Biology 121

Notes

Ecology and Organismic Biology: Plants, Ecology and Plant Physiology

by

Govindjee

About the instructor

Govindjee, who uses his given name only, earned a Ph.D. in Biophysics from the University of Illinois at Urbana-Chapaign (1960). He has served this institution as a post-doctoral fellow (1960-1961), Assistant Professor (1961-1965), Associate Professor (1965-1969) and Professor of Plant Biology and Biophysics (1969-present). His research is in the area of oxygenic photosynthesis (the process by which plants, algae and cyanobacteria produce fuel, fiber and oxygen for all of us on this Earth). He is co-author of *Photosynthesis* (John Wiley, 1969), and three articles on the basics of photosynthesis in *Scientific American* (July, 1965; December, 1974; and February, 1990). He is editor of several books including *Bioenergetics of Photosynthesis* (1975), *Photosynthesis*, Volumes 1 and 2 (1982) and *Light Emission by Plants nd Bacteria* (1986) (Academic Press). Currently he is editor of the Historical Corner section of *Photosynthesis Research*, and the series editor of *Advances in Photosytnthesis* (Kluwer Academic). In the past, he has taught courses in honors biology, plant biology and biophysics, both at the undergraduate and graduate levels.

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Acknowledgments

I am thankful to Professor Evan DeLucia for sharing with me the Lecture Outlines of Biology 121 for the Spring of 1995, and to Professor Carol Augspurger for explaining several concepts in Ecology. Thanks are also due to SOLS Artist Service for most of the figures shown here. The 1995 version was typed by Margaret Hughes. I specially thank Norman Lee for his patience and for typing the 1998 text.

Cover

The cover shows some of the Biology 121 students, in 1995, on the UIUC Quad; they volunteered to demonstrate both the electron and proton translocation in plant photosynthesis.

Question

Have you already read Parts I and II of Raven and Johnson's Biology (pp. 1-163)

☐ yes
☐ no

> "Tom, Tom the piper's son
> Stole a pig and away he ran
> But the only tune that he could play.
> Was over the hills and far away"

About the course & the book

"Plants are the vital component of our ecosystems that essentially make sunlight edible."

Topics of the second half of Biol. 121 are (the numbers in parentheses refer to chapter numbers and pages in Raven and Johnson's Biology 4th ed.):
[Reading assignments are to be found under individual lectures.]

EXAM I -- Thursday, February 19, 7-9PM

A. Plant Physiology

Lab 7 Structure and Development:	**March 9 - 13**
Lab 8 Light Reactions of Photosynthesis:	**March 16 - 20**
Lab 9 Transpiration:	**March 30 - April 3**

Essential Concepts:

March 11 (1) *Cell Structure and Function; Vascular Plant Structure*

Transport, translocation and nutrition:

March 13 (2) *Transport in Plants: Water, Water Uptake and Transport*
March 16 (3) *Nutrition and Transport in Plants: (A) Transport of sugars*; (B) *Plant nutrition*

EXAM II -- Thursday, March 19, 7-9PM

Biochemistry and metabolism:

March 20 (4) *Biochemistry: Light reactions of Bacterial and Plant Photosynthesis*

SPRING BREAK

March 30 (5) *Biochemistry: Electron Transport and Photophosphorylation*
April 1 (6) *Metabolism: Carbon Assimilation*

Growth and development

April 3 (7) *Environmental Effects: Physiological and Ecological Implications*
April 6 (8) *Growth and Development: (A) Control Systems -- Growth Regulators; (B) Photoperiodism and Rhythms*

B. Ecology

Lab 10 Ecosystem Ecology:	**April 6 - 10**
Lab 11 Population Biology:	**April 13 - 17**
Lab 12 Species Interaction:	**April 20 - 24**

Ecosystems:

April 8 (9) *Biological Communities: Distribution and Adaption*
April 10 (10) *Ecosystems; Dynamics of Ecosystems: Energy Flow and Productivity*
April 13 (11) *Ecosystems: Biogeochemical cycles*
April 15 (12) *Ecosystems: Carbon Cycle,and Climate; Future of Biosphere*

Communities:

April 17 (13) *Communities: Structure of Community and Succession*
April 20 (14) *Communities: Diversity*

EXAM III -- Thursday, April 23, 7-9PM

April 24 (15) *Communities: Species interactions*
April 27 (16) *Plant reproduction*
April 29 (17) *Seed dispersal*

Populations:

May 1 (18) *Population Dynamics; Population Ecology: Demography and life history*
May 4 (19) *Population Ecology: Models of Population Growth*

Overview:

May 6 (20) *Summary of lectures 1-19; Structure and Function; Water Uptake and Transport; Transport of Sugars; Plant Nutrition; Photosynthesis - the "Light Reactions; the "Dark Reactions"; Physiological and Ecological Implications; Control Systems in Plants — Growth Regulators; Tropisms; Photoperiodism and rhythm;*

General Discussion on Climate and Civilization

Have you ever imagined a world with no hypothetical situations?

FINAL EXAM -- Tuesday, May 12, 1:30-4:30PM

PLANT PHYSIOLOGY

Plant Physiology

Lectures 1-8 will deal with plant physiology. Plant physiology is a study of plant function. It includes dynamic processes of growth, metabolism (photosynthesis, respiration, etc), and reproduction in plants. Currently, it is one of the most interdisciplinary area of plant biology that draws heavily from plant biochemistry, plant biophysics and plant molecular biology. In this course, we shall attempt to integrate it with plant ecology, and emphasize the organismic aspects of plant physiology. Plant ecology will be discussed in lectures 9-19.

> "Believe nothing
> merely because you have been told it,
> or because it is traditional,
> or because you yourself have imagined it,
> Do not believe what your teacher tells you,
> merely out of respect for the teacher,
> But whatever after due examination and analysis,
> you find to be conducive to the good of the benefit,
> the welfare of all beings,
> that doctrine believe and cling to,
> and take it as your guide."

Standards for inconsequential trivia, jockingly*

10^{-15} bismol	= I femto-bismol
10^{-12} boos	= I picoboo
1 boo^{2}	= I boo boo
10^{-18} boys	= I attoboy
10^{12} bulls	= I terabull
10^{1} cards	= decacards
10^{-9} goats	= I nanogoat
2 gorics	= I paregoric
10^{-3} ink machines	= I millink machine
10^{9} los	= I gigalo
10^{-1} mate	= I decimate
10^{-2} mental	= I centimental
10^{-2} pedes	+ I cnetipede
10^{6} phones	= I megaphone
10^{-6} phones	= I microphone
10^{12} pins	= I terapin

* From Philip A. Simpson: The NBS Standard 15 (1 January, 1970). NOTE: 1 μM (micrometer) is one millionth of a meter or one thousands of a millimeter; it was often referred to as just a micron (μ) in the past.

Lecture 1: Essential Concepts: Cell Structure and Function; Vascular Plant Structure

[Plants do not move; plants are autotrophs and so...]

Reading assignment:

(1) Raven and Johnson, 4th ed., **Chapter 5, pp. 86-113, Chap. 6, pp. 115-141, Chap. 35, pp. 757-780;** (2) **These Notes**

By the end of your preparation of this topic, you should be able to:

♦ 1. Describe the basic biochemical components of plant membranes, their arrangement in the membrane, and their functions.

♦ 2. Describe the basic qualities of a plant, its parts and their functions at the organ, the tissue, the cell, and the organelle levels.

♦ 3. Describe the components of a leaf and relate the structure of the following to its function: guard cell; mesophyll cell; chloroplast; thylakoid membrane; grana; stroma matrix; mitochondria.

♦ 4. Distinguish between "light" and "dark" reactions of photosynthesis,between C-3, C-4 and CAM plants..

♦ 5. Describe an equation that describes the flux of water vapor and carbon dioxide into and out of leaves.

♦ 6. Define and describe the following **concepts** and **terms**: (Dictionary is not provided for these words.) Cuticle; Conductance, Dark reactions of photosynthesis; Diffusion; Fluid mosaic model of membrane; Light reactions of photosynthesis; Lipids; Ohm's law analogy; Osmosis; Proteins (integral and peripheral); Resistance; Water-use efficiency.

Outline of presentation:

(Figure and table numbers are either from Raven and Johnson, 4th ed., **or from these notes**)

♦ 1. The size of things:	Fig. 5.3	p.89
♦ 2. Biochemical components of a membrane:	Fig. 6.2 - 6.3	p.117
	Table 6.1	p.119
	Fig. 6.5	p.120

♦ 3. Cell structure and function: Table 5.1 p. 96

- A prokaryotic green oxygenic bacteria: Fig. 5.7 p. 93

- Structure of a photosynthetic reaction center: Fig. 6.7 p. 120

(1988 Nobel Prize in Chemistry awarded to H. Michel,J. Deisenhofer, and R. Huber)

♦ 4. Some of the basic qualities of a plant are:

- They are the primary producers (solar energy collectors).
- They are "non-motile", but have indeterminate growth habits. [They cannot walk or talk !]
- They grow towards light.
- They lose water and must have a mechanism against desiccation.
- They do transport water and food, i.e., they have a vascular system.

♦ 5. Plants, their parts and their functions:

• Basic morphology:	Fig. 35.1	p. 758
• Meristems:	--See p.764 for information;	
	Fig. 35.6	p. 764
	Fig. 35.7	p. 765
	Fig. 35.13	p. 768
• Monocot and Dicot leaves:	Fig. 35.25	p. 775
• Plant and animal cells:	Figs. 5.9 and 5.10	pp.94 - 95
	Figs. 1.1 and 1.2	**Notes**
• Roots	Fig. 35.5	p. 761
	Fig. 35.7	p. 765
	Figs. 35.13 and 35.14	pp. 768 - 769
	Fig. 37.4	p. 807
• Stems	Fig. 35.16	p.770
	Figs. 35.17 and 35.18	p.771
• Plant cell examples	Fig. 35.8 and 35.9	pp. 765-766
	Fig. 35.10 and 35.11	p.767

• Xylem and Phloem:	Fig. 35.17	p.771

♦ 6. Leaf, and its parts, and functions:

• Leaves:	**Fig. 1.3**	**Notes**
	Fig. 35.23	p.774
	Fig. 35.24	p.775
• Leaf cross section	Fig. 35.17	p.771
	Fig. 35.27	p.777
• Chloroplast:	Fig. 5.21	p.104
	Fig. 10.15	p. 225
• Mitochondrion:	Fig. 5.20	p.103
• Grana and stroma:	Fig. 10.16	p.225
• Dark and light reactions of photosynthesis:	Fig. 10.21	p.229
• Leaves of C-4 and C-3 plants:	Fig. 10.9	p.228

♦ 7. Flux of water vapor and CO_2 into and out of leaves:

• Diffusion:	**Fig. 1.4**	**Notes**
	Fig. 6.10	p.126
• Diffusion equation:	**Table 1.1**	**Notes**
• CO_2 and water exchange in leaves:	**Fig. 1.5**	**Notes**
• Rates of CO_2 flux:	**Table 1.2**	**Notes**
• Resistance to CO_2:	**Table 1.3**	**Notes**
• Water use Efficiency:	**Table 1.4**	**Notes**
• Guard cells & their function:	**Fig. 1.6**	**Notes**
	Fig. 6.14	p.128
	Fig. 35.12	p.768
	Fig. 37.6	p.808

Table 1.1 Diffusion Equation

$$J = -D \left(\frac{\text{concentration gradient}}{\text{distance}} \right)$$

Where J = the amount of a species crossing a certain area per unit time, for example moles of water (or CO_2) per meter^2 per second, and is termed the ***flux density***.

The driving force is the concentration change (gradient) of the species divided by the distance, the negative sign is set by convention because the movement is towards the lower concentration.

The ability of different species to diffuse depends upon their characteristics and, thus, on their ***diffusion coefficient***, D.

Units:

$mol\ m^{-2}\ s^{-1}$ for J
$mol\ m^{-3}$ for concentration gradient
m for distance
$m^2\ s^{-1}$ for D

m = meter; s = second

Ohm's law: $I\ (\text{current}) = \frac{V(voltage)}{R(resistance)}$

Table 1.2 Rates of CO_2 Flux

Range of maximum values for net photosynthesis. Conditions: 0.03 % (by volume) CO_2; saturating light intensity; optimal temperature and adequate water supply. Data of many authors. CAM = Crassulacean Acid Metabolism; C3- plants: First CO_2 fixation product is C-3 acid; C-4 plants first CO_2 fixation product is C-4 acid.

Plant group	*CO_2 uptake*
	mg dm^{-2} h^{-1}
C4 plants	30 - 80
C3 plants (sun)	20 - 40
C3 plants (shade)	4 - 20
CAM (in dark)	10 - 15
Deciduous trees (sun)	15 - 25
Deciduous trees (shade)	5 - 10
Lichens	0.5 - 2
Seaweeds	3 - 10

Table 1.3 Resistance to CO_2

*1. From turbulent air to boundary layer on the leaf
*2. At the stomata
*3. At the cuticle
4. At the plasmalemma
5. At cytosol
6. At chloroplast envelope membrane
7. In the stroma to the Enzyme

*Resistance for water vapor has the same pathway. Typical values for water vapor conductances (inverse of resistances) are for:

1.	Boundary layer:	320-3,200 mmol* $m^{-2}s^{-1}$
2.	Open stomata:	70-700 mmol $m^{-2}s^{-1}$
	Closed stomata:	0 mmol $m^{-2}s^{-1}$
3.	Cuticle (Crops):	4 to 16 mmol $m^{-2}s^{-1}$

** m = milli*

Table 1.4 Water Use Efficiency

J = Flux Density (amount per area per time)

$$J(\text{water vapor}) = \frac{\textit{Water vapor gradient}}{\Sigma \textit{Resistance to water flow}}$$

$$J(CO_2) = \frac{CO_2 \textit{ gradient}}{\Sigma \textit{ Resistance to } CO_2 \textit{ flow}}$$

$$\textbf{Water Use Efficiency (WUE)} = \frac{J(CO_2)}{J(\textit{water vapor})}$$

C4- plants have higher WUE than C3 plants

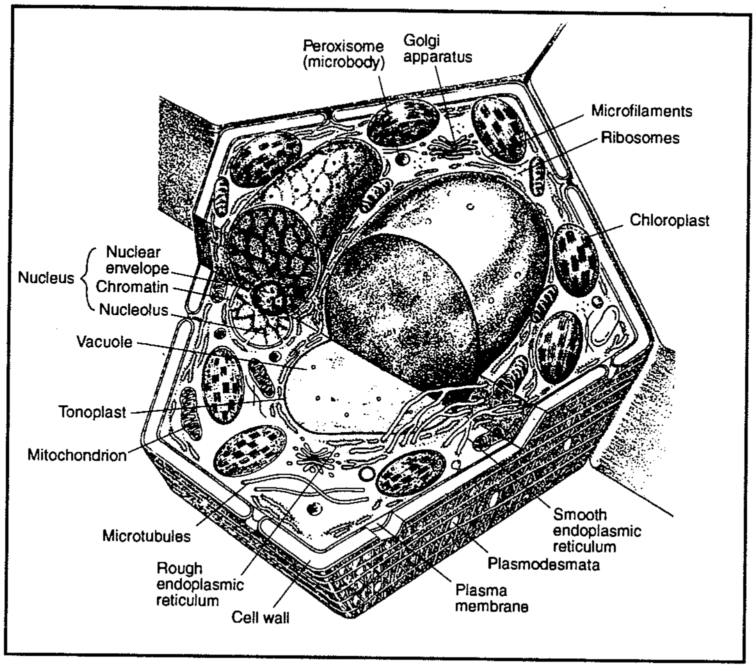


Fig. 1.1. A Plant Cell. Diagram prepared by UIUC/SOLS Artist Service in 1995. Note chloroplasts (where photosynthesis occurs), vacuole and cell wall and plasmodesmata (connection between cells), among other important things. See Fig 5.10, p. 95, Raven and Johnson for a good diagram.

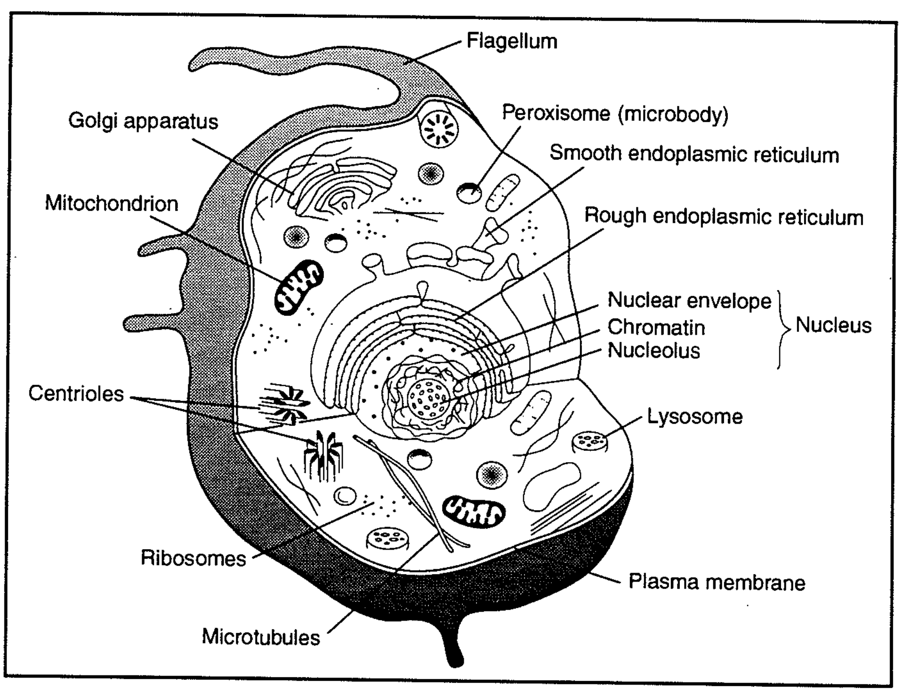


Fig. 1.2. An Animal Cell. Diagram provided by UIUC/SOLS Artist Service in 1995. Note the absence of cell wall and chloroplasts. See Fig 5.9, p.94, Raven and Johnson for a good diagram

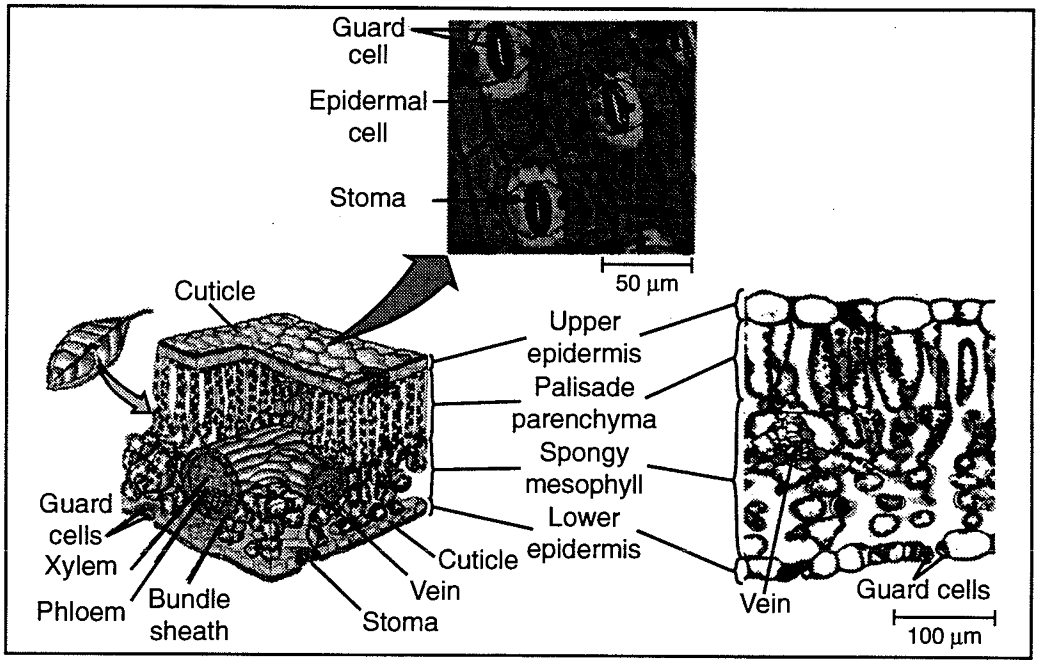


Fig. 1.3. A cut-out leaf showing cuticle, upper epidermis, stoma, vascular system (xylem and phloem) (lower left); surface view of guard cells and stoma (top); and a section of a leaf epidermis; palisade parenchyma and spongy mesophyll cells (lower right).

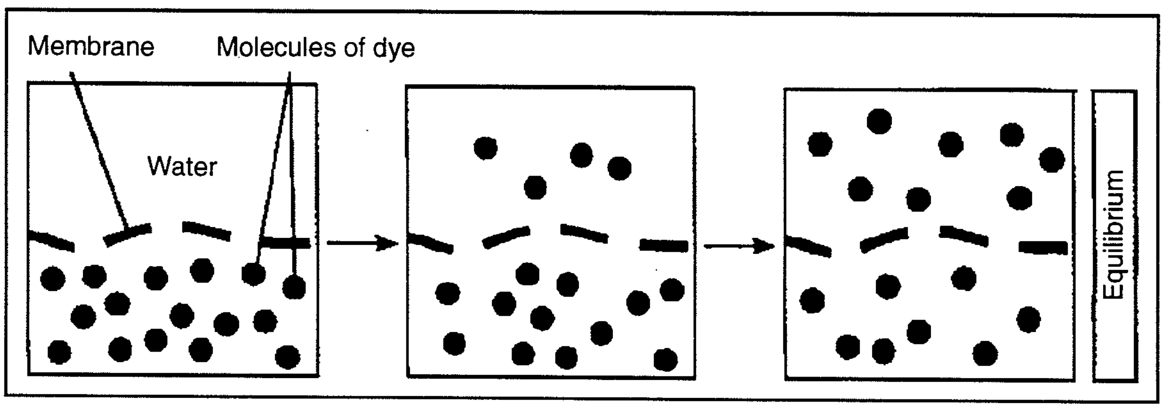


Fig. 1.4. A simple diagram showing diffusion of molecules from high to low concentration.

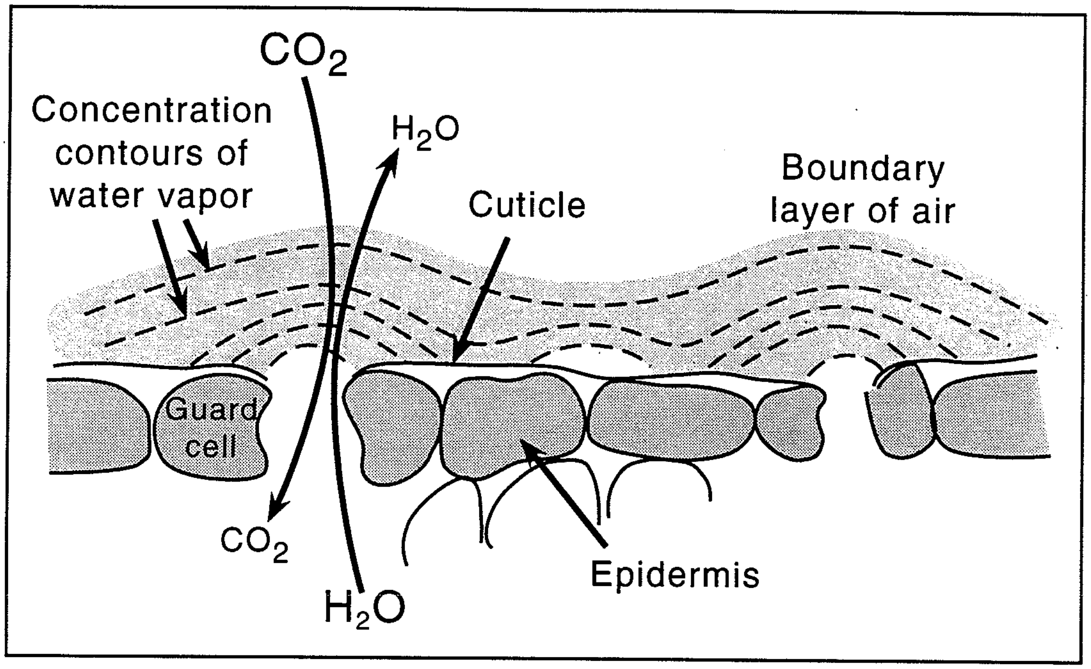


Fig. 1.5. Diagram showing entry of CO_2 into and departure of water from the inside of the leaf through a stoma surrounded by guard cells. In many leaves there may be 10,000 stomata/cm^2, covering approximately 1% of the surface of a leaf. The flux movement of both CO_2 and H_2O follows their diffusion coefficients and their concentration gradients.

Current in Ohm's law is equivalent to rate of CO_2 movement (above).

$$\text{Ohm's Law} = \left(\frac{1}{\text{Resistance}}\right) \text{voltage,}$$

where $\left(\frac{1}{\text{Resistance}}\right)$ is conductance of CO_2 through guard cells, and

Voltage (in Ohm's Law) is equivalent to concentration difference between the two sides (outside and inside the leaf.)

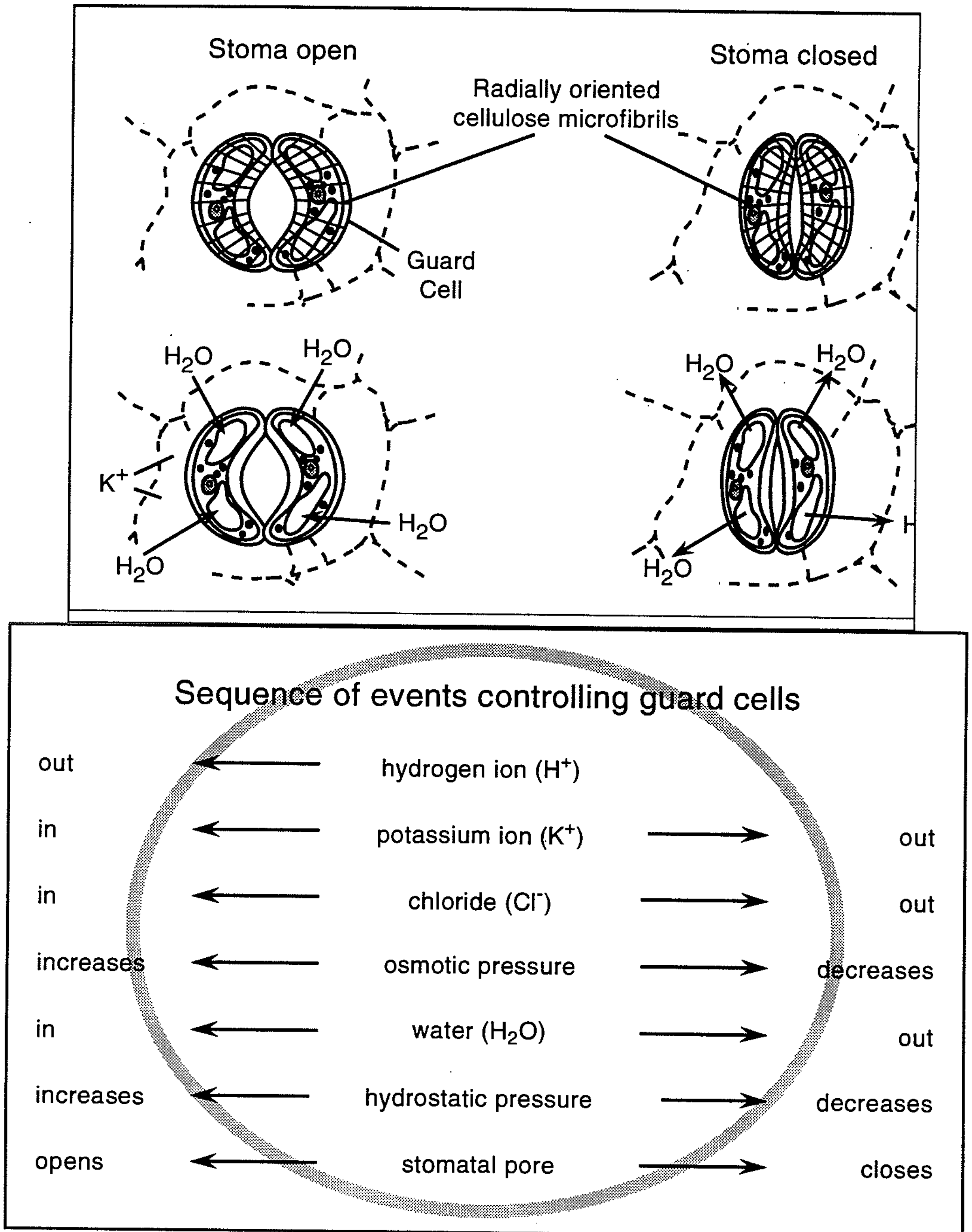


Fig. 1.6. The opening of stomata (see Fig. 6.14, p.128 in Raven and Johnson) (top graph) is explained by the following events in succession (bottom diagram, see left side).

(1) Hydrogen ions (protons, H^+) leave guard cells
(2) Potassium ions (K^+) enter guard cells
(3) This is followed by entry of Cl^- (chloride ions) into guard cells
(4) This lowers cells' water potential
(5) Thus, water enters guard cells
(6) This causes the guard cells to become turgid
(7) Due to thickened walls, fused inner walls of guard cells at their extreme ends, and radial microfibrils in the guard cells, increasing turgor causes guard cell bending and opening of stomata.

The reverse process, *i.e.*, K^+ ions leaving guard cells, leads to the opposite — the closure of stomata (see right side, bottom diagram, B).

Dictionary/Glossary/Concepts:

Autotroph: It is an organism that is self "sufficient" as it does not live on any other organism; it meets all its nutritional needs from inorganic compounds obtained from the soil and water, and energy for its life from light and also from its environment.

Meristem: Has cells that are capable of (actively) dividing by mitosis.
They are of three kinds:
(1) Protoderm that becomes epidermis;
(2) Procambium that becomes vascular tissue (e.g. xylem and phloem);
(3) Ground (basic) meristem that provide parenchyema, collenchyma, and sclerenchyma; all the functional organelles (e.g. chloroplast and mitochondria) are mostly in parenchyma.

For further reading:

See L. Taiz and E. Zeiger (1991 or later edition) Plant Physiology, Benjamin/Cummings Co. Inc., Redwood City, CA, Chapter 1 (Plant & Cell Architecture) and Chapter 2 (Energy, Enzymes and Gene Expression).

Lecture 2: Transport in Plants: Water, Water Uptake and Transport

[Water can move up the trees that are 100s of meters tall: often 30-100 liters/day...]

Reading assignment:

(1) Raven and Johnson, 4th edition., **Chapter 2, pp. 33-40, Chap. 6, pp. 126-128, pp 133-140; review Chap. 35, pp.757-777; Chap. 37, pp. 801-814;** (2) **These Notes.**

By the end of your preparation of this topic, you should be able to:

- 1. Discuss the physical properties of water including how water molecules associate (*i.e.*, hydrogen bonds; adhesion and cohesion).
- 2. Discuss the structure and characteristics of three special elements of plant cells: cell walls, vacuoles and chloroplasts.
- 3. Discuss and differentiate between diffusion, osmosis, active transport and bulk flow of materials.
- 4. Present a description of the anatomy of root, stem and leaves needed to understand the uptake and transport of water in plants.
- 5. Describe the concept of water potential, osmotic potential, turgor potential, and plasmolysis.
- 6. Describe the relationship of water potential to the physiology of the plant.
- 7. Describe the mechanism by which water moves from the soil to the outside of a leaf: the theory that includes *transpiration pull*, and *cohesion* and *adhesion* properties of water.
- 8. Define the following **concepts** and **terms**: apoplastic (movement though cell walls), symplastic (movement across plasma membranes), units of pressure (bar; megapascal, MPa = 10 bars or atmosphere)

Outline of presentation:

(Figure numbers and tables are either from Raven and Johnson, 4th ed., **or from these Notes**)

1. Properties of water and its importance to plants:	**Table 2.1**	**Notes**
	Figs. 2.12 and 2.13	pp. 33-34
	Table 2.2	p. 35

♦ 2. Some aside on plant cells.	**Table 2.2**	**Notes**
• Vacuoles:	Fig. 5.10	p. 95
• Chloroplasts:	Figs. 10.15 and 10.16	pp.223-25
• Rigid cell walls:	Fig. 5.10(b) (See page 91)	p. 95
♦ 3. A Prokaryotic green oxygenic bacteria:	Fig. 5.7	p. 93
♦ 4. Comparison of Diffusion, Osmosis, Active transport and Bulk flow:		
• Osmosis:	Figs. 6.11 and 6.12	p.127
• Active transport: (Na^+ - K^+ pump; H^+ transport)	Table 6.2 Fig. 6.20 Fig. 6.22	p. 138 p. 135 p. 137

(Peter Mitchell: Nobel Prize in 1978 in Chemistry for chemiosmotic theory for H^+ transport.)

♦ 5. Flux of water vapor and CO_2 into and out of leaves:		
• Root:	**Fig. 2.1**	**Notes**
• Xylem:	**Fig. 2.2** **Fig. 2.3**	**Notes** **Notes**
• Leaf:	**Fig. 2.4**	**Notes**
♦ 6. Water potential: definition:	**Table 2.3**	**Notes**
• Movement of water:	**Fig. 2.5** Fig. 6.13	**Notes** p. 128
♦ 7. Water potential and plant physiology:	**Table 2.4**	**Notes**
• Relationship to growth and Photosynthesis:	**Fig. 2.6**	**Notes**
• Effect of desiccation on leaf and root:	**Fig. 2.7**	**Notes**
♦ 8. The Transpiration-Adhesion-Cohesion-Tension (TACT) theory for flow of water in plants:	**Table 2.5**	**Notes**

Table 2.1. Water (H_2O)
(3/4th of the Earth is covered with it)

Important properties are:

- Partial negative charge on its oxygen
- Partial positive charge on its hydrogen
- It is polar
- It associates with other water molecules by the so-called weak *H-bonds* (~ 1/20 of covalent bond)
- Cohesion (+ high surface tension + adhesion): water can stay together in a xylem vessel
- High specific heat (organisms can resist temperature changes)
- High heat of vaporization: Leaves and humans can cool as they loose water in warm climate
- Expands upon freezing: floating ice allows life underneath
- Versatile solvent: Allows all biochemical reactions

Table 2.2 Aside on Plant Cells

Some distinctive characteristics include:

A. *Large Vacoules that store*:
- proteins & hydrolytic enzymes
- inorganic ions, K^+, Cl^-
- metabolic by products
- pigments for the autumn colors
- poisons, toxic stuff for others
- malic acid in Crassulaceae

B. *Cell Walls*
- protection
- maintenance of shape
- prevents excessive uptake of water
- plants are held up and can stand
- are thicker than membranes
- are made up of polysaccharide
- can be like steel-reinforced concrete

C. *Chloroplasts*
- are the organelle for photosynthesis allowing life on Earth (to be discussed later)

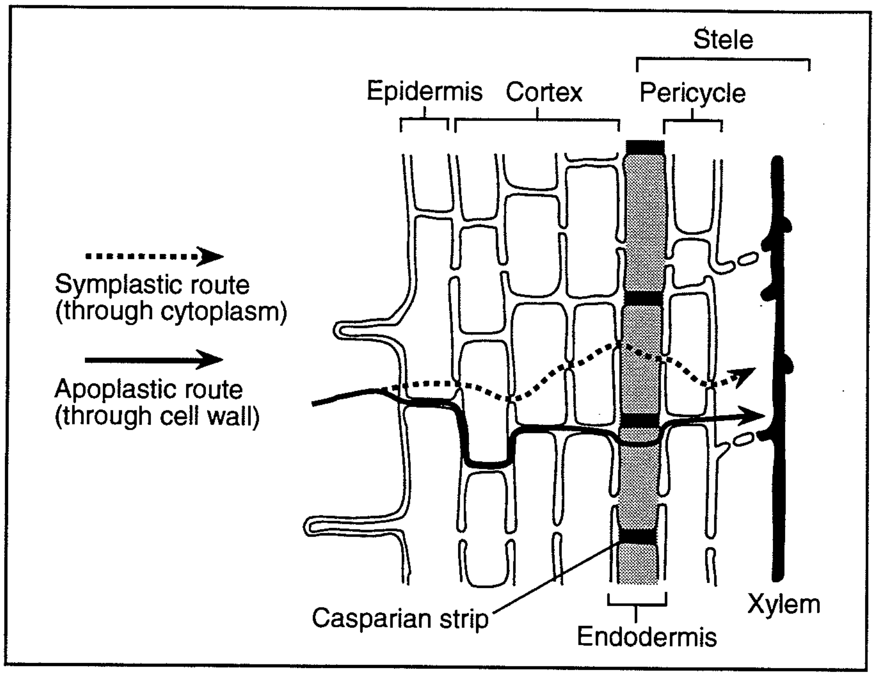


Fig. 2.1. This diagram shows the path of water movement from outside (the soil) towards Xylem; the apoplastic path is through the cell walls, and the symplastic through the cytoplasm that includes plasmodesmata (connections between cells). To avoid waxy casparian strips in Endodermis, the apoplastic route includes some symplastic path.

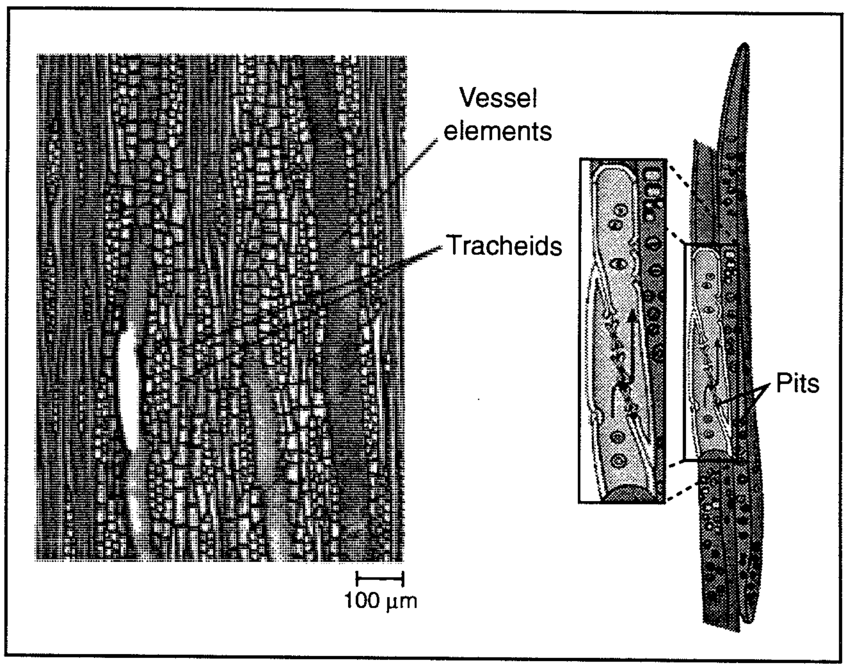


Fig. 2.2. Shows xylem in longitudinal section (left), and the details of the tracheid (right).

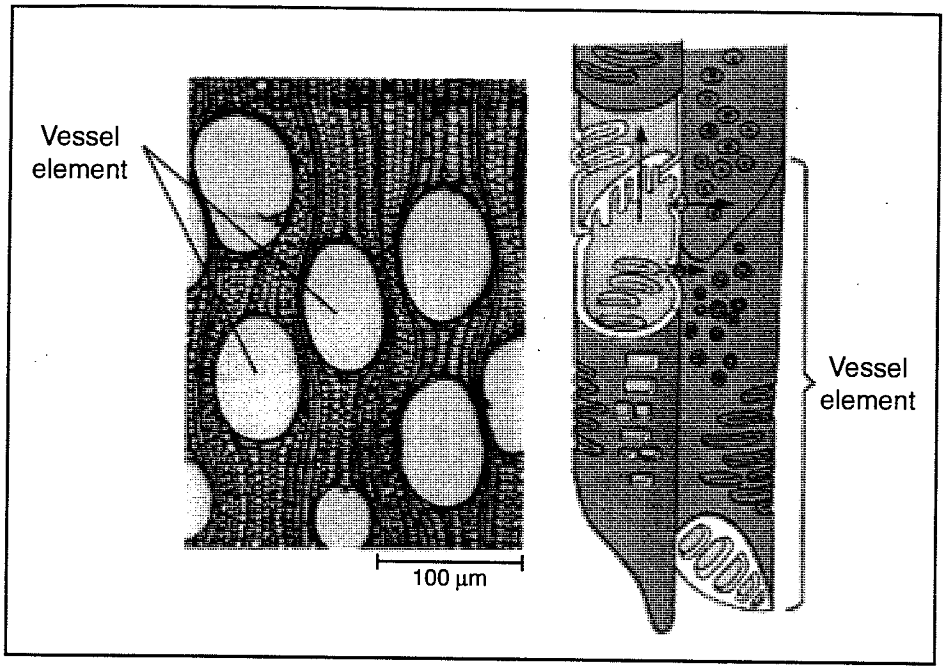


Fig. 2.3. Shows xylem in transverse section (left) and the details of the vessel elements (right).

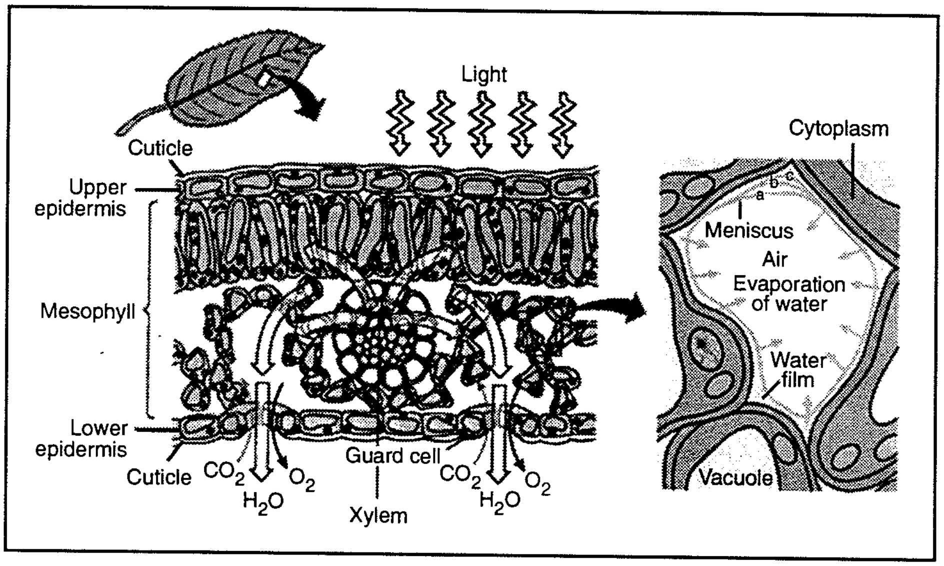


Fig. 2.4. Path of water out of the leaf to the atmosphere. The sequence is: (1) due to difference in the concentration of water molecules, water leaves the inside of the leaf to the outside through stomata; (2) this loss of water leads to water film on mesophyll cells to form concave meniscus, and a tension (negative pressure) is produced; (3) this tension pulls water out of xylem where water forms a column due to cohesive properties of water; and (4) this pull is responsible for the bulk flow of water from the roots to the leaves.

Table 2.3 Water Potential

ψWater = ψPressure+ ψ osmotic+ ψother

- Where ψ stands for potential; other includes matric forces (adhesion) and gravity, but they are too small to worry about; pressure is due to cell walls.
- ψ water = 0 for pure water
- ψwater = - ive, whenever there is any solute in it.
- Water moves from high ψ*water* to low ψ*water*
- 1 Megapascal = 10 bars (atmospheres)

- ψair (at 50% relative humidity) is ~ -95 MPa, whereas ψleaf is -0.8 MPa.
- Rate of water flow = [k, A (ψ leaf - ψair)] / [d . Patm], where k = constant, A = surface area, d = boundary layer, and Patm = atmospheric pressure. (**See Fig. 1.5 Notes**).

Flaccid Cell

Y Pressure = 0 MPa

Y osmotic= - 0.5 MPa

Y water= - 0.5 MPa

Sucrose Solution
(0.4 M)
Y Pressure = 0MPa

Y osmotic= - 0.9 MPa

Y water= - 0.9 MPa

Flaccid Cell in a 0.4 M Sucrose solution:

water will move from flaccid cell to sucrose solution causing plasmolysis

Flaccid Cell in a pure water solution:

water will move into the flaccid cell making the cell turgid. Here Y Pressure will be 0.5 MPa

Fig. 2.5. Water moves from high water potential to low water potential.

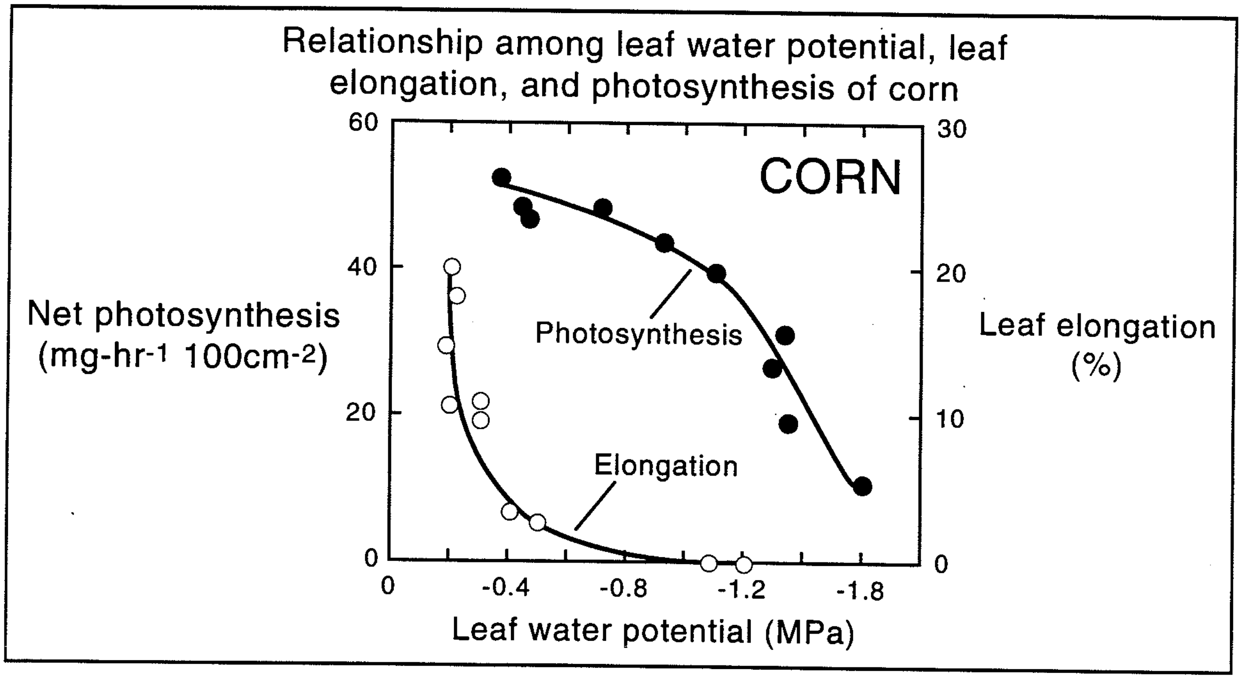


Fig. 2.6. Relationship of leaf water potential with leaf elongation and net photosynthesis of maize (corn). Data from John Boyer (1970) UIUC, Urbana.

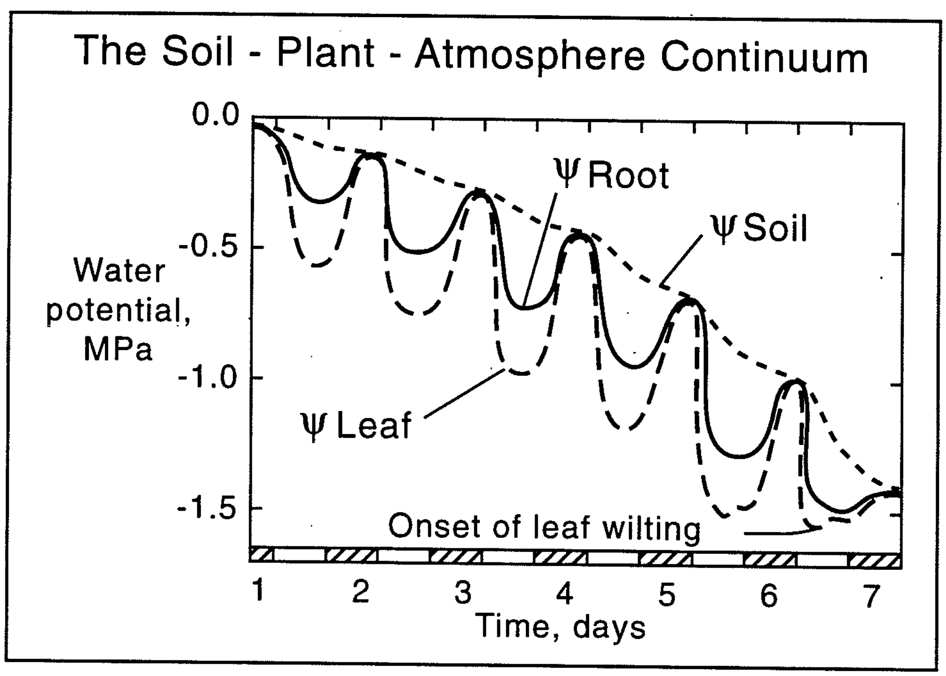


Fig. 2.7. Changes in water potentials of leaf, root and soil as the drought proceeds by holding back water. Note: Water potential is more negative in the day than during the night.

Table 2.4. Water Content of Plant Tissues

Root , Carrot	**88%**
Stem, asparagus	**88%**
Leaf, lettuce	**95%**
Fruit, watermelon	**92%**
Seed, field corn (dry)	**11%**
Seed, sweet corn (edible)	**85%**

Table 2.5. Water-Up-the-Tree : TAC*T* theory

- Water can move up the Xylem: 70-80 cm per minute.
- *Sunshine*: warms the leaf.
- *Evaporation / transpiration (***T***)*: Water moves out of the leaf, through the stomata, by concentration gradient. This is the major active driving force.
- *Adhesion (***A***)*: This property of water fights against gravity pull. It acts to maintain intact column of water in the plant; it is due to hydrogen bonds between water and other polar molecules.
- Cohesion (**C**): This pulling effect works as water column remains intact (up to 30 MPa or more) due to cohesion property of water and to the structure of xylem. Cohesion is due to hydrogen bonds between water molecules.
- Tension (***T***): The transpiration pull causes tension (negative pressure) in leaf water; water is highly tensile (see (**C**) and (**A**)). Water is pulled up the xylem.
- Water moves: There is a mass flow from roots to leaves as the transpiration occurs. Water moves from soil to roots by both solute concentration and pressure differences. This movement is important for:
  (1) Uptake of inorganic ions from soil;
  (2) Turgor for cell expansion in the plant;
  (3) Temperature regulation of the plant, particularly leaves.

For further reading:

See Chapter 3 (Water and Plant Cells) and Chapter 4 (Water Balance of the Plant) in "Plant Physiology" by L. Taiz and E. Zeiger, The Benjamin/Cummings Pub. Co., Inc., Redwood city, CA.

Lecture 3: Nutrition and Transport in Plants: (A) Transport of Sugars; and (B) Plant Nutrition, mostly mineral nutrition

● **Reading assignment:**

(1) Raven and Johnson, 4th ed., **Chap. 37, pp. 809-814; Chap. 32, pp 715-717;**
(2) **These Notes**

● **By the end of your preparation of these topics, you should be able to:**

Part A

♦ 1. Define the terms *translocation*, *source* and *sink*, and describe the structure of *phloem* (Sieve tube elements and companion cells).

♦ 2. Discuss the mechanism of transport of sugars, including the phloem loading part involving *active transport* and *transporters*.

♦ 3. Discuss the differences between water transport in Xylem (unidirectional) and sugar transport (bidirectional) in phloem.

Part B

♦ 4. Discuss the major functions of the essential *macro*-and *micronutrients* for plant growth.

♦ 5. Discuss how the method of *hydroponics* has been useful in establishing whether or not a nutrient is essential.

♦ 6. Make some educated guesses as to the nature of the possible mineral deficiency by looking at the visual characteristics of the plants.

♦ 7. Describe two important mutualisms involved in nutrient acquisition particularly for nitrogen (*N_2 fixing bacteria*) and phosphorus (*mycorrhizae*).

● **Outline of presentation:**

(Figure and table numbers are either from Raven and Johnson, 4th ed, **or from these notes**)

Part A

♦ 1. The Phloem: Sieve tube member with sieve plates; and companion cells.

Fig. 3.1 **Notes**

♦ 2. Phloem loading; role of active transport: Fig. 37.8 p. 810
Fig. 3.2 **Notes**

♦ 3. Mass flow hypothesis of sugar transport in Phloem: **Fig. 3.3** **Notes**

Part B

♦ 4. *Macronutrients* and *micronutrients* are:

C, H, O, P, K, N, S, Ca, Mg, B, Cl, Cu, Fe, Mn, Mo, Ni, and Zn

- Elemental analysis of a plant: **Table 3.1** **Notes**
- List of essential elements: **Table 3.2** **Notes**
- Major functions of nutrients: **Table 3.3** **Notes**
- Mineral uptake by plants: **Fig. 3.4** **Notes**
- Nutrient concentration dependence of growth: **Fig. 3.5** **Notes**
- Nutrient uptake and its concentration: **Fig. 3.6** **Notes**
- Establishing essentiality of Nickel: **Fig. 3.7** **Notes**

♦ 5. Diagnosis of mineral deficiency: **Table 3.4** **Notes**

♦ 6. Nitrogen fixation:

- In heterocysts of cyanobacteria:
- Rhizobium nodule: **Fig. 3.8** **Notes**
- Nitrogen fixation in Alder trees: **Fig. 3.9** **Notes**

♦ 7. Mycorrhizae: (Read pp. 715-717, Raven and Johnson, 4th Ed.)

- Effect on growth of plants: Fig. 32.2 p. 703
(Soybean plants grow much better with Rhizobium associated with their roots)
- Effect on root/ shoot ratio: **Table 3.5** **Notes**
- Effect on phosphorus availability: **Fig. 3.10** **Notes**

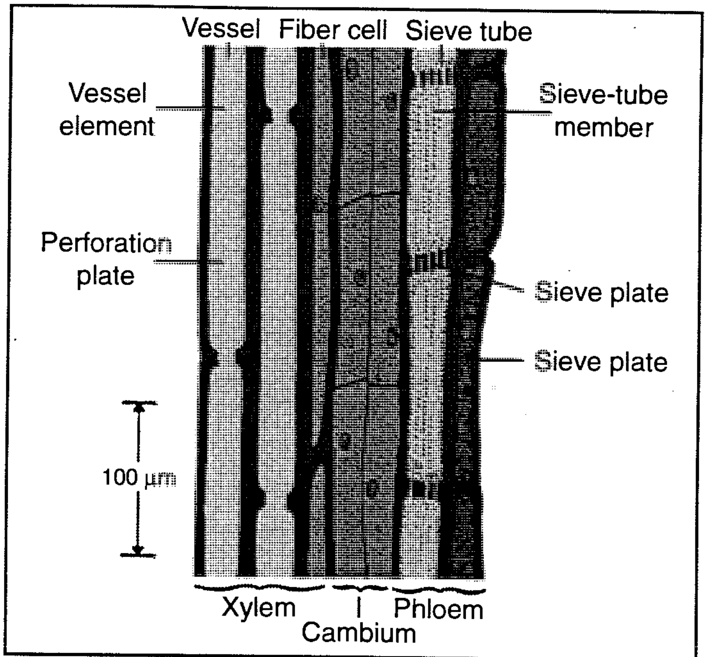


Fig. 3.1. An idealized longitudinal section of a vascular bundle in a stem showing xylem and phloem. The sieve tube member (with sieve plates) and companion cell (not seen well here) of phloem are on the right side of the diagram. (Based on Fig. 1.3 from P.S. Nobel, 1991). Diagram drawn by SOLS Artist Service, in 1995. See Fig. 35.11, p. 767, Raven and Johnson for a clearer diagram.

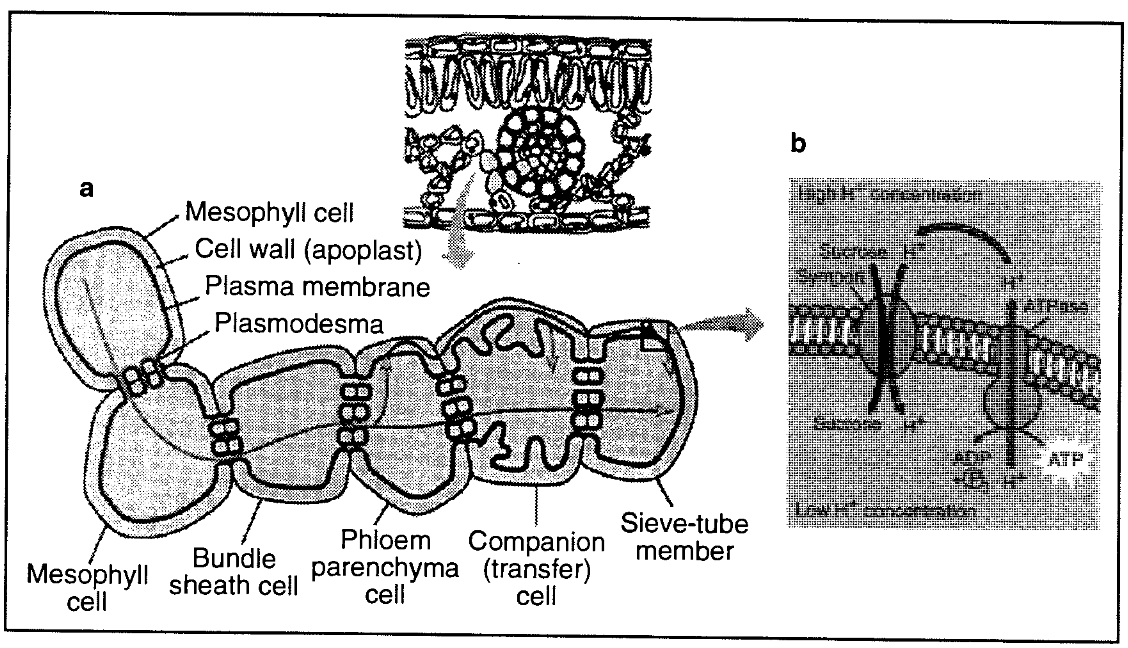


Fig. 3.2 Phloem loading. It occurs either via symplastic (i.e., via cytoplasm and plasmodesmata) pathway or apoplastic (i.e., via cell walls). It also includes "active-transport", i.e., by use of "ATP energy" via the chemiosmotic pathway: ATP hydrolysis at ATPase leads to H^+ translocation. The proton gradient then drives sucrose through a transporter protein (a symport) into the sieve tube member. (Figure based on P.S. Nobel)

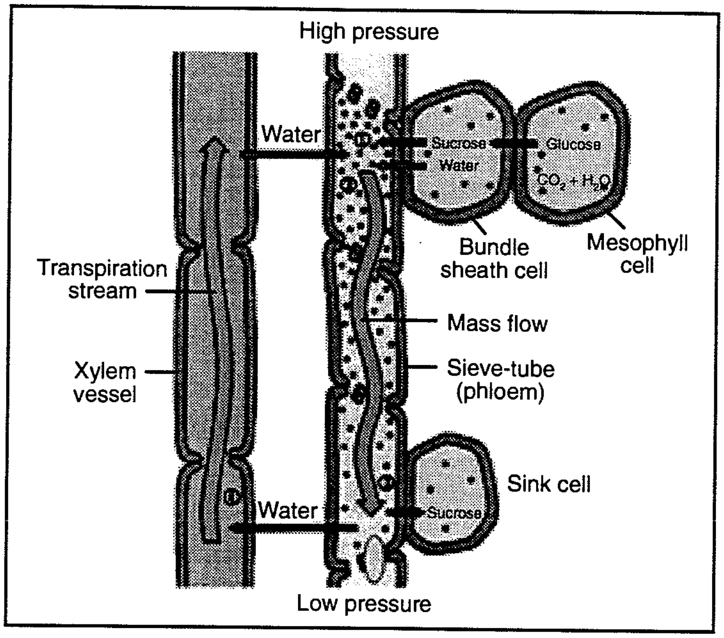


Fig. 3.3 Mass flow hypothesis. 1. Loading of sugars into sieve tube elements decreases the water potential that, in turn, leads to water uptake by osmosis from xylem; 2. the hydrostatic pressure, thus developed, forces the sugar solution to flow down the tube; 3. the unloading of the sugar to sink cell where sugar is either converted to starch of metabolized creates the gradient aiding further flow; and 4. water leaves the sieve tube elements to xylem as the water potential increases due to loss of sugar.

"Gather ye rose-buds while ye may,
Old time is still a flying
And this same flower that smiles today,
Tomorrow will be dying."

Robert Herrick

Table 3.1. Elemental Analysis of a Plant: An Example

Element	Symbol	% of total dry weight
Carbon	C	43.6
Hydrogen	H	6.2
Oxygen	O	44.4
*Phosphorus**	P	0.20
Potassium *	K	0.92
*Nitrogen**	N	1.5
Calcium	Ca	0.23
Magnesium	Mg	0.18
Aluminum	Al	0.11
Sulfur	S	0.05
Boron	B	N.D.
Chlorine	Cl	0.14
Copper	Cu	N.D.
Iron	Fe	0.08
Manganese	Mn	0.04
Molybdnum	Mo	N.D.
Nickel	Ni	N.D.
Silicon	Si	N.D.
Zinc	Zn	N.D.

N.D. = not determined
*These elements are responsible for the term N, P, K in fertilizers on the market.

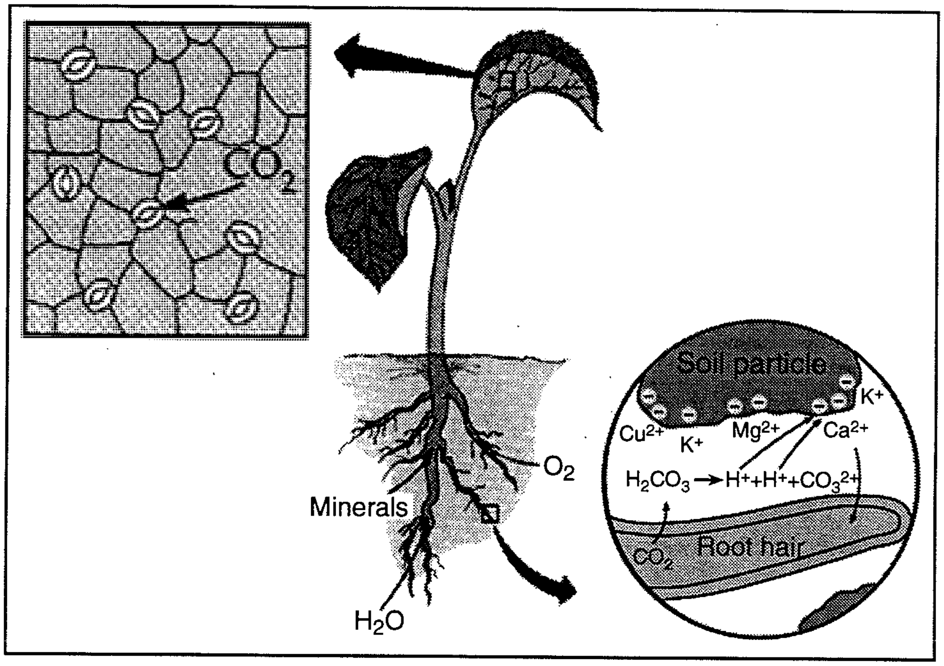


Fig. 3.4. Plants take **C** as CO_2 from air through stomata, and minerals and water from soil; O can be taken as O_2 from both air and soil. Release of CO_2 from roots leads to release of protons that displace cationsfrom soil particles which are then taken up by roots.

Table 3.2 Essential Elements: Data of P.R. Stout (1961)
(arranged in order of decreasing concentration in a plant)
(For symbols, see Table 3.1)

Element	Form Available to plant	Relative Number Compared to Molybdnum
Mo	MoO_4^-	1
Cu	Cu^+, Cu^{2+}	100
Zn	Zn^{2+}	300
Mn	Mn^{2+}	1,000
B	H_3BO_3 ($B_4O_7^=$)	2,000
Fe	Fe^{3+}, Fe^{2+}	2,000
C1	$C1^-$	3,000

Table 3.2 Essential Elements (Continued...)

Element	Form Available to plant	Relative Number Compared to Molybdnum
S	SO_4^{2-}	30,000
P	HPO_4^{2-}, H_2PO4-	60,000
Mg	Mg^{2+}	80,000
Ca	Ca^{2+}	1,250,000
K	K^+	2,250,000
N	NO_3^-,NH_4^+	10,000,000
O	O_2, H_2O	30,000,000
C	CO_2	35,000,000
H	H_2O	60,000,000

Table 3.3 Major functions of essential nutrients

Carbon: Major component of organic compounds (*carbohydrates*, fats, proteins,etc.)

Hydrogen: Major component of organic compounds

Oxygen: Major component of organic compounds

Phosphorus: Component of nucleic acid, phospholipids, various proteins, *ATP*, *ADP*; involved in photosynthesis, respiration

Potassium: Involved in the *opening of the stomates*; activation of many enzymes, charge balancing action during anion transport; operation of stomata.

Nitrogen: Component of nucleic acids, *proteins*, hormones, coenzymes, *chlorophyll* , etc.

Sulfur: Component of essential amino acid *cysteine* and *methionine*, of sulfolipids, of coenzyme A

Calcium: Formation and stability of *cell walls*; maintenance of membrane structure and permeability; activates some enzymes

Magnesium: Part of *Chlorophyll* molecule; needed for function of many enzymes (e.g., *RUBISCO*)

Boron: Several species of green algae, fungi and bacteria *do not* require it, but blue-green algae (now known as cyanobacteria) and diatoms do require it; may be involved in carbohydrate transport and nucleic acid synthesis

Chlorine: Involved in the electron transport reactions in photosynthesis (can be replaced by bromine); functions in osmosis and ionic balance

Copper: Essential in *photosynthesis* of plants (part of *plastocyanin*), essential to respiration (part of *cytochrome oxidase*), and involved in lignin biosynthesis

Iron: Part of key components of *photosynthesis*, *respiration* (e.g., *cytochromes* and *ferredoxins*). Also, essential to nitrogen metabolism, and chlorophyll synthesis

Manganese: Necessary for *Oxygen evolution* in *photosynthesis*, activates some other enzymes as well

Molybdenum: Essential part of nitrate reductase (needed for *nitrogen fixation,* nitrate reduction)

Nickel: Cofactor for an enzyme involved in metabolism of nitrogenous compounds

Zinc: Needed for synthesis of auxin Indole acetic acid, and as a cofactor in *carbonic anhydrase* (an enzyme that interconverts CO_2 and bicarbonate); also active in formation of chlorophyll

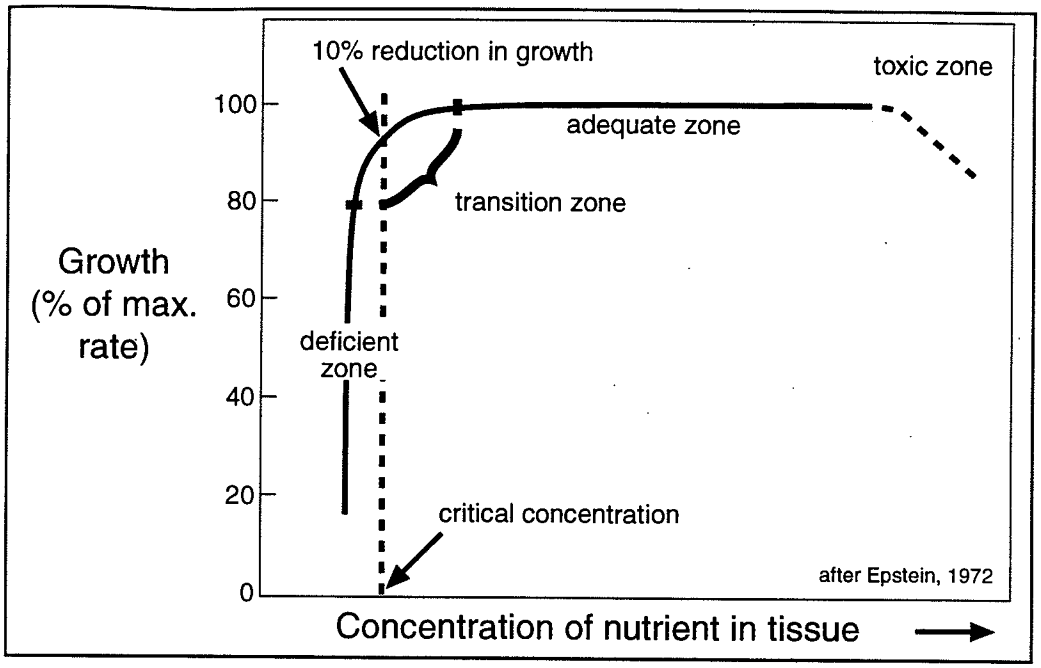


Fig. 3.5. Growth as a function of nutrient concentration in a plant tissue (data of Epstein, 1972). At low concentrations, there is nutrient deficiency and deficiency symptoms are observed. There is a broad range of adequate zone, followed by toxic zone at very high concentrations.

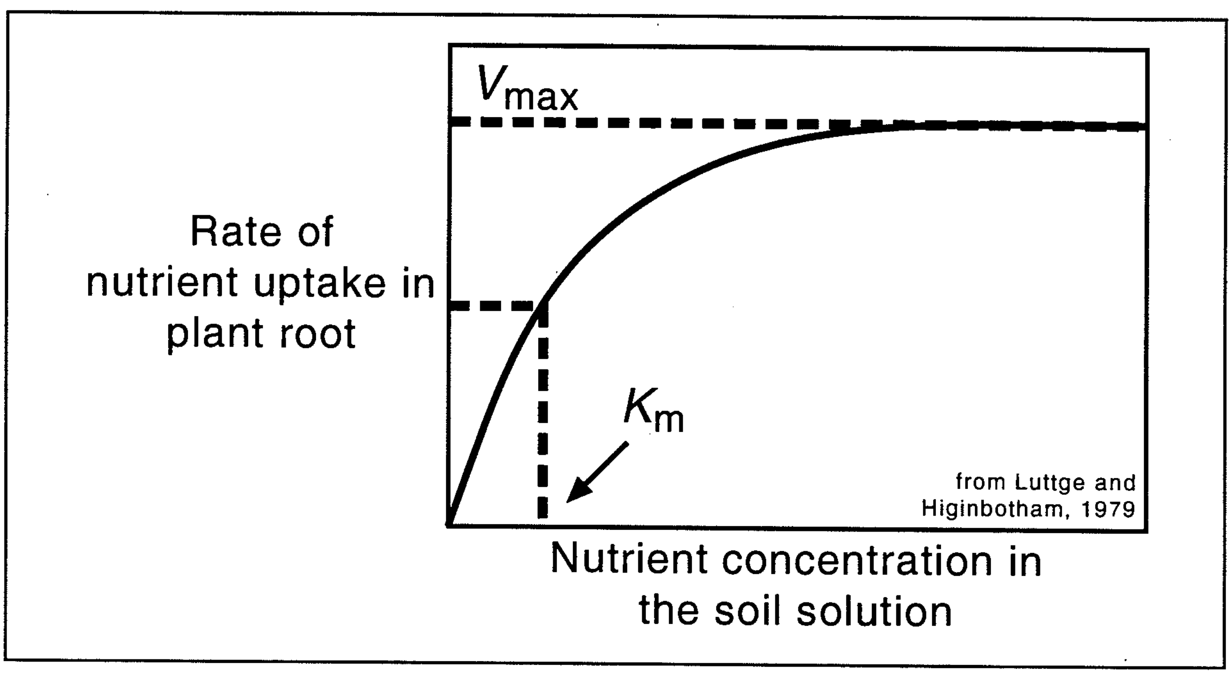


Fig. 3.6. Rate of nutrient uptake, when plotted versus nutrient concentration follows a curve that mimics the plot of a rate of an enzyme reaction versus substrate concentration, *i.e.*, the so-called Michaelis-Menten plot. Different nutrients may be defined by their Km values, *i.e.*, nutrient concentration when the rate of uptake reaches 50% of the maximum rate.

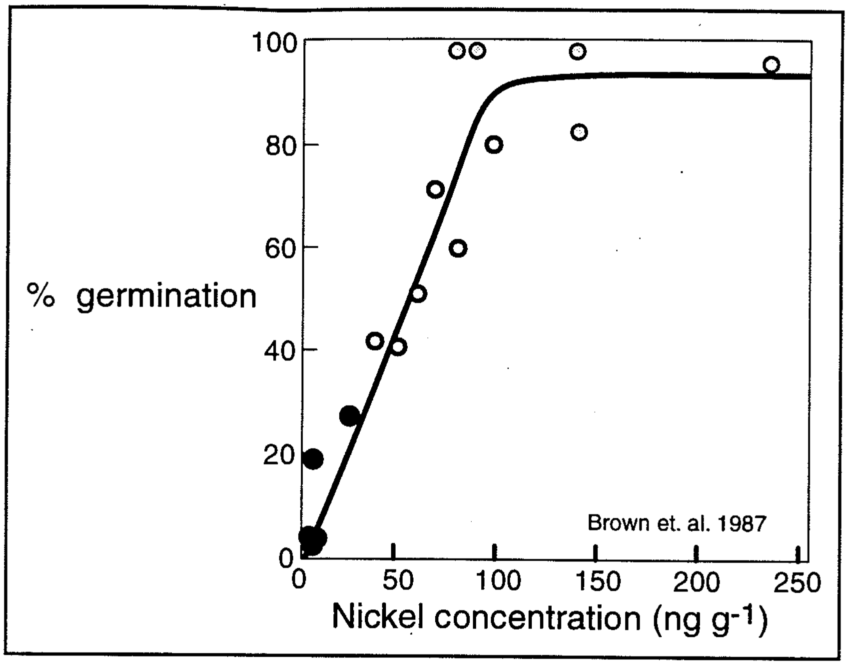


Fig. 3.7. Percent germination of barley grains with different concentrations of nickel (in nano-grams/gram dry weight) obtained by supplying mother plants with different Nickel concentration. (Data of Brown et al., 1987).

Table 3.4: A glimpse at some deficiency symptoms

Phosphorus:	Plants are dark green; pften red and purple, older leaves affected.
Potasium:	Spots of dead tissue small at tips and between veins, older leaves affected; chlorotic leaves, stunted growth.
Nitrogen :	Plants are light green; older lower leaves yellow, drying.
Sulfur :	Young leaves affected but not wilted; these leaves have light green color between veins.
Calcium :	Young leaves affected, first physically hooked -- then dying back at tips and margins: dwarf plant (see Fig. 37.9(a), p. 812, Raven and Johnson for the final result).
Chlorine:	Curled and necrotic leaves (see Fig. 37.9 (c), p. 812, Raven and Johnson).

Table 3.4, Cont'd

Magnesium: Older leaves affected, chlorotic leaves, may be red, tips and margins curled up.

Boron: Young leaves become light green at bases with breakdown there, leaves become twisted.

Copper: Young leaves are permanently wilted without spots or chlorosis (see blue-green curled leaf in Fig. 37.9(d), p. 812, Raven and Johnson).

Iron: Young leaves are not wilted but chlorotic -- but main veins are green.

Manganese: Young leaves are not wilted but spots of dead tissue are all over the leaf (see chlorotic leaves in Fig. 37.9 (f), p. 812, Raven and Johnson).

Zinc: Older leaves are affected, thick leaves, mottled appearance (spots all over) (see small necrotic leaves in Fig. 37.9 (e), p. 812, Raven and Johnson).

Table 3.5. Effects of Mycorrhizae on White Pine (Data of Hatch, 1937)

- Dry weight of seedlings increases by : 25%
- Root/shoot ratio decreases by: 30%
- Nitrogen in leaves increases by: 45%
- *Phosphorus* in leaves increases by: 190%
- Potassium in leaves increases by: 70%

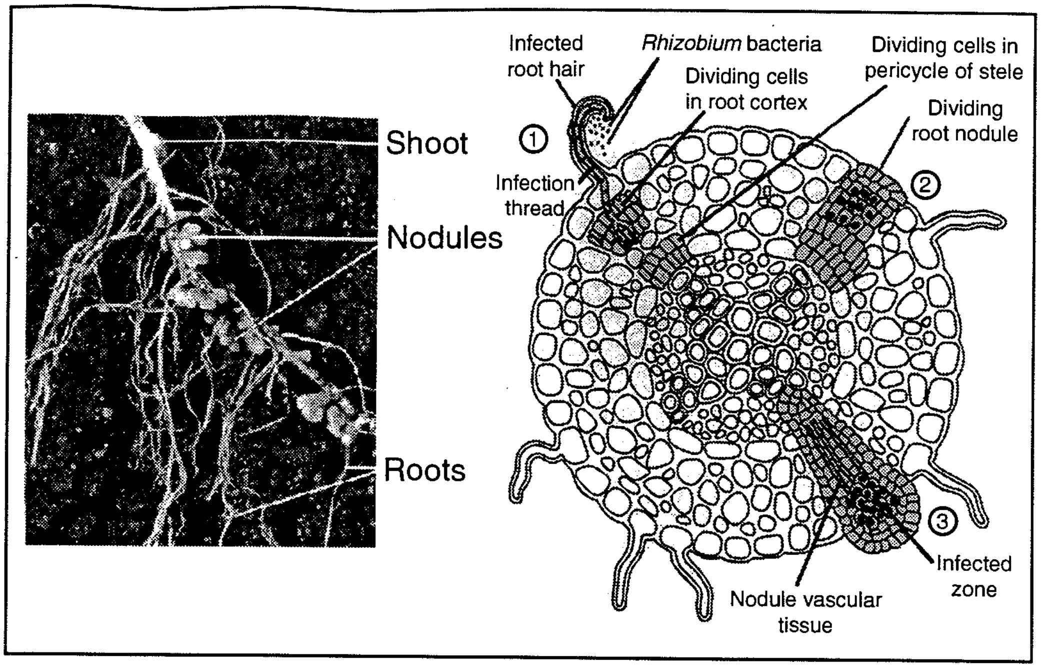


Fig. 3.8. (Left): Rhizobia nodules on a legume root. (Right): This diagram shows the coordinated activities of a legume root and the *Rhizobium* bacteria. Please follow the numbered sequence clockwise; starting at (1) (11 o'clock).

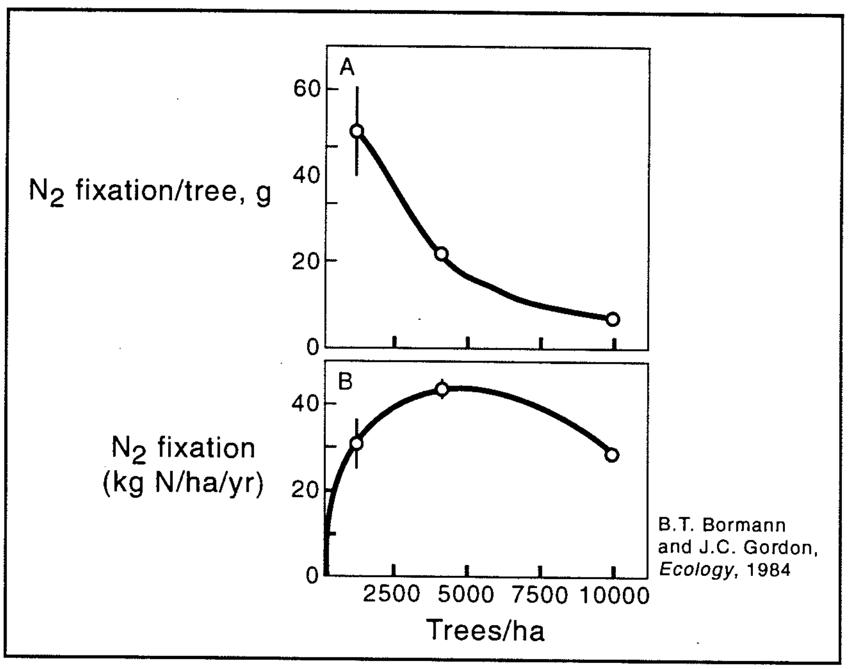


Fig. 3.9. Nitrogen fixation in red alder per tree declines as the plantation density increases (top curve) due to shading of plants that limits photosynthesis and, thus, photosynthates available to N_2 fixing bacteria. However, total N_2 fixed/area increases due to increase in number of trees (bottom curve). Data of Bormann and Gordon (1984). Diagram drawn by SOLS Artist Service, in 1995.

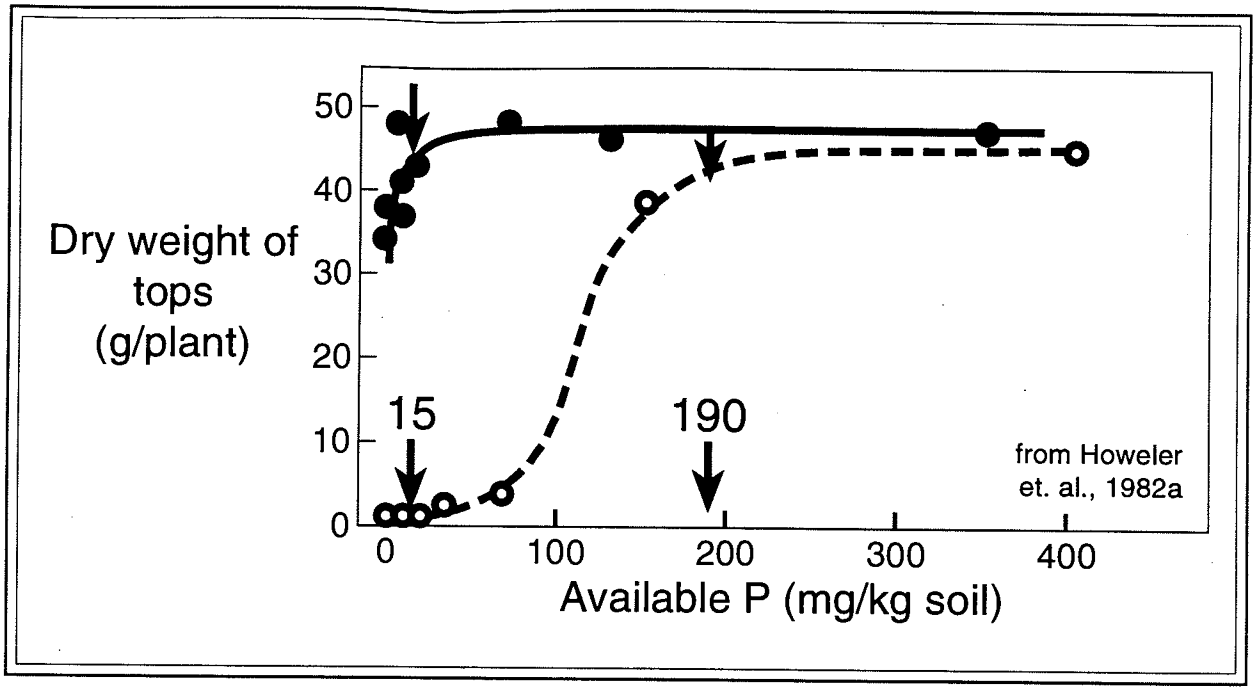


Fig. 3.10. Dry weight of tops in mycorrhizae-infectecd (upper graph) and non-infected (lower graph) cassava plants as a function of available phosphorous in the soil. Data of Howeler et al. (1982). It took much less available phosphorus (8%) to get maximum growth in infected than in uninfected plants. Diagram drawn by SOLS Artist Service, in 1995.

For further reading:

See Chapter 5 (Mineral Nutrition), Chapter 6 (Solute Transport) and Chapter 7 (Phloem Translocation) in L. Taiz and E. Zeiger "Plant Physiology", The Benjamin/ Cummings Pub. Co. , Redwood City, CA.

Lecture 4: Biochemistry: Light Reactions of Bacterial and Plant Photosynthesis

[The sun is not only the author of visibility in all visible things, but of generation and nourishment and growth. "Plato, The Republic."]

Reading assignment:

(1) Raven and Johnson, 4th ed., **Chapter 10, pp 209-232**;
(2) **These Notes**
(3) J. Whitmarsh and Govindjee (1996) "The Photosynthetic Process."
on WWW page: http://www.life.uiuc.edu/govindjee/paper/
(4) Also see Teaching Material on: http://www.life.uiuc.edu/govindjee/

Although, in reality, the only true light reactions are the reactions at the two *reaction center chlorophylls*, P680 and P700, the term has been traditionally used for all the steps that lead to the oxidation of water to oxygen, and production of the reducing power (NADPH) and of ATP.

By the end of your preparation on this topic, you should be able to:

♦ 1. Describe and discuss the overall equation of photosynthesis, i.e., the reactants and products, the source of oxygen, and the maximum quantum yield of oxygen evolution.

♦ 2. What are the major concept involved in photosynthesis up to the time light energy is converted into chemical energy?

♦ 3. Discuss the concepts of Redox Potentials, Free Energy and Entropy.

♦ 4. Discuss the reasons why light energy is needed for photosynthesis.

♦ 5. Discuss the pathway of energy from the time it is captured by the antenna pigment molecules (chlorophyll *a*, chlorophyll *b* and carotenoids) to the time it is converted into chemical energy at the reaction center molecules (the *World's most efficient solar battery*).

Outline: Order of presentation

(Figure and table numbers are either from Raven and Johnson, 4th ed., **or from these notes**)

♦ 1. *The Overall Equation:*

- Place of Photosynthesis: **Fig. 4.1** **Notes**
- The Equation: **Table 4.1** **Notes**

- Source of oxygen: water or CO_2?
- Maximum quantum yield of oxygen evolution: 0.25 (4 photons/ O_2)versus 0.125 (8 photons/ O_2) Controversy between Nobel laureate Otto Warburg (Physiology and Medicine, 1931) and grand nephew of Ralph Waldo Emerson: Robert Emerson (of UIUC, Urbana; Govindjee's professor)

♦ 2. *Light and Photosynthesis:* **Table 4.2** **Notes**

- Dual nature of light:
- Relationship of Energy with wavelength of light:
- Wavelength range of light: Fig. 10.3 p. 213; **Fig. 4.2** **Notes**
- Sunlight: **Fig. 4.3** **Notes**
- Why is light needed? **Table 4.3** **Notes**
- [Discuss concepts of redox potentials, free energy and entropy.]

♦ 3. *Absorption (Capture) and transformation of energy:* **Figs. 4.4 and 4.5** **Notes**

- Key pigment is green chlorophyll *a:* **Fig. 4.6** **Notes**; Fig. 10.5 p. 215
- [Why are plants green?]
- Absorption and Action Spectra: **Fig. 4.7** **Notes**; Fig. 10.5 p. 215
- Absorption, Fluorescence and Energy Migration: **Fig. 4.8** **Notes**
- Concept of Antenna and Reaction centers : Classical Experiments of Robert Emerson and William Arnold (1932).
- Charge separation at the *reaction center*: **Fig. 4.9** **Notes**

  [Structure of the reaction center in photosynthetic bacteria, that do not evolve O_2, was elucidated by Hartmut Michel, Johann Deisenhofer and Robert Huber; they recieved the 1988 Nobel prize in Chemistry for this work.]

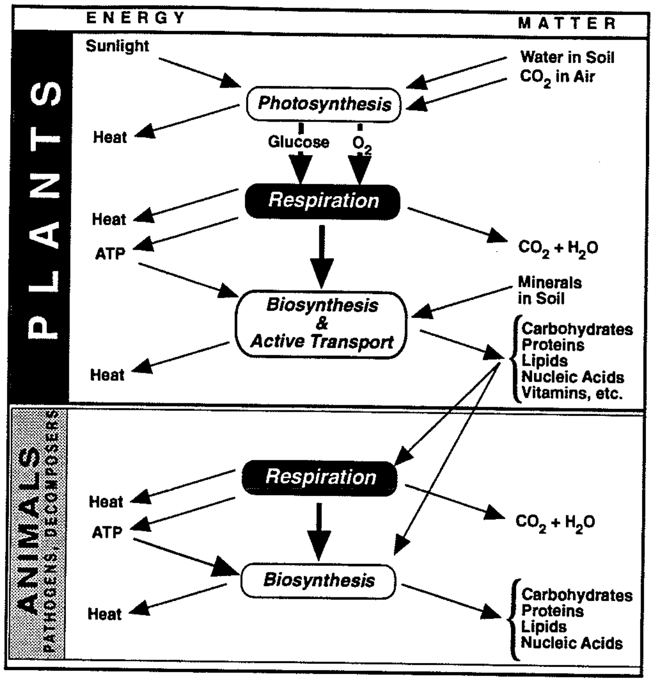


Fig. 4.1. A diagram showing the relationship of Photosynthesis and Respiration.

Table 4.1. Overall Equation for Photosynthesis

$$6\,\overset{*}{C}O_2 + 12\ \overset{\square}{H}_2\overset{+}{O} + 48 \text{ photons}$$

(Carbondioxide) (Water)

$$\Big\Downarrow \quad \text{Chloroplasts}$$

$${}^{*}C_6\overset{\square}{H}_{12}O_6 + 6\,\overset{+}{O}_2 + 6H_2O$$

(glucose) (oxygen)

The formation of glucose and oxygen from water and CO_2 requires approximately 112 kilocalories per O_2 released, i.e., 672 kilocalories per glucose and 6 O_2 formed. 8 photons of red light have available approximately 320 kilocalories per O_2 released; 48 photons of red light have 1,820 kilocalories of energy available for the formation of one glucose and 6 O_2. Thus, there is plenty of energy for the reaction to proceed, at an overall efficiency of about 37%. The minimum number of photons needed for the evolution of one O_2 molecule was claimed to be 4 photons or less by Otto Warburg, but was challenged by his student Robert Emerson, and shown to be 8 photons, and confirmed by the author, among others.

The source of oxygen in photosynthesis is H_2O, not CO_2 as shown by (1) the finding that ^{18}O labeled water, not CO_2, led to ^{18}O in the O_2 released; and (2) the Hill Reaction in chloroplasts leads to O_2 evolution when CO_2 is replaced by artificial chemicals (such as ferricyanide or dichorophenolindophenol).

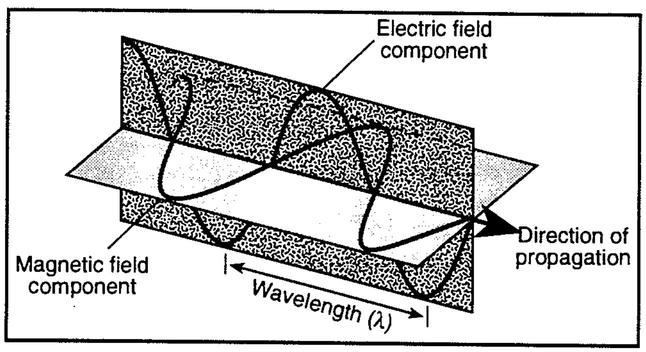
Table 4.2. About Light

- Light has a dual nature: it has both a wave and a particle character

- Energy (**E**) of a particle of light (this particle is called a photon or a quantum) is inversely related to the wavelength (λ) of light (see diagram at the bottom) through the velocity of light (**c**= 3×10^8 meters per second) and a constant, the Planck constant (**h**), named after the Nobel laureate Max Planck:

$$\mathbf{E} = \frac{hc}{\lambda}$$

A blue photon has more energy than a red photon (see **Fig. 4.2**)



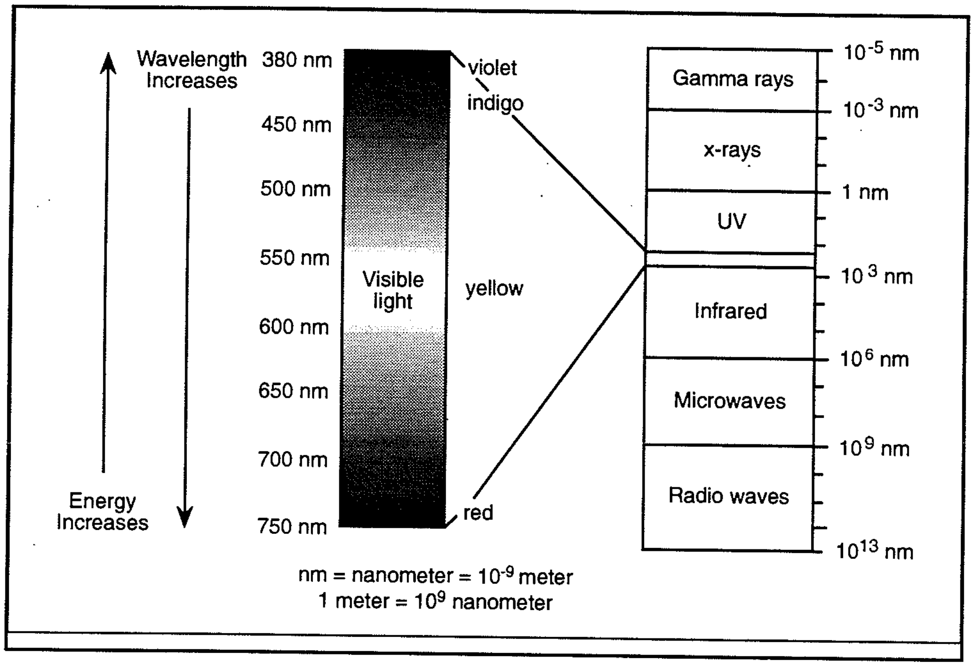


Fig. 4.2. Light is just a small portion of the overall electromagnetic waves available in the universe. Its wavelength (length of its wave) ranges from 380nm to 750nm. Chlorophylls absorb red and blue light, but transmit or reflect green light making the leaves appear green to our eyes. The equation, given in Table 4.2, shows the inverse relationship of energy to wavelength.

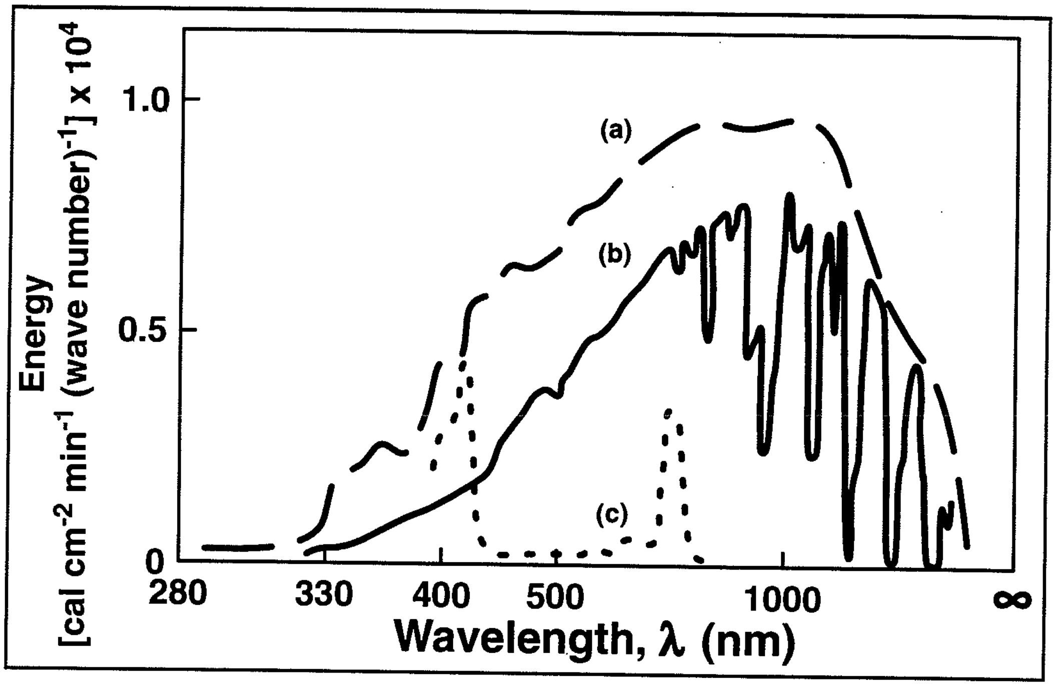


Fig. 4.3. The solar spectrum as it originates in the sun (top curve,a), as it strikes the Earth (middle curve, *b*), and the absorption spectrum of the pigment chlorophyll (bottom curve,*c*). Modified from Chapter 8, Taiz and Zeiger, *Plant Physiology*, 1991, The Benjamin/Cummings Pub., Redwood City, CA.

Earth is 150,000,000 kilometers from the sun. Since the velocity of light is 3×10^8 meters per second, you can calculate that it will take about 8 minutes for light starting on the surface of the sun to reach a chlorophyll a molecule in a leaf. However, a chlorophyll a molecule, upon receiving a photon, reaches its excited state within a femtosecond (10^{-15}).

Note that there are as many femtoseconds in a second, as there are seconds in 31 million years! Right?

Table 4.3. Why is light Needed for Photosynthesis?

Answers can be given at several levels:

- Respiration, the reverse of photosynthesis, releases energy; thus, photosynthesis must need energy.
- The products of photosynthesis (carbohydrate and oxygen) have much more energy than the reactants (CO_2 and H_2O). The difference in energy is supplied by light.
- Chemical reactions proceed in the direction that lead to negative free energy ($-\Delta G$)**. Electron transfer from H_2O to CO_2 has a positive free energy making it an impossible reaction unless light energy is added as a reactant to make the reaction possible.

** $\Delta G = -nF\Delta E$, where n = number of electrons transfered, F = Faraday Constant, ΔE = difference in redox potentials.

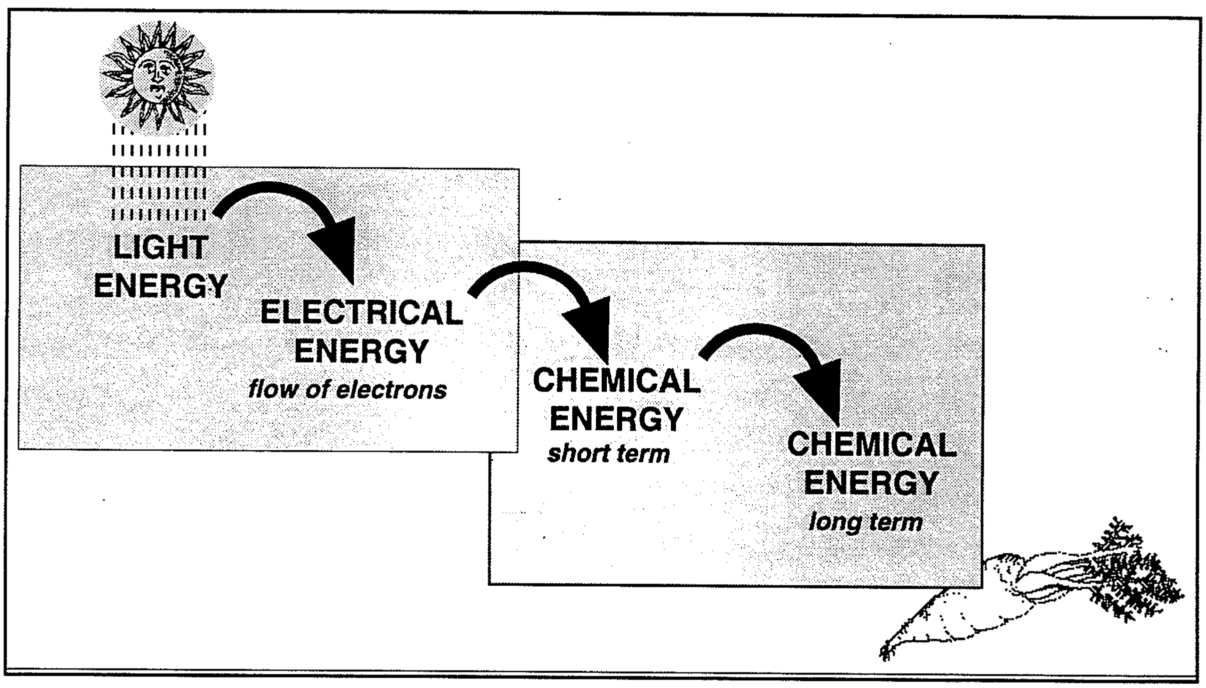


Fig. 4.4. Photosynthesis is the only process on Earth that converts light energy into chemical energy on a massive scale. The carrots we eat is made up of "sunbeams" as we might say. Diagram is courtesy of Professor T. Jacobs.

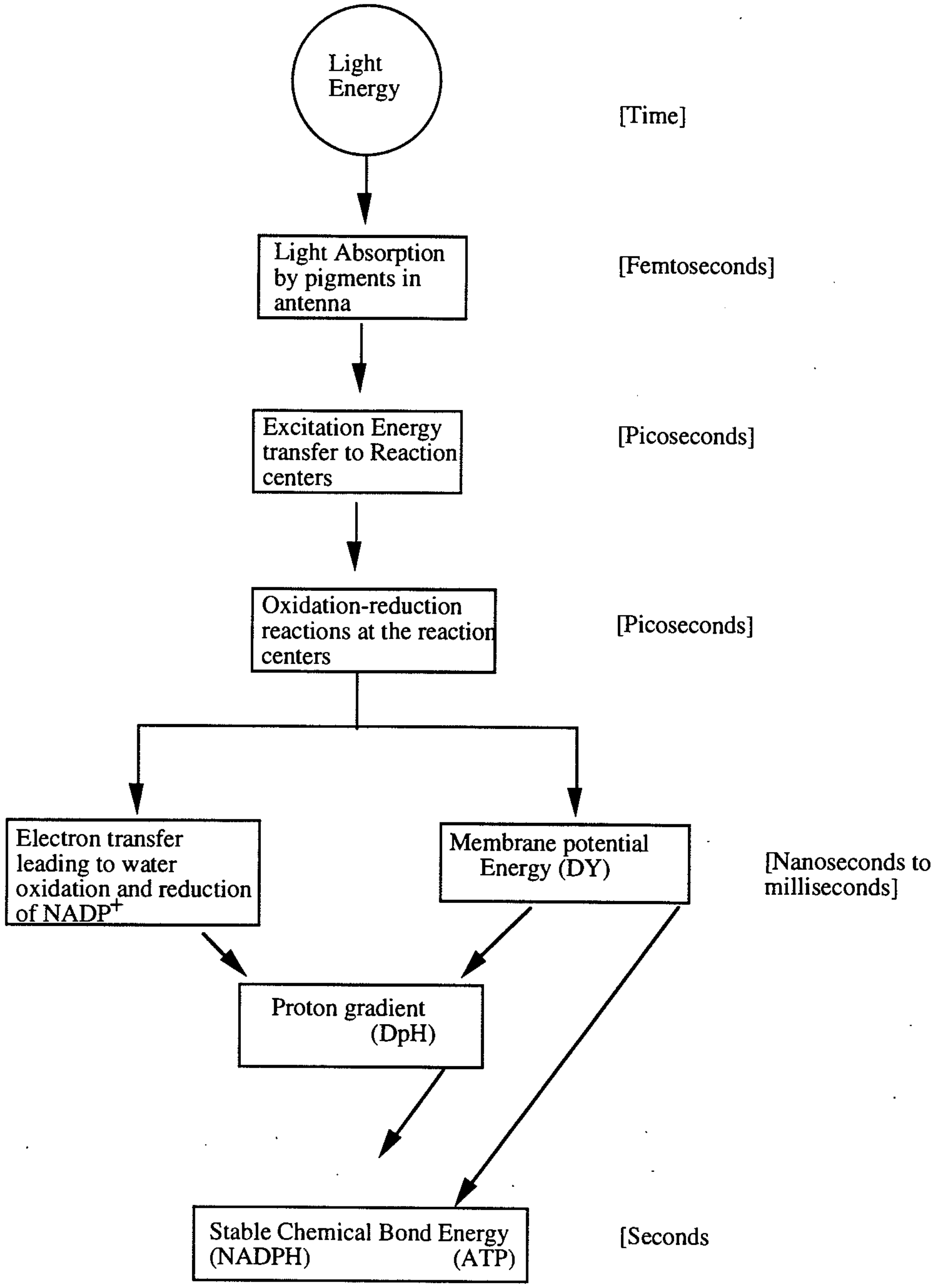


Fig. 4.5. Transformation of light energy into chemical energy. In antenna system of photosynthesis, light energy, upon its absorption by pigment molecules, is first transformed into excitation energy (where an electron in a molecule is raised from its low energy level to a high energy level). This is followed by its transfer to reaction centers where conversion into oxidation-reduction energy (chemical energy) takes place. This leads to the oxidation of water to O2 and the production of the reducing power in the form of NADPH. In addition, the oxidation reduction energy can also be in the form of membrane potential ($\Delta\Psi$) energy, as well as lead to a proton gradient (ΔpH) across the thylakoid membrane, the ΔpH + $\Delta\Psi$ together are then used to produce ATP from ADP and inorganic phosphate. Diagram by the author, modified from Whitmarsh and Govindjee.

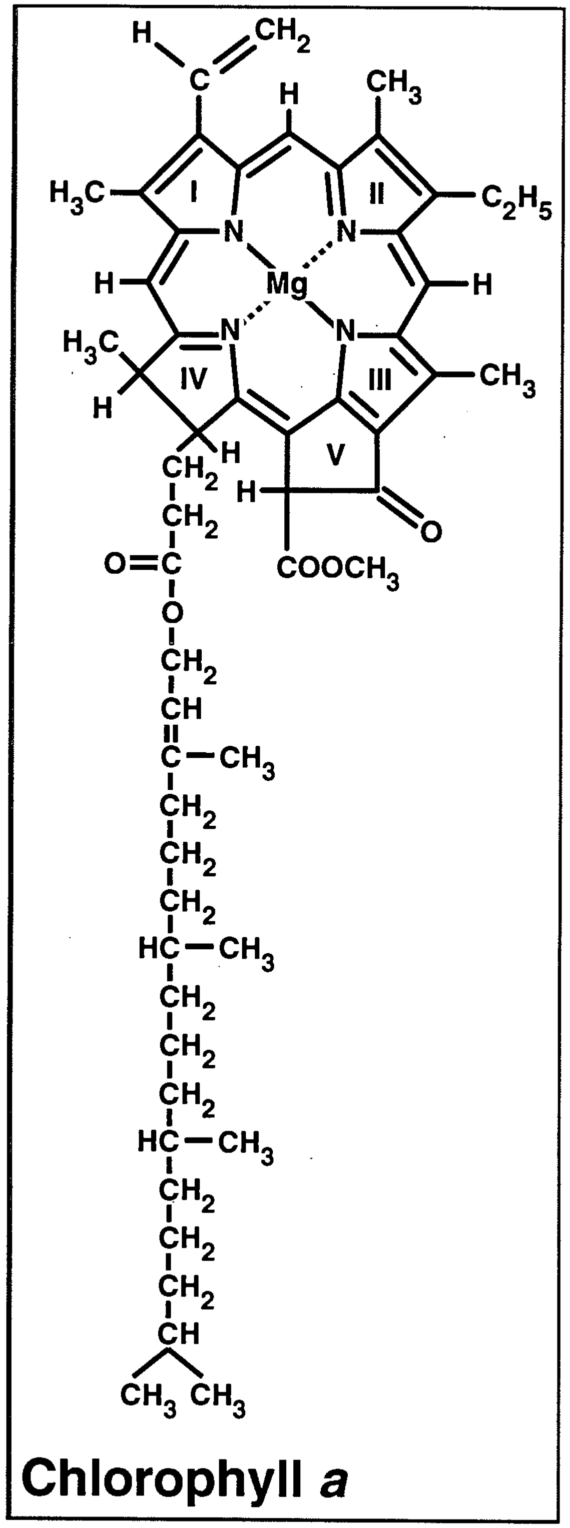


Fig. 4.6. Structure of Chlorophyll *a* molecule. Note the magnesium in the center, the four N-atoms connected to it, and the alternating single-double-bond arrangement in the rings (I-IV). Nobel laureates R. Wilstätter, Hans Fischer and R. Woodward were responsible for its structure. (Reproduced from Govindjee and Govindjee, Scientific American, December, 1974) ;

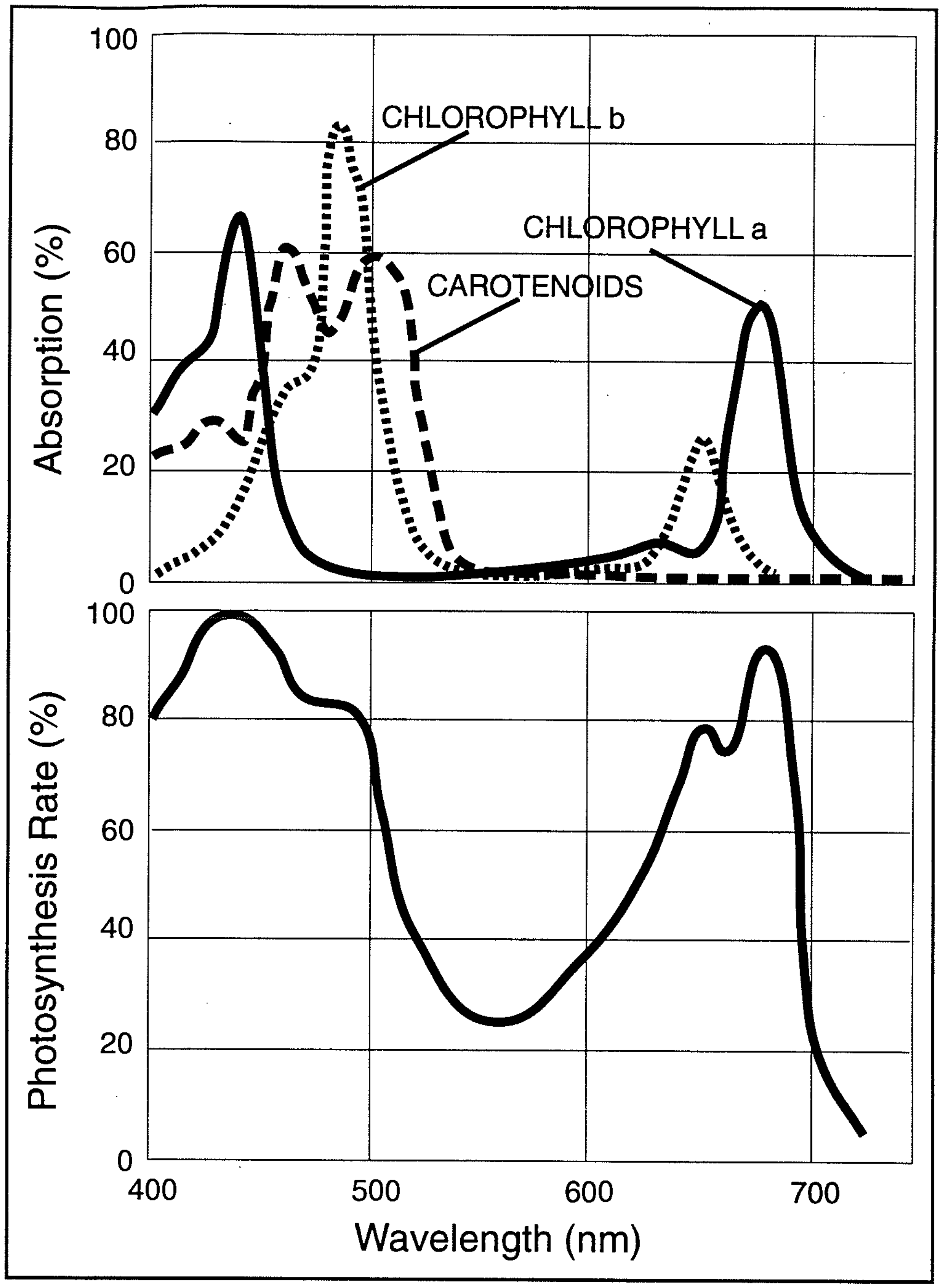


Fig. 4.7. *TOP*: Absorption spectra of chlorophyll *a* , chlorophyll b and yellow pigments carotenoids. *Bottom*: Action spectra of photosynthesis (oxygen evolution/incident photon) show peaks at wavelengths where chlorophylls *a* and *b* absorb proving that light absorbed by these pigments leads to photosynthesis. Original data of Govindjee (1961). (The earliest experiments by T. Englemann on action spectra of photosynthesis are shown in Fig. 10.6 in Raven and Johnson.)

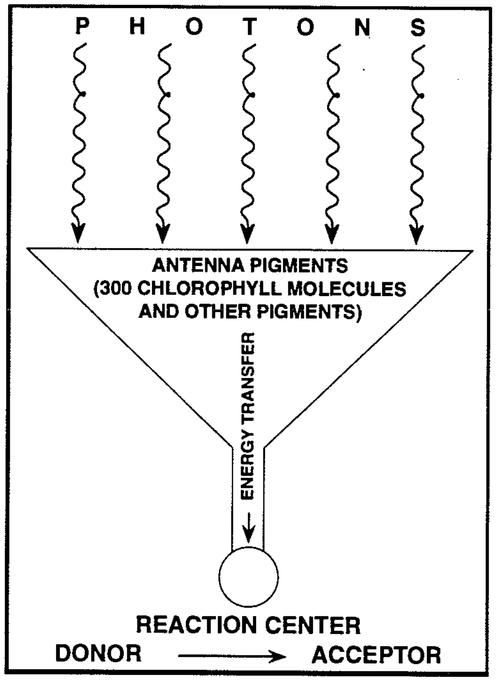


Fig 4.8. The concept of light absorption in hundreds of antenna chlorophylls followed by excitation energy transfer to a reaction center chlorophyll is shown in this "funnel" diagram. The antenna and reaction center chlorophyll molecules are physically located in different proteins. (Govindjee and Govindjee, Scientific American, December, 1974.)

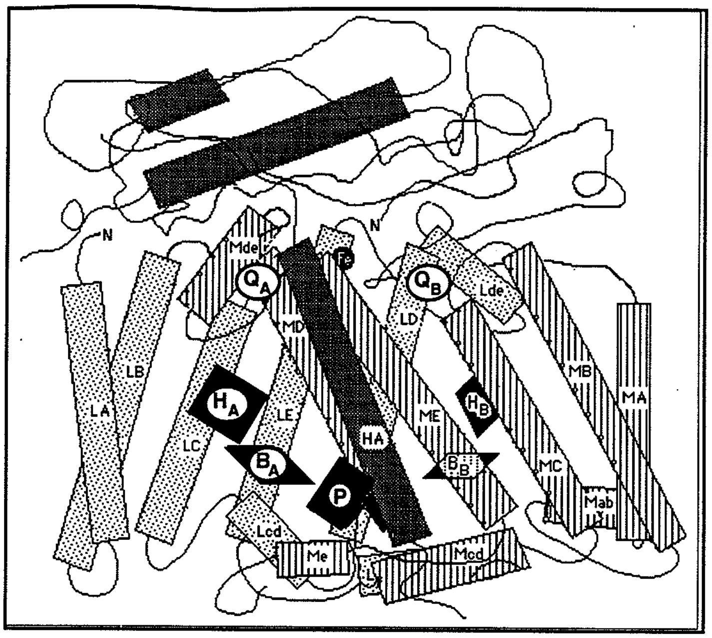


Fig. 4.9. Structure of the bacterial reaction center by Nobel laureates H. Michel, J. Deisenhofer and R. Huber. It contains three proteins: "H (shown in black) "L" (shown as dotted)" and "M" (shown as hatched bars). Both "L" and "M" have 5 helices each (labeled LA, LB, etc.) and "H" is shown in the middle of the molecule — it has one helix (HA) that goes through the membrane. P is photoactive dimer of bacteriochlorophyll; B is monomeric bacteriochlorophyll; H=bacteriopheophytin - like bacteriochlorophyll, but without Mg^{2+}; Q_A and Q_B are quinone molecules. Diagram courtesy of Prof. Colin Wraight of UIUC, Urbana.

For further reading:

See chapter 8 (Photosynthesis: The Light Reaction) in L. Taiz and E. Zeiger "Plant Physiology", The Benjamin/Cummings Pub. Co., Redwood City, CA

Lecture 5: Biochemistry: Electron Transport and Photophophorylation

Reading assignment:

(1) Raven and Johnson, 4th ed., **Chapter 10, pp 209-232** (also needed for lecture 6)
[Have you already read Chapters 8 amd 9 in Biol. 120?];
(2) **These Notes**
(3) J. Whitmarsh and Govindjee (1996) "The Photosynthetic Process."
on WWW page: http://www.life.uiuc.edu/govindjee/paper/
(4) Also see Teaching Material on: http://www.life.uiuc.edu/govindjee/

By the end of your preparation on this topic, you should be able to:

- 1. Discuss the pathway of electron transfer from water molecules, in chloroplast membranes, to the electron acceptor Nicotinamide Adenine Dinucleotide Phosphate (abbreviated as $NADP^+$).
- 2. Discuss the "clock" mechanism by which oxygen molecules are released by plants.
- 3. Discuss how the energy currency of life Adenosine Tri Phosphate (abbreviated as ATP) is made by chloroplast membranes.
- 4. Describe to your parents/friends why the following were awarded nobel prizes in chemistry: **(1)** P. Mitchell, 1978; **(2)** H. Michel, J. Deisenhofer and R . Huber, 1988; **(3)** P. Boyer and J.E. Walker, 1997.

Outline: Order of presentation
(Figure and table numbers are either from Raven and Johnson, 4th Ed., **or from these notes**)

- 1. *Pathway of electron transfer from water to $NADP^+$* producing oxygen and the reducing power (NADPH, the reduced form of nicotinamide adenine adenine dinucleotide phosphate):

• The four protein complexes:	**Fig. 5.1**	**Notes**
	Fig. 10.11	p. 221
• The Z scheme for electron transport:	**Fig. 5.2**	**Notes**
	Fig. 10.10	p. 220

♦ 2. *The Oxygen clock* :

- O_2 evolution in a series of light flashes:

[Experiments by Pierre Joliot, grandson of Marie and Pierre Curie]

- The O_2 Clock: **Fig. 5.3** **Notes**

♦ 3. *The ATP synthesis*: **Fig. 5.4** **Notes**

- A protein gradient is created by electron flow, and its dissipation via the enzyme ATPase (ATPsynthase) leads to ATP formation [an idea of Peter Mitchell for which he was awarded the 1978 Nobel Prize in Chemistry]
  Figs. 10.11 and 10.17 pp. 221 and 226

- Artificial proton gradient can make ATP:
  (Discussion of the Experiments of Andre Jagendorf)

- Protein gradients cause physical and chemical changes in the ATPsynthase that lead to the conversion of this energy into conformational and rotational energy of the γ-Sub unit of the enzyme which, is then responsible for the energy requiring step: kicking off the bound ATP to free ATP. Recent atomic resolution structure of ATPsynthase by J.E. Walker and his associates supports this picture. Boyer and Walker were awared the 1997 Nobel Prize in Chemistry for their work.

- Now, with ATP and NADPH, we can fix CO_2 (see next lecture)

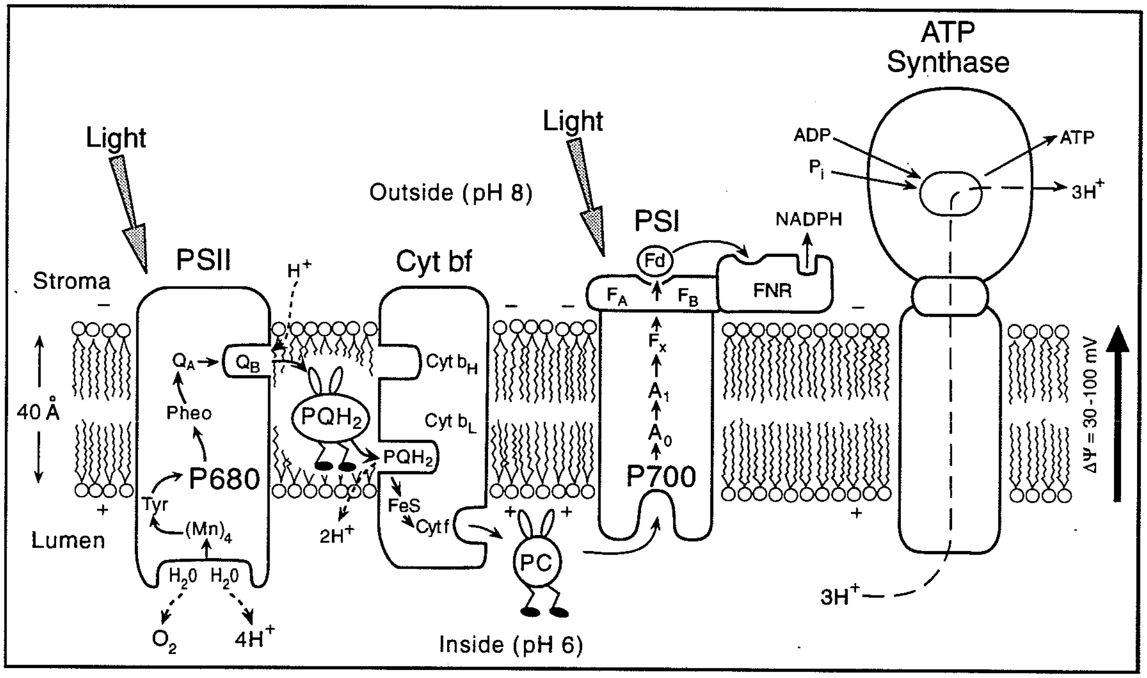


Fig. 5.1. Four major protein complexes are needed for the production of the reducing power NADPH and ATP needed for the fixation of CO_2 and production of glucose (to be discussed in the next lecture): **Photosystem II** (PSII, that oxidizes water to oxygen, reduces a plastoquinone molecule, and releases protons in the interior of the thylakoid membrane); **Cytochrome b/f** (Cytbf) complex (that oxidizes reduced plastoquinone, reduces a copper protein plastocyanin (PC), and releases protons in the interior of the thylakoid membrane); **Photosystem I** (PSI, that oxidizes reduced plastocyanin and reduces $NADP^+$,the nicotinanide adenine dinucleotide phosphate, to NADPH); and **ATPSynthase** (that uses the membrane potential, $\Delta\Psi$, and the proton gradient to produce ATP from ADP and inorganic phosphate). The membrane potential is produced and electron transport occurs when photosynthesis is simultaneously powered by light absorbed in both photosystems I and II. Electron flows from the inner side of the thylakoid membrane to the outerside of the membrane; this makes one side of the membrane more negative than the other. The names of the electron carriers except of the reaction center chlorophylls P680 (in Photosystem II) and P700 (in Photosystem I) may be ignored at the moment. Diagram modified from Whitmarsh and Govindjee (1995).

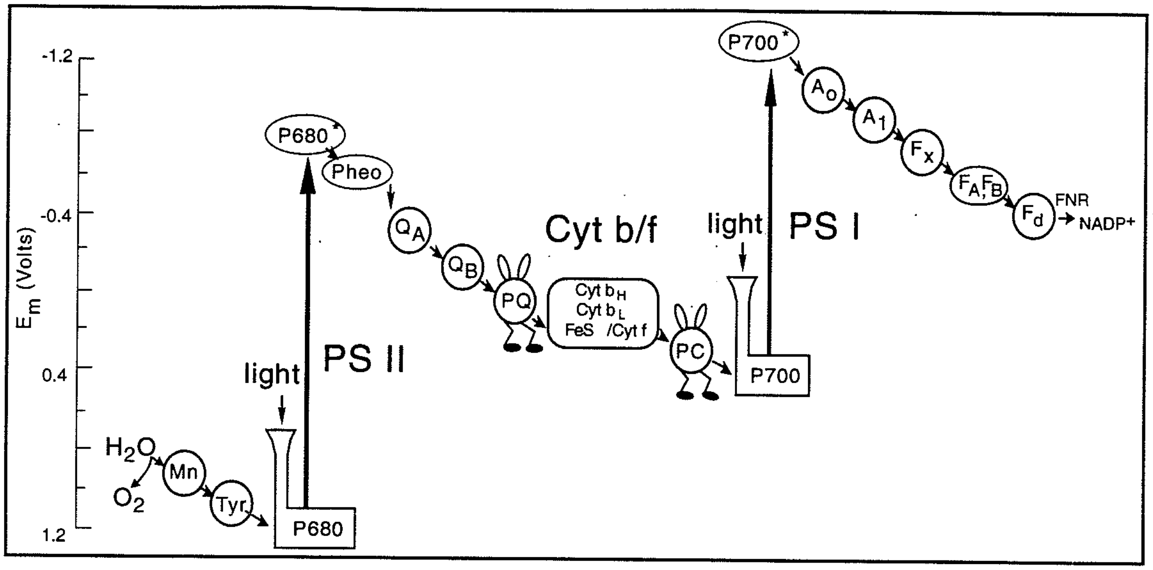


Fig. 5.2. The description given below will be explained in the class. The electron transport pathway of plant photosynthesis (see Fig. 5.1 to physically locate these intermediates there.) Photosynthesis starts by simultaneous excitation of special reaction center chlorophylls labeled as P680 and P700. Excited P680 (P680*) and P700 (P700*) have excess energy provided by light. An electron transfers out of P700* to Ao (another special chlorophyll *a* molecule) producing oxidized P700 ($P700^+$) and reduced Ao (Ao^-). At about the same time, an electron transfers out of P680* to a pheophytin (Pheo) molecule producing oxidized P680 ($P680^+$) and reduced Pheo ($Pheo^-$). These are the steps where light energy is used to produce oxidation-reduction energy. The rest of the reactions are downhill energy wise. $P700^+$ recovers to P700 receiving by an electron originating in $Pheo^-$ that is passed on to $P700^+$ via the following intermediates *in a bucket brigade manner*: from $Pheo^-$ to Q_A (a bound plastoquinone) to Q_B (another bound plastoquinone) to PQ (freely *mobile* plastoquinone) to an Iron Sulfur potein (FeS) to a cytochrome (Cytf) to a freely mobile plastocyanin (PC) and finally to $P700^+$. On the other hand, electron on Ao^- is passed on, ultimately, to the $NADP^+$ via several other intermediates (A1, a phylloquinone, Fx, F_A and F_B, three iron-sulfur proteins, and Fd, ferredoxin). The missing electron on P680+ is recovered, *ultimately*, from water molecules (H_2O) via an amino acid tyrosine (Yz) and a tatra - manganese complex (Mn). Four such reactions (utilizing a total of 8 photons, 4 in PSII, and 4 in PSI) are required to oxidize H_2O to 1 O_2 and reduce 2 $NADP^+$ to 2NADPH. The left side of the diagram shows an energy scale in terms of oxidation reduction potential (Em) at pH7. (At pH7, the standard hydrogen electrode has an Em of - 0.4 volts.) Intermediates, that are high up in the diagram, have a lower (or more negative Em) and can easily *reduce* (i.e., add an electron to) any intermediate below them in the diagram by a downhill energy wise process. Energy is needed to transfer electrons from intermediates on the lower part of the diagram to those above them. This is why "light" is needed to transfer electrons from P680 to Pheophytin, and from P700 to Ao. Diagram is modified from Whitmarsh and Govindjee (1995).

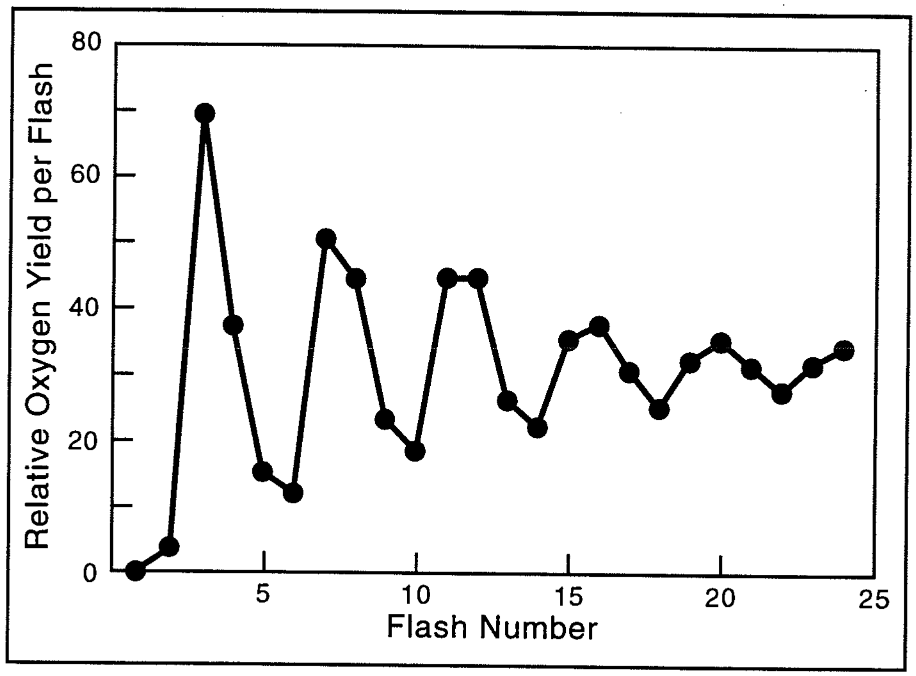


Fig. 5.3. Data of Pierre Joliot and coworkers. Yield of oxygen from photosynthetic membranes, exposed to a series of brief flashes of light oscillates with a four-point periodicity. It is highest after the third flash and peaks again four flashes later, but the variation in the amplitude gradually decreases as the number of flashes increases. The occurrence of the peaks every 4th flash is explained by the four-step cycle of the water-oxidizing clock. The main spring of the clock needs to be wound up four times: wind, wind, wind, and wind, and then it ticks once. What winds it is the light. Water oxidizing **clock** is a cyclic mechanism that supplies electrons to the oxidized P680, $P680^+$. After one flash of light, the $P680^+$, thus formed, picks up an electron from a maganese complex (4 Mn atoms) oxidizing it once. After a second flash, a second oxidation occurs at this Mn complex; after a third flash, a third oxidation occurs; and after a fourth flash, a fourth oxidation occurs, *i.e.*, the Mn complex has accumulated 4 positive (+) charges. This oxidized complex, thus, has enough oxidizing power to oxidize 2 H_2O into O_2, and to release 4 protons (H^+s) into the thylakoid lumen. It gets itself reduced with 4 electrons (from $2H_2O$) returning to the original state. To match this theory with the above data, it is necessary to propose that in darkness, the Mn complex starts already one step ahead, i.e., first time around, the 3rd flash does the trick, and, then every 4th flash. This is the oxygen clock. (Diagram from Govindjee and Coleman, Scientific American, February, 1990).

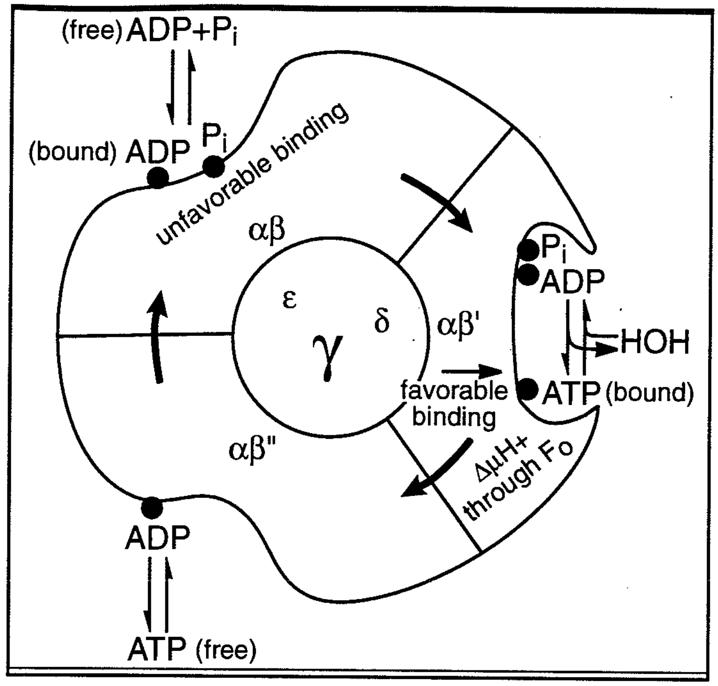


Fig. 5.4. The ATP synthase consists of a membrane portion and an exposed portion (see Fig. 5.1). The exposed portion, that looks like a door knob, has five subunits. $3\alpha, 3\beta, 1\Upsilon, 1\delta$ *and* $1 \in$). The $3\alpha, 3\beta$ are paired as $\alpha - \beta$ pairs and β συβυνιτσ αρε τηε the catalytic sites of the enzyme. The Υ subunit sort of connects the exposed part to the membrane part (Fo). The diagram shows a model of the top of the ATP synthase according to Paul Boyer of UCLA, California. In this model, there are three alternate binding sites. At one site ADP and Pi bind; at another site ADP and Pi produce bound ATP; and at the third site bound ATP is released. In this model, most energy is used to release bound ATP. Each of the three sites perform all three steps, but at different times. Thus, the activity rotates on the α–β παιρσ, The energy of the proton gradient is converted, in this model, to conformational energy of the α protein that rotates and transfers the energy to the α–β pairs for the simultaneous binding of ADP+Pi and the release of ATP. (Evidence for such a scheme has been found in a 1994 paper, published in *Nature*, on the structure of beef-heart mitochondrial ATPase, obtained by X-ray crystallography.)

For further reading:

See Chapter 8 (Photosynthesis: The Light Reaction) in L. Taiz and E. Zeiger " Plant Physiology," The Benjamin/ Cummings Pub. Co., Redwood city, CA.

Lecture 6: Metabolism: Carbon Assimilation

Reading assignment:

(1) Raven and Johnson, 4th Edition, **Chapter 10, pp. 221-232** (2) **These notes**

By the end of your preparation on this topic, you should be able to:

- 1. Discuss the three major steps (carboxylation, reduction and phosphorylation, and regeneration of the receptor molecule for CO_2) in the formation of sugars from CO_2.
- 2. Discuss the contrasting carboxylase and oxygenase function of the enzyme **RUBISCO** (Ribulose bisphosphate carboxylase and oxygenase): *Calvin cycle* versus *photorespiration.*
- 3. Describe the three different pathways for CO_2 fixation in plants labeled as *C-3*, *C-4* and *CAM*.
- 4. Discuss how these different plants function in different environment (light intensity, temperature, CO_2 and O_2 concentrations, etc).
- 5. Define the following **concepts** and **terms**: Bundle sheath cells; Kranz anatomy; PG Acid (a C-3 acid); Troise phosphate (a C-3 sugar) Ribulose bisphosphate; Peroxisome; PEPtCase'; Pyruvate (a C-4 intermediate) Malate. These should become obvious from these notes).

Outline of presentation:

(Figure and table numbers are either from Raven and Johnson 4th ed., **or from these notes**)

♦ 1. Magnitude of carbon assimilation and source of energy:	**Table 6.1**	**Notes**

♦ 2. *The Calvin cycle* (named after Melvin Calvin who was responsible for the cycle; he recieved the 1961 Nobel Prize in Chemistry for this work)

• End products of "Light Reactions" NADPH and ATP are the source of energy for *Carbon Assimilation:*	**Fig. 6.1**	**Notes**
• The three basic steps in the Calvin cycle:	**Fig. 6.2** Fig. 10.13	**Notes** p.224

[Which step is the energy requiring step?]	**Table 6.2**	**Notes**
• Experimental evidences	**Fig. 6.3**	**Notes**
• *RUBISCO*		
• The enzyme:	**Table 6.3**	**Notes**
• Carboxylation versus oxygenation:	**Table 6.4**	**Notes**
• Photorespiration:	**Fig. 6.4**	**Notes**
♦ 3. *Different Pathways for CO_2 fixation*:		
• C-3 Photosynthesis:	**Fig. 6.2**	**Notes**
• C-4 Photosynthesis: add-on to C-3 cycle:		
• Pathways in Bundle sheath and Mesophyll cells:	**Fig. 6.5** Fig. 10.18	**Notes** p. 227
• CAM Pathway:	**Fig. 6.6**	**Notes**
• Day and Night steps:	**Fig. 6.7**	**Notes**
♦ 4. A comparison of C-3, C-4 and CAM plants:	Fig. 10.19	p.228
• Comparison:	**Fig. 6.5**	**Notes**
• C-3 and C-4 plant production at different latitudes:	**Fig. 6.8**	**Notes**
• Dependence of saturating rates of photosynthesis on temperature:	**Table 6.9**	**Notes**
• Dependence of quantum yield of photosynthesis on CO_2 and O_2 concentrations:	**Table 6.10(left)**	**Notes**
• Dependence of quantum yield of photosynthesis on temperature:	**Table 6.10 (right)**	**Notes**

Table 6.1 Magnitude and Source of Energy for incorporation of CO_2 into Sugars

- 200 billion tons of CO_2 is fixed into biomass /year on Earth
- The source of energy is the solar energy converted by the light reactions into the reducing power (NADPH) and ATP; and it is specifically used in two key steps (see Figs. 6.1 and 6.2)

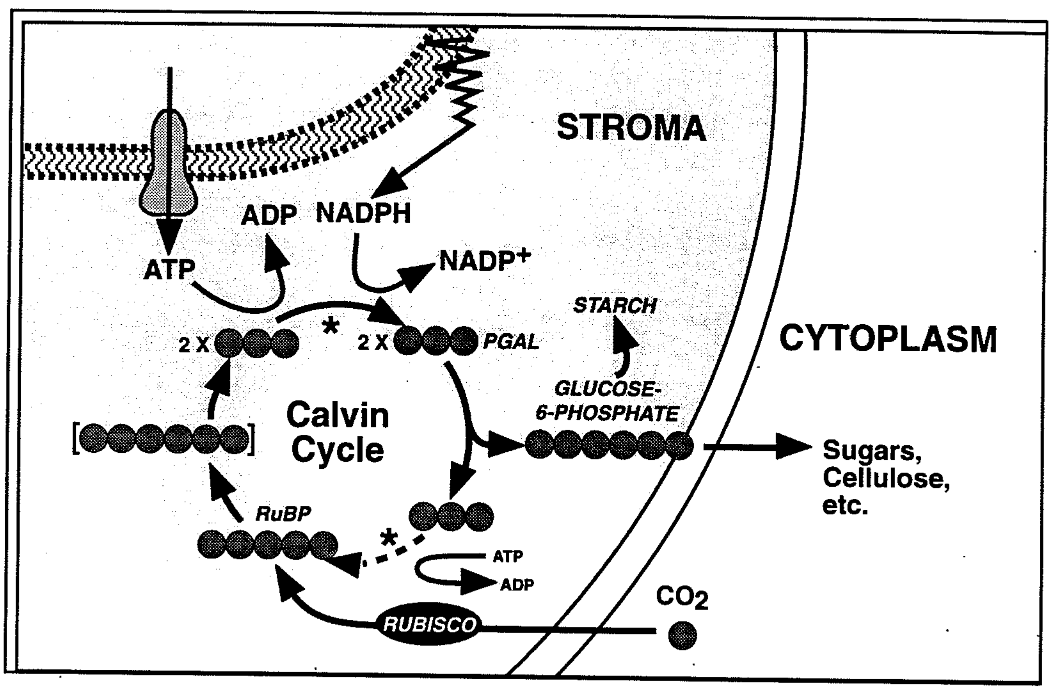


Fig. 6.1. "Light reactions" produce ATP and NADPH (on thylakoid membranes, see top left of diagram). These are used in the Calvin cycle for CO_2 fixation at two steps.. The Calvin cycle is shown here in its bare minimum. A 5-carbon receptor sugar molecule ribulose-bis-phosphate (RuBP) is converted into a transient 6-carbon intermediate by the addition of CO_2 to it, catalyzed by the enzyme RUBISCO (ribulose bisphosphate carboxylase/oxygenase). The 6-carbon intermediate splits into 2 molecules of 3-carbon intermediate phospholgyceric acid, and thus, the name *C-3* for plants that have only this cycle. It is the conversion of phosphoglycerate to phosphoglyceraldehyde (P GAL in diagram, but also called triose-phosphate, a C-3 sugar) where most of the energy from "light reaction" (in the form of NADPH and ATP) is used. These triose phosphate molecules are the source of both sugars and starch (the food our life depends upon) as well as of regeneration of the receptor 5 carbon RUBP. Diagram: courtesy of Prof. T. Jacobs, UIUC, Urbana.

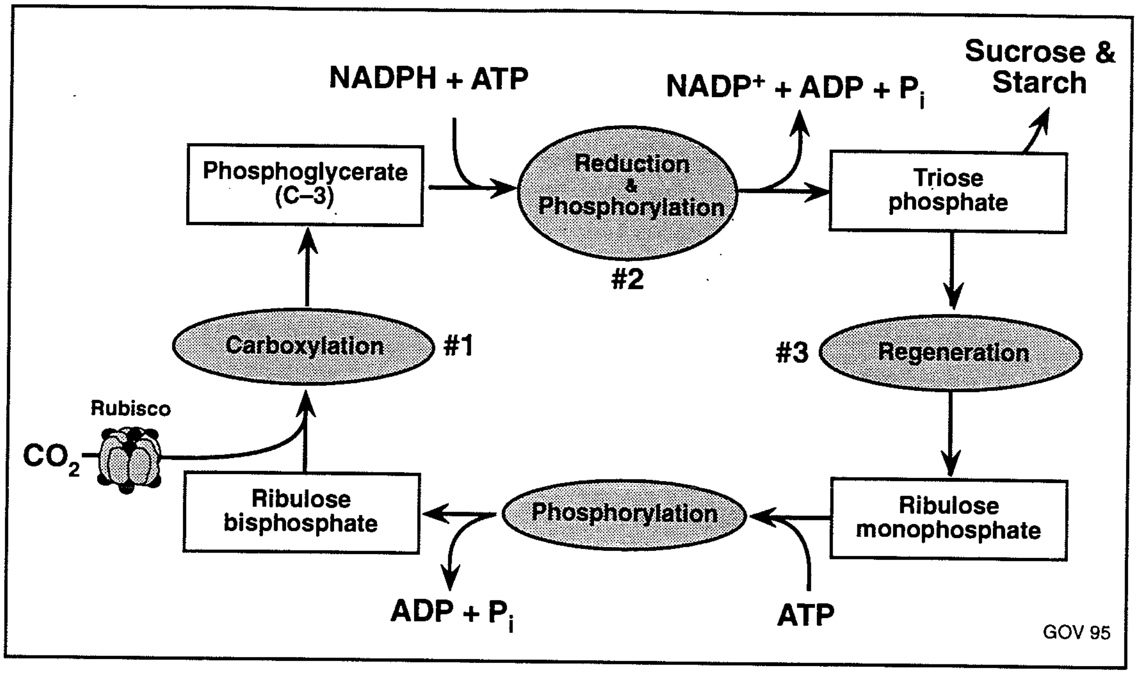
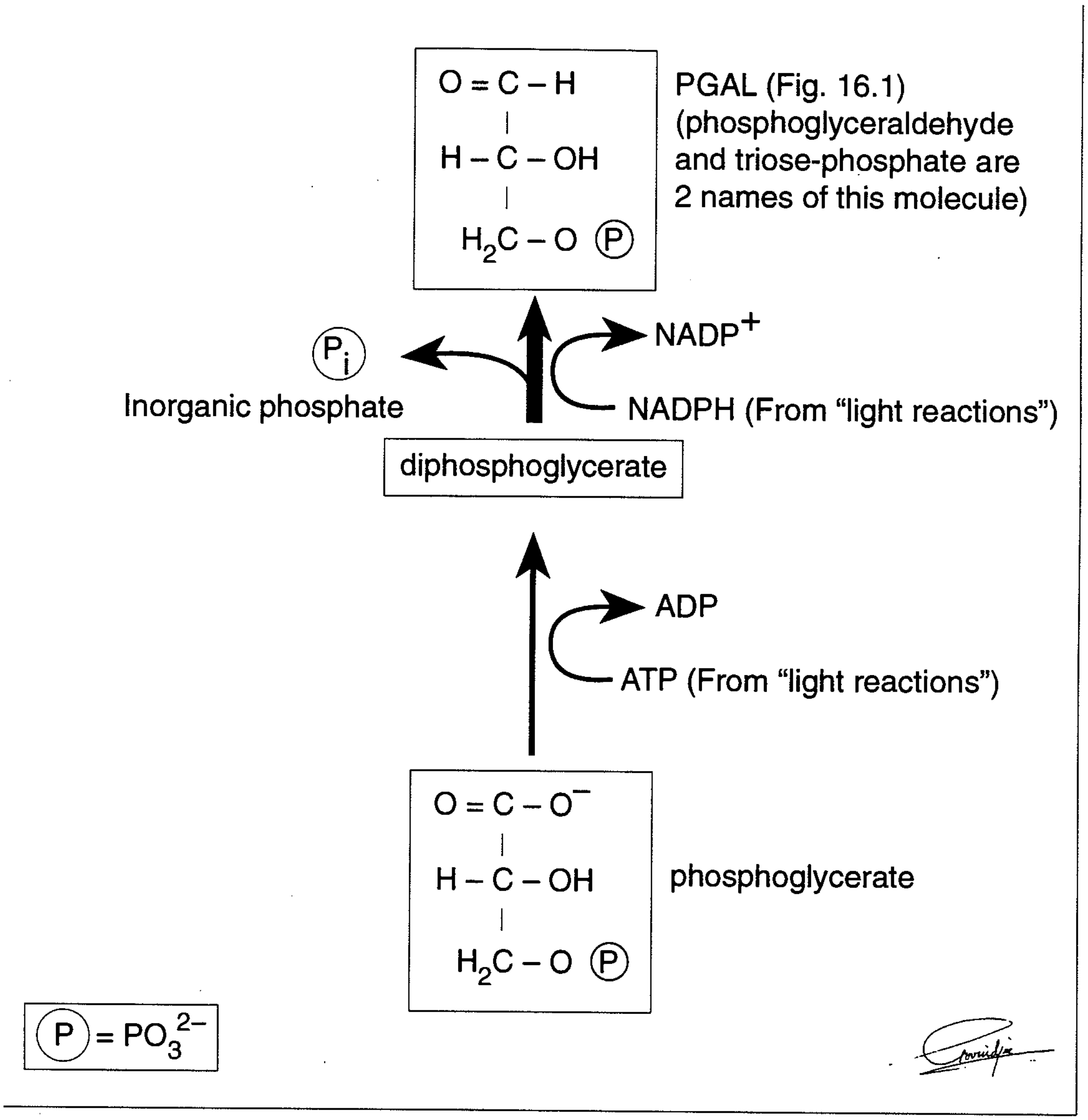


Fig. 6.2. An abbreviated scheme showing reduction of CO_2 by the Calvin cycle. Melvin Calvin received in 1961 a Nobel Prize, in Chemistry, for this work. The first step (#1) is **carboxylation**, i.e., addition of CO_2, of a receptor molecule, a 5-carbon sugar Ribulose bisphosphate-- using an enzyme RUBISCO (ribulose bisphosphate carboxylase/oxygenase). An estimated 10^7 tons of this enzyme (2kg/person) may be present on this Earth. This step (#1) leads to the formation of 2 molecules of 3-C compound phosphoglycerate. There is then **reduction,** i.e., addition or electrons of H-atoms (step #2), of phosphoglycerate to phosphoglyceraldehyde (PGAL in Fig. 6.1), also called triose phosphate. This is the step which requires energy as it is an "uphill" reaction. First phosphoglycerate is **phosphorylated** to diphosphoglycerate and only then it can be reduced by NADPH to triose phosphate. Two molecules of triose phosphate (C-3 sugar) can make one molecule of C-6 sugar. It is also used for **regeneration** of the receptor ribulose bisphosphate with an additional phosphate step, as shown at the bottom of the diagram. **For fixation of 1 CO_2 molecule, 3 ATP and 2 NADPH are needed**. Diagram modified from Whitmarsh and Govindjee (1995).

Table 6.2 The Energy Requiring Reaction



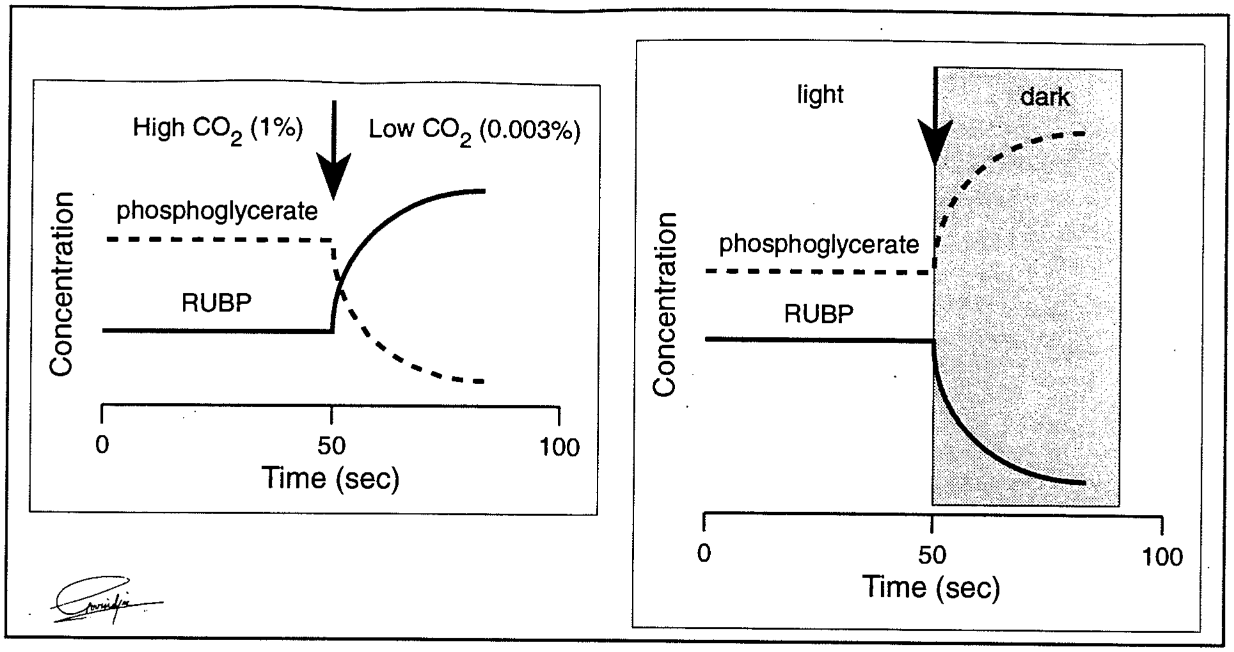
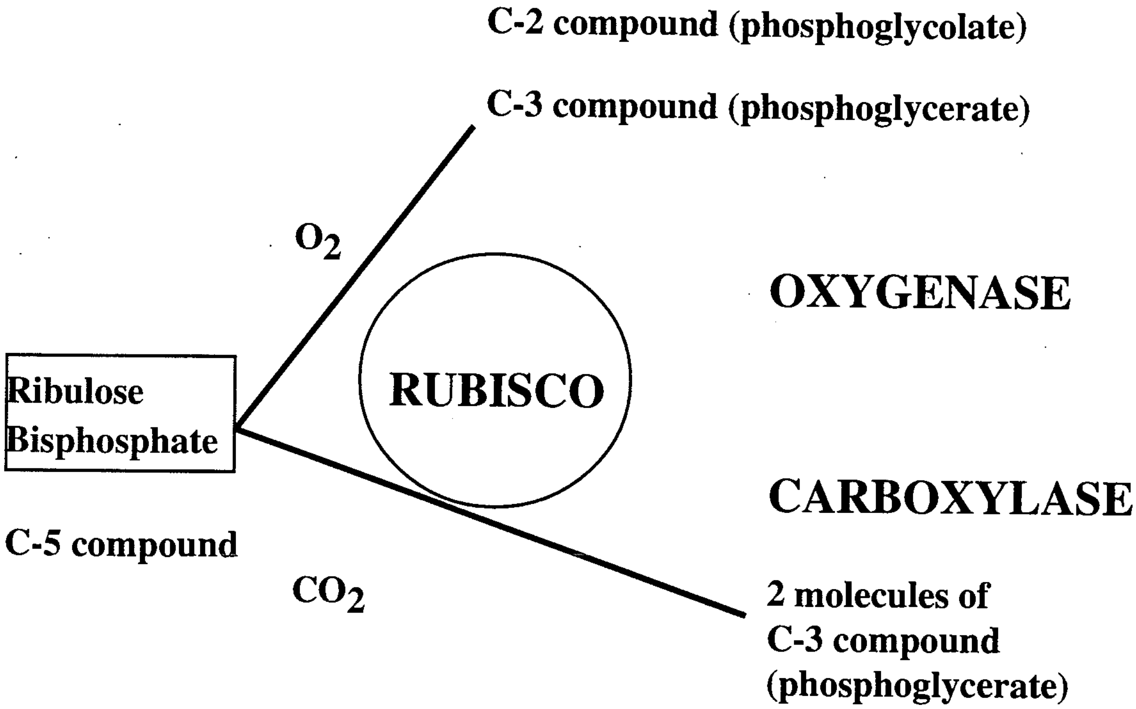


Fig. 6.3. Diagram showing the effect of lowering the CO_2 level (left) and turning off of the light (right) on the concentration of phosphoglycerate and ribulose bisphosphate (RUBP). If you see this graph together with **Fig. 6.2**, you will note that these results support the scheme there. Lowering CO_2 decreases the #1 reaction and thus phosphoglycerate decreases, but #2 and #3 steps continue for a while temporarily increasing RuBP. On the other hand, turning off the light shuts off #2, as well as the phosphorylation step (at the bottom of **Fig. 6.2**) and, thus, Ribulose bisphosphate decreases, whereas phosphoglycerate increases as #1 reaction (in Fig. 6.2), the CO_2 fixation, continues with the pool of ribulose bisphosphate already there. These experiments were crucial in the acceptance of the Calvin cycle.

Table 6.3: RUBISCO

- The enzyme RUBISCO in higher plants is made up of 8 large (53 kilodaltons) and 8 small (13 kilodaltons) subunits.
- The active site, *i.e.*, where CO_2 and O_2 are added, is in the large subunit; it is formed at the interface between two large subunits.
- About 10^7 tons of this enzyme is present on Earth; this amounts to 2 kilograms of this enzyme per person on Earth!
- It is a notoriously inefficient enzyme.
- Its atomic structure is available; thus genetic engineering to increase carboxylation/oxygenation ratio is under way.

Table 6.4. Carboxylation versus oxygenation at RUBISCO



OXYGEN COMPETES WITH CO_2 AND REDUCES CARBON FIXATION

* William Ogren, of UIUC, Urbana, was the one responsible for the first recognizing the bifunctional nature of this ensyme, and the name RUBISCO arose from this understanding.

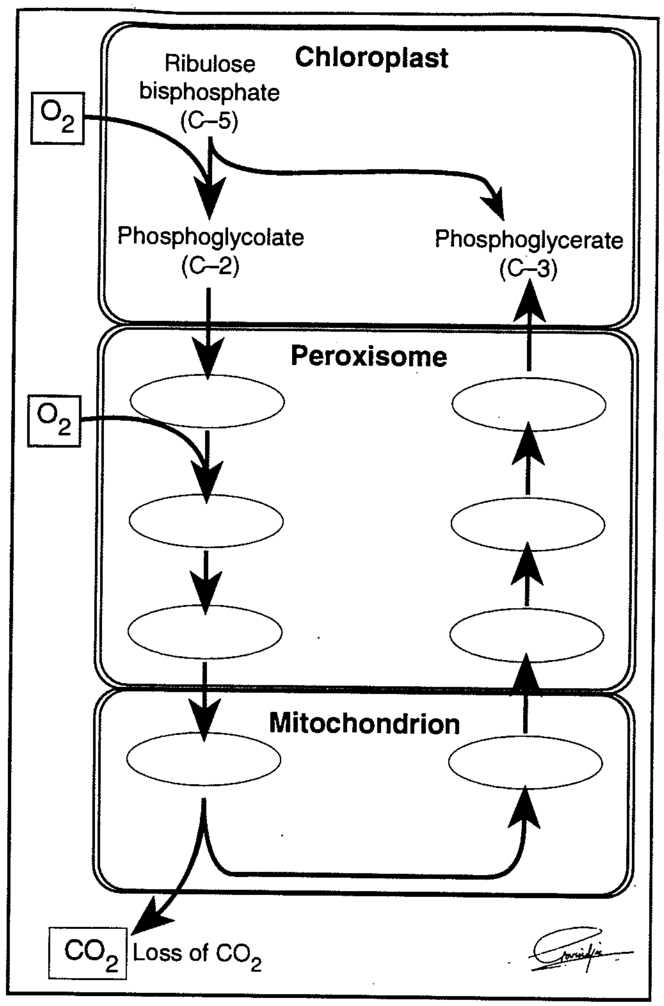
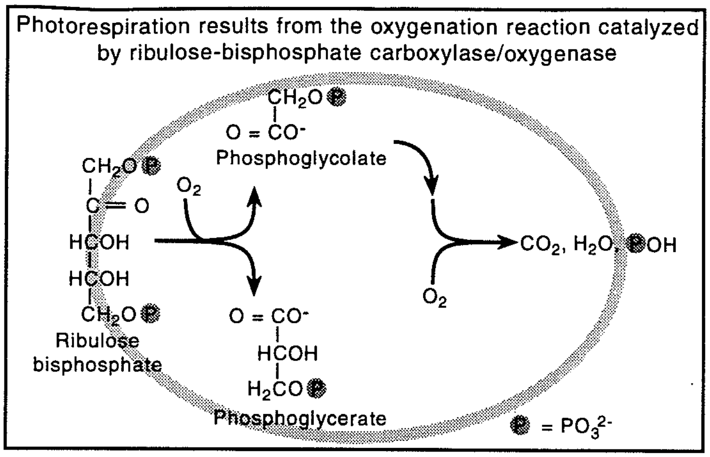


Fig. 6.4 A.. Photorespiration occurs when RUBISCO reacts with O2 (see Table 6.4) in chloroplasts. The 2-carbon glycolate enters another organelle *peroxisome* and goes through a series of intermediates there and then in *mitochondrion*. During this process, O2 is taken up in peroxisome and CO2 is lost in mitochondrion; and a part of carbon returns to chloroplast as a 3-carbon glycerate. Sounds mysterious. There is a lot of trafficking taking place. For every 2 molecules of 2-carbon glycolate, 1 molecule of CO2 is lost, and one molecule of 3-carbon glycerate returns to chloroplast. So, plants try to make the best of the bad situation. However, the process of photorespiration *undoes* photosynthesis to some extent.

Fig. 6.4B (See the top diagram on the next page): Shows the chemical structures of 5-C compound, the ribulose bisphosphate, of 3-C phosphoglycerate, and 2-C phosphoglycolate.



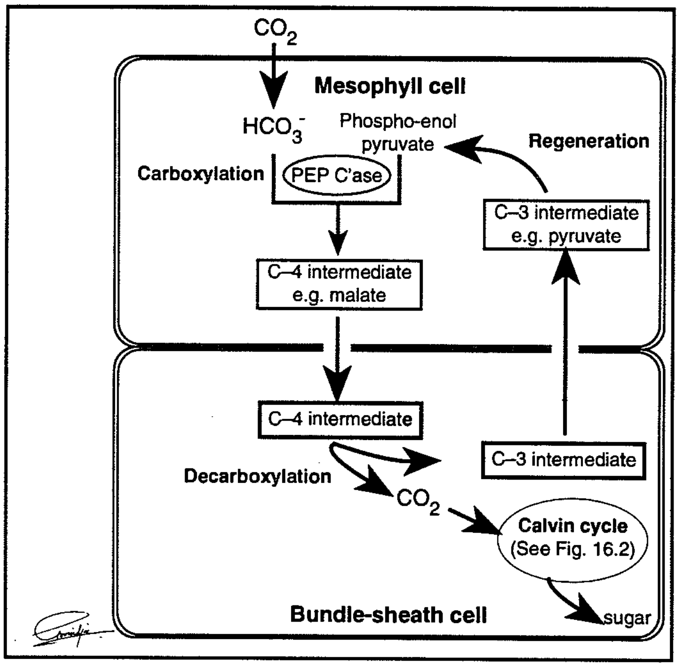


Fig. 6.5. (Bottom Diagram) The C-4 Pathway in its bare minimum. The purpose of this pathway is to concentrate CO_2; it is an "add-on" pathway as the Calvin cycle (see Fig. 6.2) is still used in these plants. Here CO_2 (in the form of bicarbonate ion, HCO_3^-) is added to a C-3 compound phosphoenol pyrurate (PEP, for short) producing C-4 intermediates (e.g. oxalo-acetate). The key enzyme is *phosphoenol pyrurate carboxylase*. It is an efficient enzyme and *does not* react with O_2! Oxalo acetate is converted into other C-4 compounds such as malate or aspartate.

This efficient carboxylation uses HCO_3^- and occurs in *mesophyll cells* of C-4 plants. The C-4 intermediates are transported to *bundle sheath cells* where the *Calvin cycle* utilizes one of its carbons (released as CO_2) and the 3-carbon intermediate returns to the mesophyll cell to *regenerate* phosphoenol-pyrurate. I would like to tell you that there is an additional *cost* involved here because 2 extra ATPs are used in the mesophyll cells.

Since phosphoenol pyrurate carboxylase (PEPC'ase) has a very high affinity for HCO_3^-, it can function at lower CO_2 levels, and the plant can afford to close their stomates. CO_2 is transported as part of C-4 intermediates (e.g. malate), CO2 is concentrated in bundle sheath cells where RUBISCO is located. This CO_2^- concentrating mechanism decreases *photorespiration..*

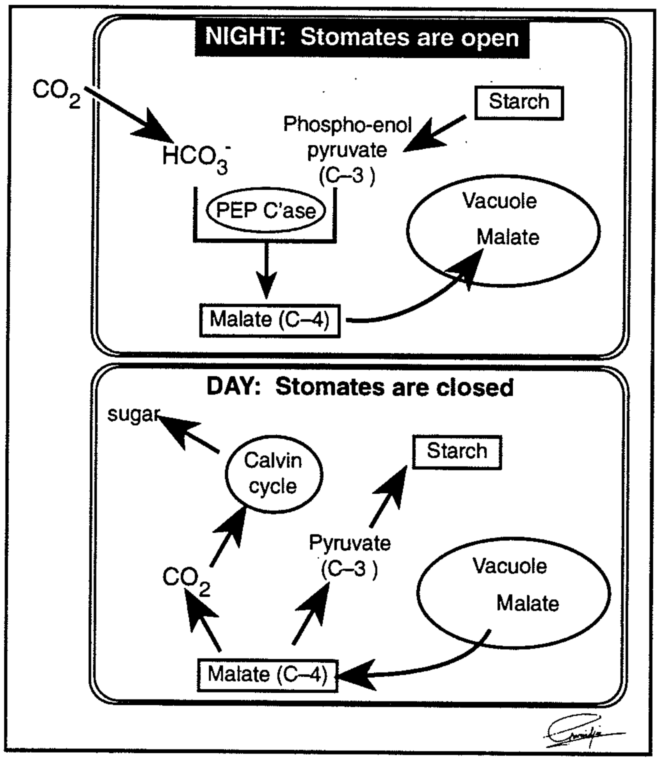


Fig 6.6 Crassulacean Acid Metabolism (CAM) pathway. Several plants are able to live in hot weather by keeping stomates closed during the day when it is hot and opening them at night when it is cold to avoid water loss.

In the dark (night), CAM plants open their stomates, and fix CO_2 by Phosphoenol-pyrurate (PEP) carboxylase, accumulating the C-4 intermediate (malate), just as C-4 plants do in light in mesophyll cells. This malate, however, is stored in the vacuole. (The PEP is formed from the starch stored at earlier times.)

In the light (day), CAM plants close their stomata, malate comes back out of the vacuole, and decarboxylates to release CO_2 that is then fixed by the Calvin cycle, and the 3-C intermediate pyrurate is converted into starch, to be used at night again.

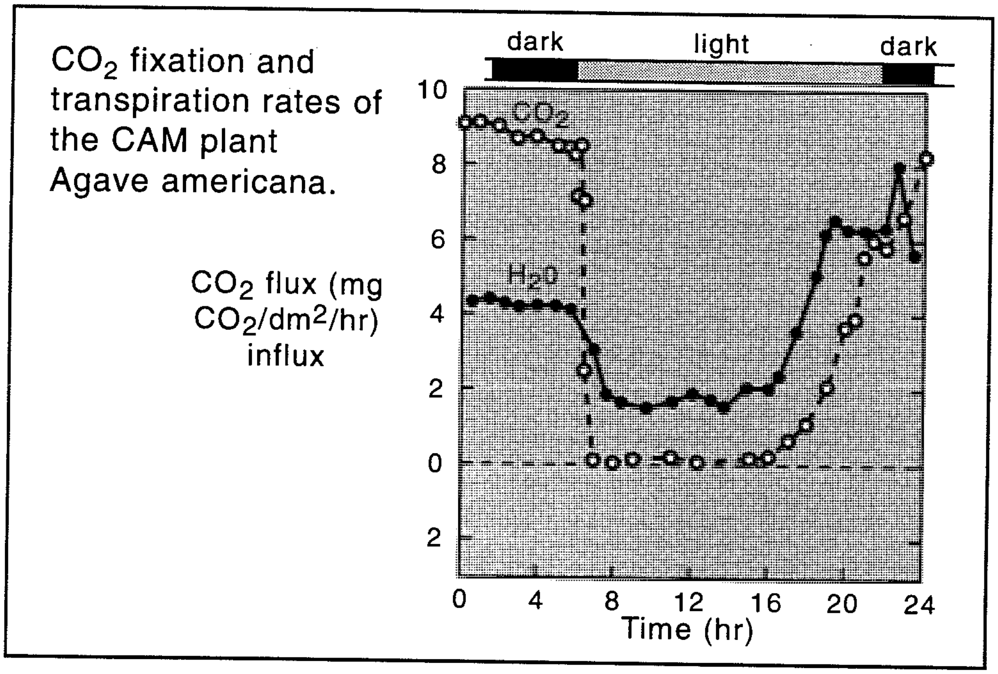


Fig. 6.7. In a CAM plant, CO_2 fixation occurs in dark. Due to lowered temperatures at night, not too much water is lost. During day, stomates are closed and no CO_2 uptake occurs. This condition, however, is good for these plants as very little water is lost, and these plants can thus survive in the hot temperatures where they grow. (Data of T.F. Neales, A.A. Patterson and V.J. Hartney, Nature, 219, 469-472, 1968.)

Table 6.5. A Comparison of C-3, C-4 and CAM plants

Characteristics	C-3	C-4	CAM
Examples	Soybean	Maize	Pineapple
Anatomy	Spongy and Palisade cells	Mesophyll and Bundle sheath cells	Cells with large Vacuoles
Growth Rates ($gdm^{-2}day^{-1}$)	1	4	0.02
Stomates	Open in day Closed at night	Open in day Closed at night	Closed in day Open at night
Water Use Efficiency ($gCO_2\ kg^{-1}\ H_2O$)	1-3	2-5	10-40
Maximum Photosynthetic Rate ($\pm 5\ mgCO_2dm^{-2}hr^{-1}$)	30	60	3
Optimum Temperature	20-30°C	30-45°C	30-45°C
Compensation point: CO_2 concentration when there is no net photosynthesis	50 ppm (parts per million)	5 ppm	2 ppm
Photorespiration	High	Low	Low
Key Carboxylating Enzyme	RUBISCO only	PEP C'ase RUBISCO	PEP C'ase RUBISCO

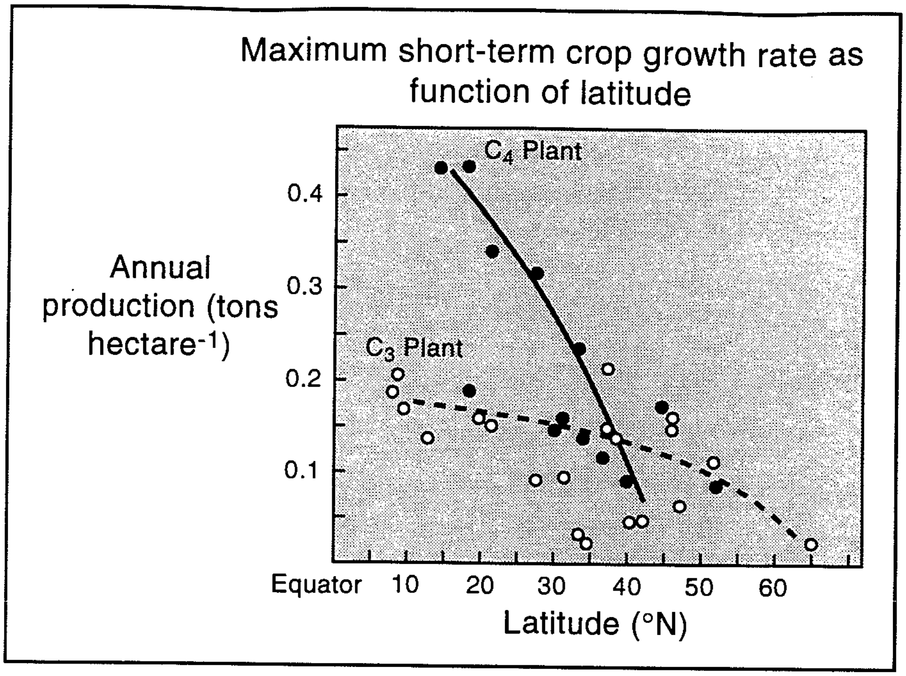


Fig. 6.8. Production (tons hectare^{-1}) of C-3 and C-4 plants at different latitudes. The C-4 plants predominate in warmer climate closer to the Equator, whereas C-3 plants predominate in temperate climate. Data compiled by Loomis and Gerakis, 1975.

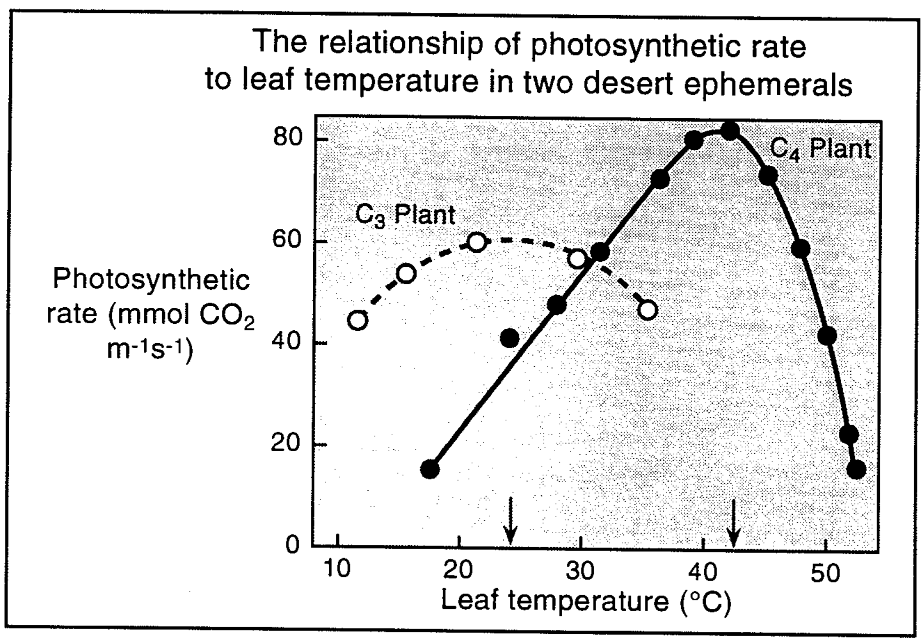


Fig. 6.9. A cool season C-3 plant has higher photosynthesis rates at lower temperature range, whereas a hot season C-4 plant has higher photosynthesis rates at higher temperatures.

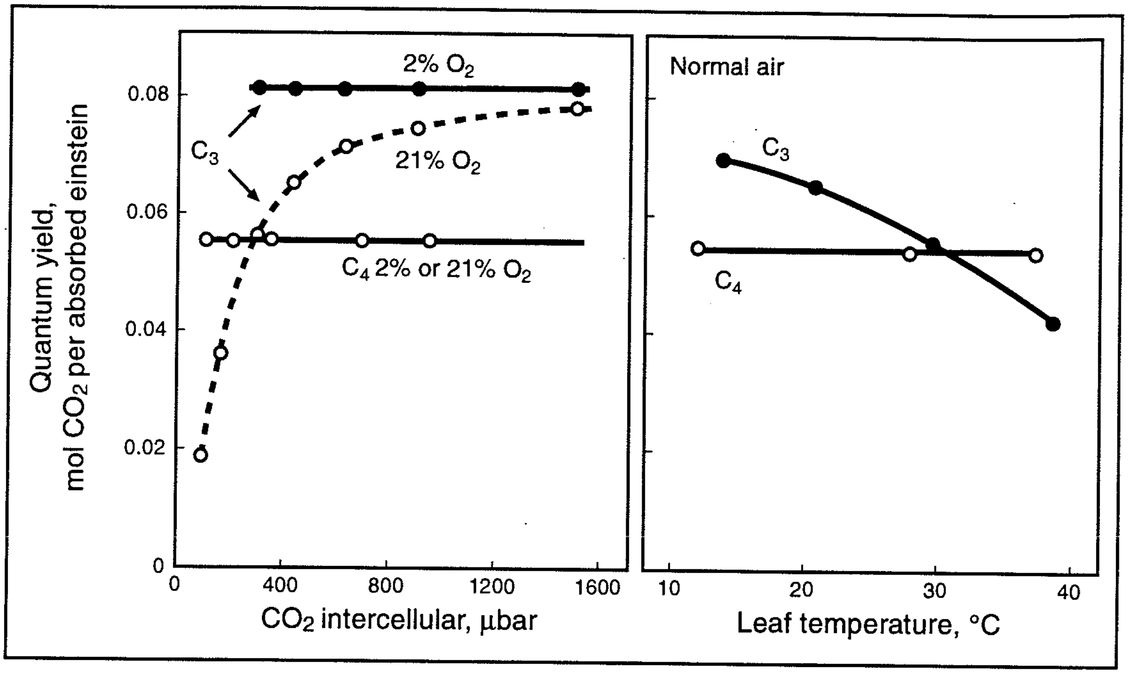


Fig. 6.10. Quantum yield of photosynthesis (molecules of CO_2 uptake or O_2 evolved, per absorbed photon; or moles of CO_2 uptake or O_2 evolved per mole of photon, also called Einstein) is calculated from the slope of the rate of photosynthesis versus number of photons absorbed at low light intensities. Its maximum value is 0.12 (or 1 CO_2/8 photons). The graph on the left shows the following: (1) At 2% O_2 (when photorespiration is absent), quantum yield of CO_2 uptake for C-3 plants is maximal at all CO_2 concentrations, whereas that at 21% (when photorespiration is high) this quantum yield of C-3 plants is very low at low CO_2 concentration, increasing with increasing CO_2 concentration. (2) In - C-4 plants (where photorespiration is always low due to the CO_2- concentrating mechanism (see Fig. 6.5)), quantum yield of photosynthesis is independent of O_2 concentration.

The graph on the right shows that the quantum yield of photosynthesis, always measured at low light intensities, is higher at lower than at higher temperatures for C-3 plants, whereas that for C-4 plants, this yield is independent of temperature. There is higher photorespiration at higher temperatures decreasing photosynthesis in C-3 plants.

For further reading:

See Chapter 9 (Photosynthesis: Carbon Metabolism) in L.A. Taiz and E. Zeiger, "Plant Physiology," The Benjamin/Cummings, Pub. Co., Redwood city, CA.

Lecture 7: Environmental Effects: Physiological and Ecological Implications

Reading assignment:

(1) Taiz and Zeiger "Plant Physiology", **Chapter 10, pp 249-256** (on reserve in Biology library).

(2) See Life Sciences Servers for Biol. 121 students. (Instructions are in your laboratory manual): Programs on Photosynthesis.

(3) **These Notes**

By the end of your preparation on this topic, you should be able to:

- 1. Describe the *Photosynthetic Active Radiation*, called *PAR*, for short..
- 2. Summarize the photosynthetic reactions beginning with light absorption (in femtoseconds, 10^{-15}s) to the time (minutes) sugars are made.
- 3. Discuss the strategies a plant uses to adjust to changes in light.
- 4. Discuss the dependence of photosynthesis on light intensity for plants that are adapted to sun or shade conditions, or grown at different light intensities.
- 5. Define the following **concepts** and **terms**: quantum yield of photosynthesis; dark respiration; light compensation point; light saturation of photosynthesis; "light-dependent" and "light-independent" reactions.

Outline of presentation:

(Figure and table numbers are from **these notes**.)

1. *Hierarchy of Processes and Sizes of things*:	**Fig. 7.1**	**Notes**
2. *Light:*		
• Amount of sun light:	**Table 7.1**	**Notes**
• Losses of light:	**Table 7.1**	**Notes**
• Photosynthetic Active Radiation:	**Fig. 7.2**	**Notes**
• Light at bottom of canopy:	**Fig. 7.3**	**Notes**

♦ 3. Summary of photosynthesis:	**Table 7.2**	**Notes**
♦ 4. Strategies for adjustment to light:		
• Chloroplast movement:	**Fig. 7.4**	**Notes**
• Discussions of lecturer's research on "How Plants Protect themselves Against Excess Light:"		
• Heliotropic responses of leaves:	**Fig. 7.5**	**Notes**
♦ 5. Dependence of photosynthesis on light intensity: maximum quantum yield of photosynthesis:	**Fig. 7.6**	**Notes**
• Light response curves of various plants:	**Fig. 7.7A**	**Notes**
• Light response curve of the same plant grown at different light intensities:	**Fig. 7.7B**	**Notes**
• Dark respiration, compensation point and light saturation:		
• Light response curves of sun and shade clones:	**Fig. 7.8**	**Notes**

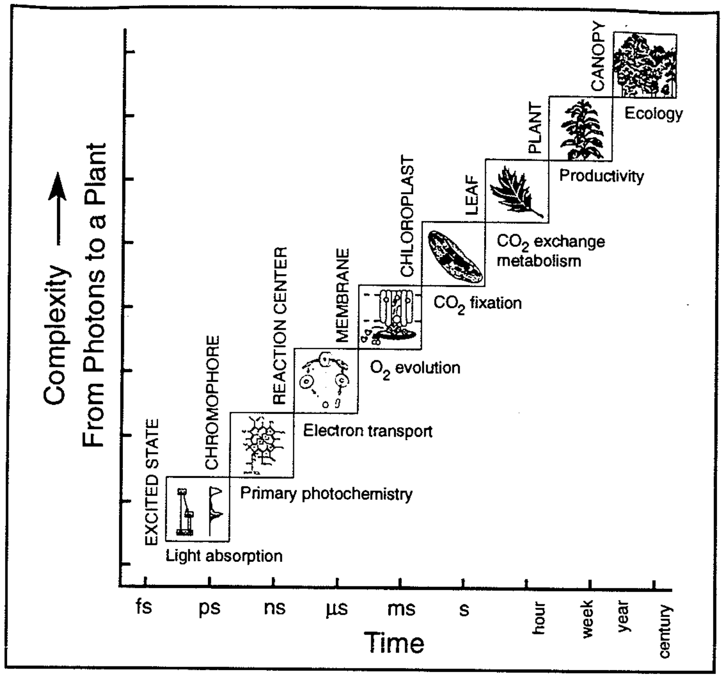


Fig. 7.1. An arbitrary diagram relating the dimensions of components of a plant with the associated processes. This diagram incorporates the ideas of Barry Osmond at the higher levels and of the author at the lower levels.

Table 7.1. Data on Sunlight

♦ Sunlight on Earth:
1.3 kilowatts (K^W) meter^{-2} (m^{-2}) or 1.3 kJ (kilojoules) m^{-2} s^{-1} (second^{-1})

- On average, it is equivalent to 2,000µmol (also called µEinsteins)m^{-2}s^{-1}

♦ Out of 100% Sunlight on Earth, only 5% or less is converted into carbohydrate because the rest is lost as:

- Not absorbed as it is at wavelengths longer than 700 nm, etc: 60%
- Reflected or transmitted: 8%
- Energy in other metabolic paths: 20%
- Heat: 8%

Table 7.2. Summary of Photosynthesis

• Photosynthesis can be broadly separated into *dark* (or light independent) and *light* (light-dependent) processes. *Traditionally*, *light* reactions are those involved in oxidation of water to oxygen and reduction of $NADP^+$ to NADPH with the accompanying formation of ATP; and dark reactions are those involved in the use of these (NADPH and ATP) to fix CO_2 into carbohydrate. The light reactions occur on *thylakoid membranes* and the dark reactions in *stroma matrix* of chloroplasts.

In **reality**, the only true light reactions are those that occur at the reaction center chlorophylls P680 and P700, all others being "dark" reactions.

• If we could start photosynthesis with brief flashes of light it will follow the sequence:

On Thylakoid membranes

- **Light Absorption**
- **Excitation Energy Transfer**
- **Primary Photochemistry**
- **Electron Transport leading to**
  oxygen evolution
  production of reducing power, NADPH
  proton translocation

In Stroma Matrix

- **CO_2 Fixation by RUBISCO and PEP C'ase**
  (all) (C-4, CAM)
- **Reduction and Phosphorylation of phosphoglyceric acid to triose phosphate using NADPH and ATP**
- **Regeneration of receptors of CO_2**
- **Formation of 6-C sugars (outside chloroplasts) and Starch (inside chloroplasts)**

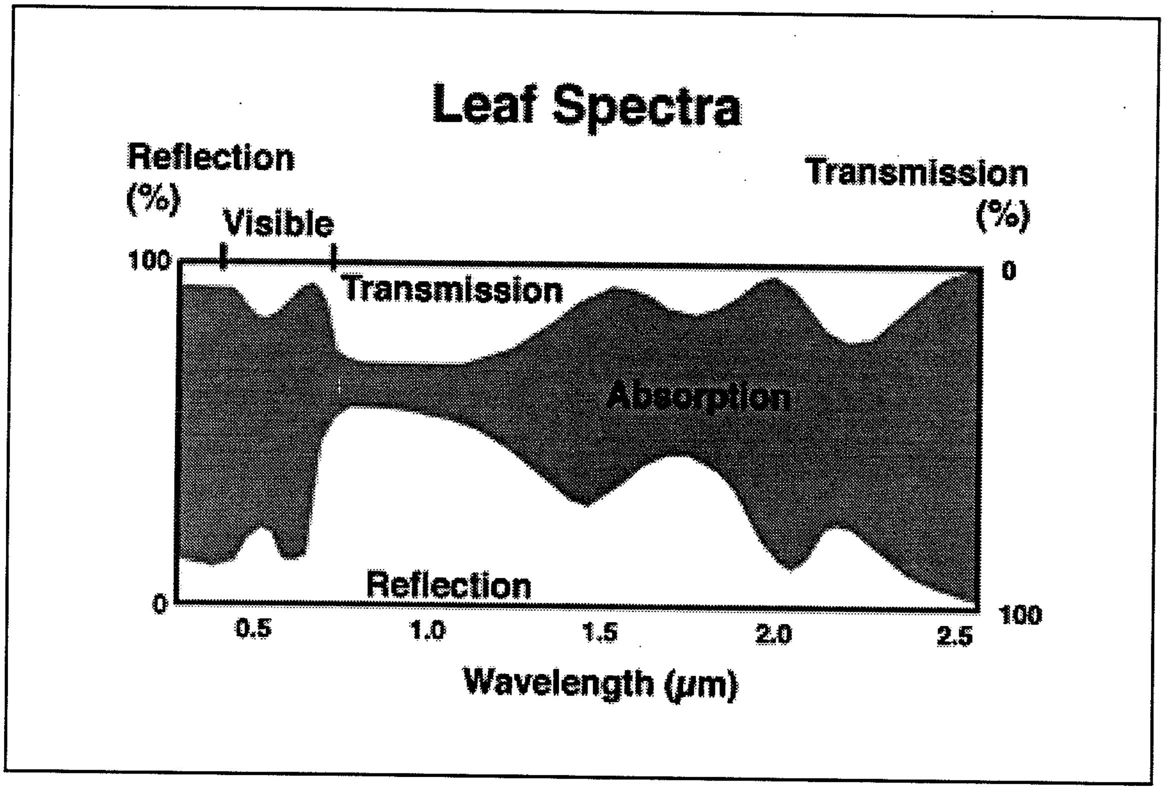


Fig. 7.2. Percentage of light absorbed, reflected and transmitted, as a function of wavelength of light. The transmitted and reflected 500-600nm light gives the leaves these green color. Also most of the light above 700 is not absorbed by the leaf. Data of Smith, 1986. PAR(= photosynthetic Active Radiation) is defined as 400-700 nm, but note that it hides the fact that data is incomplete and does not include results below 400 nm. Modified from Fig. 10.2 in Taiz and Zeiger.

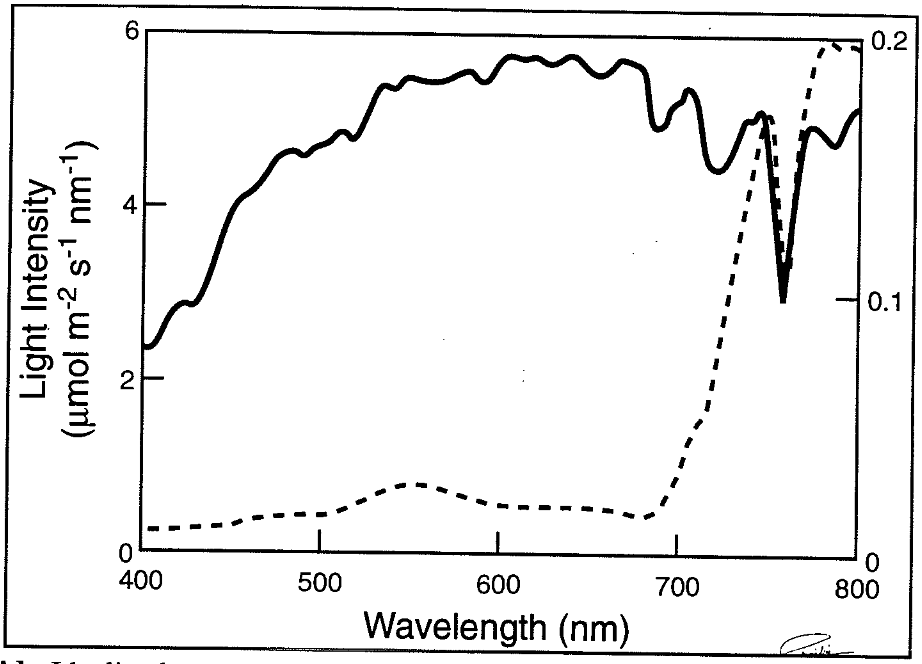


Fig. 7.3. Solid. Idealized spectral distribution of sunlight falling on the top of a forest; **Dashed**: Spectral distribution of sunlight reaching the forest floor. Data of Smith (1986). Data from Fig. 10.5 of Taiz and Zeiger. The top of the forest had an approximate intensity of 2,000 µmol $m^{-2}s^{-1}$ and the bottom of the forest 18 µmol $m^{-2}s^{-1}$. Another major difference was the nature of the color of the light. The top of the forest had the normal sunlight color, but the bottom of the forest had some green light and infra-red light.

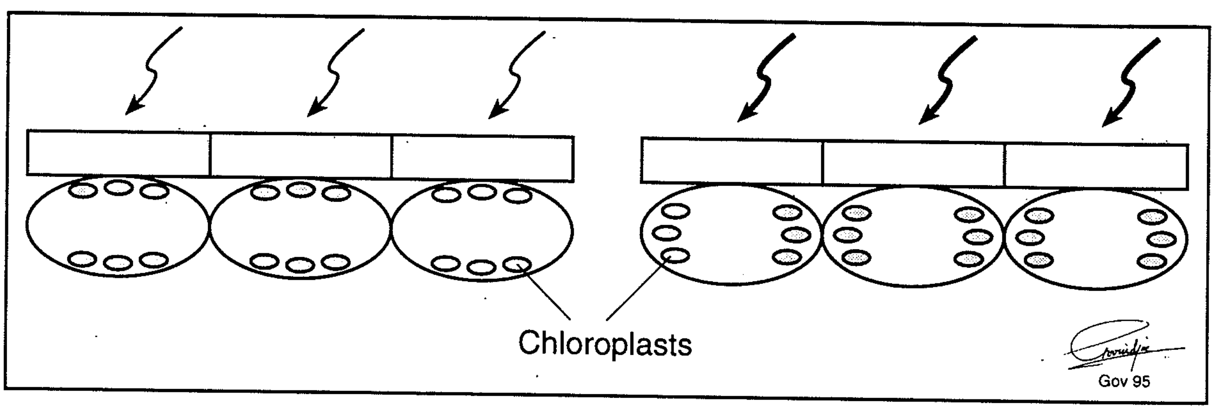


Fig. 7.4. Strategy of increasing (left) or decreasing (right) light absorption when it is not enough or too much: by chloroplast movement.

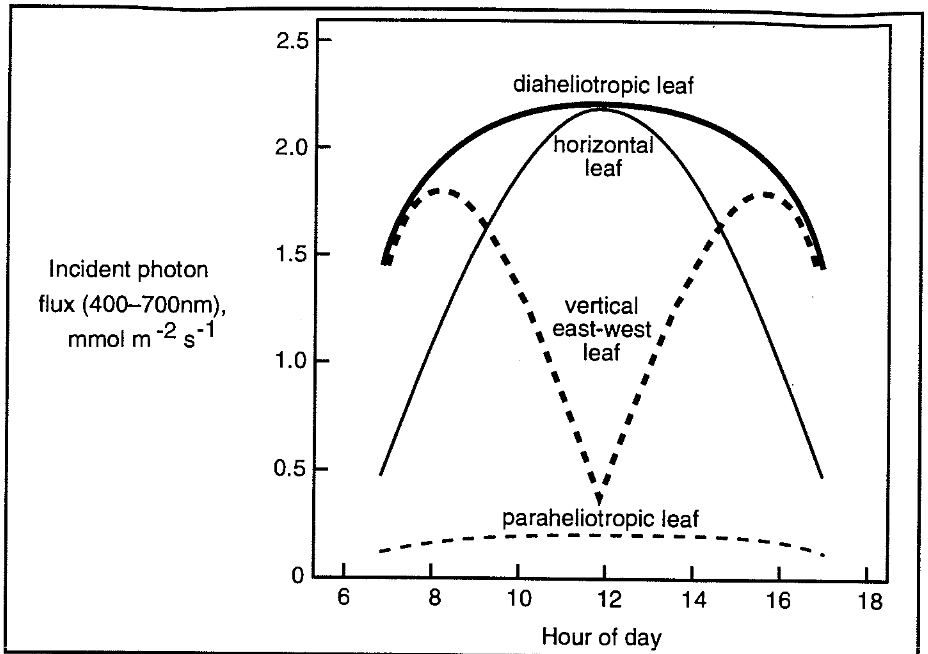


Fig. 7.5. Amount of light, in units of photons, incident on leaves of plants that have different strategies of arrangement of movement of their leaves: *diaheliotropic* leaf—that tracks the sun; a *horizontal* leaf; a *vertical* leaf facing East-West; and *paraheliotropic* leaf that moves in order to avoid the sun. Data of Ehleringer and coworkers, 1985.

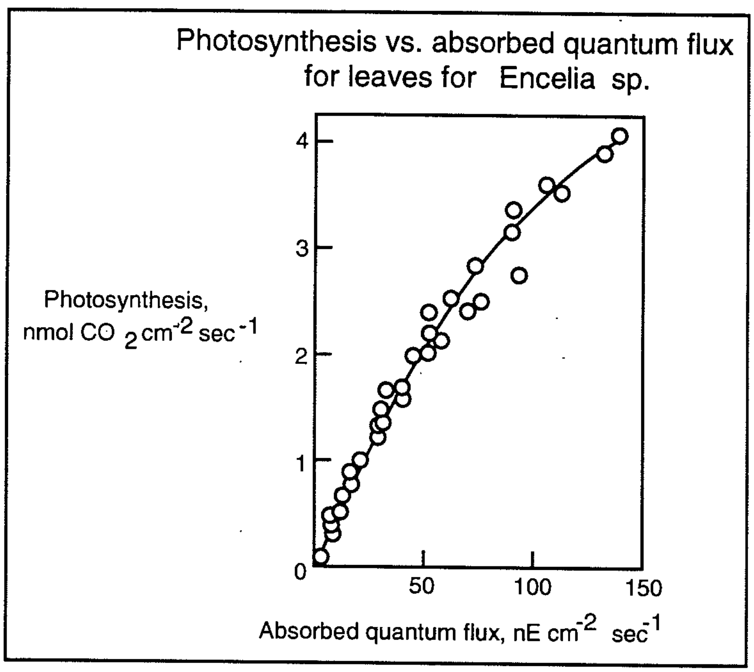


Fig. 7.6. A plot of the rate of photosynthesis as a function of the rate of absorption of photons C ≡ quanta of light in leaves of *Encelia farinosa* nE in the abscissa stands for namoeinsteins or nanomoles. The slope of the curve at low light intensities, when measured in terms of moles of CO_2 fixed per mole of photons absorbed gives the quantum yield of photosynthesis. Data of Ehleringer and Mooney, 1978.

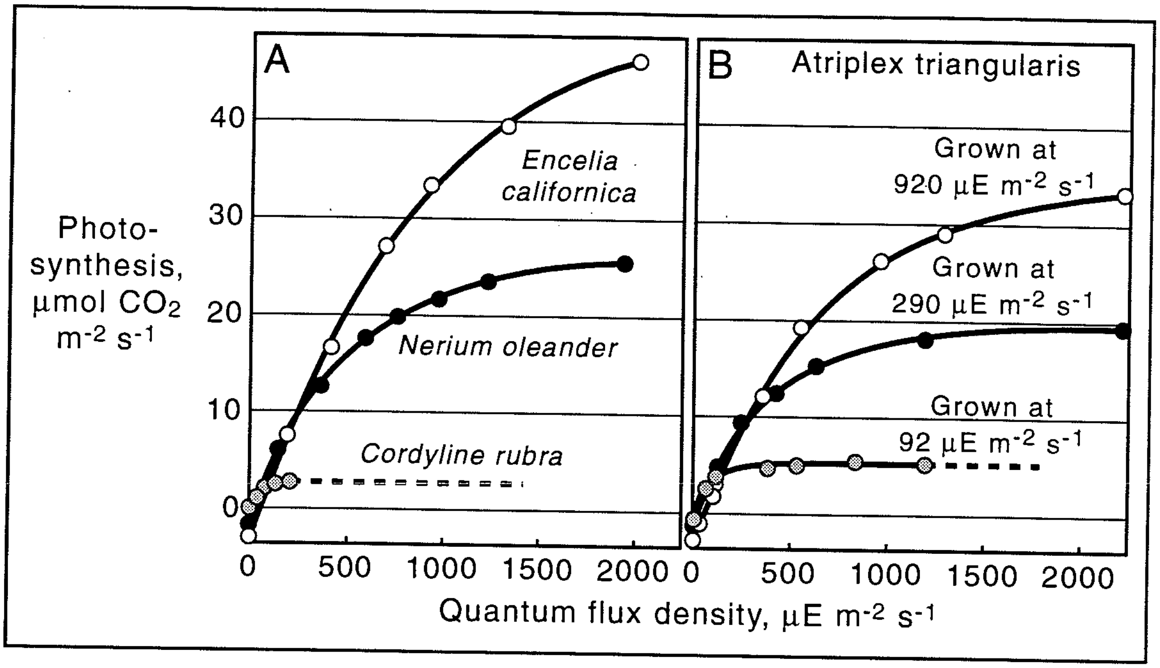


Fig. 7.7 Left: Rate of photosynthesis as a function of incident photons for a sun species grown in sunlight (top and middle curves) and a shade species grown in dim light (bottom curve). **Right:** Rate of photosynthesis of a sun species grown at diferent light intensities. Data of O. Bjorkman and co workers (1972-1978).

Note: Shade plants have usually more antenna chlorophyll molecules per reaction center chlorophyll molecules (you know P680 and P700), have higher ratio of chlorophyll b to chlorophyll a , and have thinner leaves than the sun plants. On the other hand, sun plants have higher concentrations of proteins (particularly the enzyme RUBISCO) than in shade plants. These characteristics are mostly responsible for the higher quantum yields, but lower saturation rates of photosynthesis in shade than in sun plants.

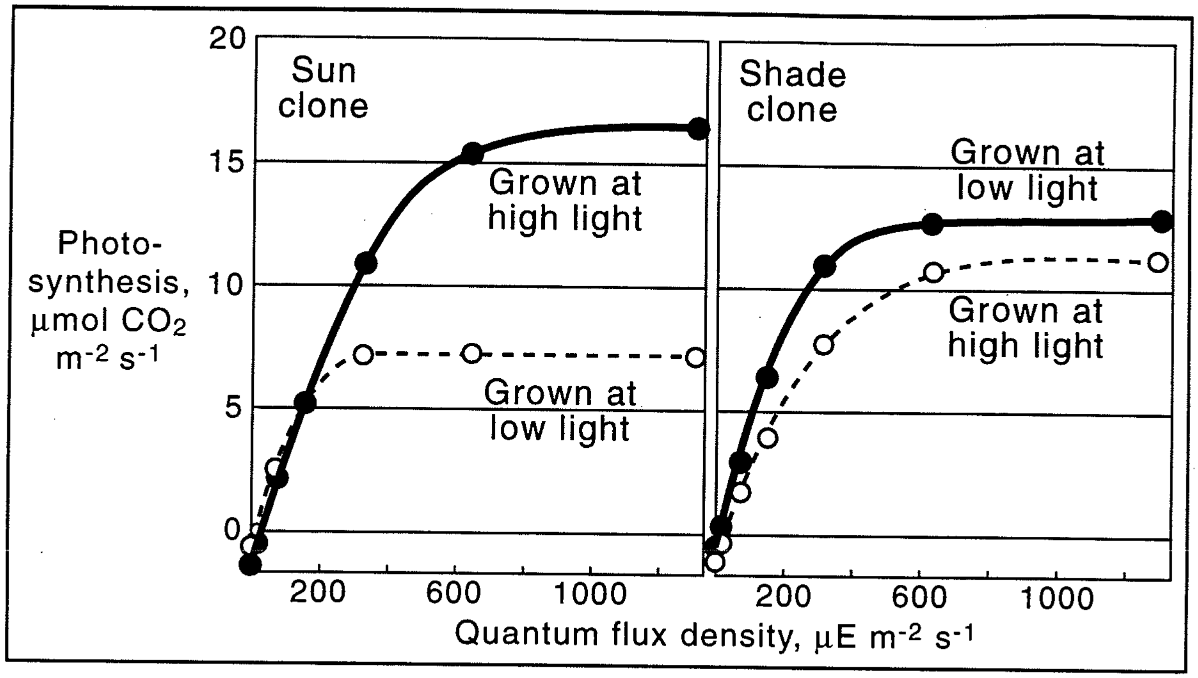


Fig. 7.8. Rate of photosynthesis as a function of incident photons from a sun and a shade clone of *Solidago virgaurea* grown at low and high light intensities. Data of O. Bjorkman and coworkers (1963). These data show the acclimation characteristics of this plant.

Lecture 8: Growth and Development: (A) Control Systems - Growth Regulators; and (B) Photoperiodism and Rhythms

 Reading assignment:
(1) Raven and Johnson 4th ed.; **Chapter 36, pp. 781-800**
(2) **These Notes**

 By the end of your preparation on this topic, you should be able to:

Part A

© 1. Present an overview of growth of plants (review on your own Chap. 35)

© 2. Locate and identify the sites of growth in a shoot, and a root (review on your own Chap. 35).

© 3. Define a growth regulator (often called a hormone) and describe some of the significant modes of action of:
(a) *auxin* (e.g. indole acetic acid); (b) *gibberelin*; (c) *cytokinin*; (d) *ethylene* and (e) *abscisic acid.*

© 4. Discuss a current theory about the regulation of the root/shoot ratio in plants.

© 5. Discuss the benefits of plant growth regulation applications in our daily life.

6. Discuss different types of plant movement.

© 7. Define the following **concepts** and **terms**: *meristems; hormone; apical dominance; senescence; phototropism; gravitropism; statolitis; rapid leaf movements; sleep movements.*

Part B

© 8. Discuss the principles by which plants respond to light.

© 9. Discuss the role of phytochrome in initiating various responses, for example, flowering and seed germination in plants.

© 10. Discuss the high-intensity responses of blue and other light on plants.

© 11. Discuss the phenomenon of circadian rhythm in plants.

© 12. Define the following **concepts** and **terms**: Pr and Pfr forms of phytochrome; photomorphogenesis; short-day and long-day plants; "florigen".

Outline of presentation:

(Figure and Table numbers are either from Raven and Johnson 4th ed., **or from these Notes.**)

© 1. Plant meristems:

• Meristems:	Fig. 35.1	p.758
• Root meristem:	Fig. 35.7 Fig. 35.13	p.765 p.768
• Apical meristem in a shoot:	Fig. 35.1	p. 758

© 2. What is a growth regulator?

Types and effects of growth regulators in a plant:	**Table 8.1** Table 36.1	**Notes** p. 785
• Auxin:	**Table 8.2**	**Notes**
• Cytokinin:	Fig. 36.5 Fig. 36.6 Fig. 36.8	p. 786 p. 787 p. 788
• Gibberelin:	Figs. 36.10-36.12	p.790
Abscisic acid:		
• Ethylene:	Fig. 35.8-35.9	p. 765-766

© 3. A possible hypothesis for auxin transport:	**Fig. 8.1**	**Notes**
© 4. A possible clue for regulation of root/shoot ratio in plants:	**Table 8.3**	**Notes**
© 5. How do growth regulators benefit our daily life?	**Table 8.4**	**Notes**

© 6. Plant movements:

• Phototropism:	Fig. 36.7	p. 788
• Gravitropism:	Fig. 36.13	p. 793

• Rapid leaf movement:	Fig. 36.16	p. 795
• Sleep movement:	Fig. 36.15	p. 794

Part B

© 7. Responses of plants to light:	**Fig. 8.2**	**Notes**
© 8. The Phytochrome system		
• Responses	**Table. 8.5**	**Notes**
• Seed germination in lettuce	**Fig. 8.3**	**Notes**
• Flowering responses	Fig. 36.17 **Table 8.4**	p. 795 **Notes**
• Action spectra of responses	**Fig. 8.4**	**Notes**
• Characteristics of phytochrome	Fig. 35.16	p. 773
• Absorption spectra	**Fig. 8.5**	**Notes**
• Chemical structure	**Fig. 8.5**	**Notes**
• Model	**Fig. 8.6** Fig. 36.18	**Notes** p. 796
© 9. Light Response of Plants	**Table 8.7**	**Notes**

© 10. Touch Response - an amazing story (Read p. 797)
(An unmolested Arabidopsis grows tall but the one touched twice/day becomes a dwarf; five specific genes are induced by touch)

- Alteration of gene expression by touch in Arabidopsis

© 11. Is there a flowering hormone?

© 12. Plants have circadian rhythms too:	**Fig. 8.7**	**Notes**
© 13. Natural light:	**Fig. 8.8**	**Notes**

<u>Table 8.1.</u> <u>What are Growth Regulators? (Also Known as Hormones)</u>

Organic compounds, that are synthesized in one part of the plant and transported to another part, where, in very low concentrations, they cause a physical response.

Table 8.2 Characteristics of Growth Regulators (see Table 36.1, Raven and Johnson p. 785 for chemical structures and other details)

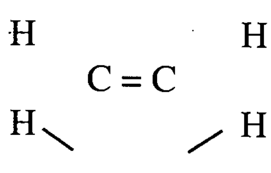
Name (Example)	Major function and characteristic
Auxins (Also see Fig. 36.8, p.788) (Indole acetic acid formed from amino acid tryptophan)	Stimulates stem and coleoptile elongation; present in apical meristem
Cytokinins (Also see Fig. 36.9, p.789) (Zeatin; adenine like compounds)	Stimulates cell division; made in roots and transported to other parts; can counteract apical dominance
Gibberelins (see p. 790) (Gibberelic acid$_3$; isoprenoids) (named after fungus Gibberella fujikuori)	Promotes unusual stem elongation in some plants
Abscisic acid (see p. 791) (15-C sesquiterpene)	Inhibits growth; closes stomata during water stress: not involved in abscission as the name may imply
Ethylene 	Promotes fruit ripening: involved in senescence and leaf abscission

Table 8.3: Root/Shoot Ratio

Increased cytokinin to auxin ratio has been shown to increase shoot/root ratio: more shoot develops

Decreased cytokinin to auxin ration has been shown to increase root/shoot ratio: more roots develop

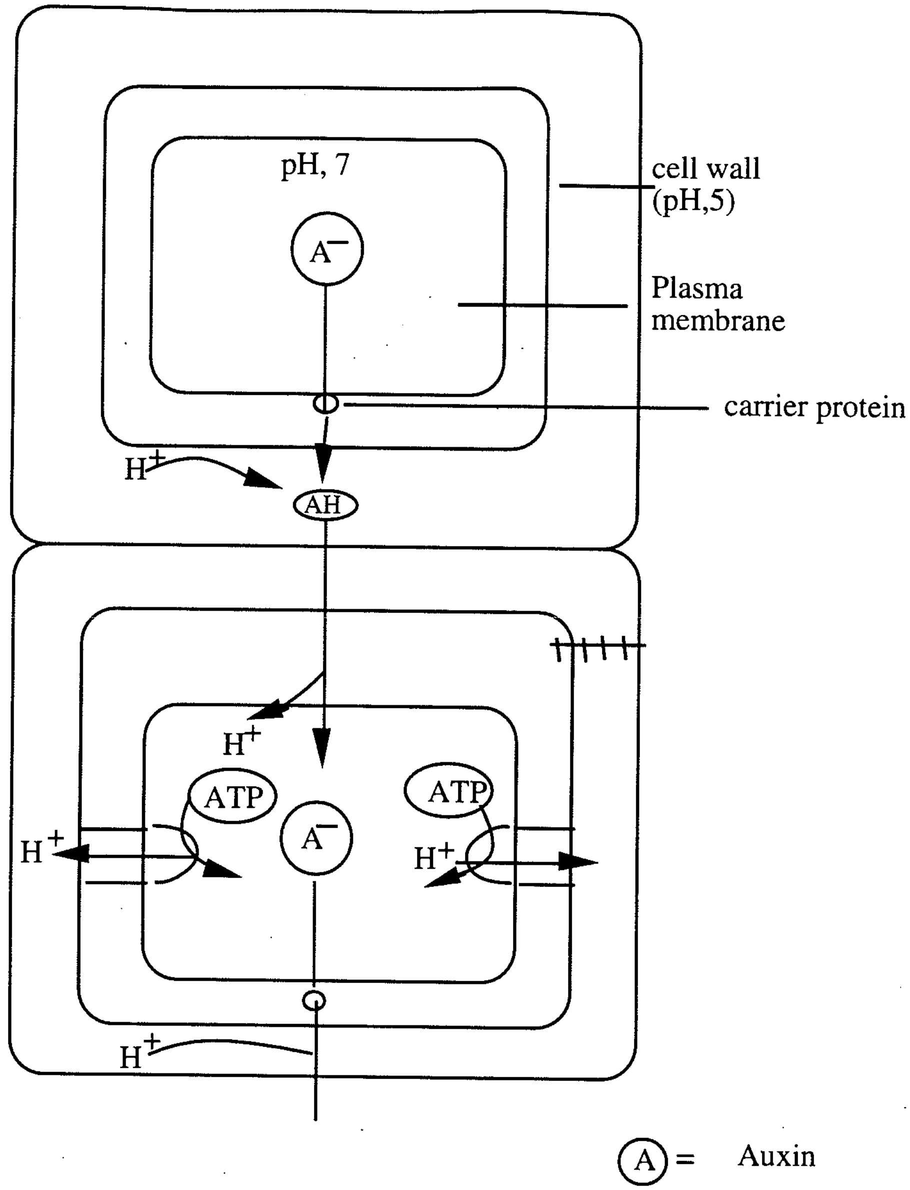


Fig. 8.1. A possible hypothesis for auxin movement. An auxin may enter from cytoplasm (pH,7) of one cell as a negatively charged species (A^-), through, perhaps, binding with a protein in its plasma membrane, to the cell wall (pH,5) becoming AH. AH can enter easily the next cell where it becomes A^- releasing a proton (H^+) there. ATP-driven ATPase enzyme drive the protons to the cell wall making it acidic. This somehow (who knows how) leads to cell enlargement. Possibly, cellulose microfibrils in the cell wall break loosening the fabric; the plastic cell can take up water and elongate.

Table 8.4: Practical uses of Growth Regulatiors

(Big Business)

- Cytokinins keep cut flowers fresh
  (weddings, birthdays, anniversaries)

- Cytokinins keep leaves greener for quite a while

- Gibberelins are used to obtain flowers on long tall stems
  (*bolting* in cabbage)

- Gibberelins are used to break dormancy in seeds

- Ethylene is used for fruit ripening; tomato ripening; banana ripening; citrus ripening

- Some growth regulators are used to induce rooting in cuttings

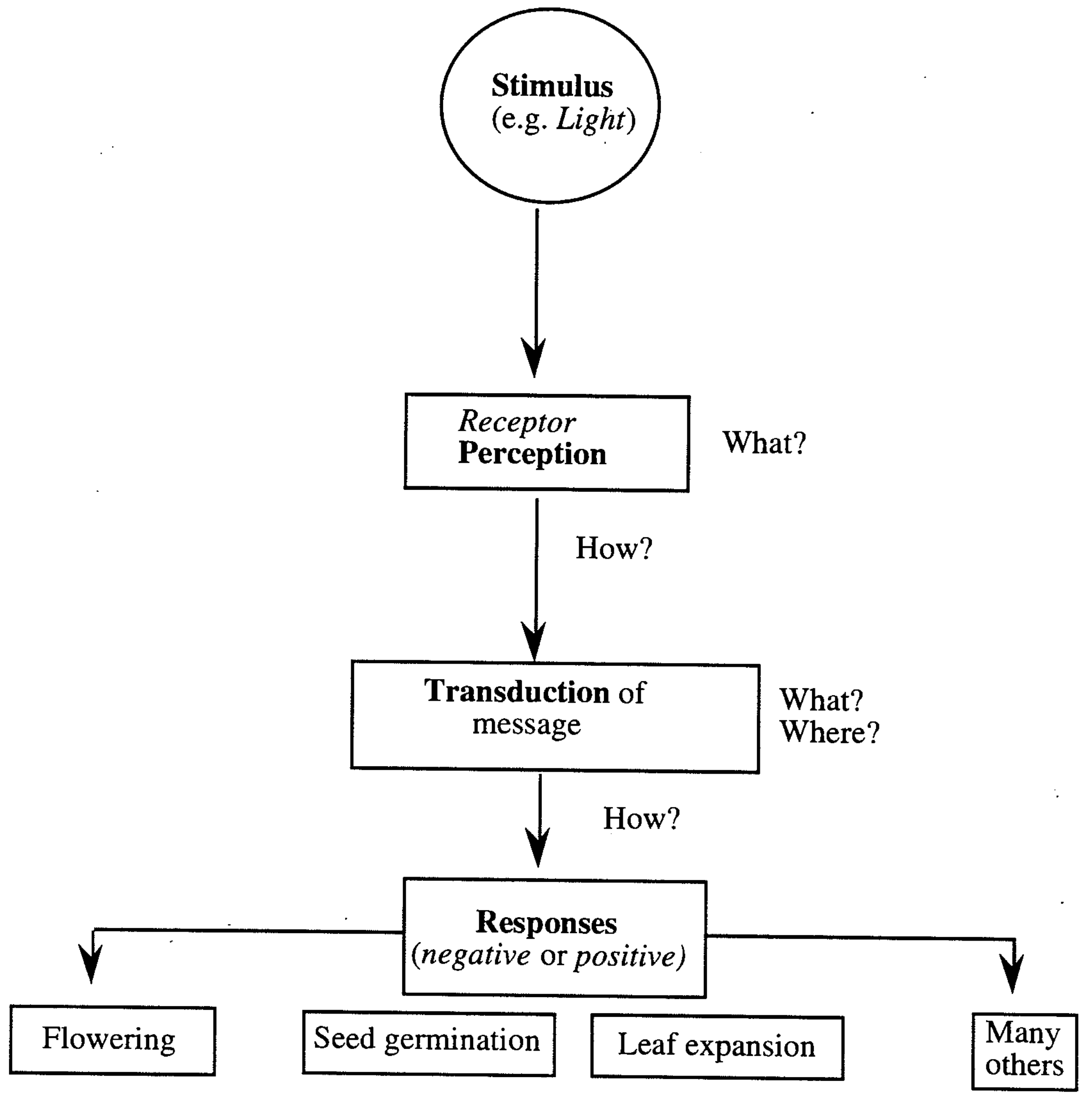


Fig. 8.2. Three major steps in initiating photomorphogenic responses by a plant. The least understood aspect is the way the message is transferred from the receptor to the site of response.

Table 8.5: Responses related to Phytochrome system

Where?	Effects of Red Light (reversed by far red light)
Seeds	Promotes germination (e.g. in lettuce)
Seedling (etiolated)	Promotes deetiolation (e.g. leaf unrolling in oat)
Adult plant	1) Inhibits internode elongation [involved in perception of shade in some sun adapted plants] 2) Inhibits flowering in short day (long night) plants; Stimulates flowering in long day(short night) plants 3) Promotes transcription of genes for the small sub units of RUBISCO and light-harvesting chlorophyll a/ chlorophyll b containing proteins 4) Sleep movements-circadian rhythm

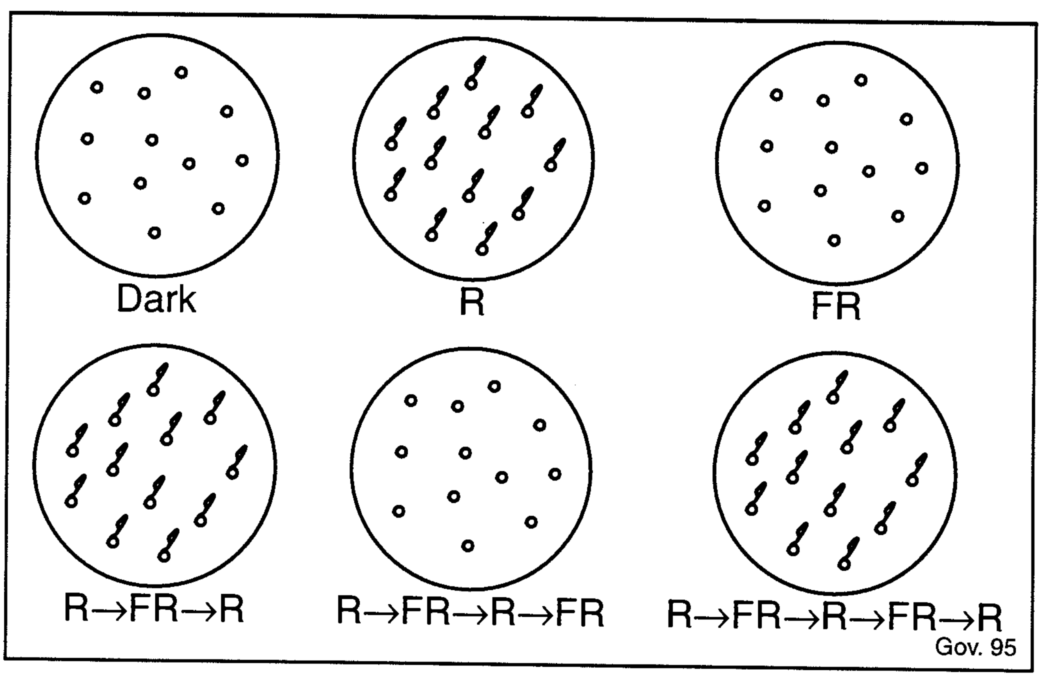


Fig. 8.3. Seed germination in lettuce as affected by exposure to red (R) or far red light (FR). Note that it is the last exposure that counts for the seeds. Idealized data of Kendrick and Frankland, 1976.

Table 8.6. Responses of Flowering to Light
(See Figure 36.17 in Raven and Johnson)

Treatment	Short-day Plant (Goldenrod)	Long-day Plant (Iris)
1. Long day Short night	None	Flowers
2. Short day Long night	Flowers	None
3. Short day Long night but few minutes of Red* (R) light in the middle of night.	None	Flowers
4. Same as above (#3) followed by a few minutes of far red (FR)* light after red light	Flowers	None
5. Same as above (#4) followed by a few minutes of red light after far red light	None	Flowers

* Red light wavelength = 665 nm; far-red light wavelength = 730nm.
An action spectra (effectiveness spectra) gave results similar to that shown in Fig. 8.4, these Notes.

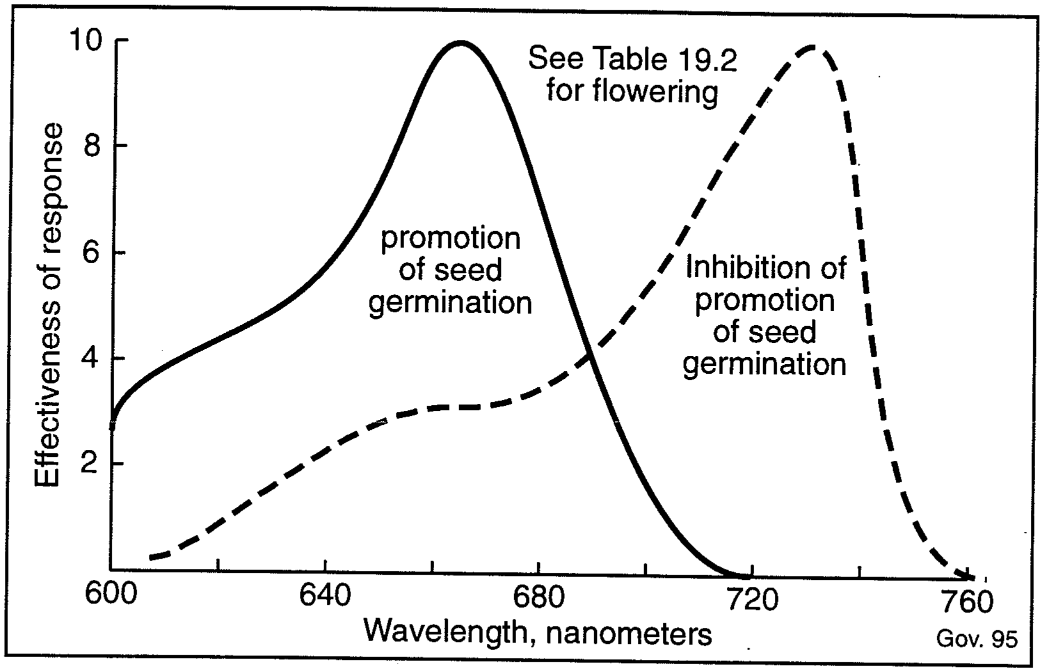


Fig. 8.4: Action spectrum (i.e. effectiveness of response per incident number of photons, as a function of wavelength of light) of promotion of lettuce seed germination and of promotion of seed germination (see Fig. 8.3, these Notes). Action spectrum for inhibition of flowering by few minutes of light given in the middle of night in short day plants peaked at 665 nm, whereas that for the reversal of this phenomenon peaked at 730nm. The red light spectrum, peaking at 665 nm, was related to the **Pr** form of a pigment phytochrome; and the far-red light spectrum, peaking at 730 nm, was related to the **Pfr** form of phytochrome. Data collected from several sources.

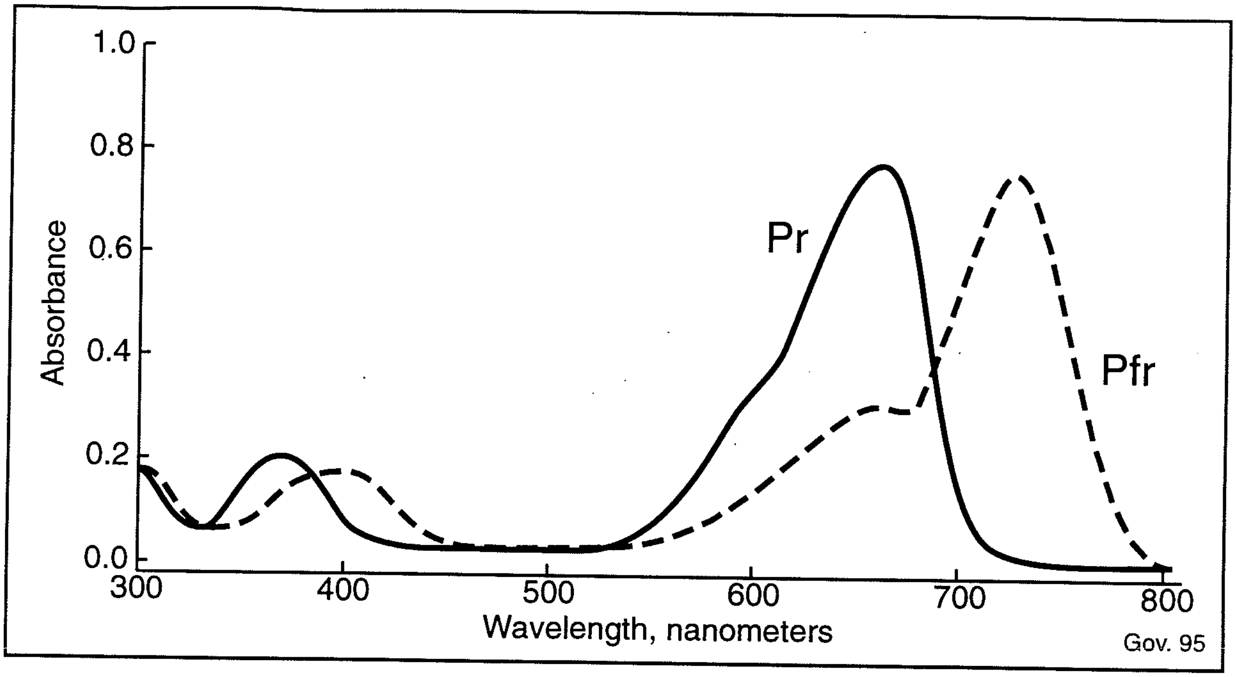
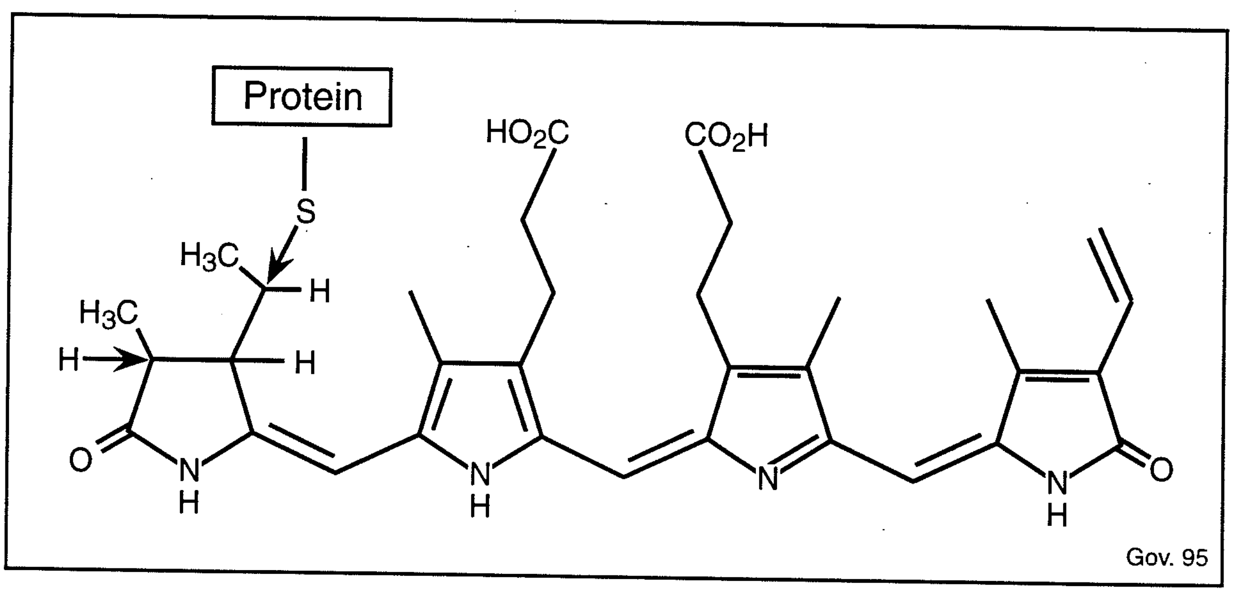


Fig. 8.5. Top: Absorption spectra of phytochrome in its Pr form (solid) and Pfr form (dashed). Bottom: Chemical structure of phytochrome: The open chain tetrapyrrole chromophore (entity responsible for color) is bound to a protein. The exact conformation of this chromophore is not shown here; it is different for **Pr** and **Pfr** forms. Phytochrome seems to be located in the membranes of the meristems.



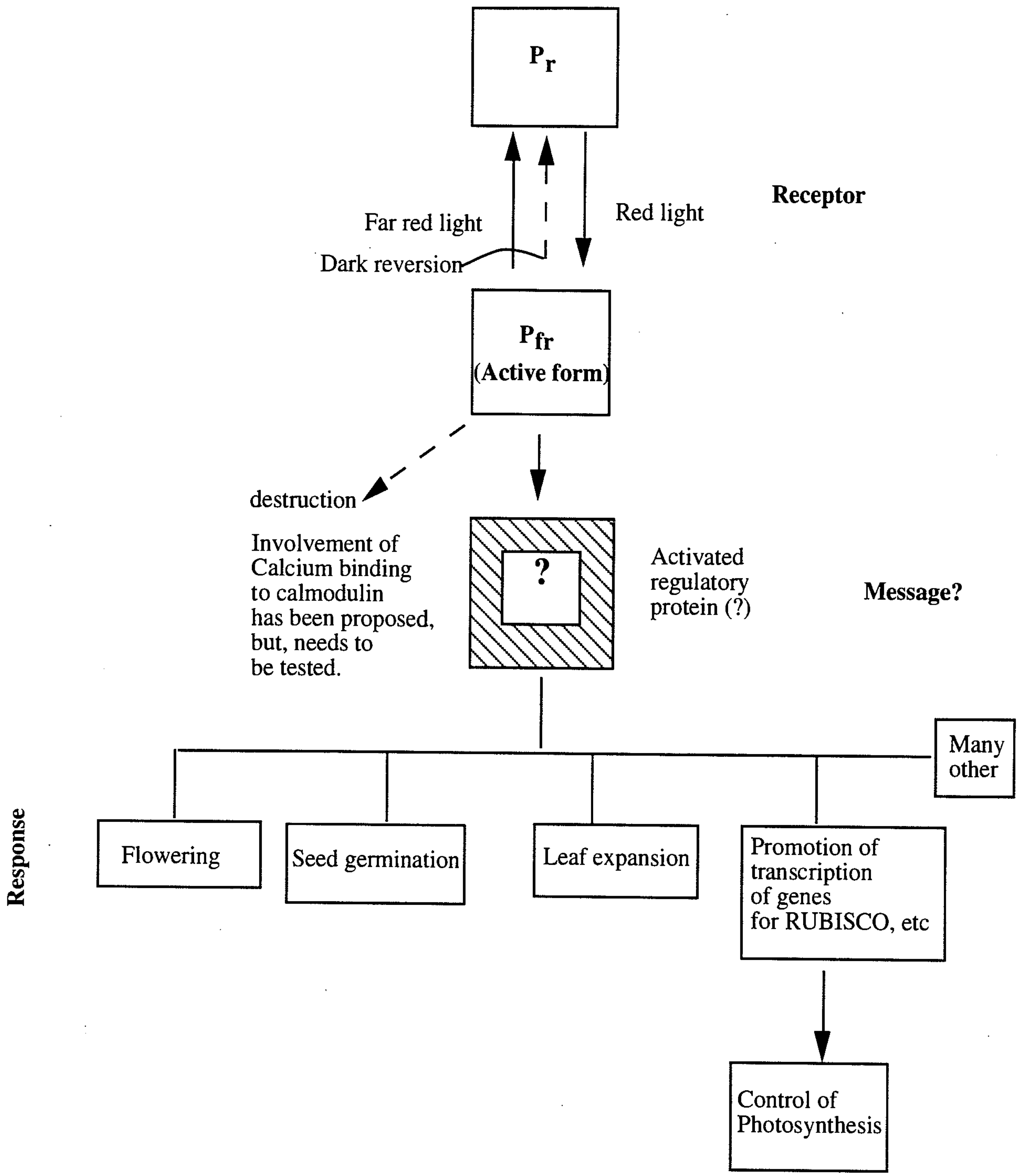


Fig. 8.6. A possible scheme for the involvement of **Pr** and **P_{fr}** forms of phytochrome in several plant responses. The intermediate step is still a black box, but is an active area of research in many laboratories.

Table 8.7. Blue light Responses*

- Synthesis of yellow-to-red pigments called anthocyanins† in seedlings of some plants and in apple skin segments
- Induction of flowering in some plants (example, henbane)
- Enlargement of cotyledons in some plants (example, mustard)
- Ethylene‡ production in some plants (example, sorghum)

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* These responses show action spectra that peak in the blue (400-500 nm) and suggest that compounds called *flavins* may be involved as receptors. They need high intensities and the effects are not reversible. In addition to flavins, absorbing blue light, far red light, absorbed by **Pfr**, also causes the same responses.

† Anthocyanins are known also to be responsible for fall colors in some leaves
‡ Ethylene is a growth regulator responsible for fruit ripening

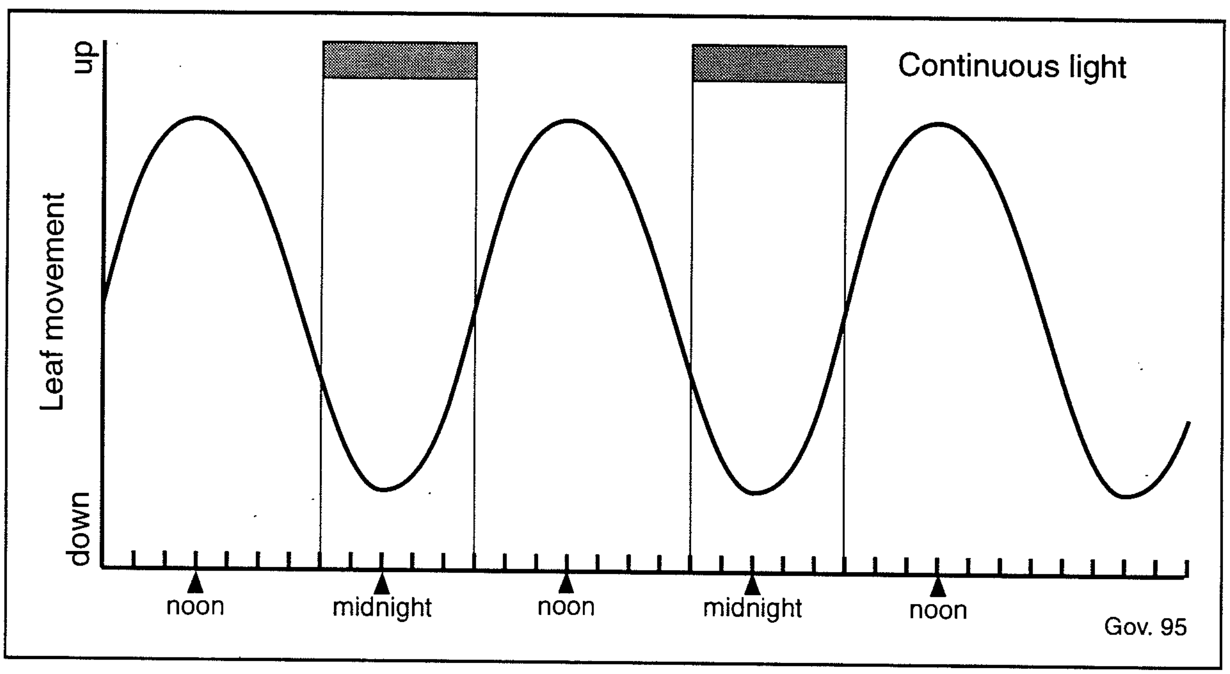


Fig. 8.7 Plants respond to a cue from the light-dark sequence of our environment. However, they have an internal clock. It is circadian (about a day) and it can go on for a while even if plants, after their clock is set, are placed in continuous light or continuous darkness. Many enzymes in plants show a circadian rhythm; photosynthesis and light emission also show circadian rhythm. The author has studied circadian rhythm in chlorophyll a fluorescence of dinoflagellates with Beazy Sweeney and Barbara Prezlin of California. Here, we show the circadian rhythm of movement of the leaf of *Albizzia* leaves that go up in the day and are lowered in the evening. Bean leaves also show a circadian rhythm; they are up in the day and droop at night as if they are sleeping at night.

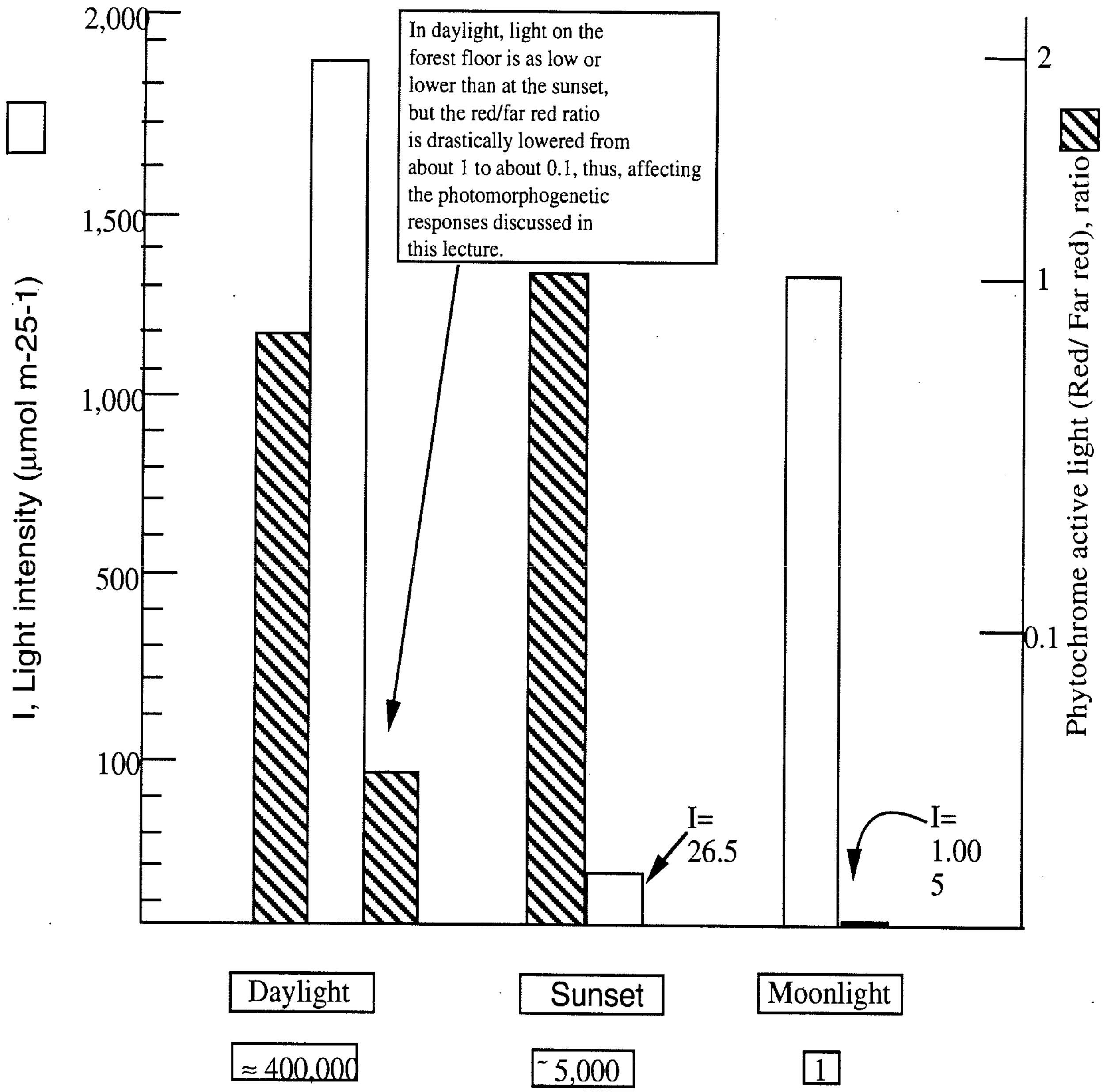


Fig. 8.8. A bar graph comparing the light intensities and the red/far red light ratios in natural light (Day light, at sunset, and moonlight). Data drawn from various sources;

For further reading:

See Chapter 15 (Cellular Basis of Growth and Morphogenesis), Chapter 16 (auxins), Chapter 17 (Gibberlins), Chapter 18 (Cytokinins), Capter 19 (Ethylene and Abscissic Acid), Chapter 20 (Phytochrome) and Chapter 21 (Control of Flowering) in L. Taiz and E. Zeiger "Plant Physiology," Benjamin/Cummings, Redwood City, CA

PLANT ECOLOGY

Lecture 9: Biological Communities: Distribution and Adaptations

Reading assignment:

Raven and Johnson, 4th ed., **Chapter 27, pp. 585-610;**
(2) **These Notes.**

By the end of your preparation of this topic, you should be able to:

- 1. Describe the major types of *Biomes* (botrh terrestrial and marine) and describe the abiotic characteristics that sustain them.
- 2. Describe the major responses of organisms to environmental variations, and how they are useful to their life.
- 3. Describe the consequences of the movement of the Earth, relative to the sun, on the climate in the Northern and the Southern hemispheres.
- 4. Define the following **concepts** and **terms**: abiotic versus biotic variable; acclimation; biome; climate; Coriolis effect; disturbance; flora; freshwater communities; homeostasis; microclimate; ocean communities; parent rock; physiognomy; rain shadow; soil; topography; vegetation.

Outline of presentation:

(Figure and Table numbers are either from Raven and Johnson, **or from these Notes**.)

♦ 1. Ecology; environment and earth:	(Our planet is a "finite" place.)	
♦ 2. Factors determining vegetation:	**Fig. 9.1**	**Notes**
♦ 3. Distribution of major terrestrial biomes in the world:	Fig. 27.12	p.598
♦ 4. Distributions of terrestrial biomes of North America:	**Fig. 9.2** **Table 9.1**	**Notes** **Notes**
♦ 5. A look at the Biomes: let us take a trip Should we go in a car? (Equator to the Poles)		
• (1) Tropical rain forest:	(See Fig. on p. 599)	
• (2) Savanna:	(See Fig. on p. 600)	

- (3) Desert: (See Fig on p. 601)
- (4) Temperate grassland: (See Fig. on p. 602)
- (5) Temperate deciduous forest: (See Fig. on p. 603)
- (6) Taiga (coniferous trees): (See Fig. on p. 604)
- (7) Tundra: (See Fig. on p. 605)
- (8) Chapparal - These are adapted to periodic fires; dense spiny shrubs with tough evergreen leaves: (See Left Fig. on p. 606)
- (9) Polar Ice and Mountain zone: (See Fig. on p. 606)
- (10, 11, 12, 13, and 14) Other Forests, etc: (See Figs. on p. 607)

♦ 6. Aquatic biomes:

- Freshwater (Ponds & lakes; streams and rivers): Fig. 27.11 p. 597
- Marine (Estuaries; intertidal zone; coral reefs; Benthos: deep sea vents):
- Oceanic zone: (See p. 589-594)

♦ 7. Climte and Vegetation:

- Climate: light and temperature: Fig. 27.1 p.586
- Climate: Northern & Southern hemisphere and cause of the seasons: Fig. 27.1 p.587
- Climate: Rain in the tropics; Dry in the desert: (See p. 588-589)
- Rain Shadow Effects: Fig. 27.3 p.588
- Climate, cannot forget wind:
- Equivalence of altitude and latitude for vegetation types: (See bottom half of p. 598)
- Relationship of water and temperature to vegetation; other factors:

(Water and temperature are two crucial factors in determining vegetation)

♦ 8. Responses of organisms to environmental variation:

- Homeostasis: regulators (compare with conformers):
  (Regulators maintain internal conduction during changes in environmental conditions, using energy; conformers allow changes in internal condition)

- Behavorial response: Plants don't have it

- Strategies to conserve water; examples: Fig. 27.4 p.589
  spadefoot toad; beetle

- Adaptation over evolutionary times; example:
  CAM plants (CAM = crassulacean Acid Metabolism)

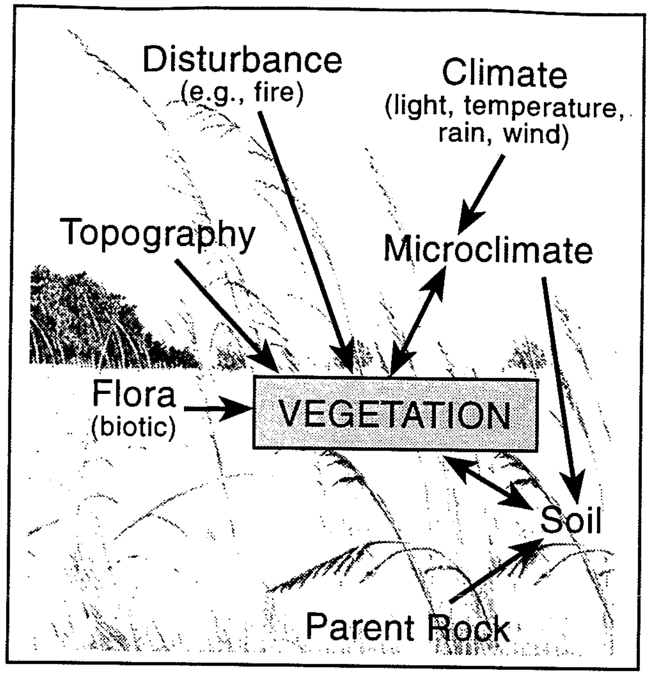


Fig. 9.1 Flow chart for vegetation.

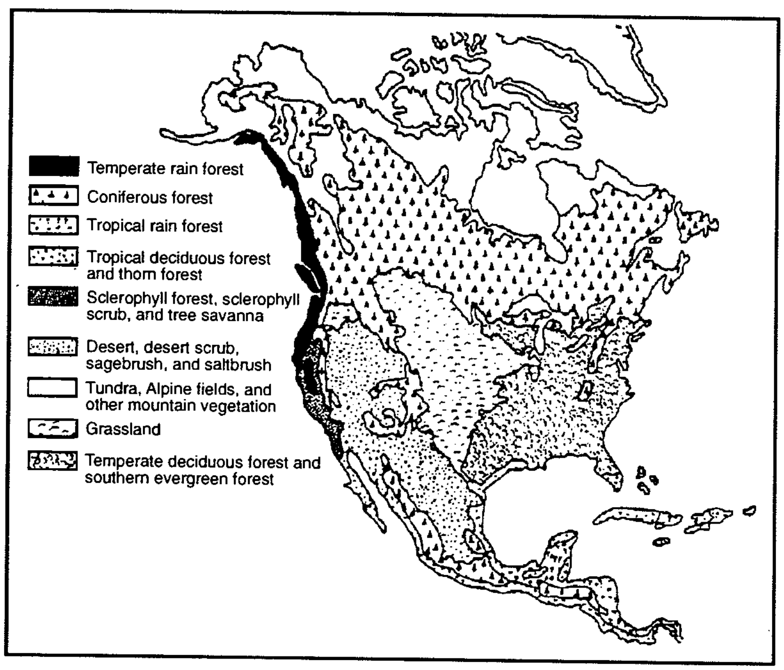


Fig. 9.2 Biomes of North America. Based on Lecture Outlines for Biol. 121, Spring, 1995.

Table 9.1. Characteristics of some biomes of North America. Modified from "Lecture Notes", Biol. 121, 1993, 1994. Spring, 1995

Biome	Abiotic Limit	Disturbance	Vegetation
Desert	Moisture temp. varies	Low	Xerophytes
Grasslands	Moisture seasonality	Fire, grazing	Perennial grasses
Temperate Deciduous forest	Temp. seasonality	Wind, fire (low)	Deciduous trees
Coniferous Forest and Taiga	Temp. moisture	Low	Evergreen conifers
Tundra	Temp. moisture	Freeze/thaw	Low stature perennials Non-vascular plants
Tropical Rain Forest	Biotic factors	Gaps	Large stature trees

Dictionary/glossary/concepts:

1. *Abiotic versus biotic variable*: non-life versus life related variables (temperature is abiotic; you are biotic)

2. *Acclimation*: a shift of the performance curve in the direction of the environmental change

3. *Biome*: one of the major assemblages of generally similar communities characterized by climate and soil conditions (an example is *Desert*)

4. *Climate*: composite weather conditions of a region such as temperature, air pressure, humidity, precipitation, sunshine, cloudiness, winds, climate structures, and biological communities, etc.

5. *Coriolis effect*: named after G. Coriolis, a french civil engineer (died 1843); earth spins on its axis and creates force that deflects wind; winds go from west to east in parallel bands; it also causes water to spin clockwise in the North and counterclockwise in the South in the oceans.

6. *Disturbance*: changing the existing state, e.g., fire

7. *Freshwater communities:* Very little of Earth's water is stored as freshwater in ponds, rivers and lakes. However, biological communities exist there. In spring and fall, lake water mixes; nutrients come to surface and oxygen goes to deep waters needed for life.

8. *Flora*: plants of a particular region or period

9. *Homeostatis*: maintenance of a steady state internal environment in the face of variations in external environment

10. *Microclimate*: climate of a small area or space

11. *Parent rock*: starting rock (mineral matter of various composition, assembled in masses)

12. *Ocean communities*: these include planktonic stratum of the surface zone of the oceans; oceans contain a great wealth of nutrients and biomass

13. *Physiognomy*: the outward appearance, e.g., the shape or the "looks"

14. *Rain shadow*: it refers to what happens to the side of the mountain that is away from the side rain falls; this side will have desert without any rain

15. *Soil*: the portion of the earth's surface consisting of disintegrated rock and humus

16. *Topography*: surface configuration of an area, especially obtained by means of surveying the area

17. *Vegetation*: all the plants or plant life of a place taken as a whole

For further reading:

See Chapter 20 in M.G. Barbour, J.H. Bark & W.D. Pitts (1987) Terrestrial Plant Ecology, Benjamin/Cummings, Menlo Park, CA.

Lecture 10: Ecosystems: Dynamics of Ecosystems; Energy flow and Productivity

 Reading assignment:
Raven and Johnson 4th ed., **Chapter 26, pp. 569-583;**
(2) **These notes**

 By the end of your preparation on this topic, you should be able to:

♦ 1. Define *ecosystem*, and describe the emergent properties of an ecosystem.

♦ 2. Describe the meaning of *trophic* levels, differences between primary producers and the consumers, and the food chain and the food web.

♦ 3. Describe energy transformation among trophic levels, and relate it to the concept of ecological efficiency, and of the "pyramids" of (a) numbers; (b) biomass; and (c) energy.

♦ 4. Describe the change in the net primary productivity (NPP) through time for a forest ecosystem and identify possible factors determining these changes.

♦ 5. Distinguish between the NPP, gross productivity (GPP) and the biomass of an ecosystem. What factors control NPP?

♦ 6. Present the reasons for differences in the productivity of different ecosystems in terms of net primary productivity, and in the percentage contribution to Earth's productivity.

 Outline of Presentation:
(Figure and Table numbers are either from Raven and Johnson, **or from these Notes.**)

♦ 1, Ecosystems; Primary producers; consumers and decomposers; autotrophic versus heterotrophic:	Fig. 26.1	p. 570
♦ 2. The food chain and the food web:	Fig. 26.6	p. 577
	Fig. 26.7	p. 578
	Fig. 26.8	p. 579
♦ 3. Energy transfers and ecological pyramids:	Fig. 26.9 (a,b, and c)	p. 580
	Table 10.1	**Notes**

♦ 4. Net Primary Productivity (NPP) and Gross Primary Productivity (GPP) Measurement (In darkness, one measures respiration only, and in light, one measures NPP that equals GPP minus respiration)

NPP = GPP - Respiration

• Changes in NPP in a forest: temperature, respiration:	**Fig. 10.1**	**Notes**
• Possible factors affecting NPP:	**Fig. 10.2**	**Notes**
	Fig. 10.3	**Notes**
	What Else?	
♦ 5. Global and U.S. Productivity (How are we doing in Champaign - Urbana?)	**Fig. 10.4**	**Notes**

Table 10.1 Ecological efficiency of a grasshopper

1. When a grasshopper eats, it may **assimilate** only 38% and **egest** 62%.
2. Only 4% of the total eaten ends up in growth and reproduction (i.e., productivity).
3. Thus, the gross growth efficiency (also called ecological efficiency) is 4% divided by 38%, that is, about 10%.

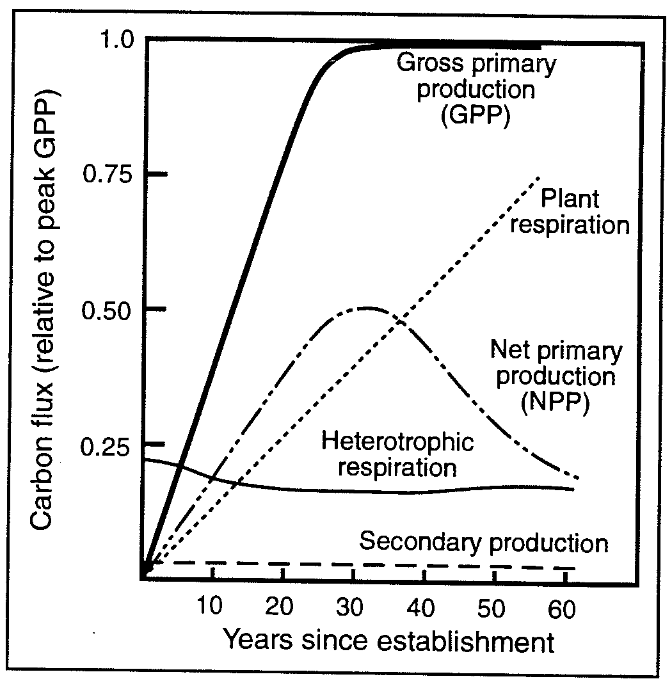


Fig 10.1. Changing patterns of ecosystem metaboliam of a forest. Diagram drawn by SOLS Artist Service, in 1995. Data from R.H. Warring and W.H. Schlessinger (Forest Ecosystem: Concepts and Management, Chap. 3, Fig. 3.1, 1985).

Notes: **(1)** Net primary production (NPP)= Gross primary production (GPP)- Respiration; all are expressed as *rates* (i.e., expressed per unit area per unit time). **(2)** In a forest, GPP may take about 30 years to reach the maximum value; this corresponds to the peak in NPP and to canopy closure in the forest. **(3)** NPP decreases as the forest ages due to respiration that continues to increase with increasing biomass (weight) of non-photosynthetic tissue.

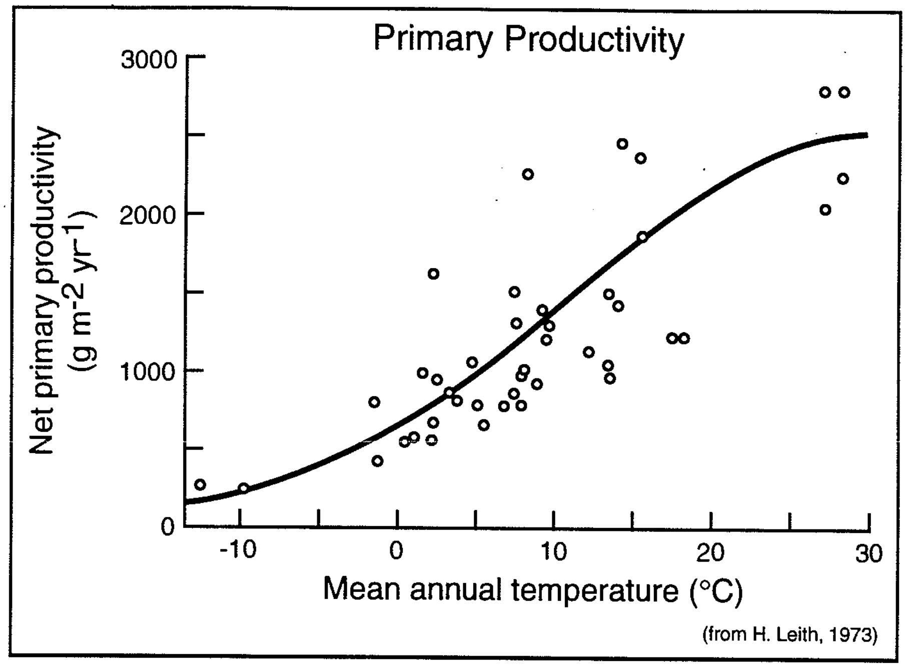


Fig. 10.2: Relationship between above ground net primary production and mean annual temperature. Data from H. Leith (Human Ecology 1: 303-332, 1973).

Notes: A knowledge of net primary productivity is important because it dictates the energy that is available for use on this Earth. Thus, there is interest in its measurement and factors that affect it. In Fig. 10.2, a curvilinear relationship to temperature is shown for a forest. In addition to the fact that several factors control NPP, the large scatter in the data tells a tale of tremendous variations, of "unknown" complex origins, that do not allow a precise correlation between the parameters being studied.

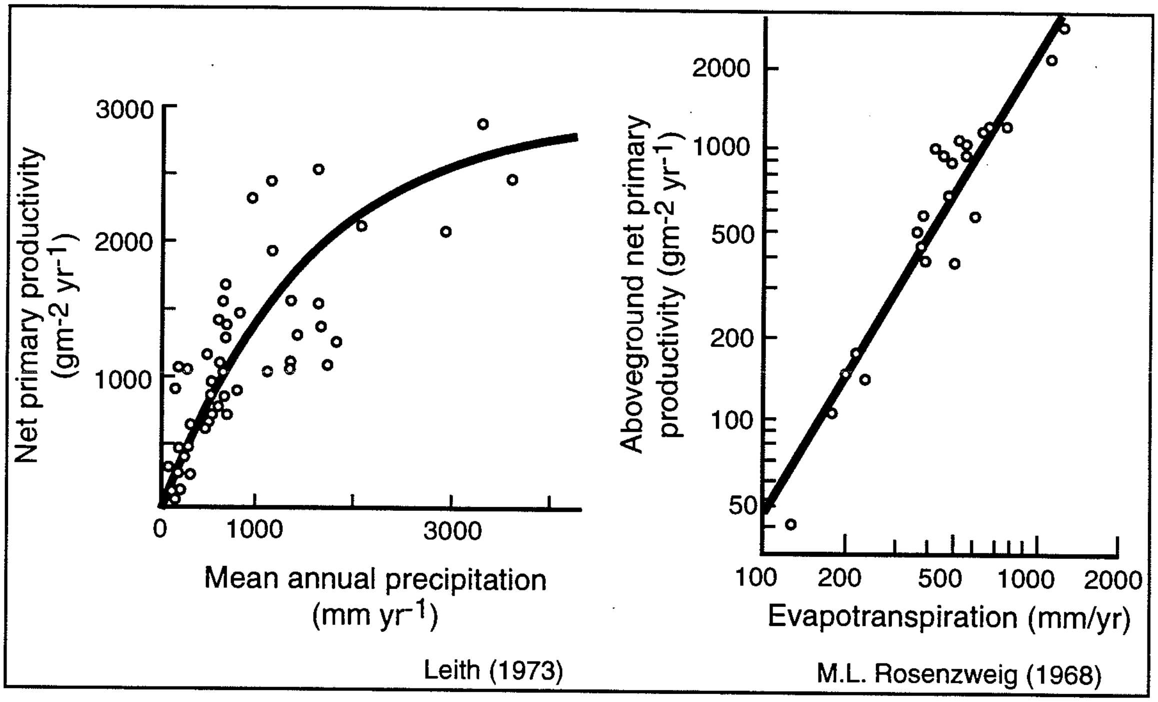


Fig. 10.3: Net Primary Productivity (NPP) in plants increase, as shown, with increasing mean annual precipitation (*left graph*: data of H. Leith: Human Ecology 1: 303-332, 1973) and with evapotranspiration of plants (*right graph*: M. L. Rosenzweig: American Naturalist 102: 67-74, 1968).

Notes: The scatter in the left curve points to other factors affecting the results as in Fig. 10.2. Although the right curve shows a linear relationship, with very little scatter, between the NPP and evapotranspiration, it cannot be taken to prove the relationship because only data for the above ground NPP is given; the data on the whole plant (including below ground roots) may invalidate the relationship.

Although it is clear that both temperature and precipitation affect NPP, the precise relationships are difficult to obtain in such a complex system.

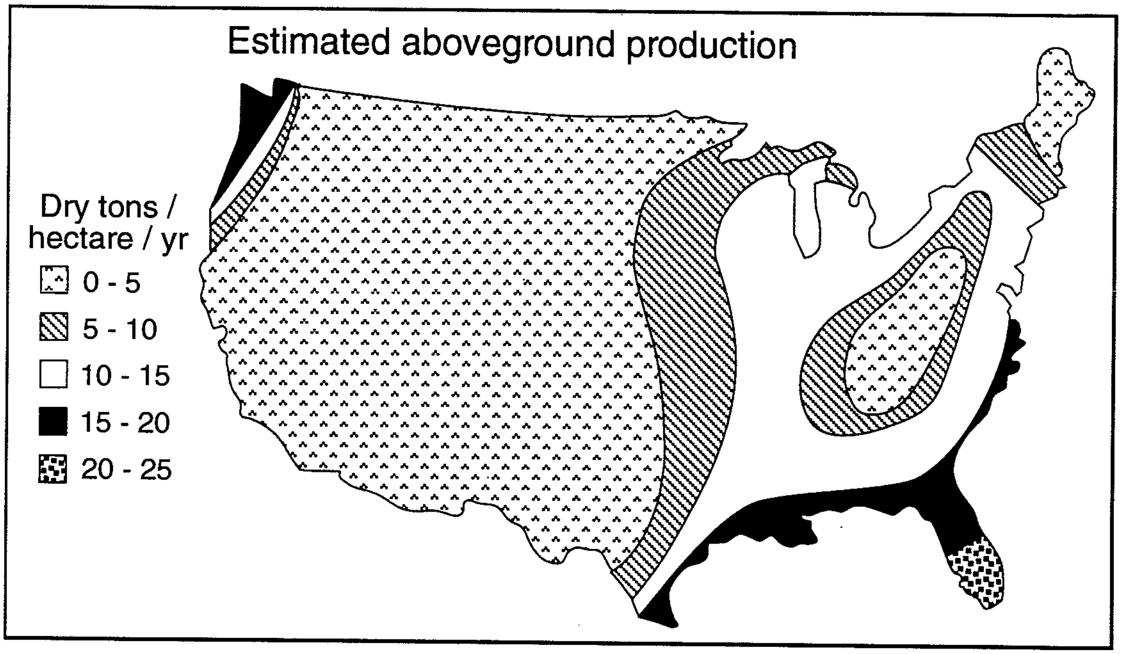


Fig. 10.4: Estimated above ground production across the mainland U.S.A. Data from Ranney and Cushman (1982).

Notes: Many researchers have suggested that the primary production is linearly related to the product of leaf area index (a number that refers to the leaf area intercepting light) and the number of months in the growing system, termed "leaf area duration". It appears that this is often a good indicator of productivity.

Dictionary/glossary/concepts

1. *Ecosystem*: is any community of interlocking organisms including their living and non-living environment described in terms of the flow of energy and the cycling of matter through their environment.

2. *Emerging property:* is that property that emerges when the sum of all the parts of a system does not equal the whole because of interactions between the parts.

3. *Energy flow*: Energy flows into ecosystems from the sun and passes from one organism to another, 90% of it being lost at each step.

4. *Food pyramids*: Plants convert only 1% of light energy that strikes them, then only 10%passes at each step.

5. *Trophic:* deals with the feeding mode of a system.

For further reading:

See Chapter 12 in M.G. Barbour, J.H. Burk and W.D. Pitts (1987): Terrestrial Plant Ecology, Benjamin/Cummings

Lecture 11: Ecosystems: Biogeochemical Cycles

Reading assignment:
Raven and Johnson, 4th ed., **Chapter 26, pp. 570-576; Chapter 28, p. 619;**
(2) **These Notes.**

By the end of your preparation on this topic, you should be able to:

- 1. Compare and contrast the major pools and fluxes of gaseous (CO_2, N^2) and sedimentary (e.g., phosphorus) cycles.
- 2. Discuss a major method for the study of biogeochemical cycles using a forest, as a component of the system.
- 3. Show the *inputs*, *biotic accumulation and storage*, and the *losses* in the example you discussed above in #2.
- 4. Discuss the effects of a catastrophic disturbance (for example, *fire*) on the accumulation of nutrients, carbon and nitrogen in a forest.
- 5. Discuss the possible reasons and the consequences of increasing CO_2 in our atmosphere.
- 6. Present to your friends examples of human activities that have been responsible, in the past, for the death of fishes in lakes, for reduction in the population of pelicans and eagles; and for the death of some sea otters in Alaska.
- 7. Define and describe the following **concepts** and **terms:** biogeochmical cycle; biological magnification; deforestation; eutrophic lakes; flux; greenhouse effect; inter-and intrasystem cycles; mycorrhiza; nutrient cycles; pool; watershed approach

Outline of presentation:
(Figure and Table numbers are either from Raven and Johnson, 4th ed., **or from these Notes.**)

- 1. Chemical cycling

• Water cycle:	Fig. 26.2	p.571
• Carbon cycle:	Fig. 26.3	p.572
• Nitrogen cycle:	Fig. 26.4	p.573

• An aside: nitrogen fixation in some shrubs/trees:	**Fig. 11.1**	**Notes**
• Phosphorus cycle [Mycorrhizae help in phosphorus uptake by plants]:	Fig. 26.5	p.574
♦ 2. The Hubbard Brook Forest study:	**Table 11.1**	**Notes**
• Effect of deforestation on loss of nitrate: (See pp. 574-576, Raven and ohnson)		
• Balancing inputs and outputs:	**Fig. 11.2**	**Notes**
♦ 3. Changes in accumulation of nutrients, carbon and nitrogen in a forest:		
• Biomass in vegetation and forest floor:	**Fig. 11.3**	**Notes**
• Accumulation of nutrients in a forest after a fire:	**Fig. 11.4**	**Notes**
• Accumulation of organic C and N in soil and forest floor:	**Fig. 11.5**	**Notes**
♦ 4. Increases in CO_2 in our atmosphere:		
• Hawaii data:		
• Possible "greenhouse effect" and comments on ozone depletion problem:	(July 11, 1988, Newsweek photos)	

Table 11.1 Notes on Hubbard-Brook Experiment

(1) Nutrients were measured in precipitation and dust in grids of collectors and provided information on the *input*. Then the nutrients were measured leaving the ecosystem (*output*) before the stream entered a narrow notched dam. Both the particulate matter, that settled before the notched dam, and the nutrients in the stream going over the dam were measured.

(2) It was found that the output as a percent of input for the various minerals followed the sequence: 98% (Na), 90% (S), 78% (Mg), 74% (Cl), 59% (Ca), 24-25% (K, Fe), 19% (N) and 1% (P).

(3) Most of the elements were mostly 90-98% in dissolved form except for Fe (0%), P (37%), C (68%), Al (60%), Si (74%) and K (78%)

(4) See statement on "Brown background" on p. 576 of Raven and Johnson, When the trees were cut down, loss of nitrogen as nitrate in the run off water increased drastically. Why?

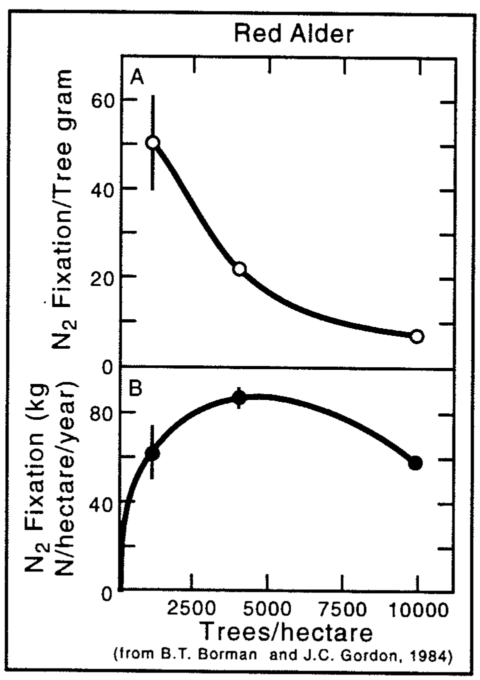
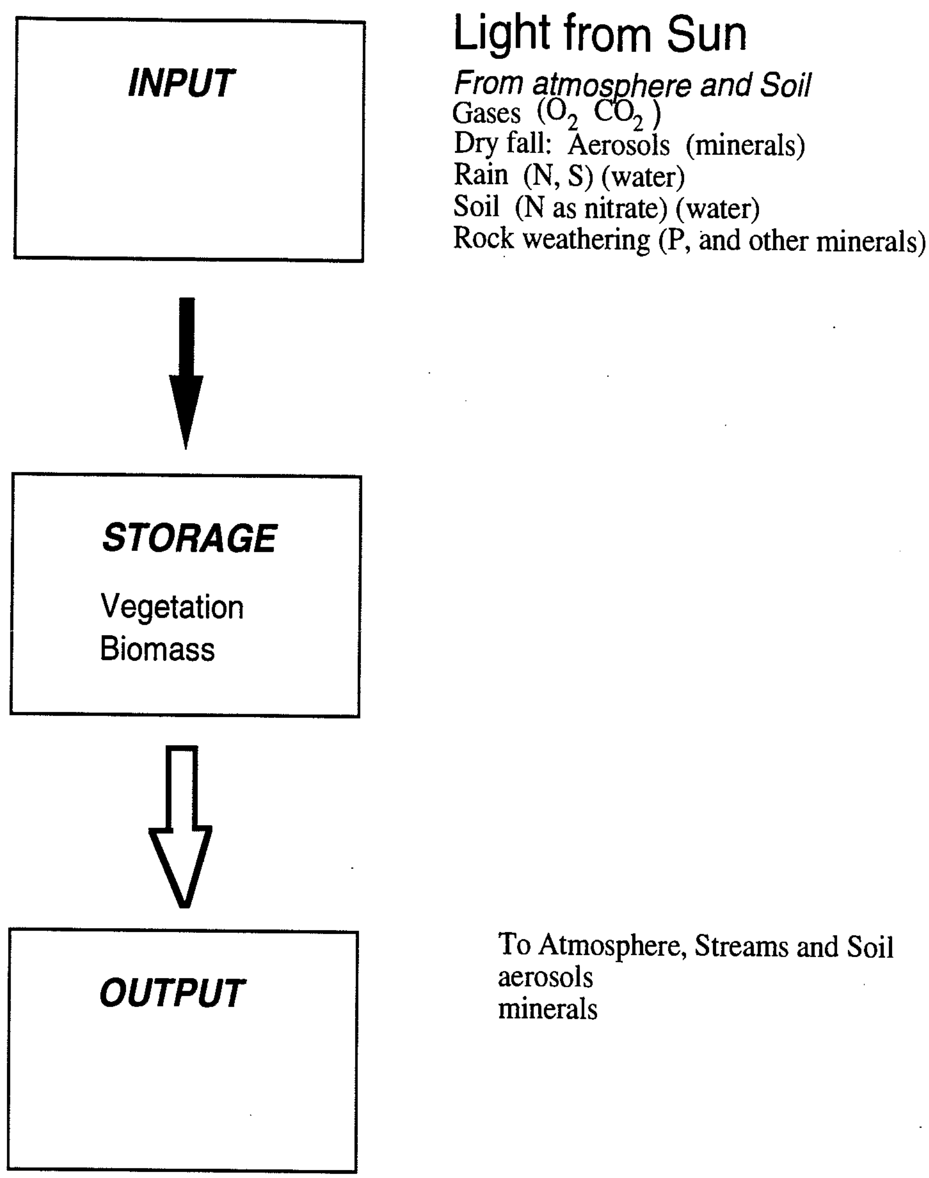


Figure 11.1 Data of Borman and Gordon (1984) on red alder show that although N_2 fixation/tree decreases, the toal N_2 fixation (per area per year) increases, reaches an optimum and then decreases with increasing tree density. Most N_2 fixers in nature are nitrogen-fixing free-living bacteria, or those associated as nodules on the roots of legume family (*Leguminosae*), and in some shrubs and trees.



Input — Output = Storage

Fig. 11.2 Input is with solid arrow, and output is with empty arrow.

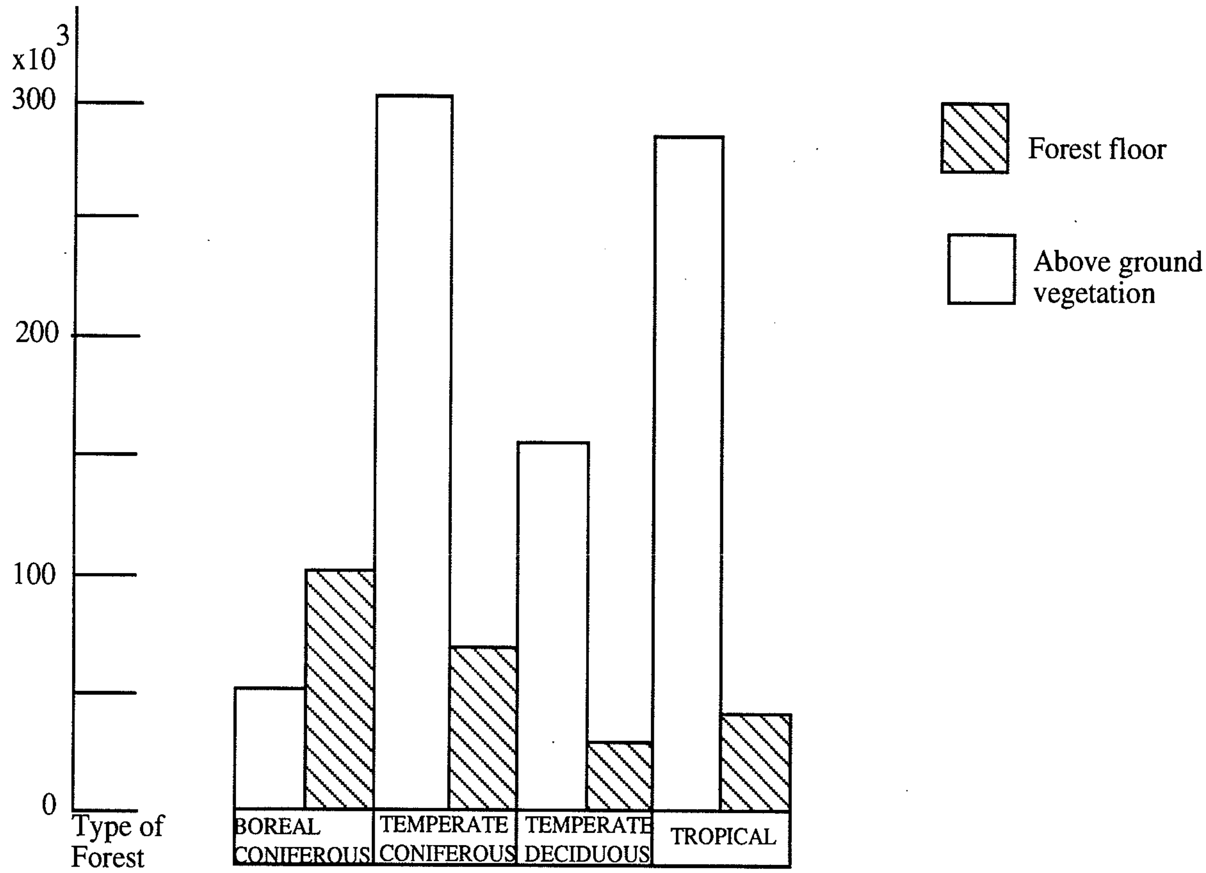


Fig. 11.3 Biomass (kilograms/hectare) in vegetation and forest floor in different types of forest. Data of Cole and Rapp (1981) and Edwards and Grubb (1982).

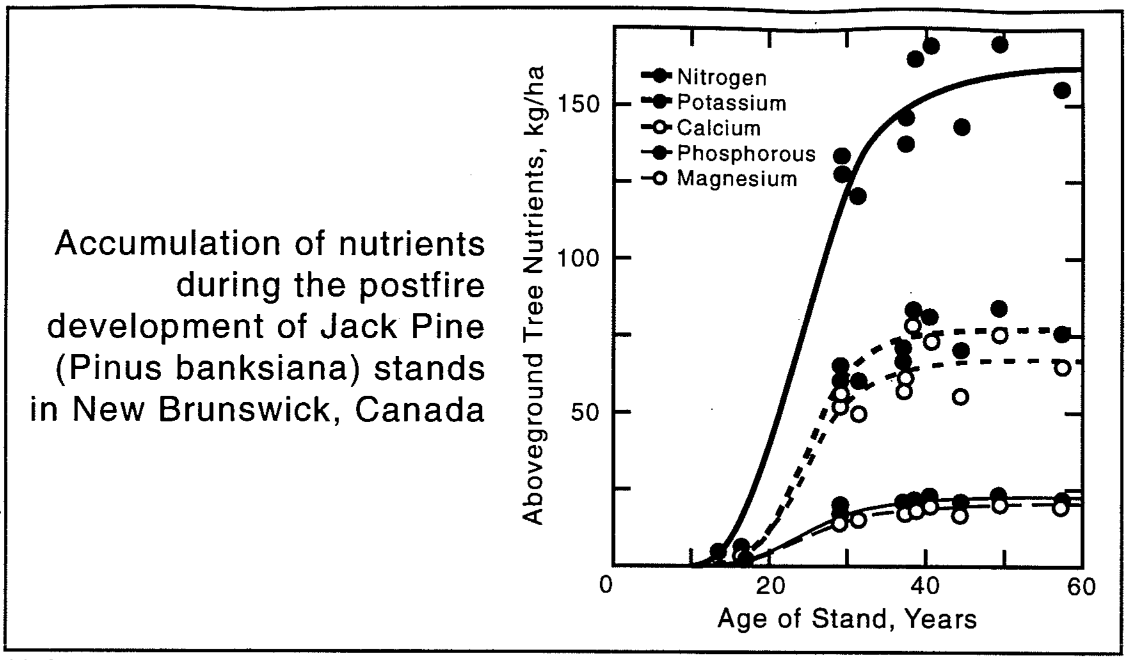


Fig. 11.4 Nutrient accumulation during forest development. The figure shows the accumulation of nutrients (N, K^{+}, Ca^{2+} ,POS(3-,4) and Mg^{2+}) in Jack pine stands as a function of the age of the forest. (Data of MacLean and Wein, 1977). An asymptote is reached when the growth of wood in trees becomes equal to the death of older trees.

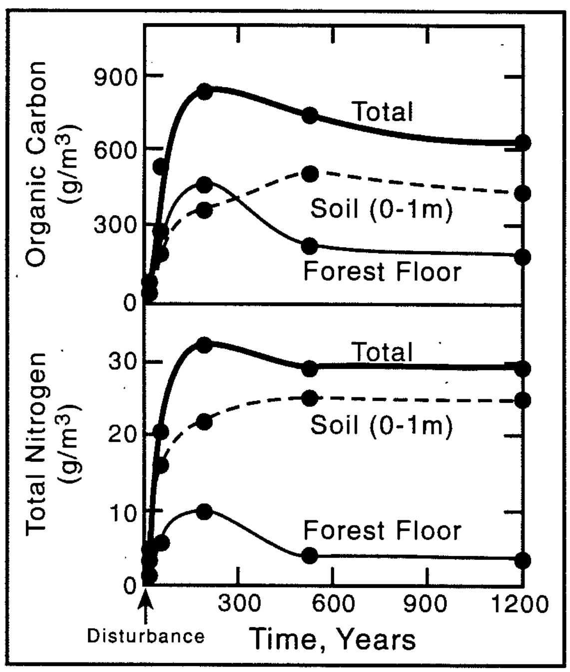


Fig. 11.5 Shows the accumulation of organic C and N in soil and on Forest floor developed on volcanic mudflows of varying age on Mount Shasta during forest regrowth. Data of Dickson and Crocker, 1953. The organic carbon in the forest floor reaches a maximum before the underlying soil because the floor gets the falling leaves and branches first. However, the storage of N was more rapid in the soil than in the forest floor because there were several N-fixing shrubs rooted in this zone.

Dictionary/glossary/concepts

1. *Biogeochmical cycle*: refers to a cycle that deals with life (bio), rocks (geo) and chemicals.

2. *Biological magnification*: when toxins (or any chemical) become more concentrated in successive levels of a food web.

3. *Deforestation*: the act of doing away with the forest.

4. *Eutrophic lake:* Greek for "well nourished lake"; here, there is an algal bloom that leads to choking up of life of fishes.

5. *Flux:* rate of flow of something, *e.g.*, of a nutrient, or energy.

6. *Greenhouse effect:* The warming of the Earth by re-radiation of heat back to the Earth by the atmosphere. When [CO_2] increases it absorbs more infrared, increasing the temperature of the Earth.

7. *Inter-and intra system cycle:* inter stands for between systems; and *intra* for within a system.

8. *Mycorrhiza (myccorrhizae)*: a symbiotic association between fungi and roots of a plant—it is plural with an "e" at the end.

9. *Nutrient cycle:* a cycle that traces the path of a particular nutrient, such as nitrogen, carbon, etc.

10. *Pool:* reservoir

11. *Watershed:* region of area drained by a river

12. *Watershed approach:* a method of study that uses a watershed

For further reading:

See Chapter 13 in M.G. Barbour, J.H. Burk and W.D. Pitts (1987); Terrestrial Plant Ecology, Benjamin Cummings, Menlo Park, CA.

Lecture 12 Ecosystems: Carbon Cycle and Climate; Future of the Biosphere

Reading asssignment:

(1) Reread Raven and Johnson 4th ed.,**Chapter 26, p. 572; Chapter 27, pp . 586-595**; **Chapter 28, pp. 618-631; these notes**
(2) Bazzaz, F.A. and Fajer, E.D. (1992). Plant life in a CO2-rich world. *Scientific American* **266** (1), 18-24.
(3) **These Notes**

By the end of your preparation for this topic, you should be able to:

- 1. Identify the major pools (reservoirs) and fluxes of the global carbon cycle.
- 2. Discuss the uncertainties in the balance of the global carbon cycle.
- 3. Describe the *greenhouse* effect and provide a physical explanation for the same.
- 4. Relate leaf biomass to net primary productivity (NPP), NPP to leaf area index (LAI), as measured by remote sensing of chlorophyll.
- 5. Discuss the potential effects of climate and other environmental changes (for example, increased CO_2 concentration, increased temperature) on vegetation and humans.
- 6. Define and, or describe the following **concepts** and **terms:** beta factor, ENSO events, gigaton, greehouse gases, leaf area index, organic matter, photosynthesis, radiation, respiration, remote sensing, short and longwavelengths, soil, source/sink

Outline: Order of presentation

(Figure and Table numbers are either from Raven and Johnson, **or from these Notes**)

- 1. **The Carbon Cycle**

• Global Carbon cycle:	Fig. 26.3	p. 572
• Accounting of C: mostly in Oceans:	**Fig. 12.1**	**Notes**
• Carbon fluxes; more going to the atmosphere:	**Fig. 12.2**	**Notes**
• Distribution of carbon:	**Fig. 12.3**	**Notes**

- The missing carbon: **Table. 12.1** **Notes**

♦ 2. The Greenhouse Effect:

A. *Changes in CO_2 on Earth*

- Evidence for CO_2 increase: **Fig. 12.4** **Notes**
- CO_2 increases as a function of latitude and time: **Fig. 12.5** **Notes**
- Past CO_2 increases: **Fig. 12.6** **Notes**
- Is this mainly fossil fuel burning and deforestation?: **Figs. 12.7(A) and (B)** **Notes**
- But don't forget the "Yo-yo" effect: **Fig. 12.8** **Notes**

B. *Changes in temperature on Earth*

- Global temperature variation: **Figs. 12.9 and 12.10** **Notes**
- Predictions of increases in temperature due to increases in CO_2 levels: **Fig. 12.11** **Notes**
- Predictions in changes in vegetation due to possible increases in temperature: **Fig. 12.12** **Notes**

C. Possible predicted changes:

- Increased photosynthesis in some plants, and, thus, increased biomass
- Long-term damage of some plants
- Floods due to melting of ice

♦ 3. Biomass and Climate

Two major climatic factors (rain and temperature) play important roles in determining which plants grow where. Biomass of a plant, related to primary productivity, can be estimated from the leaf area index (L.A.I, i.e., area of leaves divided by area of the ground), and LAI can be estimated from the ratio of the reflection of near infra red light (not absorbed by leaves) to the reflection of red light (absorbed by leaves).

- Relationship between Net Primary Productivity and leaf biomass: **Fig. 12.13** **Notes**; **Fig. 12.14** **Notes**

- Relationship between Net Primary Productivity and Leaf Area Index: **Fig. 12.15** **Notes**

- Relationship between the ratio of near infra red reflectance/red reflectance to leaf area index: **Fig. 12.16** **Notes**

[In the first approximation, then, these reflectance studies can give some estimate of biomass in certain plants.]

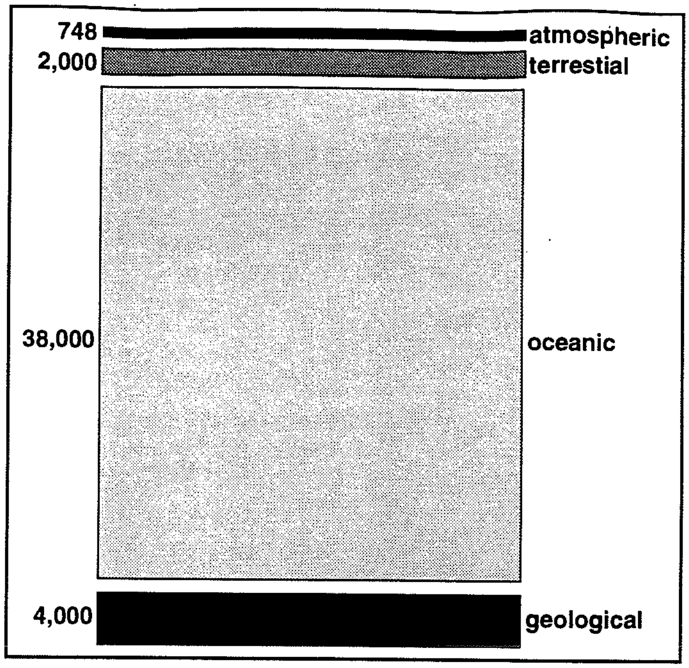


Fig. 12.1 Reservoir sizes in gigatons of carbon in our atmosphere, land (terrestrial), Ocean and buried under Earth (geological). (Data taken from Post et al., American Scientist, 1990, 78, 310-326).

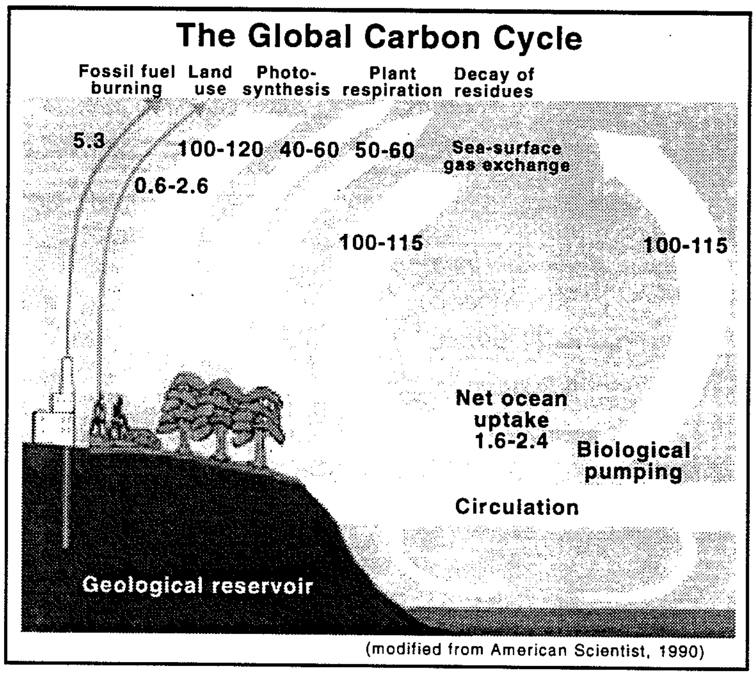


Fig. 12.2 1980 estimates of carbon fluxes in gigatons. It seems more carbon is estimated to go to the atmosphere than is accounted for by measured increases in carbon there! (Data ofPost et al., 1990).

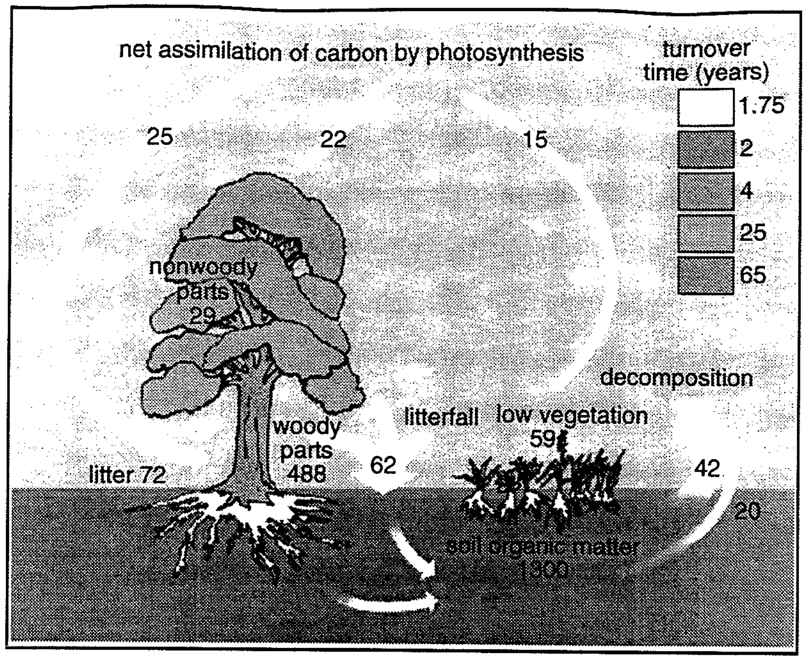


Fig. 12.3 Accounting of carbon assimilation and turnover times of carbon by terrestrial vegetation. Woody plants of a tree have low turnover but more carbon (Post et al, 1990).

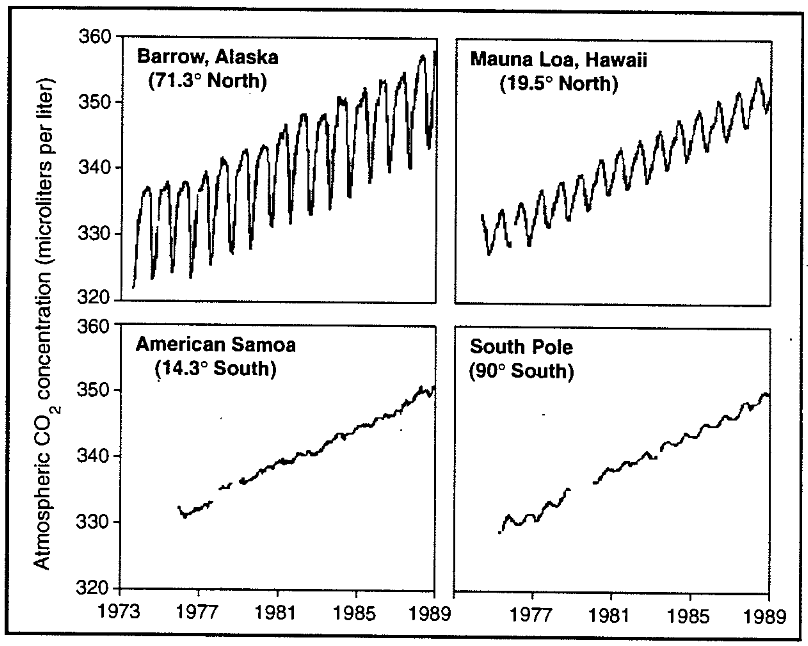


Fig. 12.4 Data on increases in CO_2 at four sites (Data of National Oceanic and Atmospheric Administration, 1986-1989) (See Post et al., 1990). Note that the depth of seasonal changes (low CO_2 in summer and high in winter) depends upon the site of measurements. **Can you speculate on the reasons for it?**

Table 12.1 The Missing Carbon: Approximately 2×10^{15} grams

Estimates in grams

Extra going to atmosphere	Extra found in
Fossil burning: 5.3×10^{15}	Increase in atmosphere: 3×10^{15}
Destruction of land vegetation: $0.6\text{-}2.6 \times 10^{15}$	Uptake by Oceans: $1.6\text{-}2.4 \times 10^{15}$
Total (A) $5.9 - 7.9 \times 10^{15}$	Total (B) $4.6 - 5.4 \times 10^{15}$

A-B= Estimated missing carbon= 2×10^{15} grams; it is suggested to go to some unknown sink? What sink?

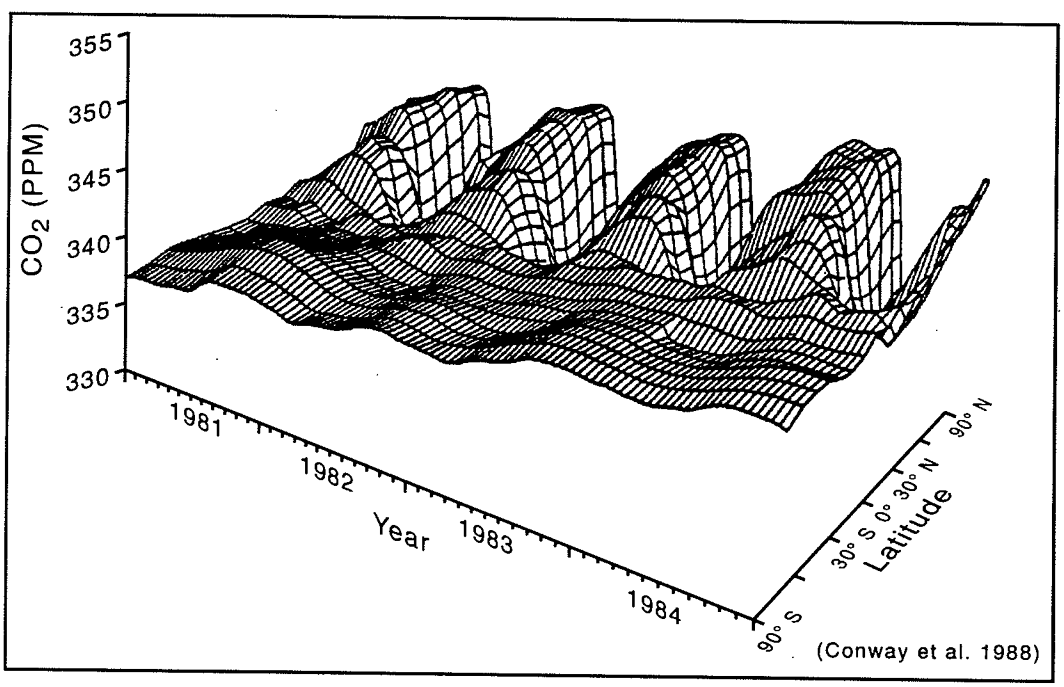


Fig. 12.5 Seasonal fluctuations in atmospheric CO_2 concentrations are largest in the Northern hemisphere (where there is more vegetation) than in the Southern hemisphere (Data of Conway et al., 1988) (Post et al., 1990). PPM stands for parts per million.

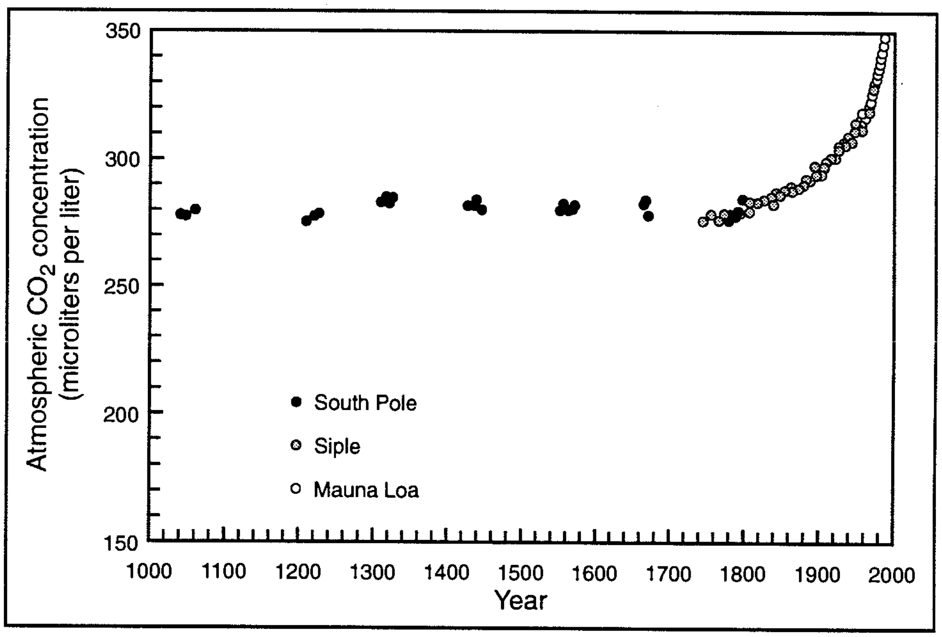
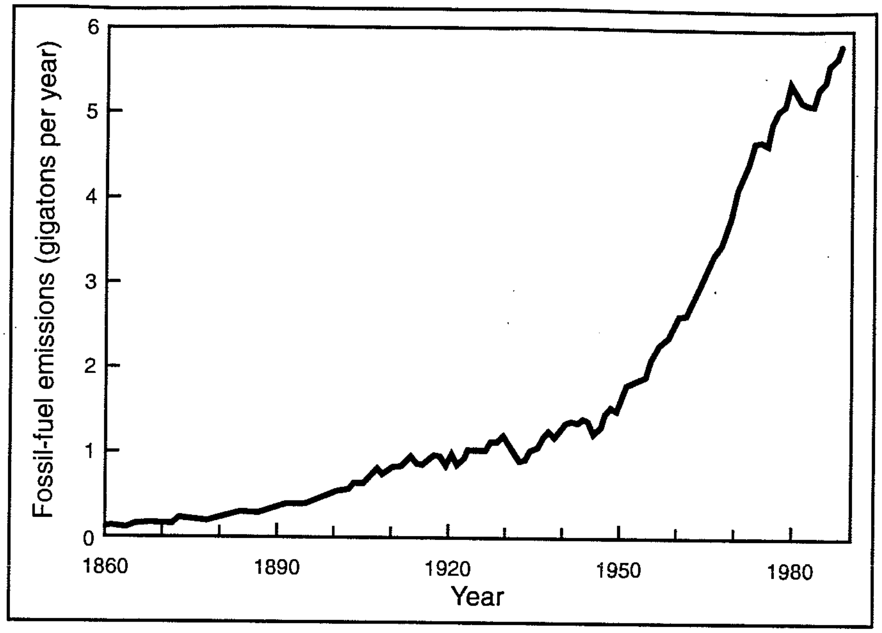


Fig. 12.6 This figure shows that atmospheric CO_2,that remained approximately constant from 1,000 to 1800 A.D., suddenly started increasing and is expected to continue to increase (Data of Post et al., 1990).



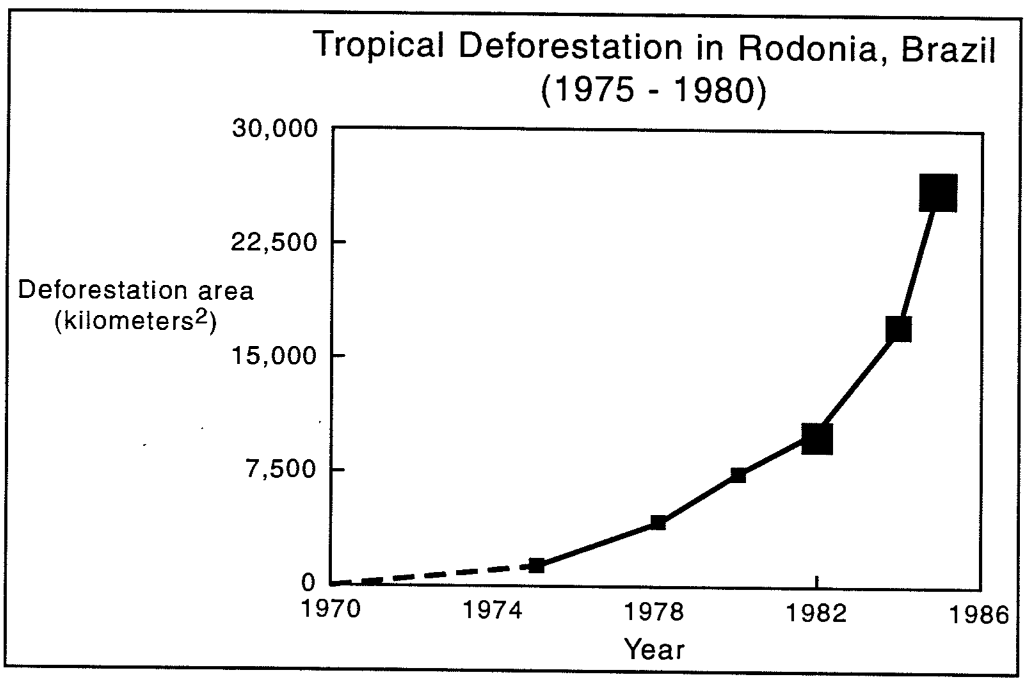


Fig. 12.7 Increases, during 1860-1980, in atmospheric CO2 concentrations (see Fig. 12.6) seem to be correlated with data on fissil fuel burning (A top) and deforestation (B bottom)(Data of Marland et al., 1988, and Mallingreau and Tucker, 1988).

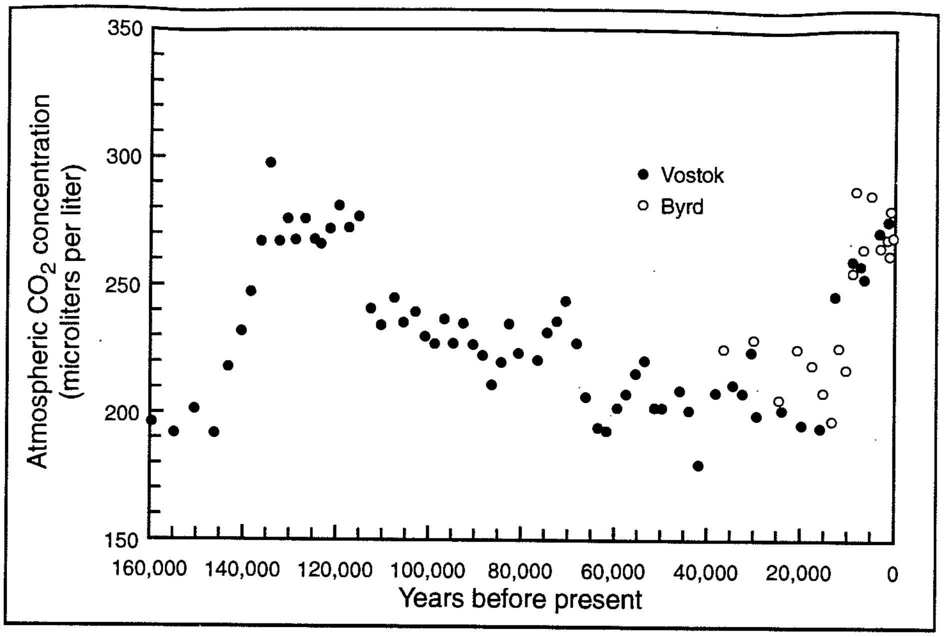


Fig. 12.8 CO_2 concentrations, measured from "ancient" air bubbles trapped in "ancient" Antartic ice-cones, peaked 130,000 years ago during interglacial period. These approached the current atmospheric CO_2 levels. Is there a giant "yo-yo" in nature? (Data of Barnola et al., 1987; Neftel et al., 1982).

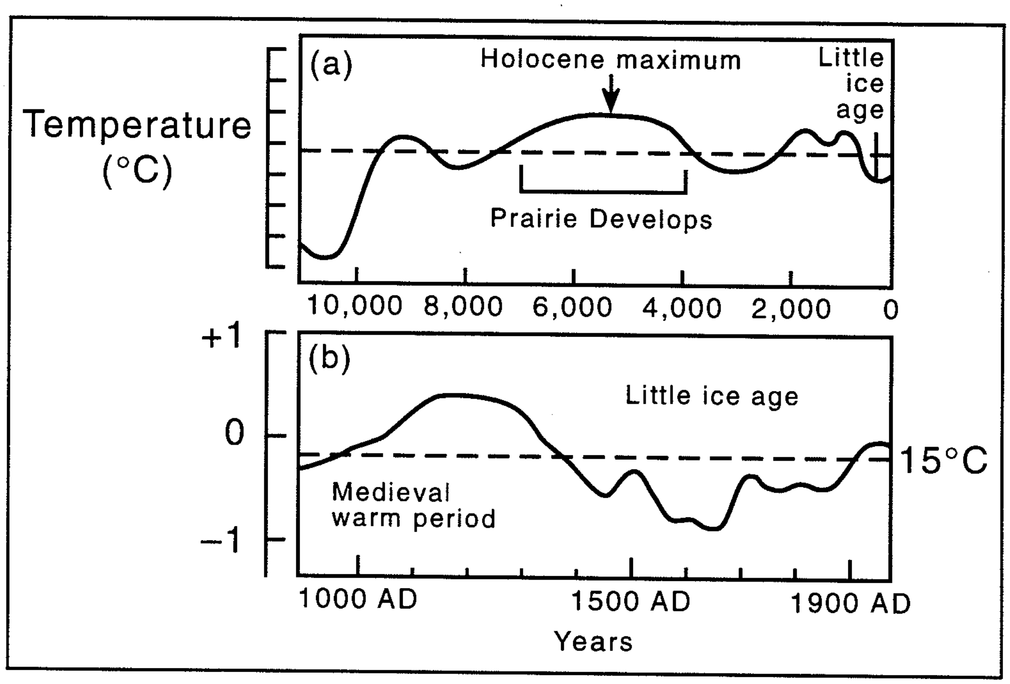


Fig. 12.9 Temperature data in (a) is during the last 10,000 years; and in (b) is during the last thousand years. Dashed line for data in 1900. About 5 to 6,000 years ago, the prairie must have developed due to the warming spell.

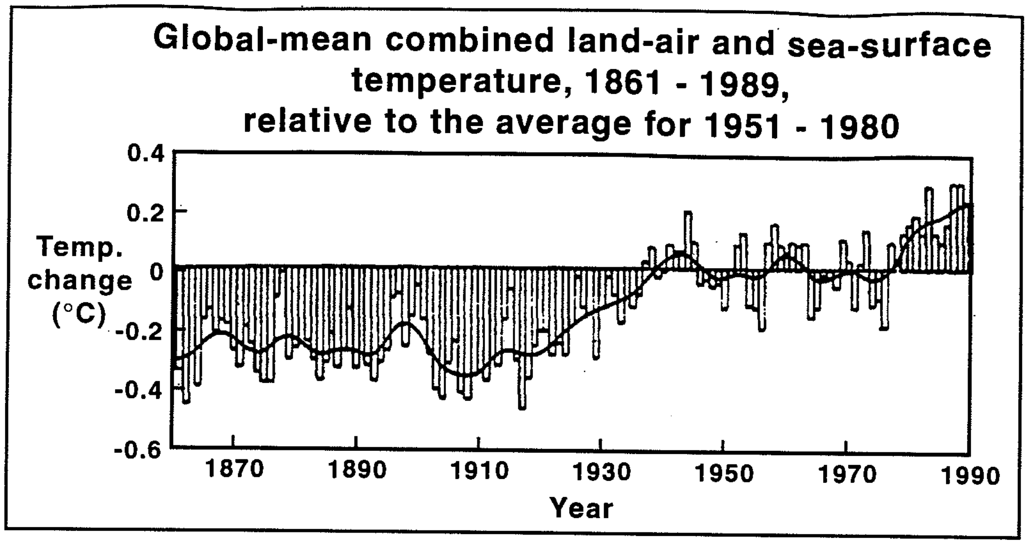


Fig. 12.10 Has the temperature been increasing on this Earth slightly and steadily since 1900?

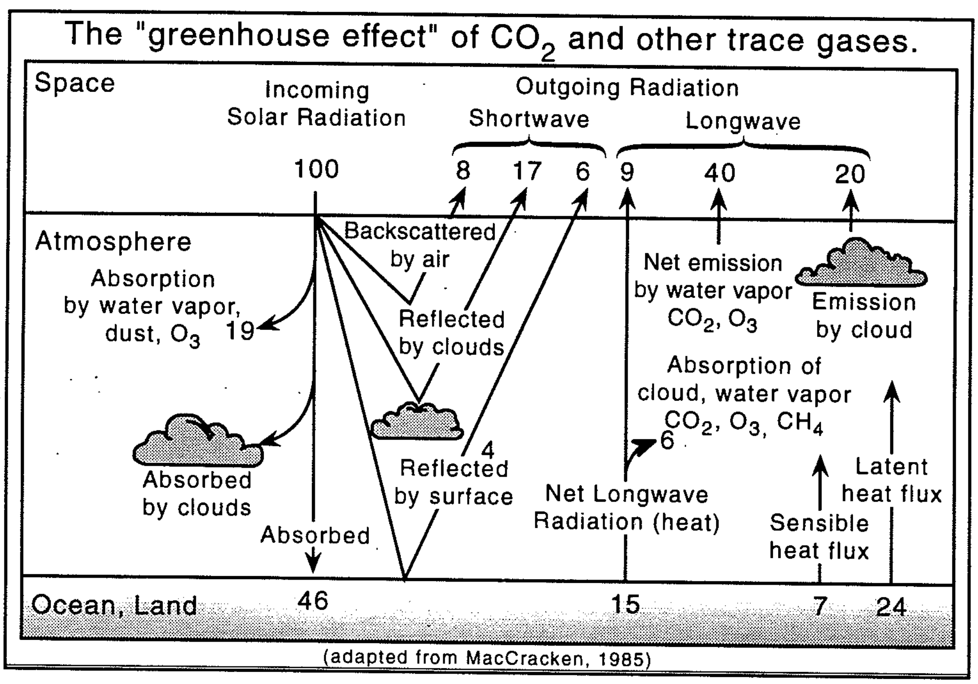


Fig. 12.11 Data of MacCracken (1985) for the "greenhouse effect" of CO_2 and other gases. Sun's radiation is dominated by shortwavelength light, but the Earth radiates longwavelength light. Since CO_2 absorbs these longwavelength radiations, and, thus, decreases it from going into space, it warms the Earth. Thus, increases in [CO_2] in Earth's atmosphere is expected to increase Earth's temperature.

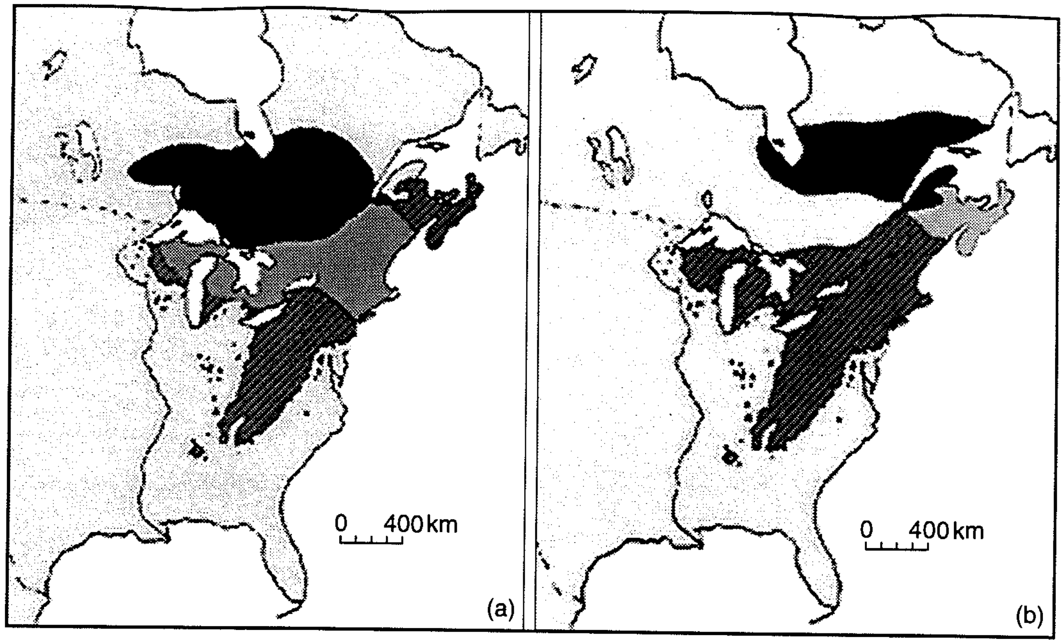


Fig. 12.12 Predictions of Davis (1988) are shown in cross-hatched area where the Eastern Hemlock trees are expected to be found 100 years from now. Dark diagonals in graphs are based on predictions of range of these trees with CO_2 doubling with climate changes proposed by (a) Hansen et al. (1983) and (b) Manabe and Wetherald (1987), whereas the light diagonal shading is for the current distribution of these trees. [The above diagram may be confusing. Thus please look carefully at the colored slide shown in class]

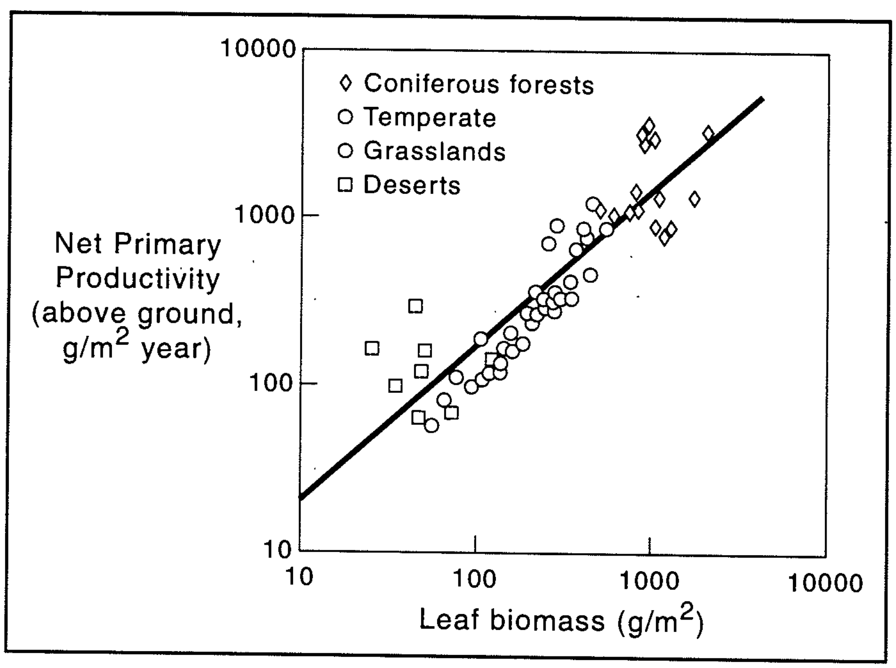


Fig. 12.13 Relationship between leaf biomass and net primary productivity in forests (Data of Webb et al., 1983).

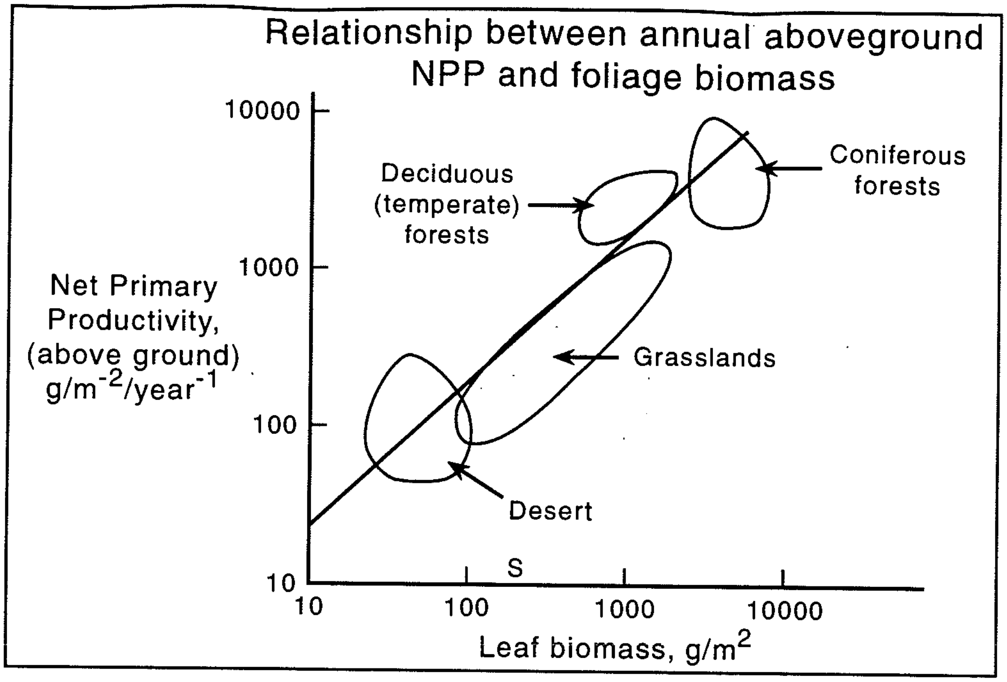


Fig. 12.14 Relationship between leaf biomass and net primary productivity in various biomes (Data of Gholz, 1982)

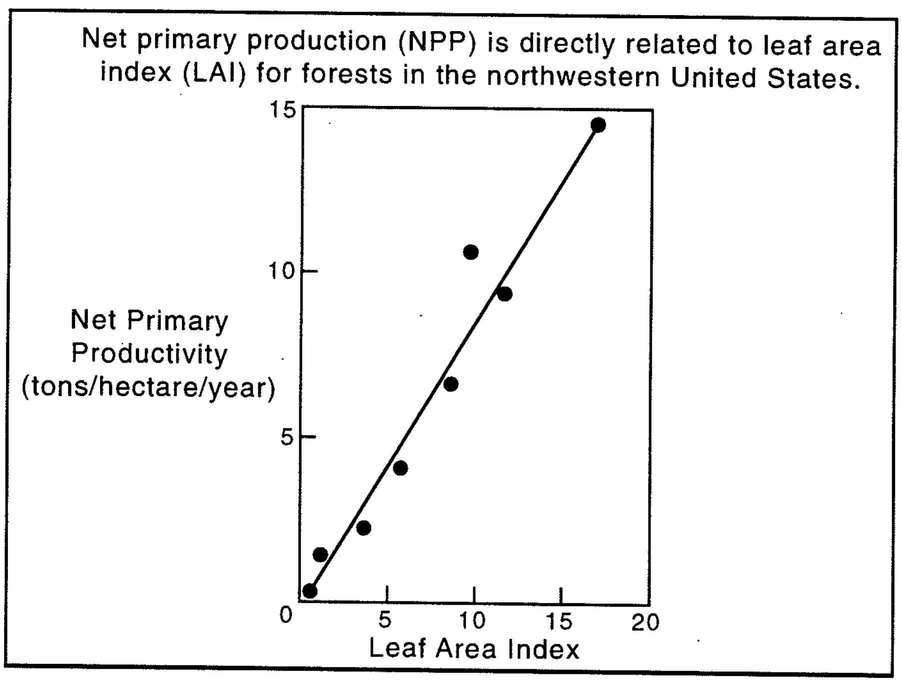


Fig. 12.15 Relationship between net primary productivity and leaf area index in forests. (Data of Gholz, 1982).

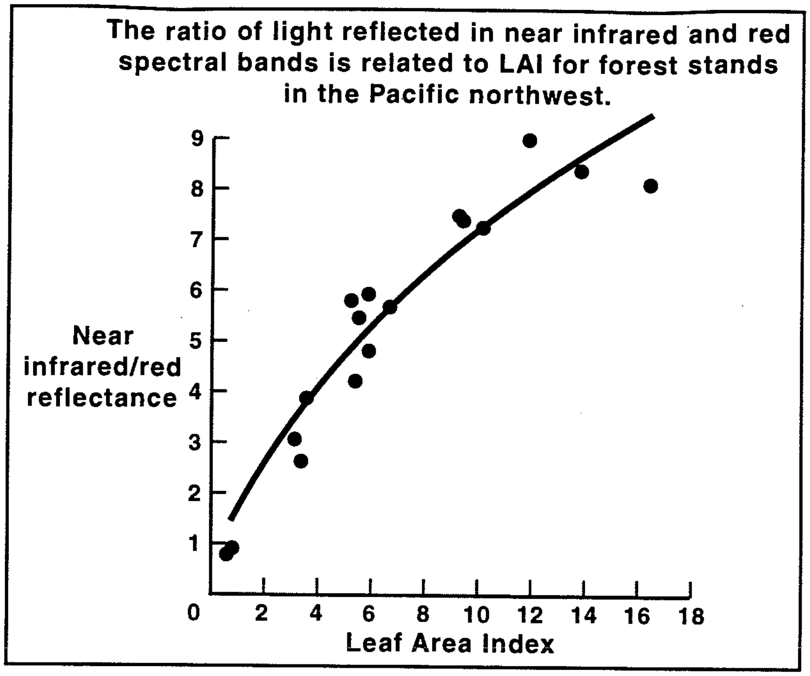


Fig. 12.16 Satellite data on the ratio of near infrared reflectance to red reflectance plotted against the leaf area index of forest stands. (Data of Peterson et al., 1987.)

Dictionary/glossary/concepts

1. *Beta factor*: refers to the concept that increased CO_2 in the atmosphere can be used to increase photosynthesis that would increase biomass and would lessen the accumulation of CO_2 in the atmosphere.

2. ENSO events: El Nino Southern Oscillation Events: Please read p. 591 of Raven and Johnson, 4th ed., for explanation; it implies sudden changes in climate/weather leading to both good and bad events.

3. *Gigaton*: a billion (10^9) tons.

4. *Greenhouse gases*: are atmospheric gases that are responsible for warming of the lower atmosphere and the Earth: CO_2, methane, nitrous oxide, ozone, water vapor and chlorofluorocarbons.

5. *Leaf area index* (LAI): area of leaves above a unit of ground surface.

6. *Organic matter*: containing compounds having a carbon backbone, often with carbon atoms arranged as a chain or ring structure.

Dictionary/glossary/concepts, continued

7. *Photosynthesis*: the physical-chemical process by which certain chlorophyll (or bacteriochlorophyll) containing organisms use light energy for the biosyntheses of organic molecules.

   Oxygenic photosynthesis: Photosynthesis by plants, algae and cyanobacteria in which water is oxidized to melecular O_2 and CO_2 is reduced to carbohydrates. $CO_2+H_2O+light \rightarrow \{CH_2O\}+O_2$, where $\{CH_2O\}$ stands for carbohydrate.

   Anoxygenic photosynthesis: photosynthesis by certain bacteria in which oxygen evolution does not occur, and the organisms use compounds (such as H_2S or organic compounds written below as H_2A) other than water to obtain hydrogen atoms or electrons to reduce CO_2 to carbohydrates.
   $CO_2 + 2H_2A + light \rightarrow \{CH_2O\} + 2A+H_2O$.

8. *Radiation, long wavelength*: the word radiation refers to the process in which energy is emitted as particles or waves, whereas long wavelength refers to the length of their waves being long. Well, what is long? This is ambiguous. In the context, it was used it refers to infra-red radiation.

9. *Radiation, short wavelength*: see just above;it refers to radiation with short wave lengths. Here again, this is ambiguous. In the context used in lecture 4, it refers to visible (including red) radiation.

10. *Remote sensing*: is the term often used when measurements on biomass, chlorophyll concentration, or leaf area index, etc. of plants are made from a remote site by using optical instruments that measure either reflectance or fluorescence.

11. *Respiration*: is the process by living organisms oxidize glucose with molecular oxygen releasing CO_2; in an overall sense, it is the reverse of oxygenic photosynthesis. $\{CH_2O\}+O_2 \rightarrow CO_2+H_2O+energy$.

12. *Soil*: the portion of the earth's surface consisting of disintegrated rock and humus. (Humus=dark organic material in soils, produced by the decomposition of vegetable or animal matter, and essential to the fertility of the earth.)

13. *Source/Sink*: A source is where something originates or starts from, and a sink is where something goes to.

Lecture 13: Communities: Structure of Community and Succession

● **Reading assignment:**

(1) Raven and Johnson, 4th ed., **Chapter 26, pp. 579-582;**
(2)Chapter 11: **Sucession**. In Terrestrial Plant Ecology, 2nd edition, H.G. Barbour, J.H. Burkand W.D. Pitts, Cummings Publishing Company, Inc., 1980, pp. 230-264
(3) **These Notes**

● **By the end of your preparation on this topic, you should be able to:**

♦ 1. Define ecological community, and discuss significant concepts of communities.

♦ 2. Describe the major characteristics of a plant community, and the factors that affect them.

♦ 3. Define succession and discuss the various types (primary and secondary) of succession.

♦ 4. Discuss some of the community and ecosystem trends during succession.

♦ 5. Compare and contrast the various mechanisms (facilitation, tolerance and inhibition) suggested for succession.

♦ 6. Define and explain the following **terms and concepts**:
Allelopathy; Association in Community; Boundary (open versus closed; continuous versus discrete); Climax of a community; clumped/contagious state; Community; Dispersion of something: Edge; Ecotone; Exponential attenuation of a parameter; Facilitation of succession; Floristics, initial, Floristics; relays; Horizontal patterns; Horizontal structure; Hydrarch succession; Individualistic hypothesis; Inhibition of a process; Light attenuation; Light quality; Organismic view of community; Pioneer species; Physiognomy of plant life forms; Richness of a community; Uniform distribution of a community; Succession; Vertical structure of a community; xerarch succession.

● **Outline of presentation:**

(Figure and Table numbers are from **these Notes** only)

♦ 1. *Communities* (assemblages of species living close enough together for potential interaction) and general views:

- individualistic versus interactive:
  [If plant species are separated and independently distributed, it is individualistic; if plant species occur together and are closely interdependent, it is interactive.]
  See **Dictionary**: Indivualistic hypothesis (Gleason's hypothesis) and Interactive/ Organismic hypothesis (Clement's hypothesis).

♦ 2. *Factors affecting communities:*

- Light intensity determines type of plant species: **Fig. 13.1** **Notes**

  - Coexistence of different species of warblers on the same spruce tree is shown in Figure 24.12 on p. 544 of Raven and Johnson, 4th ed.

  - Coexistence of several species of lizards (Anolis sp.) in a community at different heights in a forest are found; at top, sunloving lizards and at the bottom, shade loving lizards, are found.

- Biotic/abiotic factors determining the micro-environment and, thus, dispersion: **Fig. 13.2** **Notes**

- Boundry, edge and ecotone:
  [It is known that when environmental factors change abruptly, a sharp boundry exists. In magnesium-rich soils, California wildflowers predominate, whereas in sandstone soil, grasses predominate. *Edges* are sharp boundaries, but, when one community on one side can advance into community on the other side, producing overlapping regions, they are called *ecotones*.]

- *Competetion*: If a herbivore was keeping down the population of a strong competitive plant species, removal of this herbivore would lead to increases in population of this competitive species, and, thus of "death" of other less competitive plant species. Thus, the compositon of the community would change.

♦ 3. *Succession and types of succession:* community changes during succession

- Primary succession: **Fig. 13.3** **Notes**
  (When starts from no community)
  Retreating glacier → barran landscape →
  moss and lichen → alders and cotton wood → spruce and hemlock

- Secondary succession: **Fig. 13.4** **Notes**
  (When a community is disrupted)

• Walk in a forest and check overstory and saplings to get an idea of what is to come in a succession:	**Fig. 13.5**	**Notes**
• A look at the succession at one place:	**Fig. 13.6**	**Notes**

[For a photograph "Towards climax community, see Fig. 26.11 on p. 581 in Raven and Johnson.]

♦ 4. *Some trends during succession*

• Changes from early to late stages:	**Table 13.1**	**Notes**
• Relationship of plant succession to animal succession: an example from New York	**Fig. 13.7**	**Notes**

♦ 5. *Mechanisms of Succession*

• Relay *floristic* versus *initial floristic view:*	**Fig. 13.8, 13.9**	**Notes**
• Facilitation, Inhibition, Tolerance:	**Table 13.2**	**Notes**

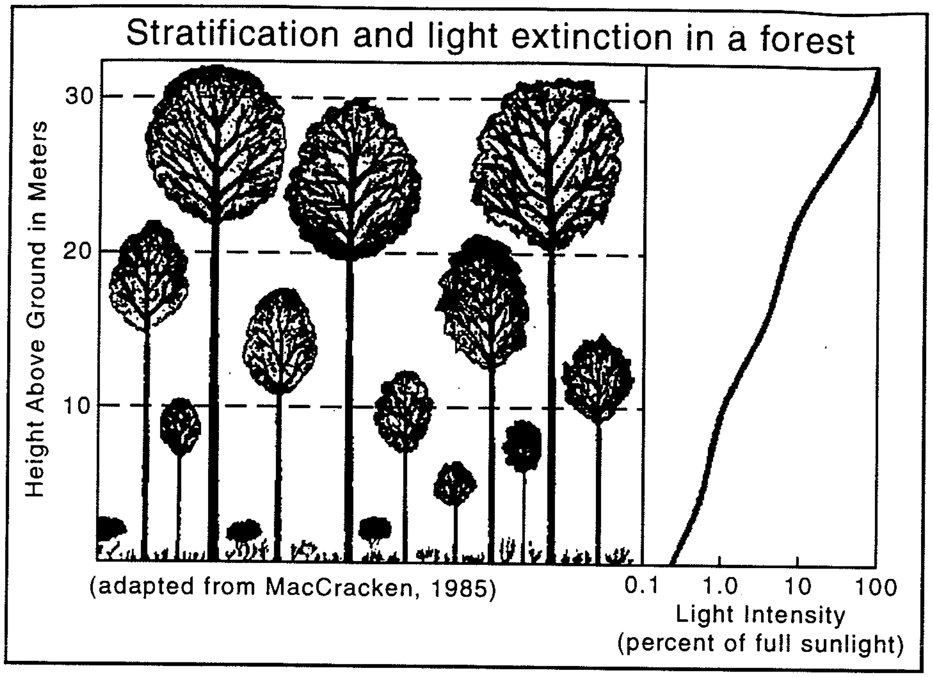


Fig. 13.1 Data of MacCracken (1985) show that plant species in a community are adapted to light intensity they receive. At the top of the canopy in a forest, the light intensity is greatest, whereas at the forest floor, it is the least (left).

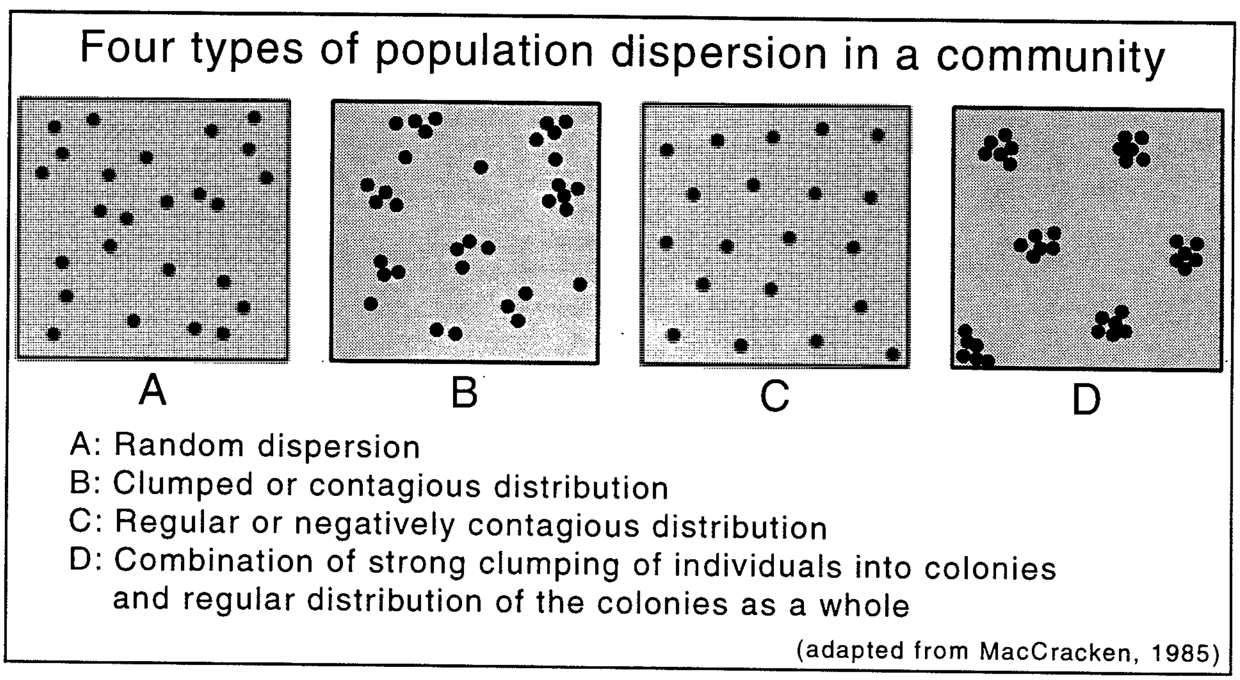


Fig. 13.2 Four types of population dispersion in a community, as drawn by MacCracken (1985). Factors such as micro climate of the soil, human factor, attraction and repulsion, allelopathy, etc. may determine these patterns. An example of uniform pattern is an apple orchard or desert shrubs.

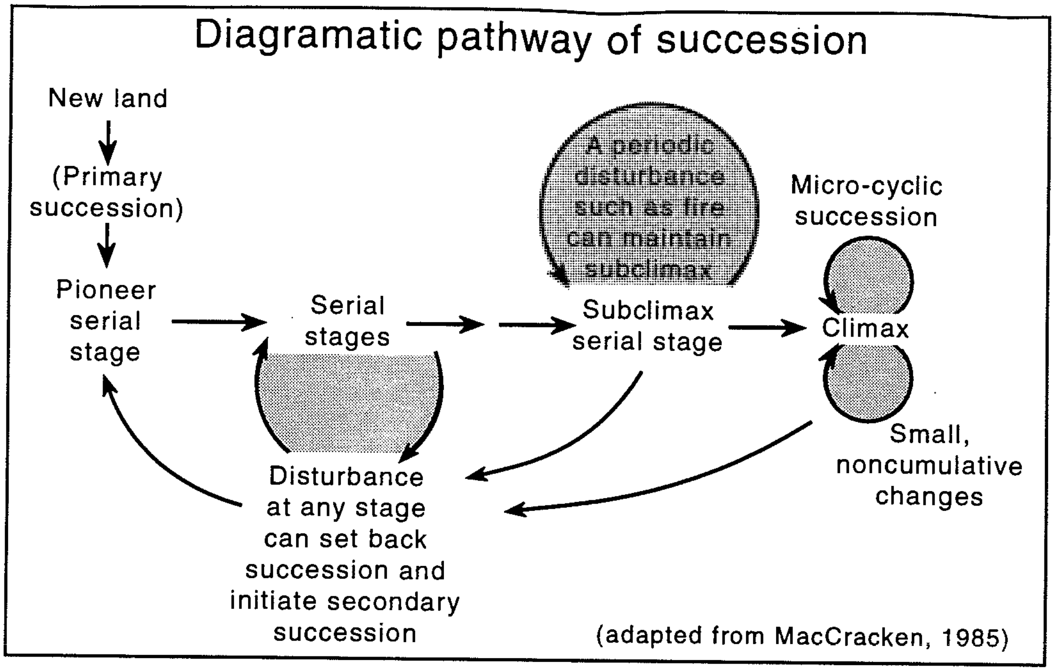


Fig. 13.3 Pathways of succession. In primary succession, one starts from a new land (after e.g., glacier retreats). In secondary succession, one starts from an area after, e.g. a fire or logging of a forest. [See Fig. 11-2 in Chapter 11 (Succession) in Terrestrial Plant Ecology, 2nd edition, M. G. Barbour, J. H. Burk and W. D. Pitts, Cummings Pub. Co., Inc., 1980, pp. 230-264]

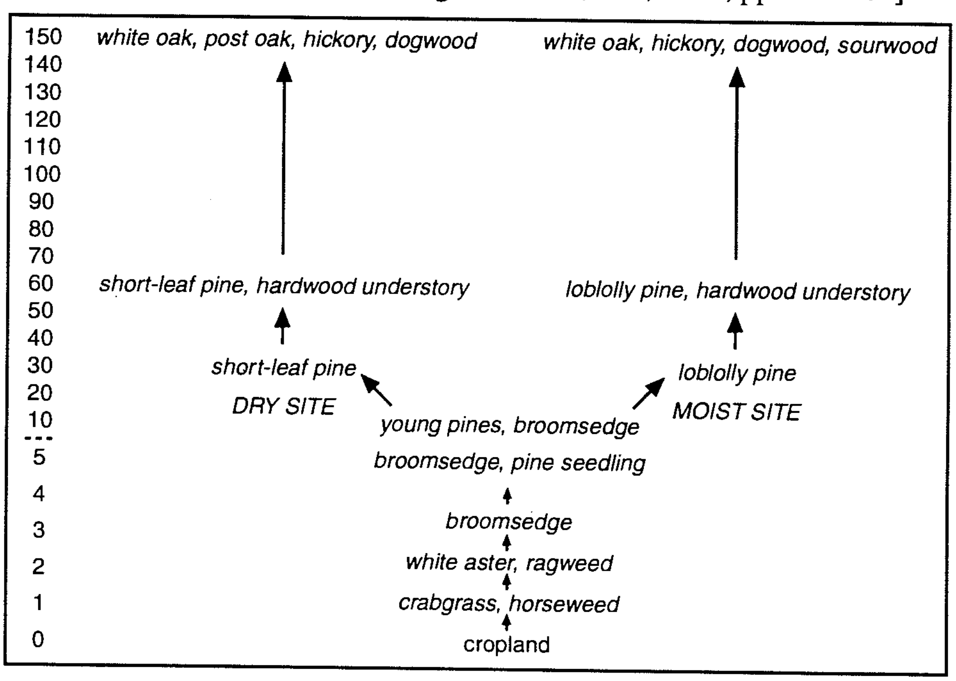


Fig 13.4 Pathway of a secondary succession in the Piedmont region. Based on data in the literature. [From Table 11-2 in Chapter 11 (Succession) of Barbour et al., 2nd ed.] Numbers on the left indicate the years after abandonment of the field. Redrawn by the author and Margaret Hughes, in 1995.

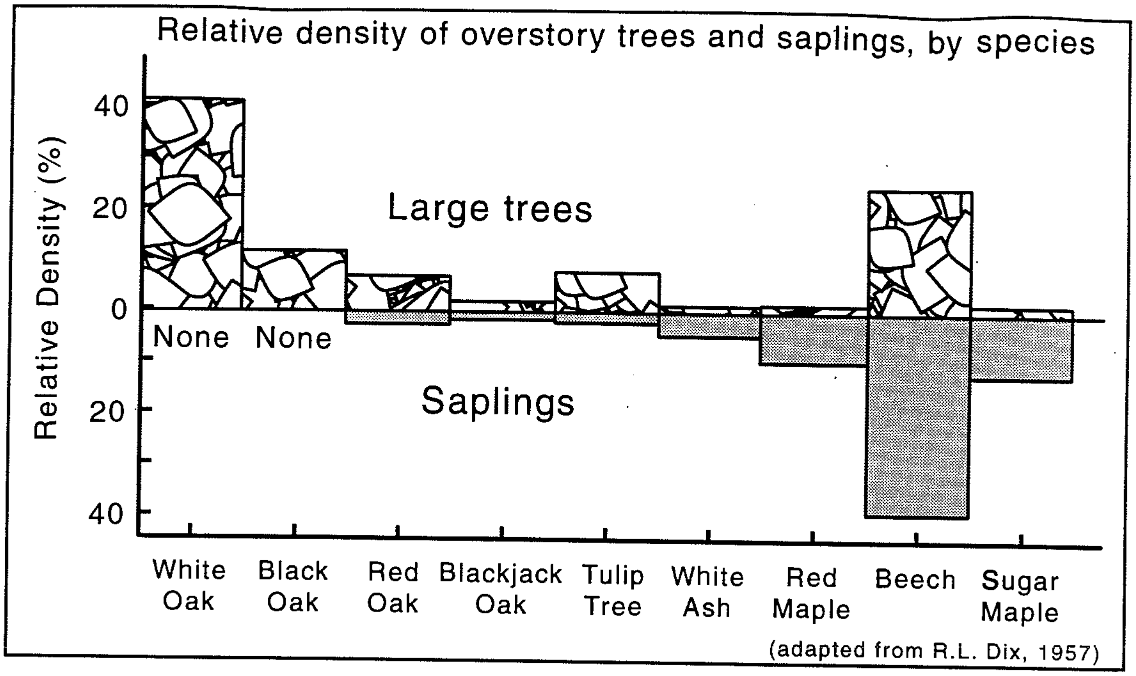


Fig. 13.5 A plot of the relative density of overstory trees and saplings by species for an oak forest near the capital of our Nation (Washington, District of Columbia). Figure adapted from R. L. Dix (1957). Data suggest that Oak trees will be replaced by beech and sugar maple as succession proceeds.

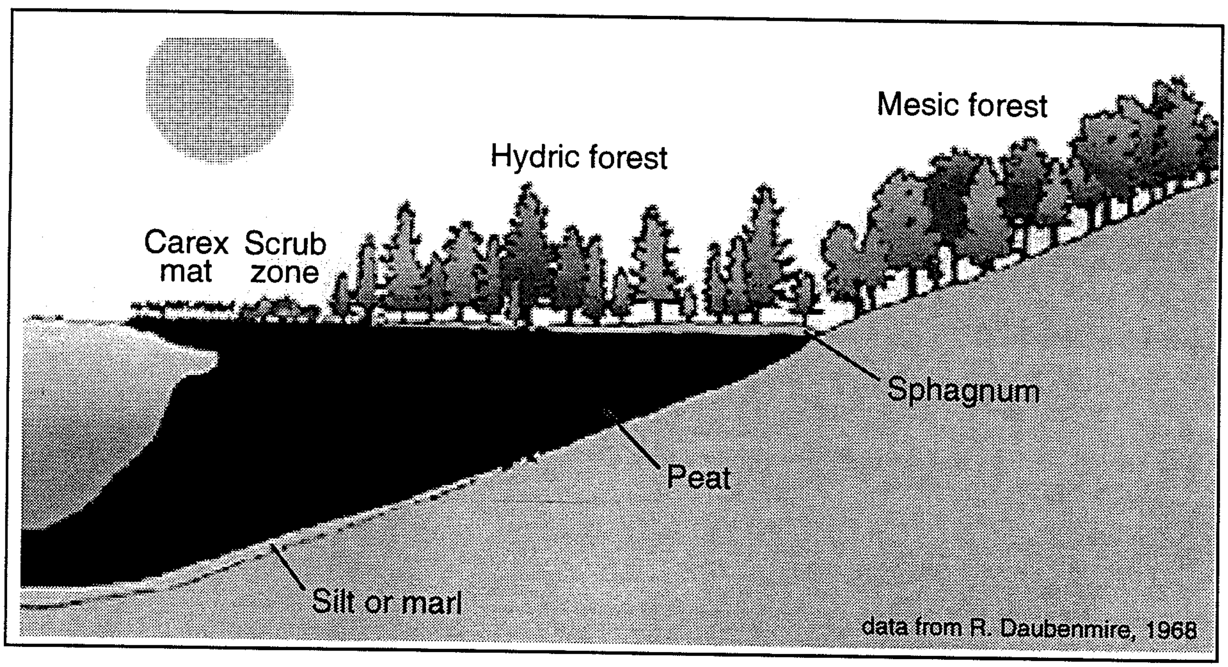


Fig. 13.6 A diagrammatic summary of a succession based on a horizontal look of communities from the "open water" region to the forest on land. Figure adapted from original figure of R. Daubenmire (1986). The terms in the diagram are: "Peat" represents sphagnum (a moss); marl represents limestone, carex mat represents sedge; and mesic represents a term for moderate condition between hydric (for wet) and xeric (for dry).

Table 13.1 Changes during succession

From Early to Late Stages

- *Biomass* increases
- *Growth forms* increase
- *Leaf forms* change from multilayered to monolayered
- *Nutrients stored* in soils (early) to those in plants (late)
- *Mineral cycling* becomes slower
- *Net primary production* may decline because of

  a) increase in non photosynthetic (woody) tissues
  b) limiting nutrients
  c) senescent overstory, etc.

- *Environment* becomes more mesic (wet)
- *Stability* (defined as slowness of change) increases
- *Species life - history character* changes from them having **r**-character (i.e., rapid growth and short life) to having **K**-character (i.e., slow growth and long life).

[Based on Table 11-3 in chapter 11 (Succession):for full reference, see Reading assignment (2)]

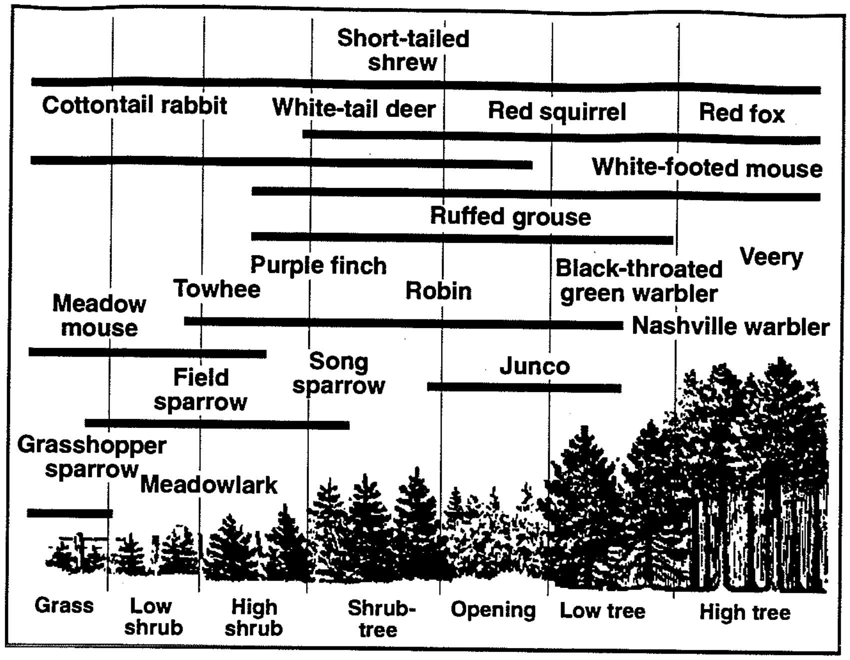


Fig. 13.7 A diagrammatic representation of the relationship of the occurrence of various animals (mammals and birds) and the vegetation in conifer plantations in Central New York State. Please not that some animal species disappear as vegetation density and height change.

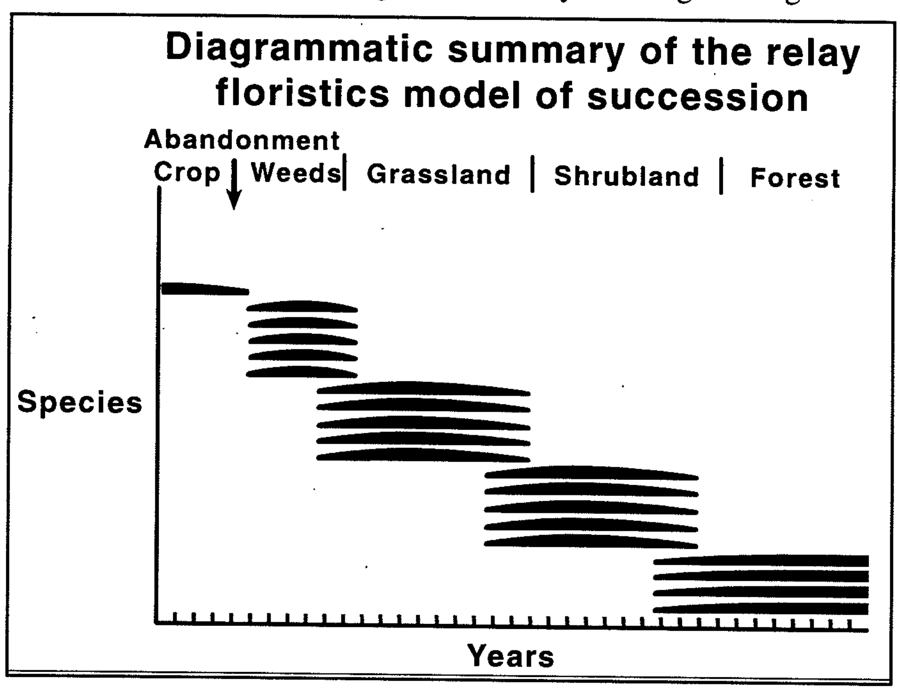


Fig. 13.8 Relay floristics model of succession. This follows the interactive (organism) view (for a description, see **Dictionary**). Thicker lines indicate greater importance of the species. [Based on F. E. Egler, see Fig. 11-17 in Chapter 1.1 (succession); detailed reference is in the reading assignment (2).]

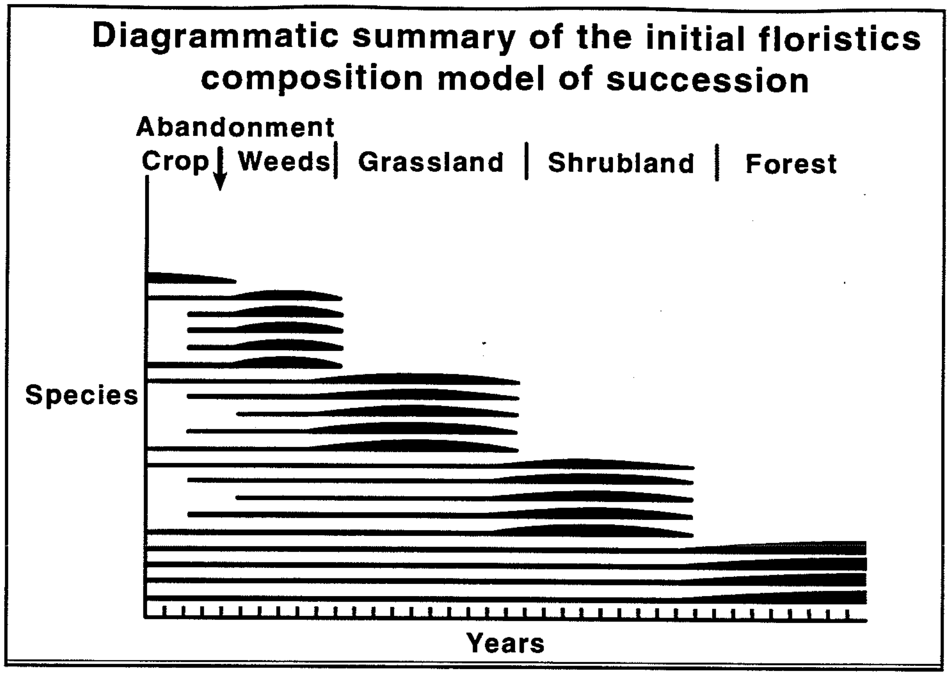


Fig. 13.9 Initial floristics model of succession. This follows the indivdualistic view (for a description, see **Dictionary**). Thicker lines indicate greater importance of the species. [Based on F. E. Egler; see Fig. 11-19 in Chapter 11 (Succession); detailed reference is in the Reading assignments (2).]

Table 13.2 Mechanics for Succession may include:

- *Facilitation :* (One species paving the way for the next.)
  When an early successional species alters conditions or availability of resources so that the entry of new species is made possible. For example, a species (A) may make the pH of the soil more acidic that is more conducive to the growth of species (B) than of (A) itself.

- *Inhibition:* (New species appear when the established plants die.)
  When an early successional species alters conditions or availability of resources so that the growth of species producing it is inhibited. An example may be an allelopathy (release of inhibitory chemicals) against one's own species.

- *Tolerance:* (Pioneer plants neither hinder nor help.)
  When all species are growing together, but the less abundant species simply tolerate the conditions until conditions change. Climax species are efficient and simply slow, but better competitors, longer lived and bigger than early inefficient but fast species. This mechanism assumes initial floristic model.

Dictionary/glossary/concepts

1. *Allelopathy:* Generally, antagonism displayed through the production of chemicals that are toxic to other species, but not to the producer. However, in some cases, allelopthy may be towards individuals of the same species.

2. *Association in a community*: Species that are found together are said to be in association in a community.

3. *Boundary:* Boundary may be classified as open or closed; continuous or discrete (obvious).

4. *Climax of a community*: Refers to the steady state of a community reached in species composition during succession.

5. *Clumped/contagious state:* Also called aggregated distribution; occurs when individuals are attracted to each other, or survive together in particular parts of environment.

6. *Community:* Collection (or assemblage) of species interacting within a defined area.

7. *Dispersion in community:* Distribution of individuals within a community.

8. *Exponential attenuation of a parameter:* Decrease (or to lessen) a parameter in an exponential fashion.

9. *Floristics:* Pertaining to flowers, literally, but usually it refers to a branch of plant geography.

10. *Hydrarch succession*: Primary succession that occurs in open water.

11. *Initial floristics:* In this model of succession, almost all species are present from the very beginning, and different ones become dominant as conditions change; there is the pattern of replacement of overlapping species.

12. *Relay floristics:* Here, associated species of each community change the habitat in such a way that new species are at a competitive advantage, i.e., one floristic leads to another. It is called relay floristic because each community relays site to next community during succession.

13. *Horizontal patterns:* Refers to patterns of vegetation in a horizontal zone.

14. *Horizontal structure:* Refers to structure of a community in a horizontal zone.

Dictionary/ glossary/ concepts, cont'd

15. ***Individualistic hypothesis for communities:*** (View of H.A. Gleason) In this hypothesis, every plant species is distributed as a result of its individual requirements, independently from every other plant species, succession is not rigidly defined, considered important, and non-equilibrium forces (disturbance) are also important considerations.

16. ***Interactive hypothesis of community:*** (Also see organismic view)Community is an assemblage of closely-linked species, locked into association by mandatory interactions that cause the community to function as an integrated unit (a super-organism).

17. *Light quality:* Refers to color of light; appropriately range of wavelenths of light.

18. ***Organismic view of communities:*** (view of F.E. Clements) (also see interactive hypothesis). Here, climax is determined by climate; succession is rigidly defined, and faithfully reproduced; equilibrium forces (competition) are important.

19. *Pioneer species:* First species to appear after a disturbance(*e.g.*, foxtail).

20. *Physiognomy of plant life forms:* Refers to looks: herbs, shrubs, etc.

21. *Richness of a community:* Refers to the number of species; greater is the number of species, richer is the community.

22. *Succession (or Sere):* Change in species composition through time; it is unidirectional change.

23. *Uniform distribution of a community:* Also called regular distribution, or even distribution; occurs when each individual has a tendency to avoid all other individuals and are found evenly distributed in a community.

24. *Vertical structure of a community:* Structure of the community from the ground level (forest floor) to the top of the canopy, or *vice versa.*

25. *Xerarch succession*: Primary succession that occurs on land.

 For further reading:

See Chapters 8, 10, and 11 in M.G. Barbour, J.H. Burk and W.D. Pitts (1987) Terrestrial Plant Ecology, Benjamin/Cummings, Merlo Park, CA.

Lecture 14: Communities: Diversity

Reading assignment:

(1) Raven and Johnson, 4th ed., **Chapter 24, pp. 721-740,**
discusses the various types of plants, but not the content of this lecture
(2) **These Notes.**

By the end of your preparation on this topic, you should be able to:

♦ 1. Define the various components (richness, evenness) of species diversity: and discuss the effect of different structure of community on species-area-curves.

♦ 2. Describe changes in species diversity with changes in altitude, latitude, and area.

♦ 3. Discuss the various factors (*e.g.*, geologic time; non-uniformness of the background; competition; predation; productivity; stability; area; distance from regions with large number of species) that contribute to species diversity on lands and on islands.

♦ 4. Discuss the possible role of diversity in enhancing community stability, resilience, and resistance.

♦ 5. Describe the following **concepts** and **terms:** biogeography; diversity; index of community similarity; niche-fundamental and realized; predation; resilience (ability to bounce back to original state after an "insult" or disturbance"); resistance; richness and stability (steadiness in composition and number); Shanon-Weiner Index of Species Diversity.

Outline of presentation:

(Figure and Table numbers are from **these Notes** only)

♦ 1. What is diversity in community?

- Richness and Evenness: **Table 14.1** **Notes**
- Species - area curves: measurements of diversity **Fig. 14.1** **Notes**

♦ 2. Changes in species diversity with

(a) altitude (elevation): **Fig. 14.2** **Notes**

(b) latitude [it is well known that when you travel from the Equator to the Artic, diversity and density decrease]

(Species density of North American birds falls from 600 in tropical regions of Central America to less than 100 species found in the arctic areas.)

(c) depth in oceans: **Fig. 14.3** **Notes**

♦ 3. Factors that contribute to species diversity:

(a) geologic time..more time more species: **Fig. 14.4** **Notes**

(b) spatial heterogeneity— example: more foliage diversity (due to plant species diversity) could lead to bird species diversity:
Fig. 14.5 **Notes**

(c) *Competition: each* species can survive over a range of environmental conditions (these environmental variables needed for the well being of the species define what is called *niche breadth*) *Generalist* species have broad niche breadth versus *specialist* species that have narrow niche breadths. Niche breadth of two species may overlap (called *niche overlap*). *Competition exclusion* may occur in which one species (#1) may outcompete the other (#2) in the niche overlap leading to a narrower niche breadth of the #2 species. **Fig. 14.6** **Notes**
[For a discussion of Niche breadth, see p. 532, 548, and 549, Raven and Johnson]

(d) A herbivore may keep the population of a dominant species (A) low and thus allow diversity, i.e., survival of species B and C. However, if the herbivore is removed, A may outcompete B and C leaving only A, thus, reducing diversity. The concept of predation can be extended to explain why trees of the same species grow only at a certain distance of the parent and why their probability is low in a (tropical) forest. **Fig. 14.7** **Notes**

(e) Environmental stability: In stable environments, evolution of finer specialization and adaptations have time to occur. These lead to sharper and narrower niches and thus, more species. **Fig 14.6** **Notes**

(f) *Productivity factor*. In contrast to the idea that greater productivity leads to greater diversity, data from Danish and Indiana lakes show that species diversity decreases with increases in primary productivity!
Fig. 14.8 **Notes**

> *Something to think about:*
> *All of the above factors must act together to explain species diversity*

♦ 4. Island biogeography:

- Larger islands and islands nearer to other vegetation sources have more species diversity.

  (Immigration rates are higher than extinction rates on larger islands.)

- Diversity of amphibian and reptile species seems well correlated with area of West Indian Islands

  (The large island of Cuba has about 100 amphibian and reptile species, whereas the small island of Saba has only about 8 species.)

Table 14.1: Diversity in Communities

Diversity, D, is a measure of both richness (number of species) and evenness (number of individuals in each species). One indicator is:

$$\mathbf{D} = -\sum_{i=1}^{S}(p_i)(\log_2 p_i)$$

D =	diversity of species
S =	number of species
p_i =	proportion of individuals of the total sample belonging to the i th species.

Evenness (J): It has a high value if there are equal number of individuals in each species. One indicator is:

$$J = \mathbf{D} / \mathbf{D}max$$

Where **D** = as described above and, **D**max = ln S (Natural log of the number of species)

Notes for Table 14.1:

- Species diversity is high when many equal abundant species are present.

- Diversity is also expressed by an equation equivalent to that shown in Table 14.1:

$$H' = -\sum_{i=1}^{m} (P_i) \ln(P_i), \text{ where}$$

m is equivalent to the total number of species, but practically stands for mophological types, and pi has the same meaning as in Table 14.1. H', numerically different from D, is diversity, It is often referred to as <u>*Shanon - Weiner Index of Species Diversity*</u>

<u>*Index of community similarity*</u> is given by:

$$\frac{c}{s_1 + s_2 - c}$$

where, s_1 and s_2 are number of species in community 1 and 2 and c is the number of species common to both.

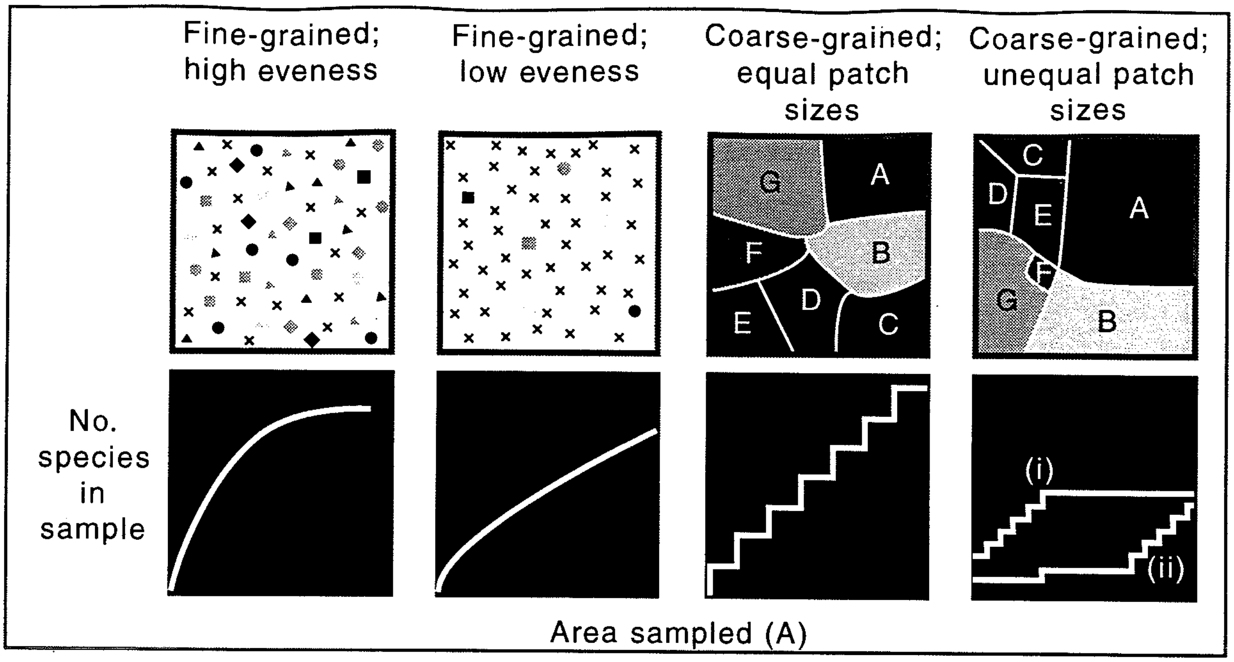


Fig. 14.1. Differences in "species-area" curves among different structures of communities. In these curves, one plots on the ordinate (vertical axis), the accumulative number of species in a sample against the area sampled on the abscissa (horizontal axis). From left to right: (1) five-grained mixture of species with high evenness; (2) five grained mixture of same number of species with low evenness; (3) coarse-grained, but equal patches; and (4) coarse-grained, but unequal patches. In the last case, different results are obtained depending upon where one starts measuring (i) in a small patch, or (ii) in a large patch. Figure modified from Fig. 1.4 by Crawley (Plant Ecology, 1986).

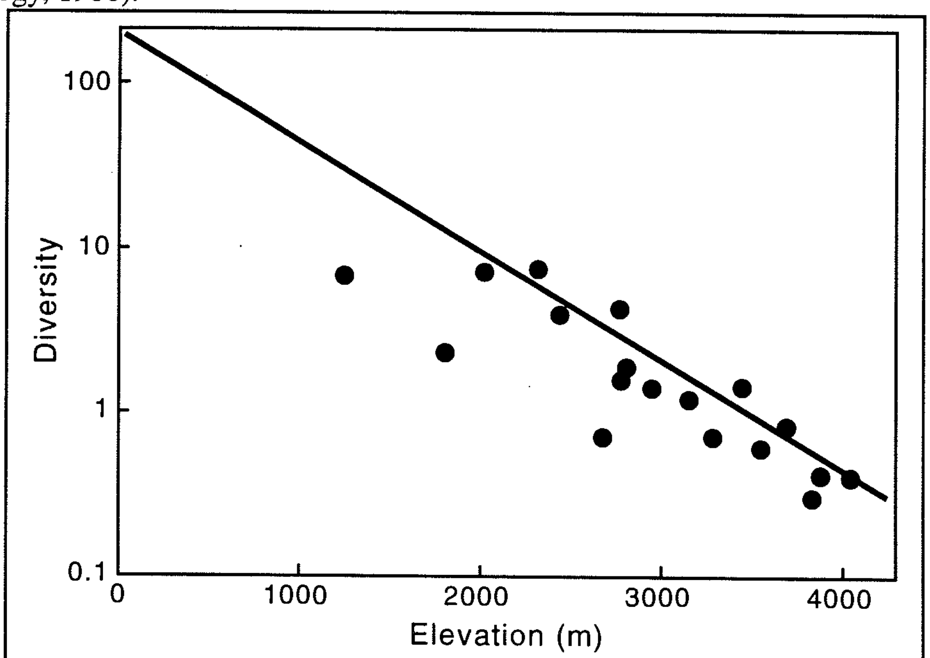


Fig. 14.2. Species diversity decreases as the altitude increases in the Himalayas. Based on data of Yoda, 1967. A similar trend is observed when one travels from the Equator to the Arctic

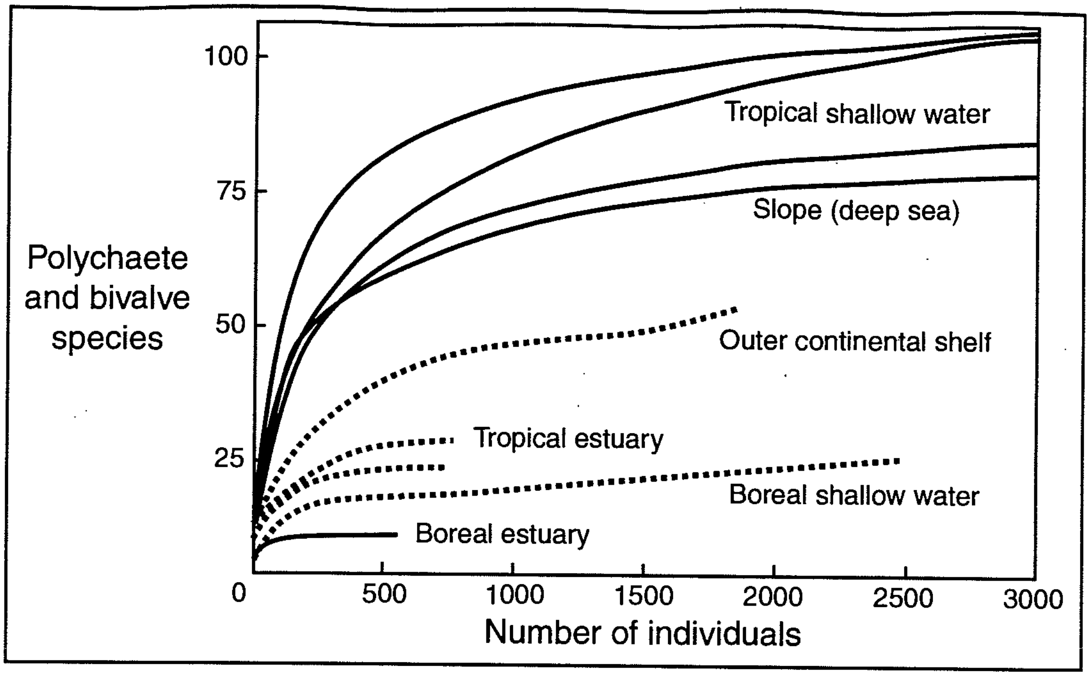


Fig. 14.3. Marine polychaete (a type of worm) and vivalve (e.g., clam, mussel, oyster) species increase with depth in the sea except for the shallow waters in the tropics. For example, there is greater diversity in the (continental) slope (deep sea) than in the continental shelf. [Boreal stands for Northern hemisphere, and estuary stands for the water passage where tide meets the currents of a stream.] Data is from Sanders and Helser (1961)

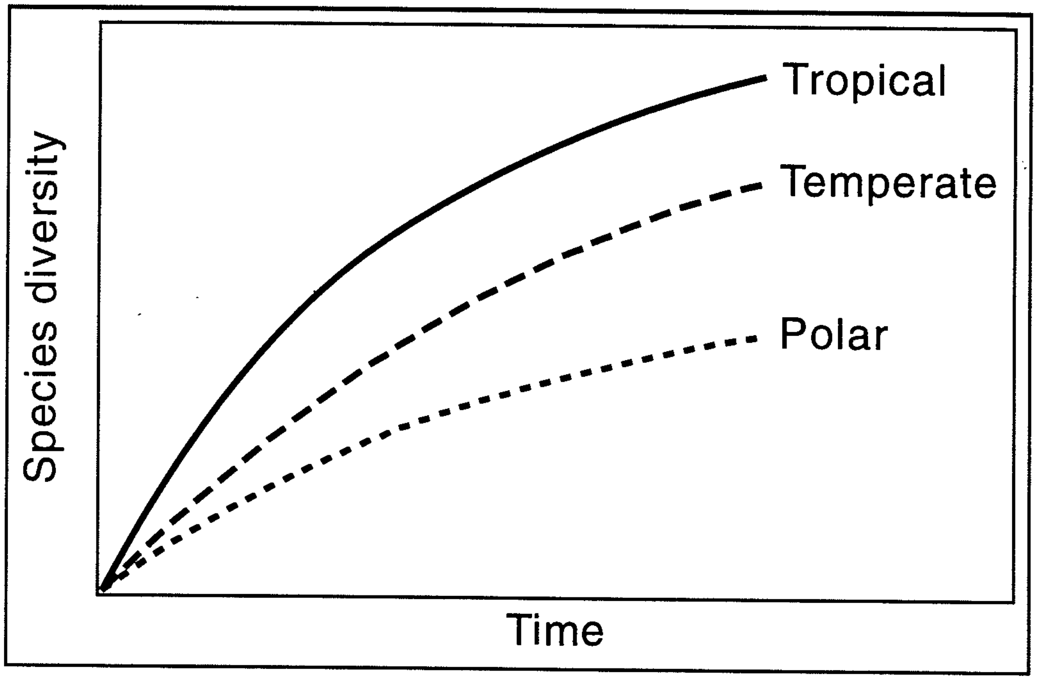


Fig. 14.4. A hypothetical time-dependent increase in species diversity in tropical, temperate and polar habitats provided there were no interruptions. In reality, the curve rises in a jagged manner. Based on a concept presented by Fischer (1960).

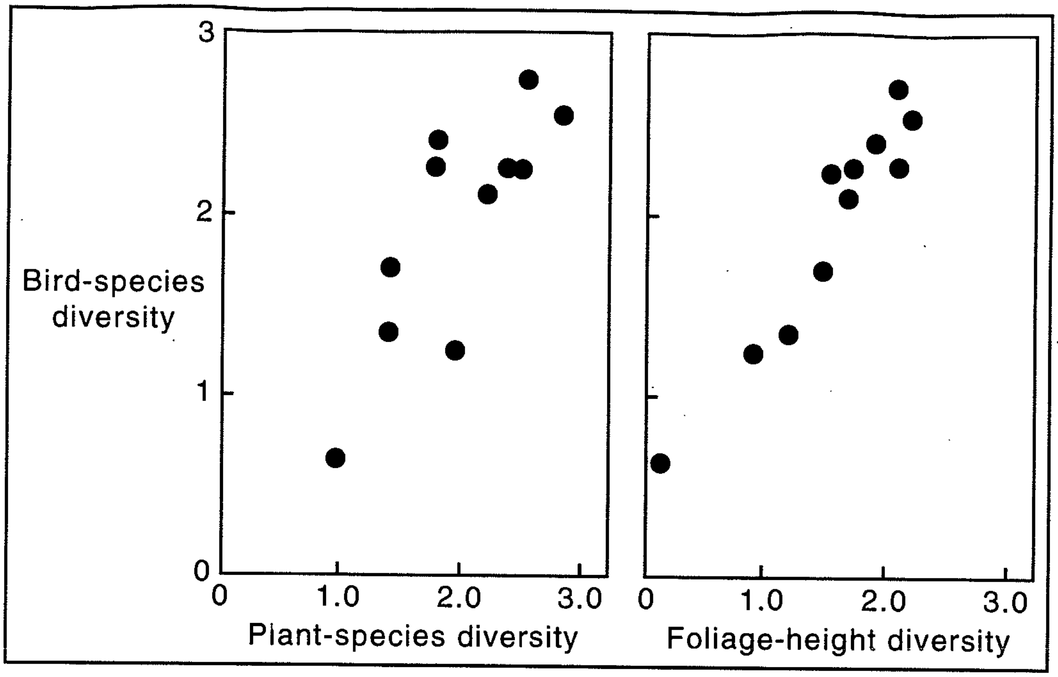


Figure 14.5. The figure on the left shows that bird species diversity increases as the plant species diversity increases in the deciduous forests of the eastern U.S.A. The figure on the right suggests that this relationship may be due to foliage height diversity. Data of MacArthur and MacArthur (1961):

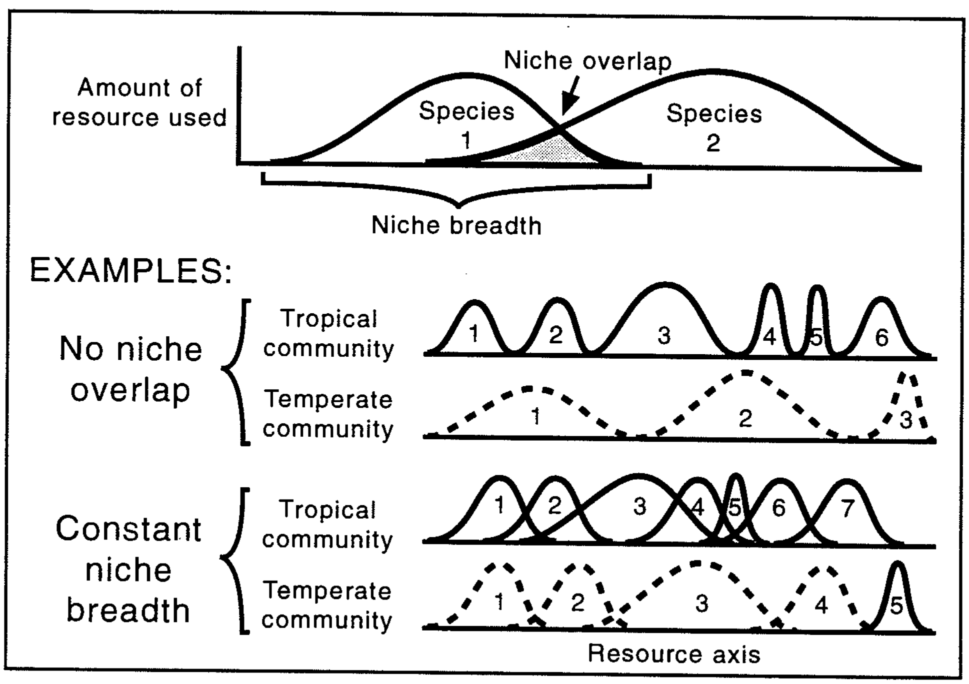


Fig. 14.6. Diagrams illustrating the concepts of niche breadth and niche overlap. Both these parameters are determined by competition within the communities. Based on Fig. 23.17 from C.J. Krebs (Ecology, 3rd edition, Harper Collins).

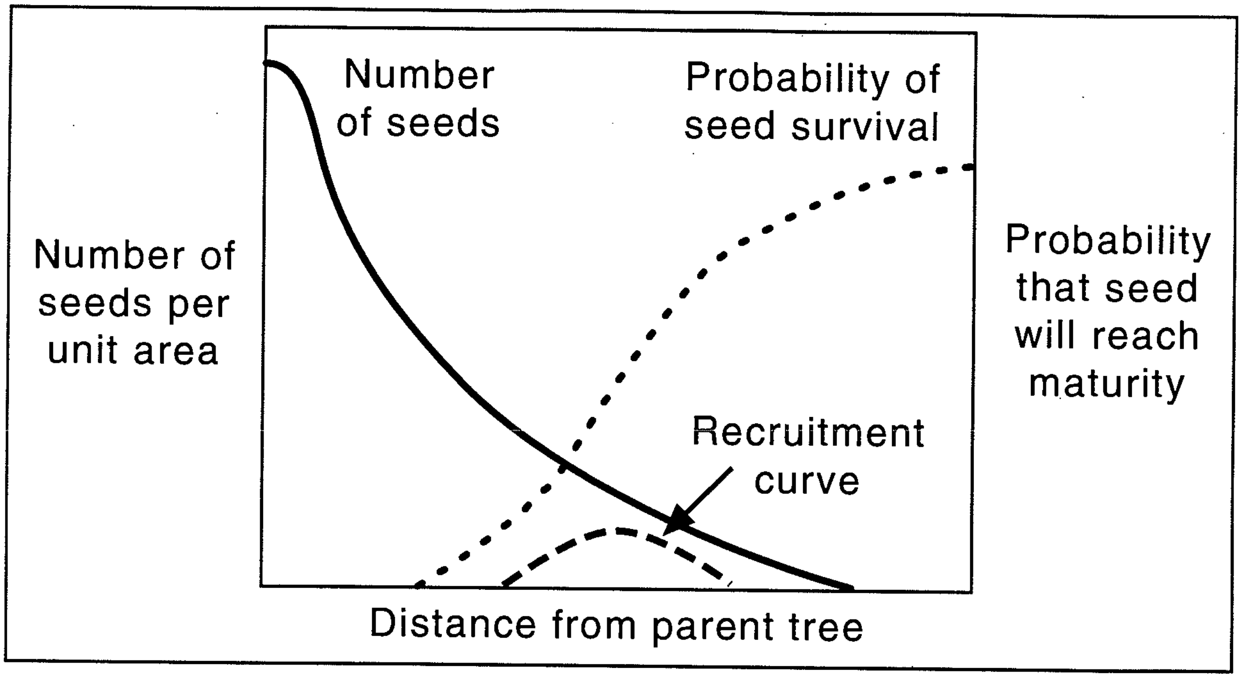


Fig. 14.7. Hypothetical model that explains (1) low recruitment of trees of the same species; and (2) why the trees grow farther from the parent tree. The graph starts where the parent tree is (left border). First of all, the amount of seed dispersed falls off rapidly with distance from the parent tree, and the eating activity of the seed and seedling animals (rodents, mice, insects, squirrels) is most evident near the parent tree as these animals are usually host-specific or territorial. The probability of survival, thus, increases as one goes away from the parent tree. The product of the two factors is responsible for the recruitment curve shown. This scenario includes the recruitment of other species near the parent tree increasing the species diversity. Based on Janzen (1970); Modified figure 23.19 from C.J. Krebs (Ecology, 3rd edition, Harper Collins).

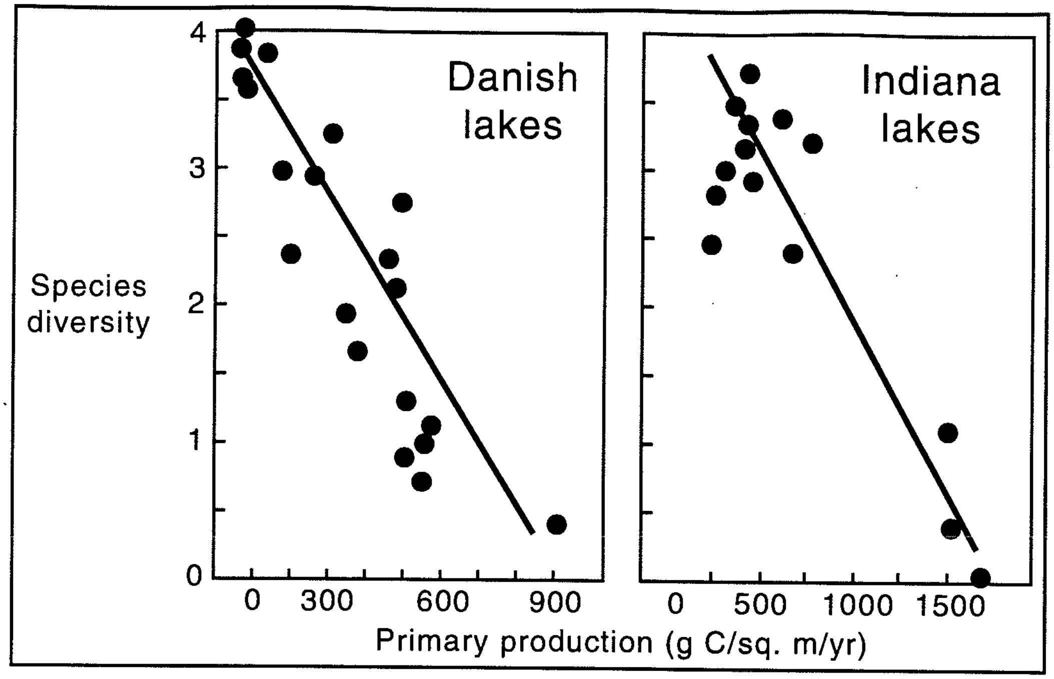


Fig. 14.8. Species diversity of an organism (do you know what chydorid *Cladocera* are?) in relation to primary production in Danish and Indiana Lakes. Data of Whiteside and Harmsworth (1967); modified figure 23.21 from C.J. Krebs (Ecology, Harper Collins).

Lecture 15: Communities: Species Interactions

Reading assignment:

(1) Raven and Johnson, 4th ed., **Chapter 24, pp. 543-546; Chap. 25, pp. 553-567; Chap 32, p. 715-717;**
(2) **These Notes**

By the end of your preparation for this topic, you should be able to:

♦ 1. Explain the different types of competition (resource competition; interference competition) between the various species.

♦ 2. Discuss an experiment that supports the competitive exclusion principle.

♦ 3. Discuss the concepts of *niche*, *niche breadth*, *resource partitioning* and *specialization* that are used to explain how several species can exist in a community

♦ 4. Discuss the different forms of predation and how the natural prey population is regulated by predation.

♦ 5. Discuss "Why is the world green?" when there are so many animals eating away plants. Please consider in your answer the means plants adopt to defend themselves mechanically, or by chemicals, or by mutualistic associations.

♦ 6. Discuss a well-known mutualistic relationship between fungi and plant roots (*mycorrhizae*), see pp. 715-717, Raven and Johnson, 4th ed..

♦ 7. In addition to those already discussed above, define the following **concepts** and **terms**: allelopathy; herbivory; insect parasitism; cannibalism; secondary metabolism; mutualism; and compensatory growth.

Outline of presentation:

(Figure and Table numbers are either from Raven and Johnson, **or from these Notes.**)

♦ 1. *Competition*: An *interference* competition is when an organism interferes with the ability of the others to access the resources by forming a territory (common in animals). *Allelopathy* (exudation of chemicals) is a form of interference competition found in plants. A (or *exploitative*) competition is when individuals simultaneously scramble for resources. If a species A has used up resources, species B cannot get it! **Fig. 15.1** **Notes**

- Effect of habitat on competition: **Fig. 15.2** **Notes**

♦ 2. *Competitive exclusion principle* — Fig. 24.B, 24.C, 24.D p. 543
Example from two species of *Paramecium:*

♦ 3. *Competing for a common resource*: *character displacement:* — **Fig. 15.3** — **Notes**

♦ 4. *Resource partitioning in the soil*: rooting system at different depths — **Fig. 15.4** — **Notes**

♦ 5. *Prey and predation:*

- Introduction of predator leads to death of the prey, but once the prey is gone, predator also dies: Paramecium (prey) and Didynium (predator) If, however, a "refuge" for the prey could be provided, prey population would increase and predator would die. — Fig. 24.13 — p.545

- Prey-Predator relationship: Mites. Correlations: not cause and effect: Similar oscillations have been observed for the population of links (carnivore predators) and snow-shoe hare (prey). (Hare population depends upon available resources, but lynx population depends upon hare population) — **Fig. 15.5** — **Notes**

- Introduction of the predator Lumprey on the trout population in the Great Lakes. Trouts (prey) began to disappear 5-15 years afterwards: — **Fig. 15.6** — **Notes**

♦ 6. Why have animals not eaten and and destroyed all the "greens"? From an earlier lecture: Please recall Trophic levels; only 10% of "greenery" is eaten. Mechanical defenses: Thorns, hooks, spines. Chemicals, secondary metabolites, poisons, toxins: strychnine, morphine, nicotine, etc. Mutualism between Acacia and ants. — Fig. 25.13 — p.565

♦ 7. *Mycorrhizae*: Fungi provide phosphorus to plants and plants provide organic material to fungi. — (Read about mycorrhizae on pp. 715-717, Raven and Johnson)

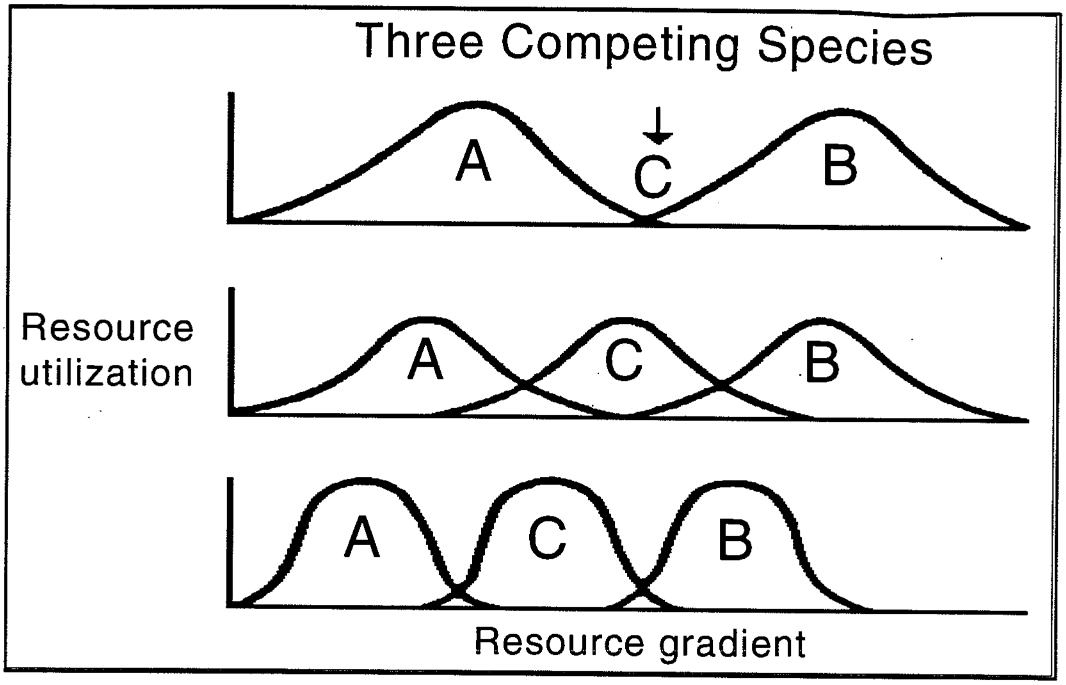


Fig. 15.1. Diagram showing how competition between species with different resource utilization can change the niche breadth. It also explains how a new species (C in this diagram), whose optimal resource utilization lies between species A and B can "come in". (Based on Figure 15.5 (Elements of Ecology by R.L. Smith).)

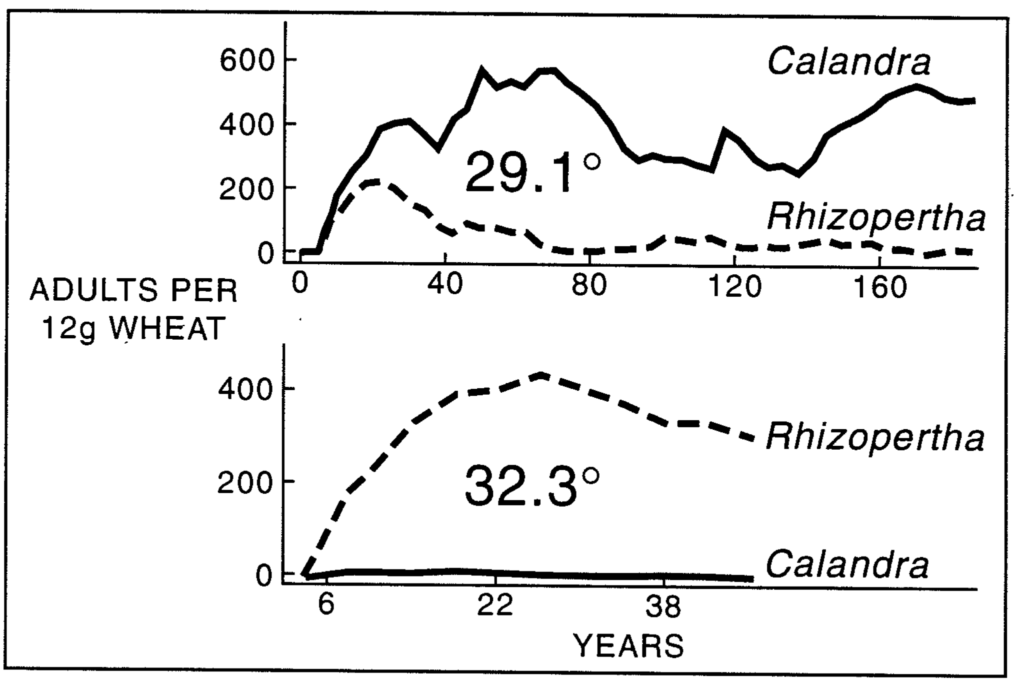


Fig. 15.2. Habitat-specific relationship between two species of adult grain flour beetles (*Calandra oryzae* and *Rhizopertha dominica*) living together in wheat of 14 percent moisture content at two temperatures. Data of Birch (1953). The relative population of the two beetles is totally inverted due to differences in temperature.

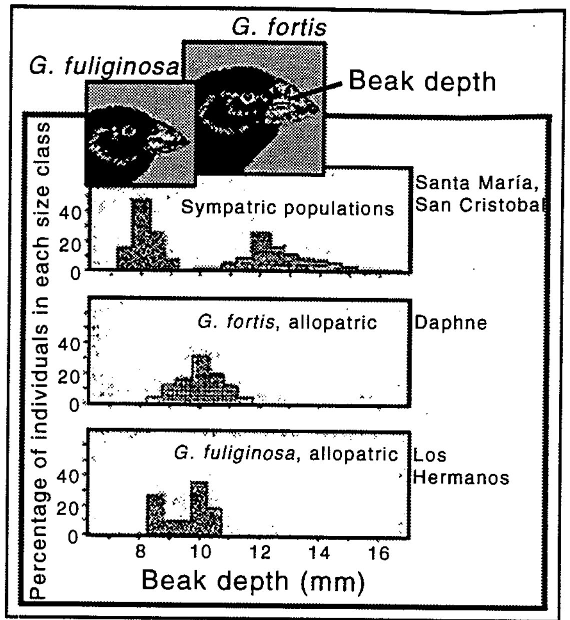


Fig. 15.3. This diagram shows how competition for a common resource can ultimately change morphology, niche breadth and niche position in Galapagos finches. Two species of allopatric (*i.e.*, separate from others of their type) finches on islands of Daphne and Los Hermanos have the same beak depth, and, presumably, eat similarly sized seeds. However, when the two species are sympatric (*i.e.*, live together) both have changed beak sizes adapting to eat different size seeds. This evolutionary change in morphology may reflect ***resource* partitioning**. (Based on data shown in Fig. 48.14, Campbell, p. 1116.)

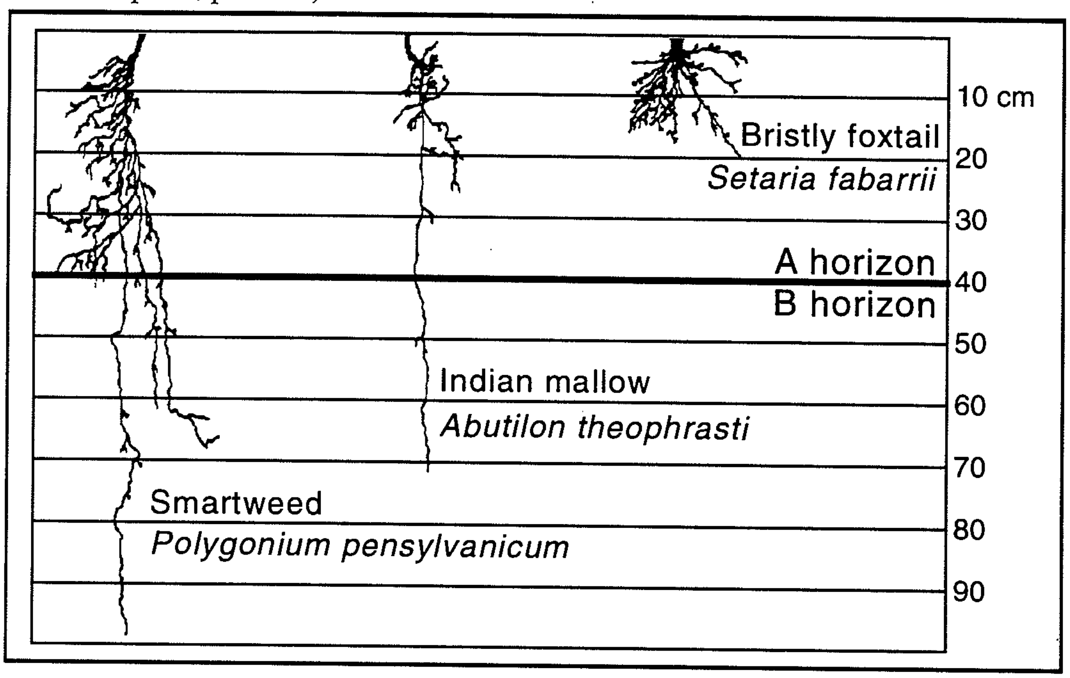


Fig. 15.4. *Resource Partitioning:* One year after disturbance in a successional plot, F. Bazzaz and co-workers (1975) noticed that the root systems of three important agricultural weeds (foxtail, velvet leaf and smartweed) occupied different depths in the soil, thus, beautifully positioning the soil resource. Courtesy of F. Bazzaz.

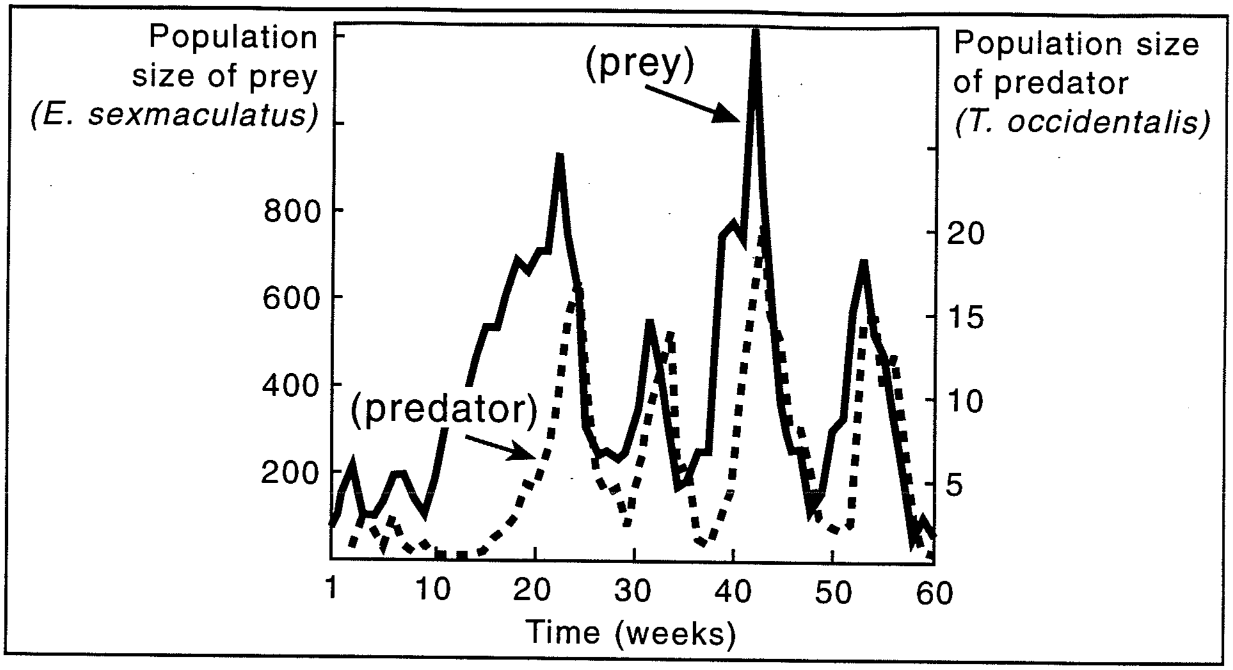


Fig. 15.5. Results from a study of Huffaker (1958) on orange -eating *Eotetranychus sexmaculatus* mite as prey and *Typhlodromus occidentalis* as predator mite. The prey mite infests oranges. When predator mite was introduced onto a single-prey infested orange, it eliminated the prey and died of starvation, as is described for another system in Fig. 48.17 in Campbell. Huffaker then placed ~ 250 oranges in such a way that the prey mite could hop, skip and jump between oranges; only 1/20th of each orange was exposed for possible feeding by the prey. In this complex system, predators exterminated any prey colony they found, but some would escape. This led to an oscillation in the population of prey as well as the predator. (Data of Huffaker and co-workers, 1963.)

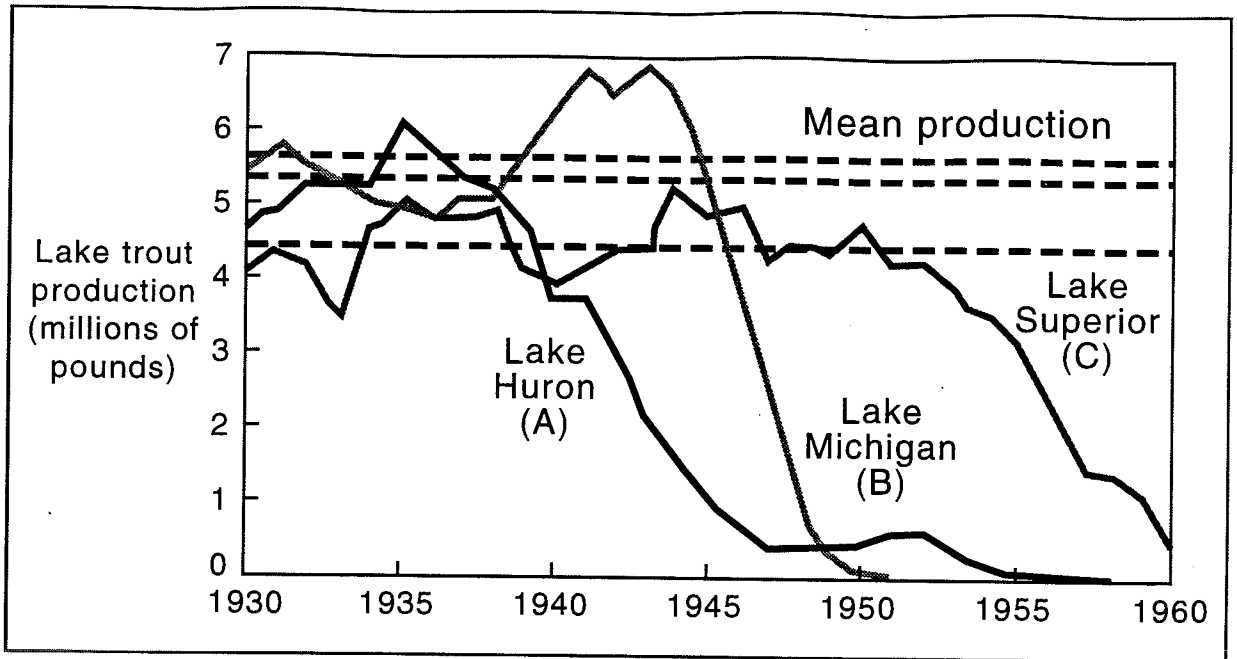


Fig. 15.6. Sea Lampreys were introduced in the 1930s in lake Huron and Lake Michigan, and in the 1940s in Lake Superior. Trouts started disappearing 5-15 years afterwards. A stable community of trouts became an unstable community after this act of "humans". Data of Baldwin (1964).

Dictionary/glossary/concepts

1. *Cannibalism:* A species eating other members of its own species.

2. *Compensatory growth:* Plants grow back after being eaten; there is wound-induced growth.

3. *Herbivory:* Animals eating plants (herbs).

4. *Insect parasitism:* Insects living on insects.

5. *Mutualism:* One living on the other to the benefit of both.

For further reading:

See Chapters 6 and 7 in M.G. Barbour et al. (1987) Tropical Plant Ecology.

Lectures 16 and 17: Plant Reproduction and Seed Dispersal

Reading assignment:

(1) Raven and Johnson, 4th ed., **Chapter 17, pp. 378-380; Chapter 33, p. 730-740; Chapter 34, pp. 741-755;**
(2) H. Howe and L.C. Westley "Ecology of Pollination and Seed Dispersal" in *Plant Ecology*, ed. by M.J. Crawley, **pp. 185-209;** (3) **These Notes**

By the end of your preparation for this topic, you should be able to:

- 1. Draw, label, and describe the function of a flower and its parts (sepal, petal, stamen, anther, pistil, stigma, style, ovary and ovule).
- 2. Discuss the angiosperm life cycle, sperm and ovule formation, fertilization, seed formation and seed germination.
- 3. Discuss the different pollination and seed dispersal syndromes and the rewards that the agents receive.
- 4. Describe the biological principles you have learned by watching the video "**Sexual encounters of the floral kind**". (See other Questions below)
- 5. Contrast the mechanisms and consequences of seed dispersal versus pollination.
- 6. Discuss the relationship between the different morphologies of wind-dispersal diaspores and their dispersal potential.
- 7. Define the following **concept** and **terms**: ballistic; diaspore; wing loading; nectary; nectar thief; nectar guide; floral reward.

Questions for "Sexual Encounters of the Floral Kind": Just for you

1. Why do flowers have showy petals?
2. What are the advantages of cross-pollination?
3. List two characteristics of wind pollinated flowers.
4. How do both the animal and the plant benefit from pollination by animals? What are the types of rewards offered to the animals?
5. Give a thorough description of the pollination of an orchid by a wasp. What event sybchronizes the emergence of the wasp and the flowering of the orchid?
6. Describe how pollination is achieved in the Water Lily.
7. What characterizes hummingbird pollinated flowers?
8. Describe the pollination of the Arum lily by carrion flies. Why is the Arum lily common on the small islands of the Mediterranean?
9. What is the reward to the pollinator of the Arctic Dryas flower? How does the flower collect heat?
10. Describe some bizarre things you saw in the video.

Outline of presentations:

(Figure and Table numbers are either from Raven and Johnson, **or from these Notes**.)

♦ 1. *From Flower to the Seedling*

• Parts:	Figs. 33.11 and 33.12	p. 734
• Angiosperm life cycle:	Fig. 33.14	p. 738
(human)	Fig. 12.14	p. 261
• Life cycle of green alga	Fig. 31.12	p. 687

- Development of gametes (There is first meiosis then mitosis, followed by formation of pollen grain or embryosac)
- Fertilization (There is a double fertilization of egg and of two polar nuclei leading to zygote and endosperm)

• Embryo and/Seed formation:	Fig. 17.17	p. 379
	Fig. 35.2	p. 759
• Seed and Seed germination:	Fig. 33.7	p. 730
	Fig. 33.13	p. 737
	Fig. 35.4	p. 761
♦ 2. *Pollen and Seed dispersals*	**Table 17.1**	**Notes**
• Pollen Dispersal Syndrome:	**Table 17.2**	**Notes**
• Seed Dispersal Syndrome:	**Table 17.3**	**Notes**

♦ 3. *Dispersal and distances*

• Propagule dispersion:	**Fig. 17.1**	**Notes**
• Seedling survival:	**Fig. 17.2**	**Notes**
• Morphologies of wind-dispersed diaspore:	**Fig. 17.3**	**Notes**
• Descent rate and wing loading relationship:	**Fig. 17.4**	**Notes**
	Table 17.4	**Notes**

Table 17.1: Pollen and Seed Dispersal: A comparison
(Based on ideas of Wheelwright and Orians, 1982)

Questions	Pollen dispersal	Seed dispersal
What is target?	Stigma of the flower of the same species	Any suitable site allowing germination
What is the motivation of the animal agent to go to the target?	To collect nectar, fragrance and/or pollen itself	None: just happens the animal agent depends upon the nature of the seed and animal
What are the cues to go to the target?	Flower color, shape, fragrance	None
What are the advantages to the plant for constant visits by the agent?	High: it ensures reliable and correct pollen transfer	High or low: depends upon the availability of effective or destructive agents

<u>Table 17.2</u> **<u>Examples of Pollination Syndromes</u>**
(i.e. group of related or coincident things) (Based on data of several researchers)

Agent	Anthesis (time flower opens)	Flower Color	Flower Odor	Flower Shape	Reward to agent
<u>Insects</u>					
Beetles	Day & Night	Dull	Fruity	Flat or bowl shaped; radial symmetry	----
Bees	Day & Night	Variable; not red	Sweet	Flat to broad tube bilateral, or radial symmetry	Sucrose-rich nectar for long tongued bees; hexose-rich nectar for short tongued bees
Butterflies	Day & Night	Variable; Pink	Sweet	Upright; radial symmetry	Often sucrose-rich nectar
Vertebrates					
Birds	Day	Vivid: often red (Hummingbird)	None	Tubular; curved intricate designs	Ample sucrose-rich nectar
Abiotic					
Wind	Day & Night	Drab green	None	Small sepals & petals are absent; lots of pollen	None

Table 17.3 Some Examples of Seed Dispersal Syndromes
(i.e. group of related or coincident things)(Based on data of several researchers)

Agent	Color	Seed Order	Form	Reward to agent
Insect dispersal				
Ants	unimportant	None	Eliaosome (oily body) attached to seed coat	oil; has a chemical attractant
Vertebrate dispersal Squirrel (A hoarding animal)	Brown	Weak or aromatic	Touch thick walled nuts (e.g. acorns from oak)	Seed itself
Bats	Green, white or pale yellow	Musty	Pendant seeds	Pulp rich in lipid or starch
Frugivores (fruit-eating) birds	Black, blue, red, orange or white	None	Small or medium sized arillate (i.e. with appendage) seeds, berries or drupes	Often only sugar or starch
Abiotic dispersal				
Wind	Usually green or brown	None	Minute size, wings, plumes, or balloons (See Fig. 17.3, 17.4 and Table 17.4	None
Self dispersed				
Explosive dehiscence (Natural bursting open)	Various	None	Explosive capsukes or pods	None

<u>Table 17.4</u> <u>Aerodynamic behavior of morphological groups of wind-dispersed diaspores</u>

(After Carol Augspurger of UIUC, Urbana, IL).

[**See figure 17.3, these Notes**, also from C. Augspurger, 1986]

Morphological Group	*Behavior in still Air*
Floater	Floats downward in a vertical line
Rolling autogyro	Rotates on two axes simultaneously around diaspore's longitudinal axis and around one end in a semi-tight spiral
Autogyro	Rotates tightly around the seed end of the diaspore
Undulator	Glides and undulates, but not with cumulative forward motion.
Helicopter	Spins tightly around a vertical line; similar to autrogyro with added wing
Tumbler	Tumbles but not around a consistent axis; rotates around a vertical line, but in a large spiral

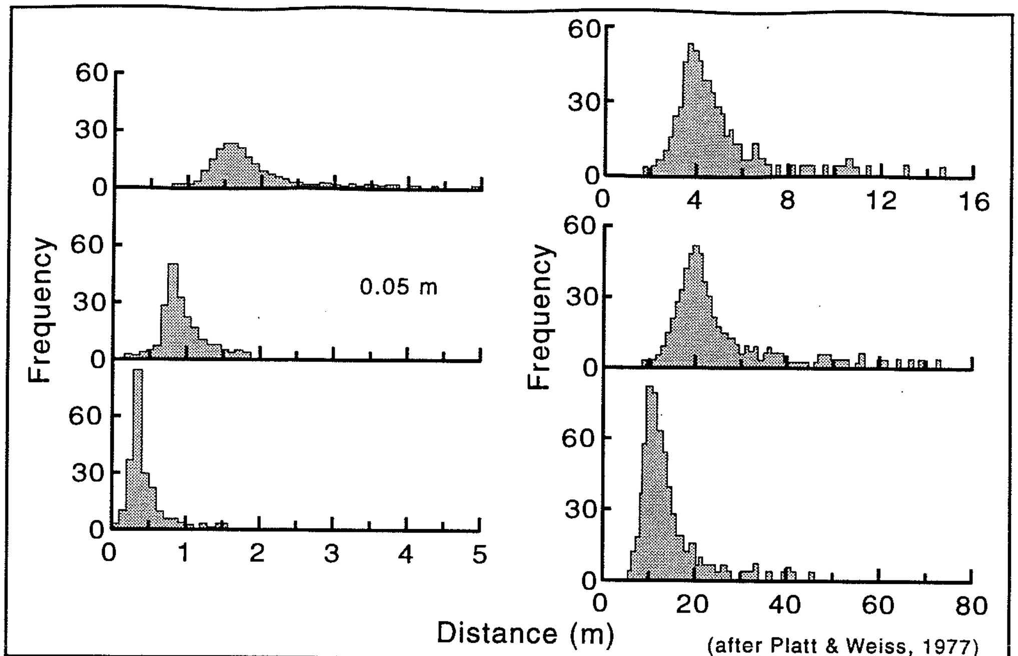


Fig. 17.1. Propagule (propagable part of a plant) dispersion of six species in 10-15 kilometers/ hour winds in a prairie. Frequency is plotted as a function of distance (in meters). The rate of descent (terminal velocity) for each was: *left* (top to bottom): *Oenothera biennis*: 120 cm/ second; *Verbena stricta*: 166 cm/second; *Mirabilis hirsuta* 217 cm/second; *right* (top to bottom): goldenrod: 33.6 cm/second; *Apocynum sibricum*: 9.9 cm/second; milkweed: 24.9 cm/ second. Data of Platt and Weiss (1977). What controls the dispersion rate is the ratio of weight/ area.

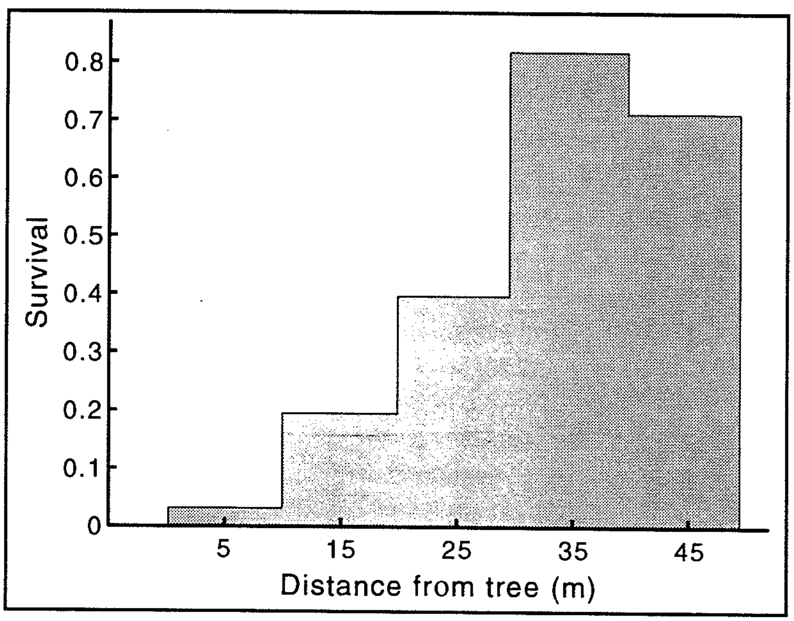


Fig. 17.2. Survival (in percents) of seedlings of the tree *Virola surinamensis* as a function of distance from fruiting trees of the same species. Measurements were made 12 weeks after seeds were placed on the soil surface of a forest in Panama. Data of Howe et al. (1985). First, Weevils ate disproportionate amounts of seeds underneath the parent trees. Later rodents, tapirs and deer continued to kill the seedlings.

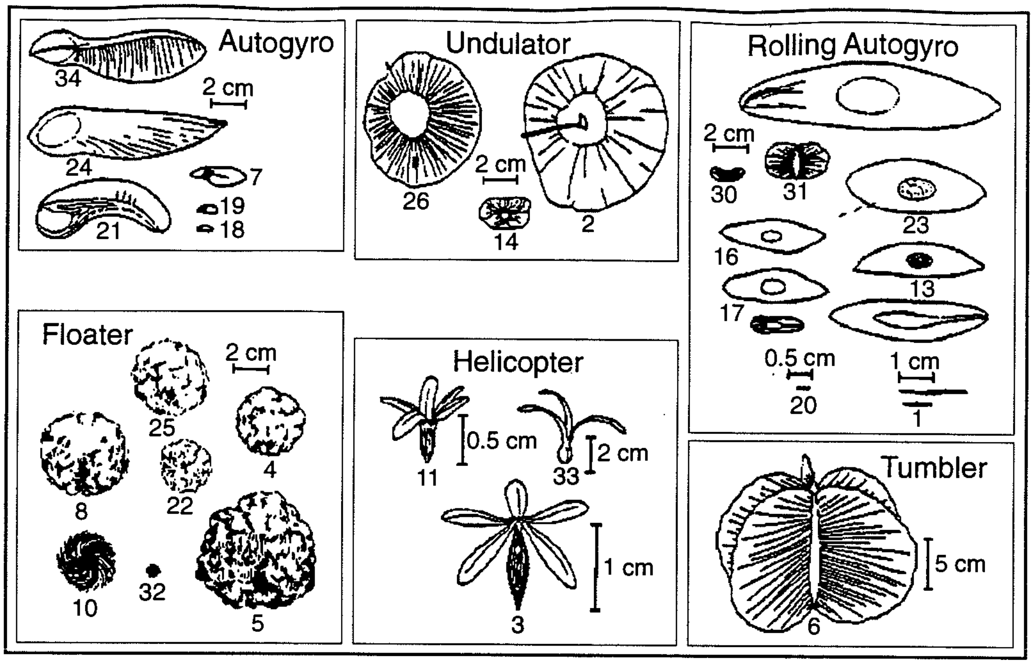


Fig. 17.3. Morphologies of the diaspores of many tree species using wind dispersal on Barro Colorado Inland, Panama. The numbers below a diaspore refer to different species (names are not given here). The names above a group refer to their aerodynamic classification (see Table 17.4 for behavior patterns). Data of Carol Auspurger, 1986. Morphologies in dispersal seeds and fruits dictate the type of aerodynamic motion of diaspores.

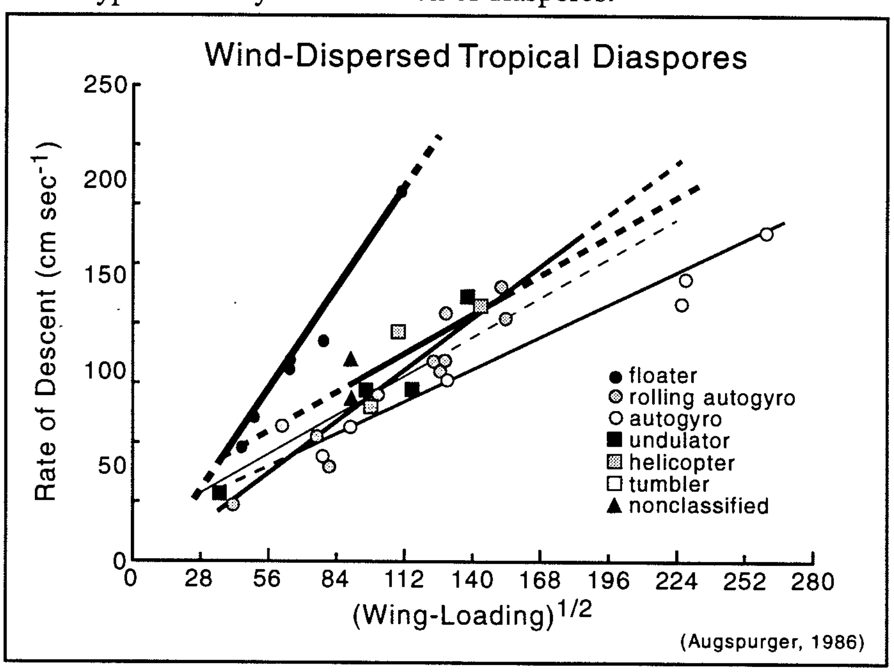


Fig. 17.4. C. Augspurger (1986) showed that the rate of descent (cm sec^{-1}) of diaspores (See fig. 17.3 and Table 17.4) are related to the square root of the wing-loading (weight/area). Dotted lines are for visual clarity of data.

Dictionary/glossary/concepts

(Also consult a vocabulary of Botanical Terms on p. 736 of Raven and Johnson.)

1. *Ballistic dispersal:* Dispersal by means of a projectile action.

2. *Depauperate species:* Those that fall short of natural development or size.

3. *Diaspore:* Seeds or fruits that undergo dispersal.

4. *Double Fertilization:* the process, unique to angiosperms in which one sperm fuses with the egg to form a zygote and the other with 2 polar nucleii to form endosperm.

5. *Endosperm:* the usually triploid food supply of an angiosperm seed.

6. *Floral reward:* It is what an agent receives from the plant when it helps it spread pollens. It is often sucrose-or hexose containing nectar, but even proteins (amino acids) in the pollens themselves.

7. *Frostheaving:* an upthrust of ground caused by freezing of moist soil.

8. *Fugitive species*: Not a permanently established species.

9. *Leptokuritc seeds*: Bulging or curved seeds.

10. *Nectar guide*: Any structure that acts as a guide to the nectar.

11. *Nectar thief*: it is an organism that can get the nectar without helping the plant in pollination, etc. (examples are some wasps and bees).

12. *Nectary*: It is the place where plants store nectar; it can be at the base of a flower, or even on a stem.

13. *Oviposit*: To lay eggs used (especially for insects).

14. *Platykurtic seeds*: Flattened seeds.

15. *Propagule*: A part of a plant that is propagable.

16. *Vagility*: it refers to capacity of an organism to compete successfully in the struggle for existence.

17. *Wing-loading*: Weight/area

Lecture 18: Population Dynamics; Population Ecology: Demography and Life Histories

[*Demography* is study of vital statistics that affect population size]

Reading assignment:
(1) Raven and Johnson, 4th ed., **Chapter 24, pp. 532-551**;
(2) **These Notes**

By the end of your preparation on this topic, you should be able to:

- 1. Discuss the major factors that determine the rate of change in population size.
- 2. Describe the relationship of the age-structure of a population to its rate of growth?.
- 3. Discuss the different types of survivorship curves and their significance. [*Age structure* refers to the proportion of individuals in different age groups.]
- 4. Describe the reason (or reasons) why all the organisms do not reproduce early and continuously.
- 5. Discuss the differences in characteristics of the individuals of the so-called "**r**-selected" (opportunistic) and "**K**-selected" (equilibrial) species.
- 6. Define the following **concepts** and **terms**: natality rate; modular versus unitary growth; mortality rate; age structure; life history; semelparous and iteroparous organisms; **r**-selected and **K**-selected organisms.

Outline of presentation:
(Figure and Table numbers are either from Raven and Johnson, **or from these Notes**)

- 1. Factors that determine population size
  - A. Birth rate; immigration: **Fig. 18.1** **Notes**
  - B. Death rate; emigration:
  - C. Age-structure: **Fig. 18.2** **Notes**; Fig. 24.9 p. 541

♦ 2. Comments on generation time and sex ratio:
(5 μM E. coli doubles in minutes, but 100m long sequoias last for 100 years.)

"Small organisms have short generation times achieving reproductive maturity quickly. Generation time increases with body size because larger organisms take longer to reach the size at which they can reproduce." Often, number of males is unimportant.

♦ 3. *Effect of fecundity* (number of babies or seeds per individual) on Population:

- Results on Births and Mortality as a function of age in red deers: **Fig. 18.3** **Notes**

- Results on Probability of survival of palm trees as a function of fecundity: **Fig. 18.4** **Notes**
  Note: There is a cost of reproduction.

♦ *Types of Survivorship curves:*

- How many individuals are found to be around as a function of the age of the population? There are three major category of results:
  Type I: High constant number, then drop at old age (example: large mammals)
  Type II: Continuous drop with age (example: annual plants)
  Type III: Fast drop at early age (example: fishes)

Fig. 18.5	**Notes**
Figs. 24.7 - 24.8	p. 540

♦ 5. *Characteristics of* ***r****-selected and* ***K****-selected organisms:*

- In general, the number of organisms increase as the resource increases and then they reach an equilibrium. Certain organisms allocate lots of resources to reproduction, grow rapidly in temporary habitats (**r-selected**), produce lots of seeds and have short life spans, whereas others allocate most resources to growth and in building competitive ability, grow slowly, produce less seeds and have long life spans; they reach the carrying capacity (K) and remain constant in number (**K-selected**). For detailed characteristics,see:

Table 18.1	**Notes**
Fig. 18.6	**Notes**
Fig. 18.7	**Notes**

- $\frac{\Delta N}{\Delta t}$ = (b-d) N = rN, where $\frac{\Delta N}{\Delta t}$ = change of number of individuals (N) with time,

b= birth rate, d= death rate, and r = (b-d)

Fig. 18.1
Top

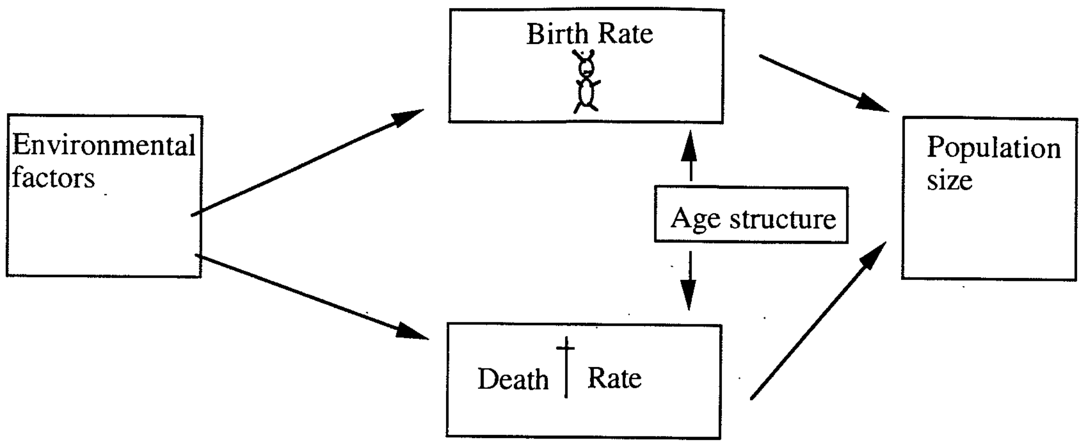


Fig. 18.1
Bottom

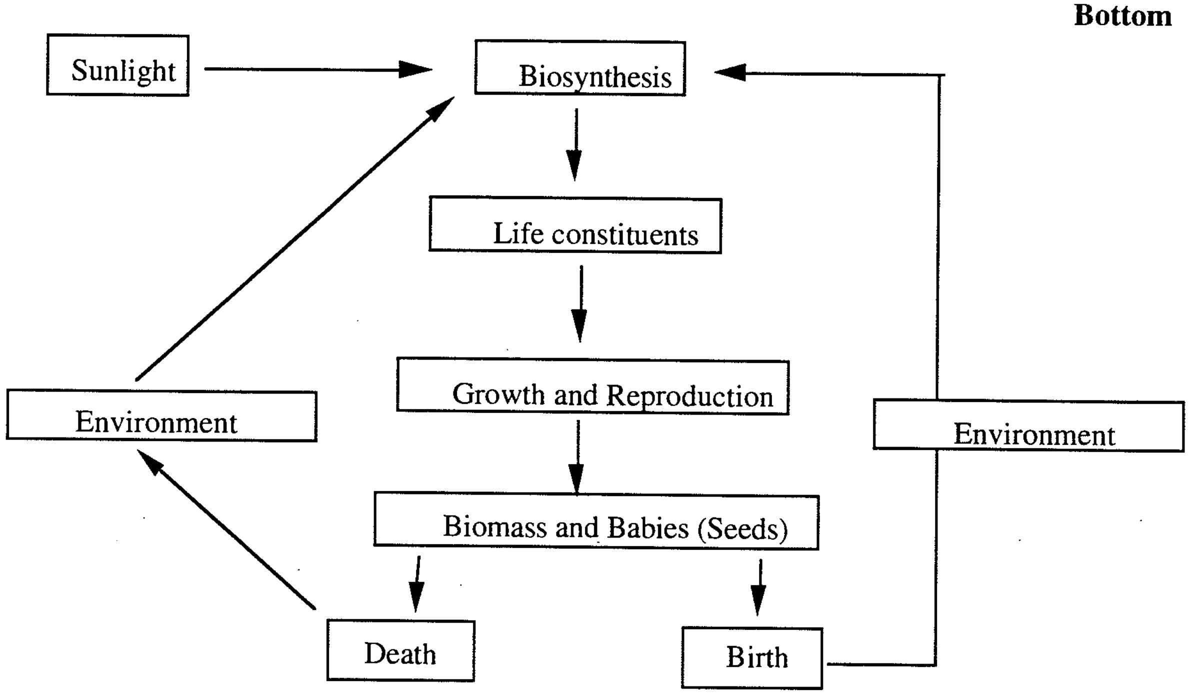


Fig. 18.1. (Top) A diagram showing the factors that control the population size. (Bottom) A diagram showing that the ultimate source of all life is driven by sunlight. Growth and reproduction are two aspects of life. Death leads to the transfer of the biomass into the environment to be utilized later, and birth leads to production of more individuals that carry on the life processes again. Supply is ultimately from sunlight, but the life constituents (carbohydrates, proteins, and fats) are the immediate suppliers. Growth (and maintenance) and reproduction are the Processes, the products being the biomass and seeds (or babies), and the profit is the increased numbers and increased competitive ability or organisms.

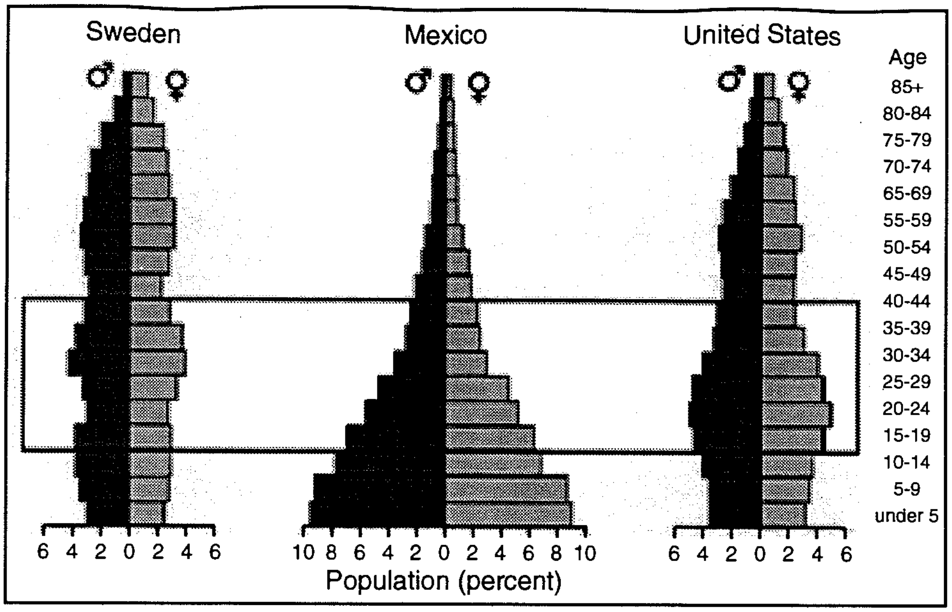


Fig. 18.2. 1985 data on age structures of Sweden, Mexico and USA. Sweden had a constant population size and, thus, stable age structure. However, Mexico had a lot of its population among its young, and, thus, ready for an "explosion" of its population. USA population was also expected to be stable for a while. Do you see where the World War II baby boom is in our population? What age are they now? **Also see Figs. 24.8 and 24.9, p.541, Raven and Johnson, 4th ed.**

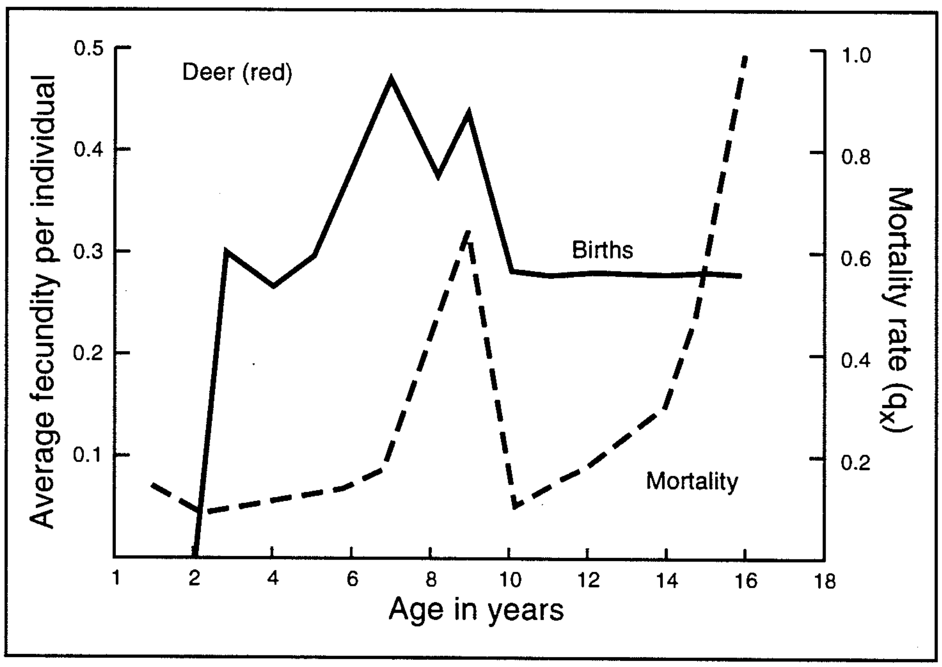


Fig. 18.3. Data of Lowe (1969) for the births and deaths of red deers. As the number of babies per female deer increases with age, the death rate also increases, and, thus their survivorship. It appears that energy expended in repeated reproduction works against the potential for survival. Fecundity on the ordinate refers to number of babies, and mortality rate to probability of death during an age interval.

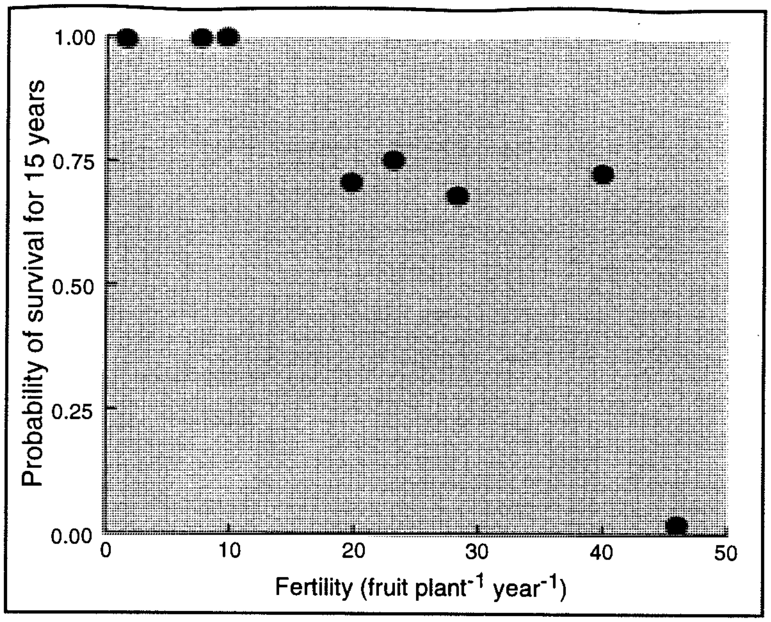


Fig. 18.4. Data of Pinero and co-workers (from Journal of Ecology 70: 473-481) on the probability of survival for 15 years as a function of fecundity (fruits per plant per year) of 10 year old palm tree (*Astrocaryum mexicanum*).

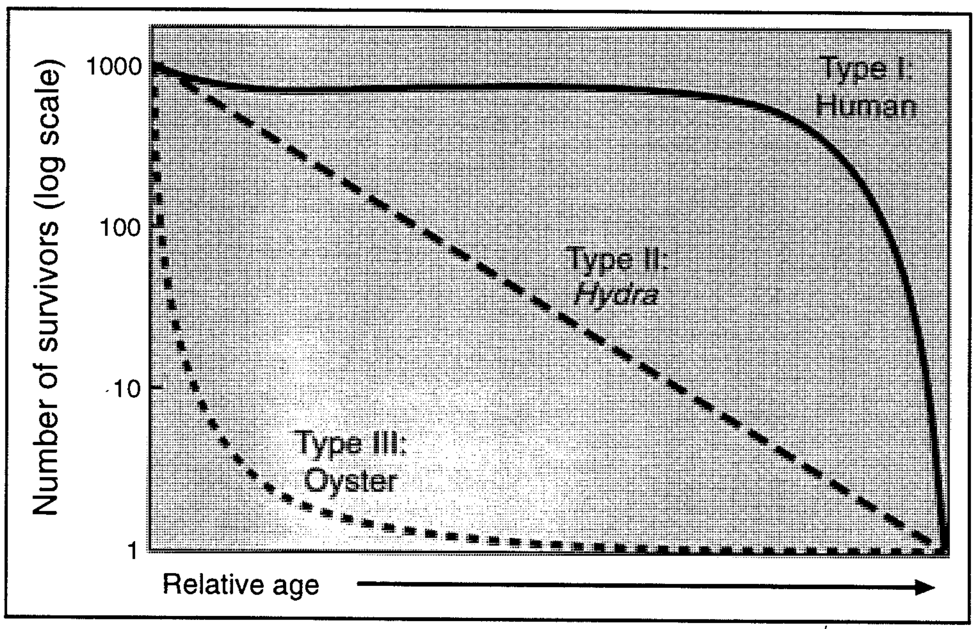


Fig. 18.5. Idealized data of Pearl (1928). Type I curve is an idealized curve reflecting results for large mammals, type II for annual plants and type III for fishes. The small dip at young age for type I reflects infant deaths. Also see **Table 18.1.**

Table 18.1 Differences between r-selected and K-selected life history patterns

Characteristics	r-selected	K-selected
Population size	It has an intrinsic high rate(r) or natural increase; variable in time; not in equilibrium	Fairly constant in time; at or near the carrying capacity (K) of the habitat
Examples	Desert Ephimerals (opportunistic species)	Redwood (equlibrial species)
Climate	Variable/unpredictable; uncertain	Fairly constant and/or predictable; more certain
Mortality	Often catastrophic (high) depending upon external factors; density independent	Usually low; Density dependent: highest mortality when population size is high
Competition	Variable	Keen
Life span (maturation time)	Short (annuals) (short < 1 year)	Long (perennials) (long > 1 year)
Age at forest reproduction	Early	Late
Numbers/ reproductive episode	Many	Few
Selection favors	Rapid development; early reproduction; small size; single reproduction period in life span	Slow development; greater competitive ability; delayed reproductivity; large size; repeated productivity

Table 18.1 continued

Characteristics	r-selected	K-selected
Seeds	Small; dispersed over large area	Large; poor dispersal
Allocation	Mostly to reproduction	Mostly to growth
Overall results	High Productivity of seeds; short life span; adaptive	High efficiency;increased and competitive ability and they survive for long time

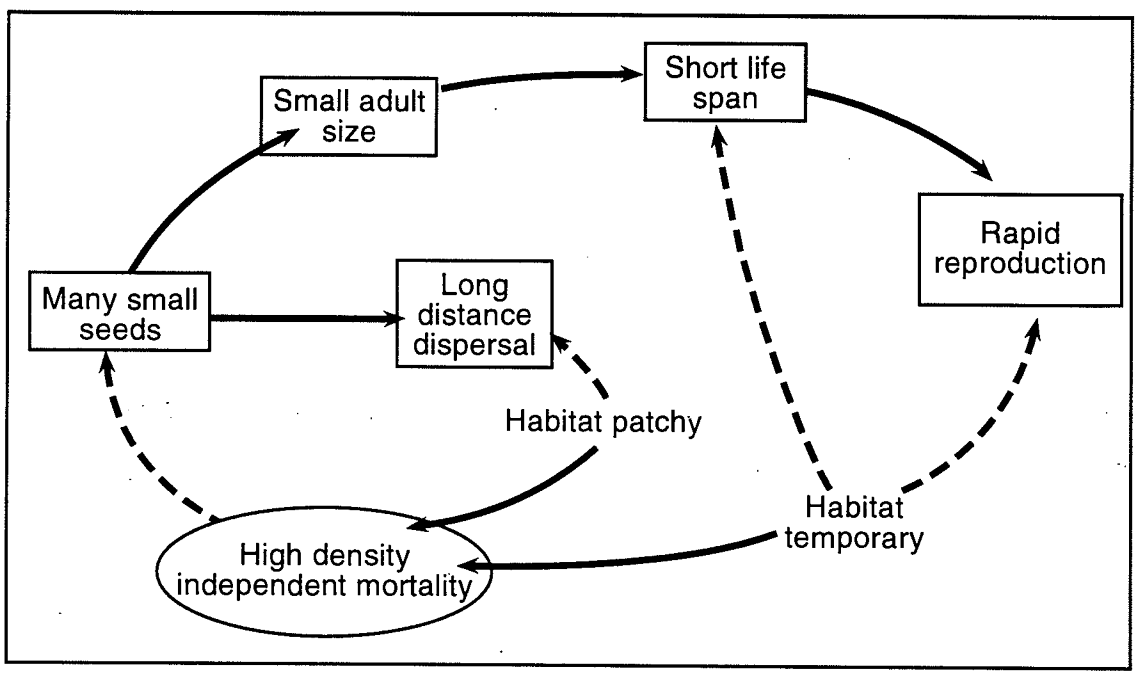


Fig. 18.6. A model for **K**-selected population. Solid arrows indicate which plant characteristic is related to which plant or habitat characteristic, and dashed arrows indicate which selective force leads to what plant or habitat characteristic.

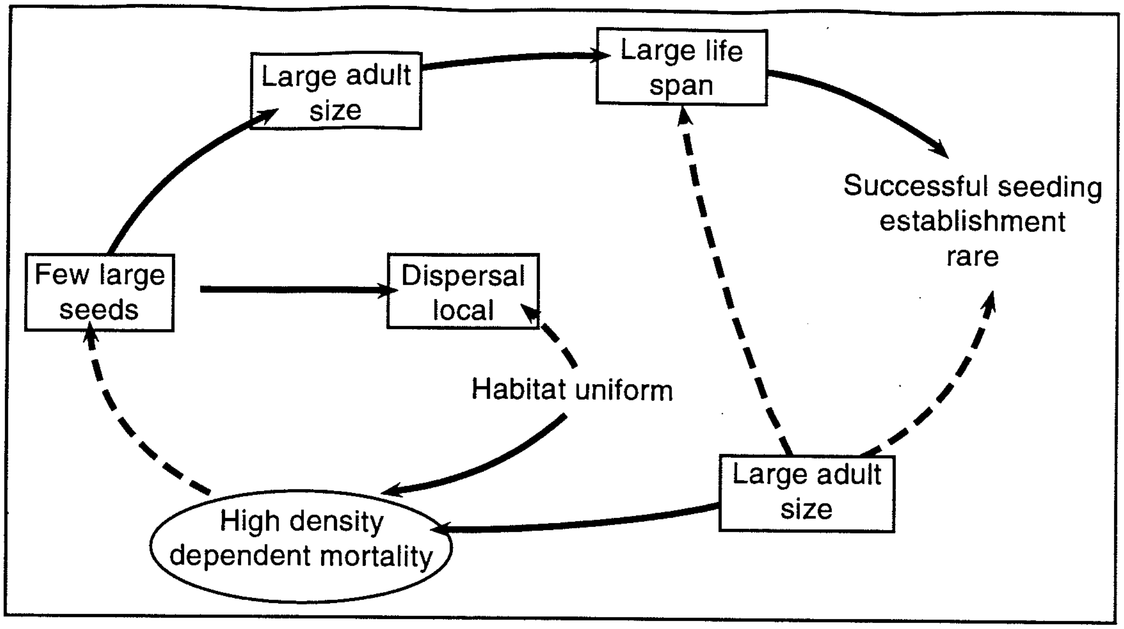


Fig. 18.7. A model for **K**-selected population. Solid arrows indicate which plant characteristic is related to which plant or habitat characteristic, and dashed arrows indicate which selective force leads to what plant or habitat characteristic.

Dictionary/glossary/concepts

1. *Age-structure:* Proportion of individuals in different age groups.

2. *Annuals:* They live for one year.

3. *Biennials:* They live for 2 years.

4. *Density dependent population control:* biotic factors are involved.

5. *Density independent population control:* abiotic; e.g. weather, factors are involved.

6. *Fecundity:* Quality of producing "fruits", especially in abundance, *i.e.* refers to number of descendent produced/individual.

7. *Iteroparous:* Equivalent to polycarpy, multiple births, or reproduce repeatedly.

8. *K-selected organisms:* In these organisms, their numbers are fairly constant in time; they are at or near the carrying capacity of the habitat (**see Table 18.1**).

9. *L-shaped versus Bell shaped curves:* A plot of number of radishes as a function of their dry weight often follow a L-shaped curve, whereas a plot of number of students in Biol. 121 as a function of their heights may follow a Bell shaped curve.

Dictionary/glossary/concepts cont'd

10. *Life History*: This term refers to patterns of allocation of resources to growth and maintenance (survivorship) and reproduction over a lifetime of the organism.

11. *Natality*: This term refers to birth.

12. *Modular versus unitary growth:* modular systems have repetitive parts and grow new parts and shed parts (e.g. plants), whereas unitary systems don't have repetitive parts (e.g. flower beetles, humans).

13. *Mortality*: This term refers to death.

14. *Perennial*: They live for a longtime.

15. **r**-selected organisms: In these organisms their numbers increase with time; they are below the carrying capacity of the habitat (**see Table 18.1**) .

16. *Semelparous :* Equivalent to monocarpy, or one birth; example is century plant (Agave) that flowers in 16-20 years; there are some trees in tropics that produce seeds in 200 - 300 years..

17. Sexual selection: An example of sexual selection is in mate cannibalism. After a male spider has completed its mating, he is eaten by the female spider.

For further reading:
See Chapter 5 in M.G. Barbour et al. (1987) Terrestrial Plant Ecology.

Lecture 19: Population Ecology: Models of Population Growth; Future of Biosphere

[*This lecture ends our excursion into Ecology. It is expected by many that by the year 2025, there will be 8.4 billion people on this Earth.*]

Reading assignment:

(1) Raven and Johnson 4th ed., **Chap. 24, pp. 532-551; Chap 28, pp. 612-614;**
(2) **These notes.**

By the end of your preparation on this topic, you should be able to:

♦ 1. Define population and discuss the exponential and logistic growth models for it, both mathematically as well as graphically.

♦ 2. Discuss the concept of the carrying capacity "K".

♦ 3. Describe the density-dependent and density-independent control of population growth.

♦ 4. Discuss the major conclusions reached on the concepts of population and its control.

[Note: Some of you may wish to evaluate the Pros and Cons of World policies and your beliefs that affect the Human population growth in our World. However, these answers are strictly between you and your conscience. Please read chapter 28.]

♦ 5. Define the following **concepts** and **terms**. abiotic and biotic factor; population

Outline of presentation:

(Figure and Table numbers are either from Raven and Johnson, 4th ed., **or from these Notes.**)

♦ 1. Population (Number of a single species: in a defined area having potential to interbreed.)

(See p. 532 and p. 535, Raven and Johnson; to see the impact of human population, you need to go to India or China, especially at the railroad stations.)

♦ 2. Exponential versus logistic growth:

- Mathematical representation: **Table 19.1** **Notes**
  r = intrinsic rate of growth = birth rate minus death rate

- Graphical representation: **Fig. 19.1** **Notes**
- Example of logistic growth: **Fig. 19.2** **Notes**

♦ 3. Human population:

- World population: **Fig. 19.3** **Notes**
- US Population: **Fig. 19.4** **Notes**

♦ 4. *Population: Computer program & Open Discussion*

> *"Books are the masters who instruct us*
> *without rods and ferrules.*
> *Without harsh words and anger,*
> *without clothes or money.*
> *If you approach them, they are not asleep;*
> *if investigating, you interrogate them,*
> *they conceal nothing.*
> *If you mistake them, they never grumble;*
> *If you are ignorant,*
> *they cannot laugh at you."*

Table 19.1 (A): Exponential Growth (J-shaped curve)

$\frac{dN}{dt}$ = infinitesimal change in number of individuals (N)
with respect to infinitesimal time (t)
= ([birth rate, b] - [death rate, d] N
=rN
where, r= intrinsic rate of growth of the population

(1)

A simple integration of the simple differential equation gives:

$$Nt = Noe^{rt}$$

(2)

where Nt = number of individuals at time t, and No = number of individuals at the starting time (zero), e is the base 2.718. A plot of $\frac{e}{N}$ as a function of t shows an exponential growth curve (**see Fig. 19.2, left**). Here r is constant, and can be listed as rmax.r = max

---

Table 19.1 (B): Logistic Growth (S-shaped curve)

In logistic growth, the population size (N) can never exceed K (the carrying capacity of the system) because of resource limitation. Here, then, r is not constant, but varies with population size N and the carrying capacity K, as follows:

$$r = r_{max} \frac{(K - N)}{K} \qquad (3)$$

$$\text{Thus, } \frac{dN}{dt} = rN$$

$$= rmax\left(\frac{K - N}{K}\right) N$$

A plot of N as a function of t, for the logisitc growth, starts out as the exponential growth curve K>>>N initially, but as the population grows, r slows down, and N approaches a constant calue of **K (see Fig. 19.1**)

Exponential growth:

$$dN/dt = (\text{birth rate} - \text{death rate})N$$

$$(\text{birth rate} - \text{death rate}) = r$$

$$dN/dt = rN \quad \text{or} \quad [N_t = N_o e^{rt}]$$

r is the intrinsic rate of growth

Logistic growth:

$$dN/dt = r \quad N \quad [(K-N)/K]$$

$$dN/dt = rN\left(\frac{K-N}{K}\right)$$

K = carrying capacity

Fig. 19.1. (*Left*): Population growth predicted by the exponential model where unlimited population increase occurs under conditions of unlimited resources. The initial rate of growth, r, is maximal and constant (r max) and the population N is given by No e^{rt}, where No. is the initial population, e is the base 2.718, and t is the time. The rate of change dN/dt increases as N increases with time t. (*Right*): Population growth predicted by the logistic model where population growth is limited by the carrying capacity (K). Here the rate of growth r decreases with time since it is affected by both K and N as follows: $r = r\ max\ \frac{(K - N)}{K}$.

[**See Table 18.1** for differences between the r-selected (Fig. 19.1, left) and K-selected (Fig. 19.1, right) organisms.]

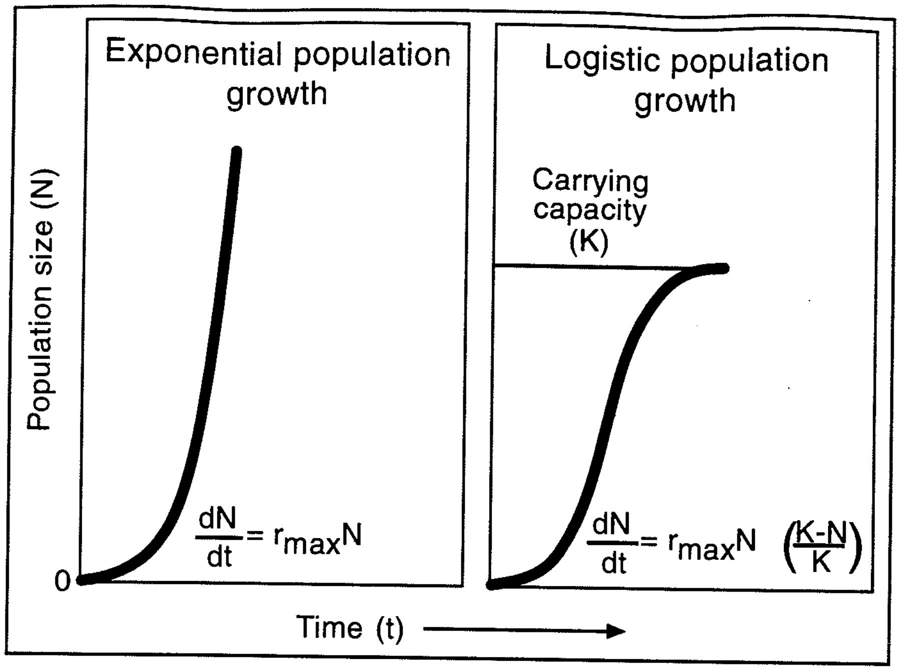


Fig. 19.2. 1913 data of Carlson for growth of a population of yeast cells, as presented by Pearl (1927). Here the carrying capacity (K) was 665 due to nutrient limitation in the growth flask. These results show logistic growth.

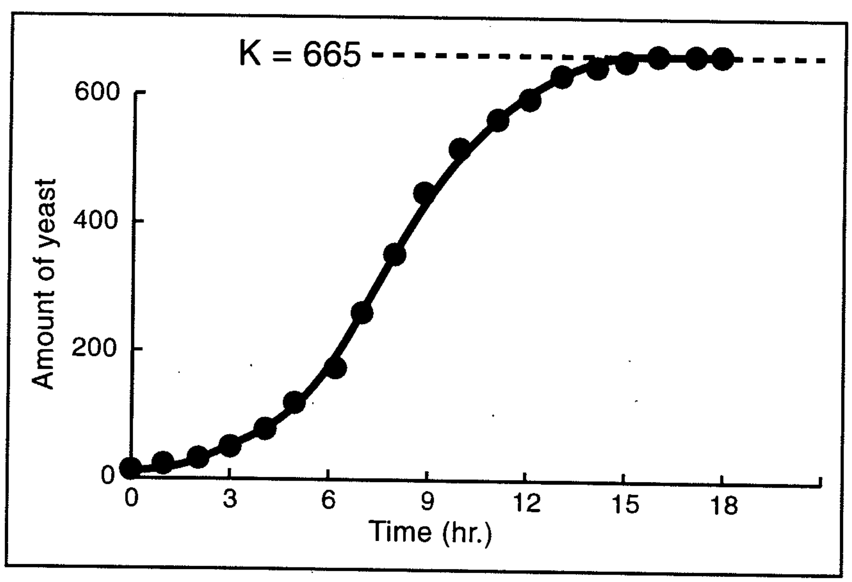


Fig. 19.3 (*A*). Growth of human population over its historical or estimated records (data from Population bulletin, vol 18, No. 1). Note the dip in the population during the Bubonic plague, but particularly note the almost "exponential like" growth in modern times. This alarming fast-rising curve is of great concern because of the limited carrying capacity of our Earth. Factors that limit the growth could be drastic and unpalatable. Thus, all of us must think about ways and means that would lead to an understanding and acceptable solution of the problem in a sensible, ethical and moral manner.

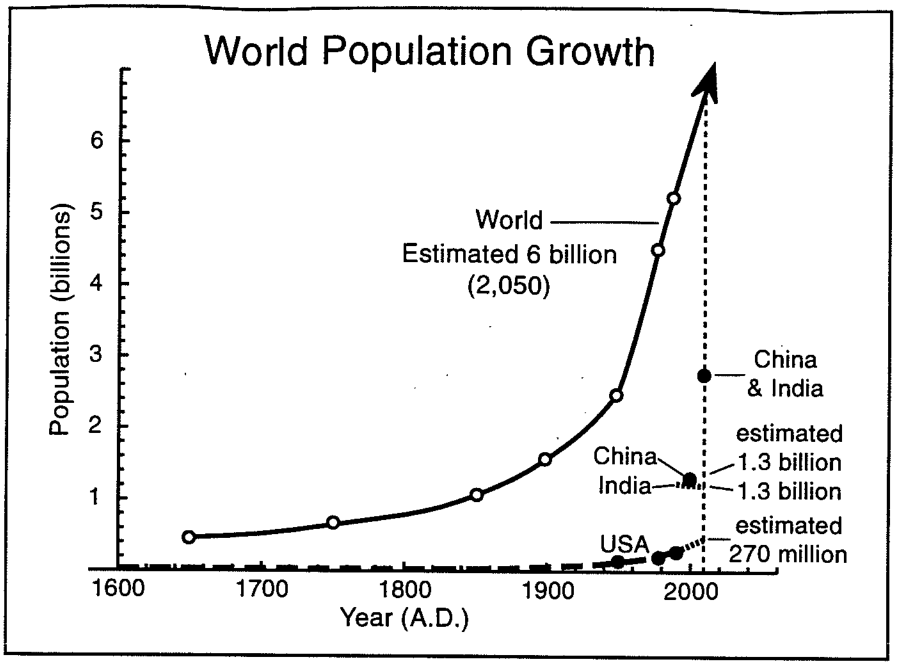


Fig. 19.3 (*B*): Population of the world during 1650- present compared with that of USA. Also shown is the estimated populations for China and India for the year 2020. These two countries are expected to make upto 50% of the world population!

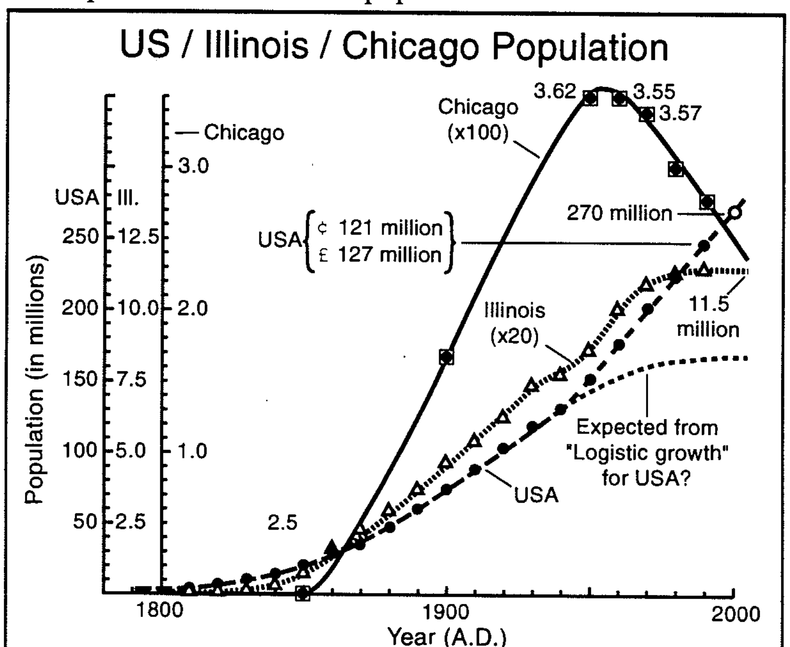


Fig. 19.4. Population of USA, in millions, as a function of time from 1790 till 1990. The desired curve is the "logistic growth" extrapolation curve. Obviously, our population growth has been faster than that predicted from the early data. Data from many developing countries show enormously larger growth rates. Data from Illinois (triangles) plotted on a 20x enlarged scale, and from the City of Chicago (squares) plotted on a 100x enlarged scale provide a different story. What do you think are the reasons for these different trends. Data plotted by Govindjee from the World Almanac (1994).

Dictionary/glossary/concepts

1. *Abiotic limitations:* Refers to non-biotic factors such as weather (hot spell, cold spell, etc), nutrients, fire, volcano eruption. Abiotic factors are responsible for density-independent control of population.

2. *Biotic limitation:* Refers to factors that are related and affected by other organisms—such as competition, disease , eating by insects, (hervbivory) et c. Biotic factors are responsible for density-dependent control of population.

3. *Population:* Usually, it refers to the number of a single species, but more specifically to members of a species in a defined area having potential to interbreed.

Lecture 20: Overview; General Discussion on Climate and Civilization

Reading assignment:

(1) Review: lectures 1-19
(2) Review Chapters 24 through 28 ; and Chapters 33 through 36
(3) Al Gore "Climate and Civilization: a short history", Chapter 3, in "*Earth in the Balance: Ecology and Human Spirit*"

Optional reading:
(4) Ann Gibbons "*How the Akkadian Empire was Hung out to Dry*", Science 261: 985 (1993)
(5) Arie S. Isar "Climatic change and the History of the Middle East" American Scientist 83, 350-355 (1995)

By the end of your preparation of the topics covered, you should be able to:

- 1. Provide an overview of the structure and function of plants, and their components, with particular emphasis on transport of water and sugars; mechanism of photosynthesis; and how environmental factors, particularly light, control plant growth and development.

- 2. Provide an overview of the Biological Communities; Dynamics of Ecosystems; Interaction between Species; Population Dynamics; and the Future of our Bio sphere.

- 3. Discuss an example of a relationship between climate change and its consequences on human civilization.

- 4. Discuss some of the *lessons* learned from "climate history" and a possible scenario for our future, based on these lessons.

Outline of presentation :(Table numbers are from **these Notes** only.)

- 1. Summary of Govindjee's portion of Biology 121.
- 2. Climate change and the human response
  - 2,200 BC: Death of Akkadian Empire in *Mesopotamia:* **Table 20.1** **Notes**
  - 1300-1350 AD: Temperature change and *Black death* in Europe: **Table 20.2** **Notes**
  - 1815-1819: Effects in Europe and USA of volcano eruption in Indonesia: **Table 20.3** **Notes**

- 1845: Potato blight in Ireland: **Table 20.4** **Notes**

♦ 3. Possible lessons from history and interactions of human response and environmental change: **Table 20.5** **Notes**

Table 20.1. In Mesopotamia (now Iraq) - 2,200 B.C.

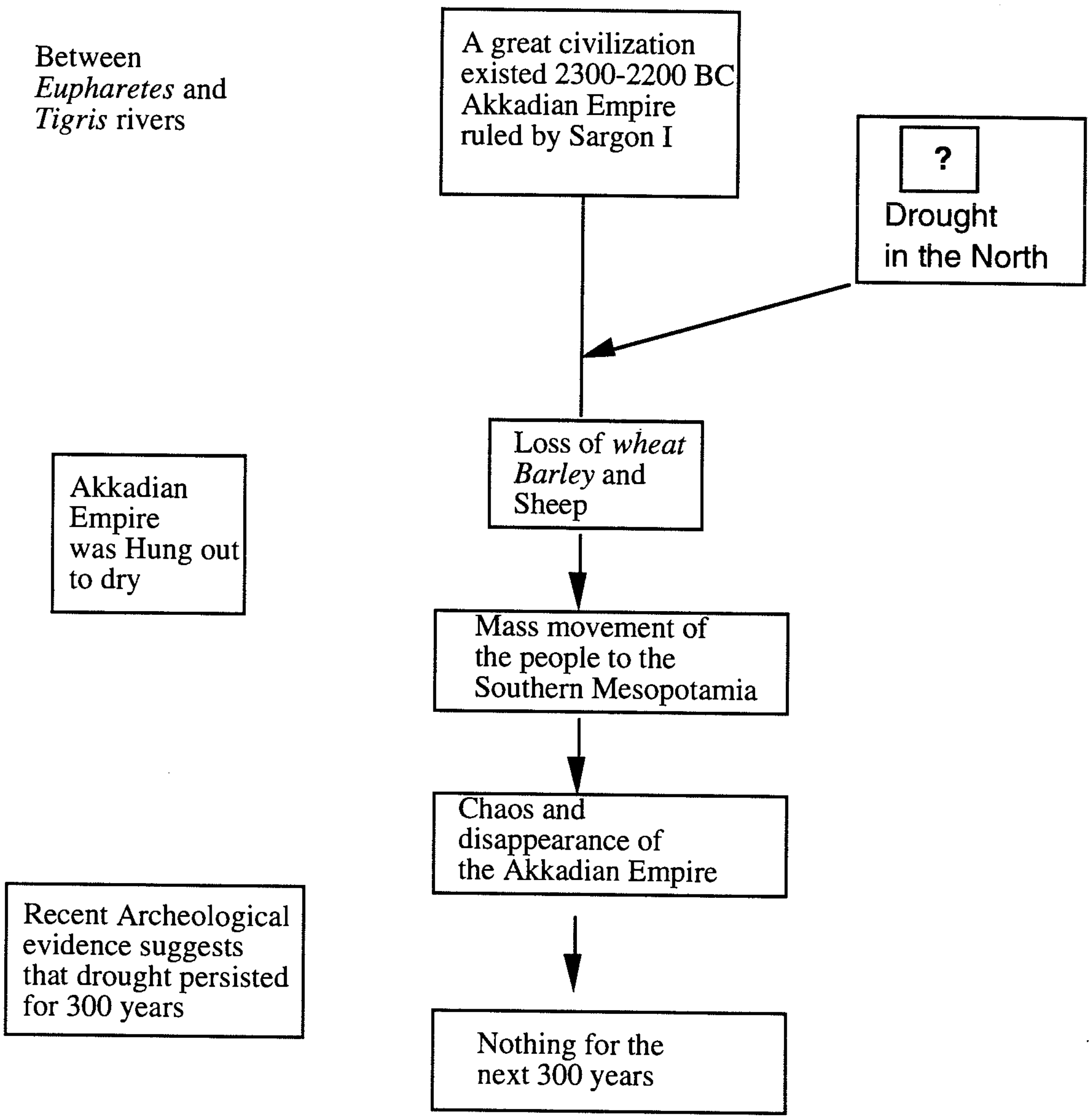


Table 20.2 Black Death of 1345

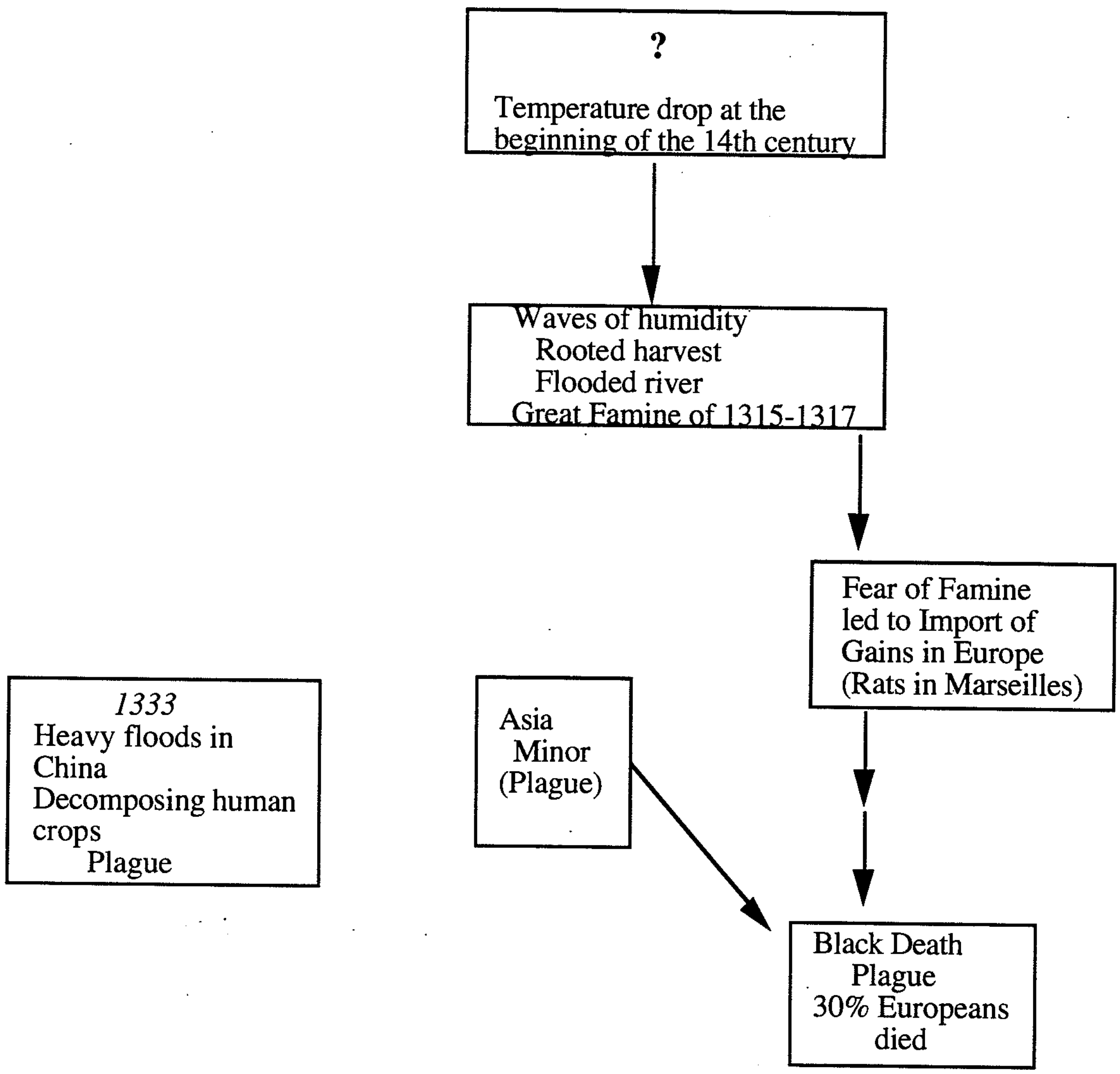


Table 20.3. Climate Change to Social Change

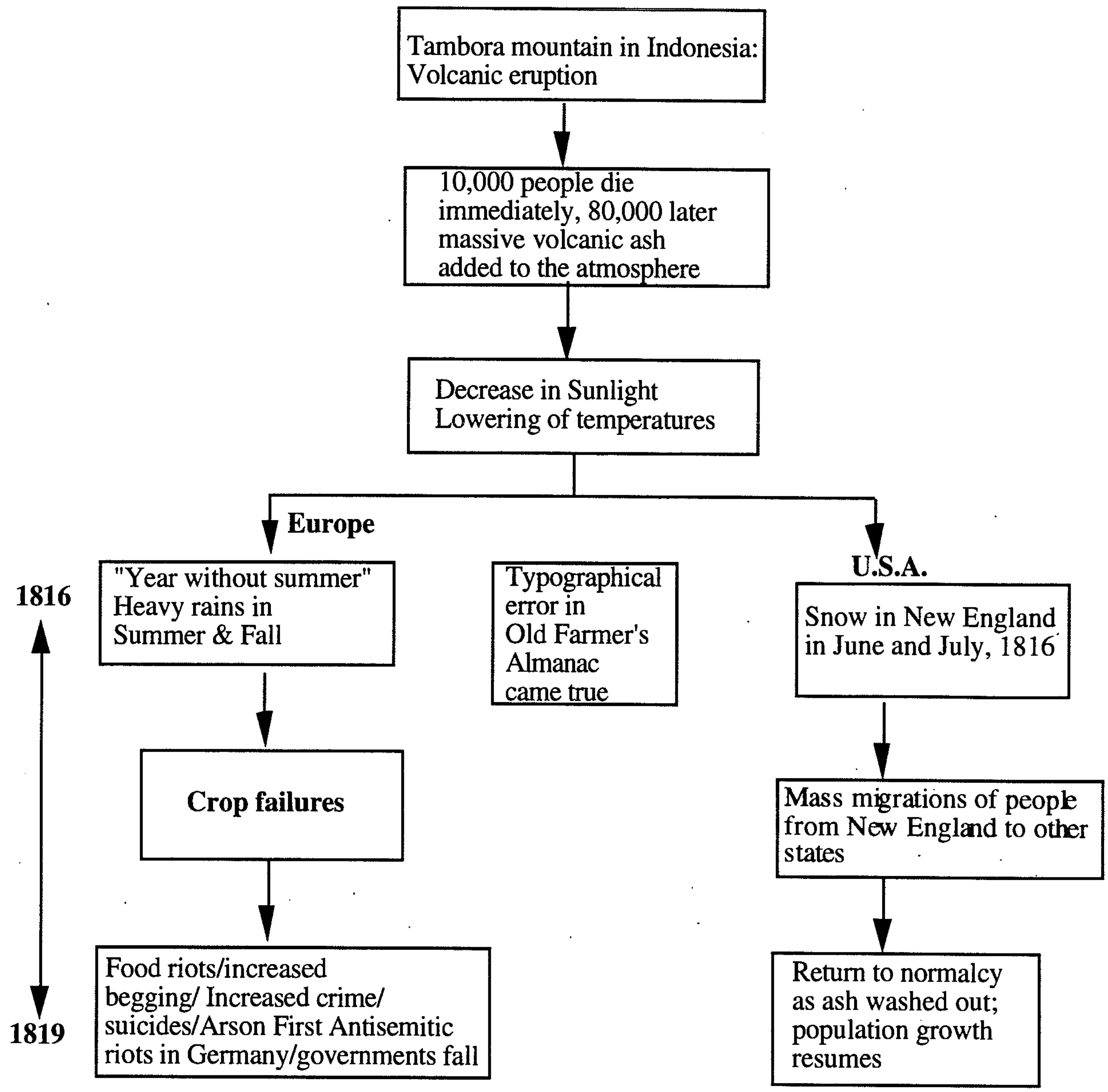


Table 20.4. Potato Blight of 1845 (Ireland)

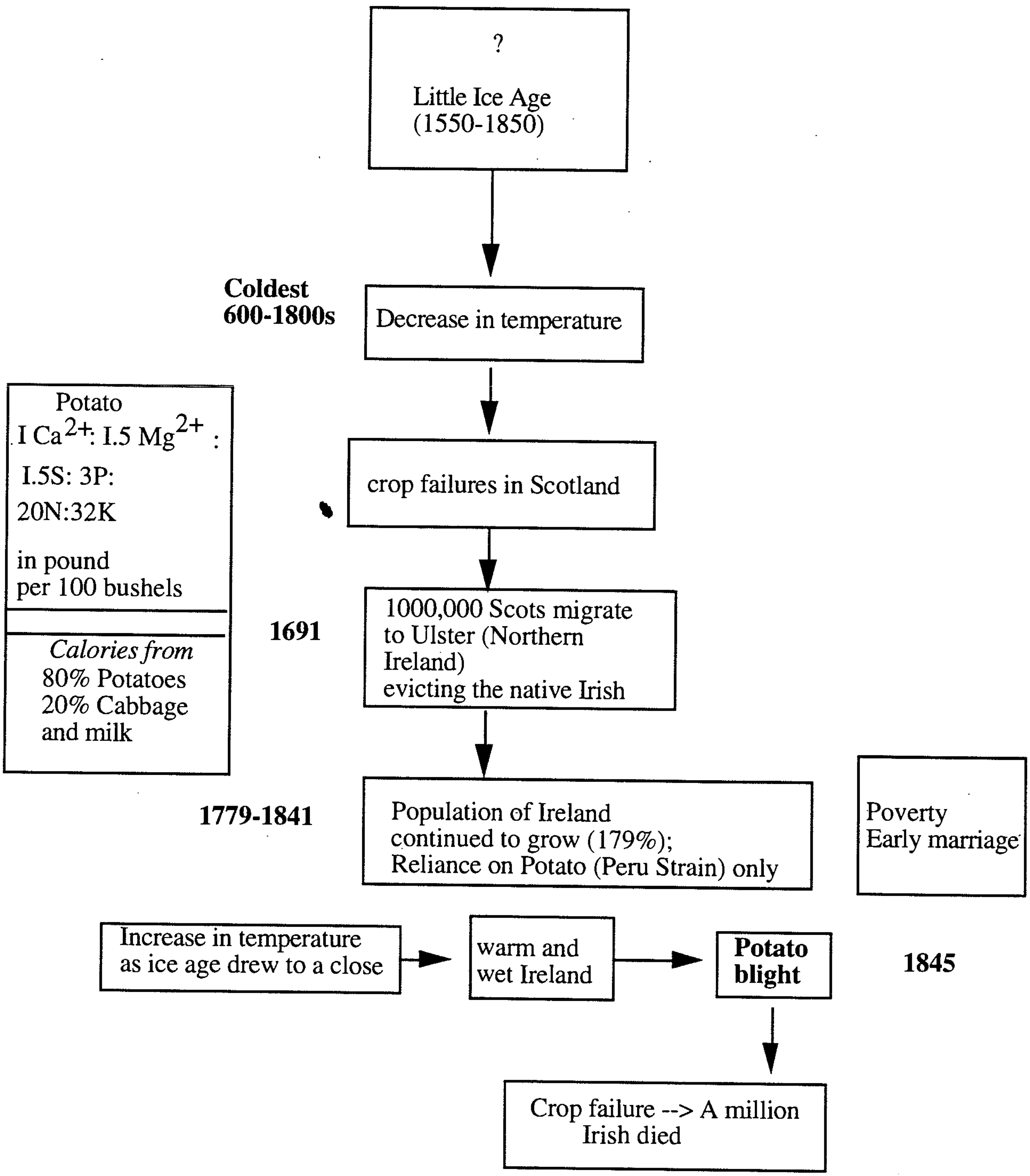


Table 20.5. Lessons from History

- Small changes in temperature on Earth have caused havoc in our society. Thus, please consider seriously the possible "global warming" on our earth.

- Dependence on one crop for food is a very bad idea as was the case in Ireland.

- Increase in population have led to disappearance of several civilizations in the past. Thus, please consider seriously the problem of increasing of "population" on our Earth with limited capacity.

- Changes in patterns of land use have led to the "dust Bowl" of the 1930s in Kansas and other states, and of mass migrations, and of major political changes in the US. Thus, please consider seriously the possible consequences of the problem of "cutting down trees" and replacing them with apartment buildings.

The End