The Carbon Cycle 3

- I. Introduction: Changes to Global C Cycle (Ch. 15)
- II. C-cycle overview: pools & fluxes (Ch. 6)
- III. Controls on GPP (Ch. 5)
- IV. Controls on NPP (Ch. 6)
- V. Controls on NEP (Ch. 6)

Powerpoint modified from Harte & Hungate (http://www2.for.nau.edu/courses/hart/for479/notes.htm) and Chapin (http://www.faculty.uaf.edu/fffsc/)

IV. Controls on NPP

- A. Components of NPP
- B. Physiological Controls on NPP
  - 1. Plant Respiration
  - 2. Allocation
- C. State Factor and Interactive Controls on NPP
  - 1. Climate
  - 2. Parent material/nutrient availability
  - 3. Organisms
  - 4. Time

V. Controls on NEP

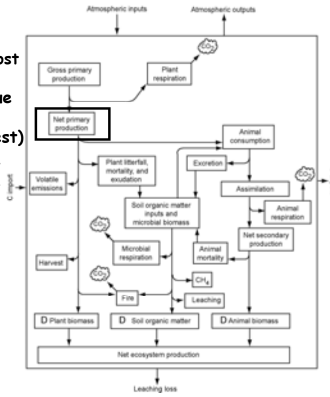
- A. Measuring NEP
- B. Controls on NEP
  - 1. Uptake/release imbalance
  - 2. Disturbance

NPP = GPP - R_{plant}

NPP = ΔPlant/Δt + C_{lost}

C_{lost}: exudates, vol. emissions, herbiv., tissue turnover (litterfall), disturbance (fire, harvest)

- **NPP is total energy available to rest of ecosystem**



6.8

Table 6.2 Components of NPP

Components of NPP	% of NPP	
New plant biomass	40-70	
Leaves and reproductive parts (fine litterfall)		10-30
Apical stem growth		0-10
Secondary stem growth		0-30
New roots		30-40
Root secretions	20-40	
Root exudates		10-30
Root transfers to mycorrhizae		10-30
Losses to herbivores, mortality, and fire	1-40	
Volatile emissions	0-5	

What do we usually measure??

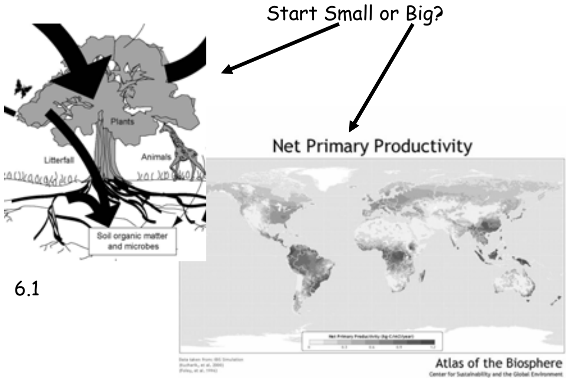
Litterfall
Stem growth
Sometimes roots

That leaves ~30% or more unaccounted for

What do we really care about?

- Biomass increment and carbon storage
- Energy available to other trophic levels
- Energy transfer to mycorrhizae (maybe)
- Root exudates (maybe)
- Volatile emissions (maybe; important for atmos chem but less so for C accounting).

Controls on NPP
Start Small or Big?



6.1

Plate 3

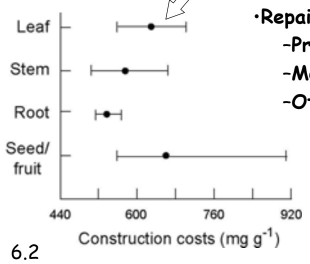
B. Physiological controls on NPP

1. Respiration

- NPP = GPP – Respiration

Respiration provides energy for essential plant processes

$$R_{plant} = R_{growth} + R_{maint} + R_{ion}$$



- Repair of
  - Proteins
  - Membranes
  - Other stuff

Probably correlates with GPP

Respiration cost of growth is similar among species and plant parts

6.2

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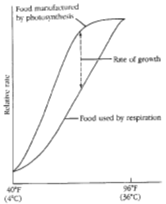
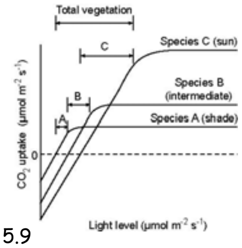
b. What controls maintenance respiration?

- Plant chemistry
  - especially protein content
- Environment
  - especially temperature and drought

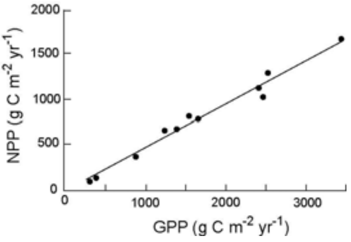


http://www.ext.colostate.edu/pubs/garden/07710.html



5.9

NPP is about half of GPP when looking across biomes



6.6

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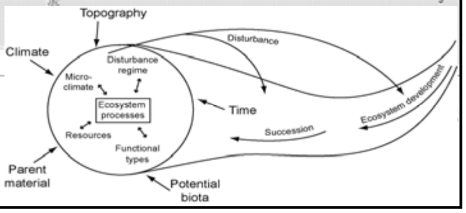
2. Allocation (pp.132-135)

Plants allocate most growth to tissues that maximize capture of limiting resources

- Allocate to roots when dry or nutrient poor
- Allocate to stems, leaves when light is limiting
- Constantly adjust allocation
  - Prevents overwhelming limitation by any one resource
  - Tends to make plants limited by multiple resources

C. State factor and interactive controls on NPP

Data taken from: IBIS Simulation
(Kucharik, et al. 2000)
(Foley, et al. 1996)



1.3

NPP varies 14-fold among biomes

Table 6.3. Net Primary Productivity of the Major Biome Types Based on Biomass Harvests[a].

Biome	Aboveground NPP (g m^{-2} yr^{-1})	Belowground NPP (g m^{-2} yr^{-1})	Belowground NPP (% of total)	Total NPP (g m^{-2} yr^{-1})
Tropical forests	1,400	1,100	0.44	2,500
Temperate forests	950	600	0.39	1,550
Boreal forests	230	150	0.39	380
Mediterranean shrublands	500	500	0.50	1,000
Tropical savannas and grasslands	540	540	0.50	1,080
Temperate grasslands	250	500	0.67	750
Deserts	150	100	0.40	250
Arctic tundra	80	100	0.57	180
Crops	530	80	0.13	610

Biomass is greatest in tropical and temperate forests

Table 6.4. Biomass distribution of the major terrestrial biomes[a].

Biome	Shoot (g m^{-2})	Root (g m^{-2})	Root (% of total)	Total (g m^{-2})
Tropical forests	30,400	8,400	0.22	38,800
Temperate forests	21,000	5,700	0.21	26,700
Boreal forests	6,100	2,200	0.27	8,300
Mediterranean shrublands	6,000	6,000	0.5	12,000
Tropical savannas and grasslands	4,000	1,700	0.3	5,700
Temperate grasslands	250	500	0.67	750
Deserts	350	350	0.5	700
Arctic tundra	250	400	0.62	650
Crops	530	80	0.13	610

[a] Data from [Roy, 2001 #3858]. Biomass is expressed in units of dry mass.

Half of global biomass and a third of global NPP is in tropical forests (total area x production/area)

Table 6.5. Global distribution of terrestrial biomes and their total carbon in plar biomass[a].

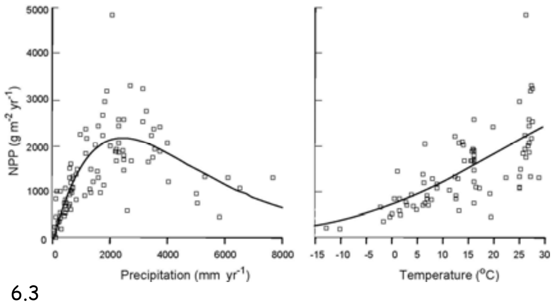
Biome	Area (10^{6} km^{2})	Total C pool (Pg C)	Total NPP (Pg C yr^{-1})
Tropical forests	17.5	340	21.9
Temperate forests	10.4	139	8.1
Boreal forests	13.7	57	2.6
Mediterranean shrublands	2.8	17	1.4
Tropical savannas and grasslands	27.6	79	14.9
Temperate grasslands	15.0	6	5.6
Deserts	27.7	10	3.5
Arctic tundra	5.6	2	0.5
Crops	13.5	4	4.1
Ice	15.5		
Total	149.3	652	62.6

[a] Data from [Roy, 2001 #3858]. Biomass is expressed in units of carbon, assuming that plant biomass is 50% carbon.

C.1. Climate

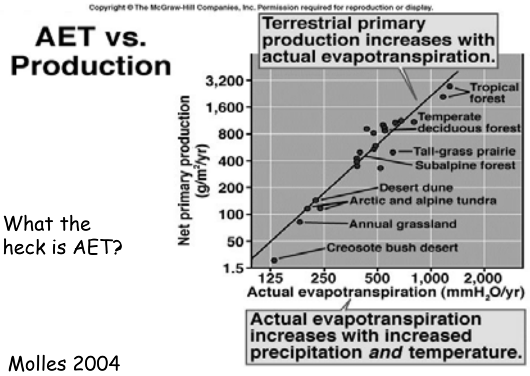
Global patterns of NPP vary with climate

Increases with ppt (up to max at ~2-3 m/yr)
Increases exponentially with temperature
High variance due to variation in other state factors



6.3

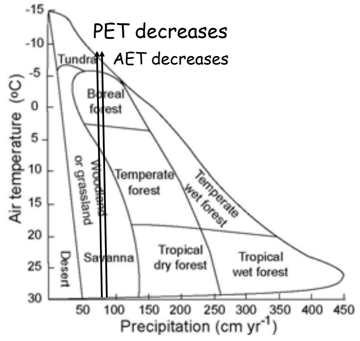
AET does better than temp or ppt alone.



What the
heck is AET?

Molles 2004

PET responds mostly to changing temp (and wind) AET is PET as constrained by available precip.

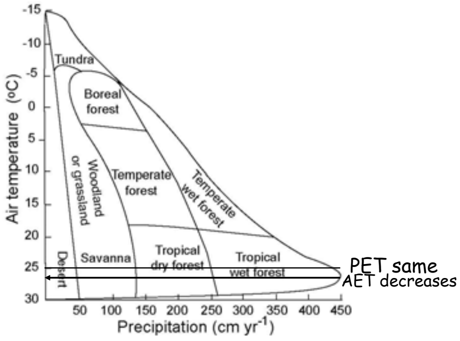


PET decreases

AET decreases

2.21

PET responds mostly to changing temp (and wind) AET is PET as constrained by available precip.

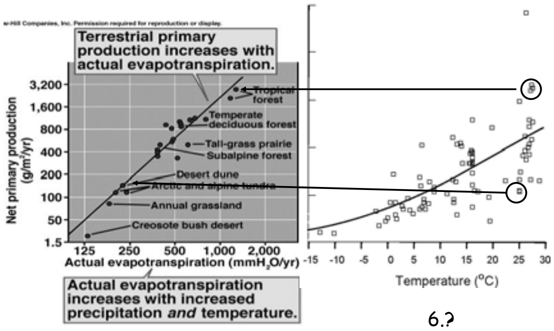


PET same

AET decreases

2.21

AET does better than temp or ppt alone.



Terrestrial primary production increases with actual evapotranspiration.

Actual evapotranspiration increases with increased precipitation *and* temperature.

Molles 2004

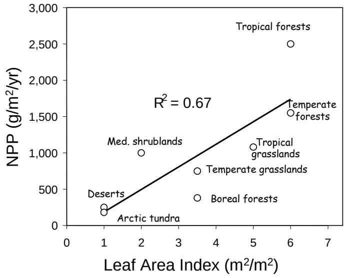
6.?

NPP per unit leaf area and time is fairly similar across biomes

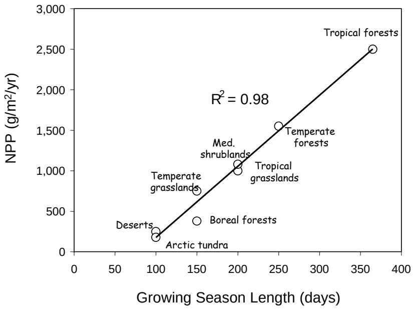
Table 6.6. Productivity per day and per unit leaf area[a].

Biome	Season length[b] (days)	Daily NPP per ground area (g m^{-2} d^{-1})	Total LAI[c] (m^{2} m^{-2})	Daily NPP per leaf area (g m^{-2} d^{-1})
Tropical forests	365	6.8	6.0	1.14
Temperate forests	250	6.2	6.0	1.03
Boreal forests	150	2.5	3.5	0.72
Mediterranean shrublands	200	5.0	2.0	2.50
Tropical savannas and grasslands	200	5.4	5.0	1.08
Temperate grasslands	150	5.0	3.5	1.43
Deserts	100	2.5	1.0	2.50
Arctic tundra	100	1.8	1.0	1.80
Crops	200	3.1	4.0	0.76

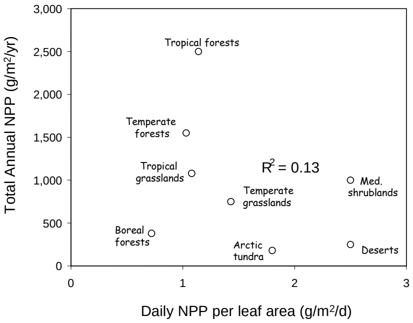
Leaf Area Index Correlates with NPP



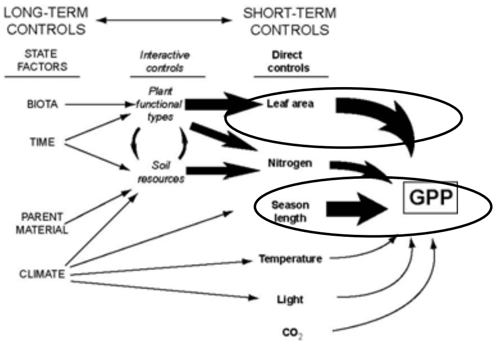
Length of the Growing Season Correlates with NPP



Productivity per unit leaf area does not correlate with NPP



This suggests that LAI and season length are strong controllers of NPP as well as GPP

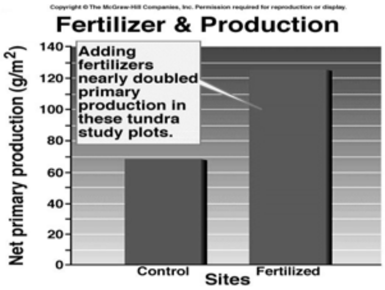


5.1

2. Parent material/soil resources

a. Nutrient limitation of NPP

- **Soil fertility gradients**
- **Fertilization**



Molles 2004, 18.4

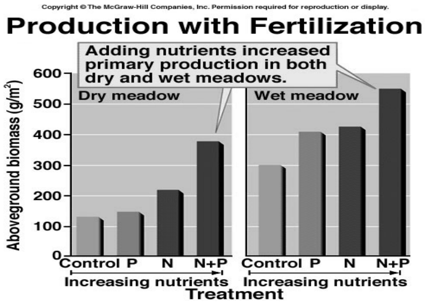
Which nutrients limit production?
What do we mean by "limitation"?

Simplistic view: Liebig's law of the minimum – only one resource is limiting, that in most limited supply

But, multiple resource limitation of NPP is frequently observed…

Which nutrients?

Primary limitation, secondary limitation, co-limitation



Molles 2004, 18.5

Why is NPP often limited by multiple resources?

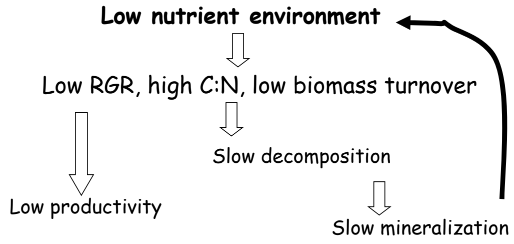
- Adjustment of allocation to prevent overwhelming limitation by one resource
- Environment changes seasonally and from year to year
- Different resources limit different species

b. Climate effects are in part mediated by belowground resources.

In ecosystems where correlations suggest a strong climatic limitation of NPP…

…experiments and observations indicate that this is mediated primarily by climatic effects on belowground resources.

c. Interactive effects of nutrients & vegetation: Soil/vegetation feedback



Low nutrient environment

Low RGR, high C:N, low biomass turnover

Slow decomposition

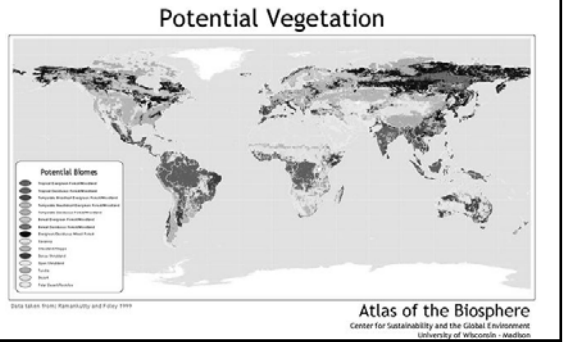
Low productivity

Slow mineralization

Chapin 1980

3. Organisms

a. Vegetation composition determines growth potential – both across and within biomes



Data taken from: Ramankutty and Foley 1999

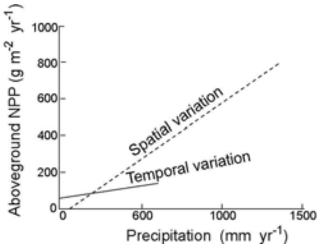
b. Organisms x Climate interactions:

Direct effects of climate on growth: short-term temporal variation

Effects on species composition: spatial variation

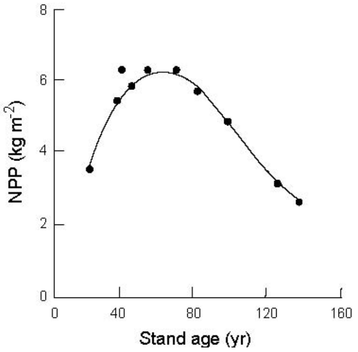
(which determines growth potential)

(takes time to adjust to climate)



6.5

4. Time: Disturbance and succession are major causes of variation in NPP within a biome



6.

V. Net ecosystem production (NEP)

NEP = GPP – $R_{ecosyst}$

$R_{ecosyst}$ = R_{plant} + R_{het}

NEP = NPP – R_{het}

NECB = GPP – R_E +/- F_{lat}

NECB = dC/dt (Chapin et al. 2006)

= (ΔPlant + ΔHet + ΔSOM)/Δt +/- F_{lat}

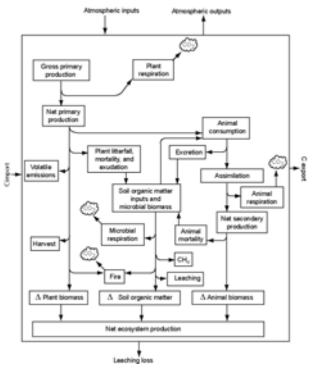
See Box 6.1

NEP and NECB (NBP at large scales) is most relevant to long-term sequestration of CO_2 from atmosphere

The problem of definition vs. measurement

NEP is the difference between GPP and $R_{ecosyst}$
NEP = ~NECB if lateral transfers are small

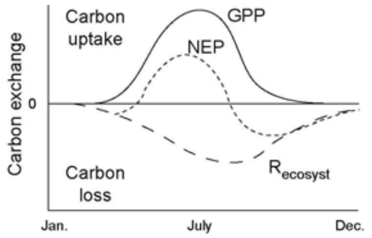
F_{lat} in: migration
sediments
dissolved C



F_{lat} out: dist., mig., leaching, sed., volatile emissions, CH_4

6.8

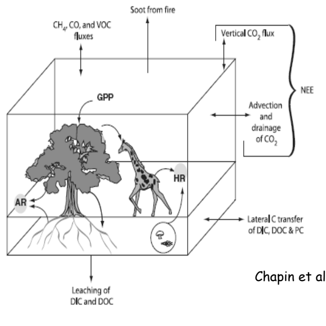
NEP is the balance between two large fluxes:
GPP and ecosystem respiration



6.9

A. Measuring NEP

Net ecosystem exchange

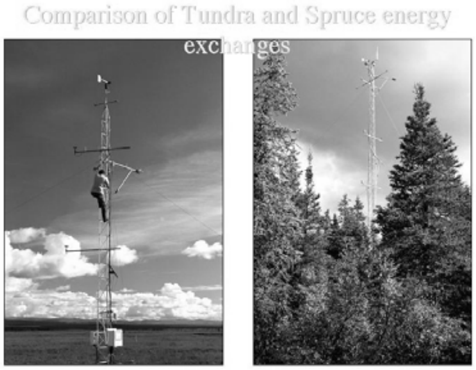


Chapin et al. 2006

- **NEE = net atmospheric CO_2 flux**

Measuring NEE - chambers

Measuring NEE – Eddy covariance towers (eddy flux)



B. Controls on NEP, NEE, NECB

1. Represents net carbon storage in ecosystem (imbalance between *C* uptake and *C* loss)
2. Strong dependence on disturbance
   - Negative when disturbance frequent (fire, tillage)
   - Positive during recovery from disturbance (succession)

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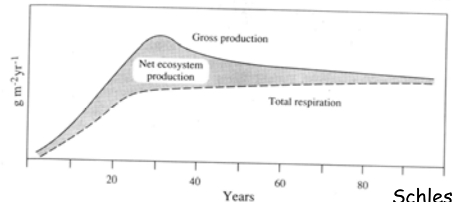

Figure 5.14 Generalized trends in primary production and respiration during ecosystem development. Modified from Odum (1969).

Schlesinger 2001

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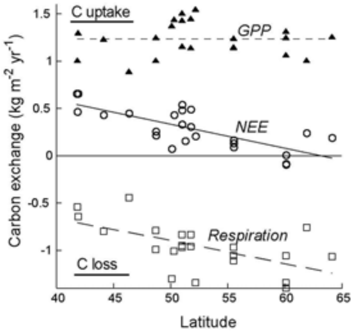
3. Biome differences in NEE reflect large net carbon loss by respiration at high latitudes



6.10

Valentini

Why is NEP positive (NEE negative) in most ecosystems?

- Maybe all ecosystems accumulate *C* between disturbances
- Maybe bias in site selection
  - Researchers prefer productive sites?
- Maybe carbon loss by leaching is significant
- Maybe terrestrial biosphere is gaining carbon
  - due to elevated CO_2 and N deposition

Summary

1. Controls on NPP are similar to those on GPP.
2. R_{plant} consists of respiration for growth, maintenance, and ion uptake.
3. While variable temporally within ecosystems, across ecosystems NPP is ~50% of GPP.
4. NEP, NECB reflect net storage of *C* within an ecosystem.
5. Disturbance regime is the main controller of difference between NEP and NECB in natural systems.
6. Humans are influencing many factors (temp, nutrient avail, disturbance regimes) that could alter the balance of GPP and $R_{ecosyst}$ and thereby alter NEP and NECB.

Eddy flux – advantages