  - where:
  - F_S = soil surface CO_2 efflux
  - F_E = leached C
    - Assumed to be less than 1% of TBCF (per year) in closed canopy forest (Giardina & Ryan 2002)

TBCF

- **$TBCF = F_S + F_E - F_A + \Delta C_S + \Delta C_R + C_L$**
  - where:
  - F_S = soil surface CO_2 efflux
  - F_E = leached C
  - F_A = litterfall

TBCF

- **TBCF = F_S + F_E - F_A + ΔC_S + ΔC_R + C_L**
  - where:
  - F_S = soil surface CO_2 efflux
  - F_E = leached C
  - F_A = litterfall
  - ΔC_S = change in C in mineral soil (see Burton & Pregitzer 2008)
    - Site specific
    - Volumetric pits
    - Combustion at high temperature (1000°C) with elemental analyzer
    - Problems: removal of inorganic C, stone%, organic soils, forest heterogeneity
    - Some assume no change below a certain depth (Giardina & Ryan 2002)

TBCF

- **TBCF = $F_S + F_E - F_A + \Delta C_S + \Delta C_R + C_L$**
  - where:
  - F_S = soil surface CO_2 efflux
  - F_E = leached C
  - F_A = litterfall
  - ΔC_S = change in C in mineral soil
  - ΔC_R = increment of C in root biomass
    - Coarse roots (>10 mm diameter): relationship between coarse root biomass and aboveground biomass
      - 20-30% of aboveground woody biomass (Burton and Pregitzer 2008)
      - Dead roots important
    - Fine roots
      - Some assume no net change during course of study and overall C stock can be low compared to other components (Burton and Pregitzer 2008; Giardina et al 2003)
      - Some argue that models must take this into account (Wolf et al 2011)
      - Sorting, labor intensive

from Giardina et al (2003)

TBCF

- **TBCF = F_S + F_E - F_A + ΔC_S + ΔC_R + C_L**
  - where:
  - F_S = soil surface CO_2 efflux
  - F_E = leached C
  - F_A = litterfall
  - ΔC_S = change in C in mineral soil
  - ΔC_R = increment of C in root biomass
  - C_L = Litter layer mass
    - Litter traps, dried samples, assume 50% C

from Giardina et al (2003)

Allocation and Partitioning

- Individual level:
  - Above-ground:below-ground
  - DBH/Height
  - Fine Root:LA
- Individual as part of NPP (from Wolf et al 2011)
  - Importance of ontogeny
  - Gfol (NPPfol/density of stand)
  - Gfroot (NPPfroot/density of stand)
  - Gcroot (NPPcroot/density of stand)
  - Gstem (NPPstem/density of stand)
- Stand level (from Nouvellon et al 2012)
  - TBCF/GPP
  - ANPP/TBCF
  - ΔB_w/ANPP
  - ΔB_w/GPP

"Carbon allocation in forest ecosystems" by Litton et al 2007

- Annual carbon flux and partitioning cannot be inferred by biomass ratios.
  - Multiyear accumulated wood
  - Storage in roots
  - Short lived leaves and fine roots
  - Annual plants could be an exception

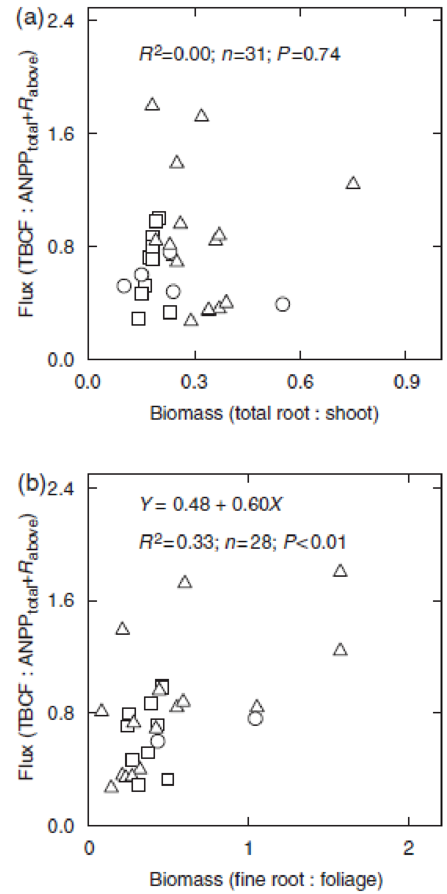


Fig. 2 Carbon flux is poorly related to biomass in forest ecosystems. Biomass ratios and flux (TBCF: ANPP$_{total}$ + R_{above}, an ecosystem carbon flux analog to root : shoot biomass) were not related for (a) total root : shoot across diverse forest ecosystems that represent gradients in resource availability, stand age and competition. A somewhat better relationship existed between (b) flux and fine root : foliage biomass. Triangles are needleleaf evergreen forests, circles are temperate deciduous forests, and squares are broadleaf evergreen forests. TBCF, total belowground carbon flux.

"Carbon allocation in forest ecosystems" by Litton et al 2007

- There is a correlation between different component fluxes and GPP:
  - foliage production
  - foliage respiration
  - wood production
  - wood respiration
  - total belowground carbon flux

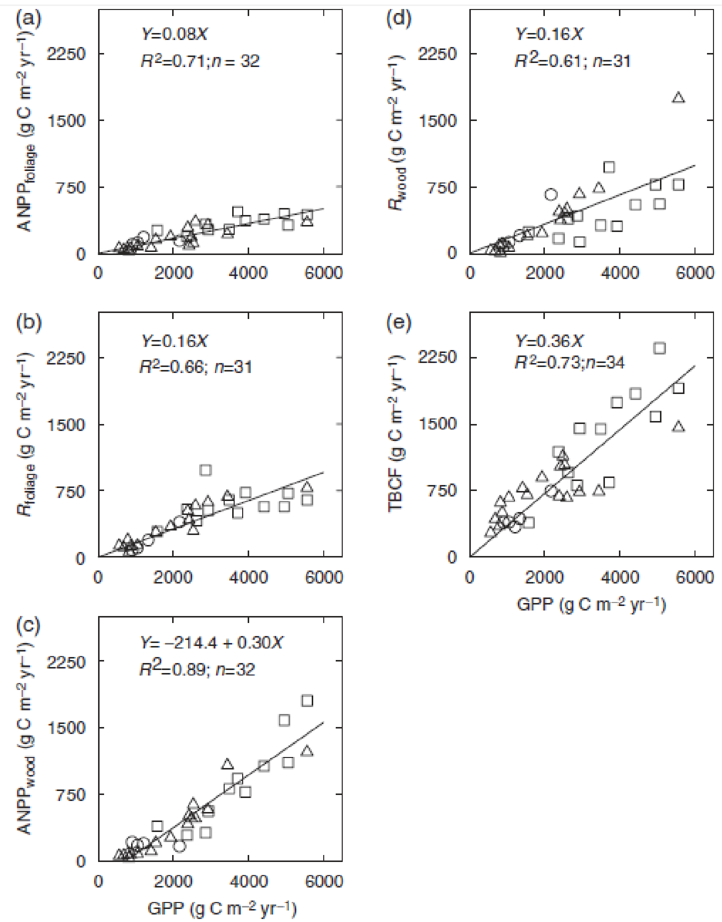


Fig. 4 (a) Foliage production ($ANPP_{foliage}$), (b) foliage respiration ($R_{foliage}$), (c) wood production ($ANPP_{wood}$), (d) wood respiration (R_{wood}), and (e) total belowground carbon flux (TBCF) all exhibited strong linear relationships with GPP across diverse forest ecosystems ($P < 0.01$). Zero-intercept regressions were used where the constant was not significant at $\alpha = 0.05$. Triangles are needleleaf evergreen forests, circles are temperate deciduous forests, and squares are broadleaf evergreen forests. GPP, gross primary productivity.

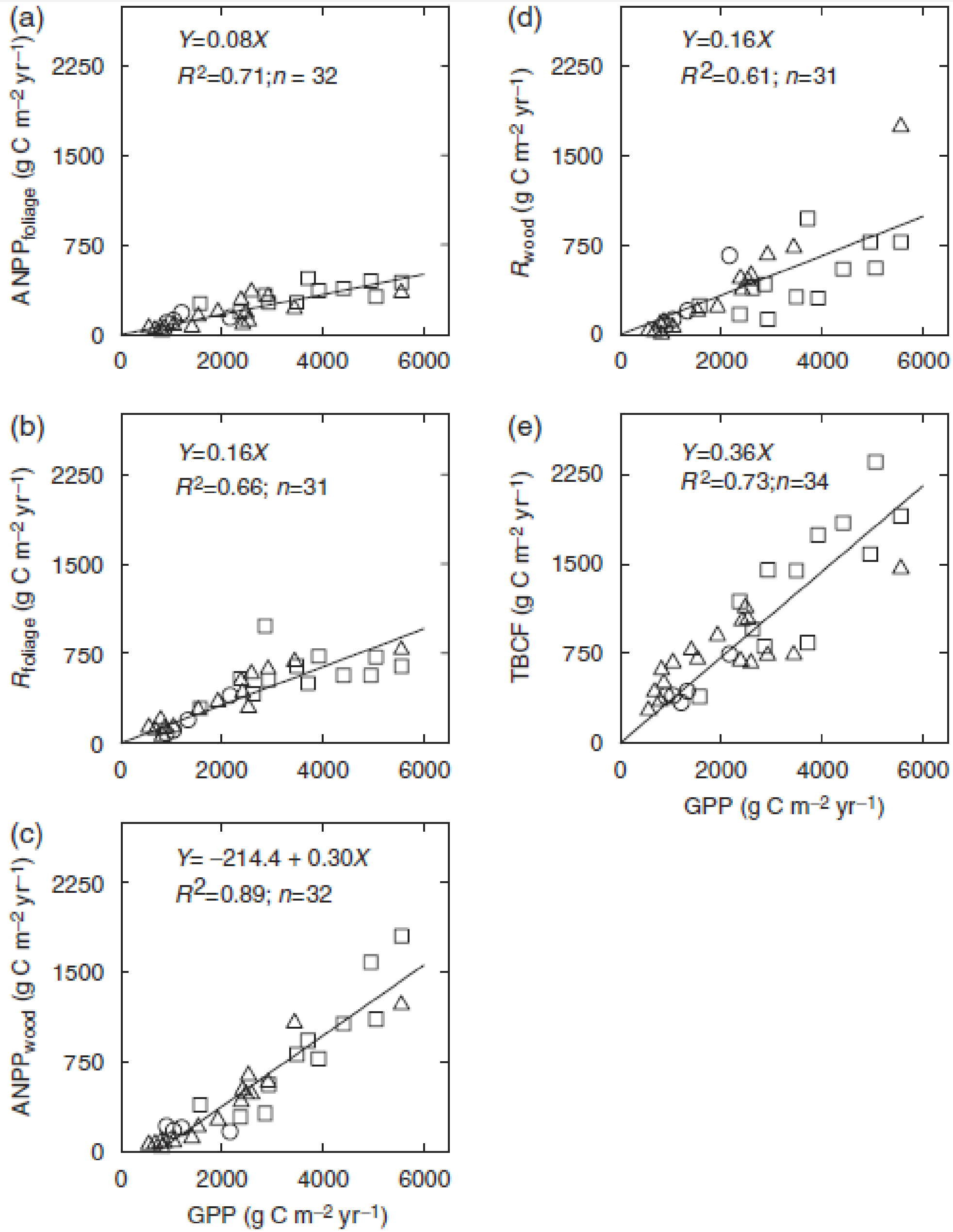


Fig. 4 (a) Foliage production ($ANPP_{foliage}$), (b) foliage respiration ($R_{foliage}$), (c) wood production ($ANPP_{wood}$), (d) wood respiration (R_{wood}), and (e) total belowground carbon flux (TBCF) all exhibited strong linear relationships with GPP across diverse forest ecosystems ($P < 0.01$). Zero-intercept regressions were used where the constant was not significant at $\alpha = 0.05$. Triangles are needleleaf evergreen forests, circles are temperate deciduous forests, and squares are broadleaf evergreen forests. GPP, gross primary productivity.

"Carbon allocation in forest ecosystems" by Litton et al 2007

- Total belowground carbon flux increases with aboveground net primary productivity
  - ANPP may not accurately predict TBCF

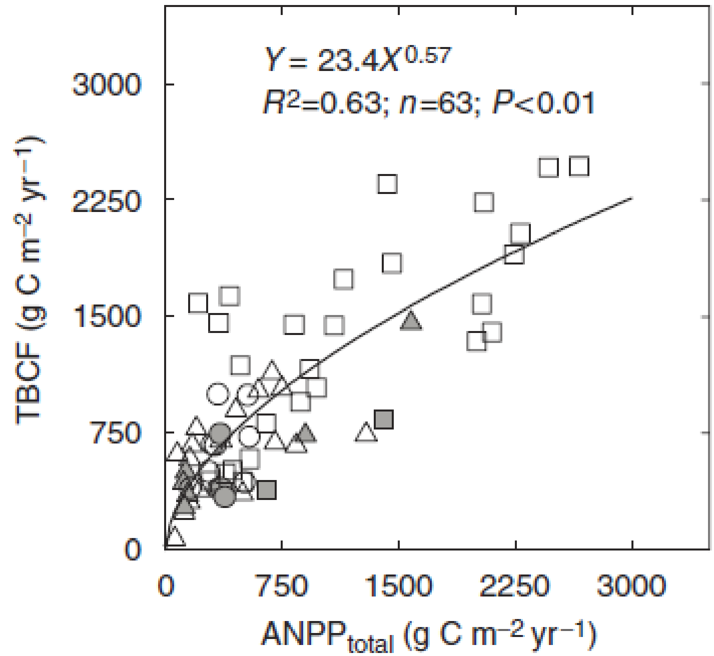


Fig. 5 Across forests, carbon flux to belowground (TBCF) increased with total aboveground net primary production ($ANPP_{total}$). TBCF was estimated as soil-surface CO_2 efflux minus aboveground litterfall plus any measured changes in soil carbon pools for all studies except those indicated with gray fill, where TBCF was estimated as $BNPP_{root} + R_{root}$. Triangles are needleleaf evergreen forests, circles are temperate deciduous forests, and squares are broadleaf evergreen forests. TBCF, total belowground carbon flux.

"Carbon allocation in forest ecosystems" by Litton et al 2007

- Autotrophic respiration is strongly and positively related to GPP
- Again, the relationship differs between components
  - Less increase in wood respiration than foliage respiration per increase in GPP
    - Wood has less metabolic activity

"Carbon allocation in forest ecosystems" by Litton et al 2007

- GPP partitioning to respiration is constant across a wide range of GPP in forest ecosystems
  - Averge 57% of GPP
- Does not vary with resource availability, competition or stand age

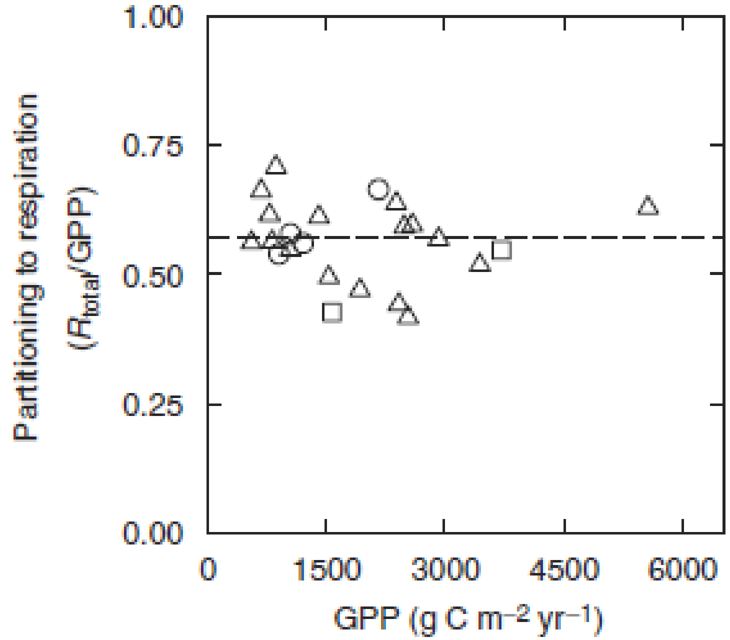


Fig. 7 There was a strong central tendency in partitioning to respiration (R_{total}) across diverse forest ecosystems that represent gradients in resource availability, stand age and competition [0.57 ± 0.02 (Mean ± 1 SE)]. The dashed line is the slope of the relationship between GPP and R_{total} ($R_{total} = 0.57 \times GPP$; $R^2 = 0.95$; $n = 23$; $P < 0.01$). However, partitioning to R_{total} did vary across sites – the range for studies analyzed was 42–71%. Triangles are needleleaf evergreen forests, circles are temperate deciduous forests, and squares are broadleaf evergreen forests.

“Carbon allocation in forest ecosystems” by Litton et al 2007

- There were variations across different sites- 42%-71% of GPP
  - 71% boreal spruce
  - 66% boreal pine
  - 68% tropical forest

“Carbon allocation in forest ecosystems” by Litton et al 2007

- GPP partitioning to ANPP increases and to total belowground flux decreases with increasing stand age
  - Exceptions:
    - *Eucalyptus saligna* in Hawaii
    - Lodgepole pine in Wyoming

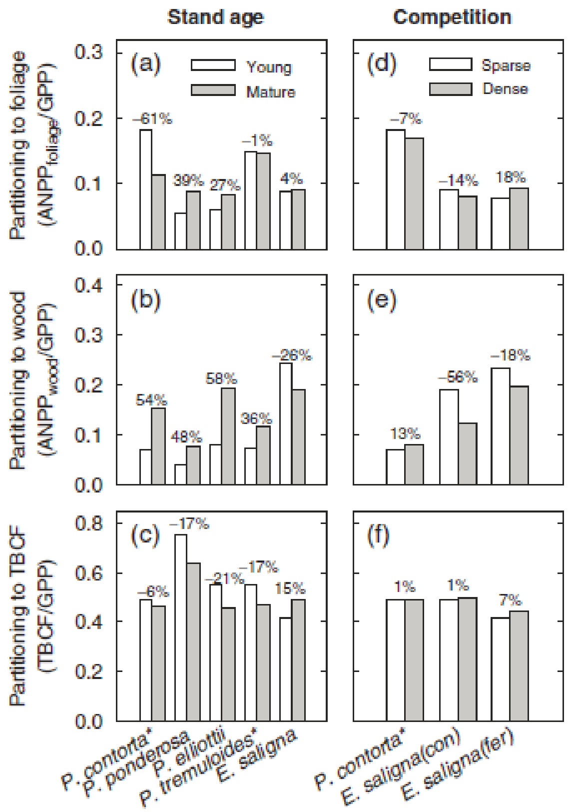


Fig. 8 Carbon partitioning varied with stand age (a–c), but not competition (i.e. tree density; d–f). Variation with age was a result of increased partitioning to (a) $ANPP_{foliage}$ and (b) $ANPP_{wood}$, (c) and decreased partitioning to TBCF in mature stands for all sites but *Eucalyptus saligna*. Data are from Litton *et al*. (2004) for *Pinus contorta*, Law *et al*. (2001) for *Pinus ponderosa*, Ewel *et al*. (1987) and Gholz & Fisher (1982) for *Pinus elliottii*, Fornwalt (1999) for *Populus tremuloides*, and Ryan *et al*. (2004) for *E. saligna*. For studies denoted with an *, $R_{foliage}$ and R_{wood} were estimated using relationships with $ANPP_{foliage}$ and $ANPP_{wood}$ (Fig. 6a and b). TBCF, total belowground carbon flux.

"Carbon allocation in forest ecosystems" by Litton et al 2007

- Intraspecific competition (tree density) had no consistent effect on GPP partitioning between ANPP and TBCF
- Increased nutrient and water availability increased partitioning to ANPP and decreased partitioning to TBCF
  - Except P
  - Response to water had more variability

Carbon allocation in forest ecosystems” by Litton et al

- Priorities do NOT exist for the products of photosynthesis.
  - such that carbon is used first by higher priority tissues and only released to other tissues when those needs are satisfied
  - Because with increased GPP, all pools and fluxes increased.

Partitioning and Climate

Table 6. Annual C fluxes ($g\ m^{-2}\ year^{-1}$) at the three forest sites

	Tropical	Temperate	Boreal
Component fluxes:			
Above ground vegetation:			
(1) Gross photosynthesis of tree foliage (G_p)	3040[1]	1725	963
(2) Respiration of tree foliage	410[2]	191	216[7]
(3) Respiration of tree wood	390[2]	196	87[8]
(4) Leaf and wood detritus	700[3]	360[4]	51[5]
(5) Net biomass increment	170[3]	150[4]	110[5]
(6) Transport to roots (1) – (2) – (3) – (4) – (5)	1370	828	499
Below ground vegetation:			
(7) Respiration of roots	680[1]	395	143[6]
(8) Net root biomass increment	60[1]	39	30[6]
(9) Root detritus production	630[1]	395	326
(10) Total ground respiration	1650[2]	753	592
(11) Heterotrophic Respiration (10) – (2) – (3)	970	359	449
(12) Autotrophic Respiration (15) – (11)	1480	782	446
Soil:			
(13) Change in SOM (4) + (9) – (11)	+360	+396	–72
(14) Total C influx (1)	3040	1725	963
(15) Total C efflux (14) – (16)	2450	1140	895
(16) Net ecosystem exchange (NEE)	590	585	68
(17) N_p (1) – (2) – (3) – (7) or (4) + (5) + (8) + (9)	1560	944	517
(18) N_p/G_p (17)/(1)	51%	55%	54%
Mean carbon residence times (years):			
(19) Biomass	16	10	12
(20) Soil and litter	15	10	106
(21) Total ecosystem	29	18	89

[1] from Malhi *et al*. 1998, Malhi *et al*. unpublished data; [2] from Meir *et al*. 1996, for another site in Rondonia; [3] from Higuchi *et al*. (1997); [4] from Edwards *et al*. 1989; [5] from Gower *et al*. 1997; [6] from Steele *et al*. 1997; [7] from Rayment 1998; [8] from Lavigne & Ryan 1997

from Malhi et al 2004

Partitioning and Nutrient Availability

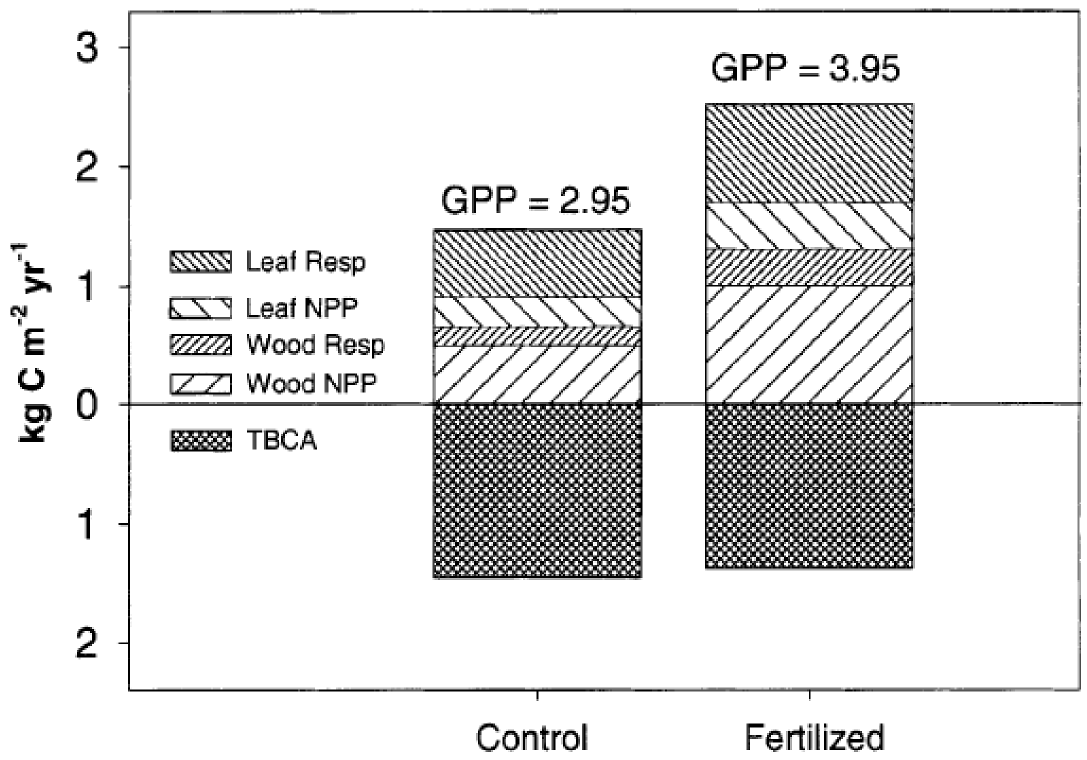


Fig. 1 Gross primary production (mean of three years of postfertilization data) in unfertilized and adjacent fertilized stands of *E. saligna* in Pepe'ekeo, Hawai'i, and the constituent above and belowground components (see the Appendix for term definitions).

from Giardina et al (2003)

Partitioning, Water, and Nutrients

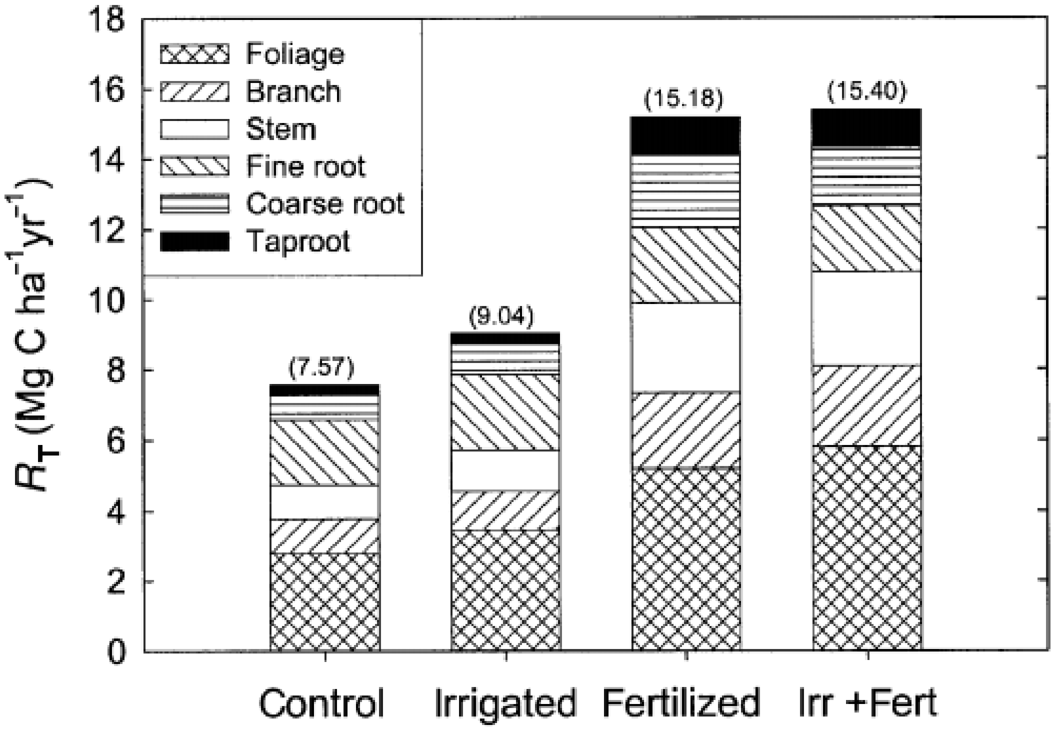


Fig. 2 Mean annual carbon flux from total respiration (R_T) (maintenance plus growth respiration) by tissue component in 12-year-old loblolly pine plantations. Values were generated using Eqns (2) and (3).

from Maier et al 2004

Partitioning, Water, and Nutrients

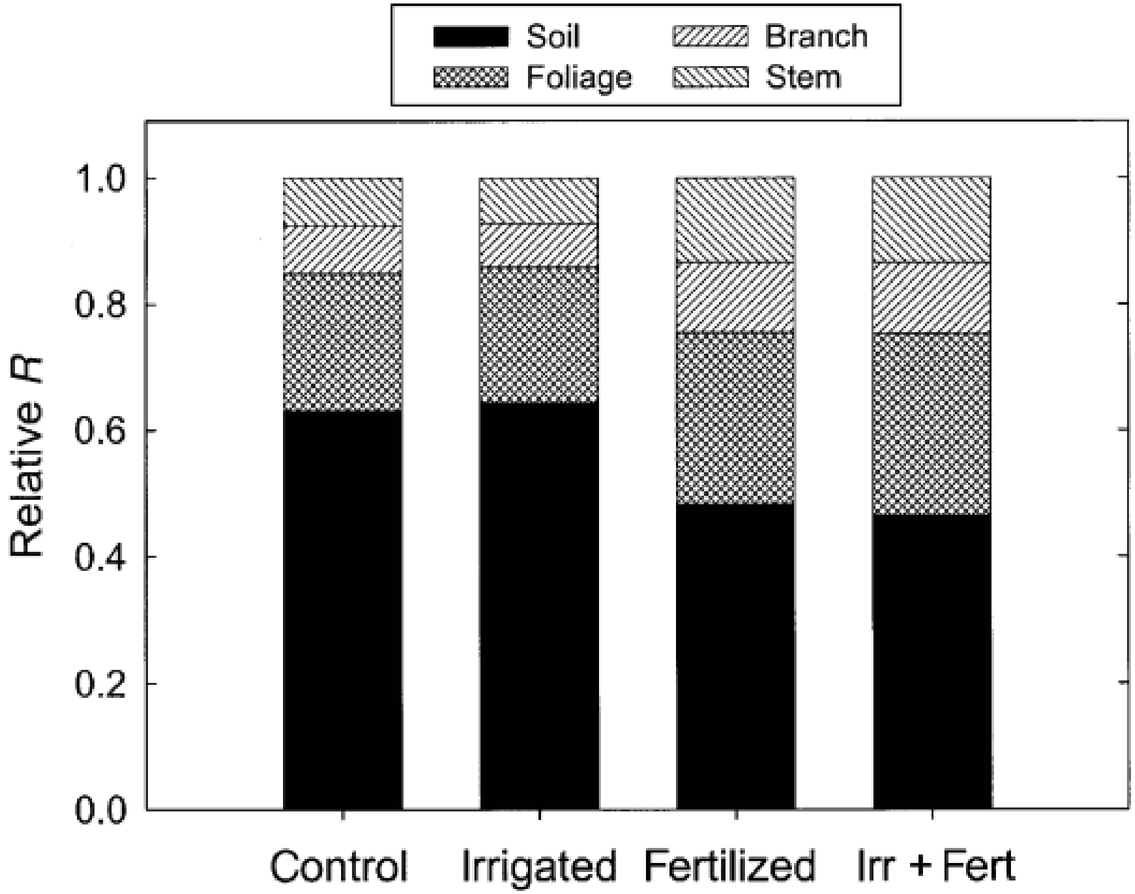


Fig. 6 Fraction of ecosystem respiration (R_E) generated from soil and aboveground components.

from Maier et al 2004

"…Carbon Allocation in Monocultures and Mixed Species Plantations… in Brazil" by Nouvellon et al 2012

- **Jean-Pierre Bouillet**
  - Cirad scientist
  - Currently visiting professor at the **University of Sao-Paulo** (USP-Esalq) in Brazil
  - Silviculture of mixed-species Eucalyptus plantations
  - Diploma (1984) and PhD (1993) in Forest Sciences from Engref, Nancy (France)
  - Experience in French Guyana (tree breeding), Madagascar (pine and eucalyptus), Congo (productivity of eucalyptus), and France (management of tropical forest ecosystems)
  - Published more than 35 peer-reviewed journal articles

"...Carbon Allocation in Monocultures and Mixed Species Plantations... in Brazil" by Nouvellon et al 2012

http://intens-fix.cirad.fr/var/intens_fix/storage/images/intens-fix/faits-marquants/visite-de-j.p.-bouillet-a-orleans-le-30-mai-2011/31152-2-fre-FR/visite-de-j.p.-bouillet-a-orleans-le-30-mai-2011.jpg

“…Carbon Allocation in Monocultures and Mixed Species Plantations… in Brazil” by Nouvellon et al 2012

- Yann Nouvellon
  - Department of Atmospheric Sciences at the University of Sao Paulo in Brazil
  - Has 158.79 Impact Points and 74 followers on Research Gate

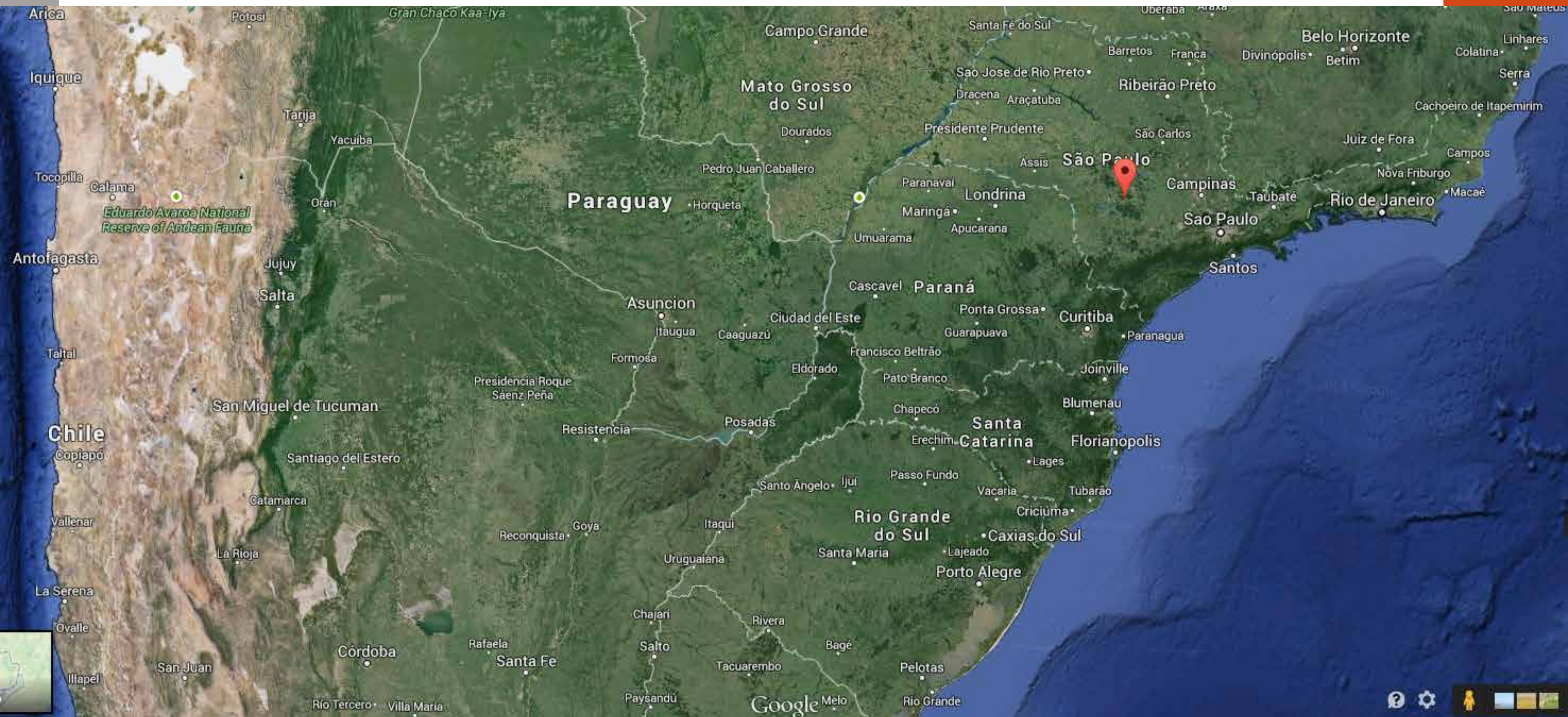
http://www.researchgate.net/profile/Yann_Nouvellon2/

"…Carbon Allocation in Monocultures and Mixed Species Plantations… in Brazil" by Nouvellon et al 2012

http://www.cirad.fr/var/cirad/storage/images/site-cirad.fr/actualites/toutes-les-actualites/communiques-de-presse/2011/plantations-d-eucalyptus/63396-1-fre-FR/plantations-d-eucalyptus-combiner-sylviculture-et-genetique-pour-une-hausse-raisonnee-des-rendements_lightbox.jpg

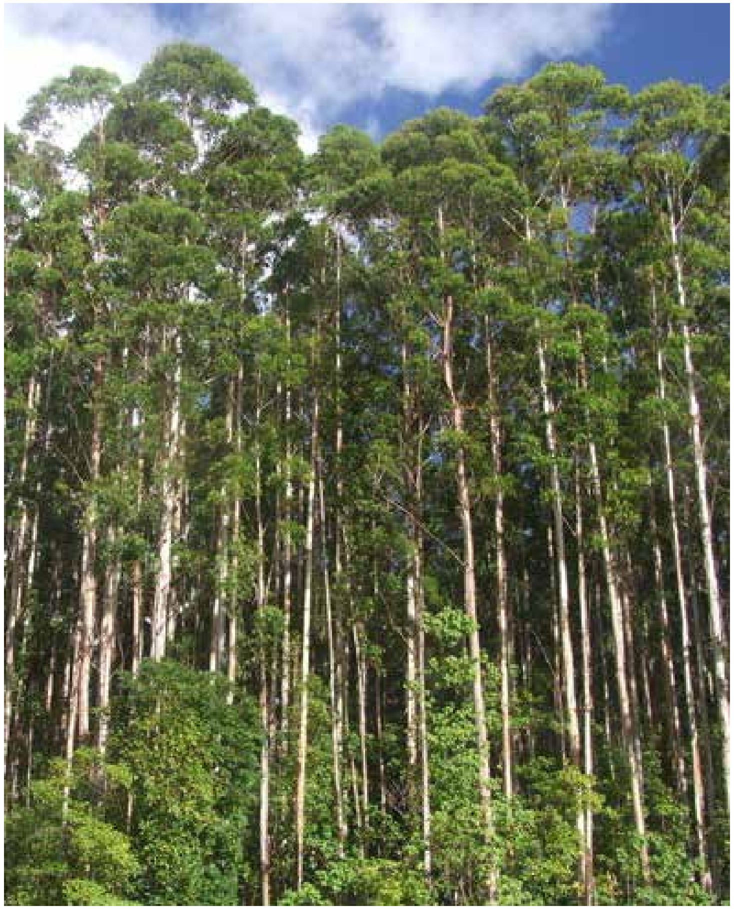
http://mw2.google.com/mw-panoramio/photos/medium/45827198.jpg

“...Carbon Allocation in Monocultures and Mixed Species Plantations... in Brazil” by Nouvellon et al 2012



"…Carbon Allocation in Monocultures and Mixed Species Plantations… in Brazil" by Nouvellon et al 2012

- *Eucalyptus grandis* summary
  - Height: 43-55m
  - Diameter: 122-183cm
  - Growth: 2 m year^{-1}
  - Characteristics: shade intolerant
  - Plantations: >500,000 ha worldwide
  - Uses: pulpwood, poles, pallets, veneer, landscaping
  - Natural distribution
    - Soils: alluvial and volcanic loams
    - 26-33 degrees S
    - Mean minimum temperature from 2-10°C and maximum up to 29°C
    - Rainfall: 1020-1780mm with distinct dry season



http://www.na.fs.fed.us/pubs/silvics_manual/volume_2/eucalyptus/grandis.htm

http://www.ctahr.hawaii.edu/forestry/Data/photos/Eucalyptus-grandis-WTMA-27yr-crop2.jpg

“…Carbon Allocation in Monocultures and Mixed Species Plantations… in Brazil” by Nouvellon et al 2012

- *Acacia mangium* summary
  - Height: up to 30 m
  - Growth: ~1 m $year^{-1}$
  - Characteristics: shade intolerant
  - Plantations: extensive worldwide (eg. 1.5 Mha in Asia in 2006)
  - Uses: pulpwood, pallet, timber
  - Natural distribution
    - Soils: alluvial and volcanic, sandy or loamy; tolerates acid (< 4 pH) and low nutrient soils well
    - At the edges of rainforests or coastal plain
    - Mean minimum month from 15-22°C and maximum up to 31-34°C
    - Rainfall: 1500-3000 mm with distinct dry season

http://www.kew.org/plants-fungi/Acacia-mangium.htm

http://www.pachamamaforest.com/uploads/images/Plantation_3.jpg

"...Carbon Allocation in Monocultures and Mixed Species Plantations... in Brazil" by Nouvellon et al 2012

Questions: Is lower production in mixed plantations due to a shift in partitioning to TBCF?

Hypotheses:

1. Species differences for wood production were partly explained by different C partitioning strategies
2. Lower partitioning to aboveground biomass mostly explains lower wood production in the mixture in comparison to the eucalypt monoculture

“…Carbon Allocation in Monocultures and Mixed Species Plantations… in Brazil” by Nouvellon et al 2012

- Tree Growth
  - Mixed plot
    - *Eucalyptus grandis* dominated
      - Higher growth rate
  - Mean tree height was intermediate
  - Stand basal areas
    - Not different between the 3 treatments
    - Mixed plot
      - Individual basal area
        - *Eucalyptus grandis* greater than in monoculture
        - *Acacia mangium* less than monoculture
          - Interspecific competition

“…Carbon Allocation in Monocultures and Mixed Species Plantations… in Brazil” by Nouvellon et al 2012

- Mixed Plot
  - *Acacia mangium*
    - Higher height/basal area than monoculture
      - Less number of stems
  - *Eucalyptus grandis*
    - Opposite case
- Total Above Ground Biomass Wood Biomass
  - Affected by stand height
    - *Eucalyptus grandis* monoculture -highest
    - Mixed Plot- intermediate
    - *Acacia mangium* monoculture-shortest

“…Carbon Allocation in Monocultures and Mixed Species Plantations… in Brazil” by Nouvellon et al 2012

- Above Ground Biomass
  - Mixed plot
    - Greatest leaf biomass
      - leaf biomass/Total aboveground biomass
    - *Eucalyptus grandis*
      - 43% more wood biomass per tree
      - 74% more leaf biomass per tree
    - *Acacia mangium*
      - 53% less wood biomass
      - 24% less leaf biomass
- No differences in leaf litterfall
- Litterfall accounted for:
  - 24% ANPP *Eucalyptus grandis* monoculture
  - 22% ANPP *Acacia mangium* monoculture

"...Carbon Allocation in Monocultures and Mixed Species Plantations... in Brazil" by Nouvellon et al 2012

- Total Belowground Carbon Flux (TBCF)
  - Cumulative Soil CO_2 efflux (F_{scum})
    - Lowest in *Acacia mangium* monoculture
    - Highest in the mixed plot
      - 54% more near *Eucalyptus grandis* monoculture
  - Annual litterfall (L_{cum})
    - Lowest in *Acacia mangium* monoculture
      - Less woody litterfal

“…Carbon Allocation in Monocultures and Mixed Species Plantations… in Brazil” by Nouvellon et al 2012

- Total Belowground Carbon Flux
  - Significantly lower in *Acacia mangium* monoculture than other monoculture
  - Forest Floor Carbon (C_L)
    - Decreased in *Acacia mangium* monoculture
    - Increased in the mixed plot and *Eucalyptus grandis* monoculture
  - No differences in C efflux from course roots and stumps from previous rotations ($\Delta C_L/\Delta t$)
  - Coarse and medium root biomass increment (ΔB_R)
    - Lowest in *Acacia mangium* monocultre
    - Highest in *Eucalyptus grandis* monoculture

"...Carbon Allocation in Monocultures and Mixed Species Plantations... in Brazil" by Nouvellon et al 2012

Ratio	*Eucalyptus grandis* monoculture (Kg C)	Mixed Plot (Kg C)	*Acacia mangium* monoculture (Kg C)
ANPP/TBCF	Higher 1.6	Lower 1.1	Higher 1.5
ΔB_w /ANPP	Higher 0.76	Lower 0.70	Higher 0.76
ΔB_w /TBCF	Higher 1.3	Lower 0.79	Higher 1.1

“…Carbon Allocation in Monocultures and Mixed Species Plantations… in Brazil” by Nouvellon et al 2012

- GPP was 30% higher in *Eucalyptus grandis* monoculture than the other monoculture
  - *Acacia mangium* monoculture was the lowest
- GPP in the mixed plot was intermediate
  - 15% lower than *Eucalyptus grandis* monoculture
  - 10% higher than *Acacia mangium* monoculture

"...Carbon Allocation in Monocultures and Mixed Species Plantations... in Brazil" by Nouvellon et al 2012

- TBCF/GPP
  - Around 25% for both monocultures.
  - 32% for the mixed plot
- The fraction allocated to above ground wood production (ΔB_w /GPP) was higher than TBCF/GPP in monocultures.
  - Opposite effect in mixed plot

"...Carbon Allocation in Monocultures and Mixed Species Plantations... in Brazil" by Nouvellon et al 2012

- Leaf Area Index (LAI) and Photosyntheticaly active radiation absorbed by the canopy (APAR)
  - About 35% higher in mixed plot than monocultures
  - No increases in production
    - Lowest light use efficiencies in mixed plot
- Light use efficiencies
  - Higher in *Eucalyptus grandis* monoculture than *Acacia mangium* monoculture

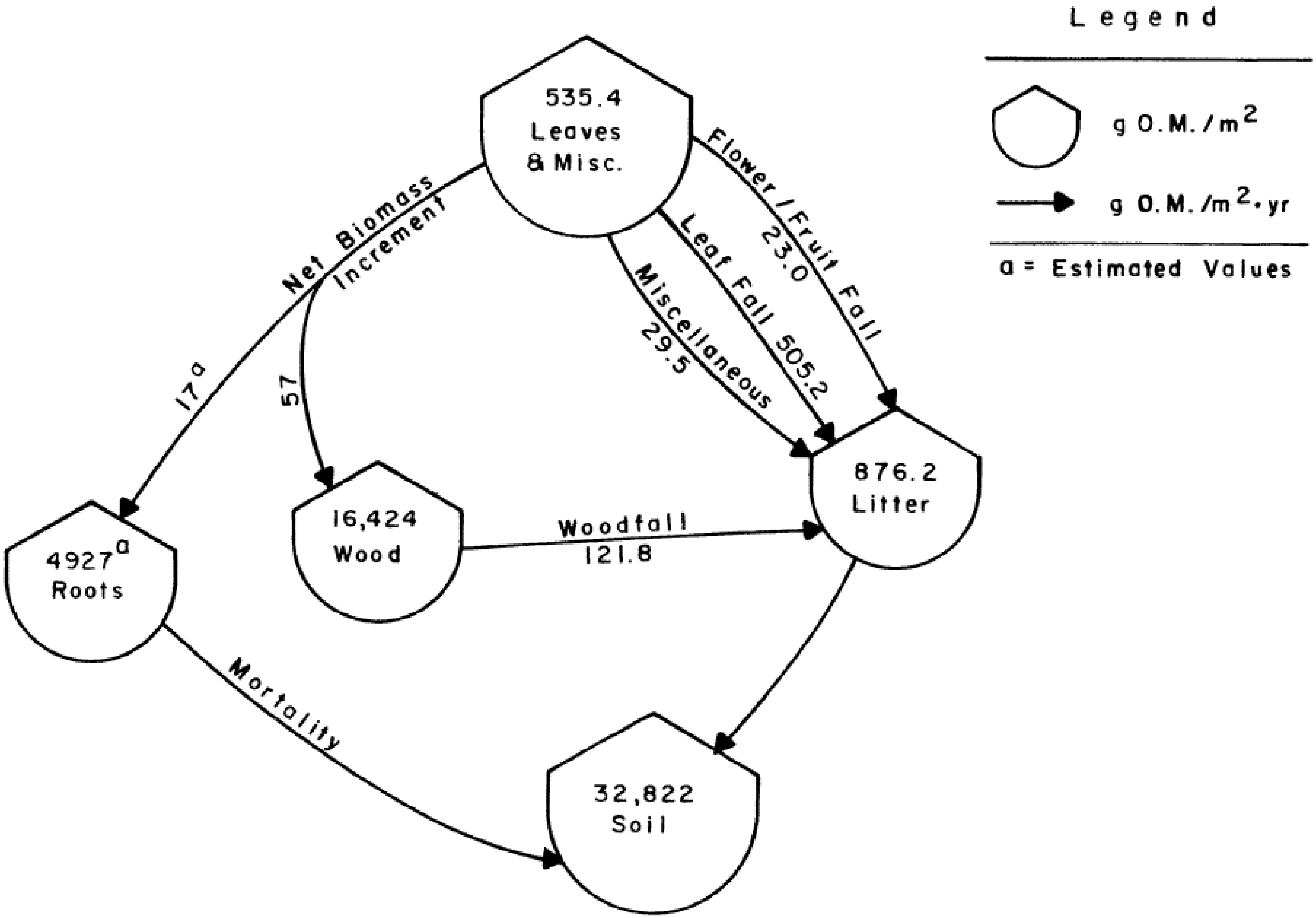


FIGURE 6. Mean annual organic matter (O.M.) budget for two 0.40-ha plots in the colorado forest.

Peter L. Weaver , Peter G. Murphy. 1990. Forest Structure and Productivity in Puerto Rico's Luquillo Mountain. BIOTROPICA 22(1): 69-82

Allocation and Partitioning

- Plasticity/adaptability of ecosystems
- Small vs. large scale lessons
- Biome variation
- Modeling

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