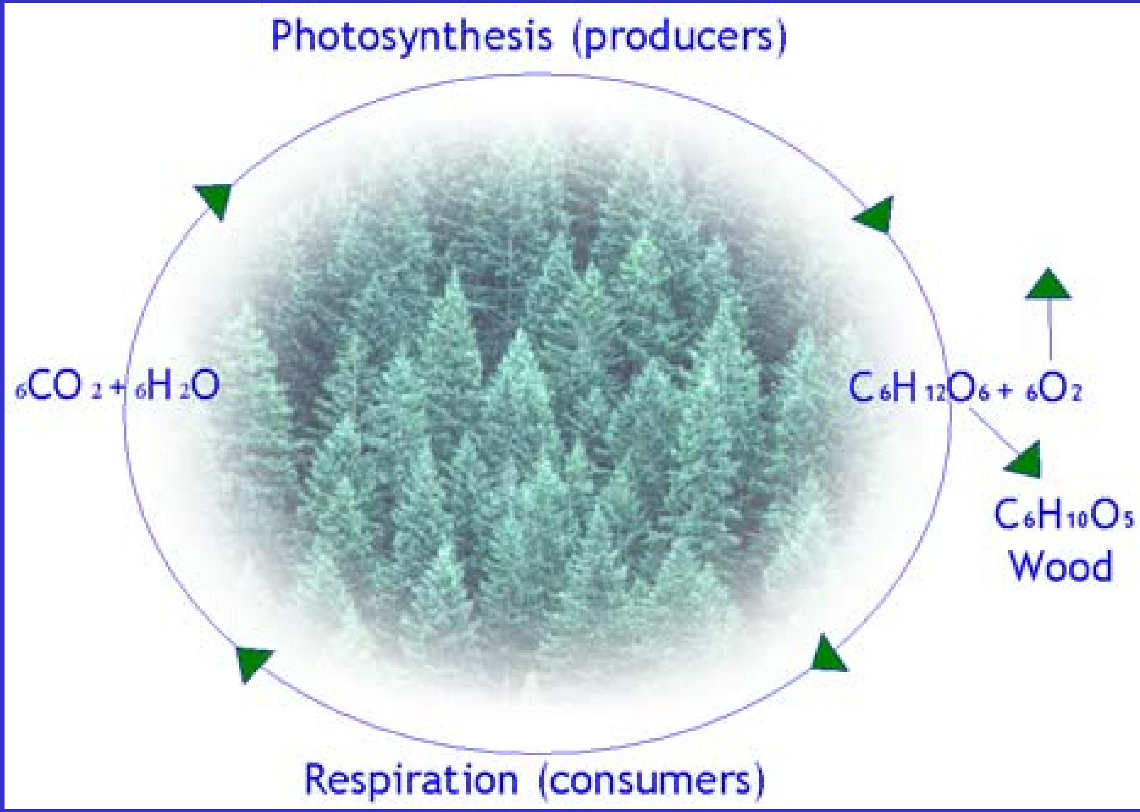
Primary Production and Respiration on Land

Production

Respiration

Decomposition



Photosynthesis: $CO_2 + H_2O + \text{energy} = (CH_2O) + O_2$

Respiration: $(CH_2O) + O_2 = CO_2 + H_2O + \text{energy}$

Carbon balance of ecosystems

GPP = Gross primary productivity

= Total ecosystem photosynthesis

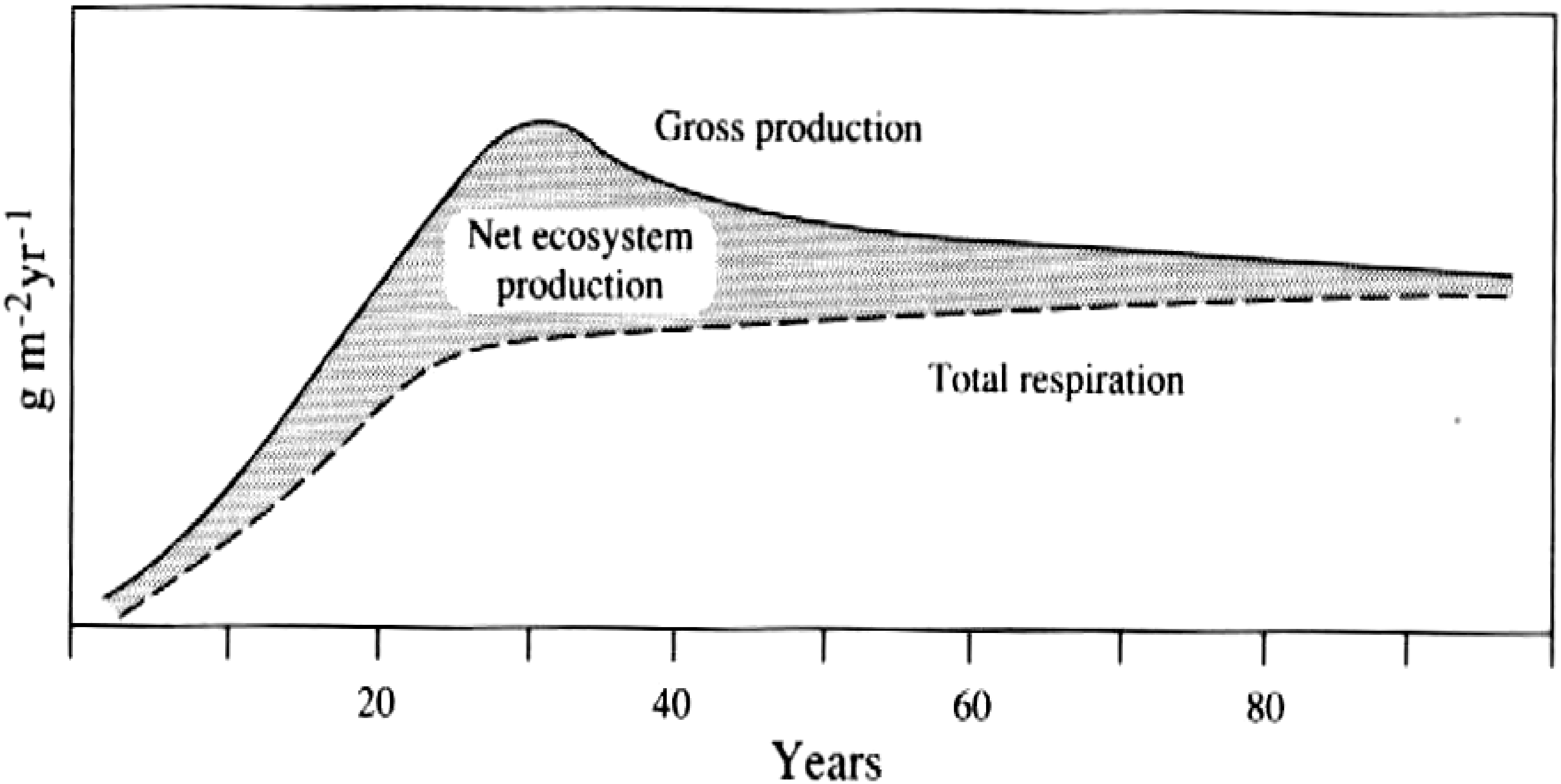
NPP = Net primary productivity

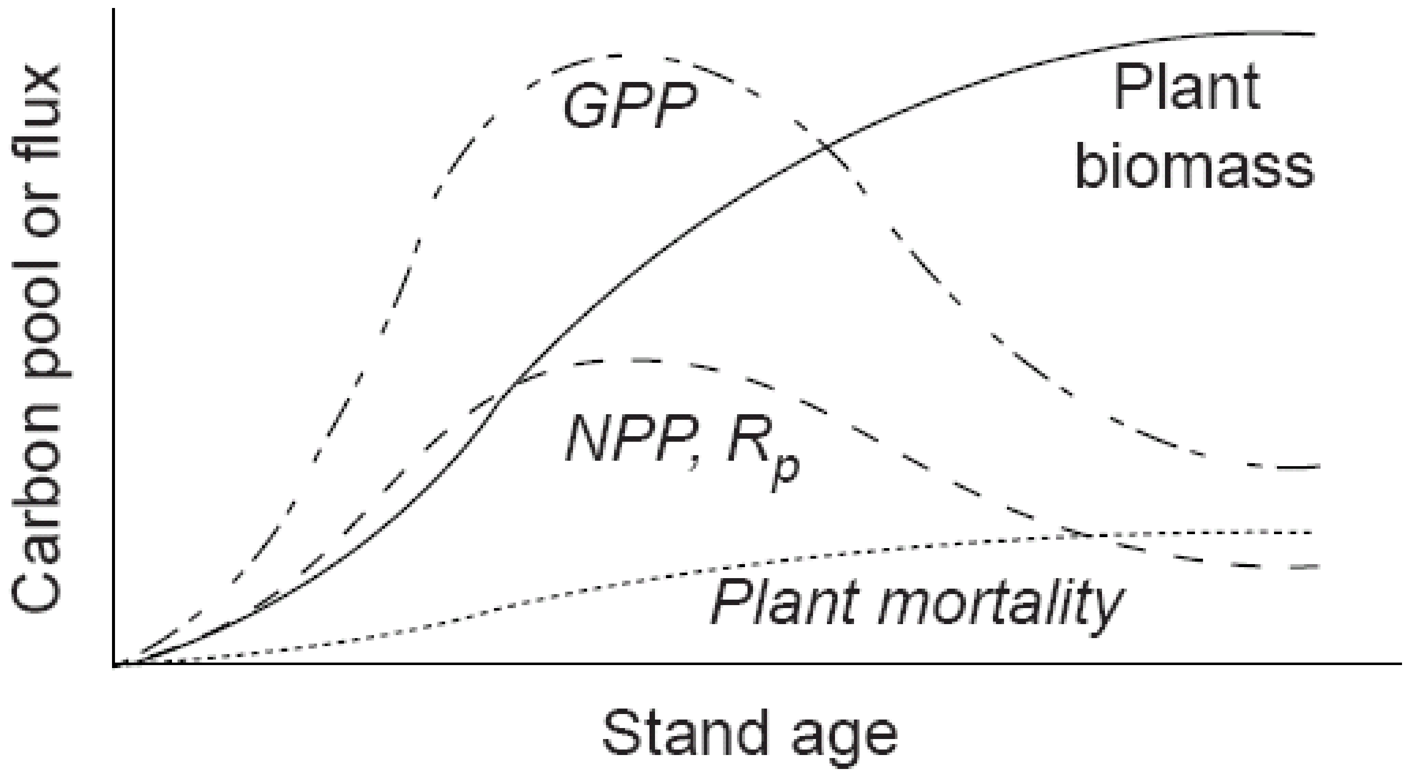
= GPP - R_{plant} = wood, etc.

NEP = Net ecosystem productivity

= NPP - R_{hetero} ~ 0

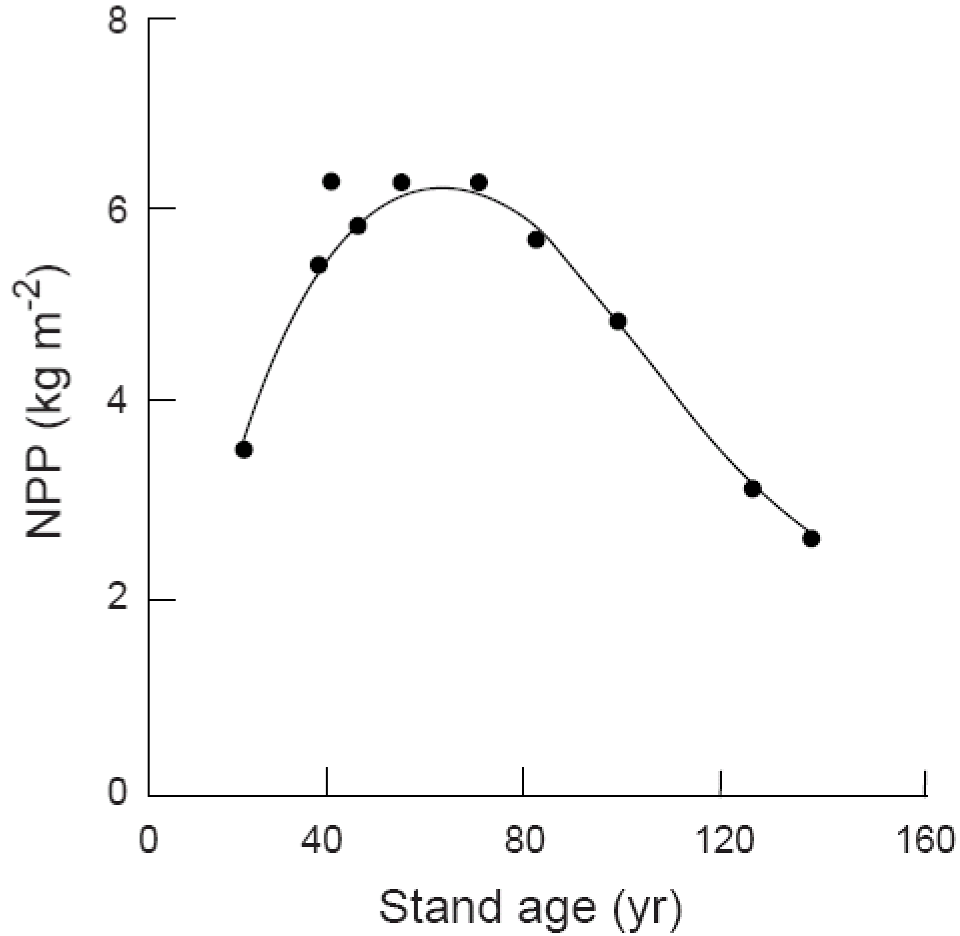
Ecosystem production





Idealized patterns of successional change in plant biomass, NPP, plant respiration (R_p), and plant mortality of a forest. NPP often reaches a peak in mid-succession, and both production and respiration decline in late succession.

From: Chapin et al. 2002



Successional changes in aboveground spruce production in eastern Russia. Modified from (Ryan et al. 1997). NPP declines after the forest reaches maximum LAI at about 60 years of age.

From: Chapin et al. 2002

Factors limiting production on land:

- Temperature
- Sun light
- Precipitation
- Nutrients
- LAI
- CO_2

Temperature

$$\text{b) } NPP_{MAT(°C)} = \frac{17.6243}{(1+e^{(1.3496 - 0.071514[MAT])})}$$

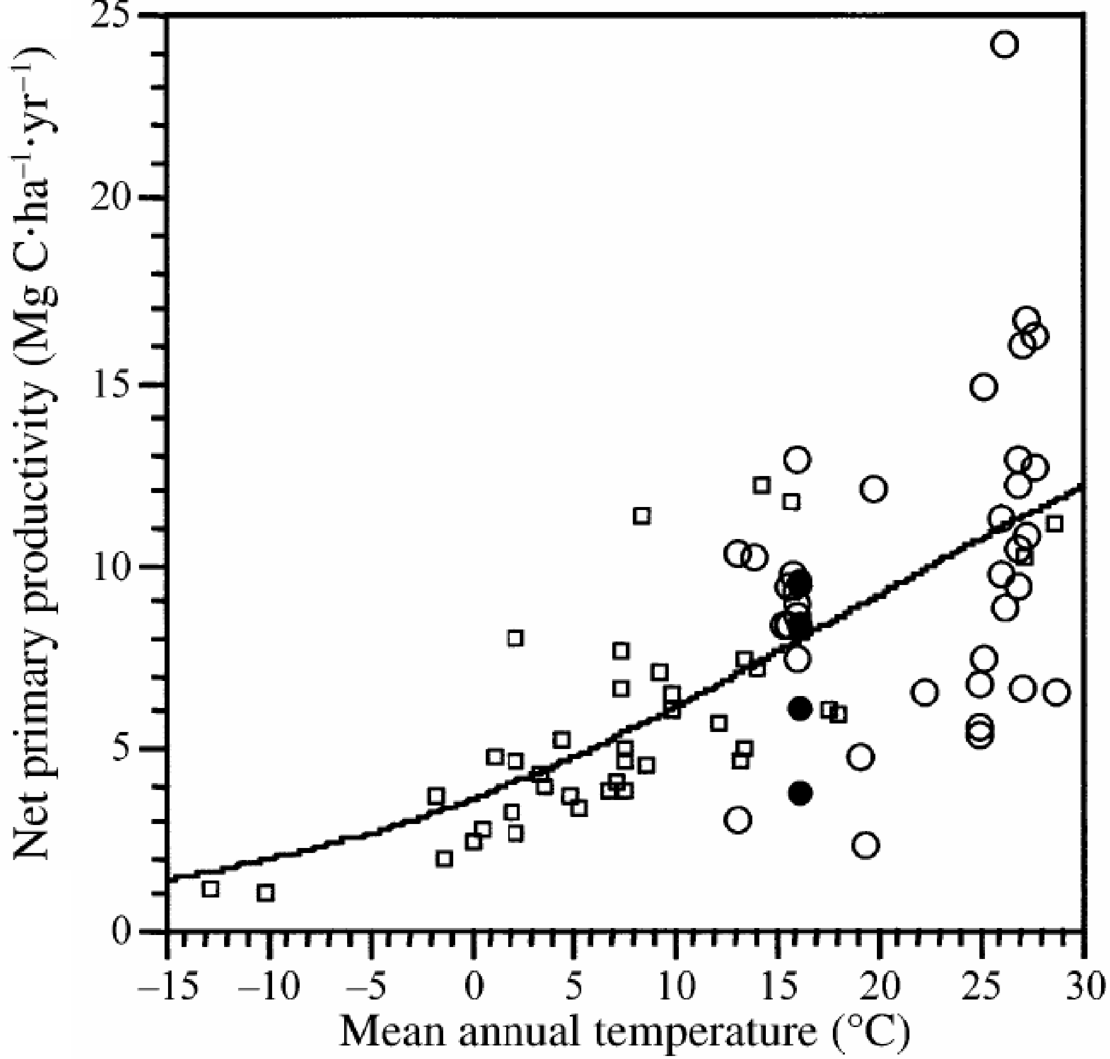
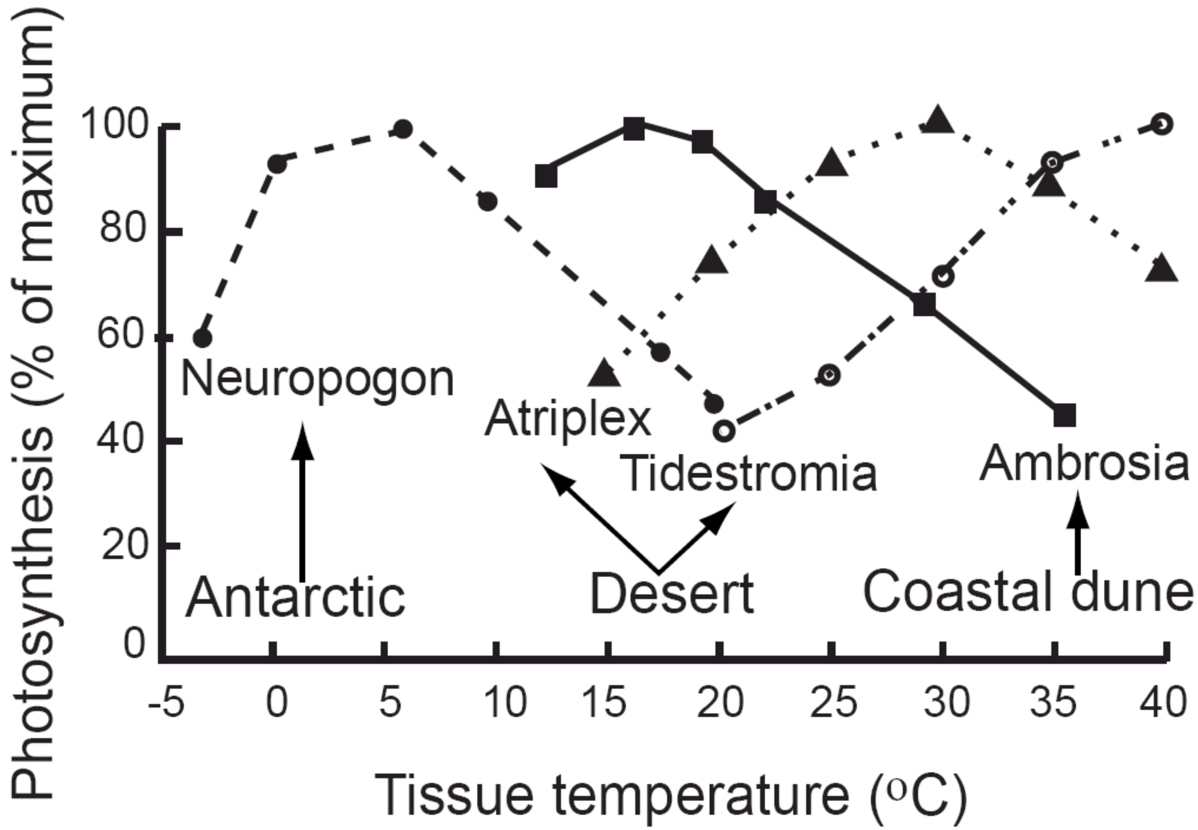
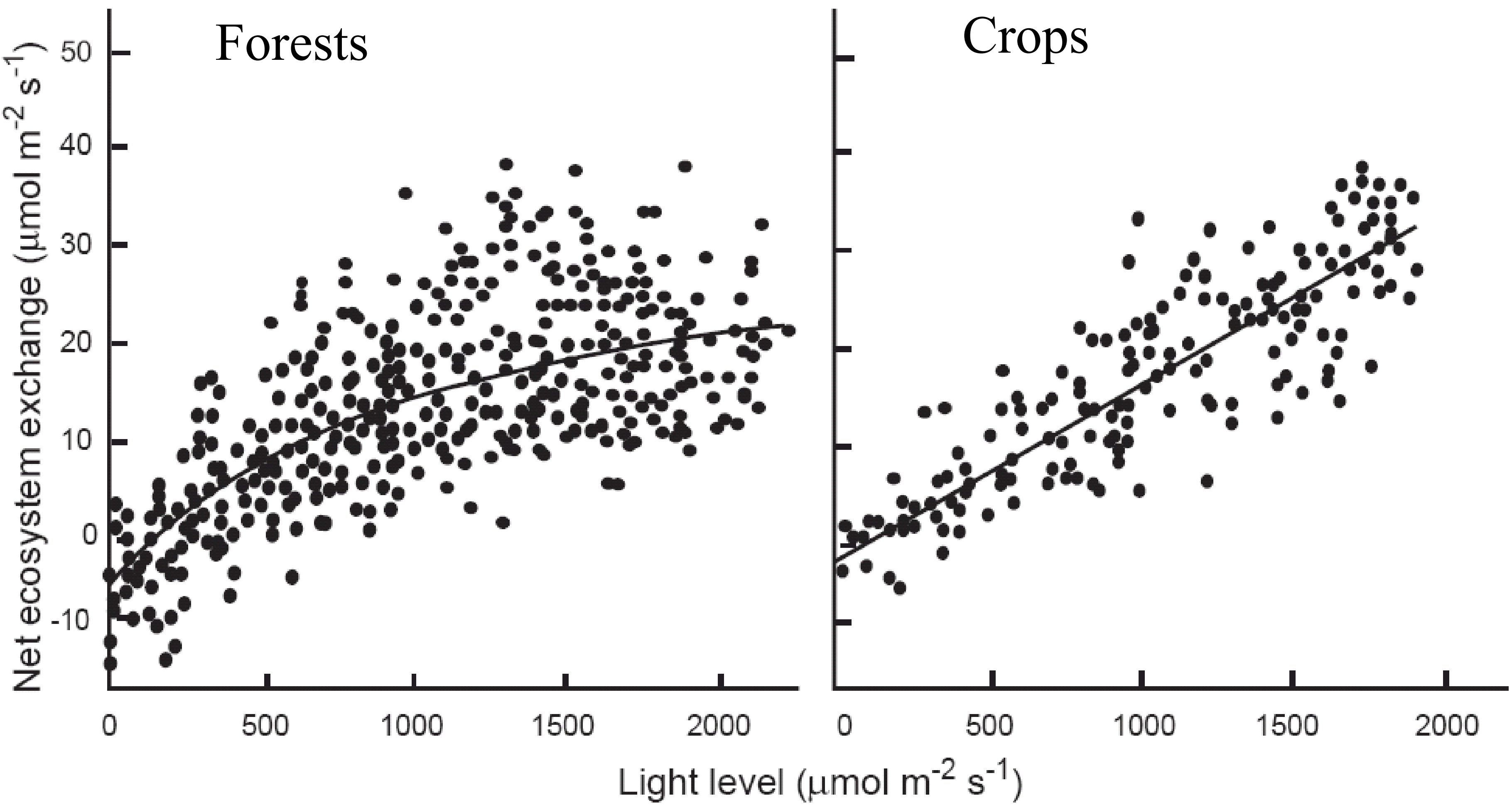


FIGURE 5.13 NPP in world forests versus mean annual temperature. *Soruce: From Schuur (2003). Used with permission of the Ecological Society of America.*



Temperature response of photosynthesis in plants from contrasting temperature regimes (Mooney 1986). Species include antarctic lichen (*Neuropogon acromelanus*), a cool coastal dune plant (*Ambrosia chamissonis*), an evergreen desert shrub (*Atriplex hymenelytra*), and a summer-active desert perennial (*Tidestromia oblongifolia*).

Sun Light



Effect of vegetation type and irradiance on net ecosystem exchange (*NEE*) (Ruimy et al. 1996). Left, forests; right, crops. Forests maintain a relatively constant light use efficiency up to 30-50% of full sun, although there is considerable variability. Crops maintain a constant light use efficiency over the entire range of naturally occurring irradiances.

a) $NPP_{MAP(mm)} = \dfrac{0.005212(MAP^{1.12363})}{e^{0.000459532(MAP)}}$

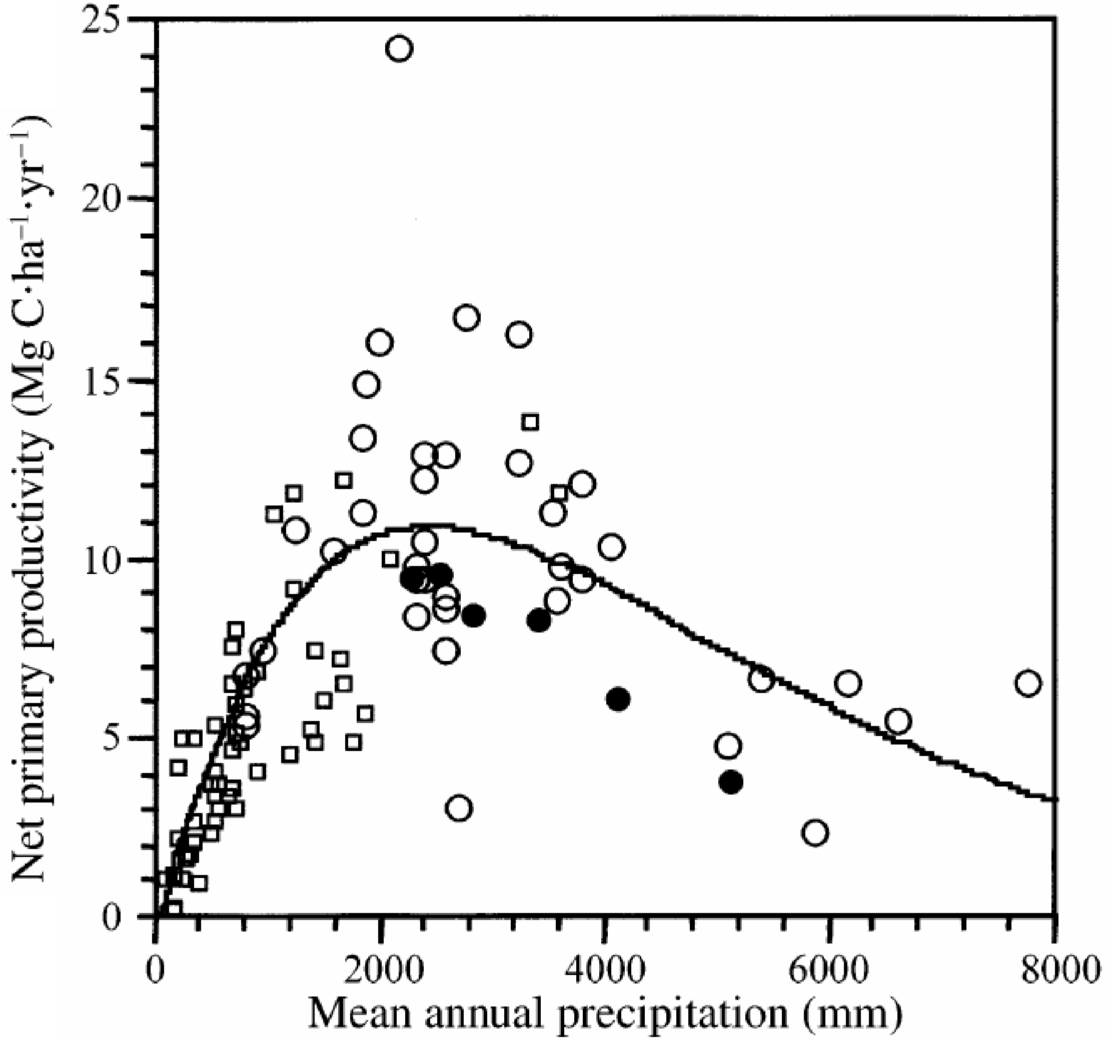


FIGURE 5.14 NPP in world forests versus mean annual precipitation. *Source: From Schuur (2003). Used with the permission of the Ecological Society of America.*

Water Use Efficiency (WUE):

WUE = mmole of CO_2 fixed / moles of H_2O lost

WUE = g of NPP / kg of H_2O used

WUE can be calculated using C and H_2O budgets, or, indirectly use ^{13}C abundance in biomass as indicators.

Nutrient Use Efficiency is a similar concept as WUE.

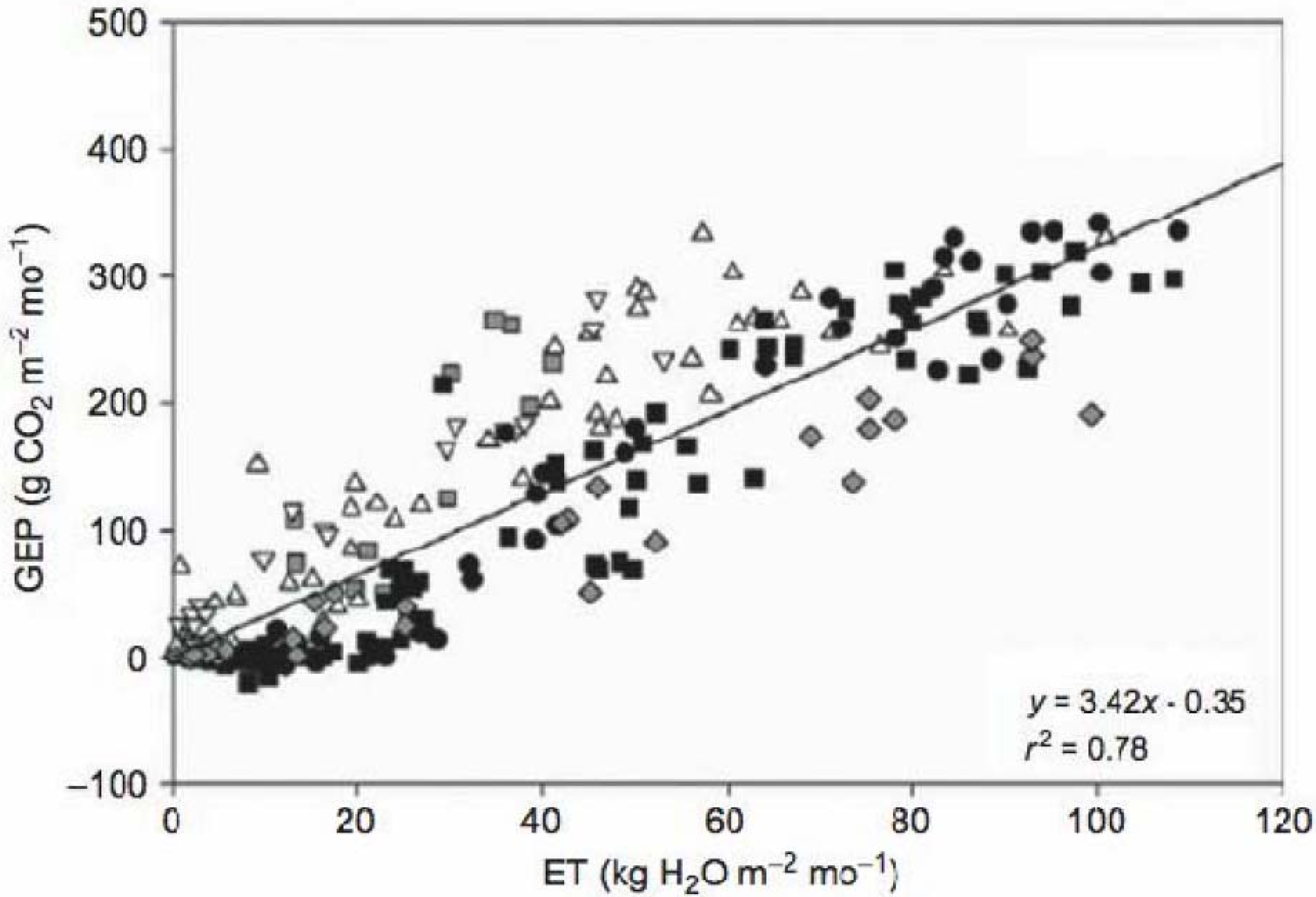
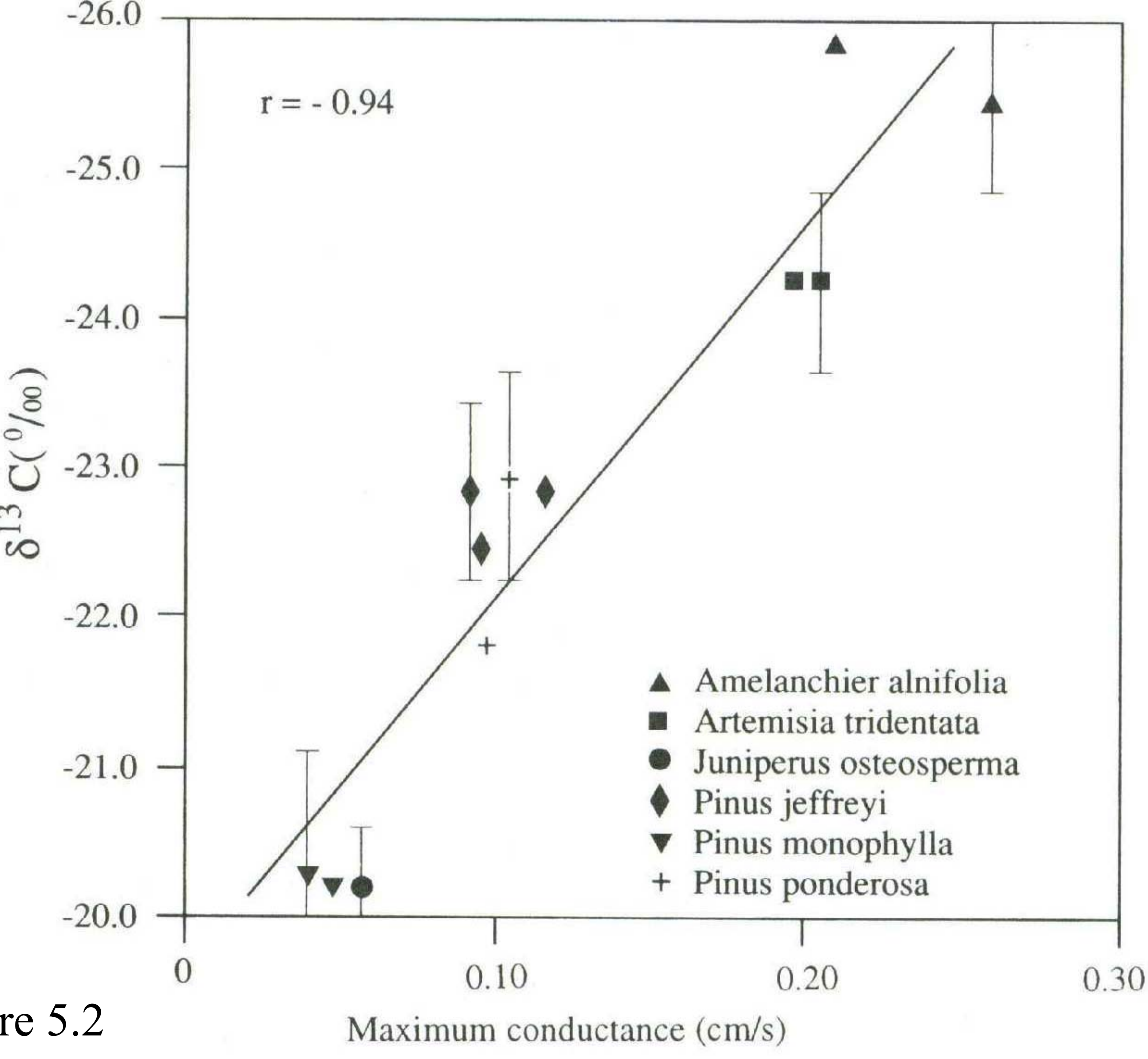


FIGURE 5.8 Monthly gross primary production and evaporation in various temperate deciduous forests, measured by eddy-covariance techniques. The slope of the line is an estimate of water-use efficiency, here equivalent to 1.4 mmol/mol (see Eq. 5.3). *Source: From Law et al. (2002).*



-26.0
-25.0
-24.0
-23.0
-22.0
-21.0
-20.0
r = - 0.94
δ13 C(0/00)
Amelanchier alnifolia
Artemisia tridentata
Juniperus osteosperma
Pinus jeffreyi
Pinus monophylla
Pinus ponderosa
0
0.10
0.20
0.30
Maximum conductance (cm/s)

Figure 5.2

The Delta Notation

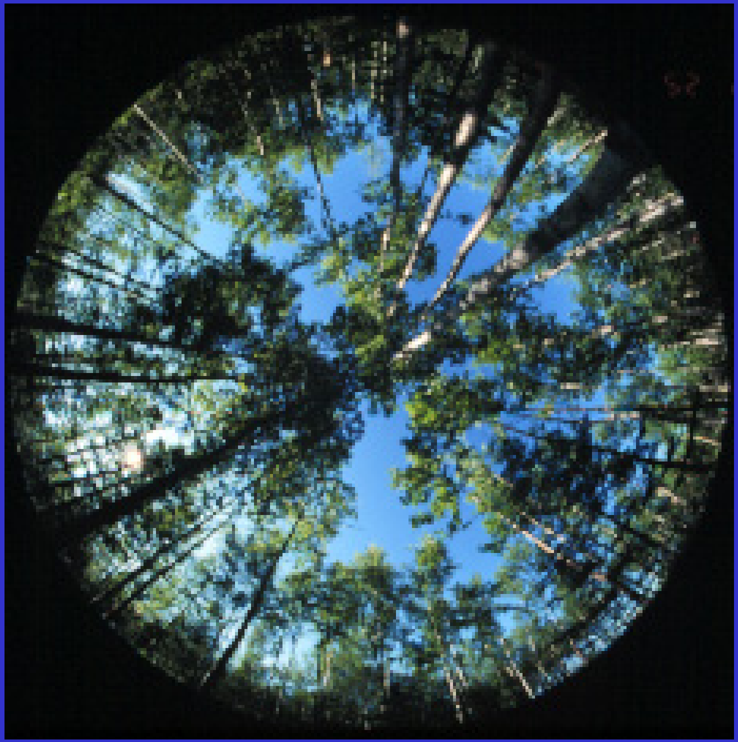
$$\delta^{13}C = [(R_{sample} - R_{std}) / R_{std}] \times 1000$$

R: $^{13}C/^{12}C$

Photosynthetic Pathways of CO_2 fixation in Higher Plants

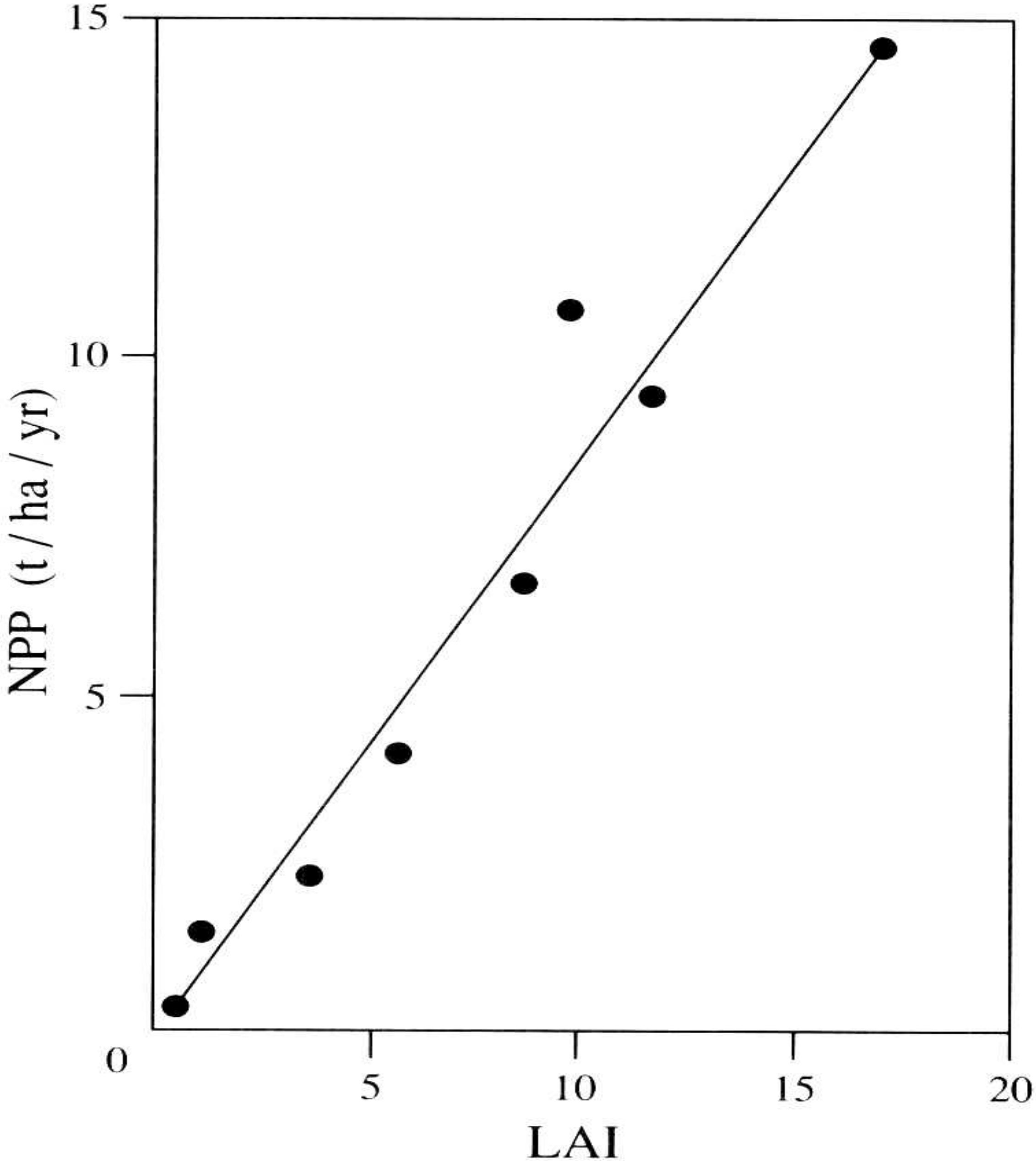
Characteristics	C_3	C_4	CAM*
CO_2 acceptor	RuBP	PEP	In light: RuBP In dark: PEP
First product of photosynthesis	C3 acids (PGA)	C4 acids	In light: PGA In dark: malate
C isotope ratio in photosynthate ($\delta^{13}C$)	**-20 to -40%o**	**-10 to -20 %o**	**-10 to -35 %o**
CO_2-compensation level	30-50 ppm	<10 ppm	In light: 0-200 ppm In dark: <5 ppm
Photosynthetic capacity	slight to high	high to very high	In light: slight In dark: medium
Dry matter production	Medium	High	Low

*CAM: Crassulacean Acid Metabolism



LAI: Leaf Area Index

NPP & LAI



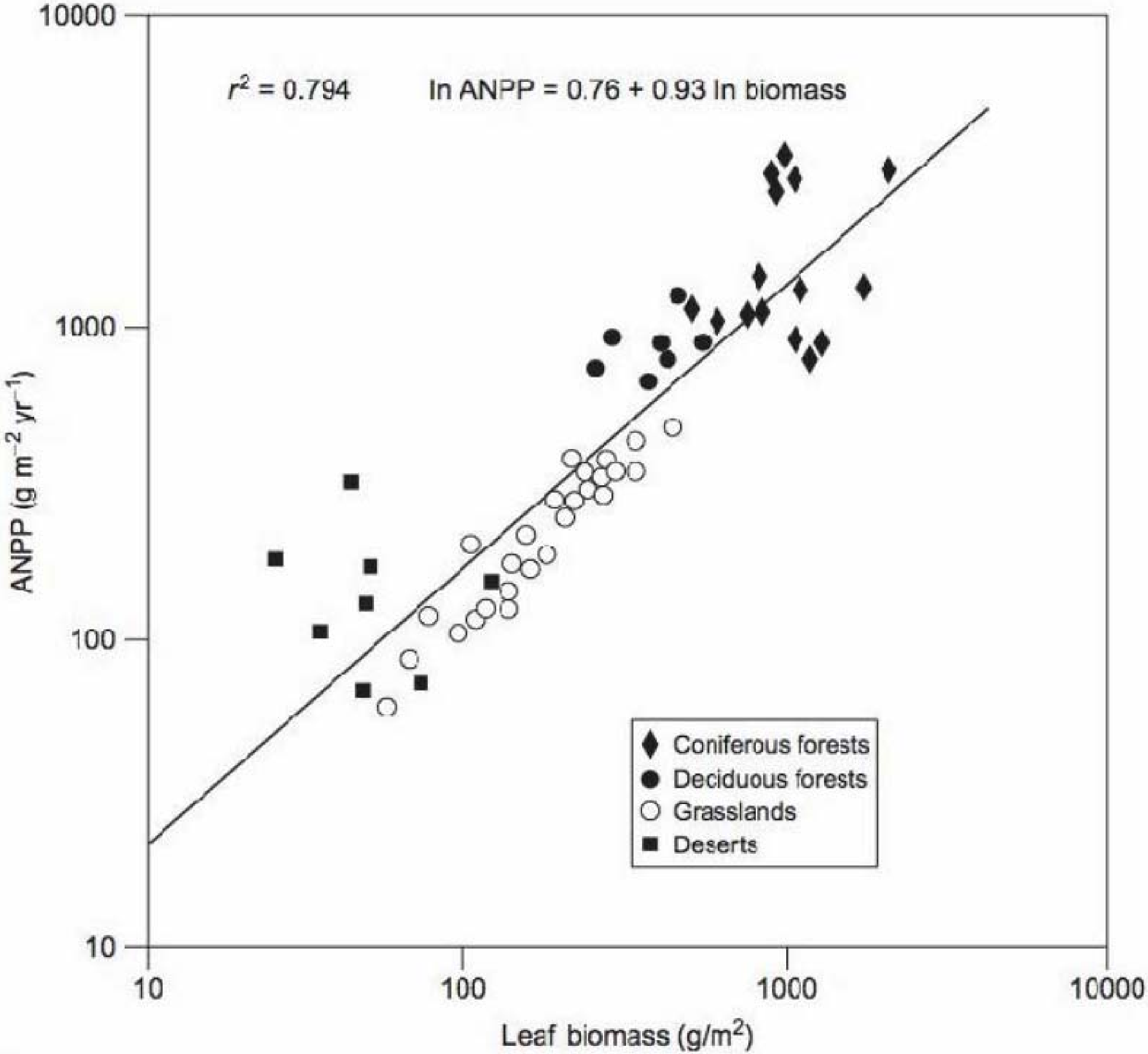


FIGURE 5.6 Using data from a variety of ecosystems in North America, Webb et al. (1983) found a strong relation between the annual aboveground NPP and leaf biomass.

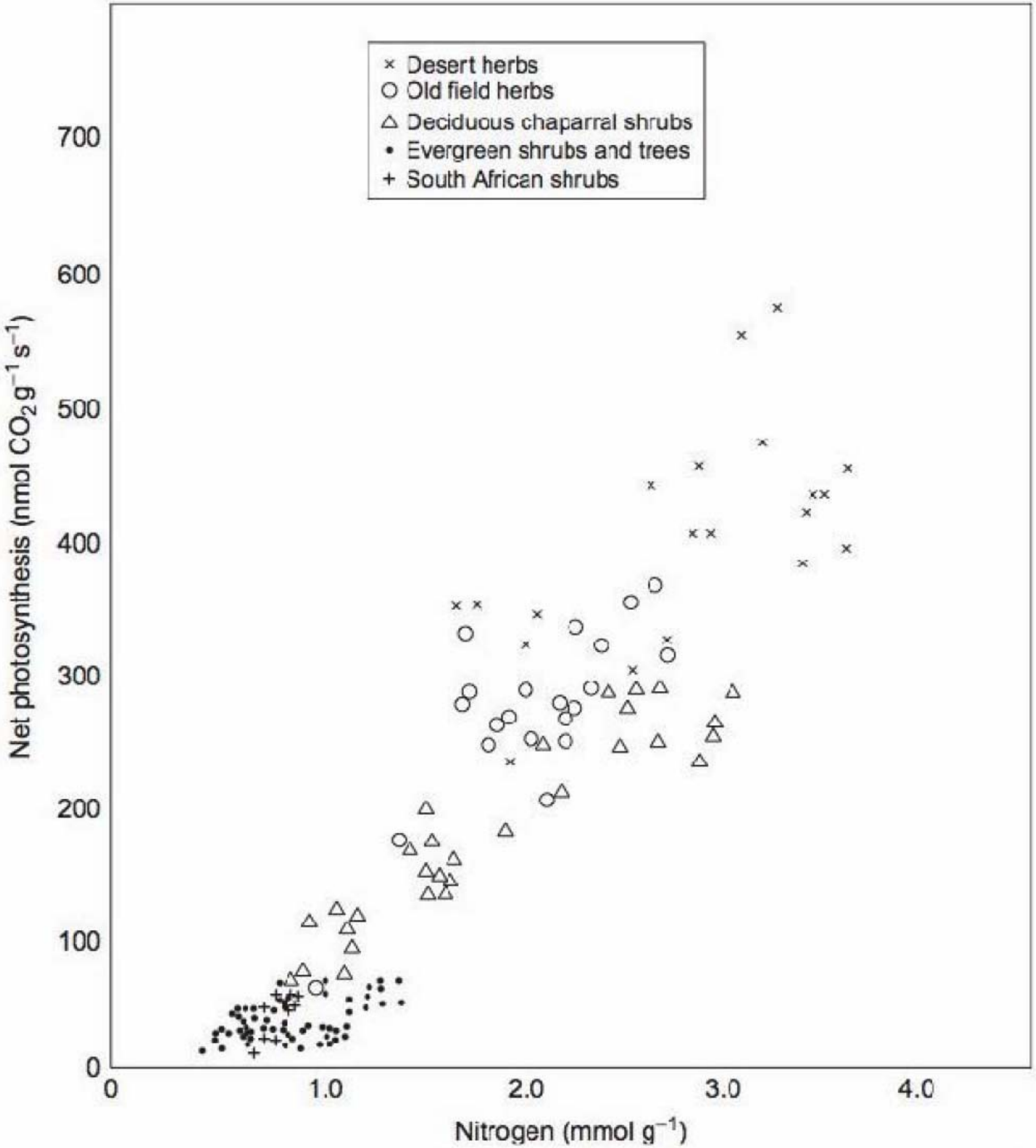
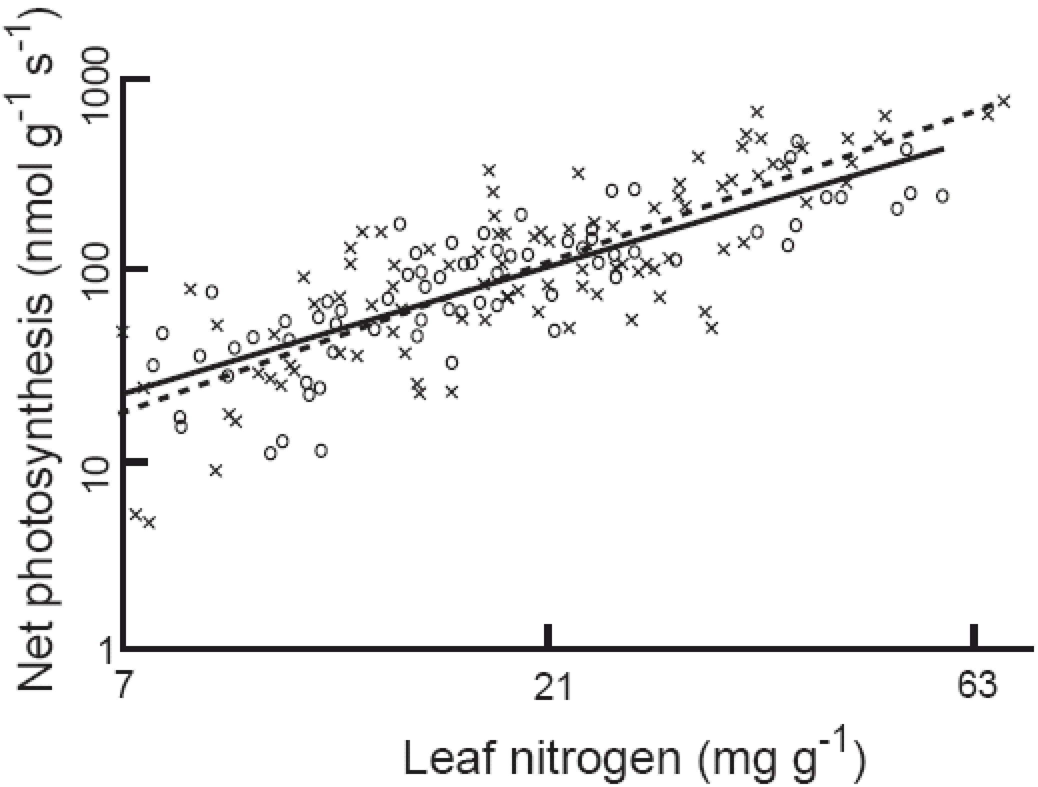
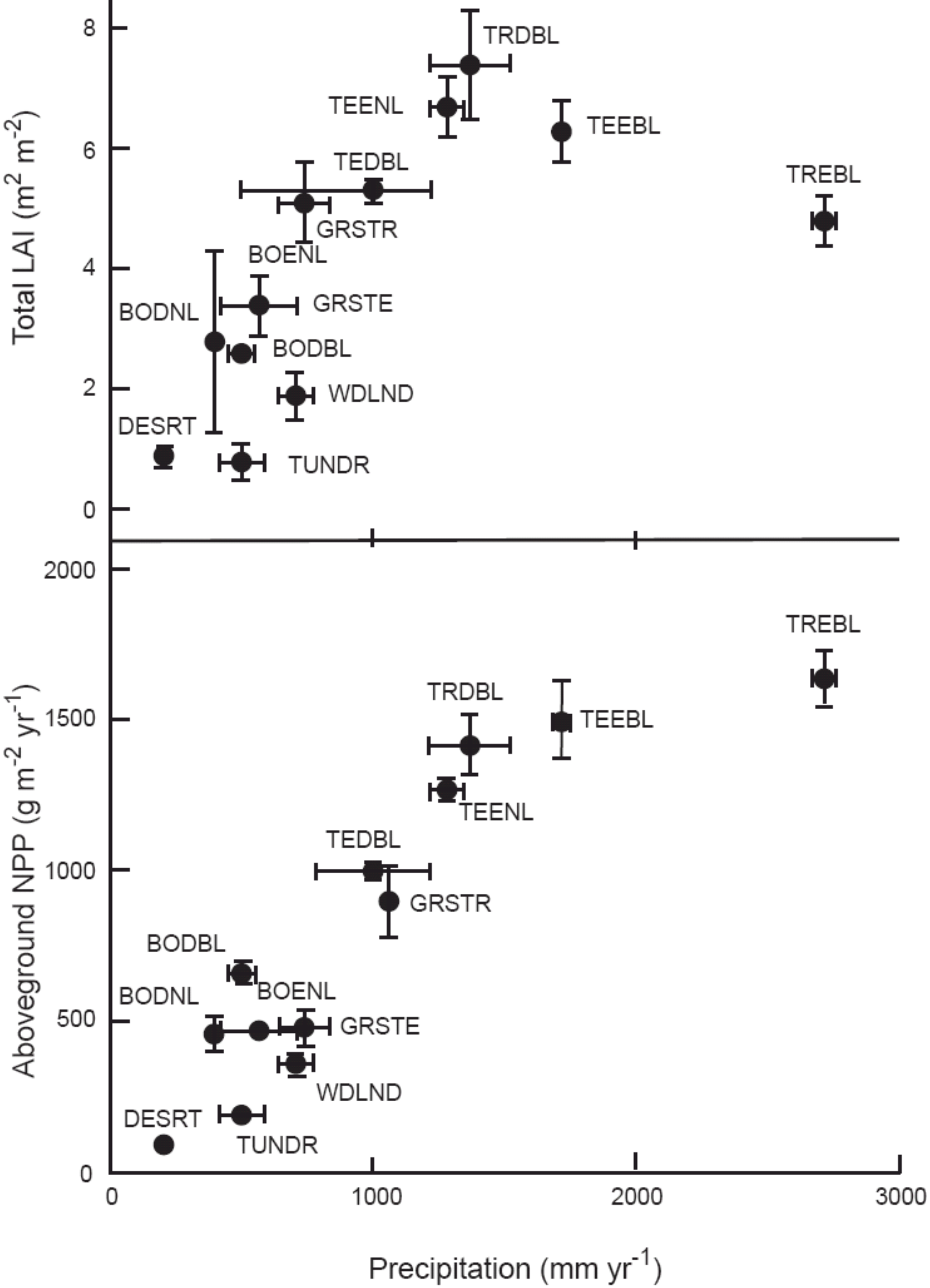


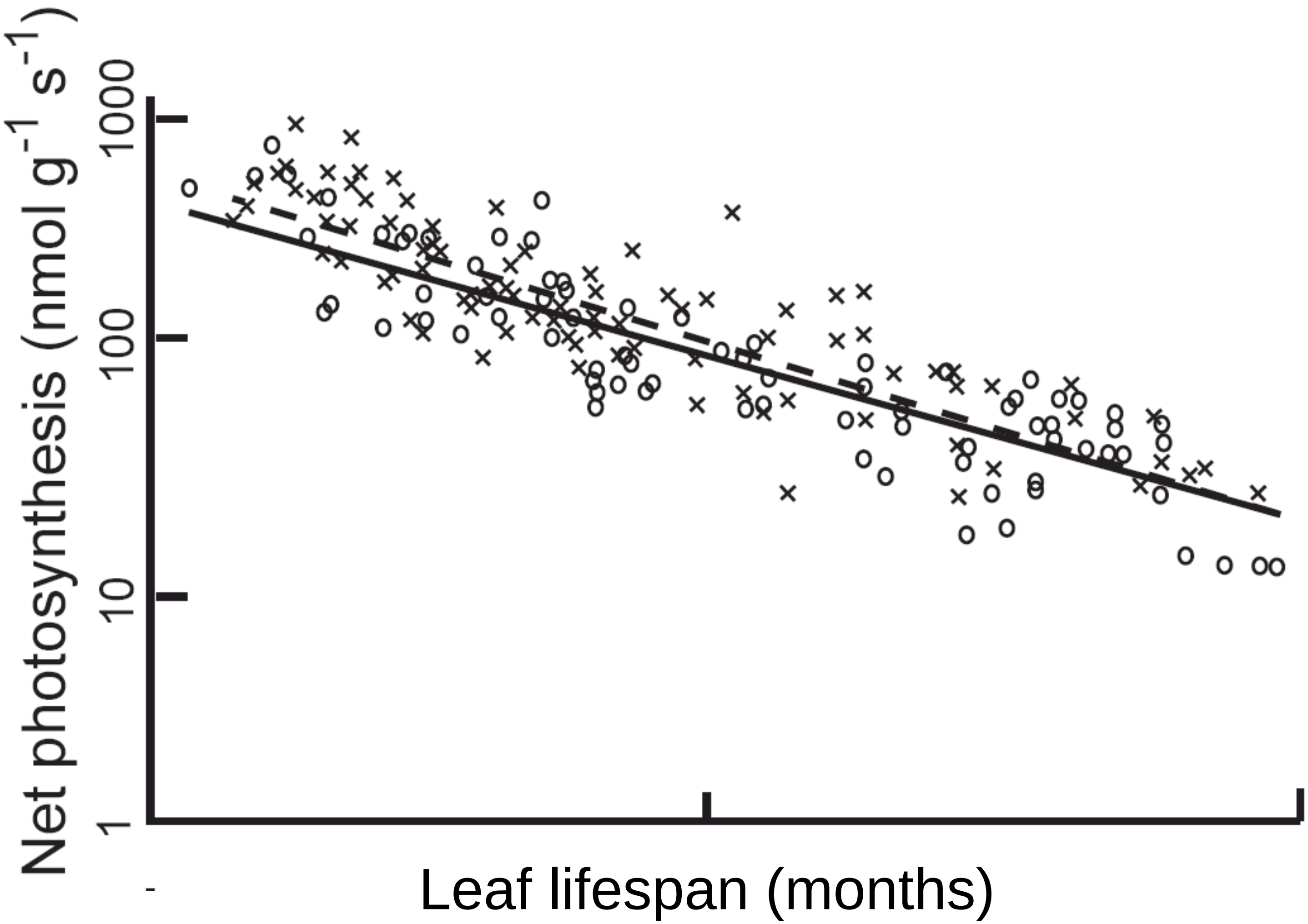
FIGURE 5.3 Relationship between net photosynthesis and leaf nitrogen content among 21 species from different environments. *Source: From Field and Mooney (1986). Used with permission of Cambridge University Press.*



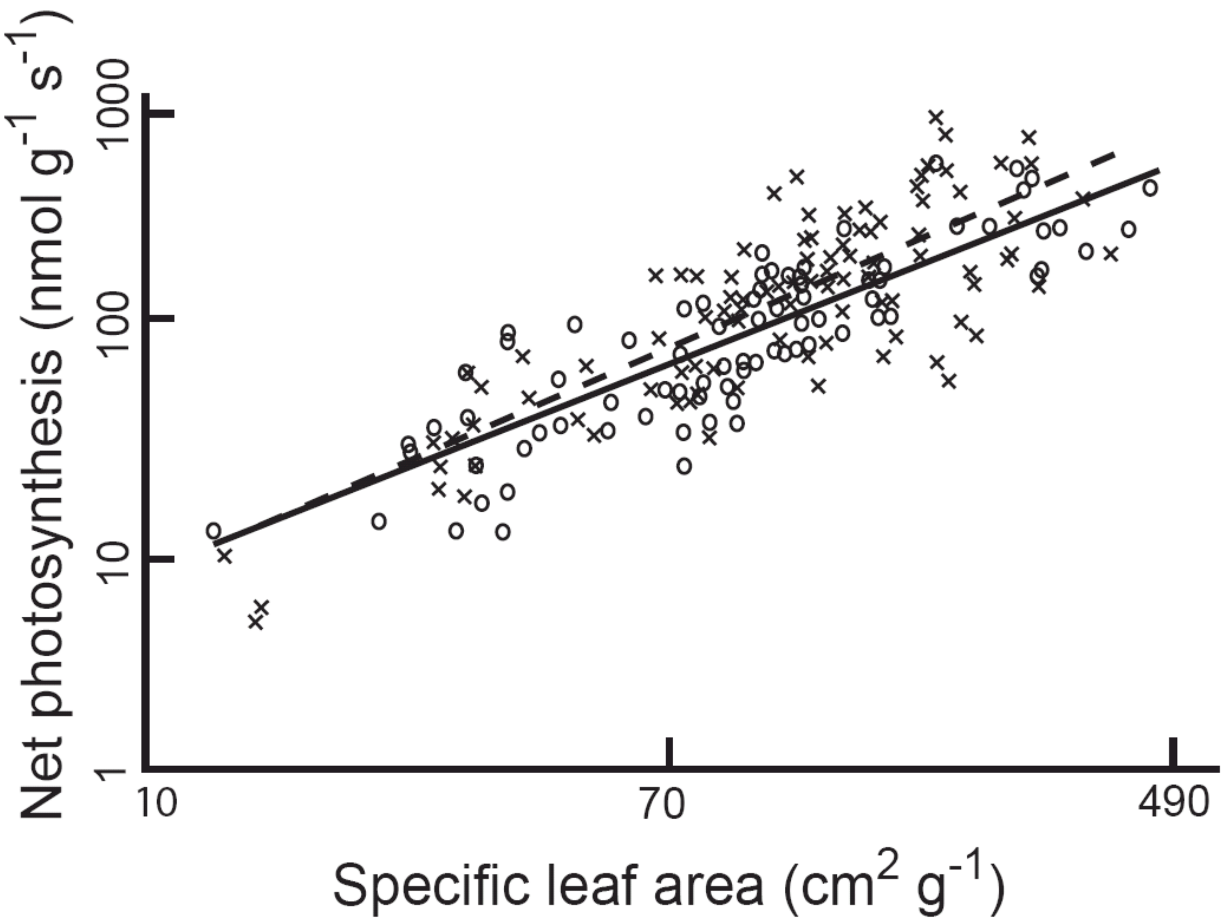
Relationship between leaf nitrogen concentration and maximum photosynthetic capacity for plants from Earth's major biomes (Reich et al. 1997). Circles and the solid regression line are for 11 species from six biomes using a common methodology. Crosses and the dashed regression line are data from the literature.



Leaf area index (LAI) and aboveground net primary production of major biome types as a function of precipitation (Gower 2000).



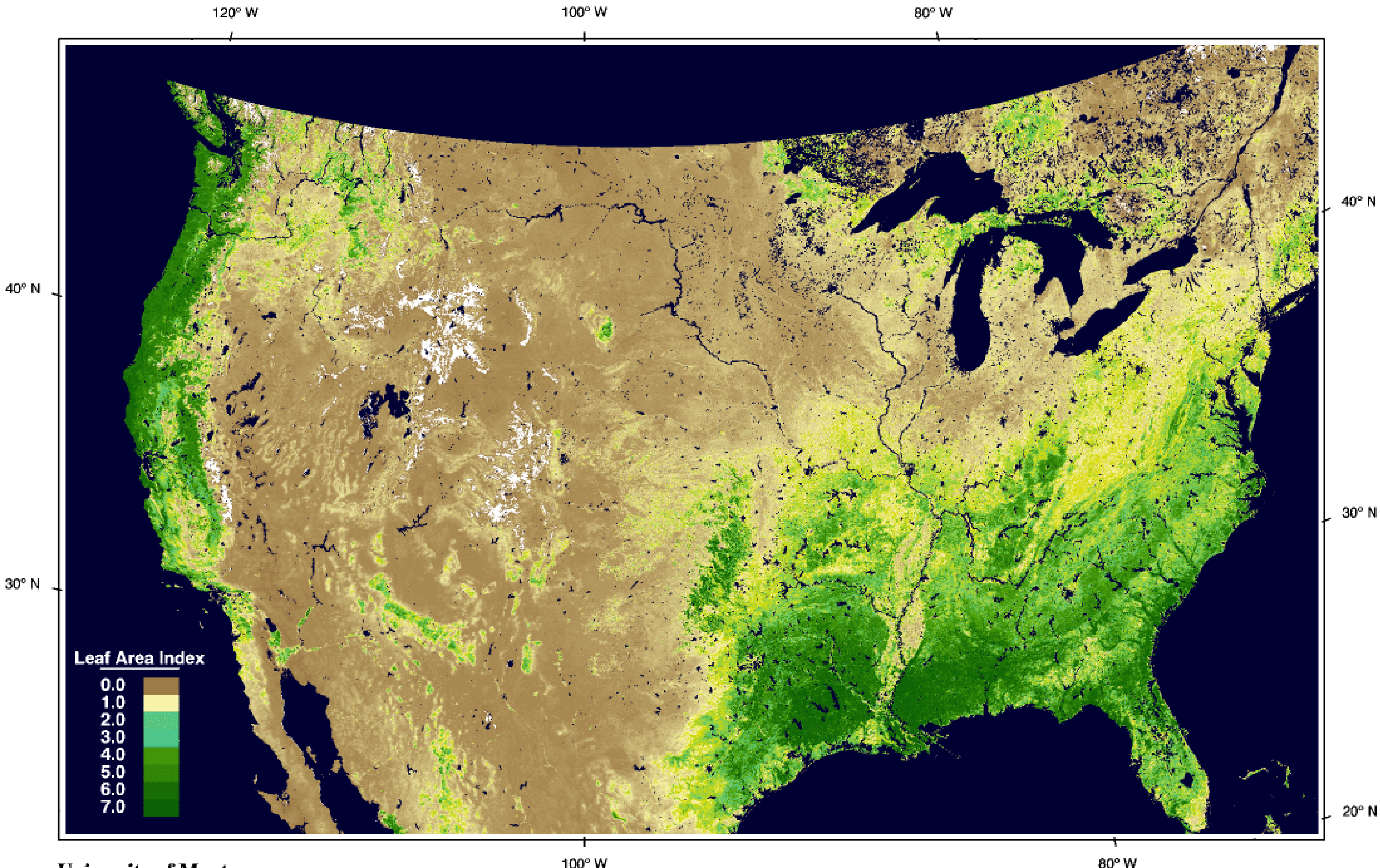
The effect of leaf lifespan on photosynthetic capacity (photosynthetic rate measured under favorable conditions), leaf nitrogen concentration, and specific leaf area (Reich et al. 1997).



The relationship between specific leaf area (SLA) and photosynthetic capacity (Reich et al. 1997). The consistency of this relationship makes it possible to use SLA as an easily measured index of photosynthetic capacity.

MODIS Leaf Area Index

Composite March 24 - April 8, 2000



University of Montana
Science Compute Facility

MODIS: Moderate-resolution Imaging Spectroradiometer

Duke's

FACE

site

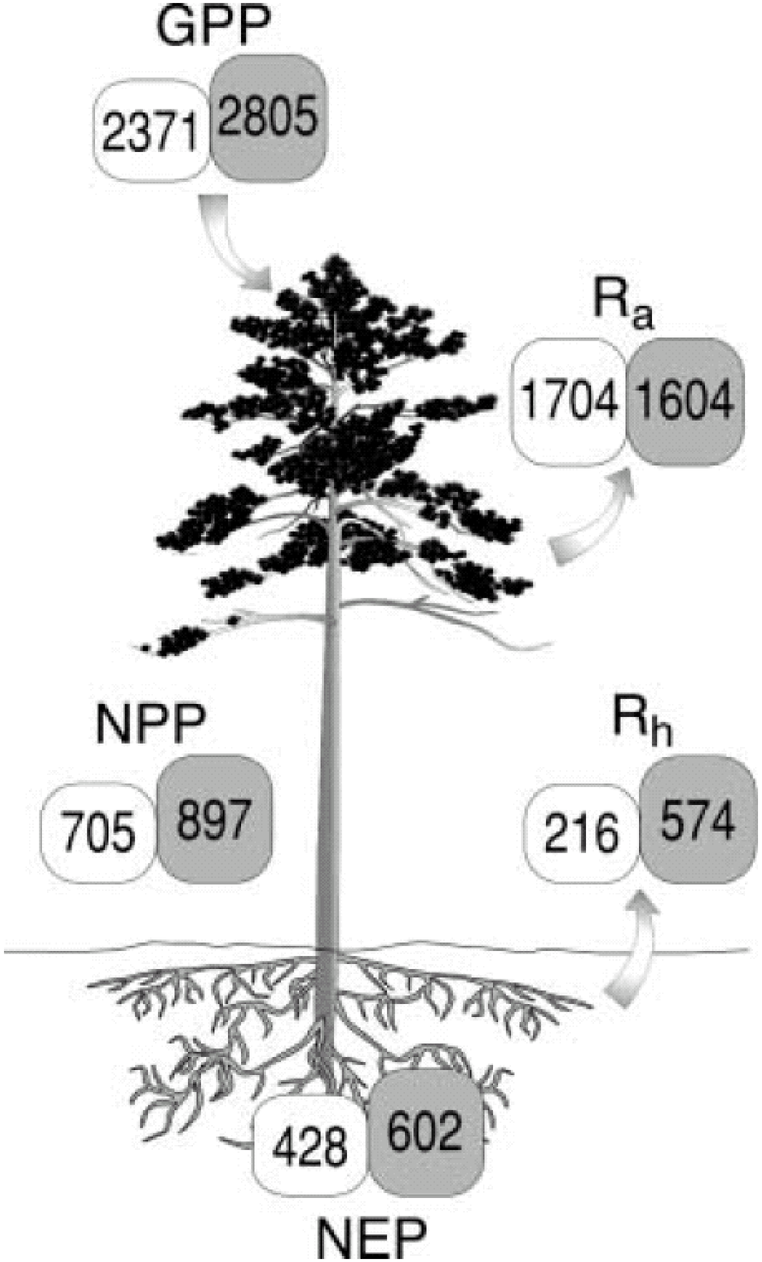


Fig. 3 Carbon budget (1998; gC m^{-2} $year^{-1}$) for a loblolly pine forest under ambient and elevated atmospheric CO_2. Each value is an average for the three ambient (*light boxes*) and three elevated CO_2 (*dark boxes*) plots. The range in values for each variable for the ambient and elevated plots, respectively, are as follows: gross primary production (GPP): 2226–2510 and 2788–2833; net primary production (NPP): 653–766 and 876–928; net ecosystem production (NEP): 392–477 and 578–635; autotrophic respiration (R_a): 1617–1765 and 1570–1645; heterotrophic respiration (R_h): 22–393 and 487–644. GPP was calculated as NEP plus R_e plus DOC, where R_e was the sum of C losses by total soil CO_2 efflux, DIC, canopy respiration, woody respiration and herbivory. NEP was the sum of wood and foliage increment, fine root increment and the accumulation of C in the forest floor. NPP was calculated as the sum of wood and foliage increment, fine root increment, litterfall, fine root detritus production, DOC, and C losses by herbivory. R_h was the sum of microbial respiration and herbivory; where microbial respiration was the difference between total soil CO_2 efflux and total root respiration (fine plus coarse root respiration) plus (22% DIC in ambient plots or 47% DIC in fumigated plots). Note that NEP does not equal NPP minus R_h for the elevated plots (see Discussion)

From: Hamilton et al. 2002(Duke FACE) Oecologia 131:250-260.

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.

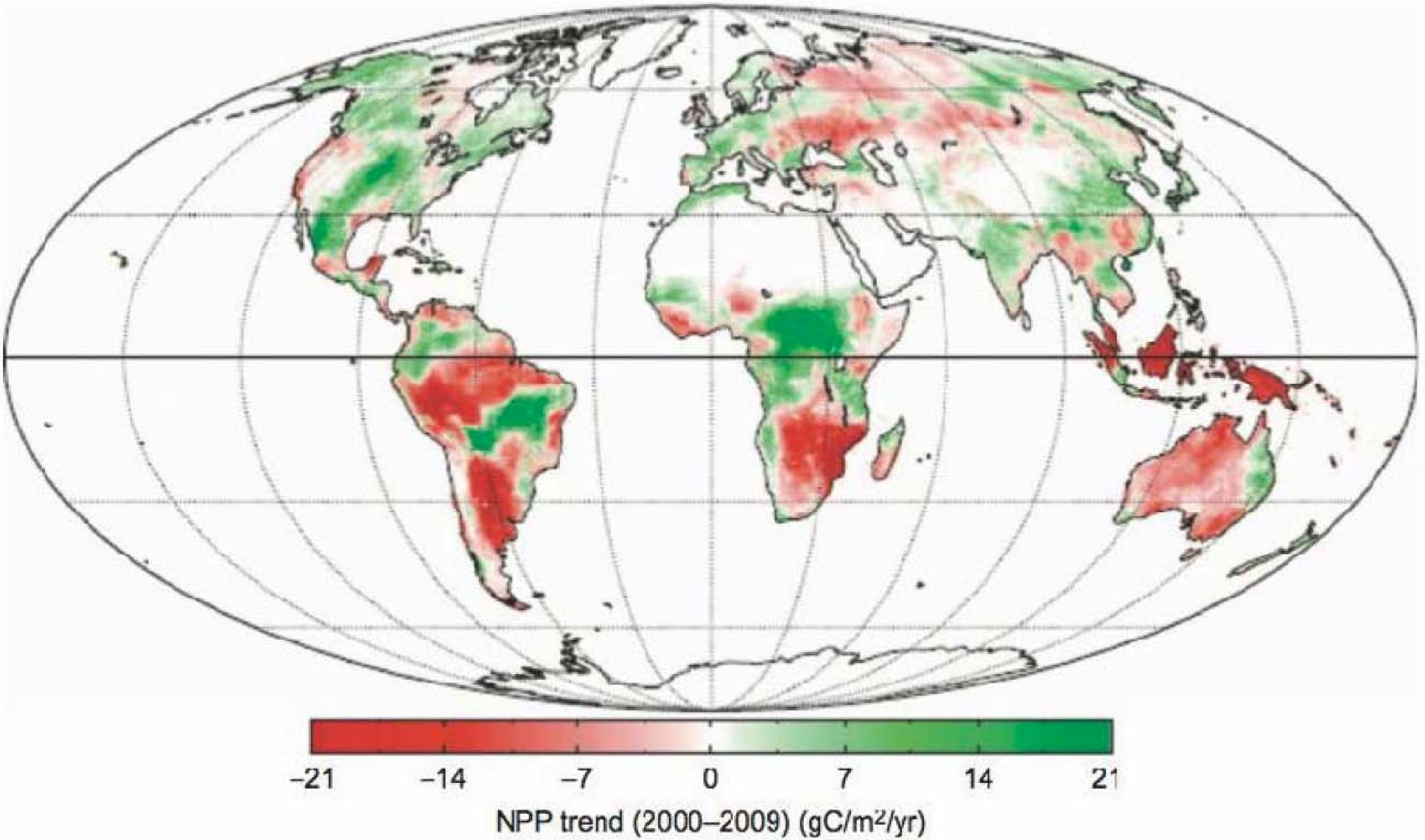


FIGURE 5.16 Change in terrestrial NPP from 2000 to 2009 from MODIS. *Source: From Zhao and Running 2010. Used with permission of the American Association for the Advancement of Science.*

Respiration

Heterotrophic Respiration

Autotrophic Respiration

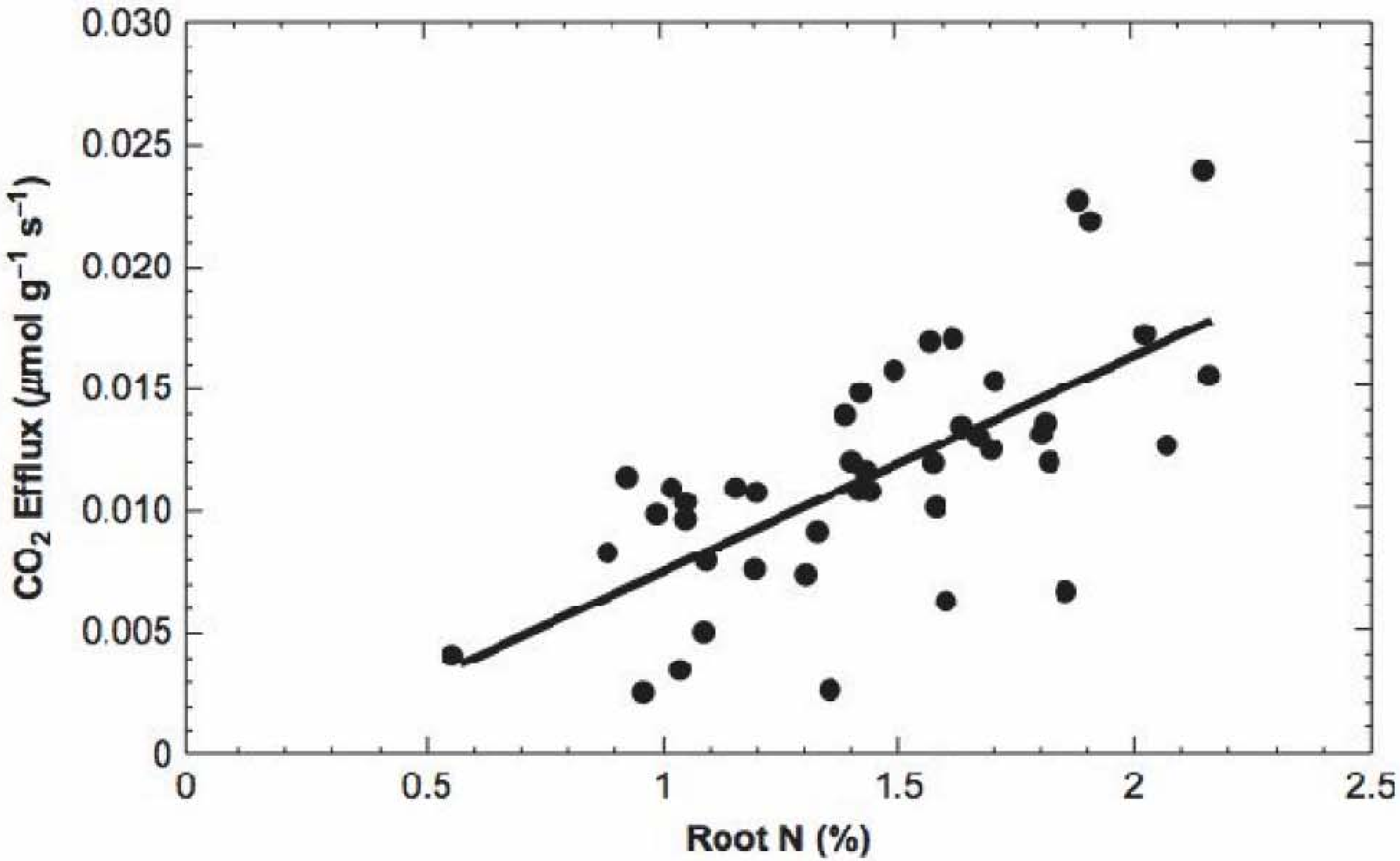
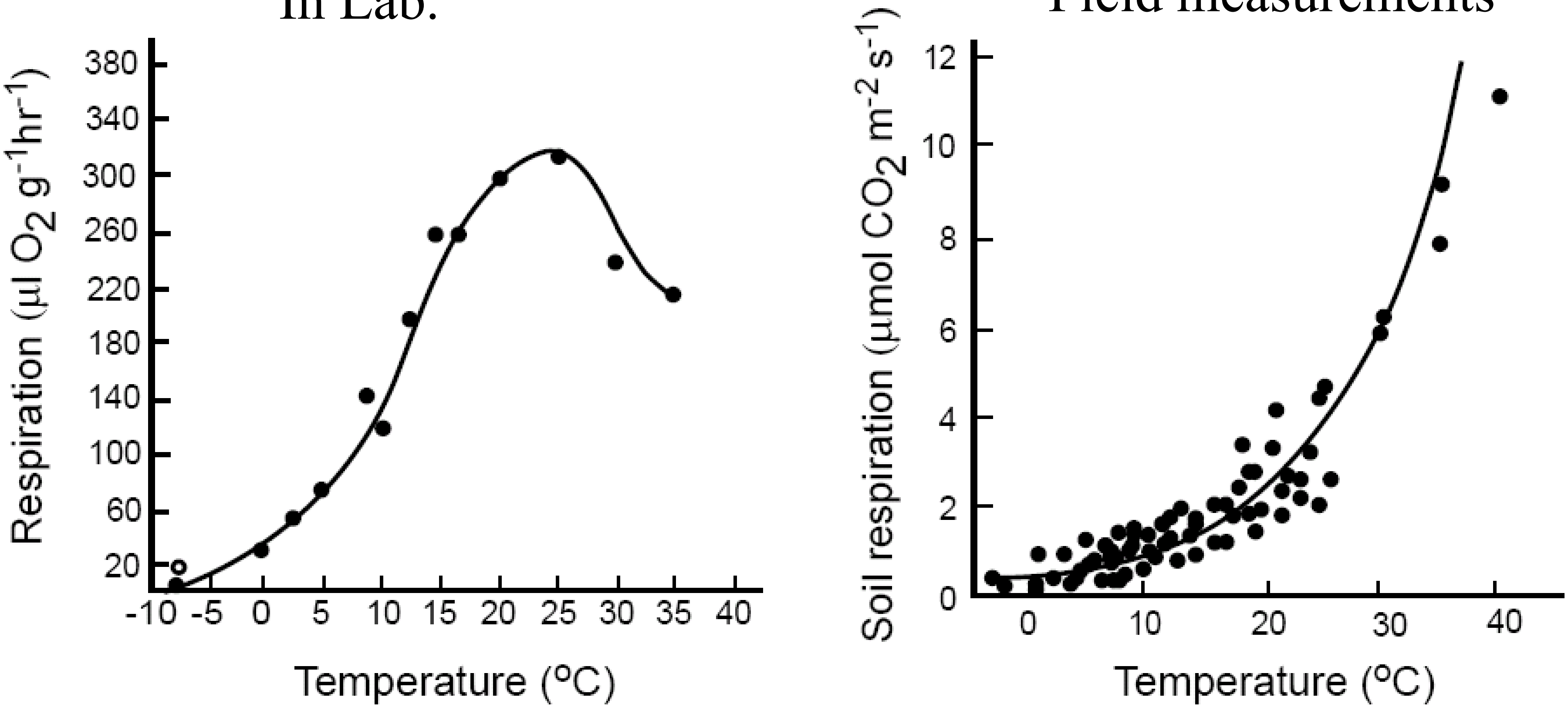


FIGURE 5.4 Root respiration as a function of nitrogen content (%) in roots of loblolly and ponderosa pine. *Source: From Griffin et al. (1997). Used with permission of Springer.*

In Lab.

Field measurements



Relationship between temperature and soil respiration in (left) laboratory incubations of tundra soils (Flanagan and Veum 1974) and (right) field measurements of soil respiration in 15 studies, where data have been fitted to have the same respiration rate at 10°C (Lloyd and Taylor 1994).

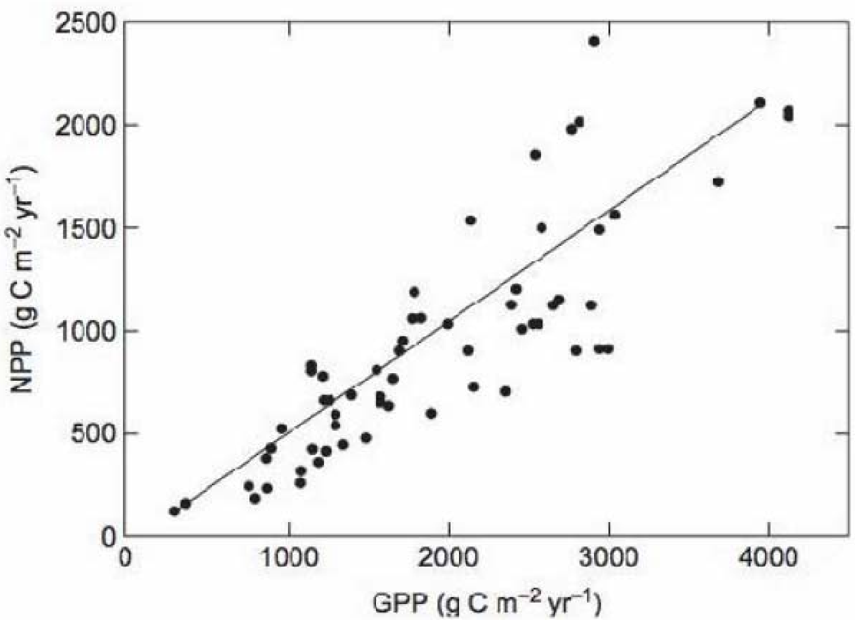
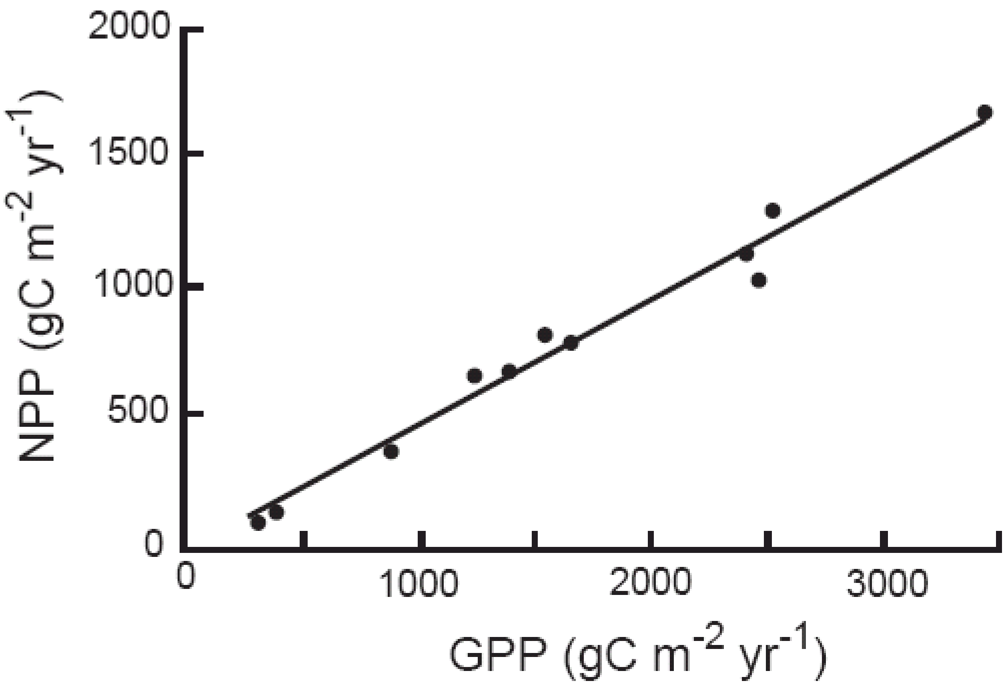
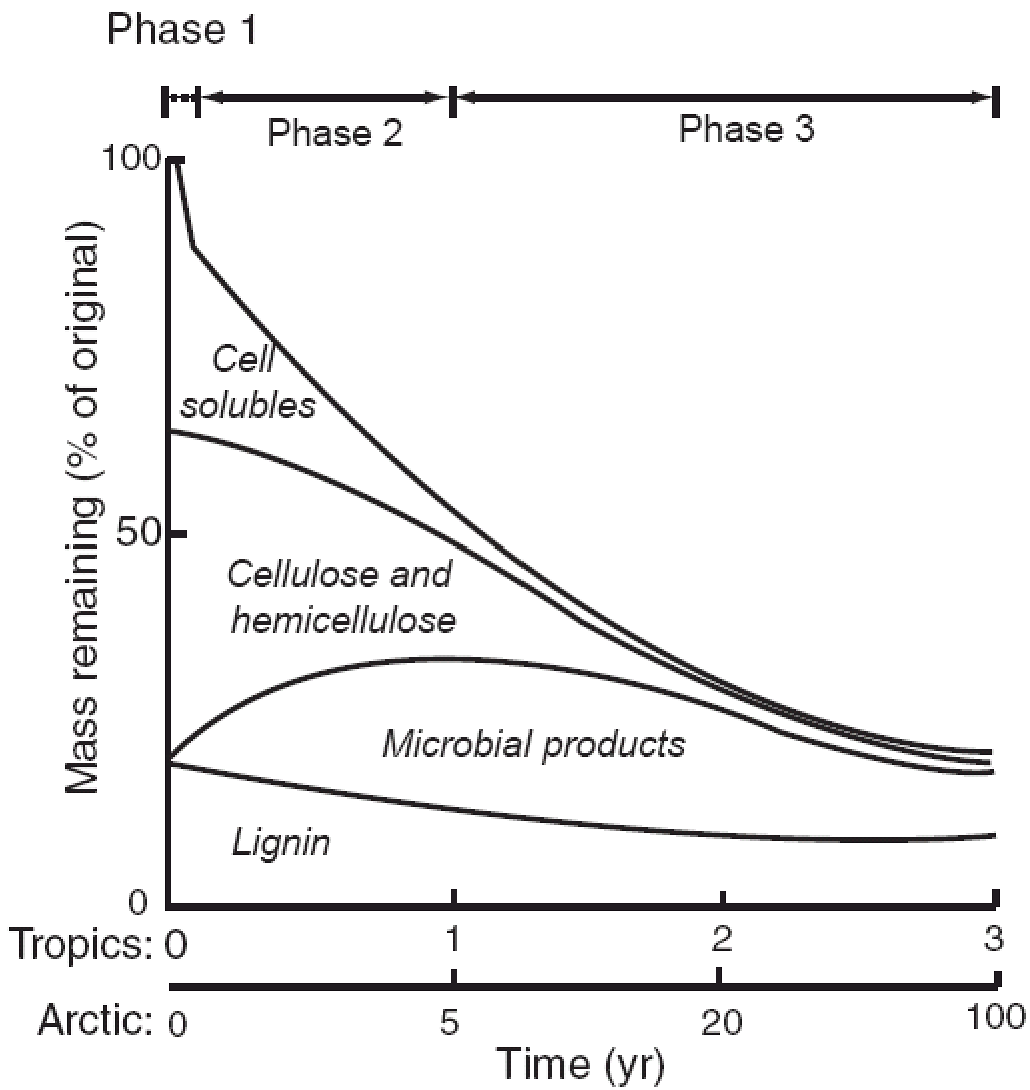


FIGURE 5.5 Relationship between net primary production (NPP) and gross primary production (GPP) in different forest types. *Source: From DeLucia et al. (2007).*

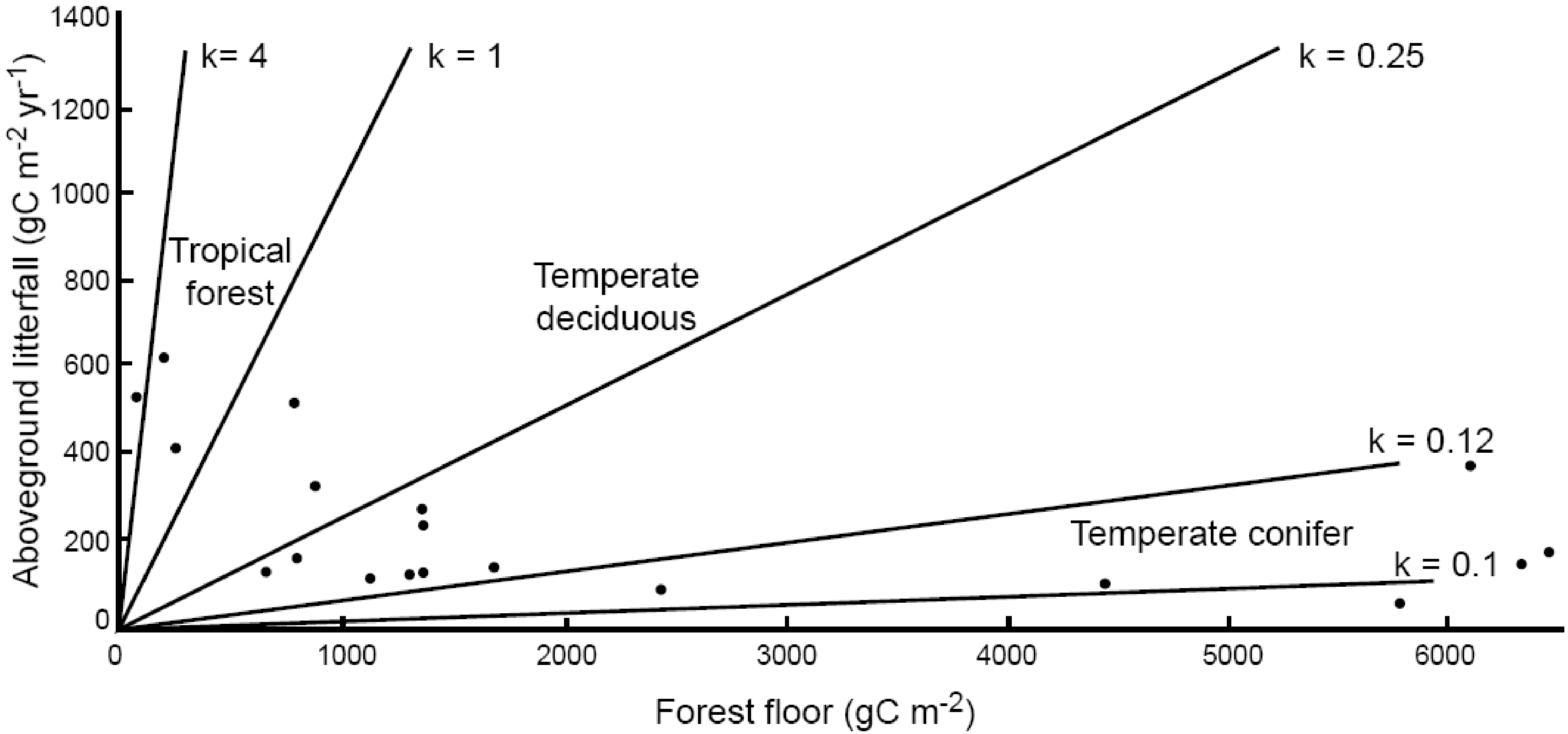


Relationship between GPP and NPP in 11 forests from the United States, Australia, and New Zealand (Williams et al. 1997, Waring and Running 1998). These forests were selected from a wide range of moisture and temperature conditions. GPP and NPP were estimated using a model of ecosystem carbon balance. The simulations suggest that all these forests show a similar partitioning of GPP between plant respiration (53%) and NPP (47%), despite large variations in climate.

Decomposition

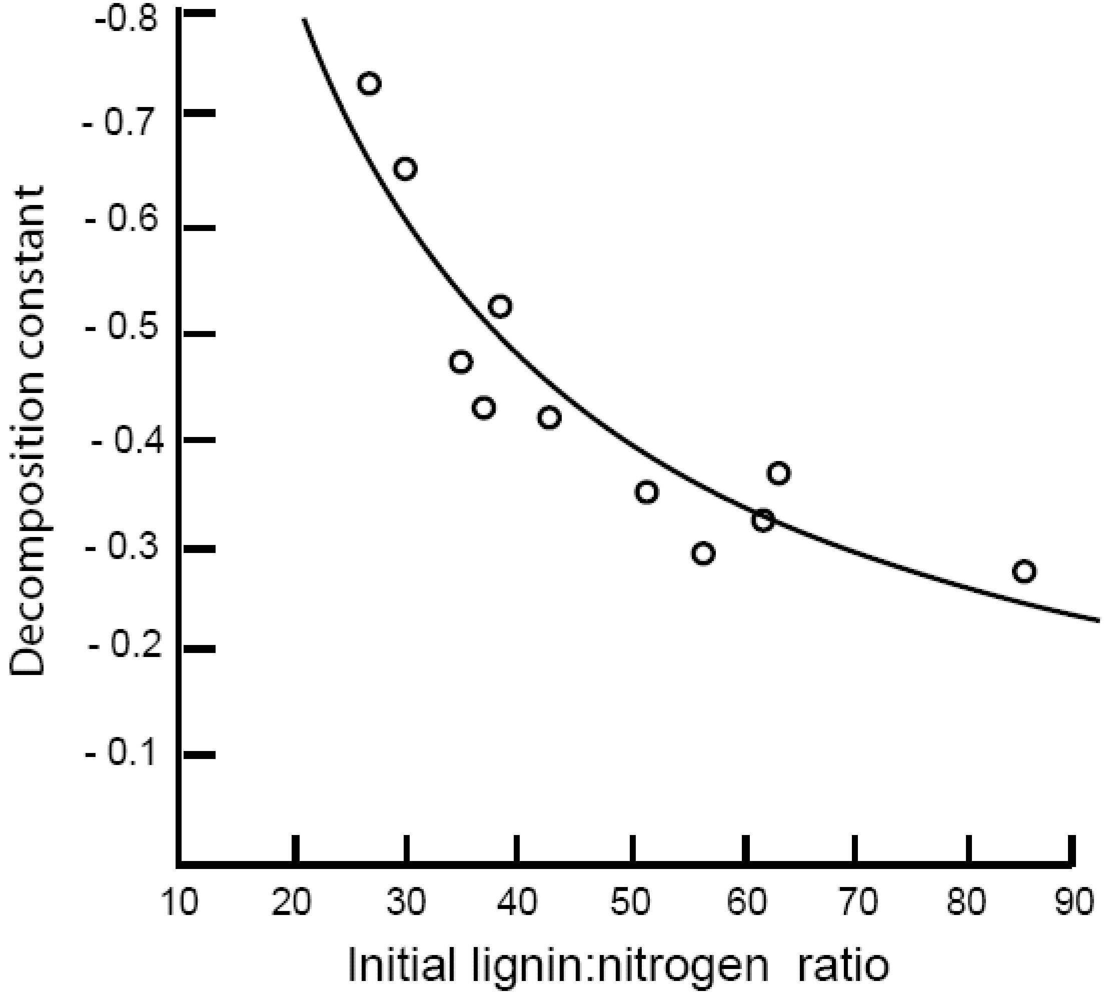


Representative time course of leaf-litter decomposition, showing the major chemical constituents (cell solubles, cellulose and hemicellulose, lignin, and microbial products), the three major phases of litter decomposition, and the time scales commonly found in warm (tropical) and cold (arctic) environments. (Chapin et al. 2002)

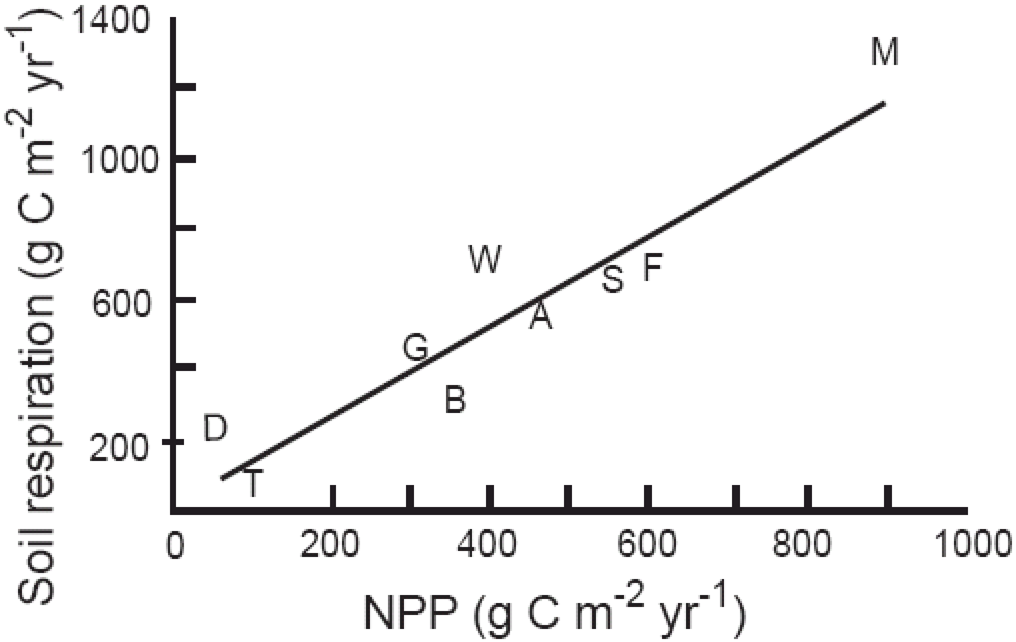


$$M_t = M_0 \, e^{-kt}$$

Forest-floor biomass and aboveground litter inputs for selected evergreen forests (Olsen 1963). Lines show the decomposition constants for the forest floor, calculated from these data.



Relationship between the decomposition constant and the lignin:nitrogen ratio of litter (Melillo et al. 1982).



Relationship between mean annual soil respiration rate and mean annual NPP for Earth's major biomes (Raich and Schlesinger 1992). Ecosystem types are agricultural lands (A), boreal forest and woodland (B), desert scrub (D), temperate forest (F), temperate grassland (G), moist tropical forest (M), tropical savanna and dry forest (S), tundra (T), and mediterranean woodland and heath (W).

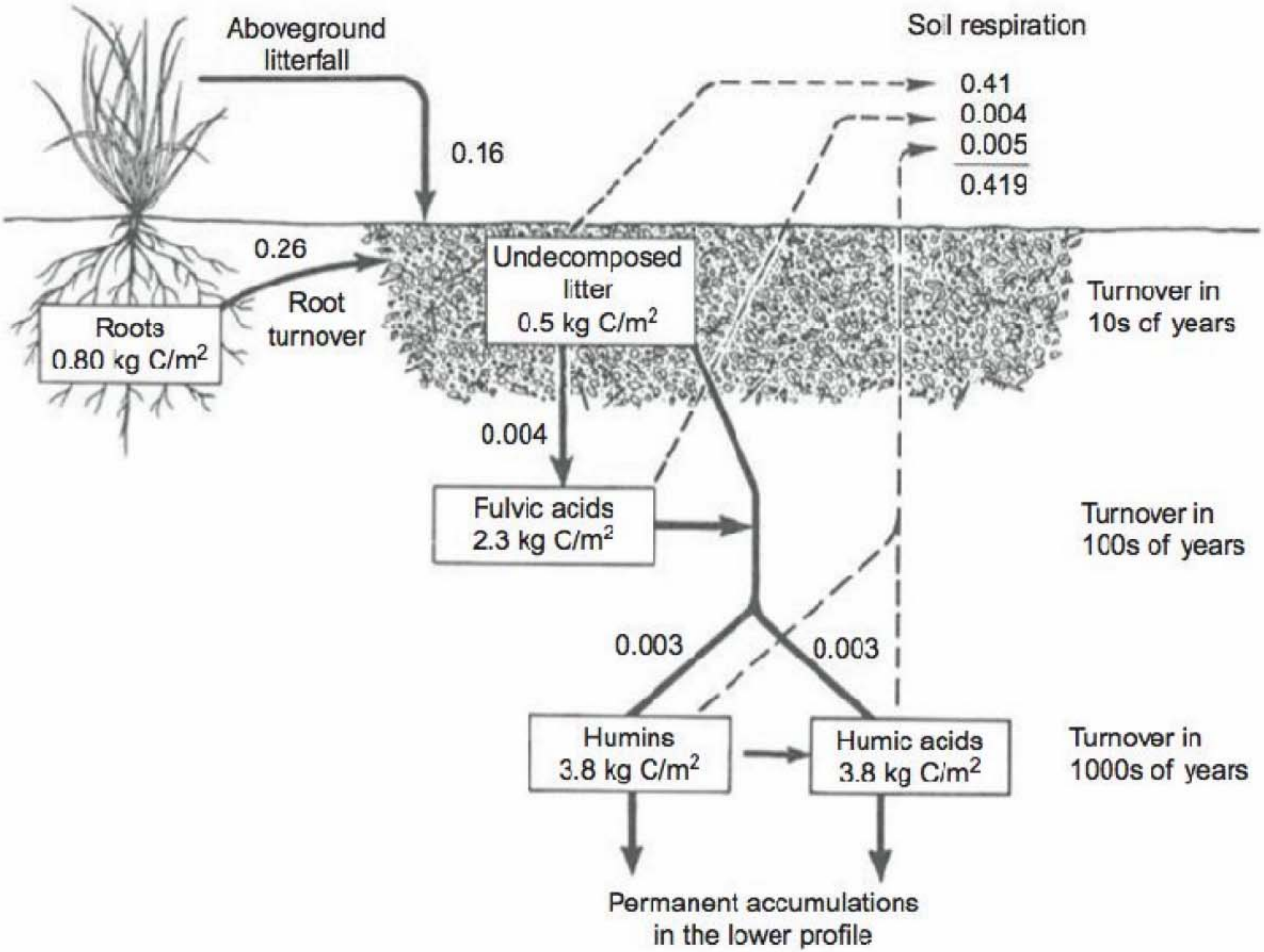
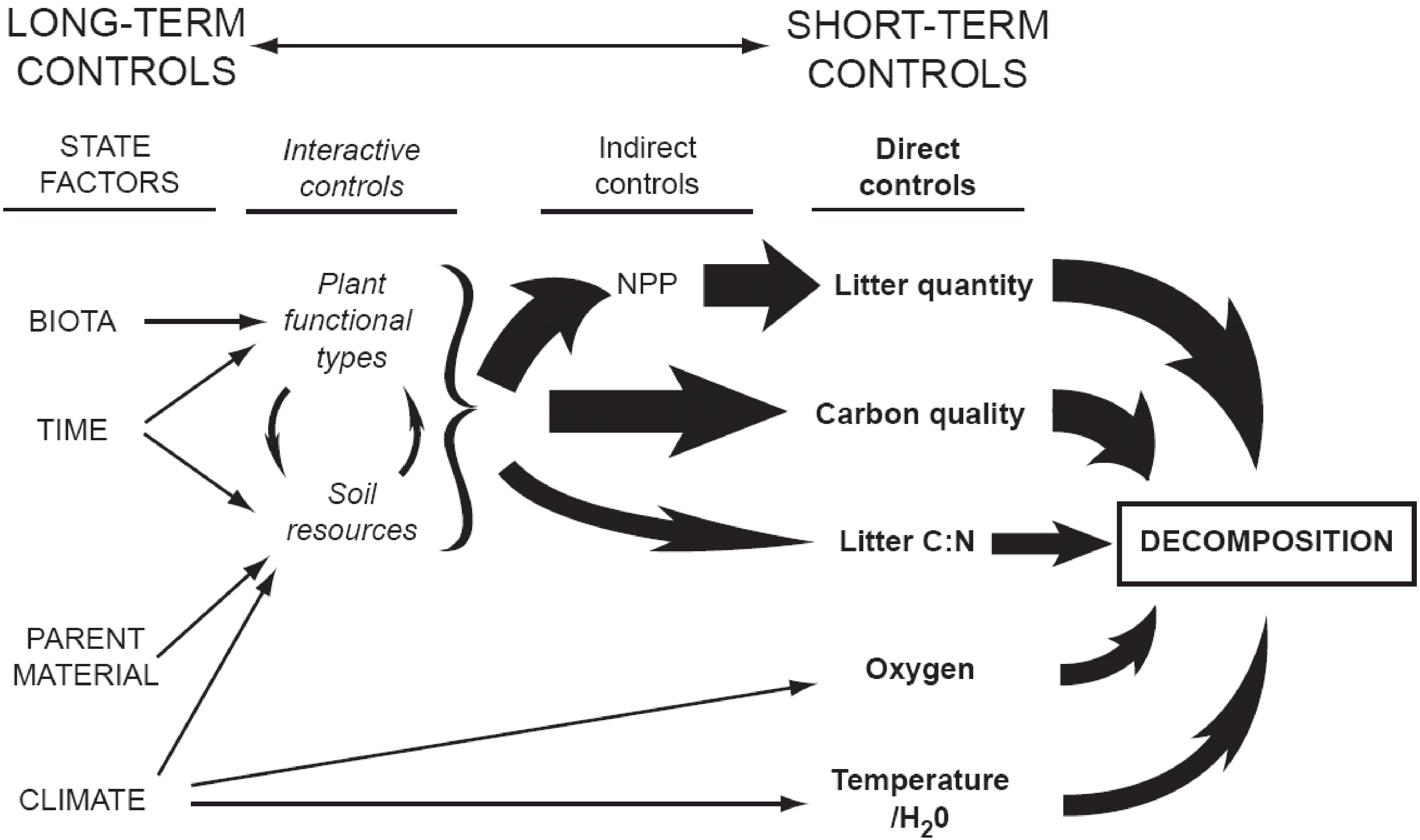


FIGURE 5.19 Turnover of detritus and soil organic fractions in a grassland soil, in units of kgC $m^{-2} yr^{-1}$. Note that mean residence time can be calculated for each fraction from measurements of the quantity in the soil and the annual production or loss (respiration) from that fraction. *Source: From Schlesinger (1977).*



The major factors governing decomposition at the ecosystem scale. These controls range from proximate controls that determine the seasonal variations in decomposition to the state factors and interactive controls that are the ultimate causes of ecosystem differences in decomposition. Thickness of the arrows indicates the strength of the effect. The factors that account for most of the variation in decomposition among ecosystems are the quantity and carbon quality of litter inputs, which are ultimately determined by the interacting effects of soil resources, climate, vegetation, and disturbance regime. (Chapin et al. 2002)