

The Biosphere

The Carbon Cycle of Terrestrial Ecosystems

OUTLINE

Introduction	135	Global Estimates of Net Primary Production and Biomass	153
Photosynthesis	136	Net Primary Production and Global Change	156
Water-Use Efficiency	138		
Nutrient-Use Efficiency	139		
Respiration	141	Detritus	159
Net Primary Production	142	The Decomposition Process	160
Measurement and Allocation of NPP	142	Humus Formation and Soil Organic Matter	161
		Turnover	163
Net Ecosystem Production and Eddy-Covariance Studies	146	Soil Organic Matter and Global Change	168
The Fate of Net Primary Production	149	Summary	170
Remote Sensing of Primary Production and Biomass	150		

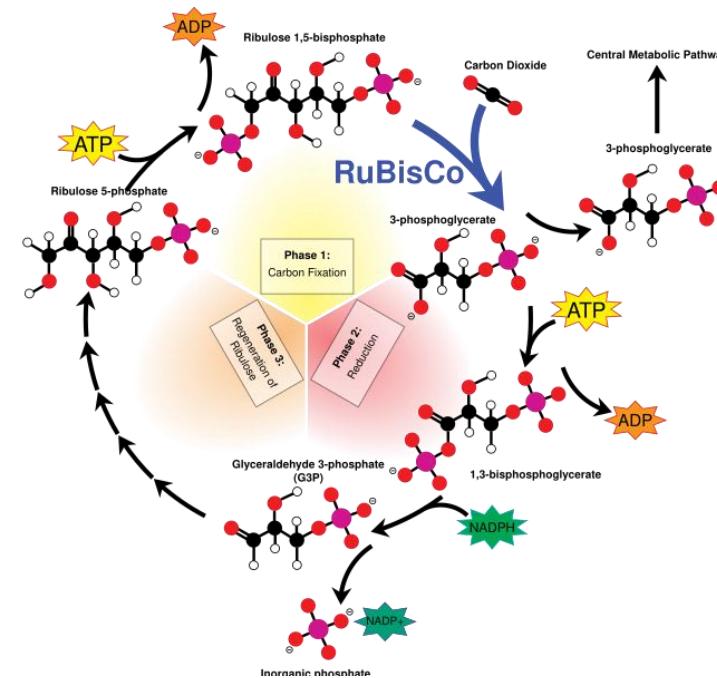
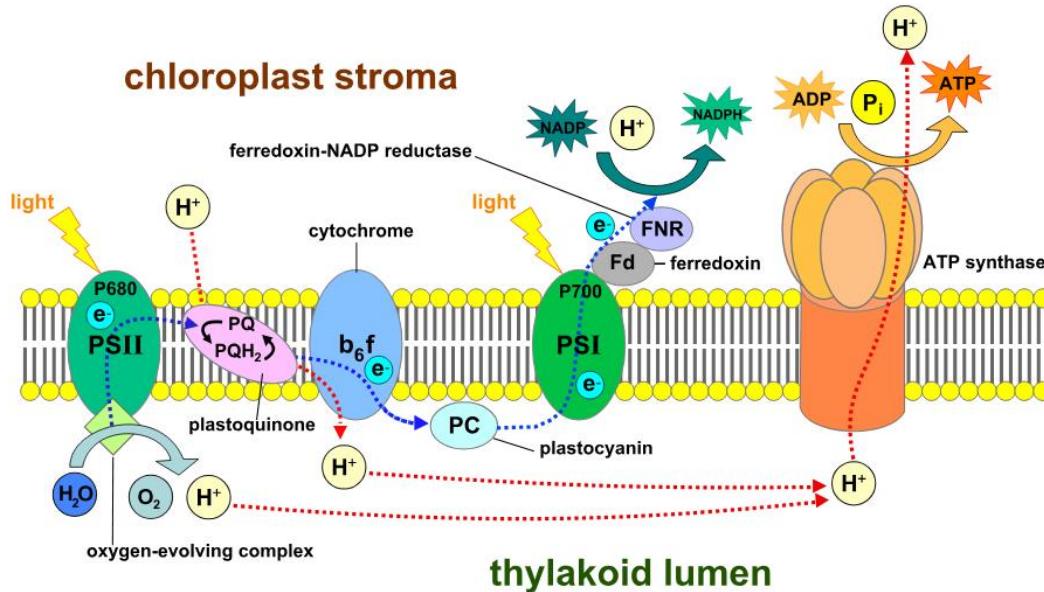
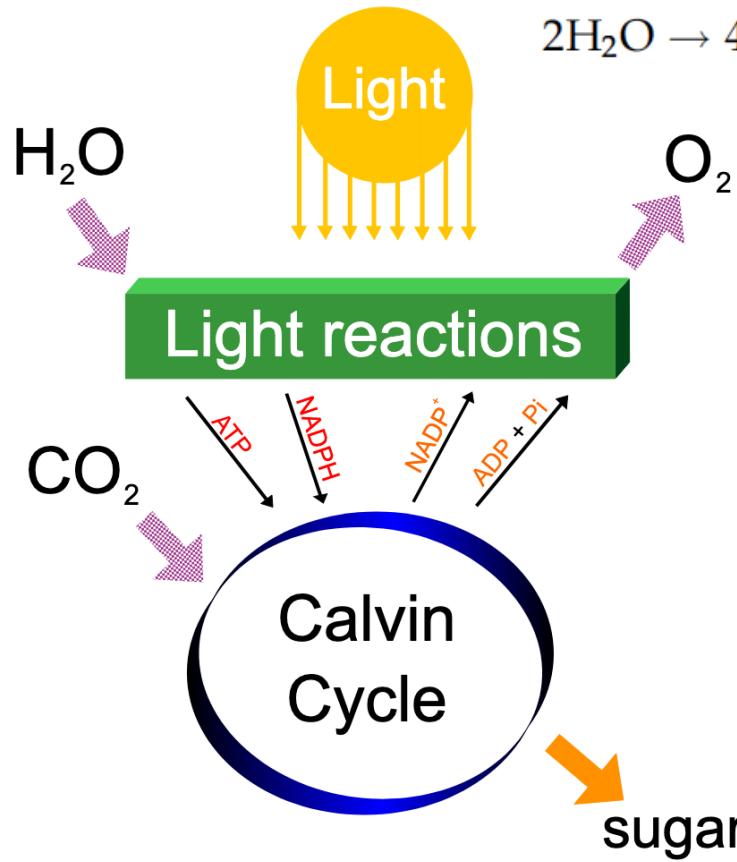
		Oxidized	Reduced	
			C	N
		H ₂ O/O ₂		S
Oxidized	H ₂ O/O ₂	X	Photosynthesis CO ₂ → C H ₂ O → O ₂	
C	C	Respiration C → CO ₂ O ₂ → H ₂ O	X	Denitrification C → CO ₂ NO ₃ → N ₂ Sulfate-Reduction C → CO ₂ SO ₄ → H ₂ S
Reduced	N	Heterotrophic Nitration NH ₄ → NO ₃ O ₂ → H ₂ O	Chemoautotrophy (Nitration) NH ₄ → NO ₃ CO ₂ → C	Anammox NH ₄ + NO ₂ → N ₂ + 2H ₂ O ?
	S	Sulfur Oxidation S → SO ₄ O ₂ → H ₂ O	Chemoautotrophy (Sulfur-based Photosynthesis) S → SO ₄ CO ₂ → C	Autotrophic Denitrification S → SO ₄ NO ₃ → N ₂ /NH ₄ X

FIGURE 1.4 A matrix showing how cellular metabolisms couple oxidation and reduction reactions. The cells in the matrix are occupied by organisms or a consortium of organisms that reduce the element at the top of the column, while oxidizing an element at the beginning of the row. *Source: From Schlesinger et al. (2011).*

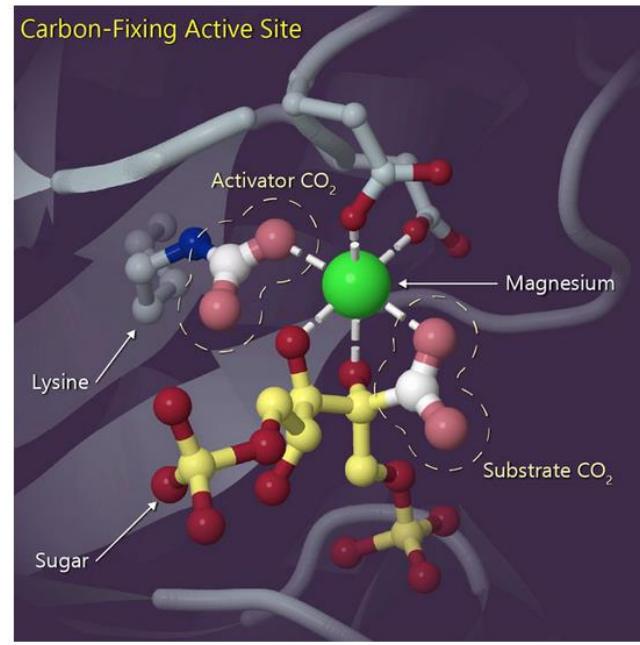
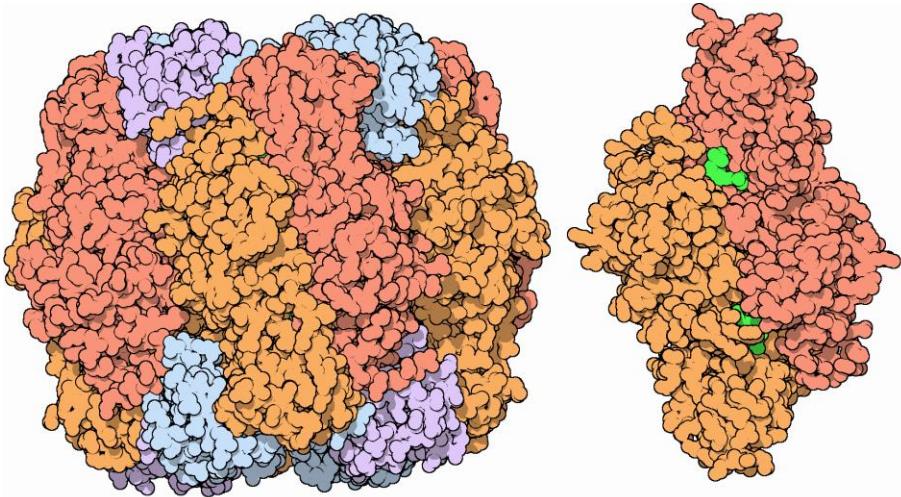
TABLE 4.1 Approximate Mean Composition of Earth's Continental Crust

Constituent	Percentage composition
Si	28.8
Al	7.96
Fe	4.32
Ca	3.85
Na	2.36
Mg	2.20
K	2.14
Ti	0.40
P	0.076
Mn	0.072
S	0.070

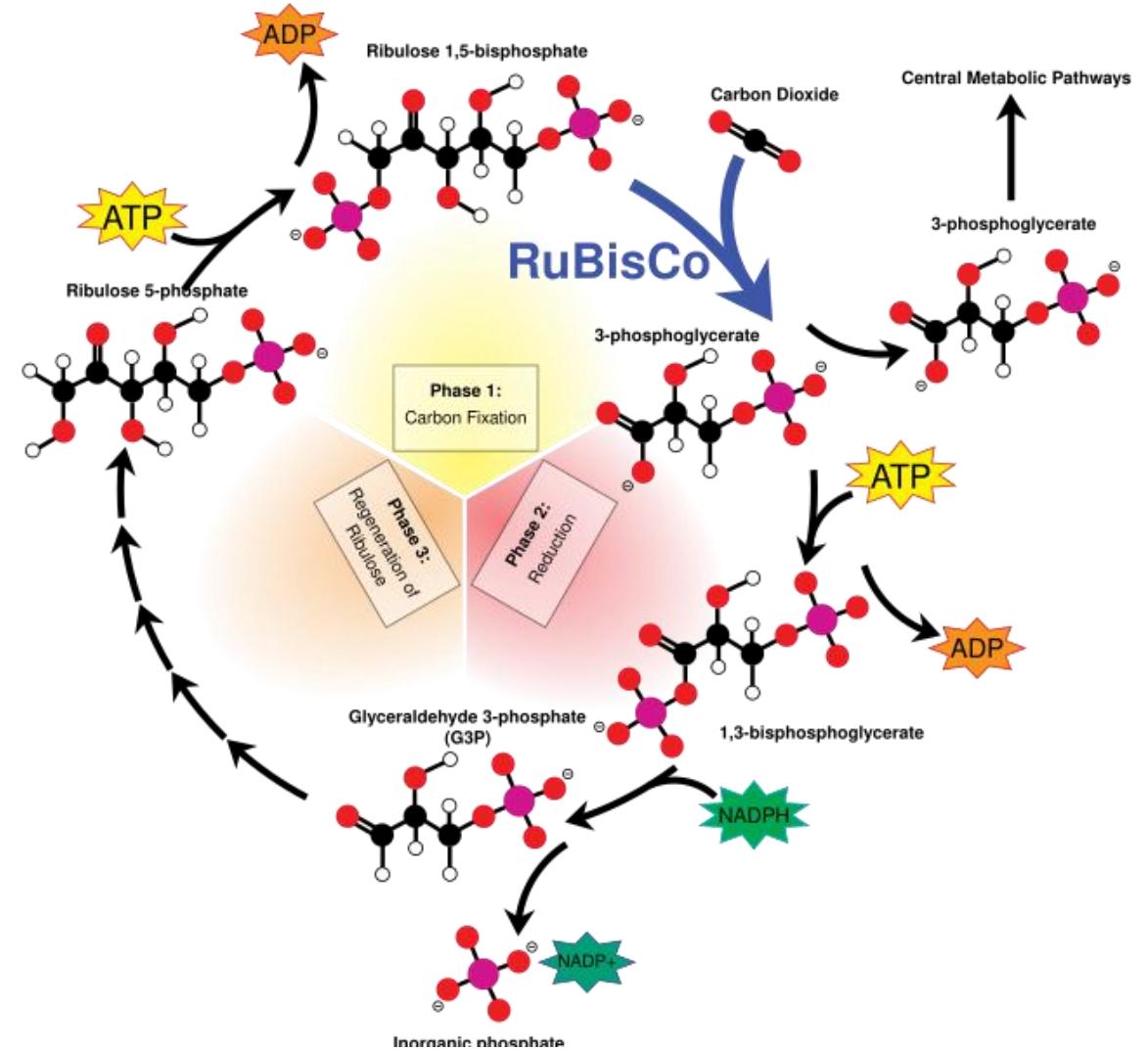
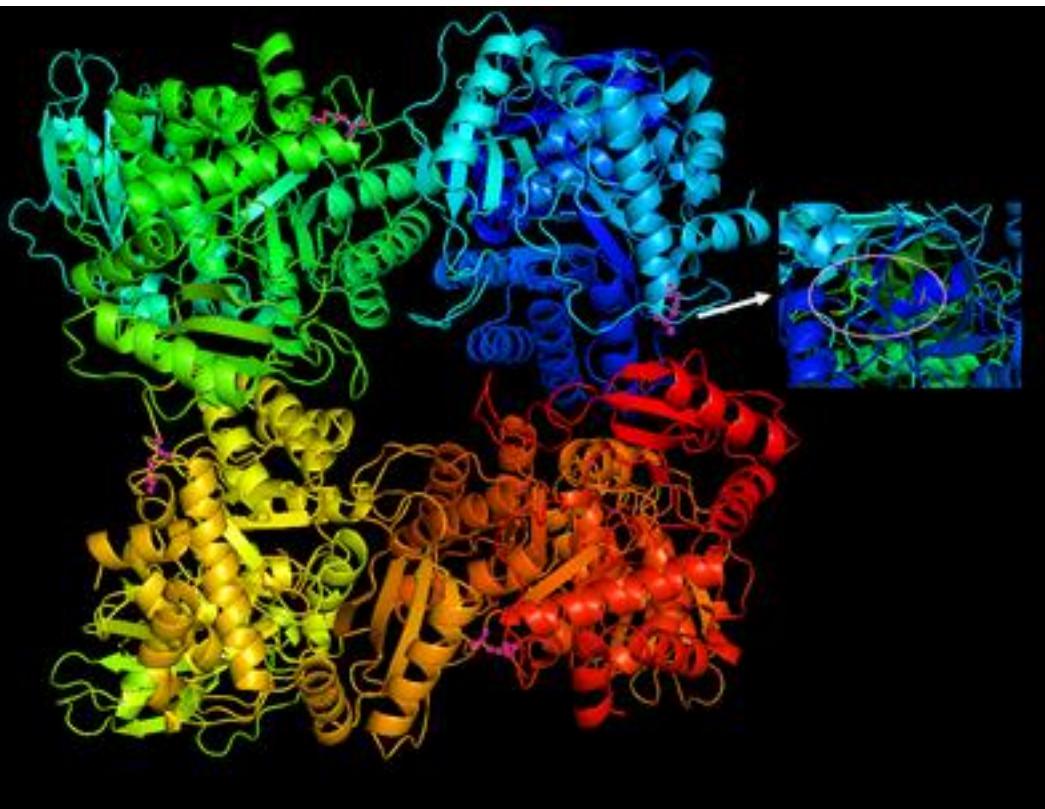
Source: Data from Wedepohl (1995).



Ribulose-1,5-bisphosphate carboxylase/oxygenase



The active site of rubisco is centered on a magnesium ion (green). It is held tightly by three amino acids: an asparagine, glutamic acid, and a modified form of lysine. The carbon dioxide molecule (left, dotted outline) attached to this lysine serves as an activator in the carbon fixing reaction. This activator carbon dioxide is different from the carbon dioxide molecule that is fixed to the sugar. During the day, the activator carbon dioxide is attached to rubisco, and removed at night to turn the enzyme "off." When rubisco is active, the exposed side of the magnesium ion is free to bind to the sugar molecule and catalyze the reaction with a substrate carbon dioxide. In this structure (PDB ID [8ruc](#)), the carbon dioxide is already attached to the sugar (right, dotted outline), giving a snapshot of rubisco in action.



Water-Use Efficiency

Transpiration – Loss of water through plant stomates.

$\text{WUE} = \text{mmoles of CO}_2 \text{ fixed}/\text{moles of H}_2\text{O lost.}$

Nutrient –Use Efficiency

Rate of photosynthesis per unit of leaf nitrogen

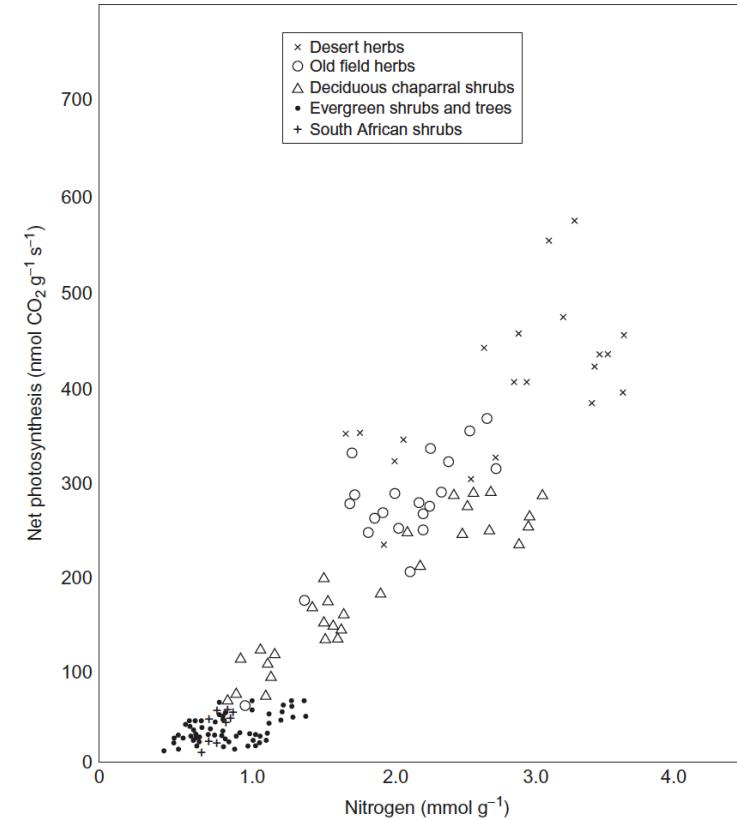


FIGURE 5.3 Relationship between net photosynthesis and leaf nitrogen content among 21 species from different environments. Source: From Field and Mooney (1986). Used with permission of Cambridge University Press.

Respiration

Photorespiration

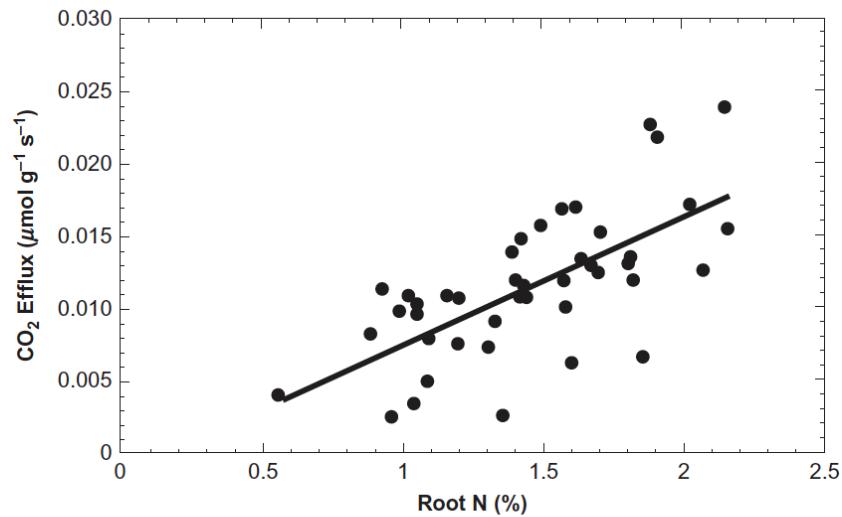
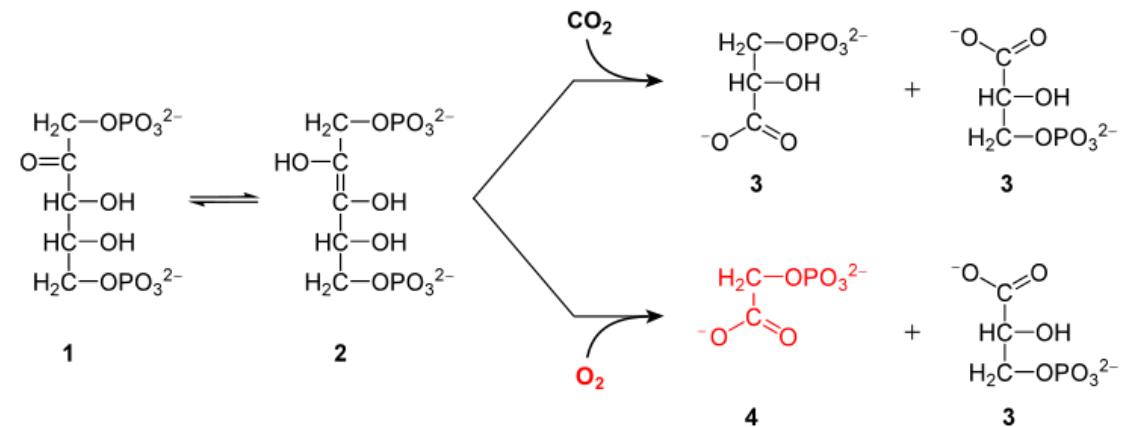
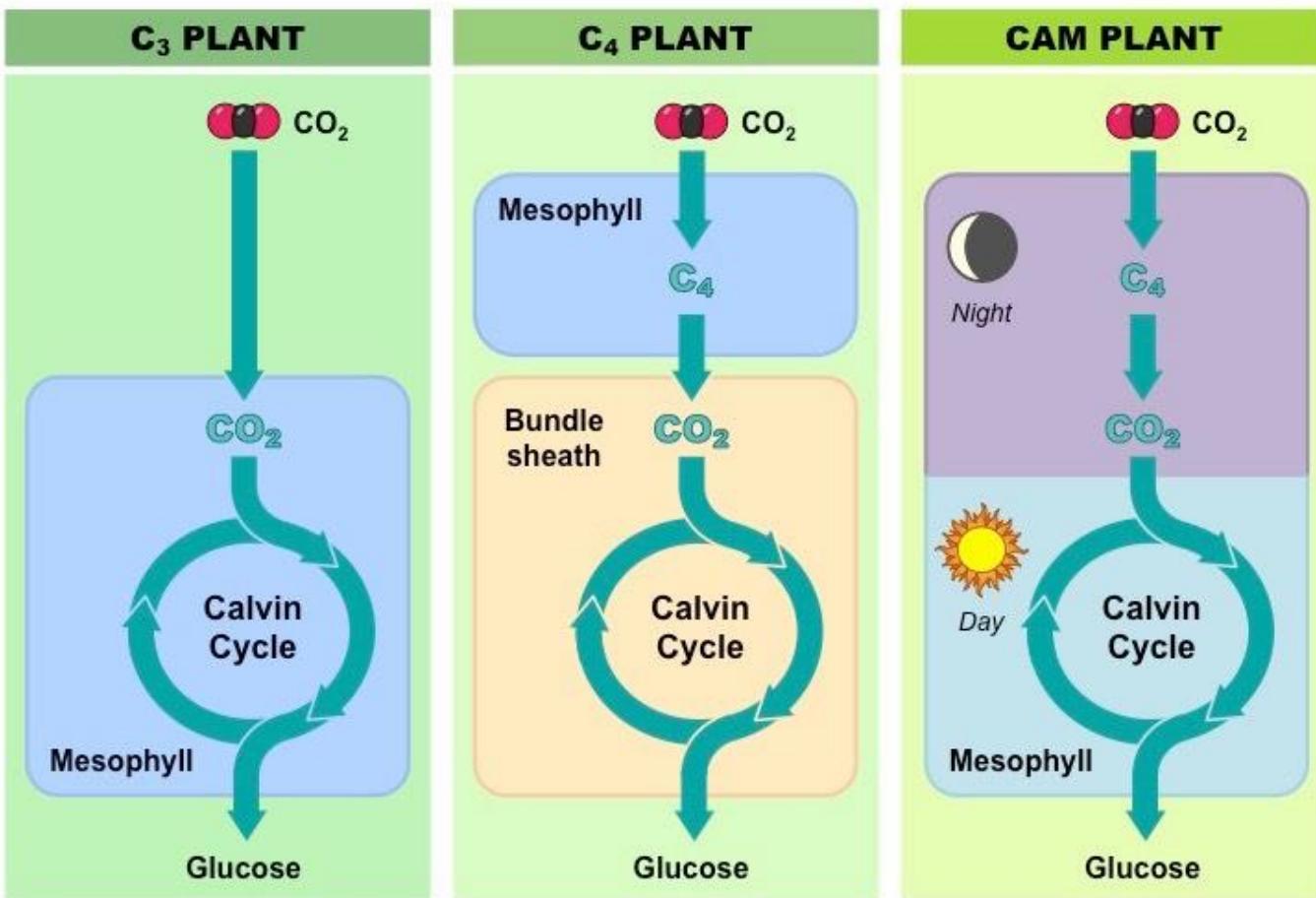
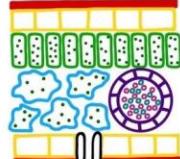
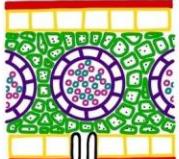
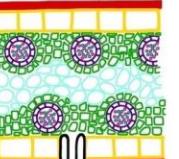


FIGURE 5.4 Root respiration as a function of nitrogen content (%) in roots of loblolly and ponderosa pine. Source: From Griffin et al. (1997). Used with permission of Springer.



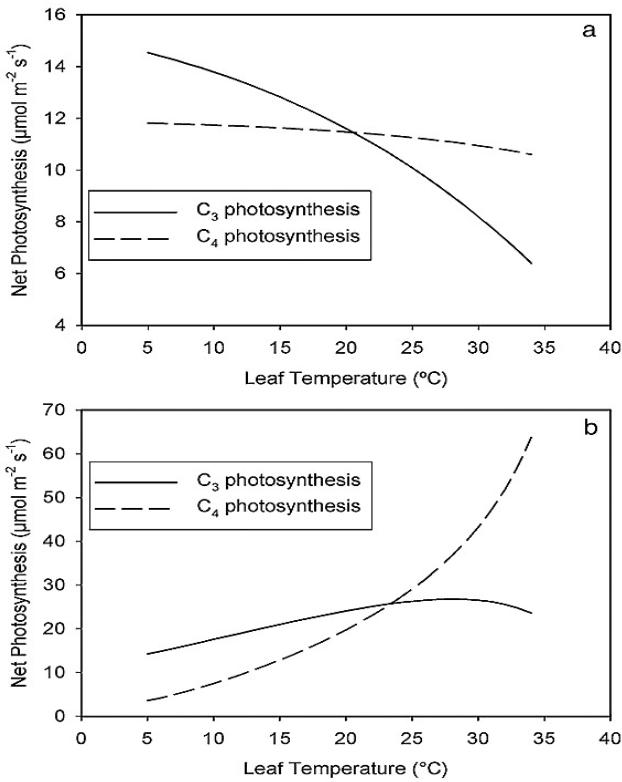


C3 C4 AND CAM PLANTS SUMMARIZED!

	C3 PLANT	C4 PLANT	CAM PLANT
SUMMARY	TEMPERATE PLANTS NO SPECIAL MODS	HOT WEATHER PLANTS SEPARATE FIXATION & CALVIN CYCLE	DESERT PLANTS NIGHT: GAS EXCHANGE DAY: PHOTOSYNTHESIS
STRUCTURE			
EXAMPLES	MOST PLANTS ARE C3 RICE, CANNABIS	CORN, SUGARCANE	CACTI, PINEAPPLES
KEY CELLS	PALISADE MESOPHYLL	PALISADE MESOPHYLL BUNDLE SHEATH	PALISADE MESOPHYLL
IDEAL TEMPERATURE	20-30°C (65-85°F)	30-40°C (85-105°F)	NIGHT: 10-15°C (50-60°F) DAY: 30-40°C (85-105°F)



Global distribution of C₃ and C₄ vegetation: Carbon cycle implications



Light Limited Conditions

Light Saturated Conditions

Net Primary Production

Gross primary production – plant respiration = net primary production

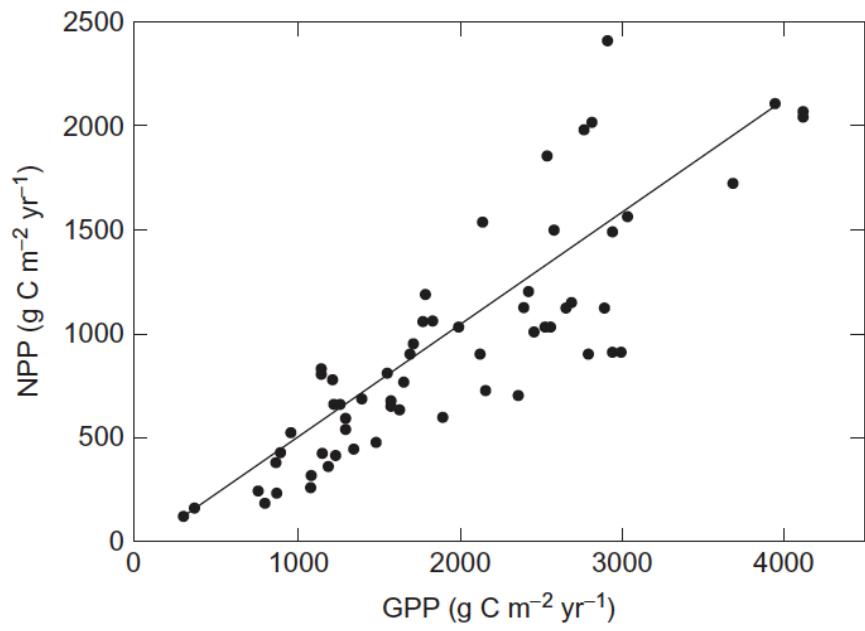


FIGURE 5.5 Relationship between net primary production (NPP) and gross primary production (GPP) in different forest types. Source: From DeLucia *et al.* (2007).

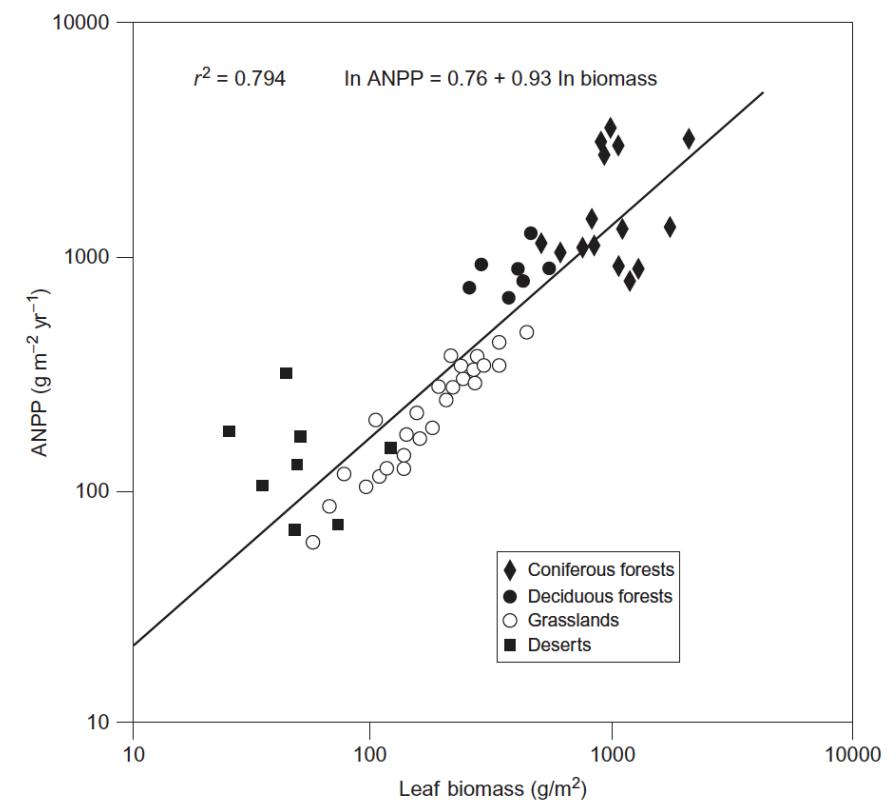


TABLE 5.1 Net Primary Production in 23- and 180-yr-old *Abies amabilis* Forests
in the Cascade Mountains in Washington

Aboveground	23-yr-old		180-yr-old	
	g m ⁻² yr ⁻¹	% of total	g m ⁻² yr ⁻¹	% of total
Biomass increment				
Tree total	426		232	
Shrub stems	6		<1	
Total	432	18.37	232	9.33
Detritus production				
Litterfall	151		218	
Mortality	30			
Herb layer turnover	32		5	
Total	213	9.06	223	8.97
Total aboveground	645	27.42	455	18.30
Belowground				
Roots				
Fine (≤ 2 mm)	650	27.64	1290	51.87
Fibrous-textured	571		1196	
Mycorrhizal	79		94	
Coarse (> 2 mm)	358		324	
Angiosperm fine root turnover	373		44	
Total root turnover	1381	58.72	1658	66.67
Mycorrhizal fungal component	326	13.86	374	15.04
Total below ground	1707	72.58	2032	81.70
Ecosystem total	2352	2352	2487	

Source: From Vogt et al. (1982). Used with permission of Ecological Society of America.

Assignments I-IV lead to the development of an NSF GRFP proposal. Each assignment successively builds and adds to each other.

In Assignment I you accomplished the following:

- 1) Familiarized yourself with the GRFP program and requirements
- 2) Developed a reverse outline and summaries of the NSF GRFP RFP.
- 3) Developed a CV.
- 4) Started a formal reference section (literature cited)

Assignment II builds on the work you started with Assignment I by developing drafts of the required materials to be entered into the GRFP Application Module and an outline of the literature review for your Research/Program Plan.

Assignment II has three parts.

I. Develop drafts of the materials required to be entered into the GRFP Application Module.

The sections that are required include:

- Personal Information
- Education
- Work and Other Experience
- Transcript PDFs
- Proposed Field(s) of Study
- Proposed Graduate Study and Graduate School Information
- Names and Addresses of at least 3 reference letter writers
- Personal, Relevant Background and Future Goals Statement PDF
- Graduate Research/Program Plan Statement PDF

Draw information from your draft CV and update your CV as needed.

II. Develop draft paragraphs for your Personal, Relevant Background and Future Goals Statement.

Draw from what you posted for Reflection 1 where you summarized your career goals and choice of major, and from your draft CV from Assignment 1.

III. Develop a draft Research/Program Plan Statement that includes the start of a literature review/background section. The literature review will include publications that inspired your choice of research or program plan and will serve as background materials that you are basing your Research/Program Plan on.

- a. Identify 1-2 papers to start your literature review.
- b. Develop reverse outlines and summaries of the papers.
- c. Identify key aspects of the papers for your literature review.
- d. Update your reference section from Assignment I to include the papers in your literature review.

Net Ecosystem Production

$$\text{NEP} = \text{NPP} - (\text{R}_h + \text{R}_d)$$

$$\text{NEP} = \text{GPP} - (\text{R}_p + \text{R}_h + \text{R}_d)$$

Net Ecosystem Production

$$\text{NEP} = \text{NPP} - (\text{R}_h + \text{R}_d)$$

$$\text{NEP} = \text{GPP} - (\text{R}_p + \text{R}_h + \text{R}_d)$$

R_p = Respiration of Plants

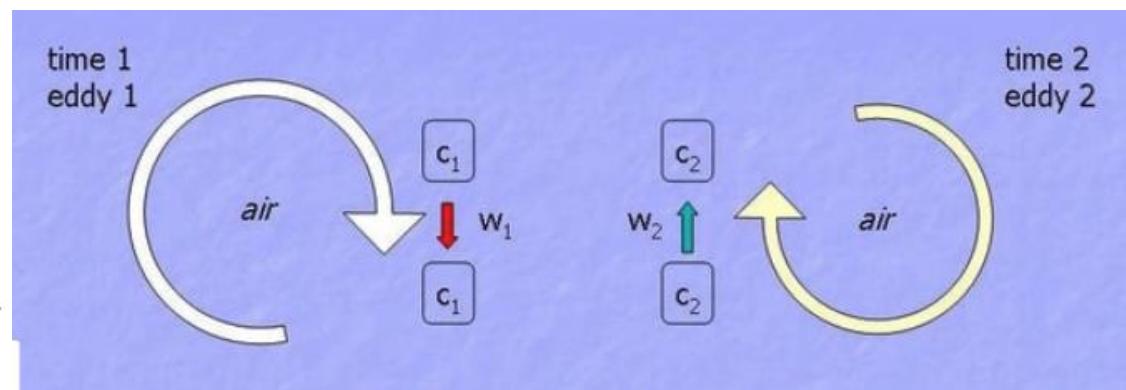
R_h = Respiration of Herbivores

R_d = Respiration of Decomposers

Eddy Co-Variance Flux



FIGURE 5.7 An eddy-covariance (flux) tower in a deciduous forest in North Carolina. Photo courtesy of G. Katul, Duke University.



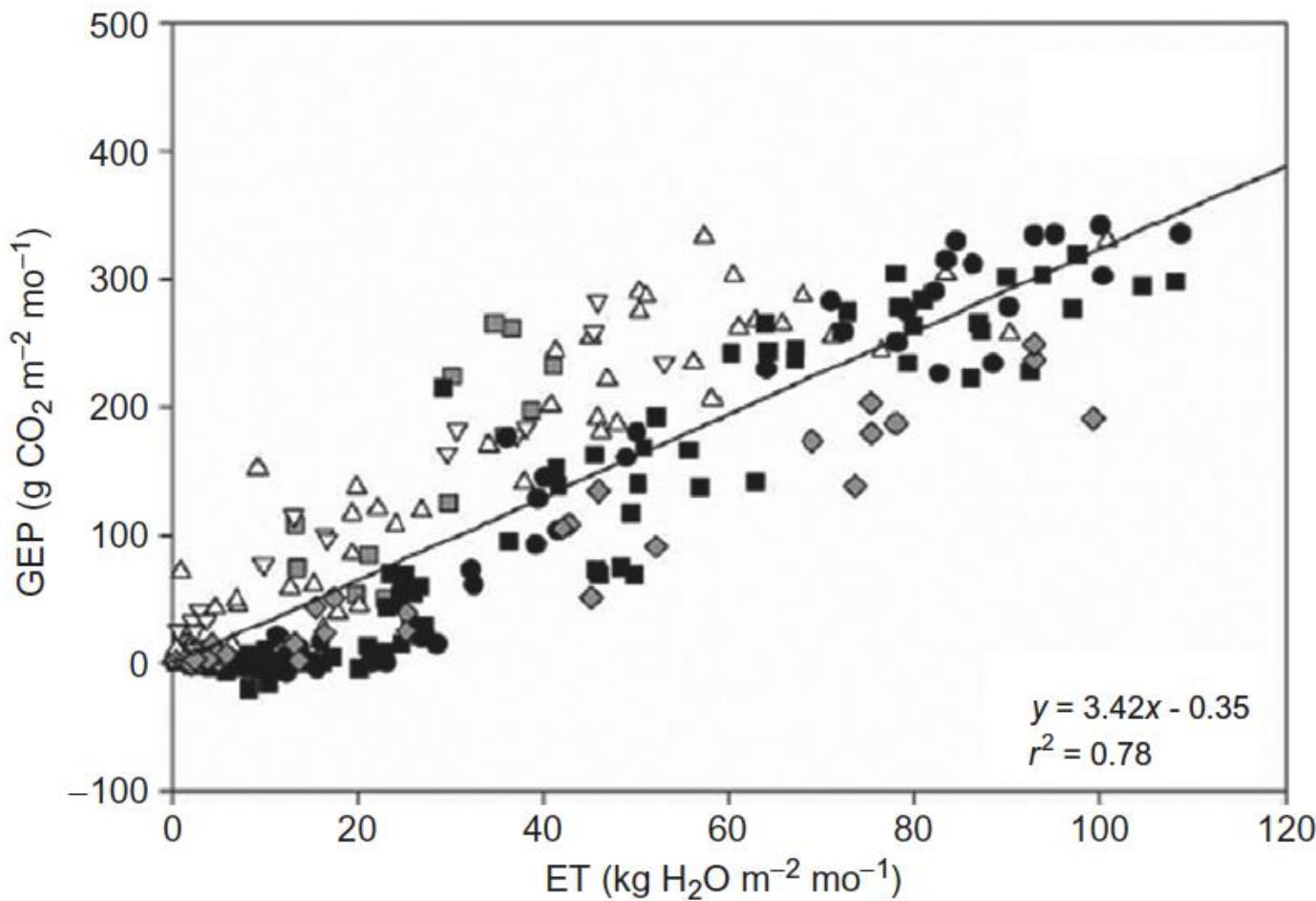


FIGURE 5.8 Monthly gross primary production and evaporation in various temperate deciduous forests, measured by eddy-covariance techniques. The slope of the line is an estimate of water-use efficiency, here equivalent to 1.4 mmol/mol (see Eq. 5.3). *Source:* From Law *et al.* (2002).

TABLE 5.2 GPP, NPP, and NEP for Some Young Temperate and Boreal Forest Ecosystems Measured by Harvest (H) and Eddy Covariance (CV) Methods

Ecosystem type	Age	Method	GPP	NPP	NEP	References
<i>Pinus sylvestris</i> (Finland)	40	CV	1005		185	Kolari et al. 2004
		H			228	
<i>Picea rubens</i> (Maine)	90	CV	1339		174	Hollinger et al. 2004
<i>Pinus taeda</i> (North Carolina)	16	CV	2238		433	Juang et al. 2006
		H		986	428	Hamilton et al. 2002
						McCarthy et al. 2010
<i>Pinus elliottii</i> (Florida)	24	CV	2606		675	Clark et al. 2004
		H			745	
<i>Pinus ponderosa</i> (Oregon)	56–89	CV	1208		324	Law et al. 2000
		H		400	118	Law et al. 2003
Mixed deciduous (Massachusetts)	60	CV	1300		200	Barford et al. 2001
		H			160	
Mixed deciduous (Michigan)	85	CV	654		151	Gough et al. 2008
		H			153	

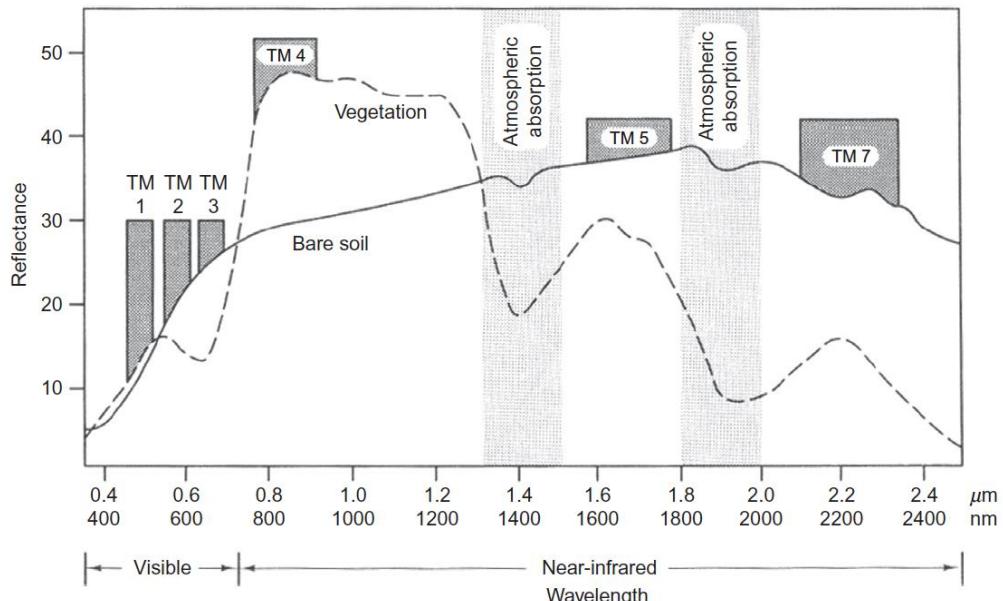
Note: All data in $\text{g C m}^{-2} \text{ yr}^{-1}$

Remote Sensing

The normalized difference vegetation index (NDVI) is calculated as:

$$\text{NDVI} = (\text{NIR} - \text{VIS}) / (\text{NIR} + \text{VIS}),$$

where NIR is reflectance in the near-infrared and VIS is reflectance in the visible red wavebands, respectively. This index minimizes the effects of variations in background reflectance and emphasizes variations in the data that occur because of the density of green vegetation. NDVI allows global mapping of a greenness index for the Earth's land surface, and satellite measurements of greenness can provide estimates of NPP, assuming that greenness is directly related to leaf area⁷ and that LAI is a good predictor of NPP (Gholz 1982; Figures 5.6 and 5.10).



$$\text{GPP} = \epsilon \times \text{NDVI} \times \text{PAR},$$

FIGURE 5.9 A portion of the solar spectrum showing the typical reflectance from soil (—) and leaf (---) surfaces and the portions of the spectrum that are measured by the LANDSAT satellite.

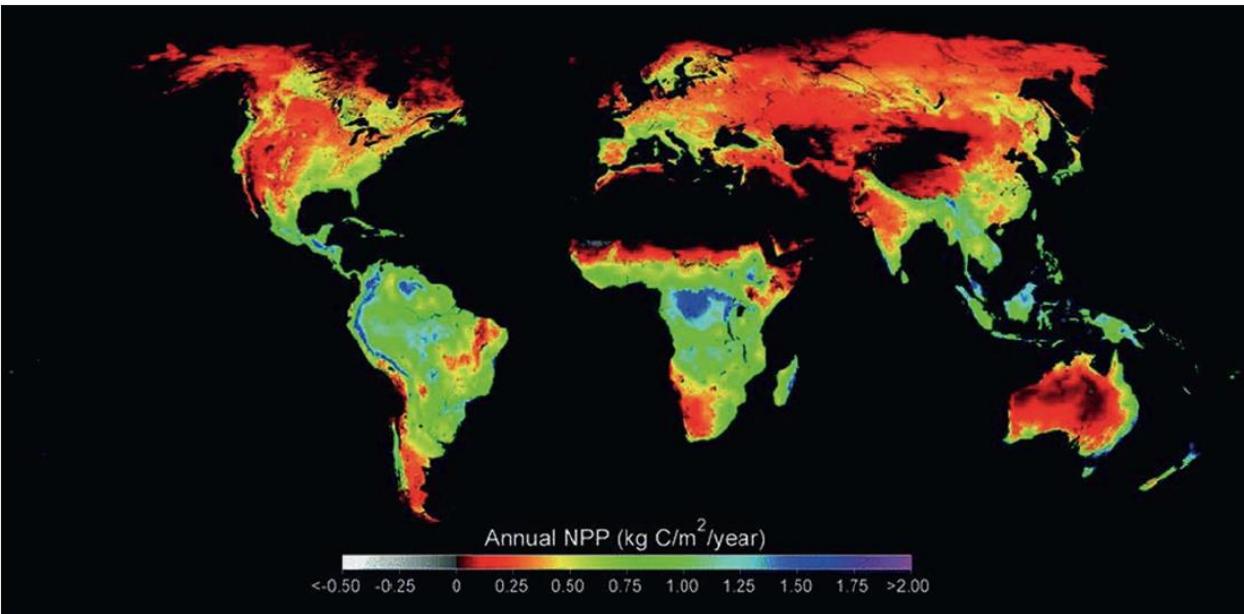


FIGURE 5.12 Distribution of global NPP on land for 2002, computed from MODIS data. Source: From Running et al. 2004, Figure 5 in BioScience, June 2004; used with permission.

TABLE 5.3 Biomass and Net Primary Production in Terrestrial Ecosystems

Biome	Area (10^6 km 2)	NPP (g C m $^{-2}$ yr $^{-1}$)	Total NPP (10^{15} g C yr $^{-1}$)	Biomass (g C m $^{-2}$)	Total plant C pool (10^{15} g C)
Tropical forests	17.5	1250	20.6	19,400	320
Temperate forests	10.4	775	7.6	13,350	130
Boreal forests	13.7	190	2.4	4150	54
Mediterranean shrublands	2.8	500	1.3	6000	16
Tropical savannas/grasslands	27.6	540	14.0	2850	74
Temperate grasslands	15.0	375	5.3	375	6
Deserts	27.7	125	3.3	350	9
Arctic tundra	5.6	90	0.5	325	2
Crops	13.5	305	3.9	305	4
Ice	15.5				
Total	149.3		58.9		615

From data compiled by Saugier et al. 2001, assuming a 50% carbon content in plant tissues.



FIGURE 5.15 The Free-Air CO₂ Enrichment experiment in Duke Forest in central North Carolina. Each plot is 30 m in diameter and surrounded by 16 towers, which emit CO₂ so as to maintain a specified concentration in the cylindrical volume of the plot to the height of the forest canopy. All other factors, including soil fertility, are allowed to vary naturally in the control and experimental plots.

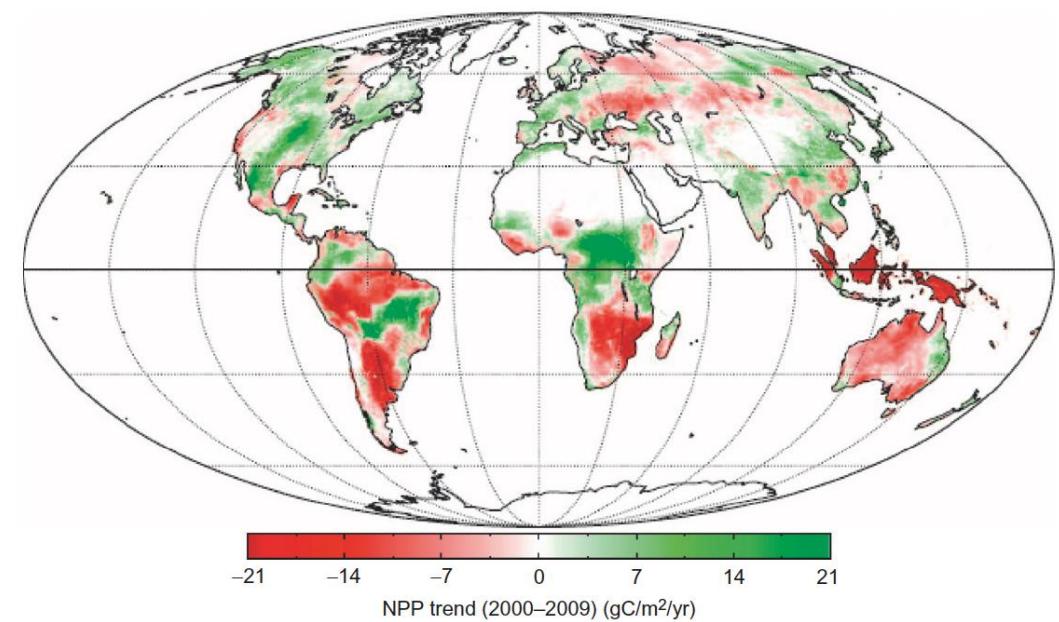


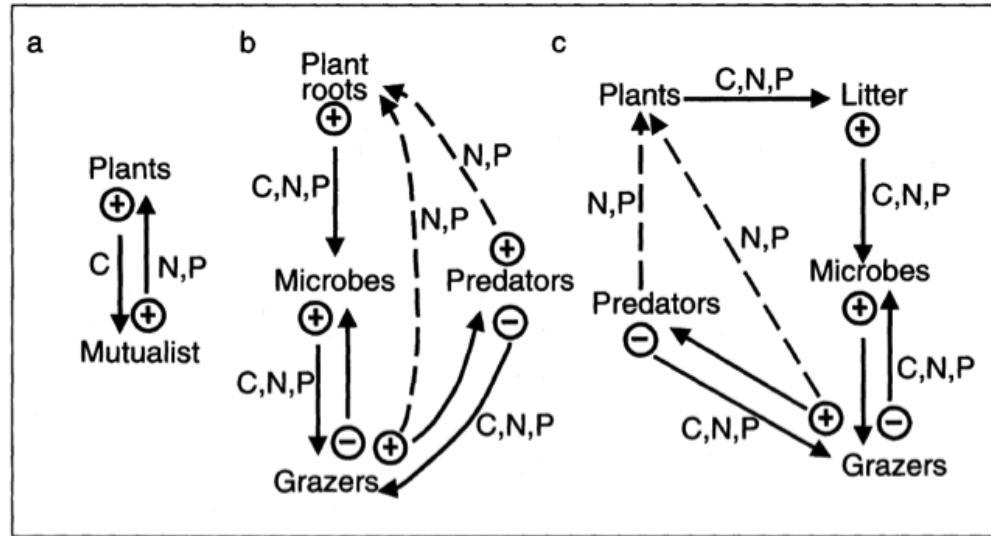
FIGURE 5.16 Change in terrestrial NPP from 2000 to 2009 from MODIS. Source: From Zhao and Running 2010. Used with permission of the American Association for the Advancement of Science.

Soil Fauna

Function

- Comminution
- Dissemination
- Trophic Interactions

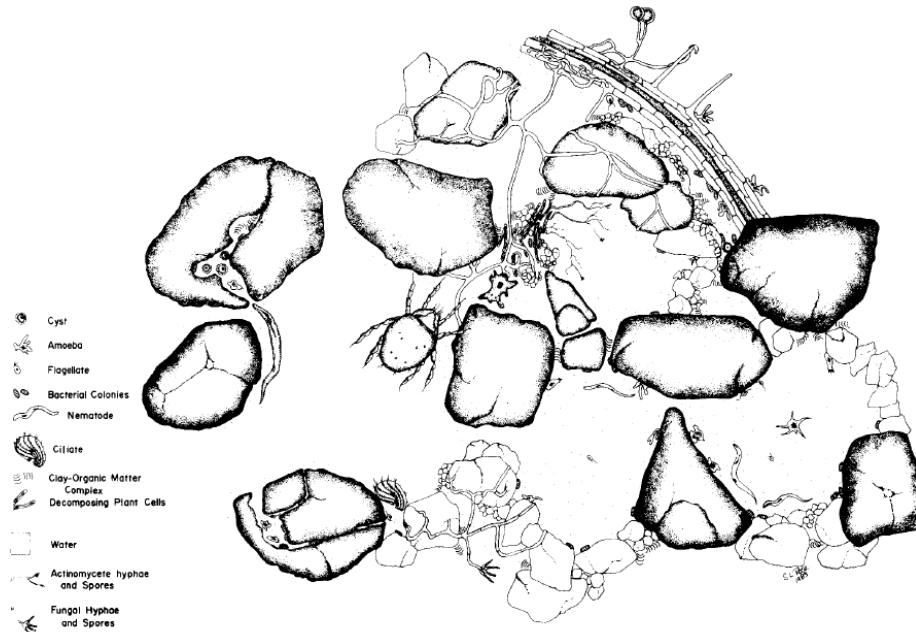




A. Rhizosphere Mutualisms

B. Rhizosphere Trophic Interactions

C. Litter Layer



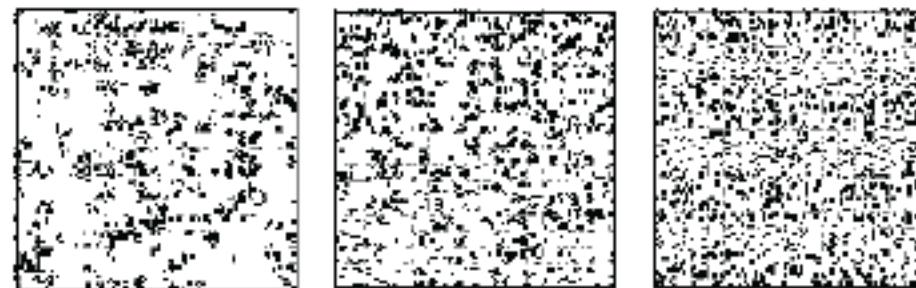
COMMINUTION

- Fragmentation
- Increased surface area
- Leaching of compounds
- C:N



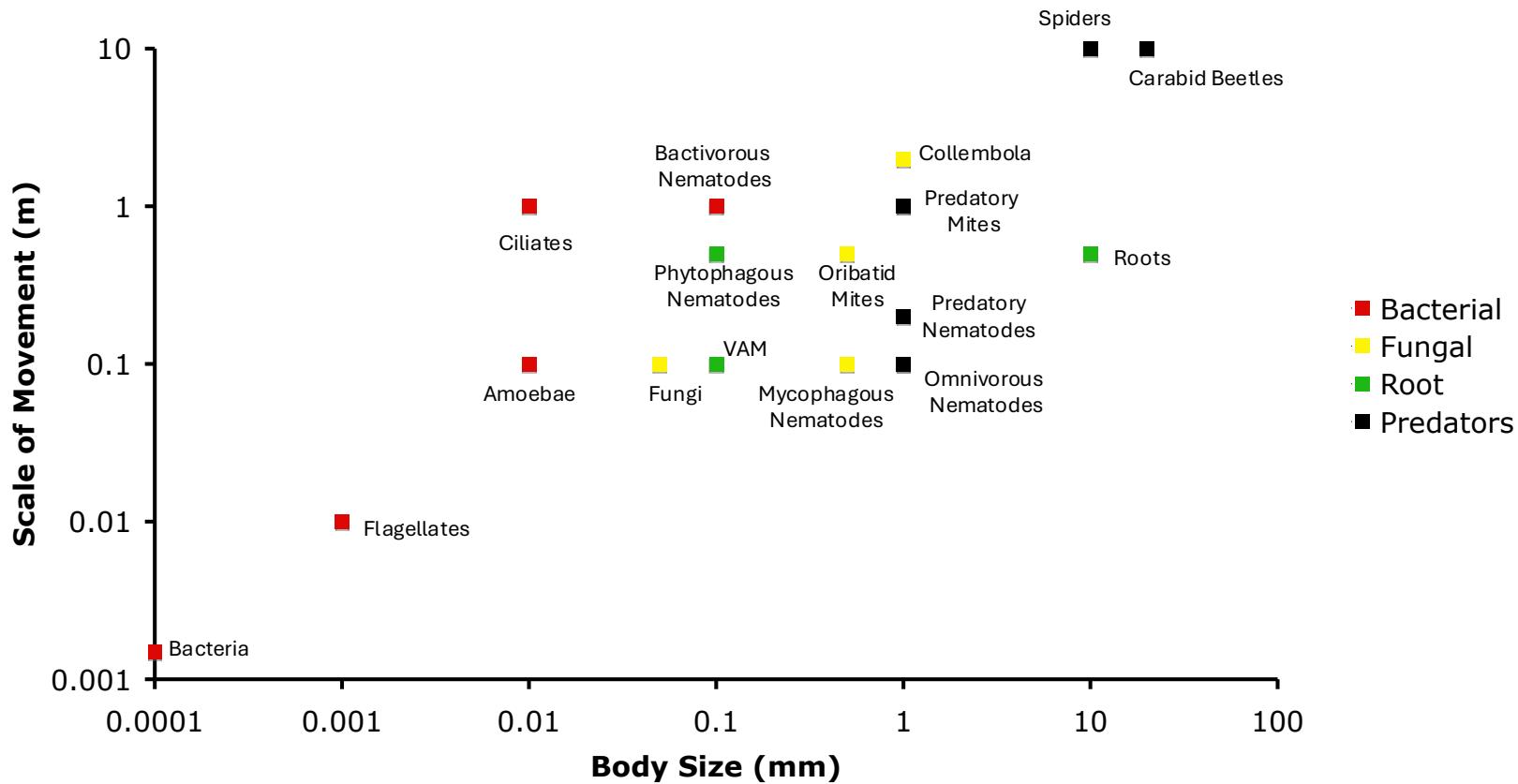
DISSEMINATION

- Dispersal
- Nutrients and Water

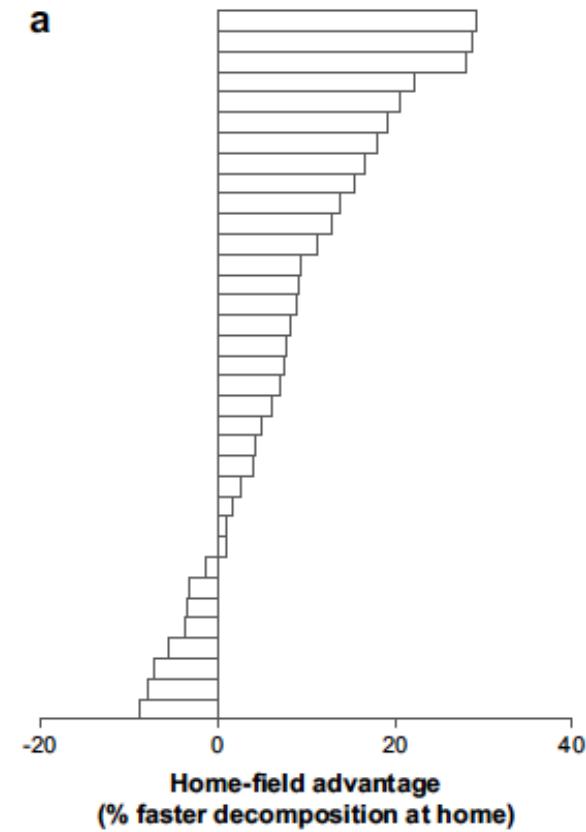
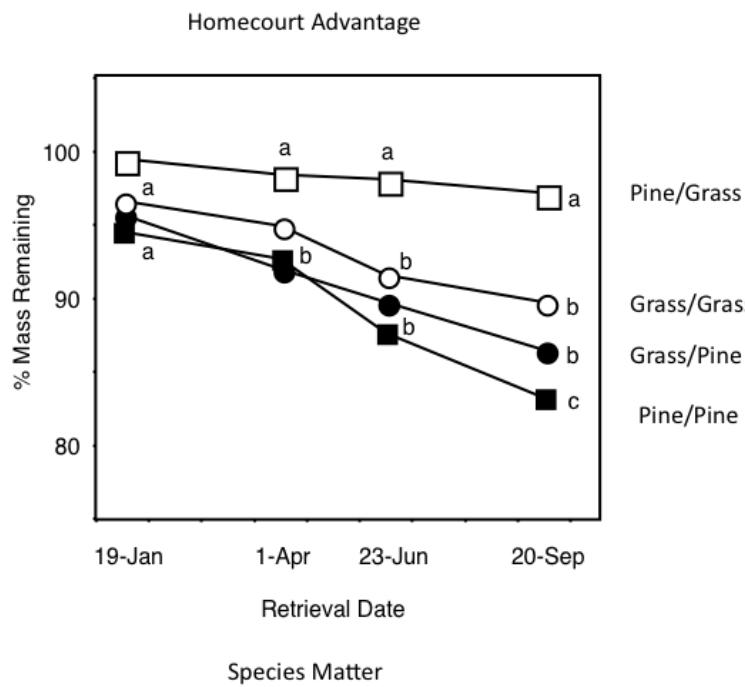
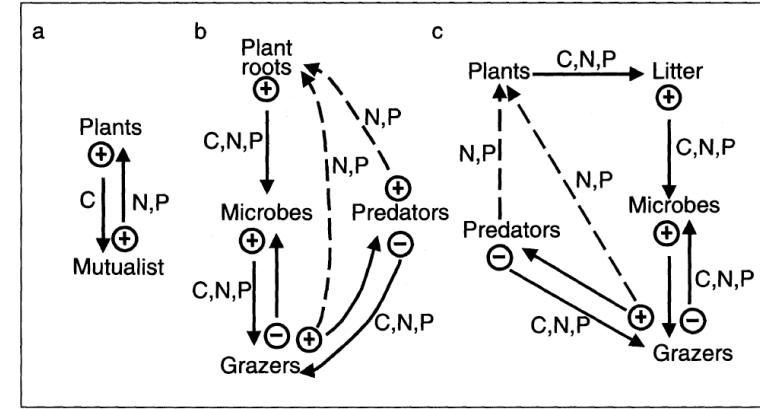


→ Increasing Contact

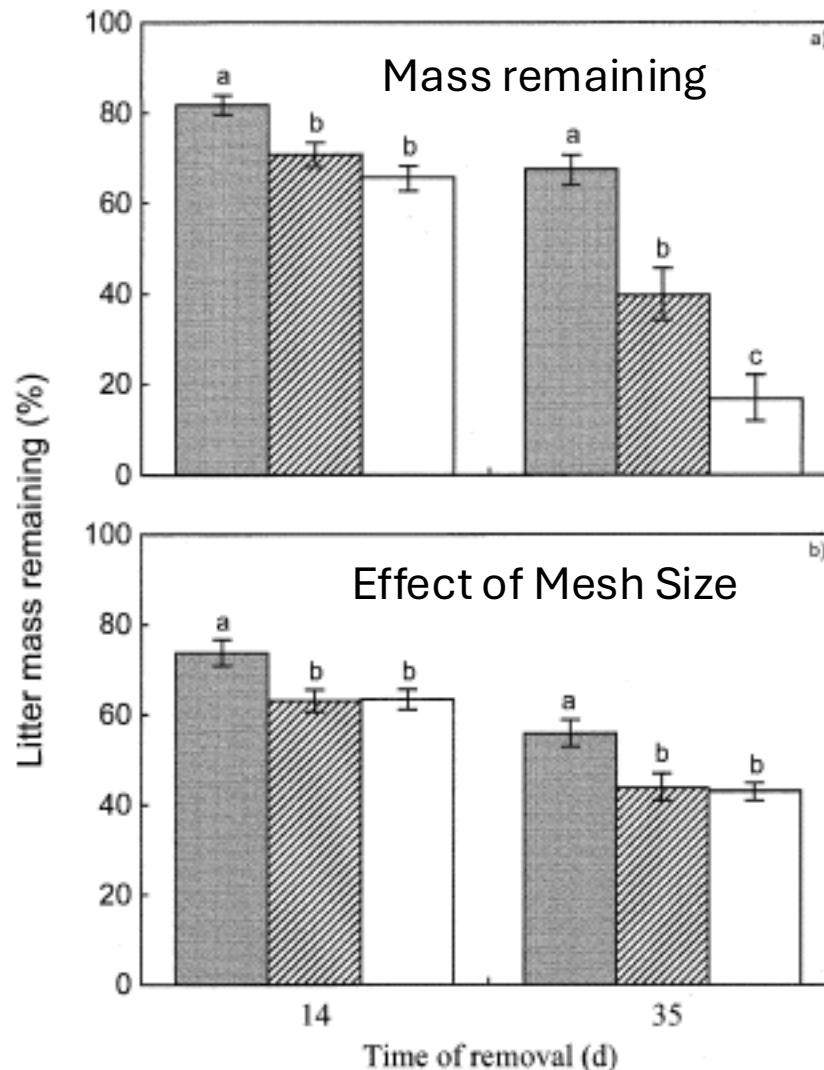
Dissemination



Litter and Decomposition



Decomposition



TROPHIC INTERACTIONS

