Physiological Ecology

I. Ecology of Individuals

- Behavior
- Physiology

Physiological ecology - concerned with the dynamic relationship of individuals to their physical environments and resources.

A. What is an individual?

- Independently living cell
- Group of cells physically attached to one another (descended from a single cell)

But ecologically, these definitions might be too restrictive


In ecology we define 2 types of individuals

1. Genetic (genet) – genetic individual, all the tissue that grows from a single fertilized egg.

2. Ecological (ramet) – ecological unit, entity noticed in the field as individual, autonomous in its use of resources.

How would you define this colony?

Workers

Entire Colony

B. What is the environment?

All elements in organism’s surroundings that can influence

- Behavior
- Reproduction
- Survival

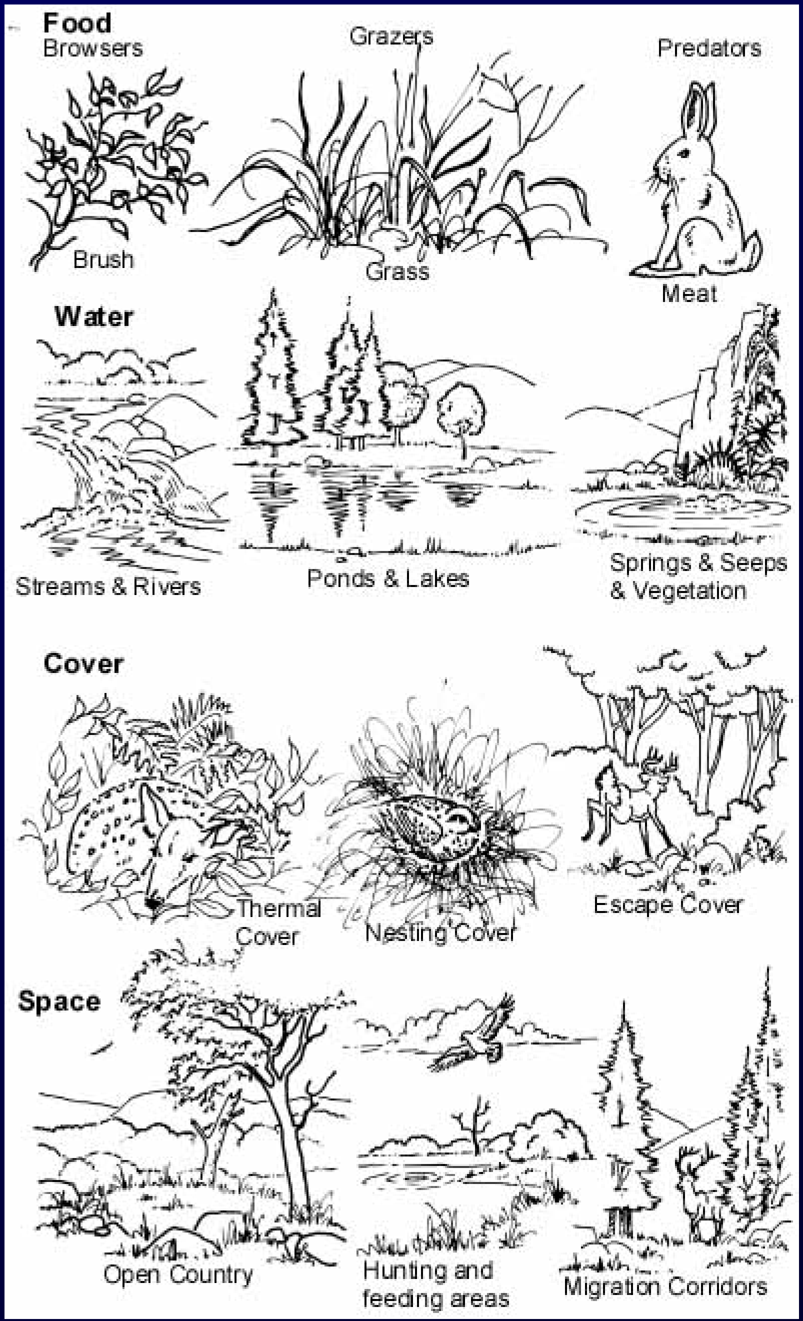
1. Abiotic – physical characteristics of the place in which organisms live (non-living)

2. Biotic – other living organisms

3. Resource – object or area that is consumed or used by an organism

4. Habitat – place in which organism usually lives,

Habitat components



4. Habitat – place in which organism usually lives,
    a. Microhabitat – particular spot

Habitat – tall grass prairie

Microhabitat – under litter layer in unburned prairie

5. Niche – occupation or means of making a living,

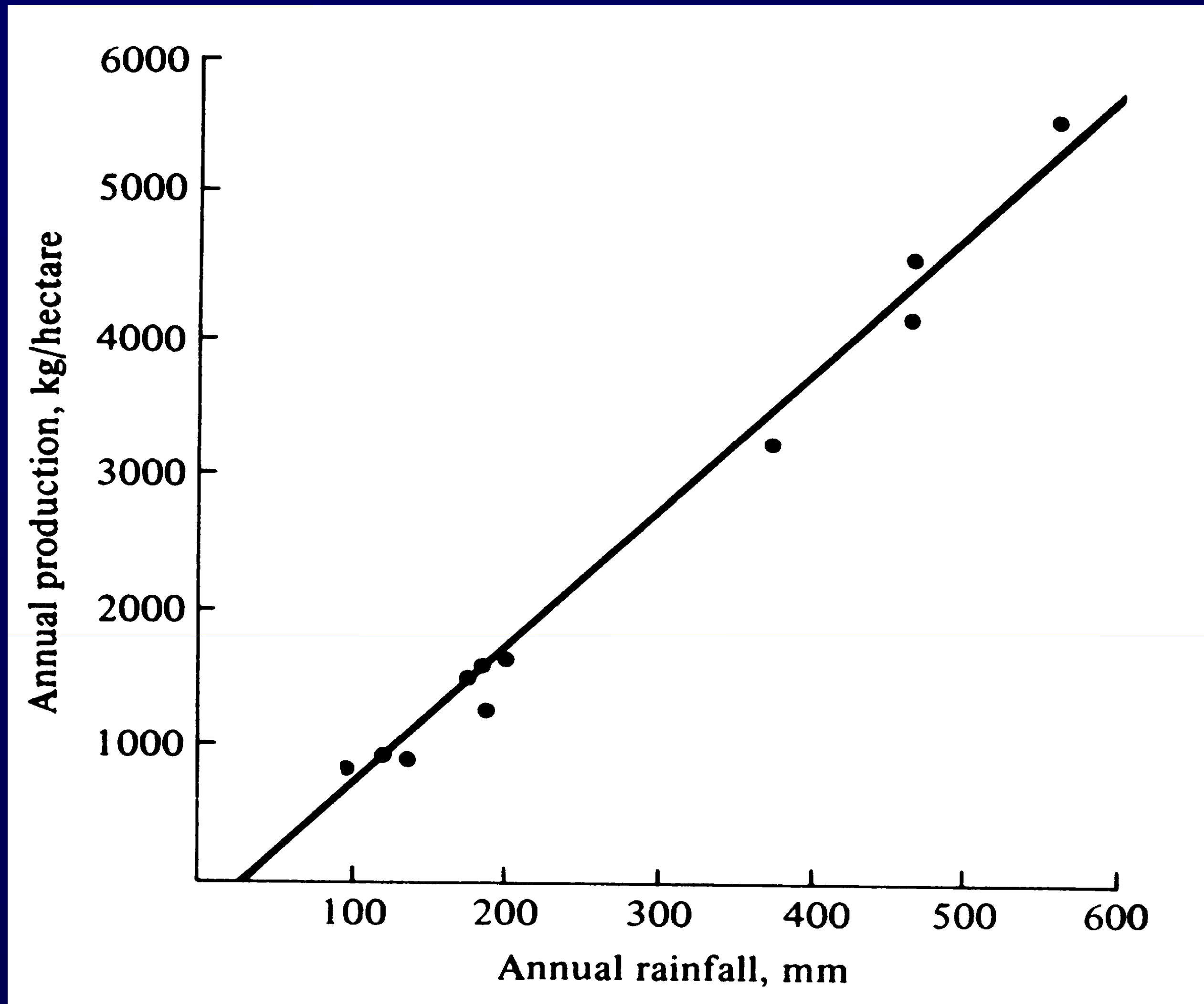
Active forager

Sit and wait predator

C. Tolerance Ranges and Limiting Factors

1. Range of tolerances occurs for all species

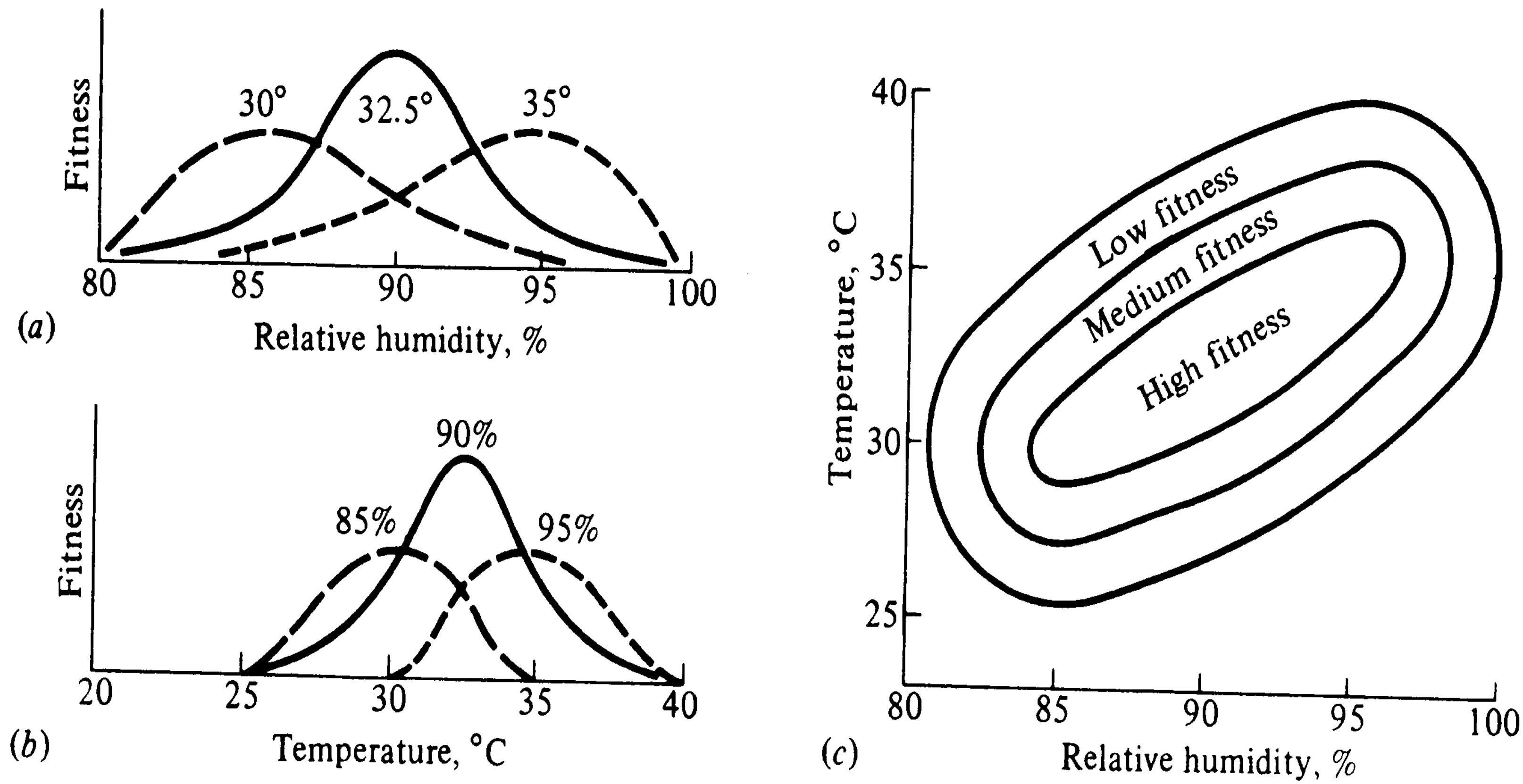
May depend on age, sex, condition



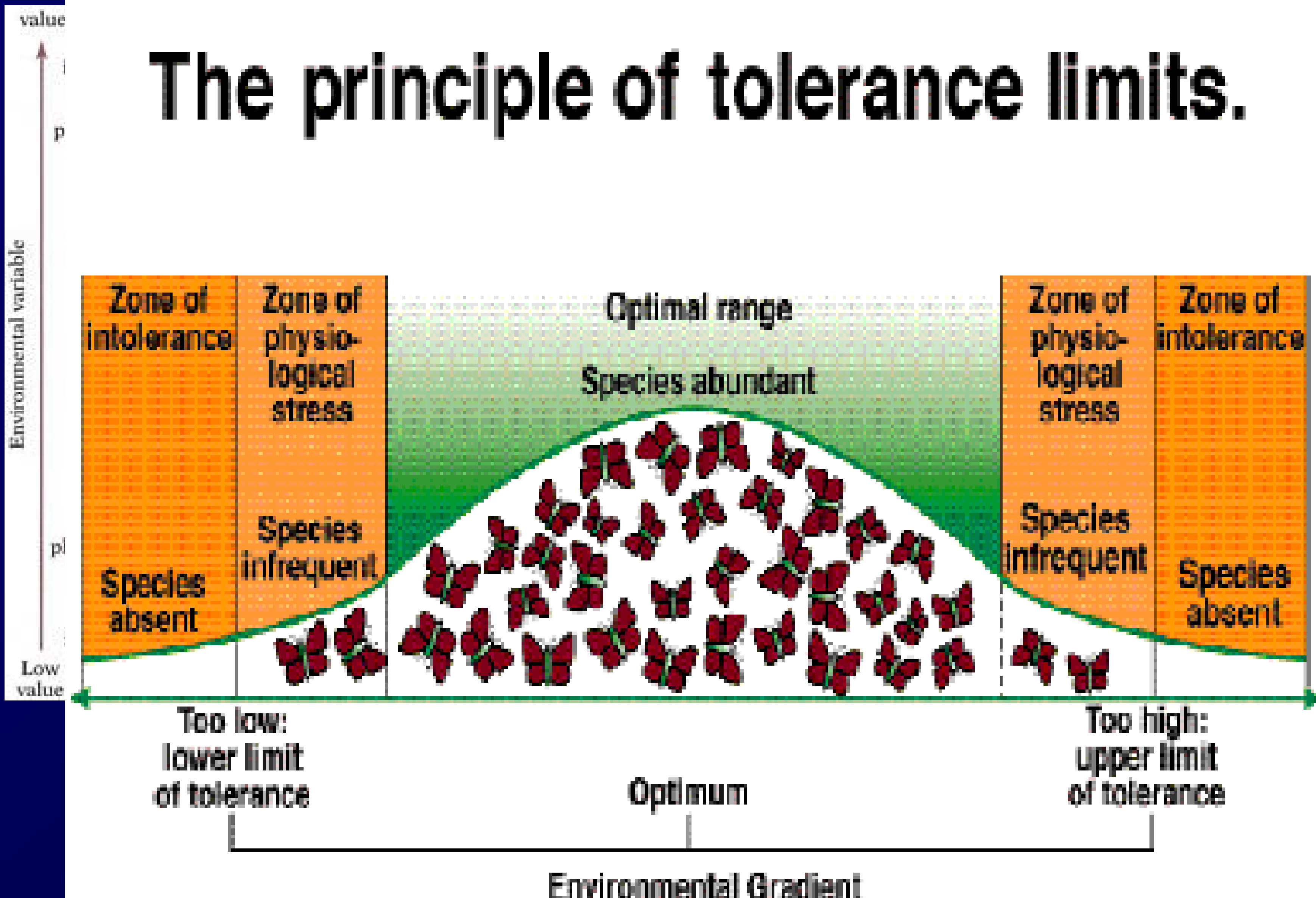
6000
5000
4000
3000
2000
1000
Annual production, kg/hectare
100
200
300
400
500
600
Annual rainfall, mm

Wide tolerance – Generalist

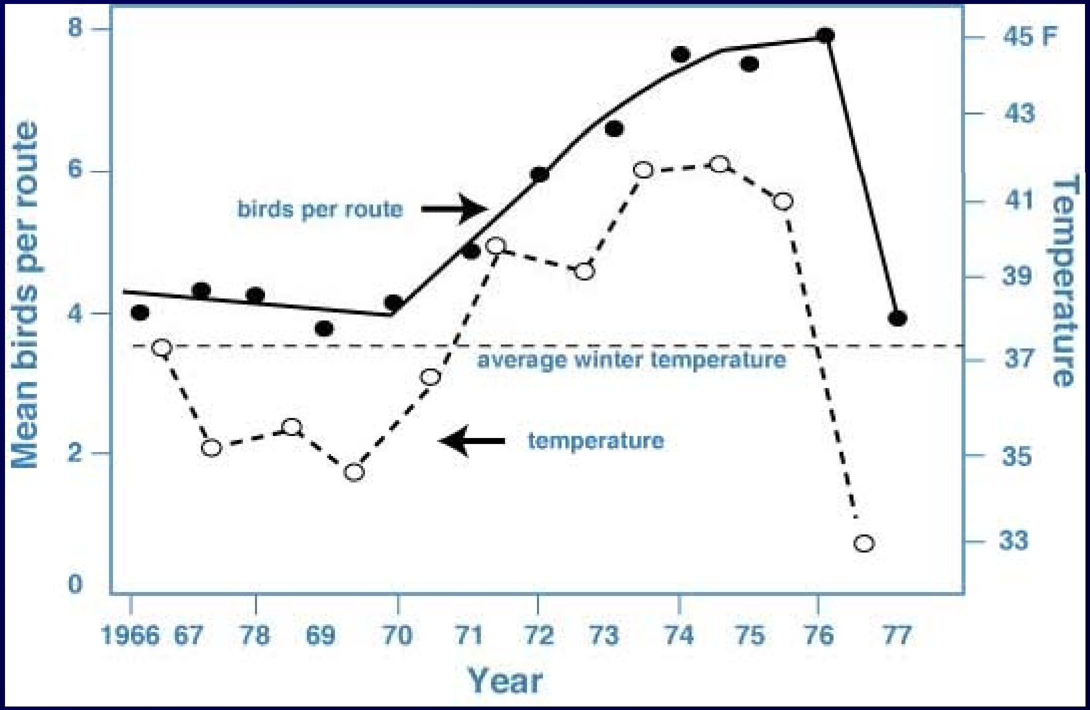
Narrow tolerance – Specialist

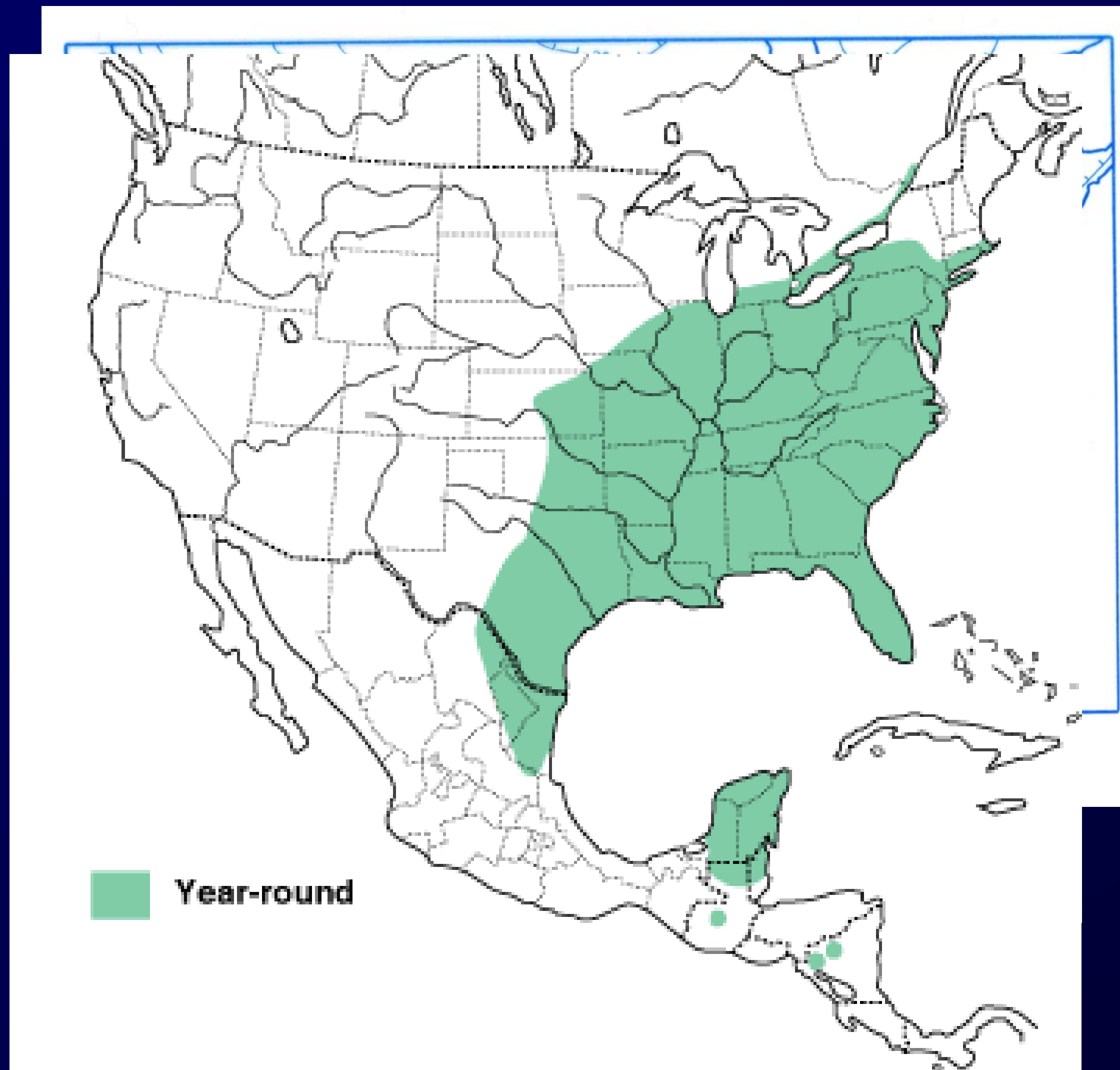

Fitness
30°
32.5°
35°
80
85
90
95
100
(a)
Relative humidity, %
Fitness
90%
85%
95%
20
25
30
35
40
(b)
Temperature, °C
Temperature, °C
40
35
30
25
Low fitness
Medium fitness
High fitness
80
85
90
95
100
(c)
Relative humidity, %

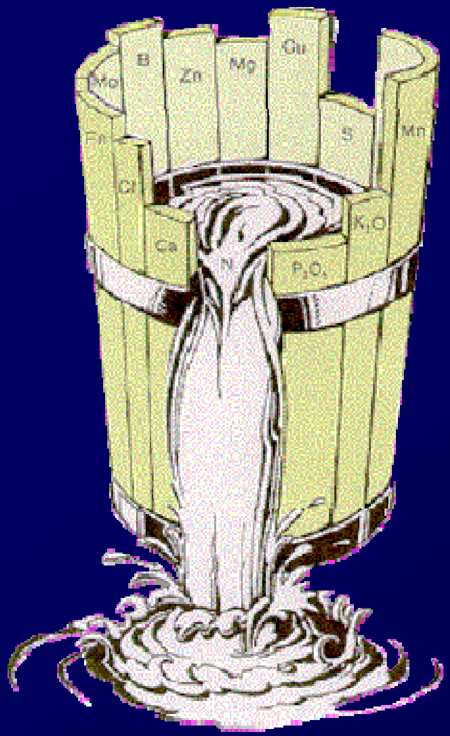
The principle of tolerance limits.



2. Environmental factors determine or limit abundance and distributions




Year-round



Liebig's Law of the Minimum 1840

The yield potential of a crop is like a barrel with staves of unequal length. The capacity of the barrel is limited by the length of the shortest stave (in this case, nitrogen), and can only be increased by lengthening that stave. When that stave is lengthened, another one becomes the limiting factor.

II. Climate

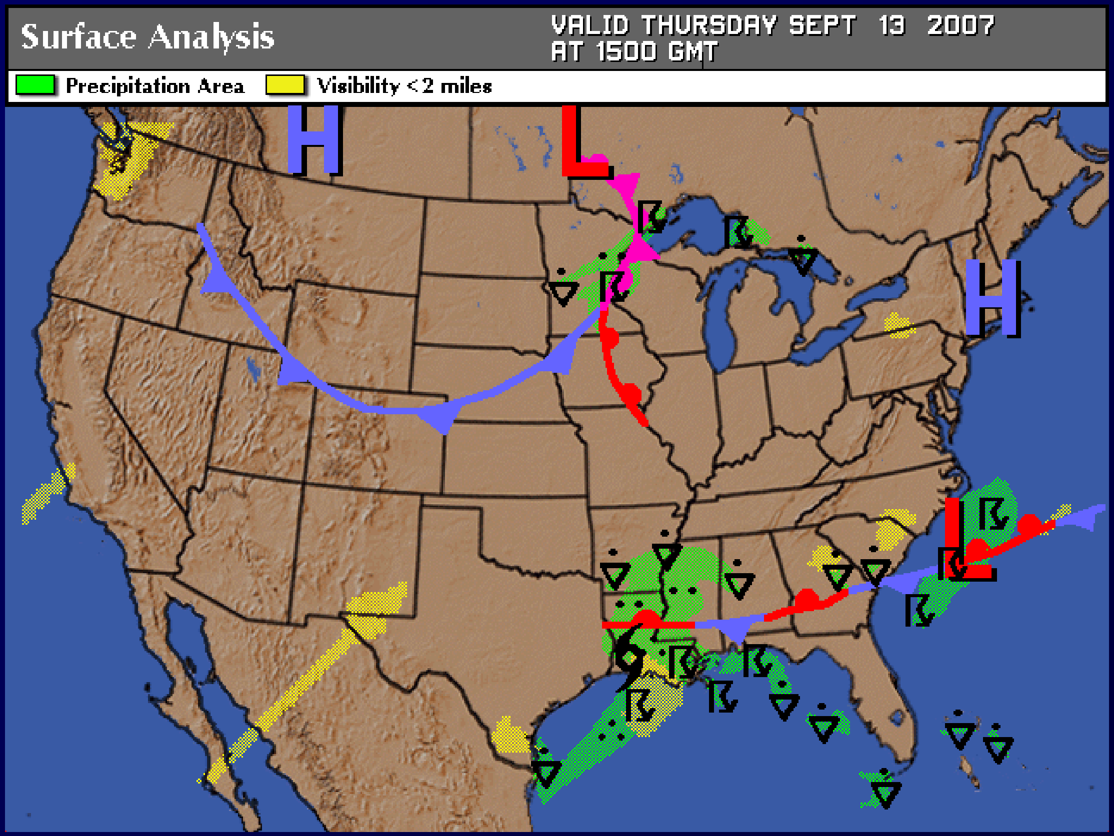
A. Macroclimate

Climatic conditions over a large area, conditions reported by weather stations

Microclimate – climatic variation on a scale of km, m, or cm

Usually over shorter periods of time

Macroclimate interacts with local landscape to produce microclimate



B. Microclimatic influences – influenced by landscape features

Quiz Time!!

1. All of the following statements concerning the hydrologic cycle are true **except**:

   A. It is powered by solar energy.
   B. Flux is determined by evaporation.
   C. Transpiration is not involved.
   D. Reservoirs include lakes, rivers oceans and ice.
   E. None of the choices are correct.

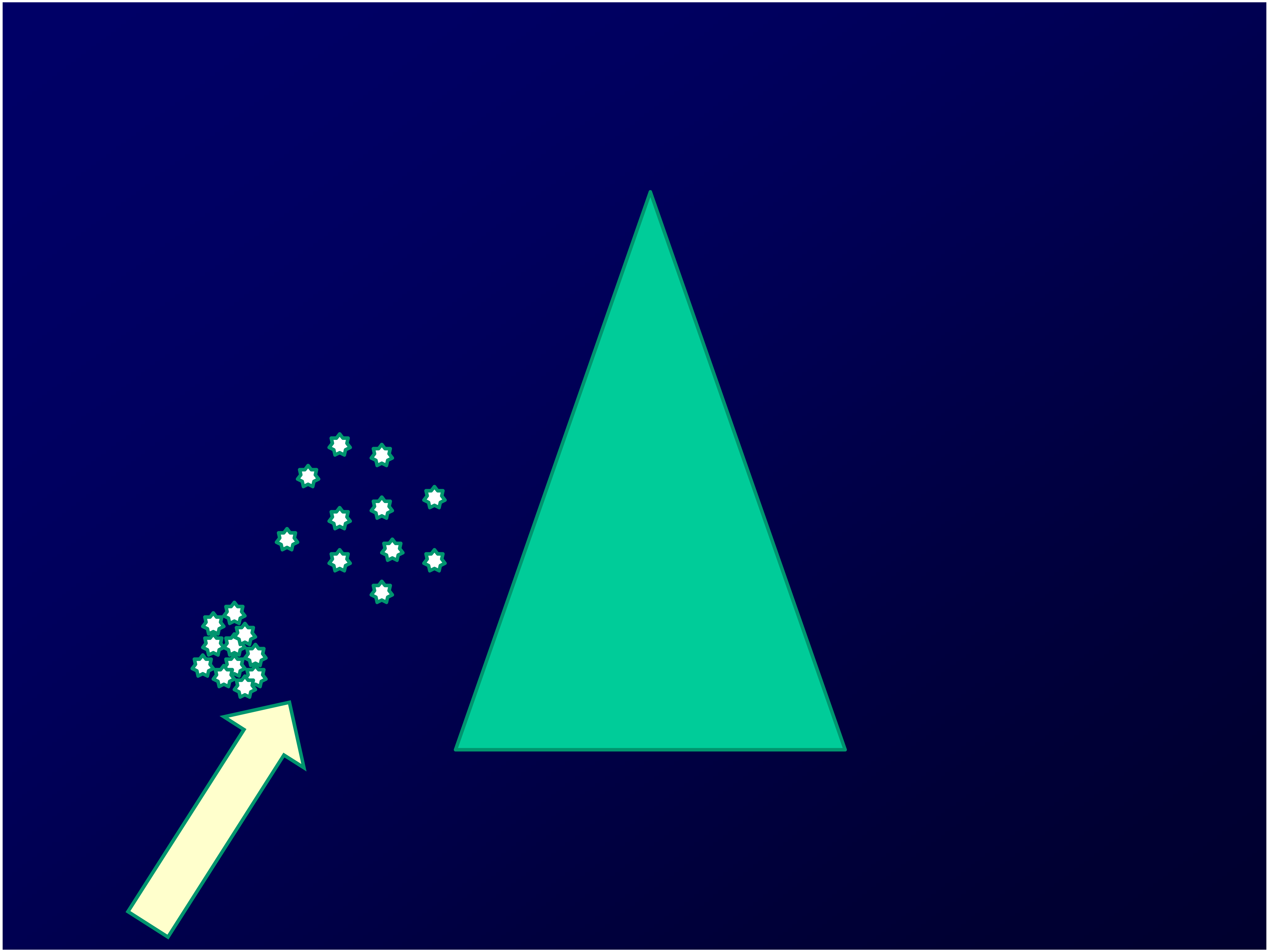
2. Bottom dwelling aquatic organisms are called _________________.

Microclimatic influences

1. Altitude – elevational cooling

Due to thermal properties of air

- Density and pressure of air decreases with increase in elevation
- Results in air expanding as it rises over Mt range



Microclimatic influences

1. Altitude

- Gas undergoes adiabatic cooling – loss of heat as molecules move further apart (10° C / km),

Also…

- Higher rate of heat loss with low density air (radiation back to sun).

2. Aspect – topographic features create microclimates

North facing slopes hold snow cover longer

3. Vegetation – Plants shade landscape, litter layer can drastically alter microclimate

Kemmerer, WY

Bare soil = 48° C

Under plant litter = 21°C

4. Color of ground – darker color absorbs solar radiation, can mean a difference of 15° in same macroclimate

5. Boulders, rocks and crevices – temperature, humidity much more benign and constant

Case Study

Effects of fire on microclimates in Tallgrass Prairie and its influence on ANPP

Primary productivity – Fixation of energy by autotrophs; rate of energy storage or increase in organic matter

Gross Primary Productivity – Total amount of energy fixed

Net Primary Productivity – The amount of energy left over after the autotroph has met own needs. (GPP – Respiration)

Fire effects on tallgrass prairie

North American Grasslands


Annually Burned


Long-term Unburned

Steers have 38% greater mass gain in May when grazed on burned rather than on unburned prairie.

- Litter layer accumulates in absence of fire

- Litter layer intercepts and reflects solar radiation
- 59% reduction in light available for shoots (1st 30 days)

• Soils 2 – 10° warmer on burned areas throughout growing season.

• Growth begins weeks earlier on burned sites.

• Leaves growing through litter layer 5-7° C warmer than on burned sites.

All factors responsible for increased ANPP on burned than unburned prairie in a normal year.

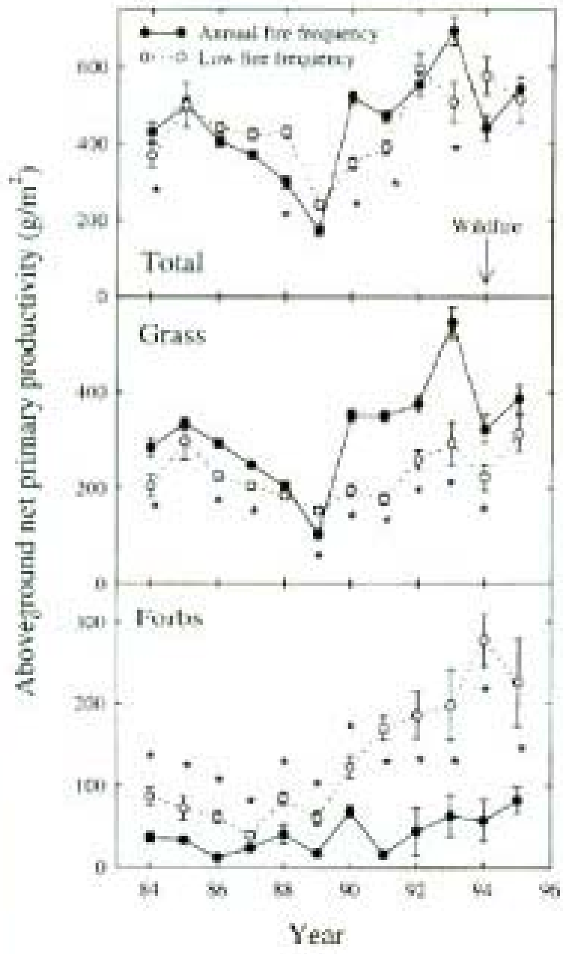


Figure 12.5. Twelve-year record of ANPP in adjacent sites exposed to an annual fire regime or a low fire frequency on Konza Prairie. Vertical bars indicate ± 1 SE of the mean, and means in years with * are significantly different at $P < 0.05$.

What happens during a drought?

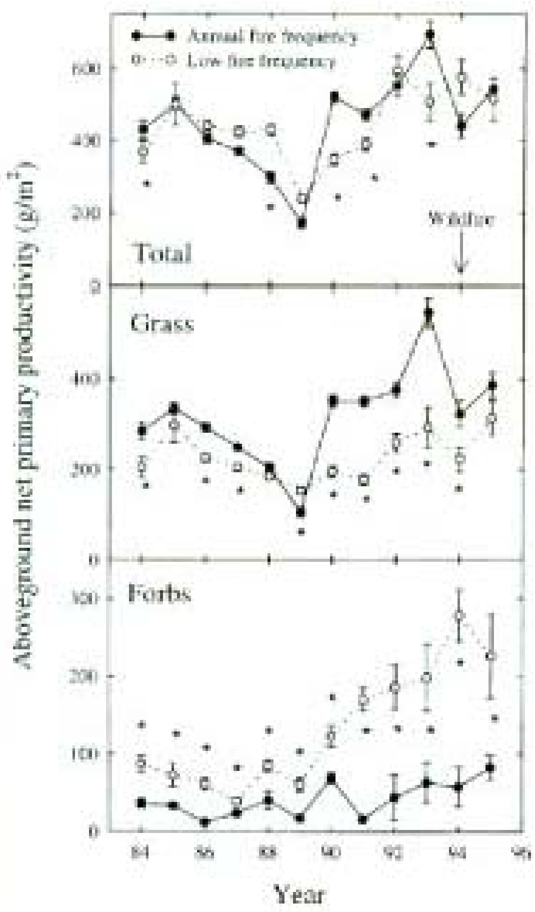


Figure 12.5. Twelve-year record of ANPP in adjacent sites exposed to an annual fire regime or a low fire frequency on Konza Prairie. Vertical bars indicate ± 1 SE of the mean, and means in years with * are significantly different at $P < 0.05$.

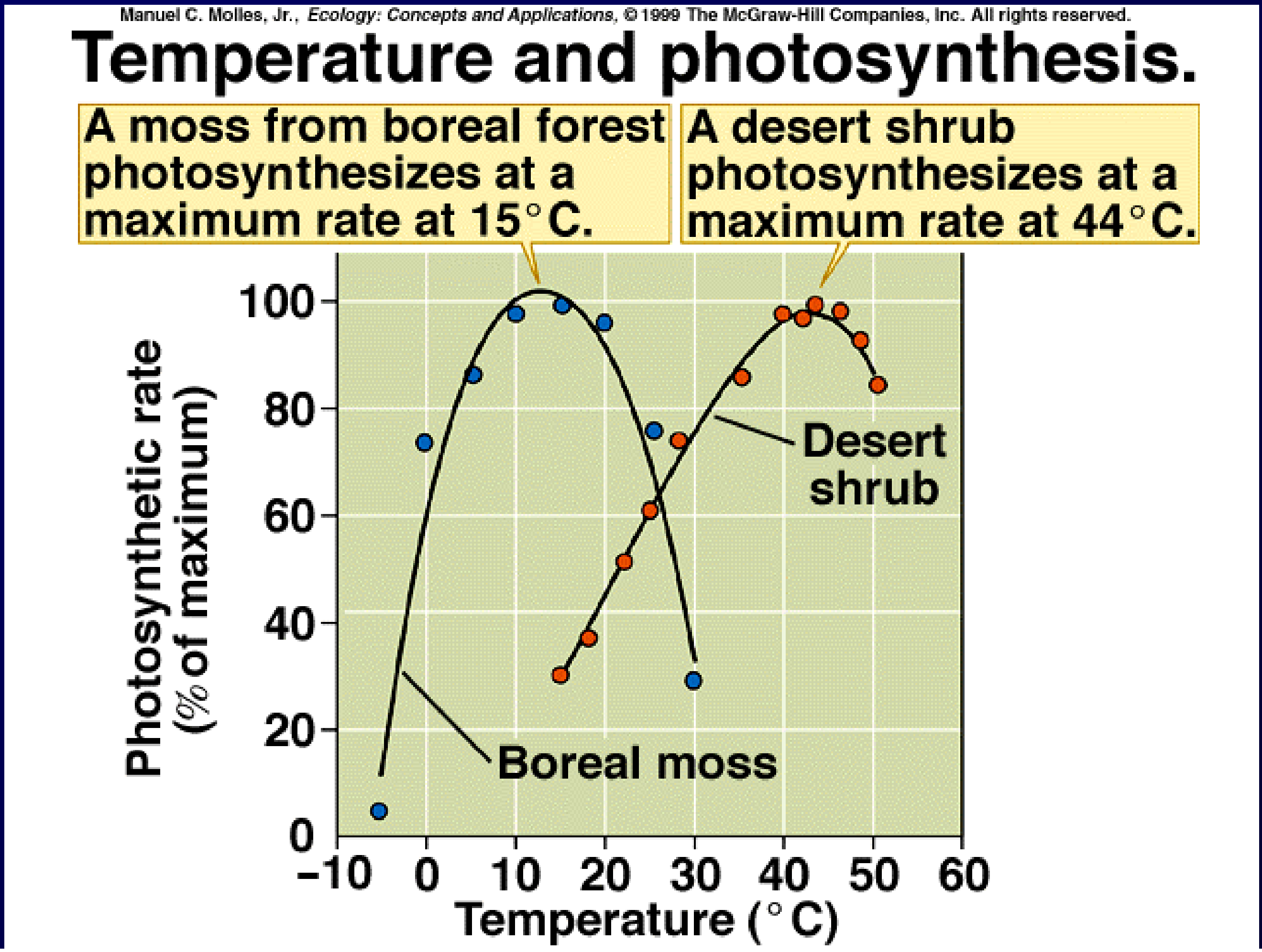
Why?

During a drought burned sites lose soil moisture faster than unburned sites.

III. Plant Physiological Ecology

A. Temperature

1. Extreme Temperatures generally reduce the rate of PSN

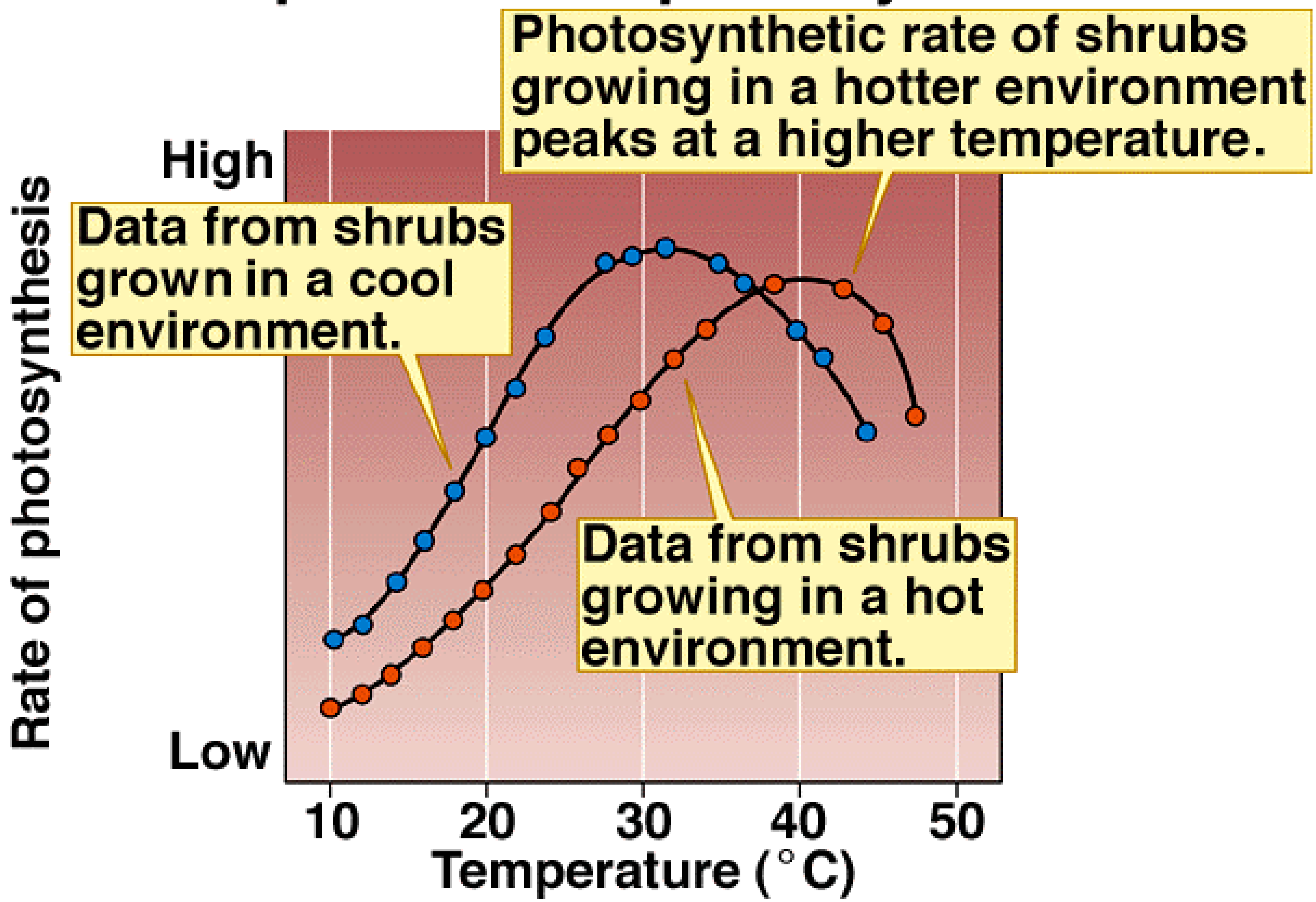


Pearcy 1977 Plant Physiology 59:795-799

took cuttings from desert shrubs (*Atriplex lentiformis*)

- grew under different environmental regimes

Growing temperatures and optimal temperature for photosynthesis.

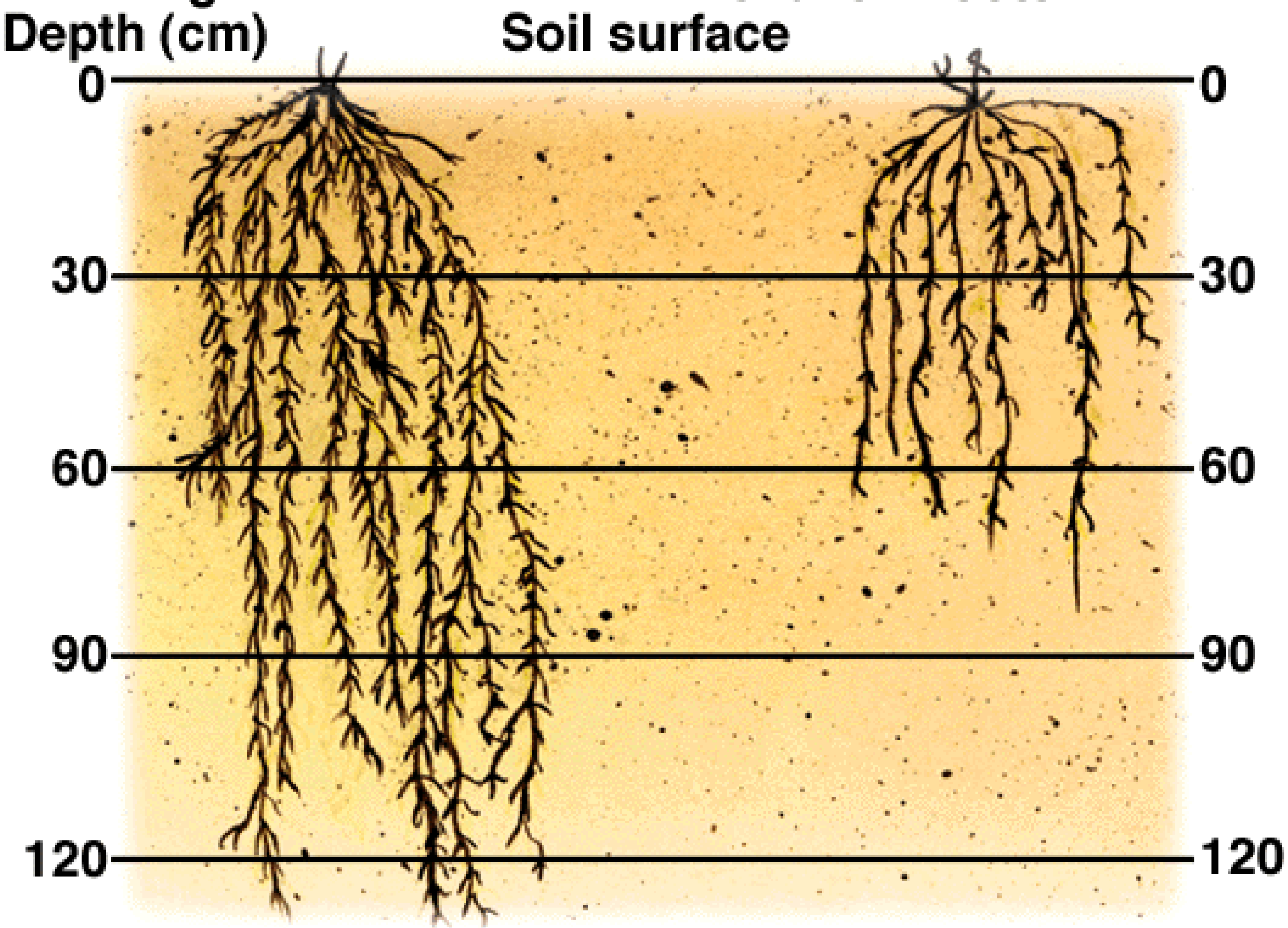


Plants are capable of acclimation!

Soil moisture and root development by a grassland forb.

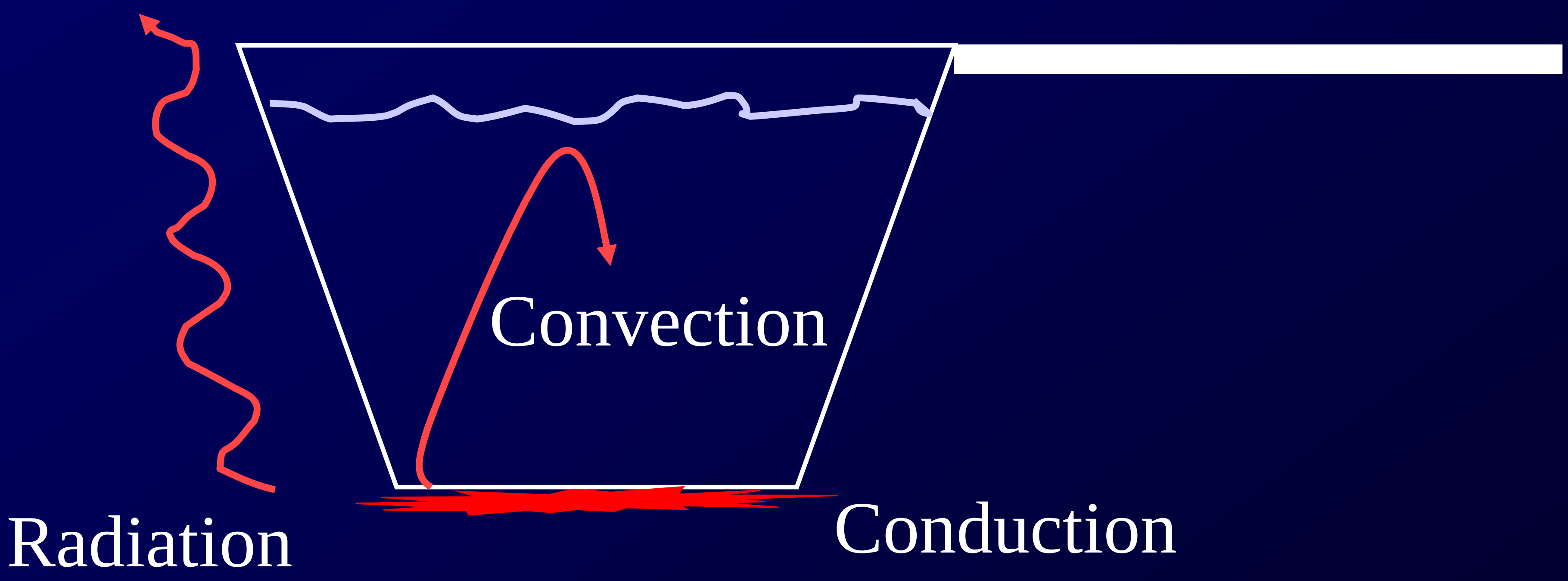
On dry sites, the forb grows a dense network of deeply penetrating roots.

On moist sites, the forb grows a sparse network of shallow roots.



2. Regulation

3 methods of heat transfer



Organisms regulate body temp by adjusting heat gains and losses

$$Hs = Hm \pm Hcd \pm Hcv \pm Hr - He$$

$$Hs = Hm \pm Hcd \pm Hcv \pm Hr - He$$

Hs = heat stored in body

Hm = heat gained from metabolism

Hcd = heat gained or lost through conduction

Hcv = heat gained or lost through convection

Hr = heat gained or lost through radiation

He = heat lost through evaporation

a. Desert plants – avoid overheating and reduce Hs

3 main options

1. Decrease Hcd – foliage placed far above the ground.

2. Increase rates of convective cooling

e.g. small leaves, open growth forms

Palo Verde

3. Reduce rates of radiant heating

reflective surfaces, pubescence, leaf orientation

Comparative Approach

Are these truly adaptations?

Species of *Encelia* distributed along moisture gradient

coastal California ⟶ death valley

Encelia californica

Encelia farinosa

Encelia californica

- coastal California species
- lacks pubescence
- reflects ~ 15% visible light
- produces 1 set of leaves

- Death Valley species
- produces 2 sets of leaves
- summer leaves highly pubescent (reflect 40% of light)
- cool season less pubescent

Encelia farinosa

Why does *Encelia farinosa* have 2 sets of leaves?

by reflecting more light there is less available for PSN.

b. Arctic and Alpine Plants –

Need to maintain high T_{leaf}

3 main options

1. Increase Hr – dark pigments to absorb light, increase radiant heat gain through position

2. Decrease rate of Hcv – convective cooling

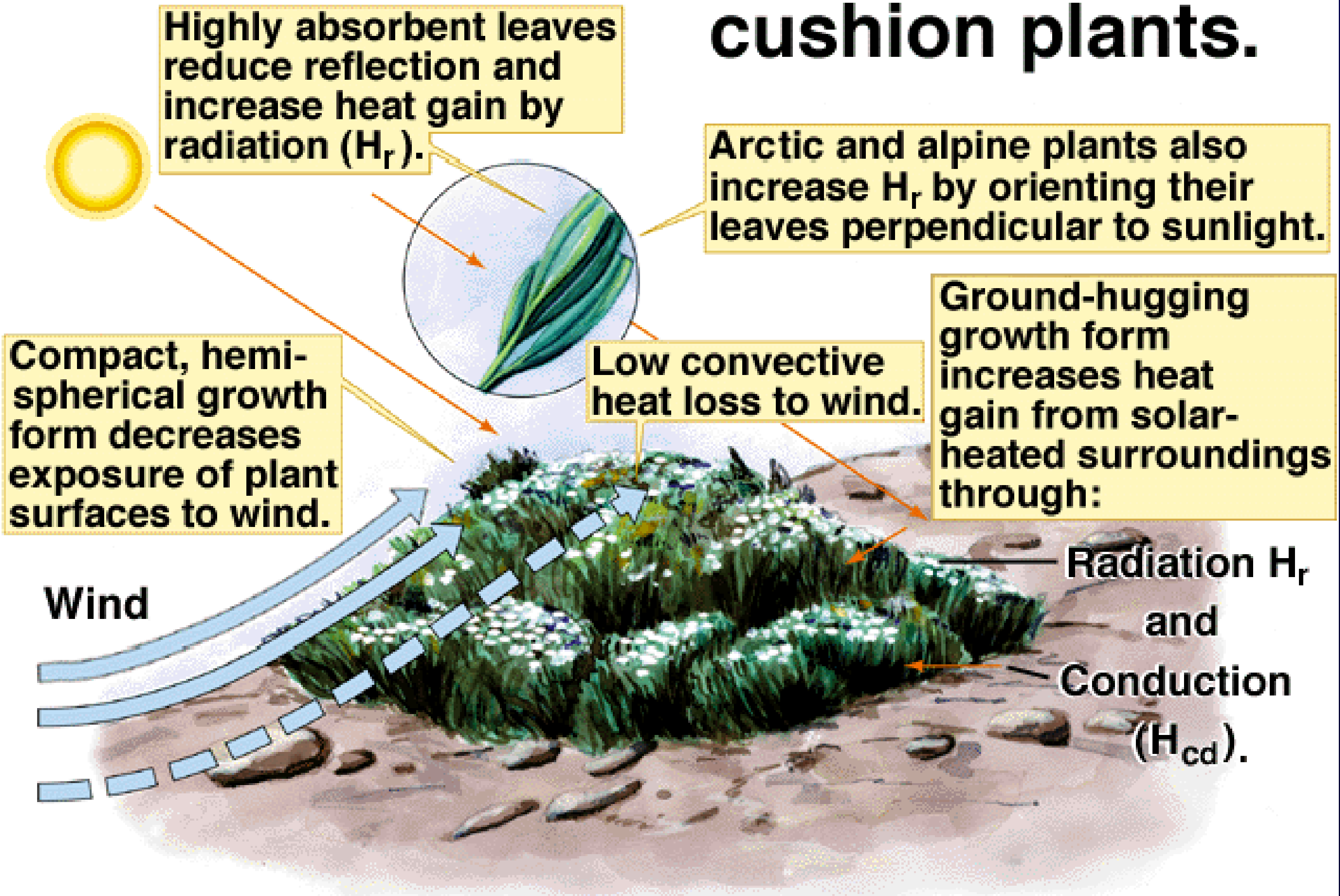
What adaptation would promote this strategy?

Assume cushion growth form (hugs ground, reduces area exposed to wind)

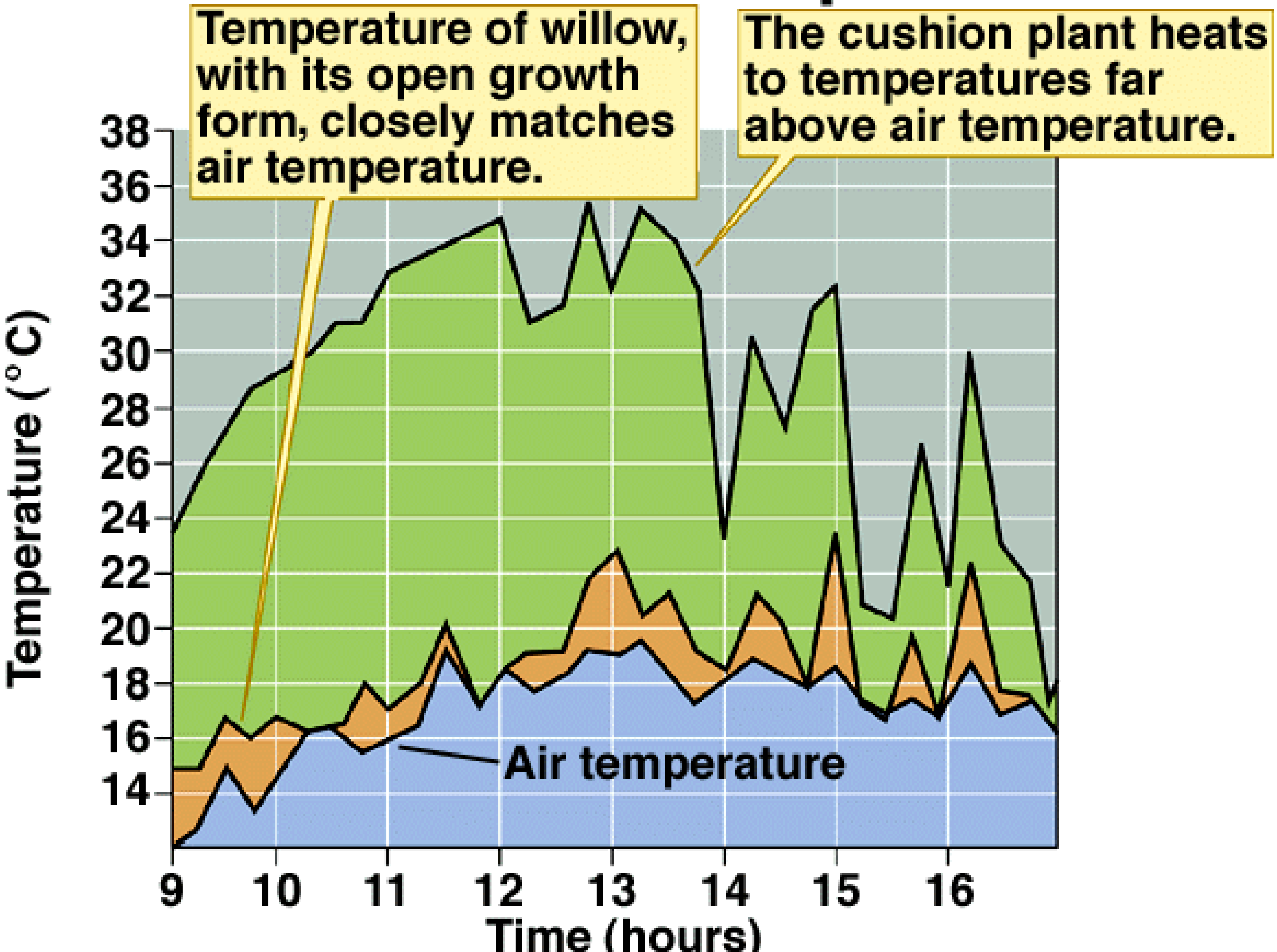
3. Increase heat gained through conduction (ground warms to temps above air)

Cushion growth form

Heat exchange by arctic and alpine cushion plants.



Growth form and temperature.

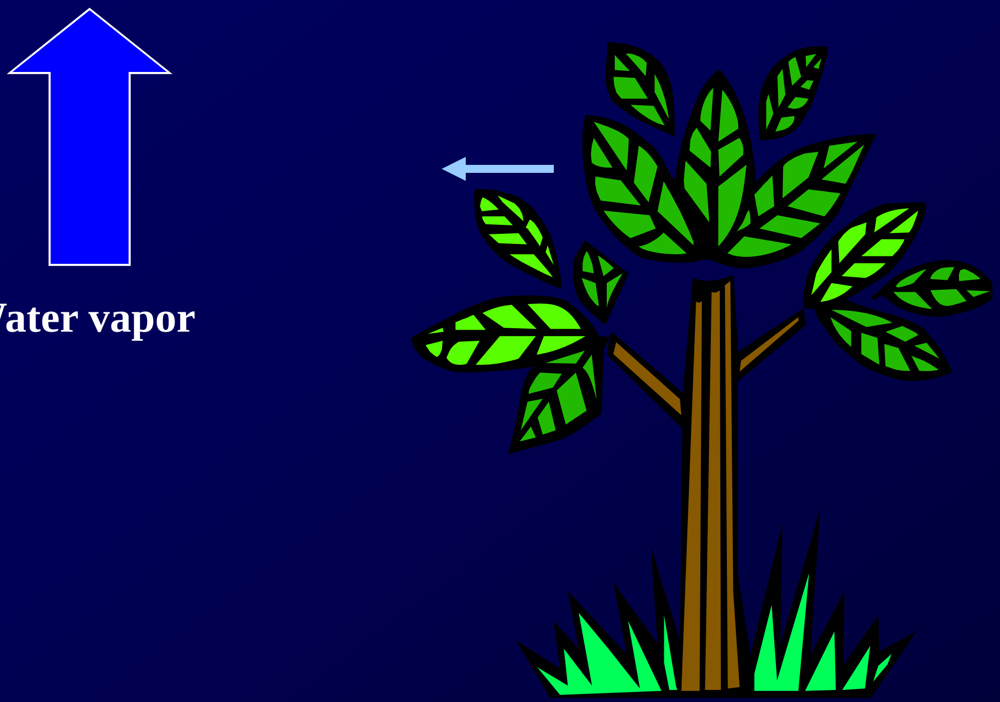


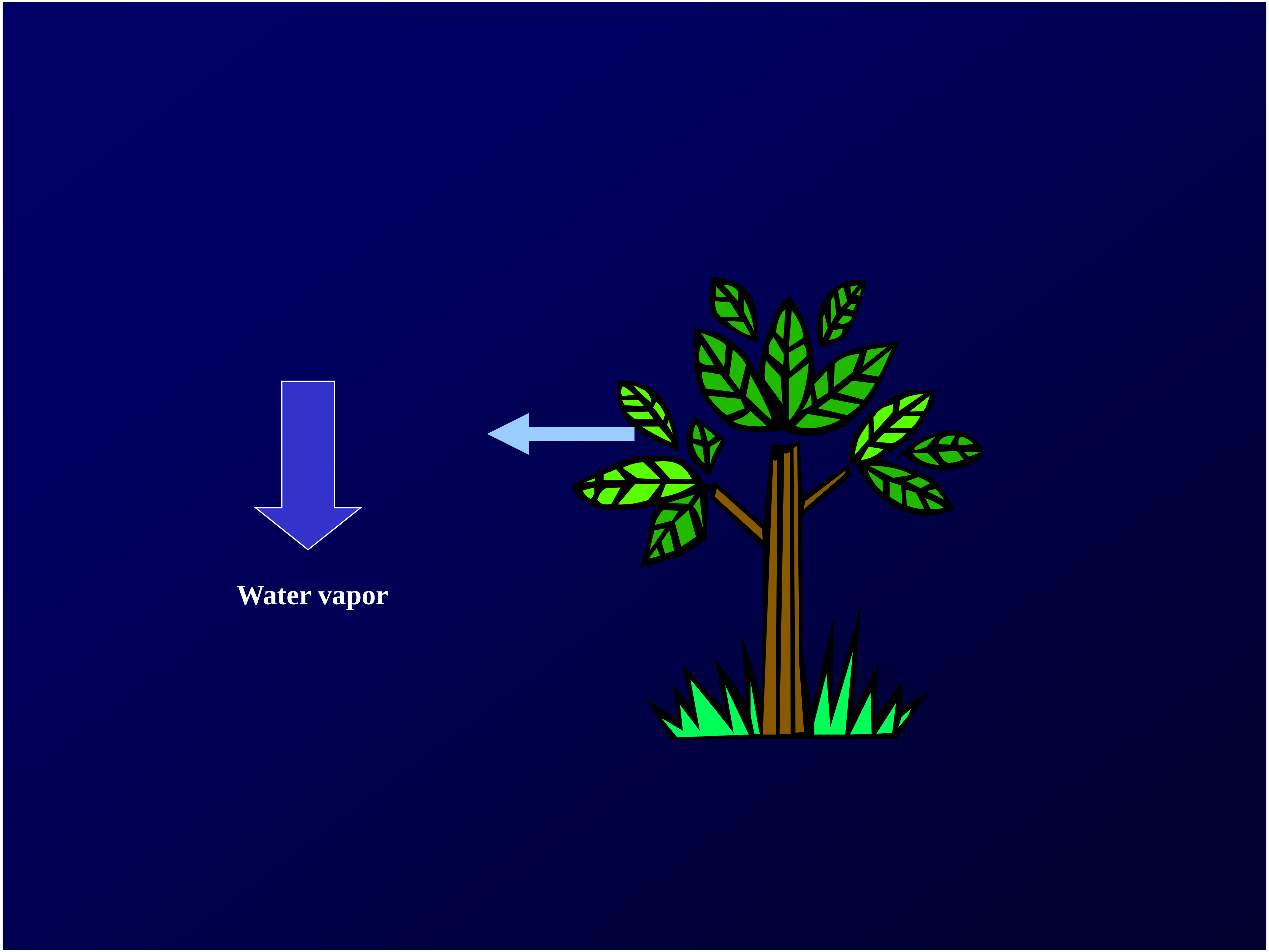
B. Water movements

Water moves along concentration gradient – huge consequence for availability to organisms

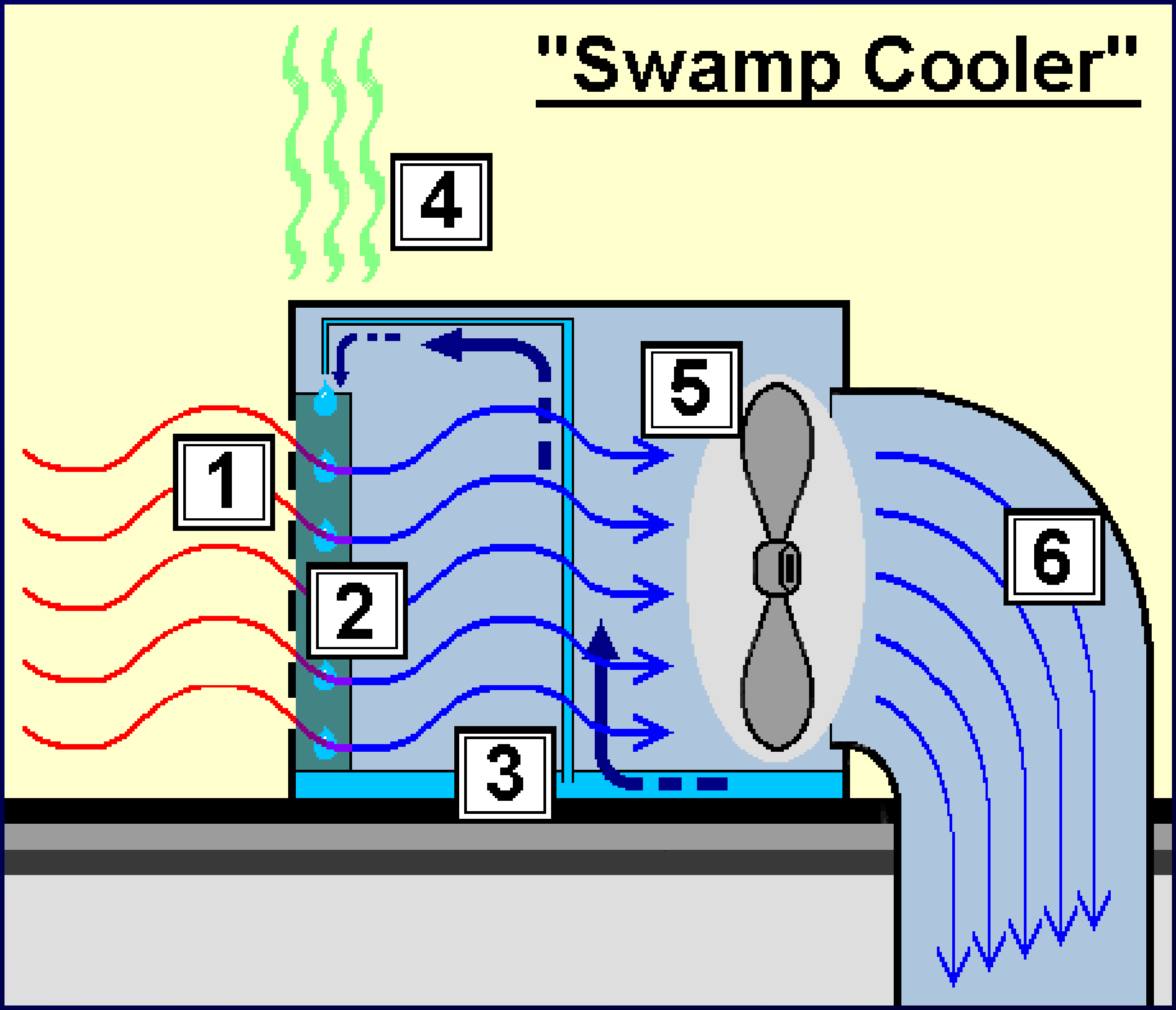
1. Measurement – potential for evaporative water loss dependent on temp and water content of surrounding air.

As water vapor in surrounding air increases, water concentration gradient is reduced and rate at which organism loses water decreases.




Water vapor

Steep gradient produces high rate of evaporation



Amount of water air can hold is a function of Temp.

Air Temp (°C)	Saturation Water Vapor Density
30	30 g/m^3
20	17 g/m^3
10	9 g/m^3

Warm air can hold more water – thus humidity is dependent on T_{air} and is expressed as Relative Humidity

RH = (water vapor density/saturation water vapor density) x 100

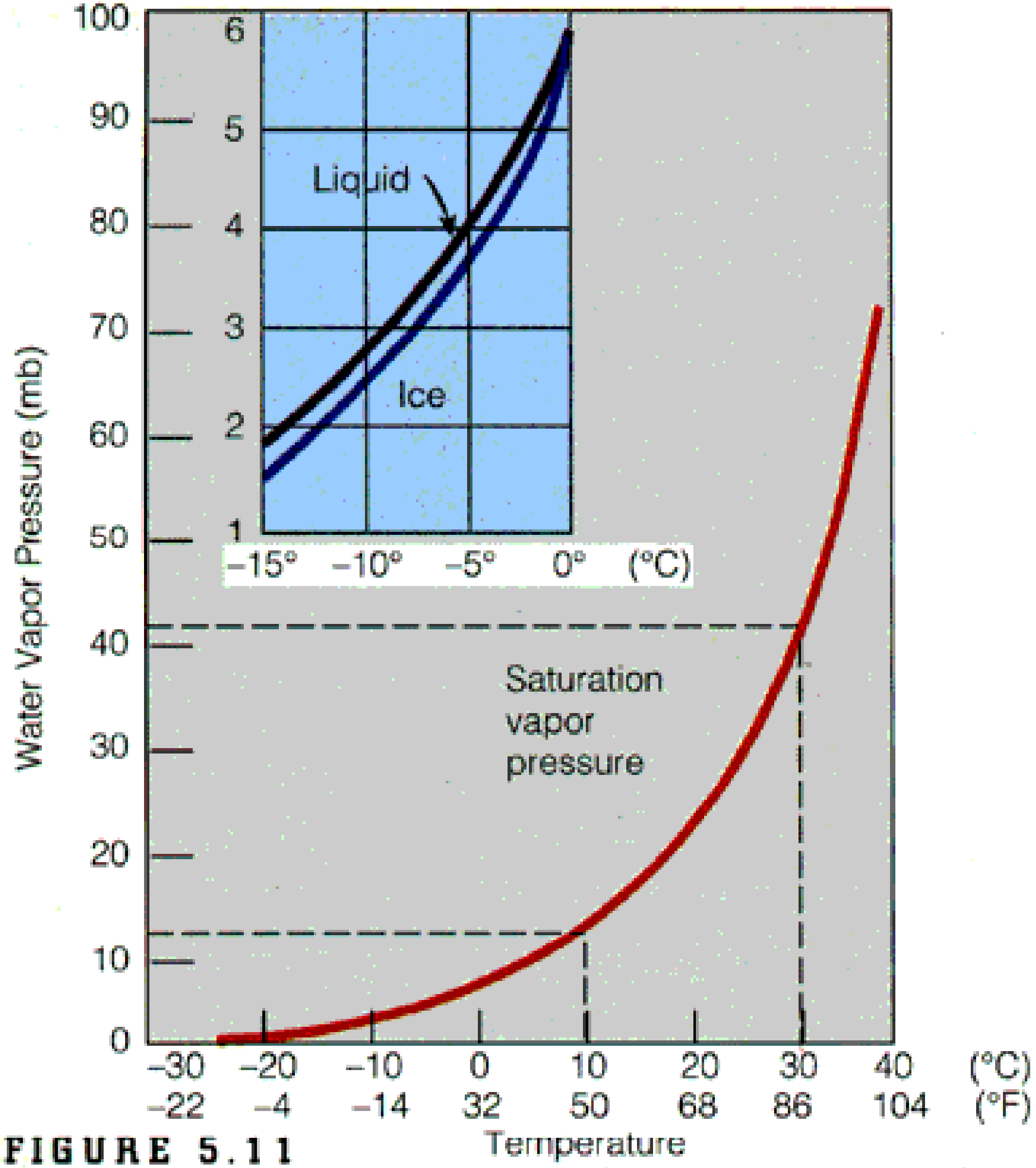
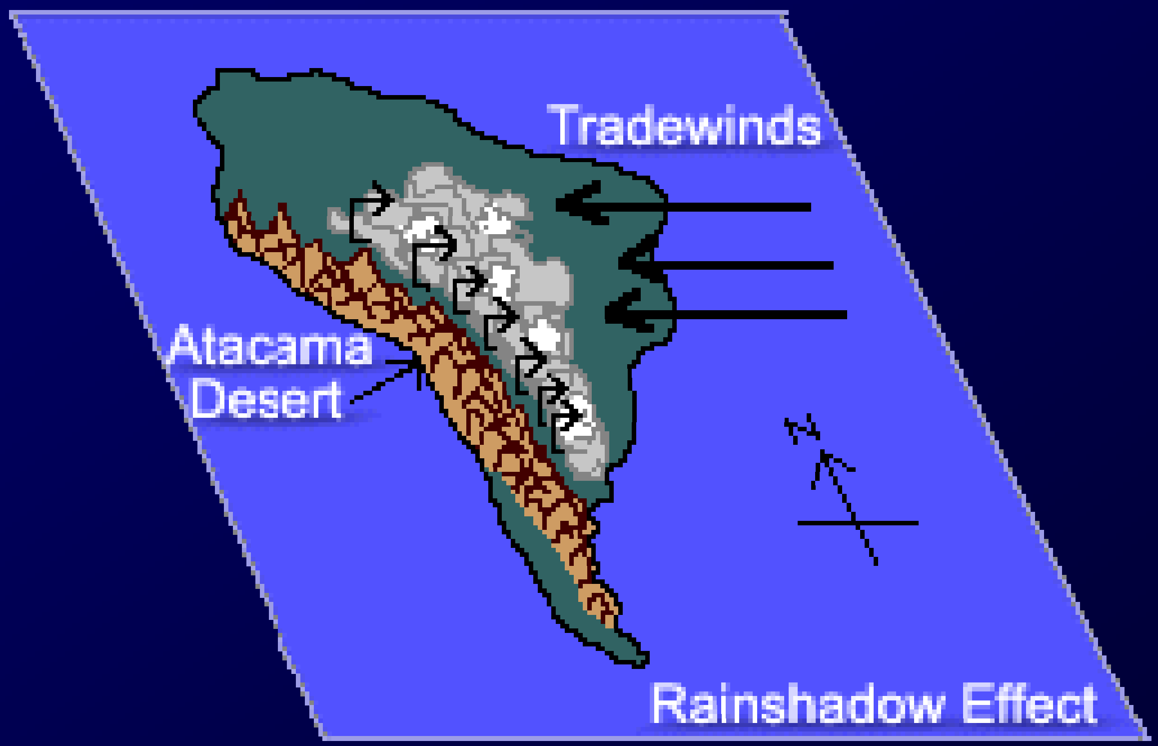


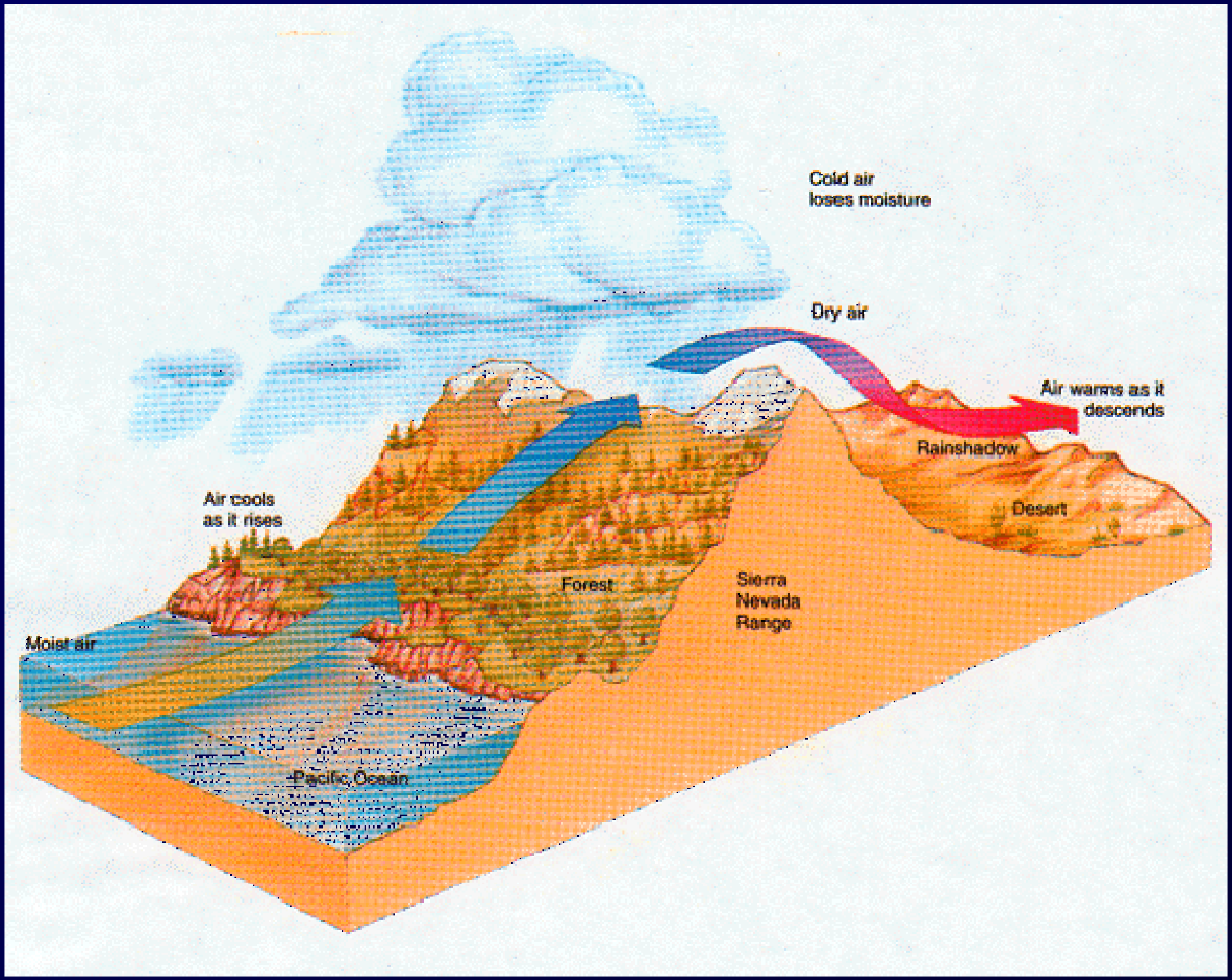
FIGURE 5.11

Saturation vapor pressure increases with rising temperature. Observe that, at below freezing temperatures, the saturation vapor pressure is greater over water than over ice.

Consequence of this – Rainshadow effect

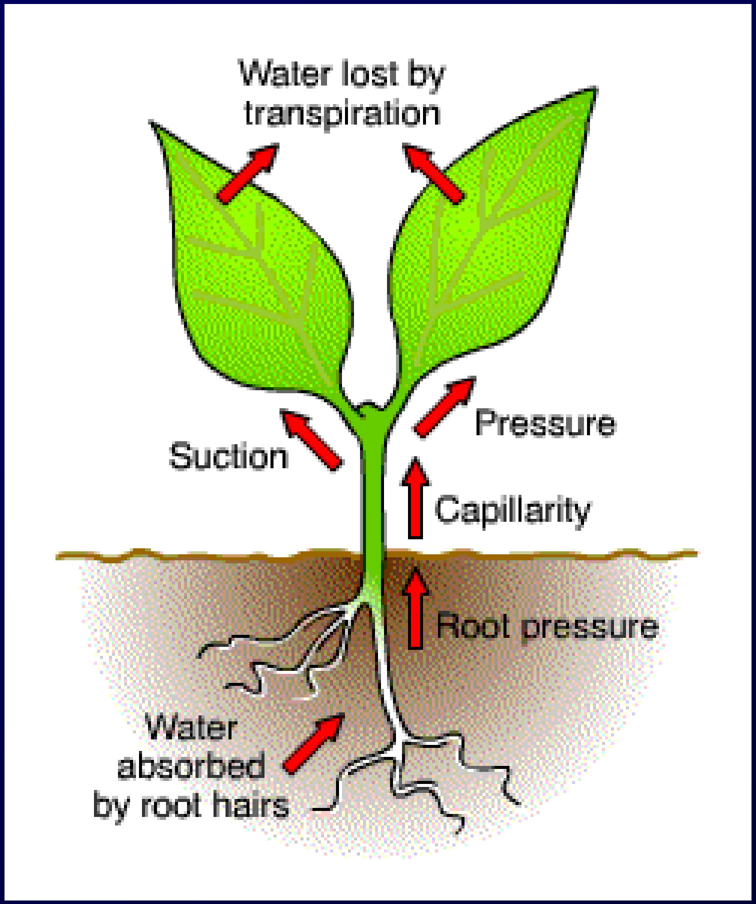


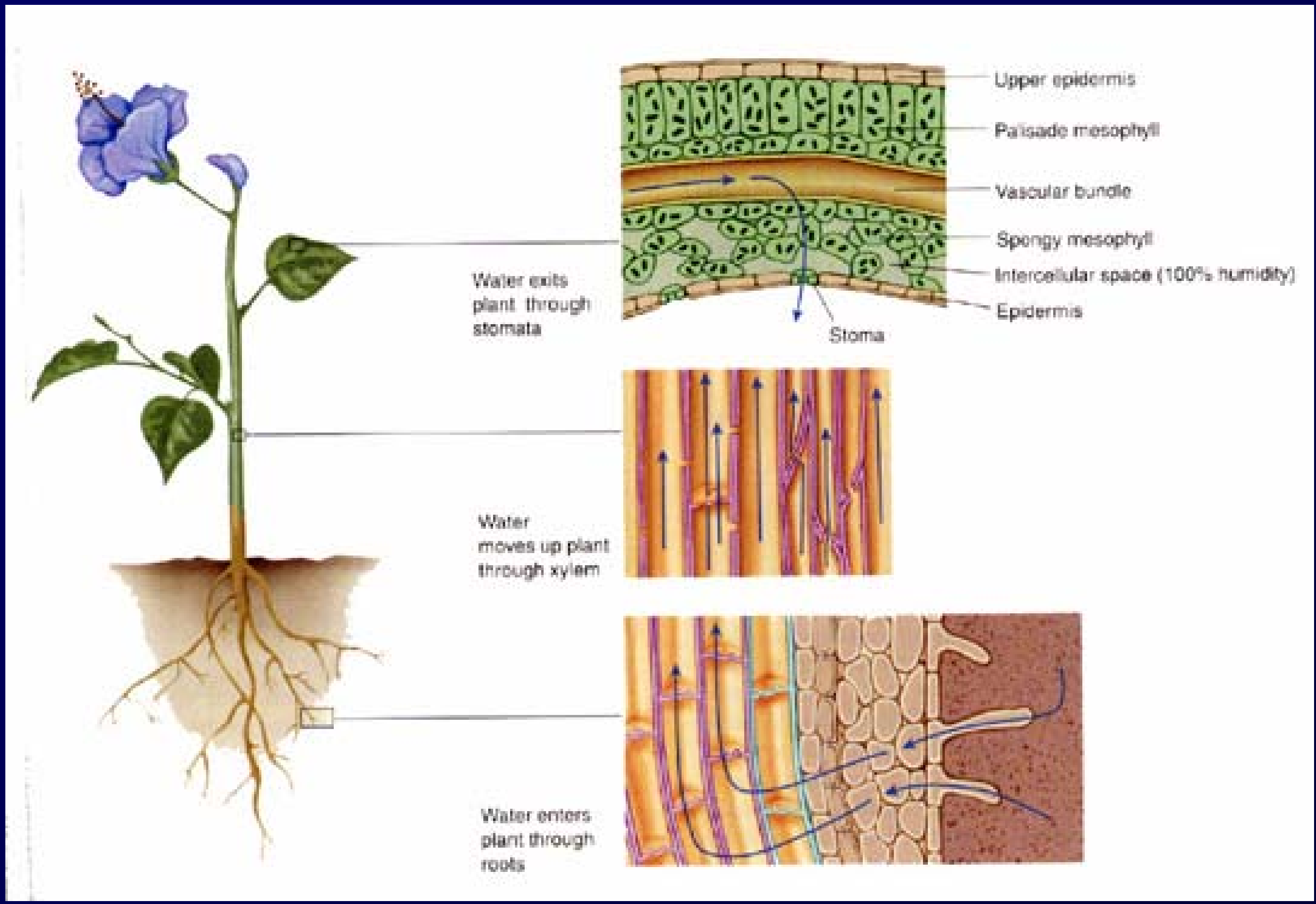
Adiabatic cooling results in T_{air} falling and thus losing moisture



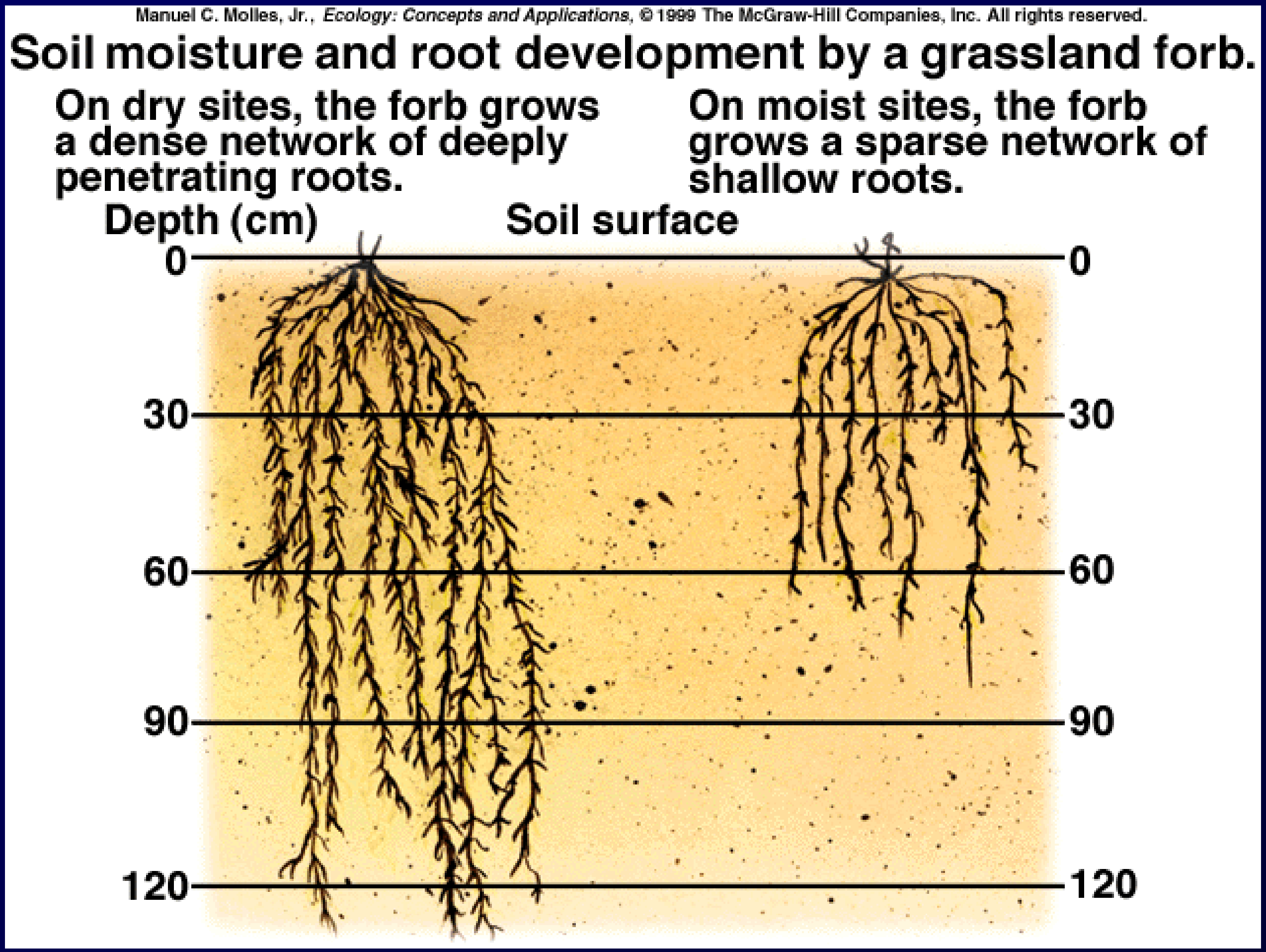
2. Transpiration and Water Acquisition

Transpiration – movement of water in plants from source (soil) to sink (air)




Upper epidermis
Palisade mesophyll
Vascular bundle
Spongy mesophyll
Intercellular space (100% humidity)
Epidermis
Stoma
Water exits plant through stomata
Water moves up plant through xylem
Water enters plant through roots

Extent of root development reflects differences in water availability

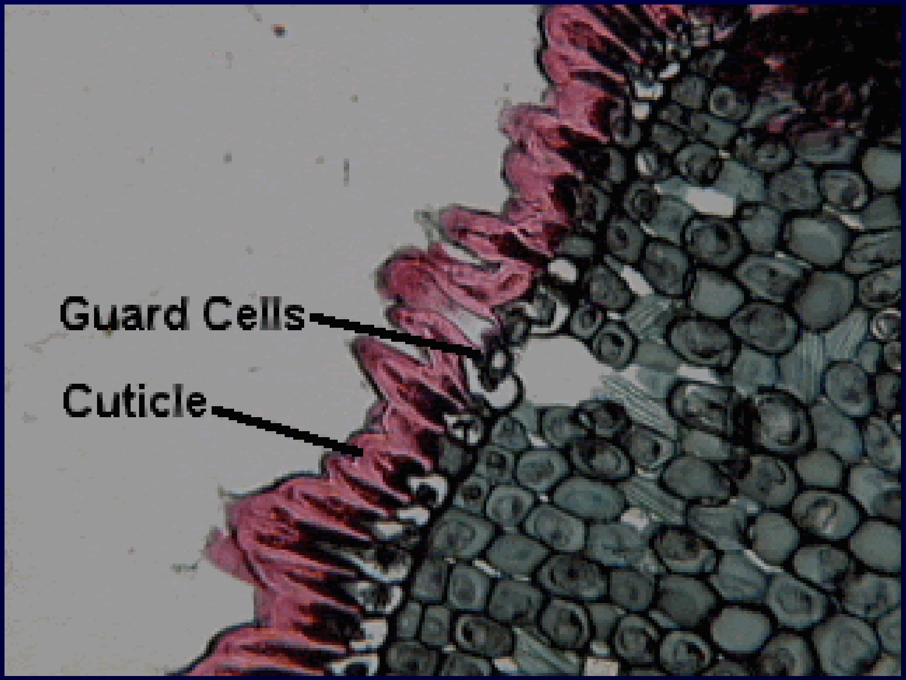


Some plants in dry climates – roots make up 90% of total plant biomass.

3. Water conservation

Plants in dry climates evolved adaptations to reduce water loss.

- water proofing leaves to reduce evaporative water loss.



- drop leaves in response to drought

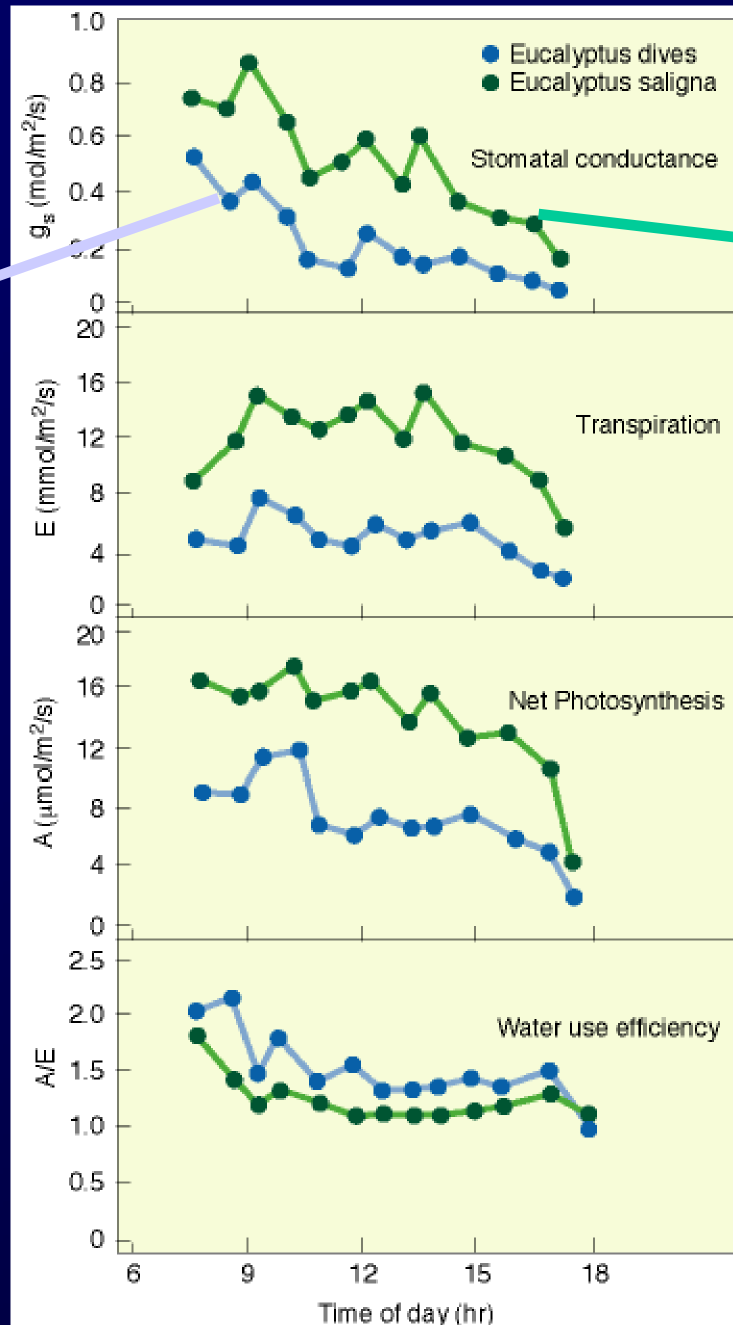
- thicker leaves – less transpiring surface

-reduction in number of stomates

E. saligna – coastal region, rainfall = 1500mm/yr

E. dives – interior regions, rainfall = 500mm/yr

Interior



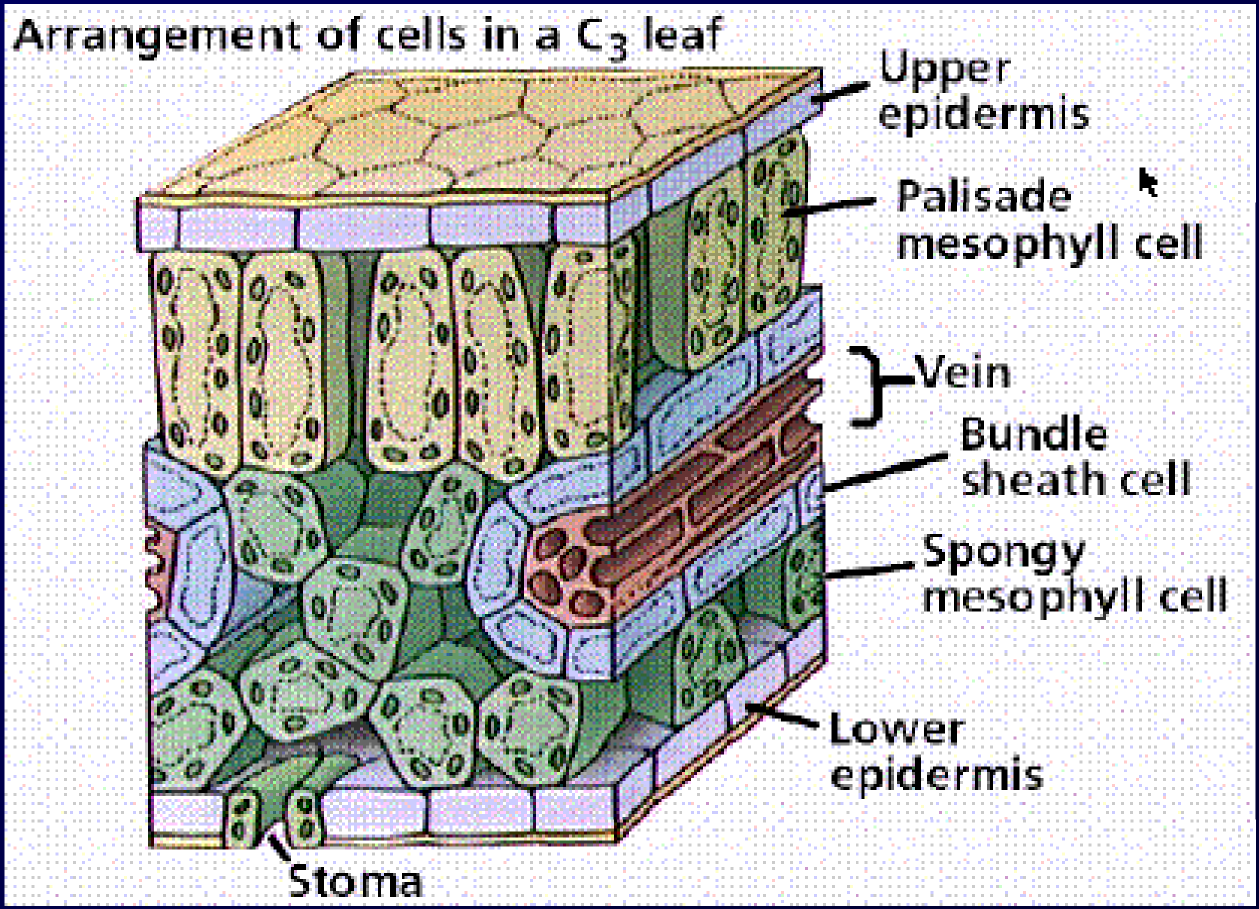
Coastal

-dormancy

Plants can go dormant during dry periods

- alternate PSN pathways

C_3, C_4, CAM

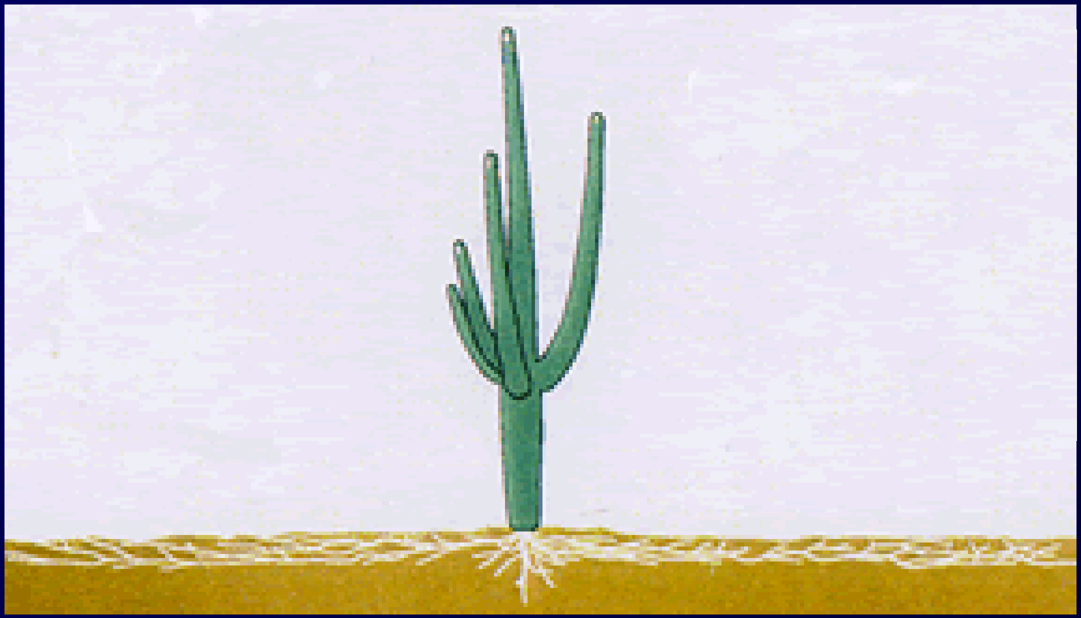


Example of xeric adapted species – Saguaro Cactus

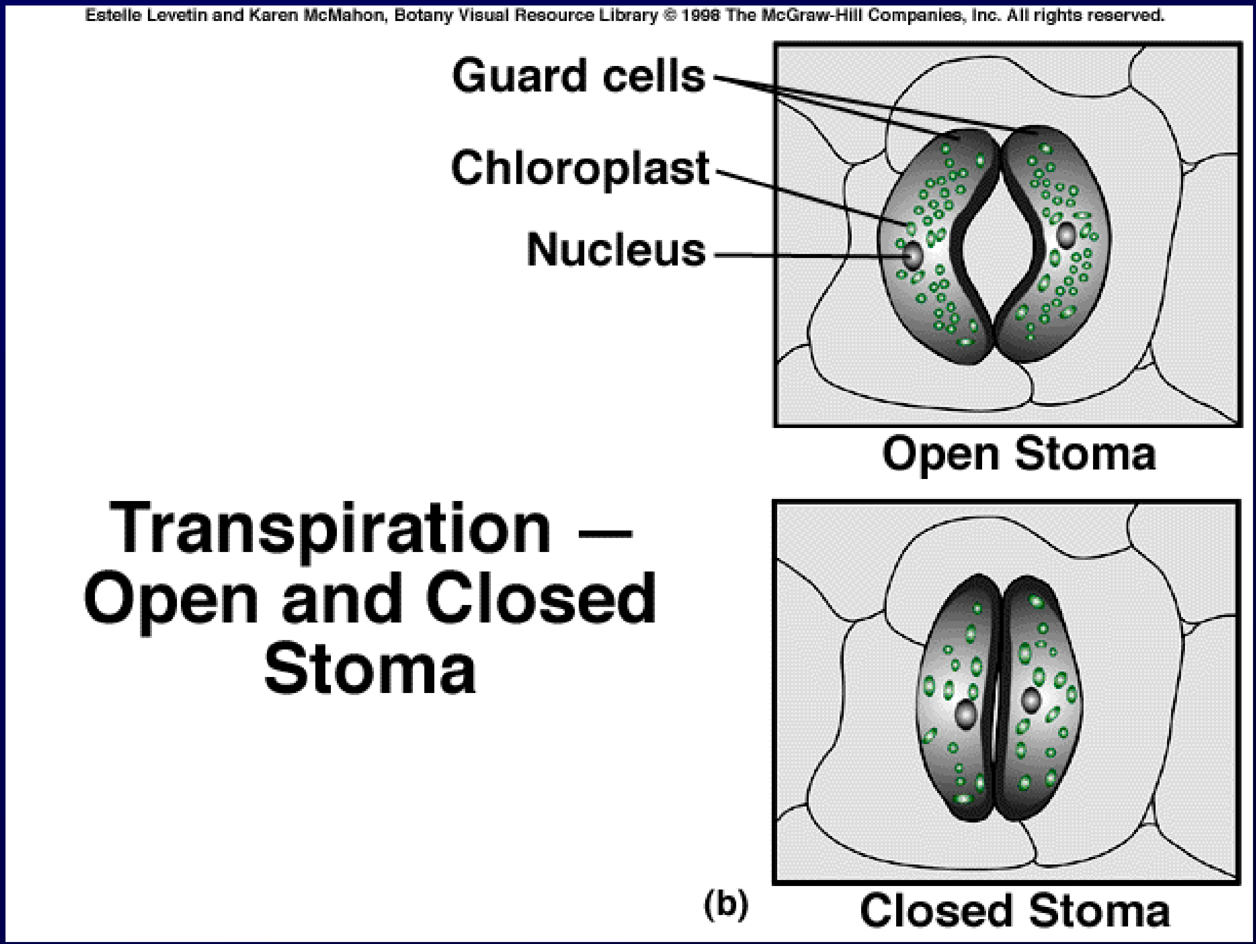
Trunk and arms act as water storage devices

Up to 1500 gal. of water!

Dense network of shallow roots, 15m tall cactus has root coverage over 700m^2 of soil (absorb water quickly – 200gal from single rainfall)



Keeps stomates closed during the day, high internal temps (able to withstand 50°C).



Angle of arms reduces radiant heating.

Top of arms covered with very thick skin.

C. Water and CO_2

Generalized formula for PSN

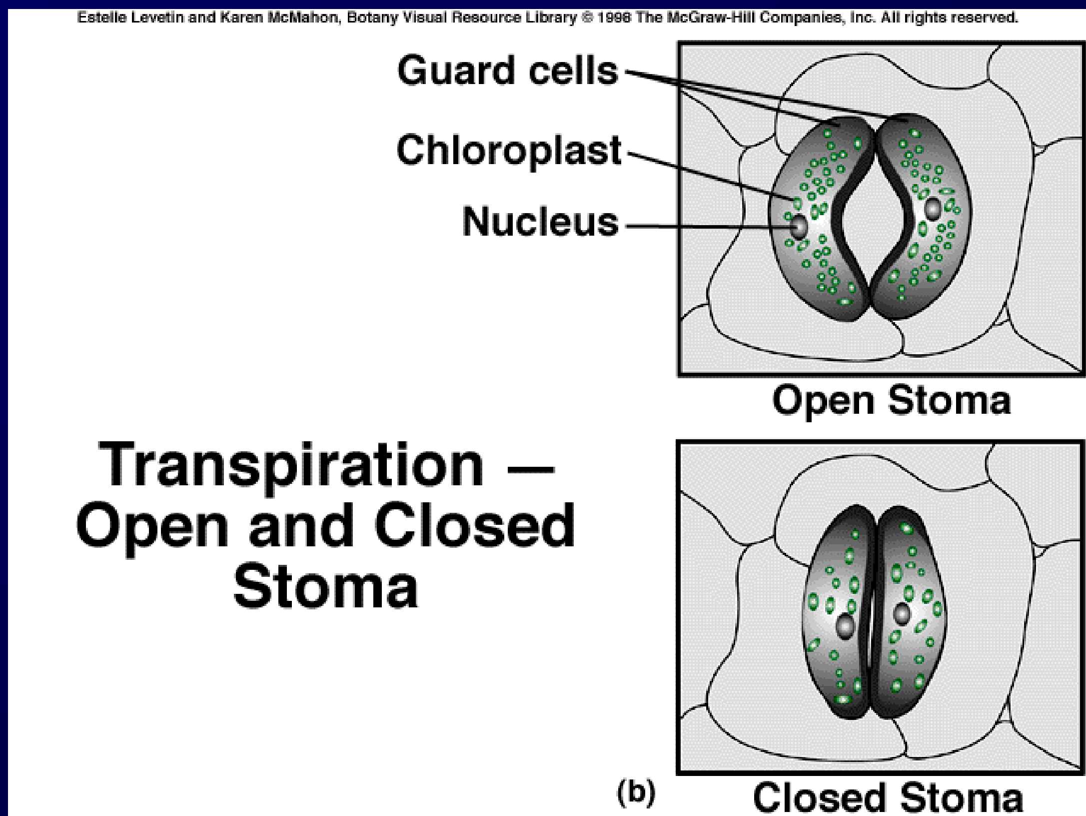
$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2 + H_2O$

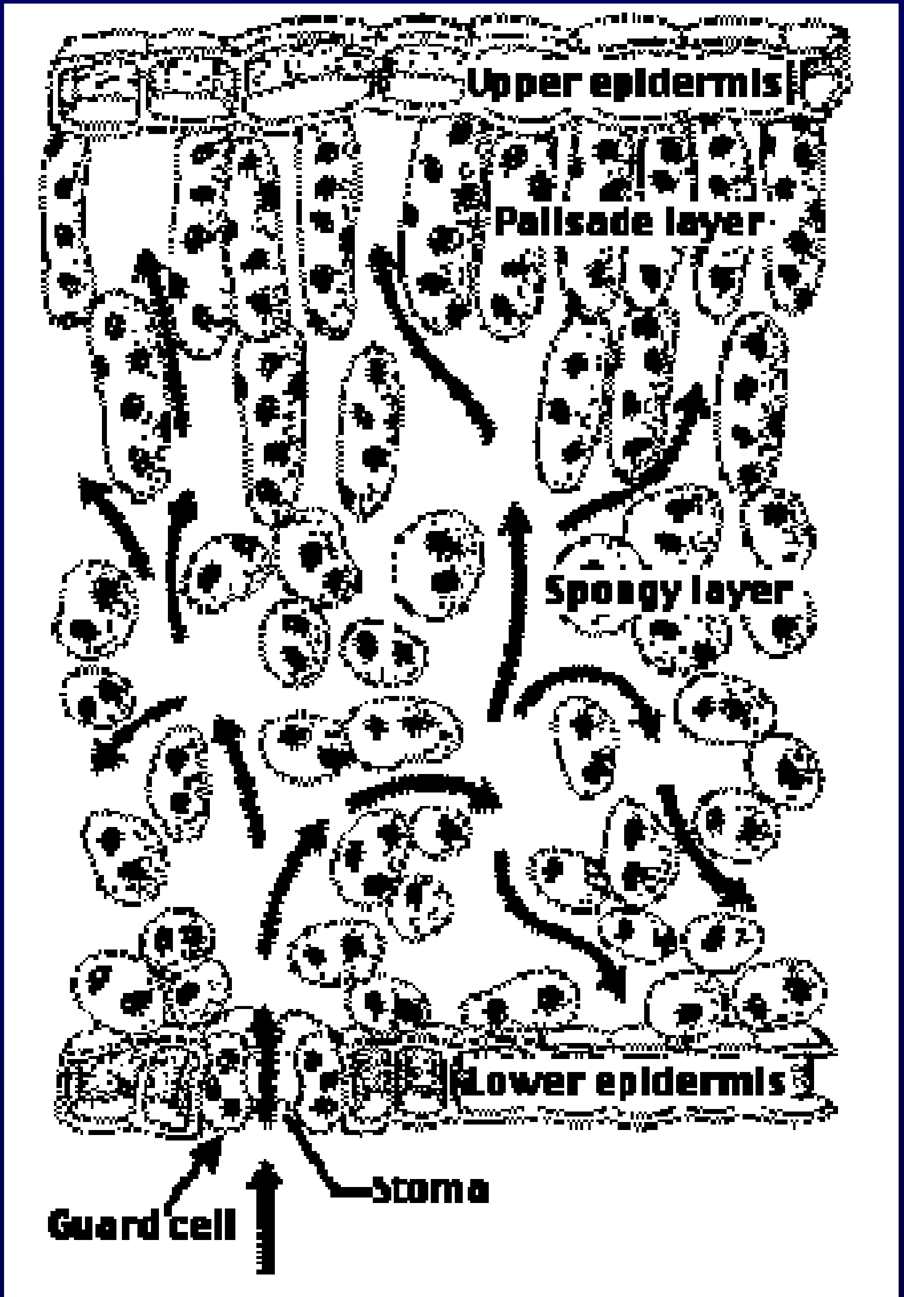
Generalized formula for Respiration

$C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO_2 + H_2O$

For plants CO_2 and H_2O are essential for life.

Stomata regulate flows.

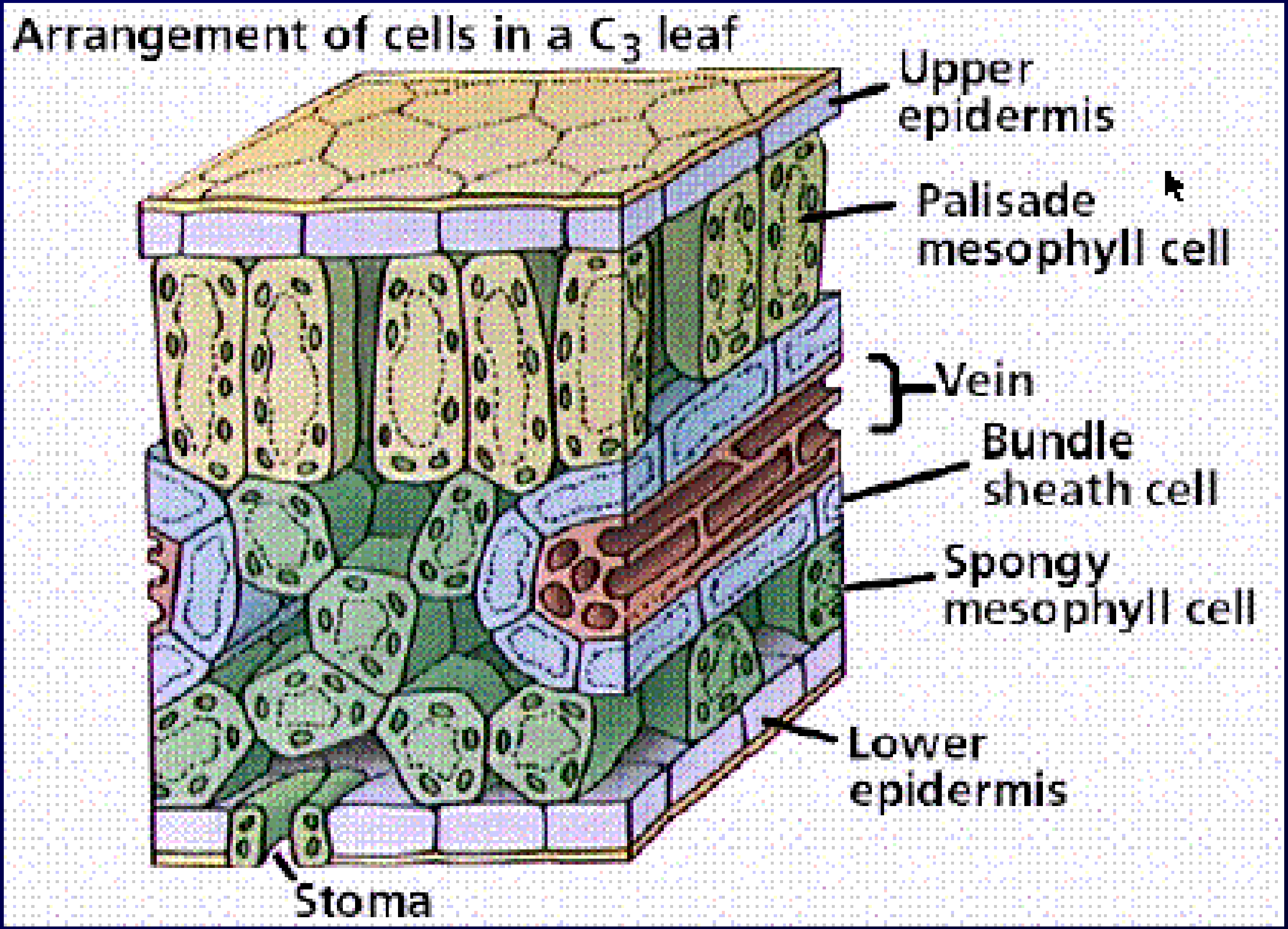



Upper epidermis
Palisade layer
Spongy layer
Lower epidermis
Stoma
Guard cell

When hot and dry, plants face trade-off --

keep stomata open to obtain CO_2 or close them to reduce H_2O loss.

PSN occurs within mesophyll cells



Step 1

Carbon fixation. An enzyme called rubisco combines three molecules of CO_2 with three molecules of a five-carbon sugar called ribulose bisphosphate (abbreviated RuBP). Six molecules of the three-carbon organic acid 3–phosphoglyceric acid (3-PGA) result.

Step 2

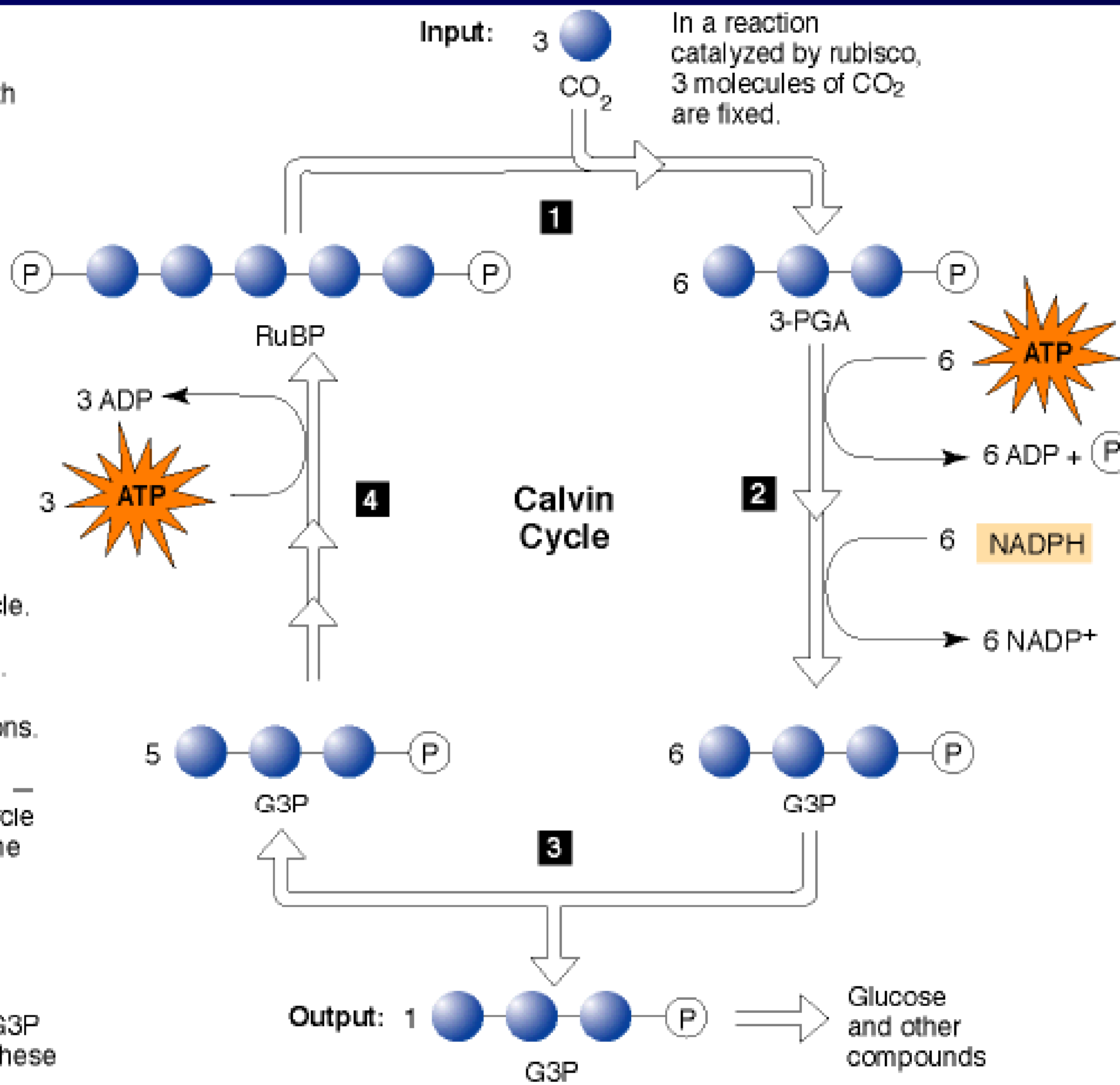
Energy consumption and redox.
Two chemical reactions (indicated by the two arrows) consume energy from six molecules of ATP and oxidize six molecules of NADPH. Six molecules of 3-PGA are reduced, producing six molecules of the energy-rich three-carbon G3P.

Step 3

Release of one molecule of G3P.
Five of the G3P from step 2 remain in the cycle. The single molecule of G3P you see leaving the cycle is the net product of photosynthesis. A plant cell uses two G3P molecules to make one molecule of glucose, which has six carbons. Since the Calvin cycle incorporates only one molecule of CO_2 — and thus only one carbon — at a time, it takes six complete turns of the cycle to make two molecules of G3P that go into one glucose molecule.

Step 4

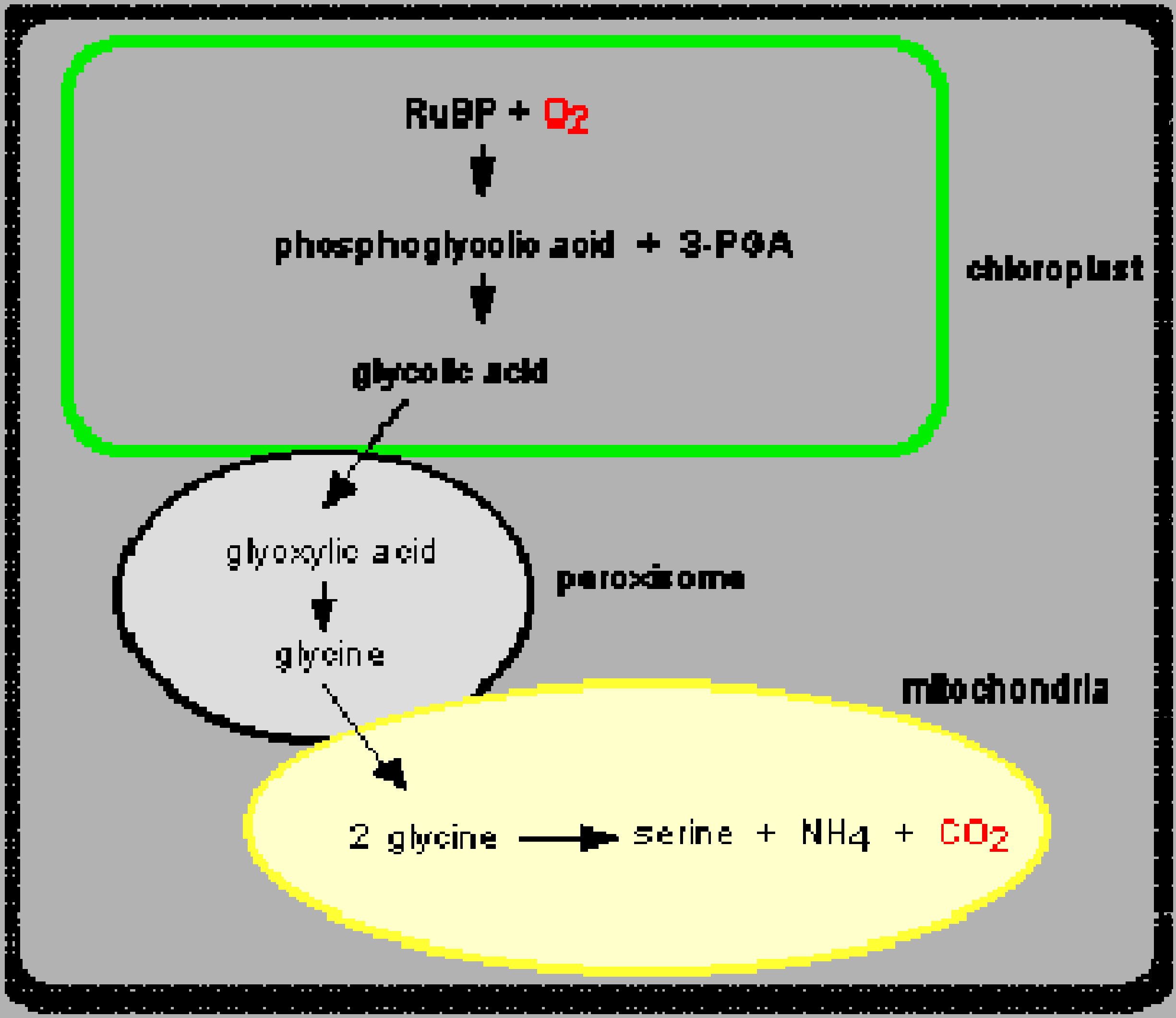
Regeneration of RuBP.
A series of chemical reactions uses energy from ATP to rearrange the atoms in the five G3P molecules, forming three RuBP molecules. These can start another turn of the cycle.



This mechanism works well except under hot dry conditions.

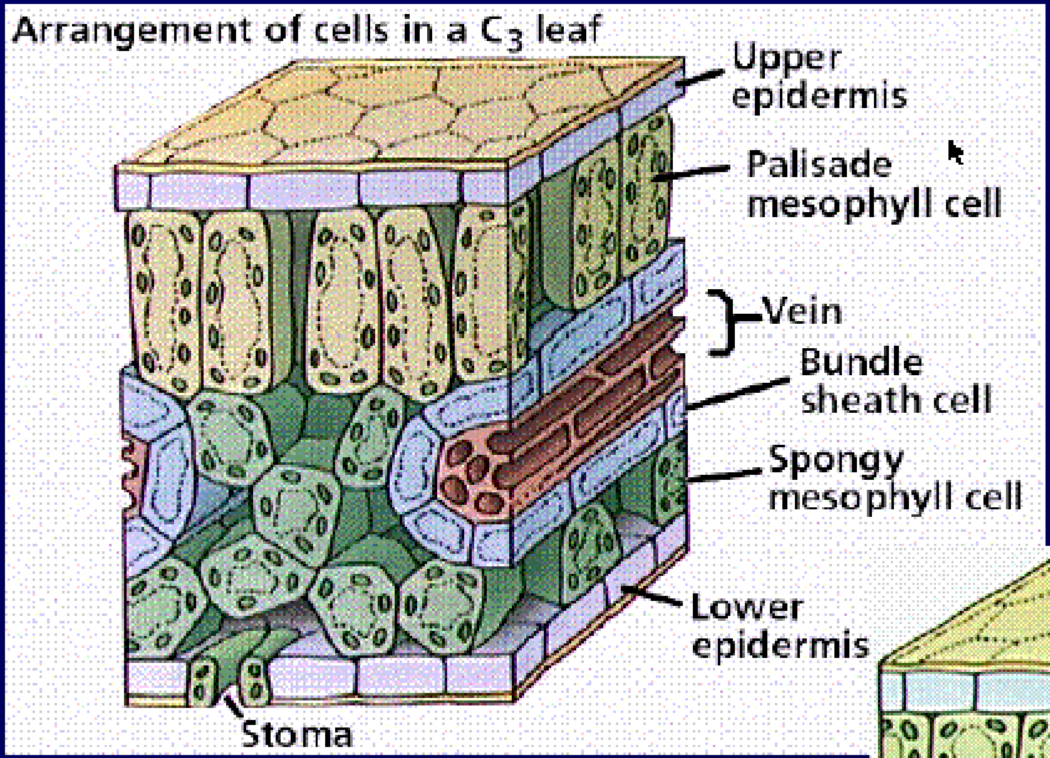
Stomates close > build-up of O_2

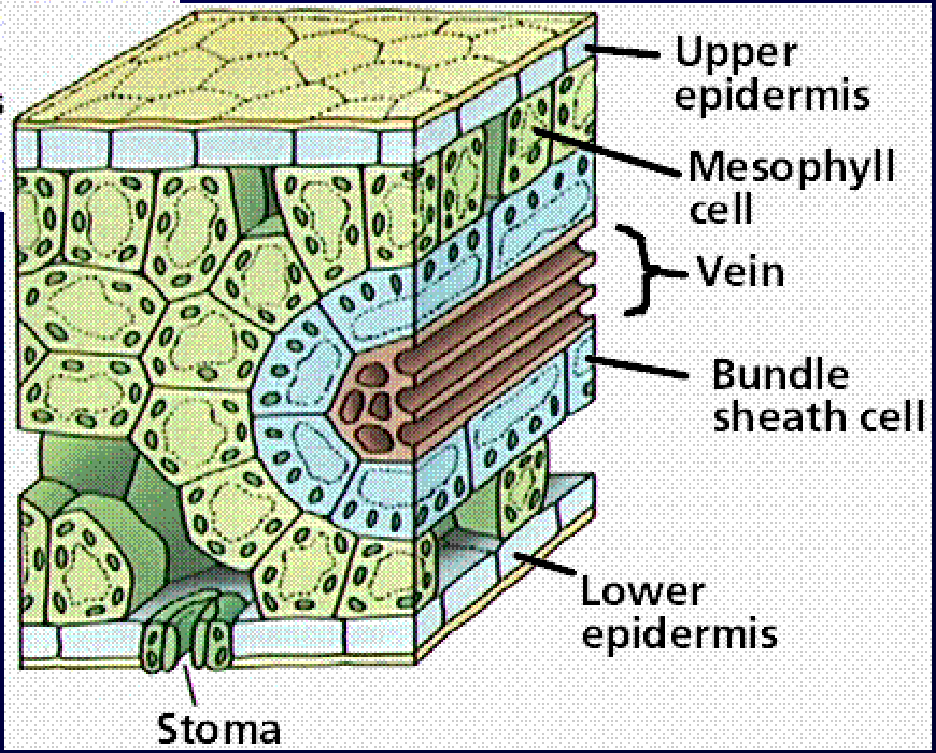
competes for binding sites with CO_2



Photorespiration involves 3 organelles

O_2 is consumed and CO_2 is lost

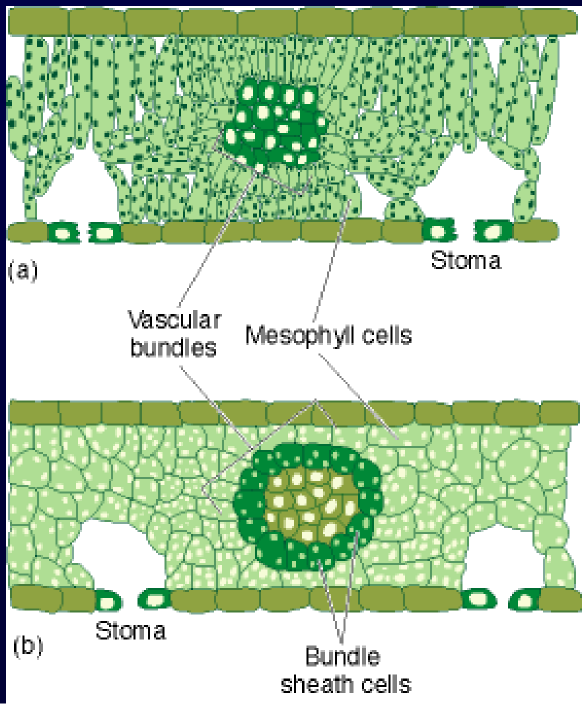




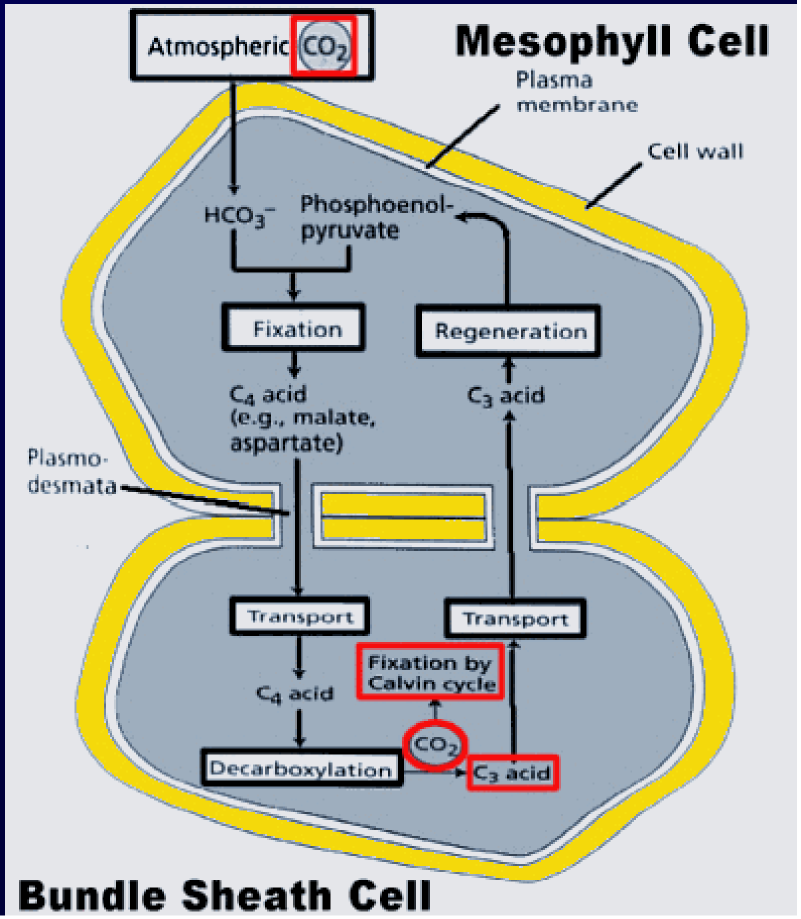
C4 PSN – bundle sheath cells

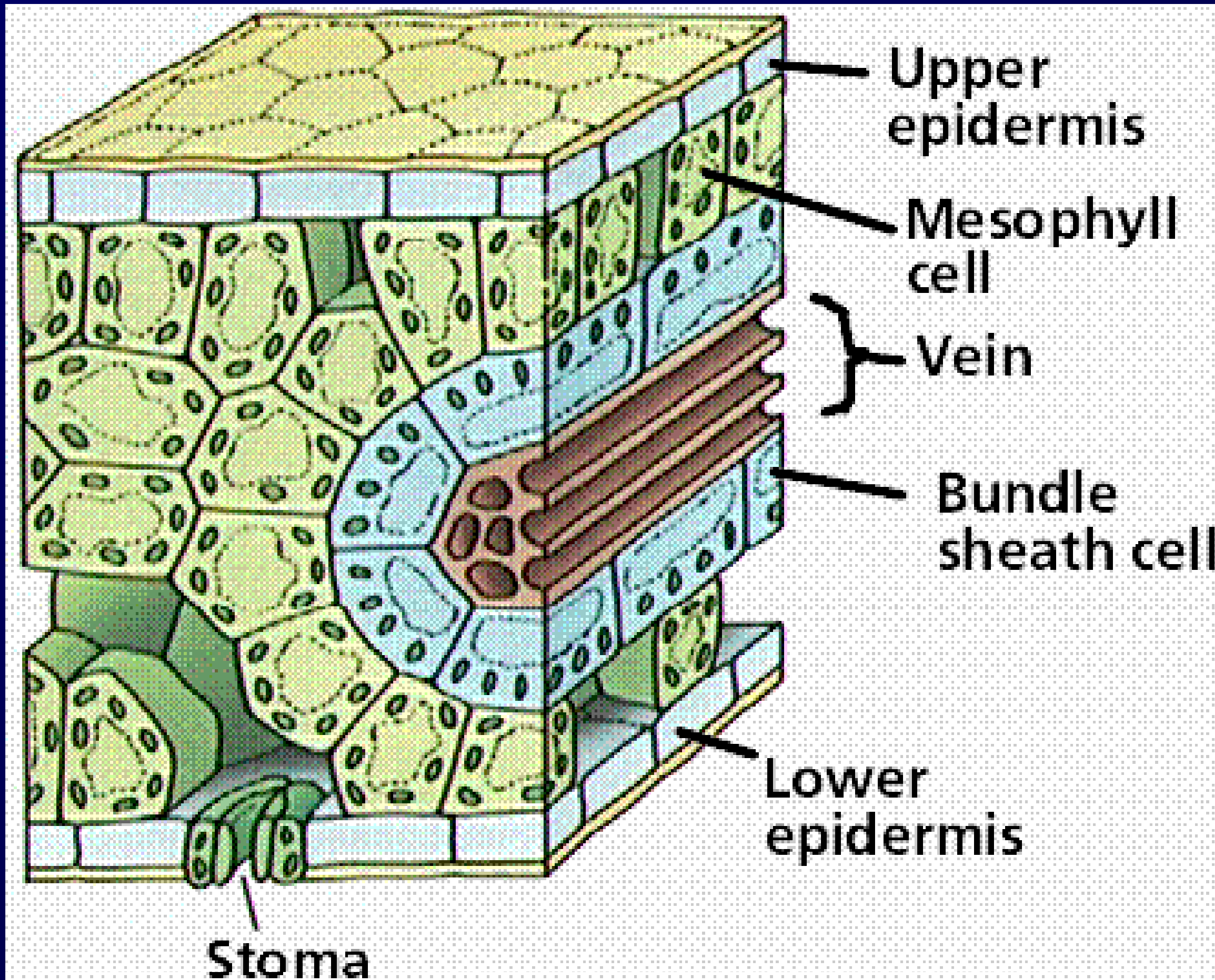
In order to bypass the photorespiration pathway , C_4 plants have developed a mechanism to efficiently deliver CO_2 to the RuBisCO enzyme.

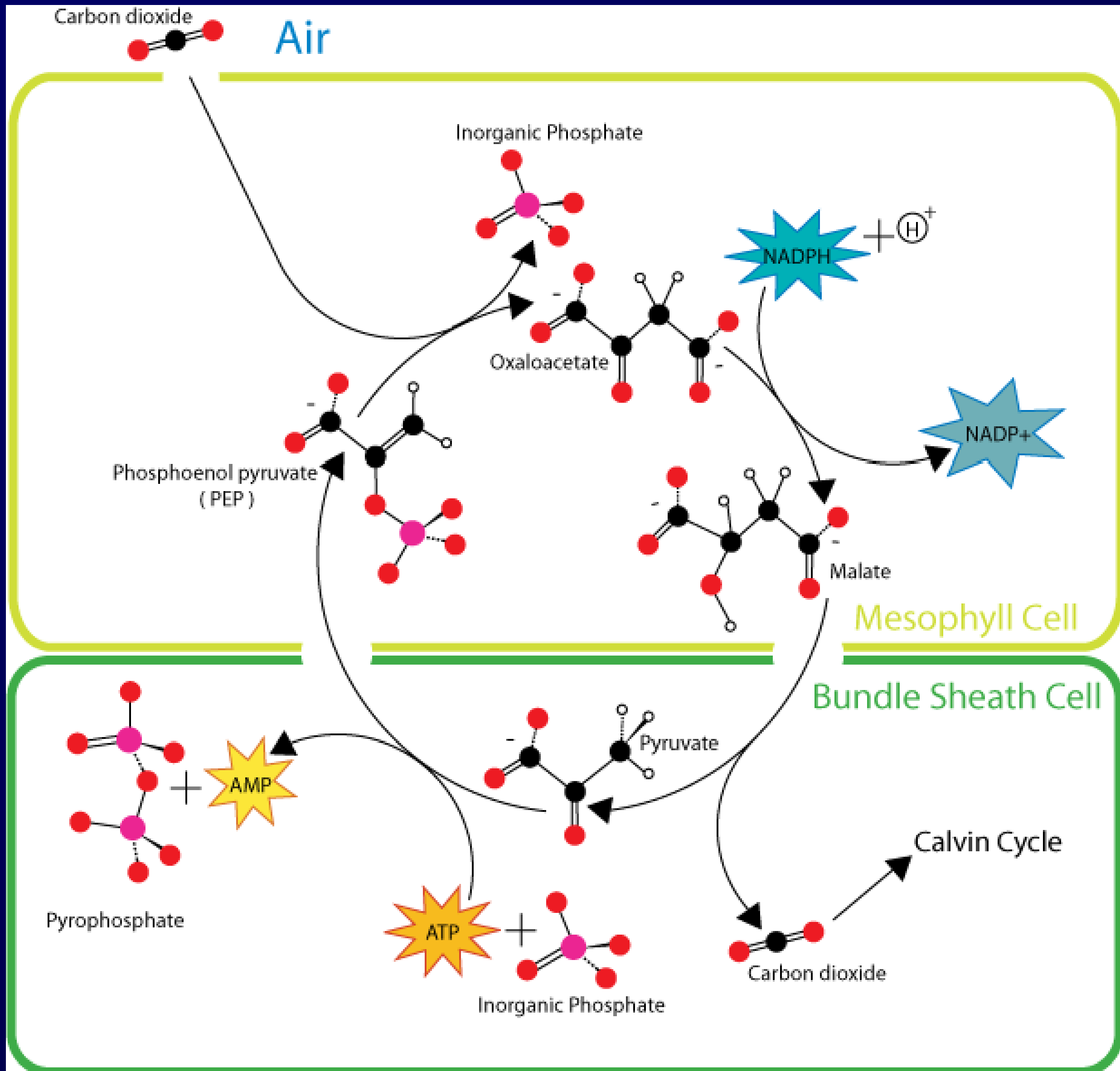
They utilize their specific leaf anatomy where chloroplasts exist not only in the mesophyll cells in the outer part of their leaves but in the bundle sheath cells as well.



Instead of direct fixation in the calvin cycle, CO_2 is converted to a 4-carbon organic acid which has the ability to regenerate CO_2 in the chloroplasts of the bundle sheath cells. Bundle sheath cells can then utilize this CO_2 to generate carbohydrates by the conventional C3 pathway.

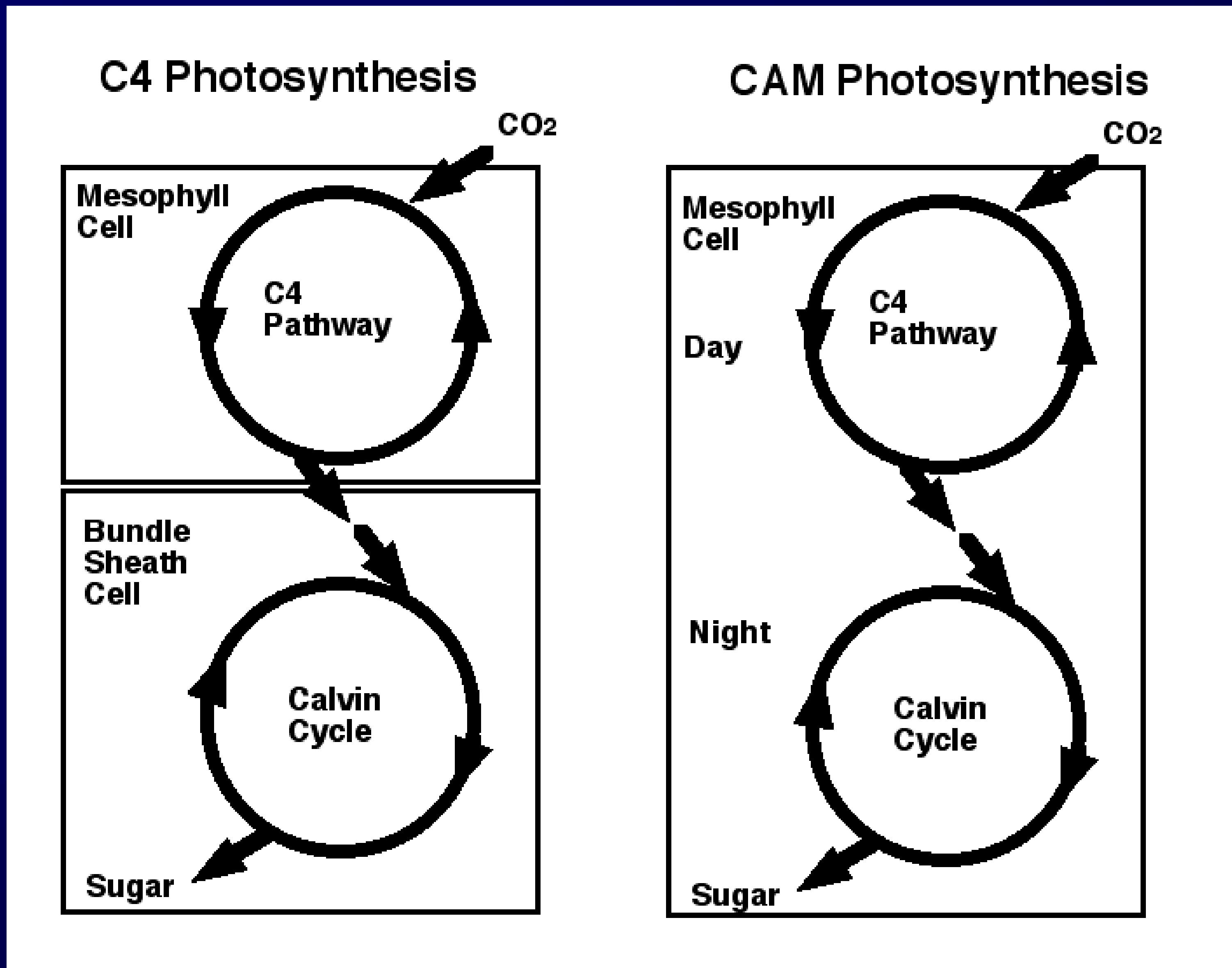



Upper epidermis
Mesophyll cell
Vein
Bundle sheath cell
Lower epidermis
Stoma



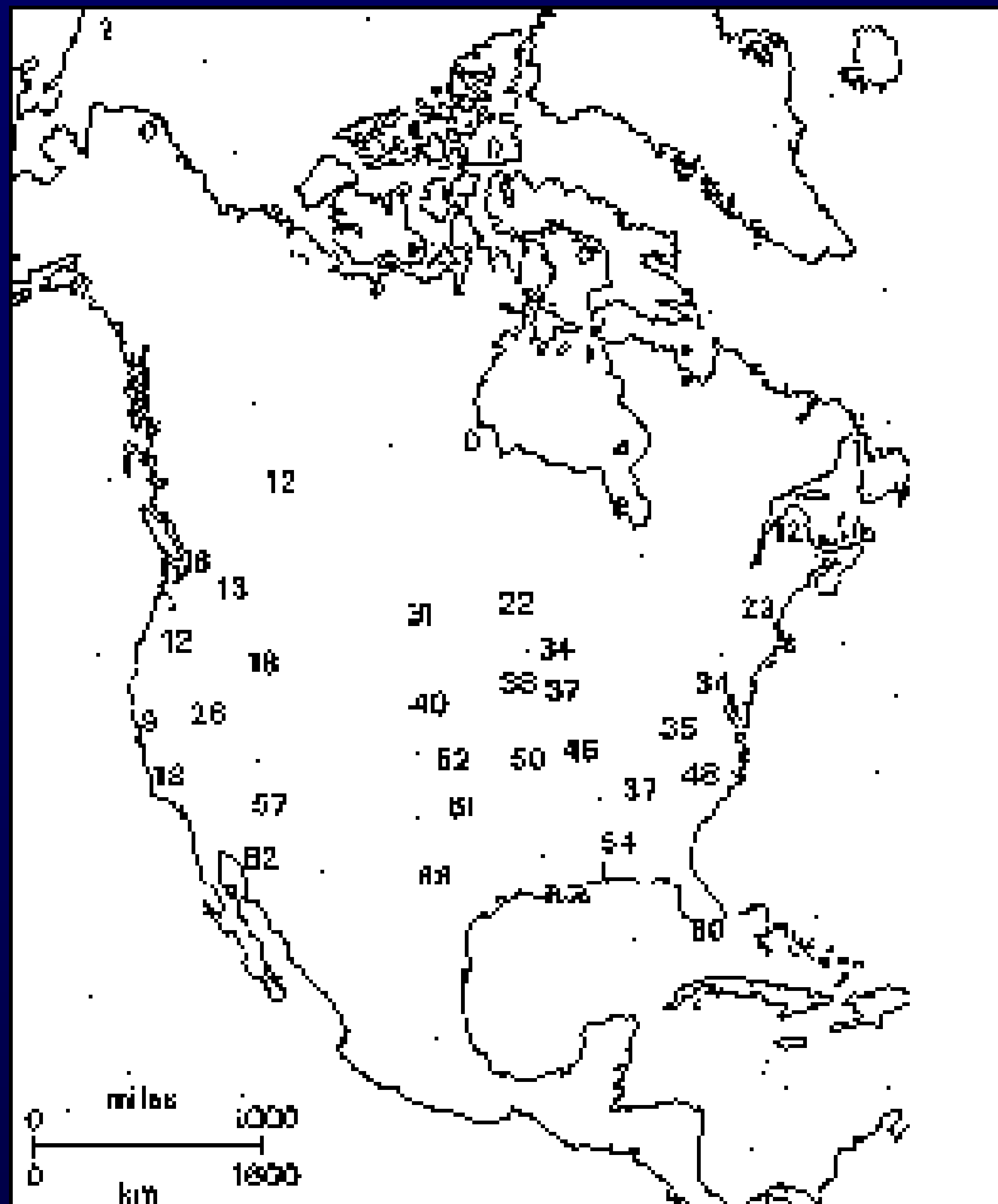
Carbon dioxide
Air
Inorganic Phosphate
NADPH
H
+
Oxaloacetate
NADP+
Phosphoenol pyruvate
(PEP)
Malate
Mesophyll Cell
Bundle Sheath Cell
Pyruvate
AMP
Pyrophosphate
Calvin Cycle
ATP
Inorganic Phosphate
Carbon dioxide

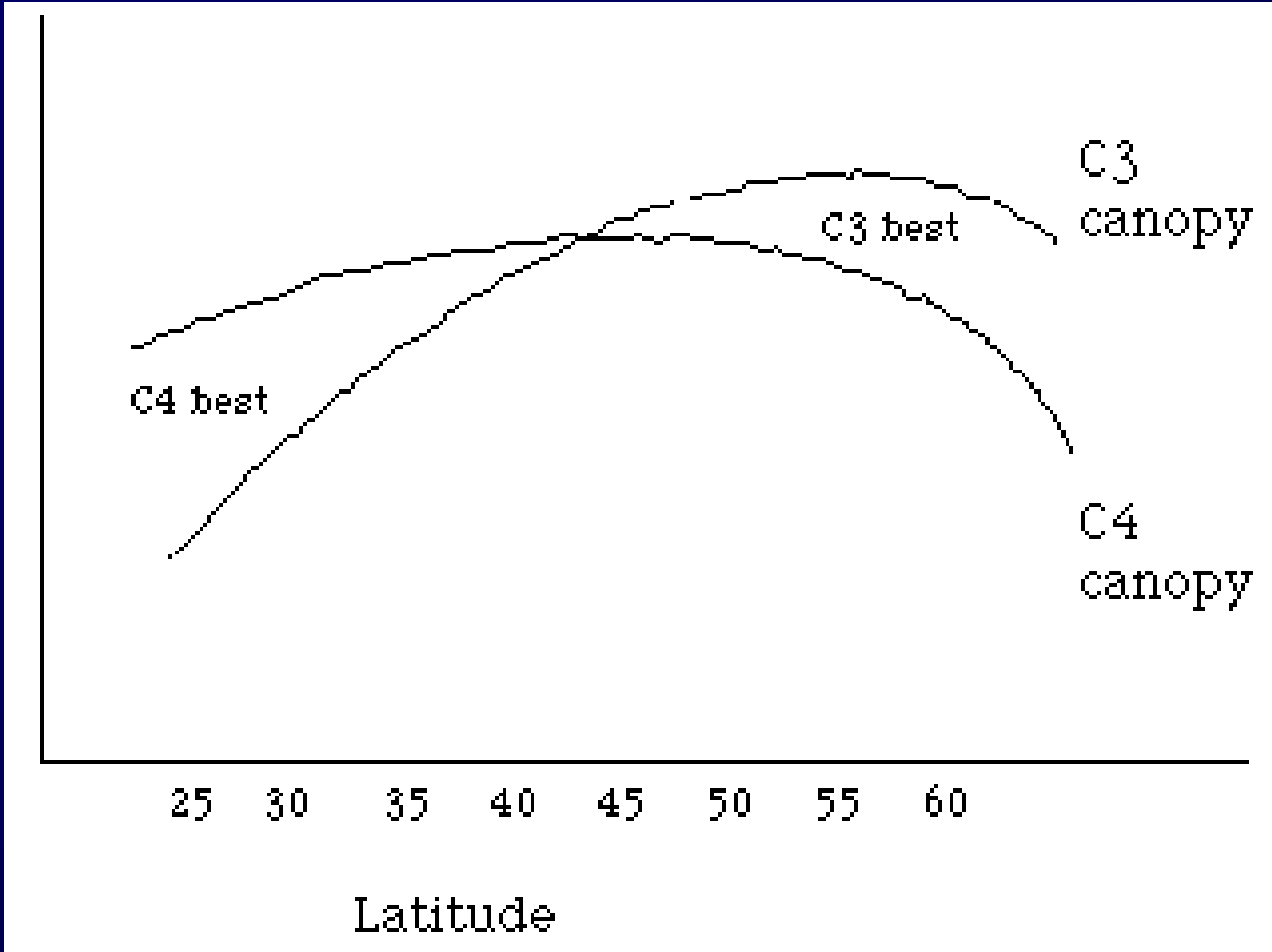
A 3rd route for PSN is called CAM


C4 Photosynthesis
CO2
Mesophyll Cell
C4 Pathway
Bundle Sheath Cell
Calvin Cycle
Sugar
CAM Photosynthesis
CO2
Mesophyll Cell
Day
C4 Pathway
Night
Calvin Cycle
Sugar

C3 plants make-up ~ 95% of all plant species on earth (Kentucky bluegrass, wheat, trees).

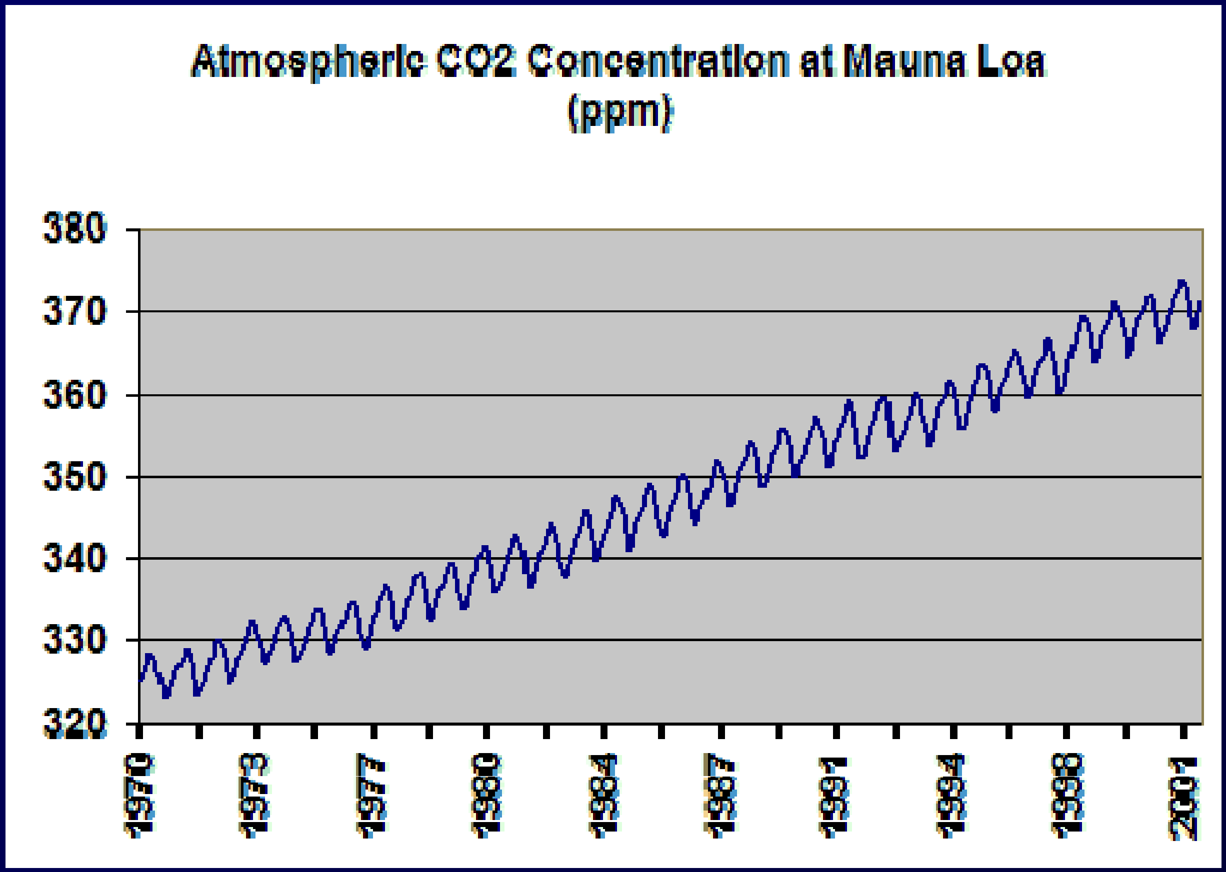
C4 plants include highly cultivated crop plants (sugar cane, corn, sunflower, crabgrass)

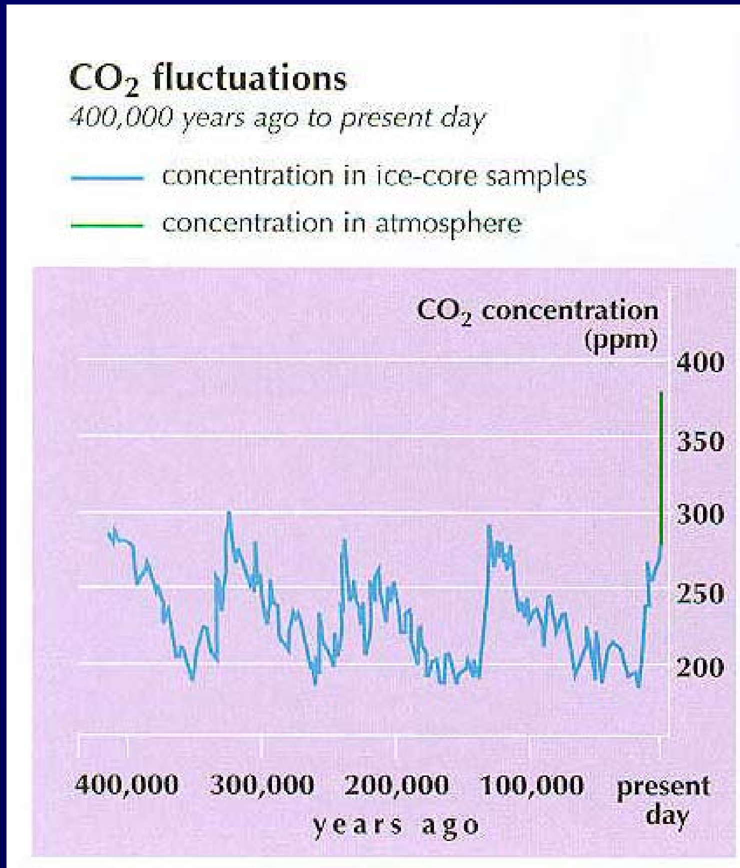

12
13
12
22
34
37
40
26
62
50
35
37
57
54
miles
0
1000
0
1600
km

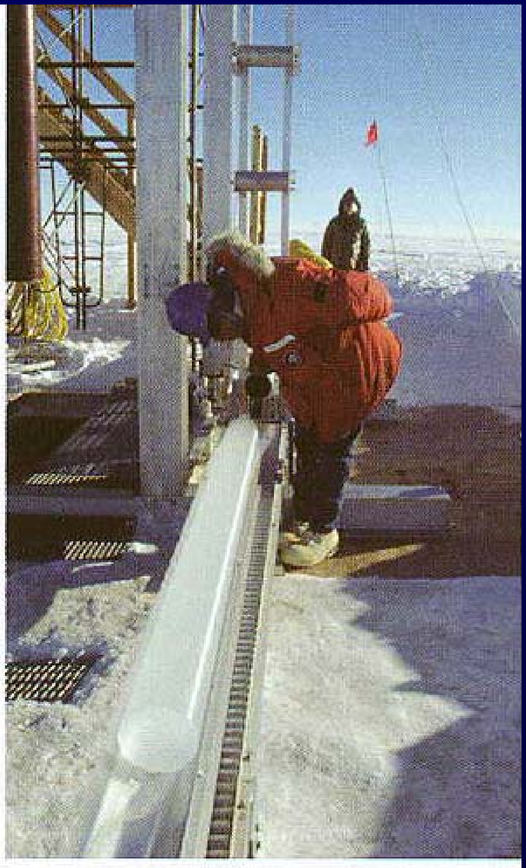


C3
canopy
C3 best
C4 best
C4
canopy
25
30
35
40
45
50
55
60
Latitude

What are the consequences for global increases in CO_2 for plant abundance and distribution?


Atmospheric CO2 Concentration at Mauna Loa
(ppm)
380
370
360
350
340
330
320
1970
1973
1977
1980
1984
1987
1991
1994
1998
2001



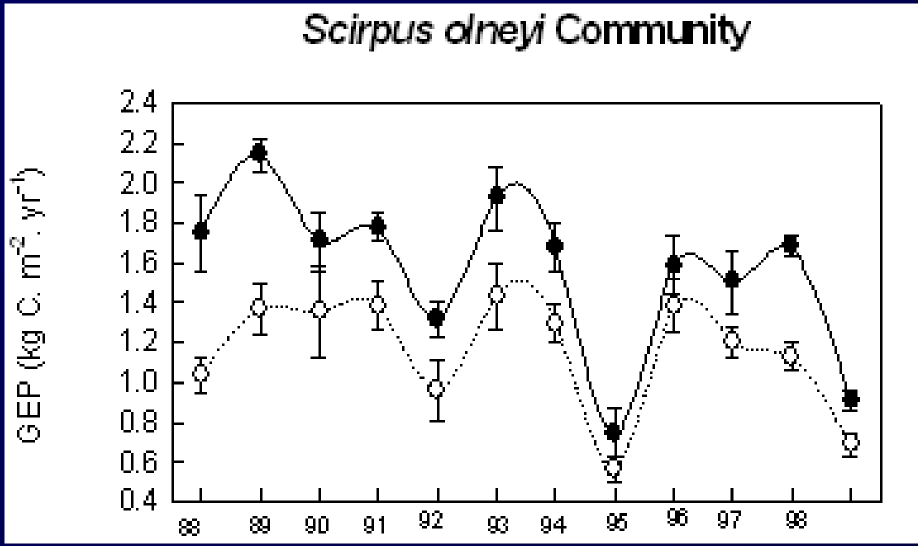


By measuring CO_2 concentrations in tiny bubbles trapped in ice we can examine CO_2 flux dating back > 400,000 years

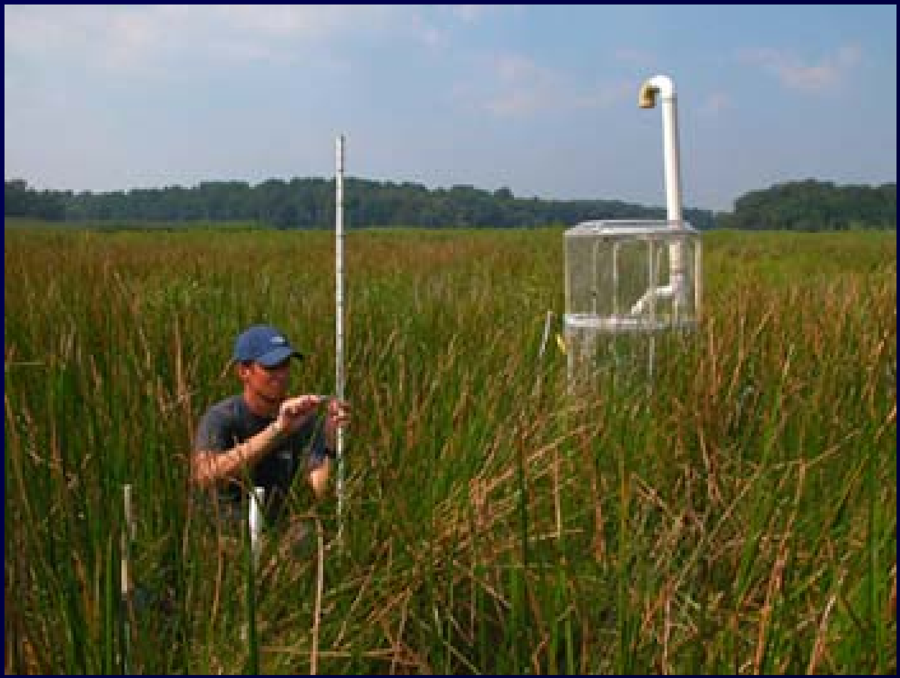
CO2 effects in Marsh Ecosystem

C3 species continue to increase PSN rates with rising CO_2 , while C4 species do not.

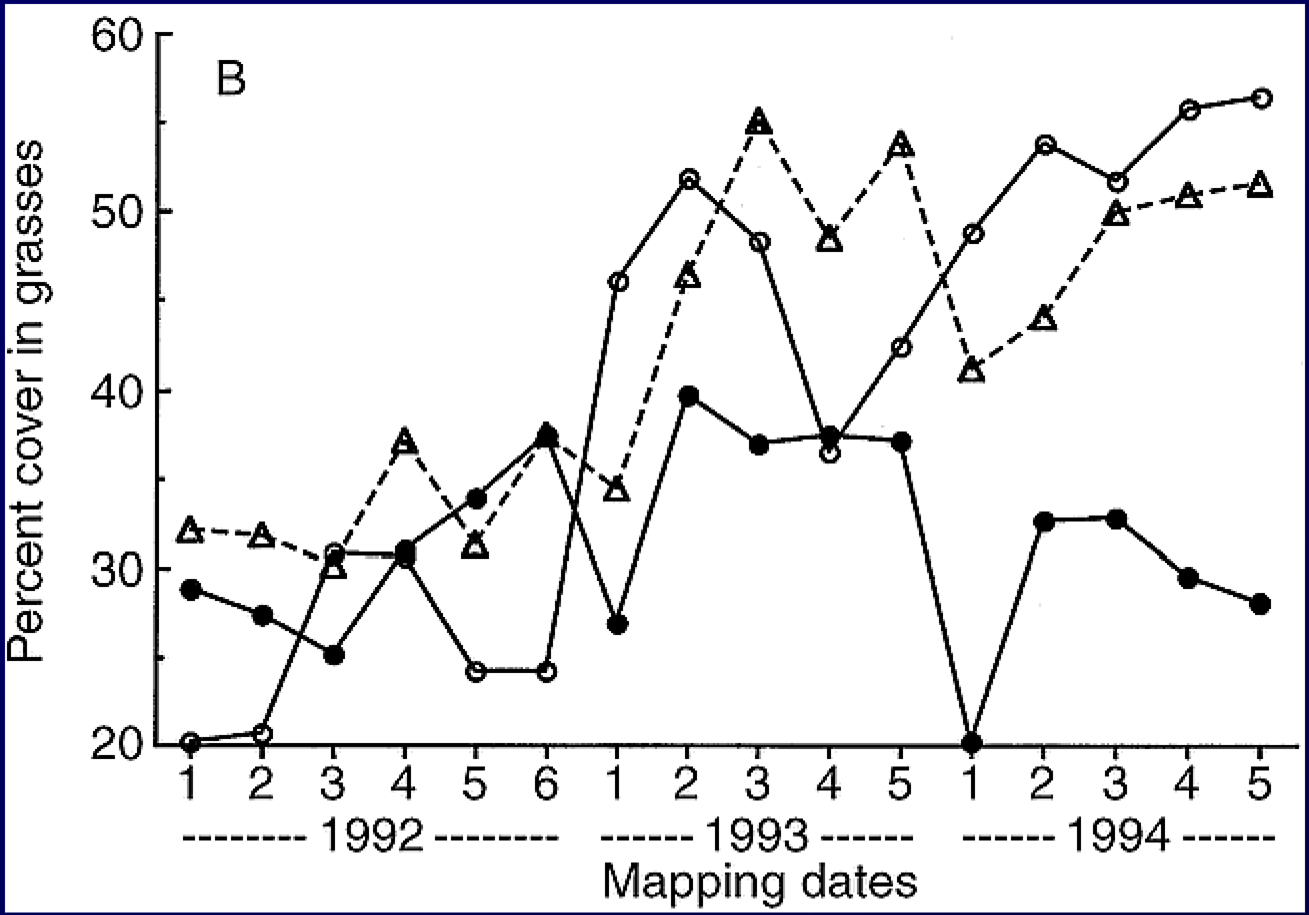
So, C3 plants can respond readily to higher CO_2 levels, and C4 plants can make only limited responses.



• Sedges may increase at the expense of grasses
• Increase growth enhanced under high salinity and low water availability.




Processes Affecting Carbon Fluxes
of Grassland Ecosystems
Under Elevated CO_2



Closed Circles = elevated CO_2 open tops
Open Circles = ambient open tops
Triangles = field controls

D. Nutrients

Unlike uptake of water, nutrient uptake requires energy expenditure

[nutrients] in the plant ~ 100 – 1000 x higher than in surrounding soil

Limiting nutrients to plants

Nitrogen

Present as either ammonium (NH_4^+) or nitrate (NO_3^-)

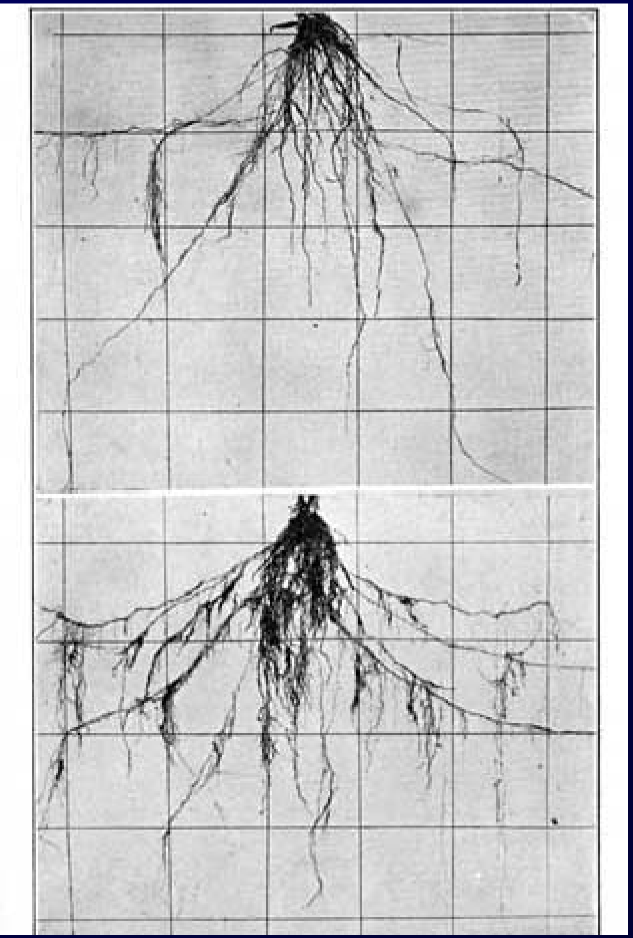
Architecture of roots determine ability to gain access to nutrients.

- Branch profusely when in contact with rich supply of nutrients

• Nitrate ions diffuse rapidly in soil water
• Phosphate ions tightly bound to soil particles

Highly branched, compact surface root improves phosphate absorption

Widely spaced extensive root system will enhance nitrate access

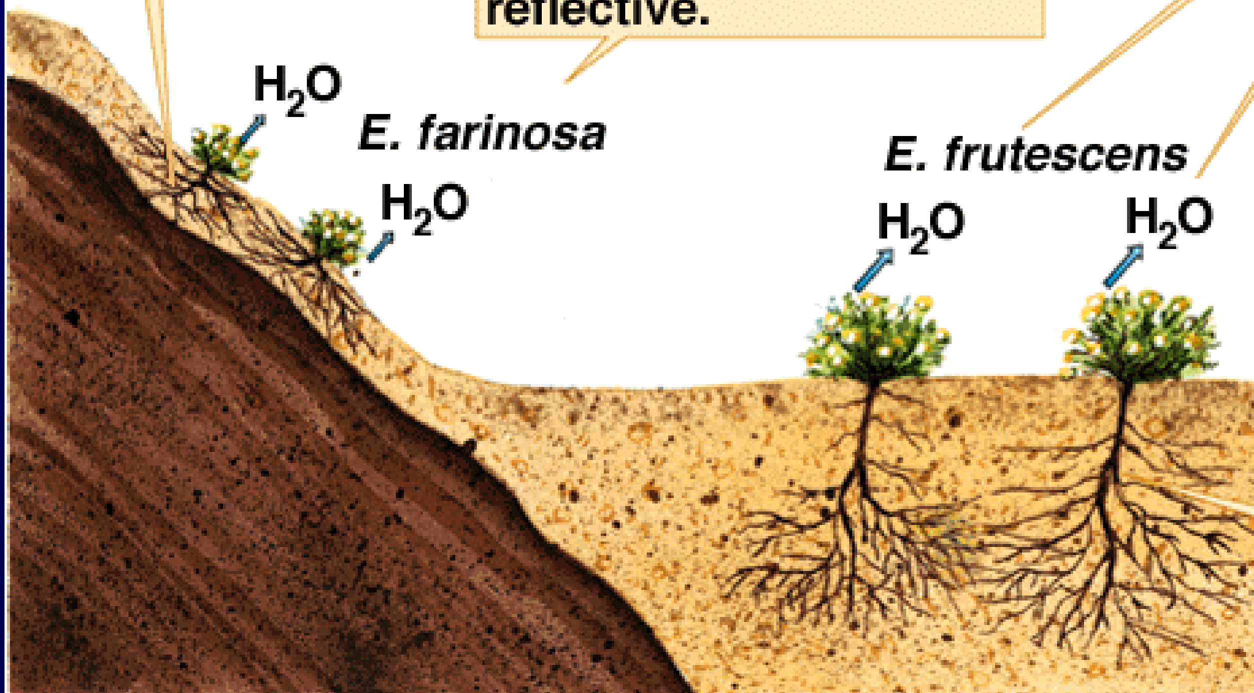


Temperature regulation and distributions of *Encelia farinosa* and *E. frutescens*.

E. farinosa grows mainly on slope habitats in shallow soils that store limited water.

Despite low transpiration rates, pubescent leaves of *E. farinosa* remain relatively cool because they are highly reflective.

The rate or transpiration by *E. frutescens* is sufficient so that its leaves evaporatively cool.



E. frutescens can maintain high transpiration rates because it exploits the greater water available in deep soils along washes.