Carbon Cycling - Respiration Processes

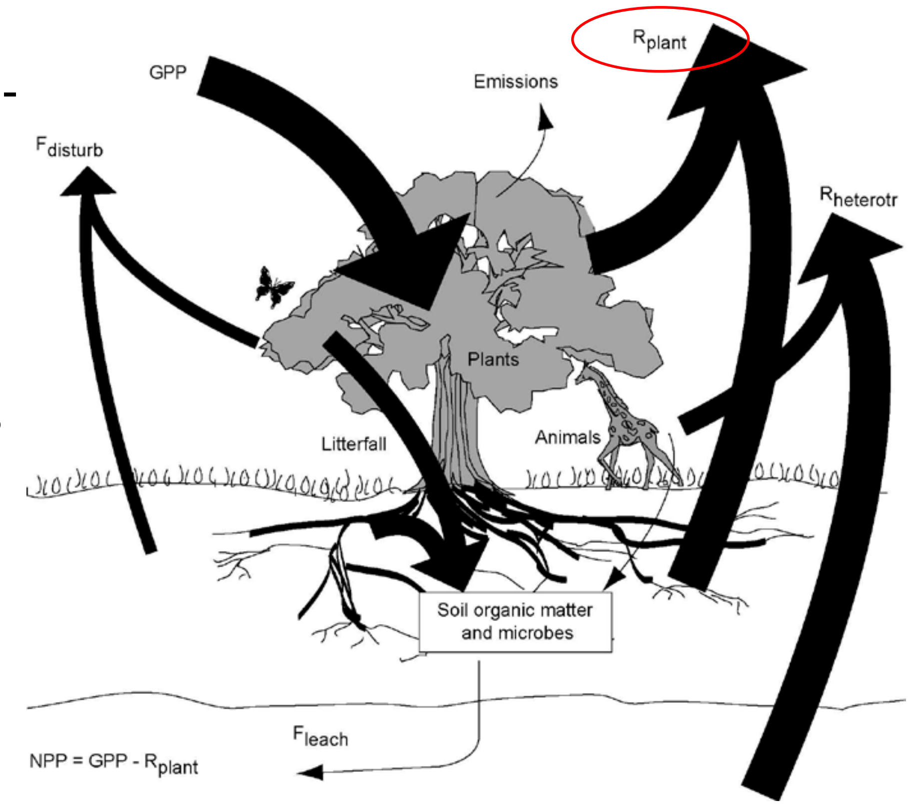
- Objective
  - Autotrophic respiration (R) in terrestrial ecosystems
    - In this lecture, $R = R_{plant}$
      - But $R_{ecosystem}$ is $R_{plant} + R_{hetero}$

Carbon Cycling - Respiration Processes

- C is the energy currency of ecosystems
  - Plant (autotrophic) production is the base of food/energy pyramids
    - Ecosystem goods and services
- Plant C cycling to a large extent controls CO_2 concentrations in the atmosphere
  - CO_2 removed via photosynthesis and returned via respiration
- Plant-derived C fundamental to belowground (i.e., soil) processes

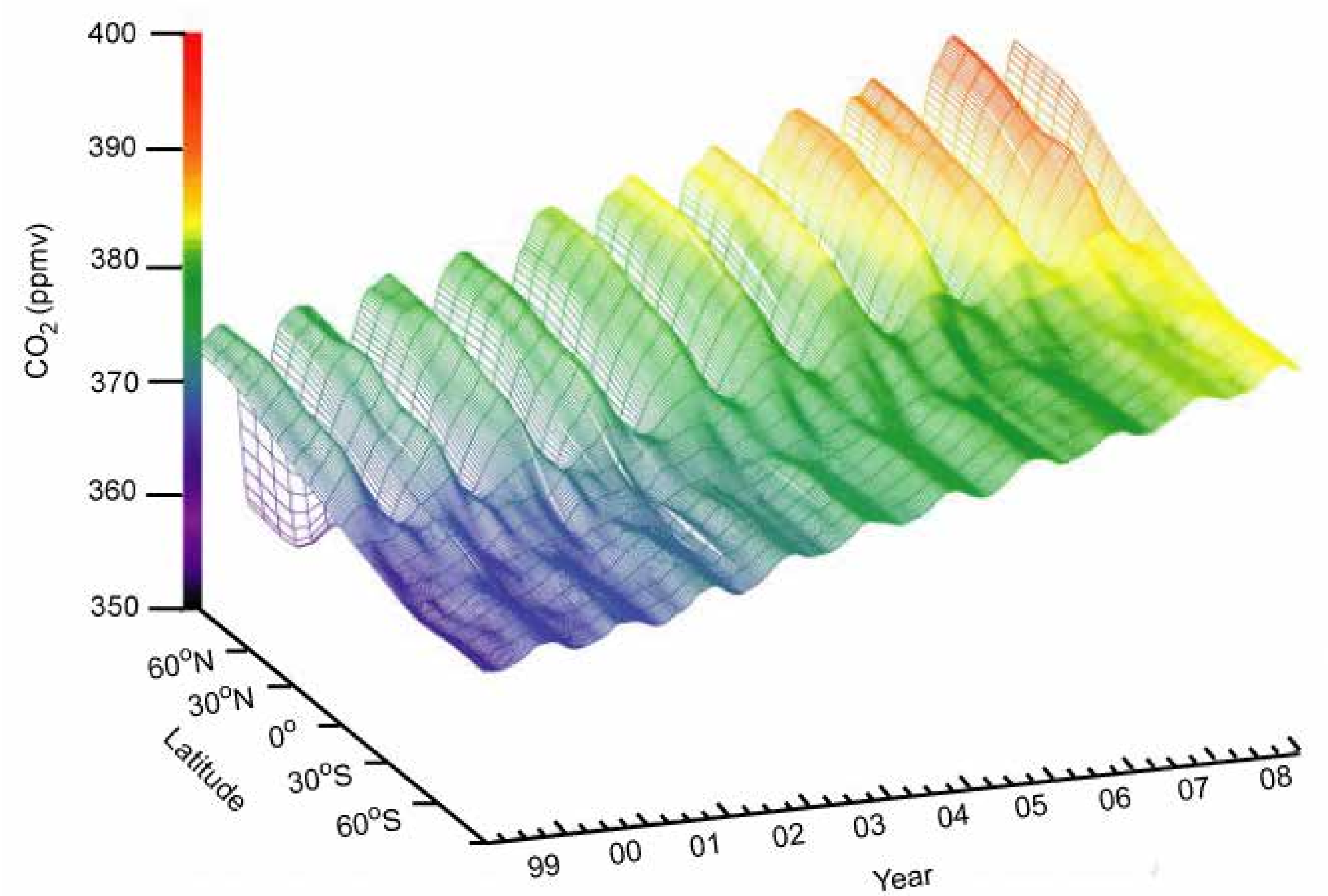
Carbon Cycling - Respiration Processes

- C enters via photosynthesis
  - – Gross Primary Production (GPP)
    - Net photosynthesis (Gross photo - R_{leaf} during the day)
  1. Accumulates in ecosystems (C sequestration) as: (a) plant biomass; (b) Microbial biomass &/or SOM; or (c) animal biomass
  2. Returned to the atmosphere via (a) respiration (*R*; autotrophic or heterotrophic); (b) VOC emissions; or (c) disturbance
  3. Leached from or transferred laterally to another ecosystem



Carbon Cycling - Respiration Processes

•Terrestrial C metabolism = The “breathing” of Earth



Carbon Cycling - Respiration Processes

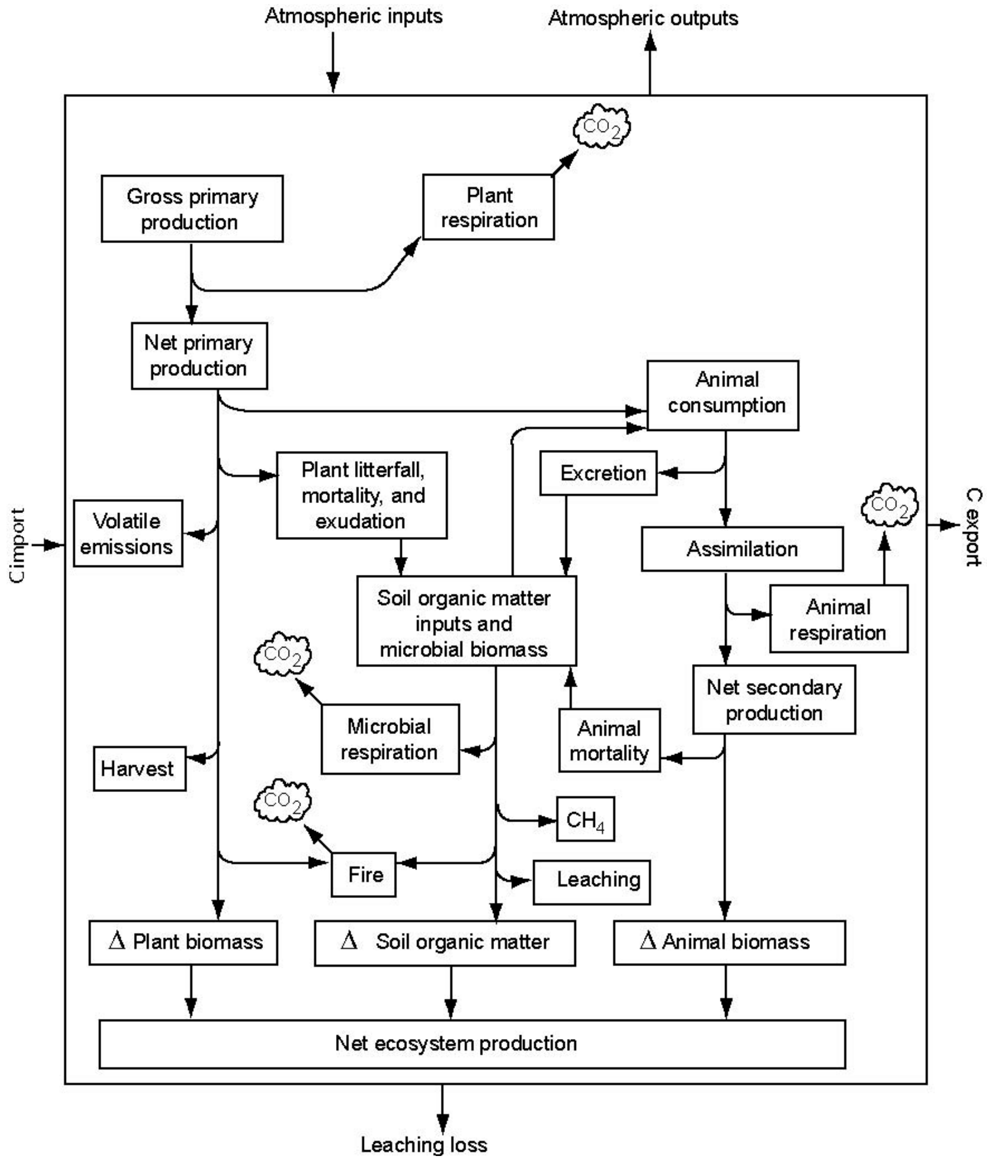
- Net primary production: net accumulation (or loss) of C by primary producers (i.e., plants)
  - NPP = GPP - R_{plant}
- Governing equation for photosynthesis:
  - $A = (C_a - C_i) * g_s$
- Respiration is much less well understood than photosynthesis
  - No governing equations

Carbon Cycling - Respiration Processes

- Why do plants (or any organism) respire?
  - Cellular respiration releases the chemical energy stored in biomass
    - Used to construct new biomass and maintain existing biomass
      - Construction/Growth respiration
      - Maintenance respiration
    - Used to acquire nutrients

Carbon Cycling - Respiration Processes

- Respiration occurs during all steps of C cycling



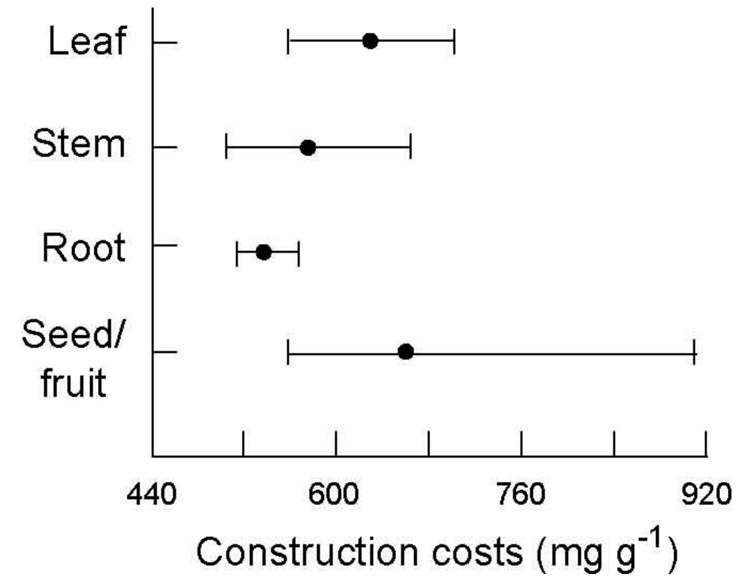
Carbon Cycling - Respiration Processes

- $R_{\text{plant}} = R_{\text{growth}} + R_{\text{maint}} + R_{\text{ion}}$
  - What respires?
    - Everything that is alive, all the time
      - Non-photosynthetic live biomass all the time; and photosynthetic biomass (i.e., foliage) at night
  - Provides energy for all essential plant processes
    - These processes require mitochondrial oxidation of CHO's to make ATP
  - NOT "wasted" C

Carbon Cycling - Respiration Processes

- R_{growth} (construction)
  - Total C cost = C incorporated into new biomass + C oxidized to generate new biomass
  - Similar across species
  - Varies widely by compound
    - Proteins, lignins, tannins, & lipids are expensive
    - Protein rich (leaves & seeds) vs. structural (woody biomass)
  - $R_{growth} \approx 25\%$ x biomass
    - Total C cost = 1.23g CHOs per g of biomass

Component	Concentration (%)	Cost ($mg\ C\ g^{-1}$ product)	Total cost ($mg\ C\ g^{-1}$ tissue)[a]
Sugar	11.9	438	52
Nucleic acid	1.2	409	5
Polysaccharide	9.0	467	42
Cellulose	21.6	467	101
Hemicellulose	31.0	467	145
Amino acid	0.9	468	4
Protein	9.7	649	63
Tannin	4.8	767	37
Lignin	4.2	928	39
Lipid	5.7	1212	69
Total cost			557

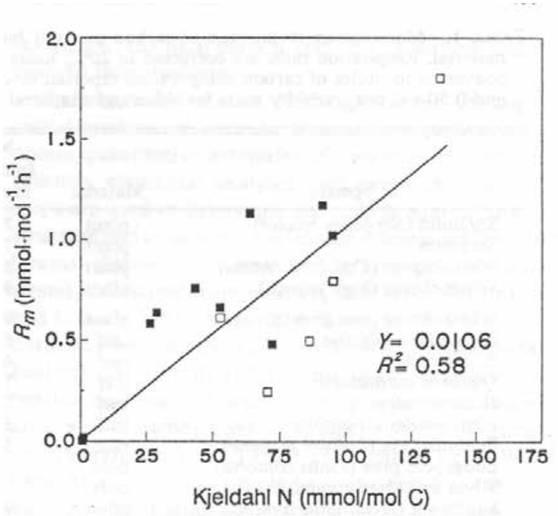


Carbon Cycling - Respiration Processes

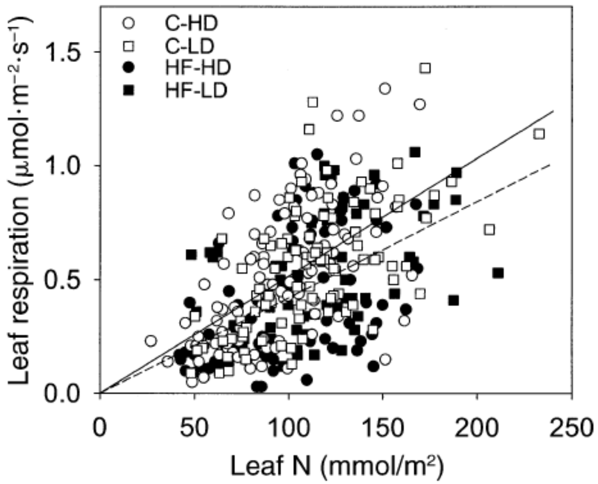
- R_{maint} (maintenance of existing biomass)
  - Maintenance and repair of non-growing tissues
    - Protein turnover (~85%)
    - Membrane replacement (lipids)
    - Maintenance of ion gradients
  - ~50% of total *R*
  - Strongly correlated with temperature and N content
    - Why N content?
    - Why temperature?

Carbon Cycling - Respiration Processes

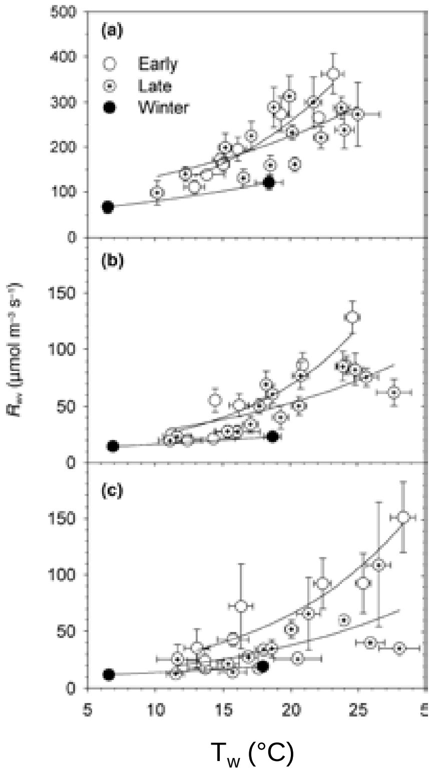
- R_{maint}
  - $R_m = 0.0106 \times$ N content
  - $R_m = R_0(Q_{10})^{(T/10)}$



(Ryan 1991)



(Ryan et al. 2004)



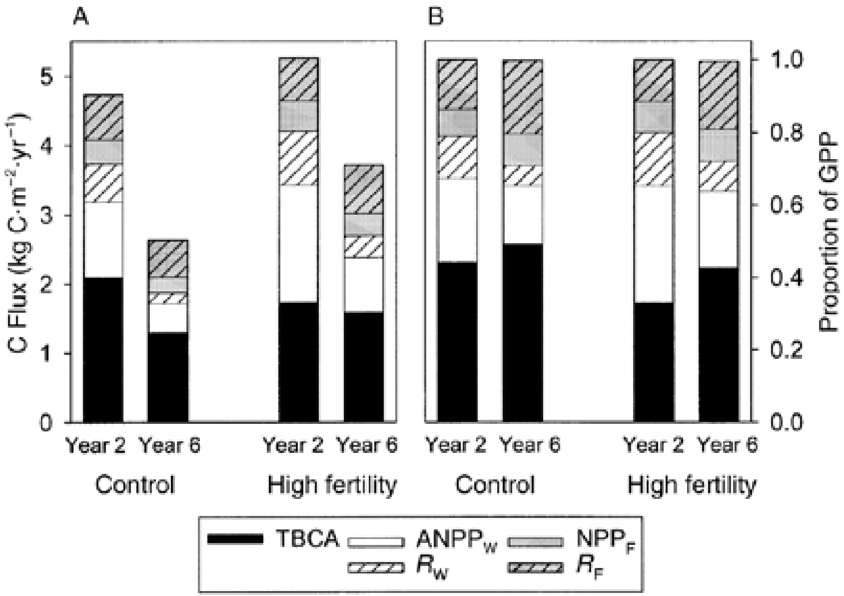
(Curtis et al. 2005)

Carbon Cycling - Respiration Processes

- R_{ion} (ion uptake)
  - Ion transport across membranes
  - Often lumped in with R_{maint}
  - 20-50% of R_{root}
    - Reduction of NO_3^- to NH_4^+
  - R_{ion} correlates well with NPP
    - Increased NPP ↔ increased nutrient uptake

Carbon Cycling - Respiration Processes

- What % of GPP goes to R?
  - As stands age:
    - % of GPP to $R_{foliage}$ ↑ but % to R_{wood} ↓, so % of GPP to R_{total} ≈
  - With increased fertility:
    - % of GPP to $R_{foliage}$ ↓ but % to R_{wood} ↑, so % of GPP to R_{total} ≈



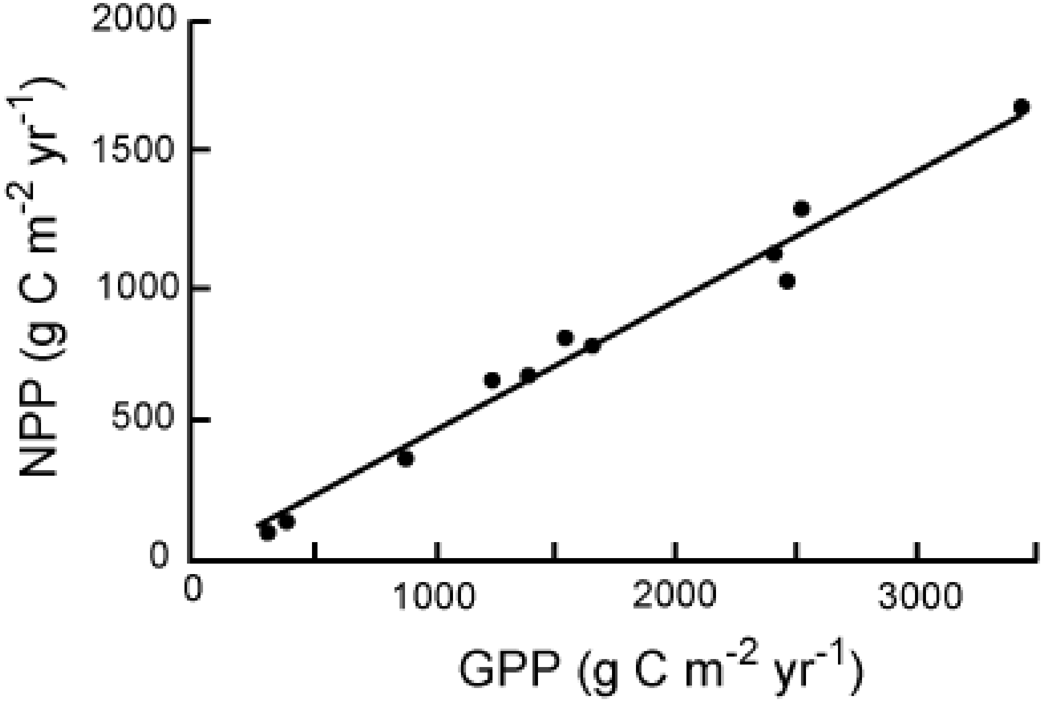
(Ryan et al. 2004)

Carbon Cycling - Respiration Processes

- Does *R* use a ~constant fraction of GPP???
  - Tremendous variability across studies
  - Carbon use efficiency (CUE) = NPP/GPP
    - 1 - CUE = % of GPP used for *R*
      - CUE of 0.43 means 57% of GPP to *R*

Carbon Cycling - Respiration Processes

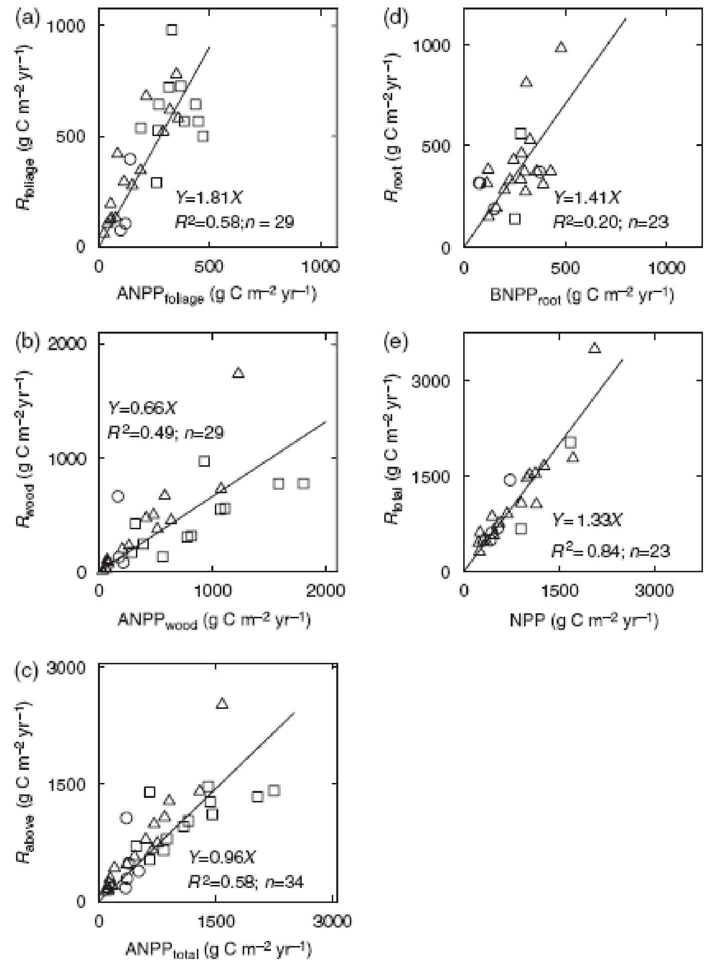
- CUE of 0.47 (± 0.04 S.D.) across 11 forests
  - 53% of GPP to *R*
- Lots of assumptions that could bias estimate



(Waring et al. 1998)

Carbon Cycling - Respiration Processes

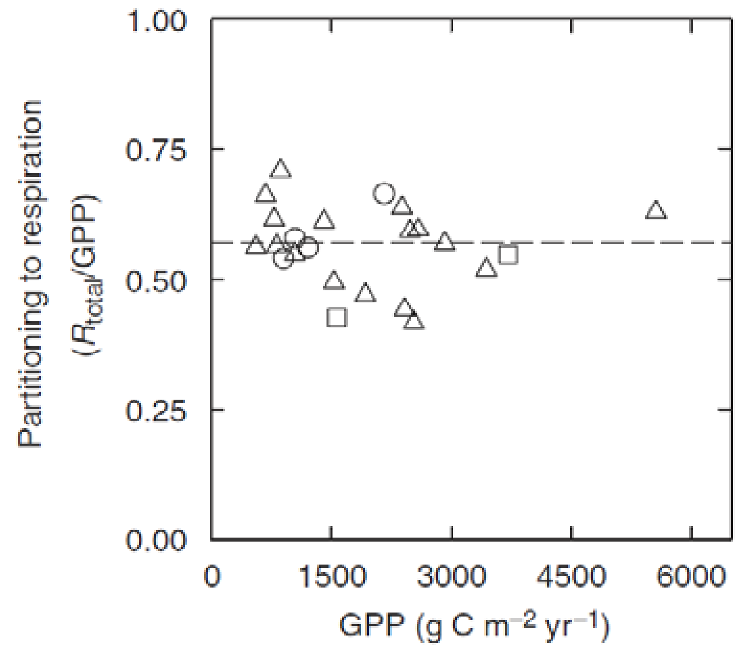
- Litton et al. (2007) examined studies that estimated stand-level C budgets (34 forests globally)
- Total CUE of 0.43 (± 0.02 S.E.)
  - 57% of GPP to *R*
- However, strong variation by component
  - CUEs of 0.36 (foliage), 0.60 (wood), 0.51 (total aboveground), 0.41 (roots), and 0.43 (total stand)



(Litton et al. 2007)

Carbon Cycling - Respiration Processes

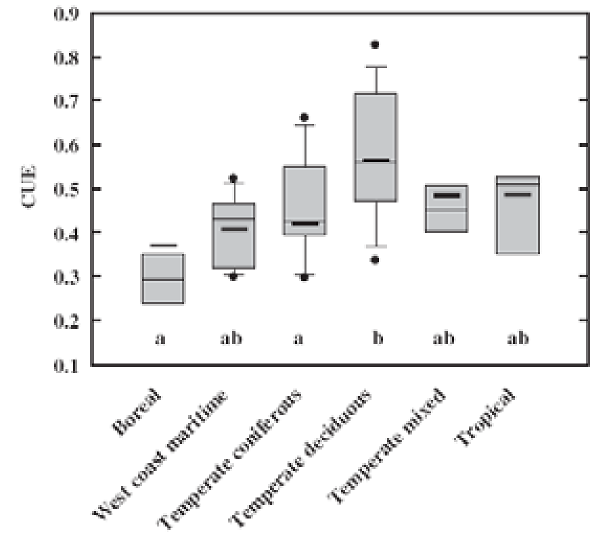
- Litton et al. (2007) examined studies that estimated stand-level C budgets (34 forests globally)
- Total CUE of 0.43 (± 0.02 S.E.)
  - ~57% of GPP to *R*
- Also varied considerably across sites
  - Total CUE ranged from 0.29 to 0.58
    - 42 - 71% of GPP to *R*



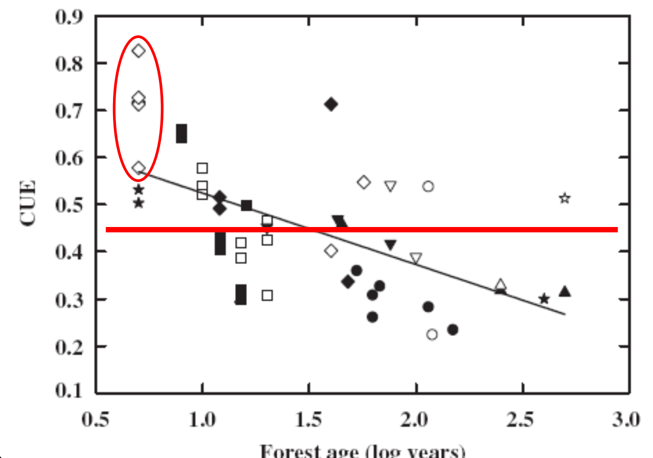
(Litton et al. 2007)

Carbon Cycling - Respiration Processes

- CUE may vary by biome



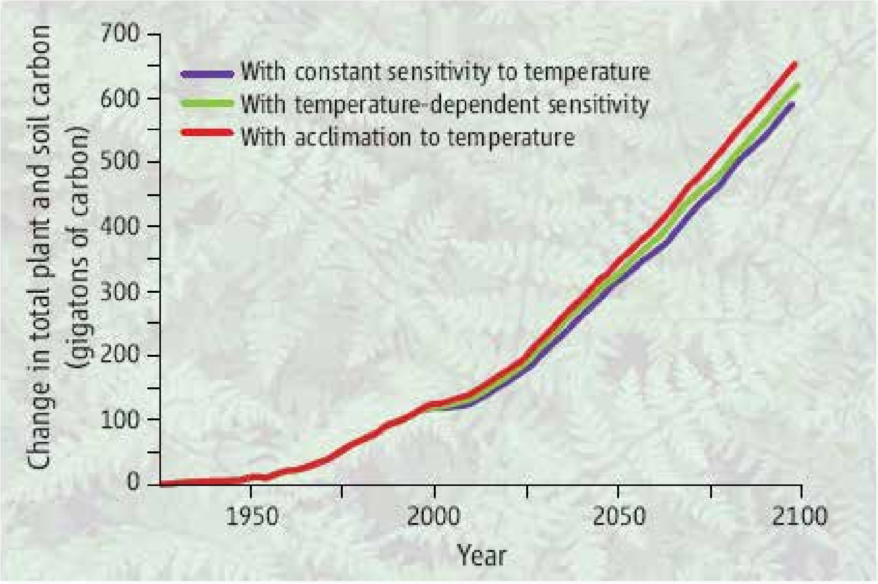
- CUE may vary with stand age
  – Apples vs. oranges?



(DeLucia et al. 2007)

Carbon Cycling - Respiration Processes

- Lots of recent focus on the sensitivity of *R* to rising temperatures
  - Climate change may impact *R* (and CUE)
  - In turn, would impact C sequestration & potentially feedback into climate change (i.e., positive forcing factor)

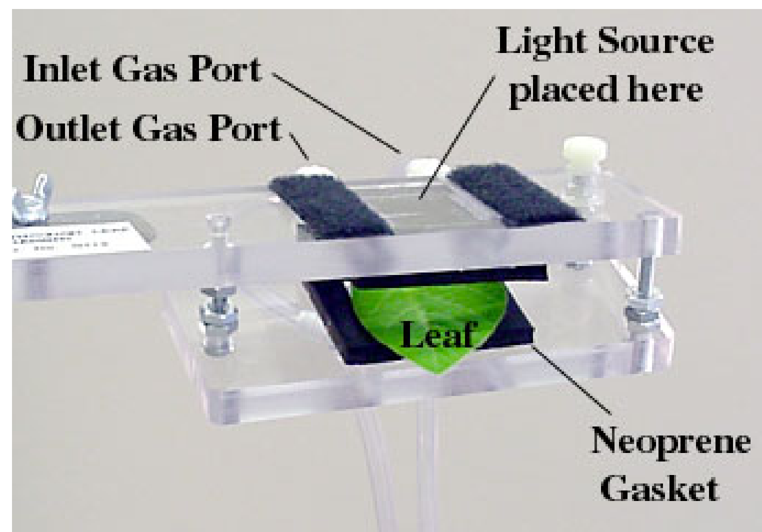


The effect of respiration. Cumulative change in global total terrestrial biosphere carbon simulated by the GTEC 2.0 model, using different temperature dependencies for leaf respiration. See the supporting online material.

(King et al. 2006)

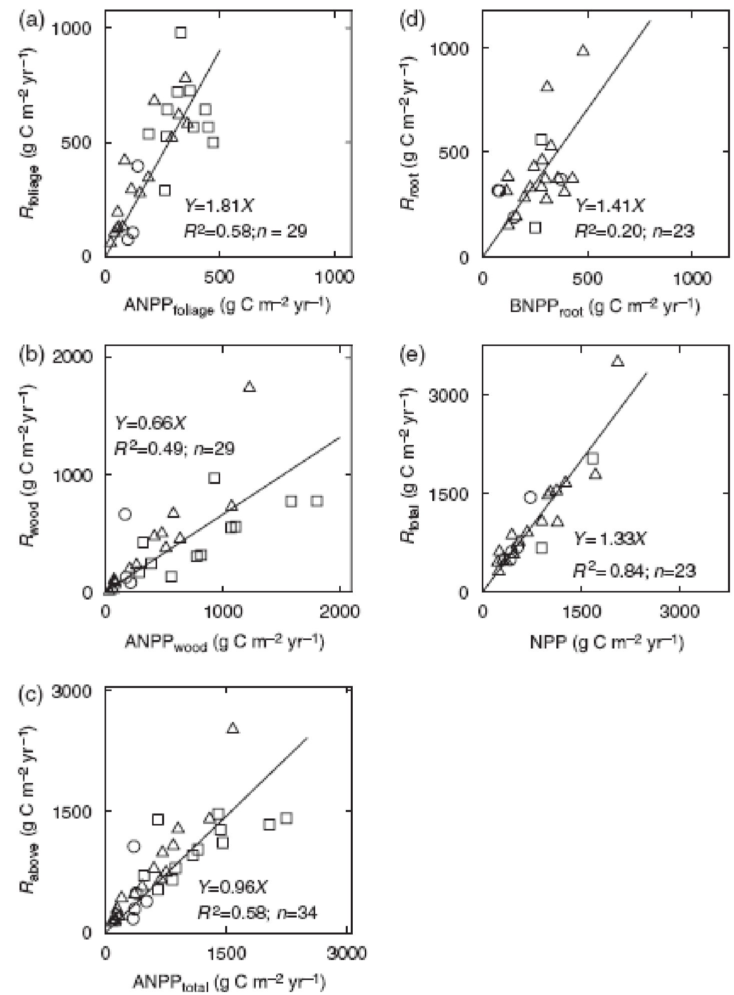
Carbon Cycling - Respiration Processes

- How do you measure *R*
  - By component (roots, wood, foliage)
    - Assume R_{growth} = 25% of biomass
      - Need to estimate new biomass added (NPP by component)
    - R_{maint} with global correlations with N and/or temperature
    - R_{maint} by establishing site-specific correlations with N and/or temperature



Carbon Cycling - Respiration Processes

- How do you measure *R*
  - Assume constant relationship between NPP and *R*
    - Should be done by component
    - With caution, however, as CUEs ranged from 0.29 - 0.58



(Litton et al. 2007)

Carbon Cycling - Respiration Processes

- How do you measure *R*
  - Models based on general principles
  - Eddy flux towers and isotopes