Plant Adaptations to Wetland Conditions

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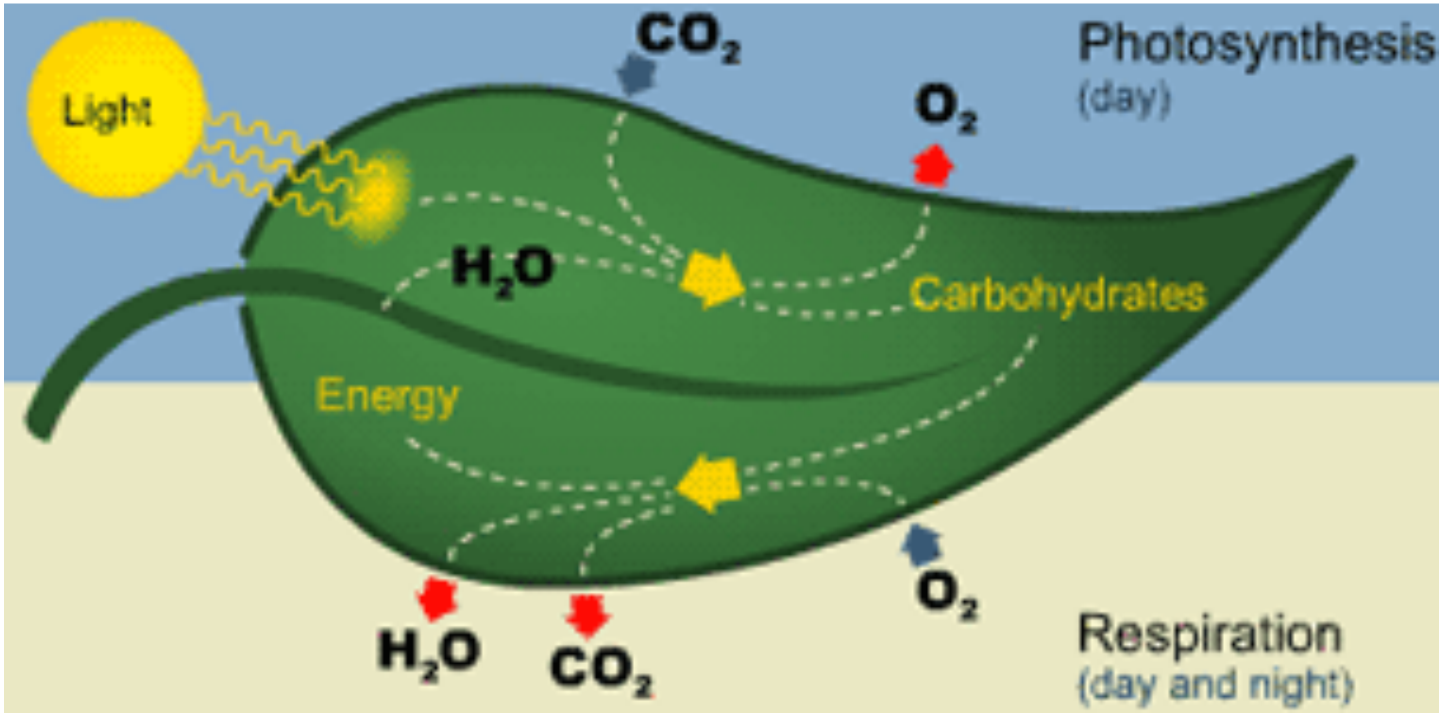
Terrestrial Plant Needs

Plants are autotrophs

Manufacture their own food from simple, inorganic materials in the environment.



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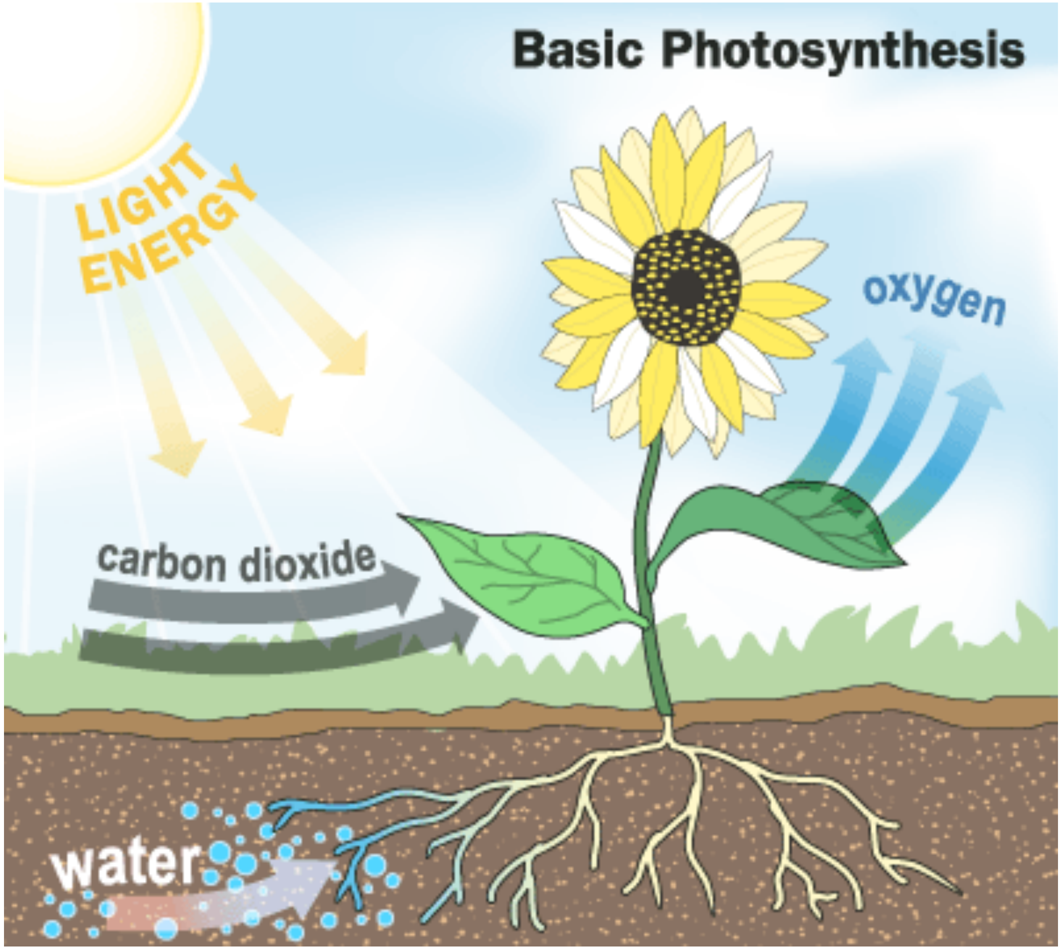
Plant Growth Requirements

1. Water
2. O_2
3. Sunlight
4. CO_2
5. Nutrients and trace elements
6. Reproduction



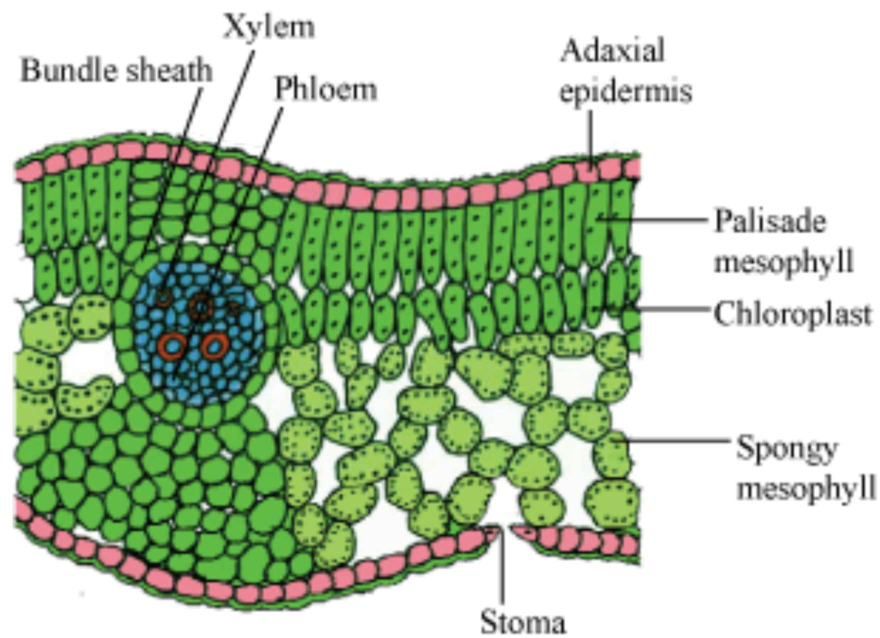
http://static.howstuffworks.com/gif/irrigation-photosynthesis.gif

Terrestrial Plants

- Colonized land about 440 million years ago.
- Required adaptations to:
  - Resist drying out
  - Exchange gases with atmosphere
  - Transport water and nutrients
  - Stay upright

Problems terrestrial plants have to solve

- Photosynthesis requires specialized cell structures
  - Chloroplasts
  - Mostly in the middle layer of cells in a leaf
    - Why?



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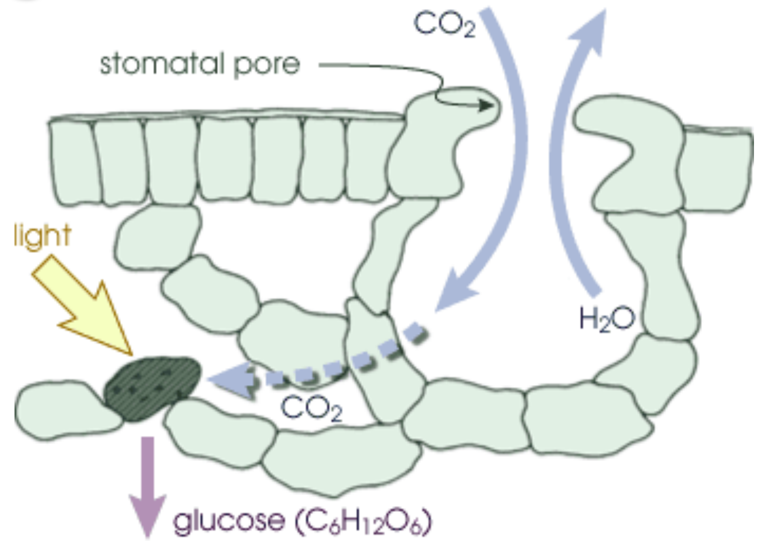
Problems terrestrial plants have to solve

- Photosynthesis requires a way to exchange gases
- BUT…..prevent loss of excessive water
  - WHERE are most stomata located? Why?



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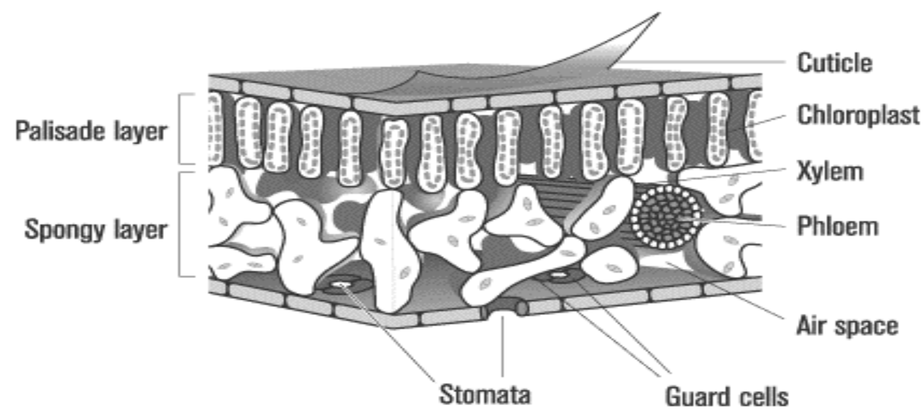
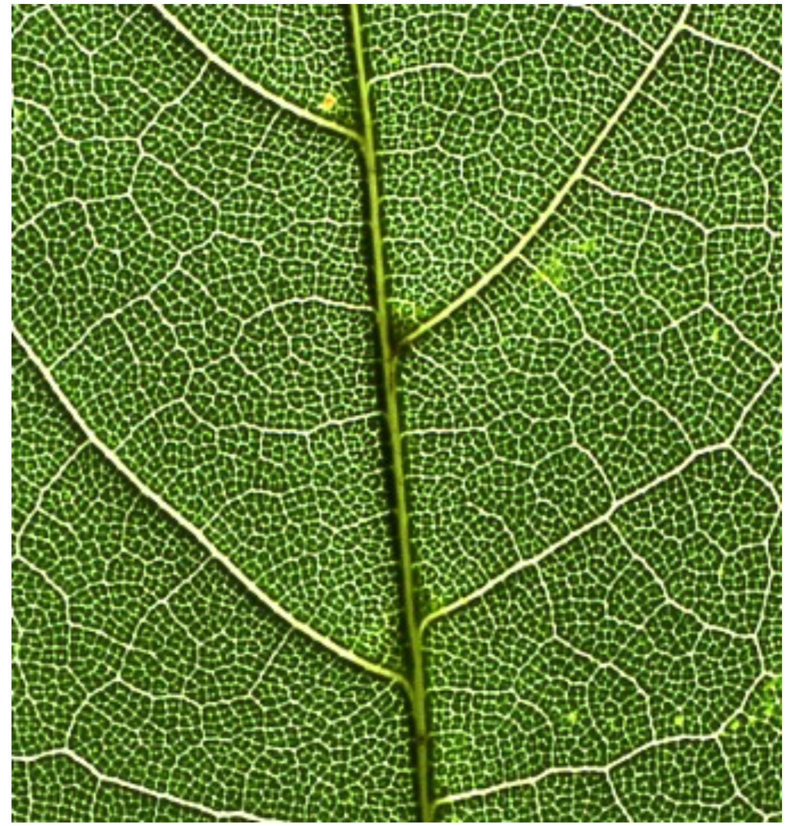


http://img.sparknotes.com/content/testprep/bookimgs/sat2/biology/0003/leafff.gif

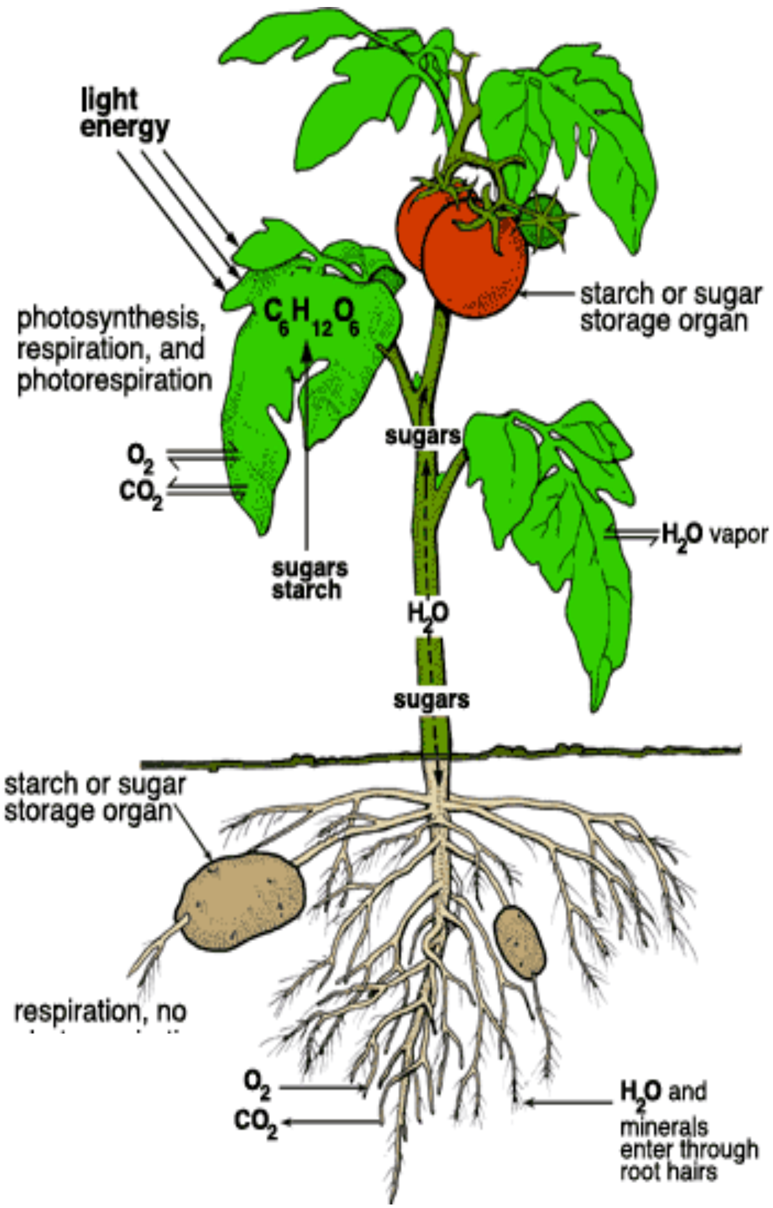
Problems terrestrial plants have to solve

- Thin leaves are required for light absorption and gas exchange, but they need SUPPORT
  - Cell walls
  - Leaf veins



http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/L/Leaf.html

Problems terrestrial plants have to solve

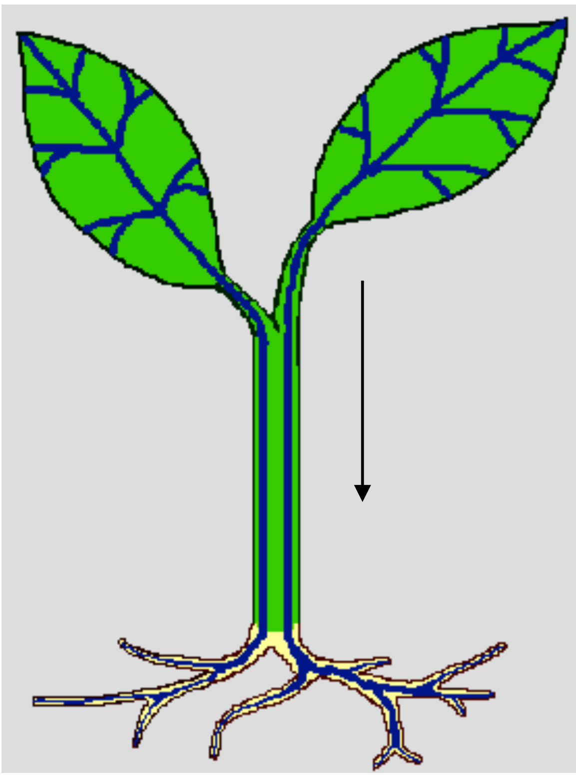


http://extension.oregonstate.edu/mg/botany/growth.html

Internal transport

- Photosynthesis requires a water supply
- "Mine" water and nutrients from the soil
  - Root system
  - Specialized transport system __xylem____

Problems terrestrial plants have to solve



http://sps.k12.ar.us/massengale/vasctissue.GIF

Internal transport

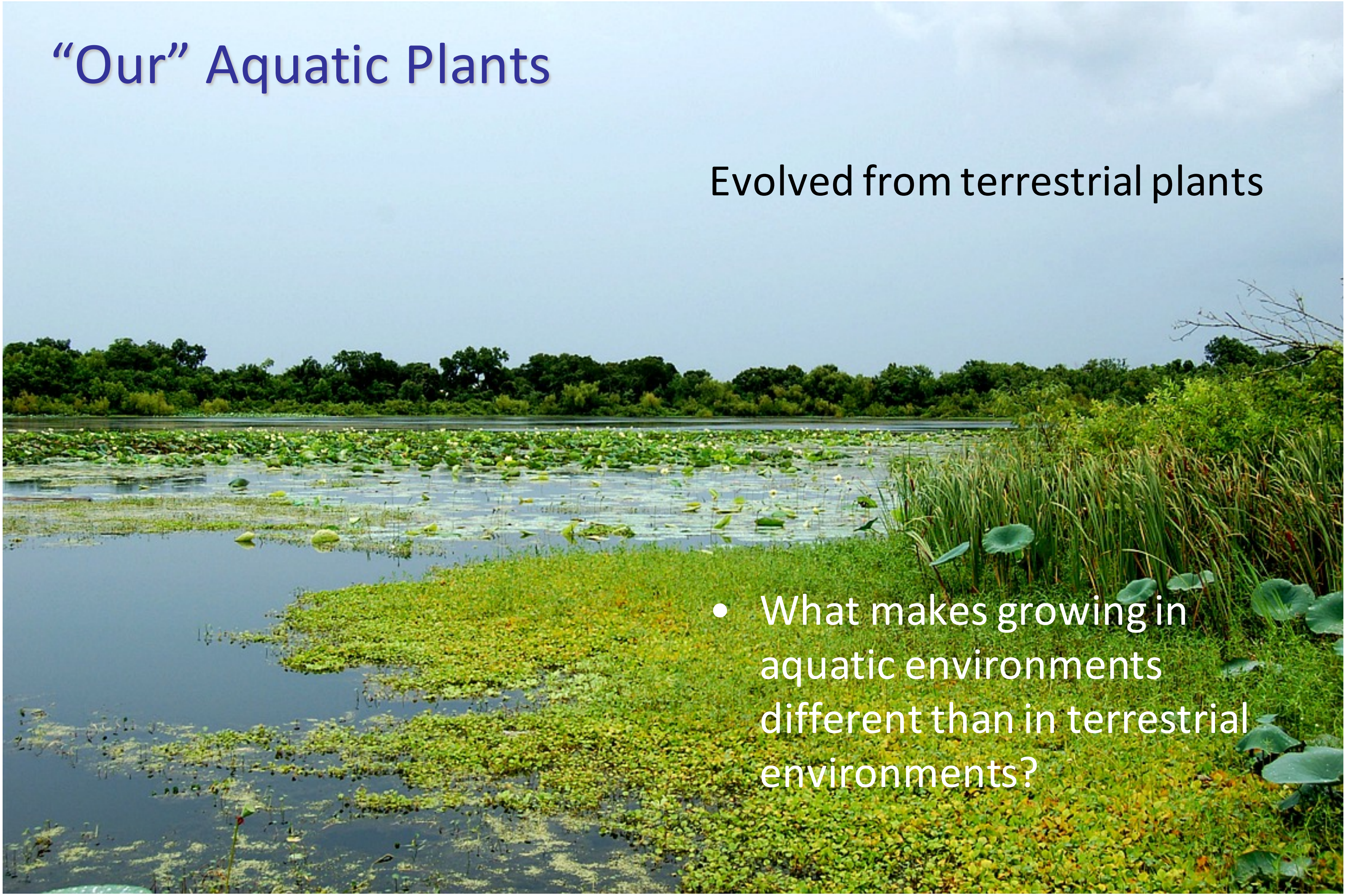
- Carbohydrates (sugars and other metabolic products) from photosynthesis needed throughout the plant
- Another transport system does this

______phloem___

Terrestrial Plant Adaptations

- Xylem and phloem became structural
- Reproductive structures elevated (pollination, dispersal)
- Structural adaptations to resist water loss
  - Volume to surface area ratio increased to control:
    - Evaporation
    - Heat buildup
    - Heat loss due to cooling
  - Cuticle became thicker
  - Stomata on undersides of leaves
    - Why?

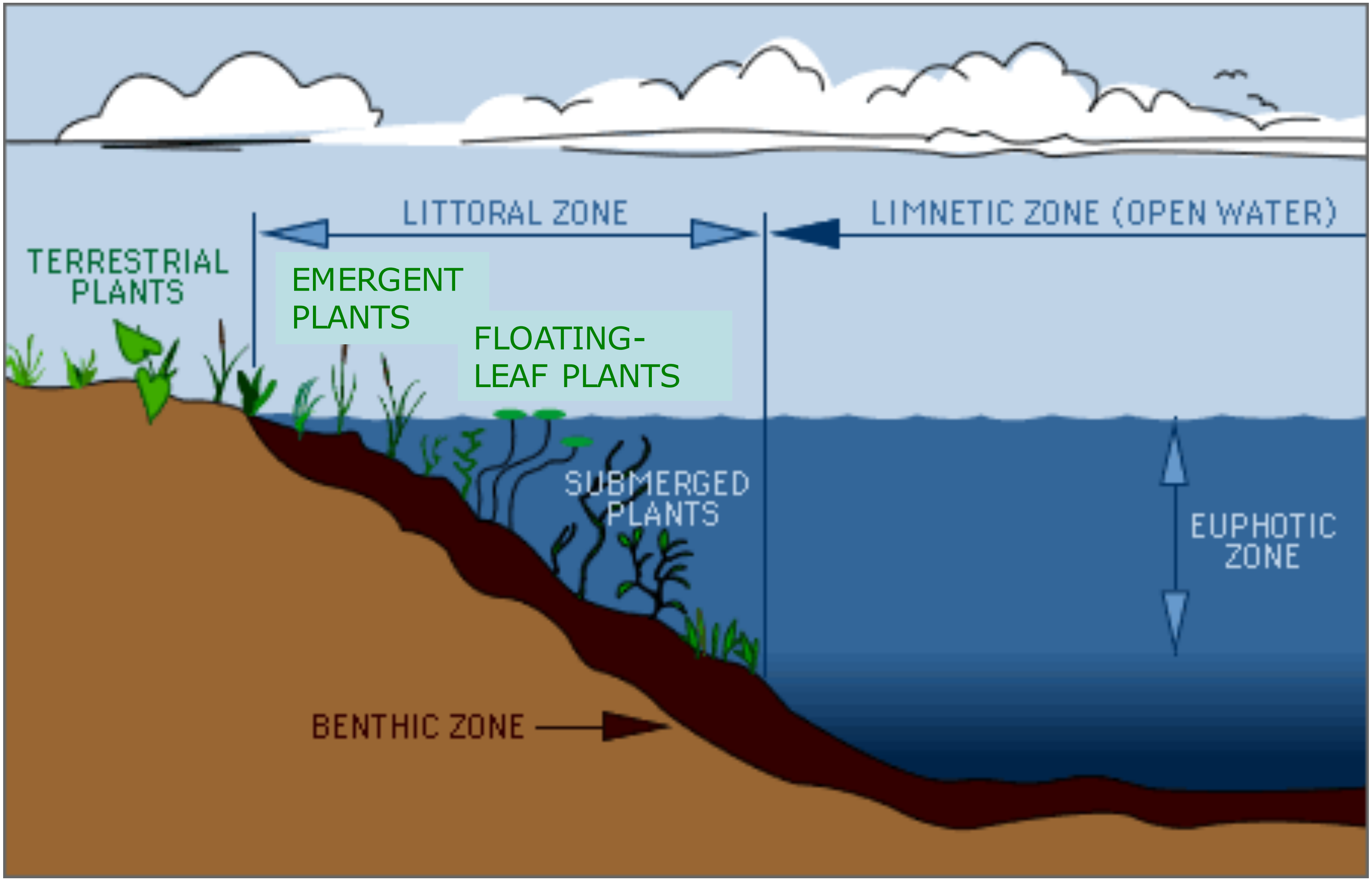
“Our” Aquatic Plants

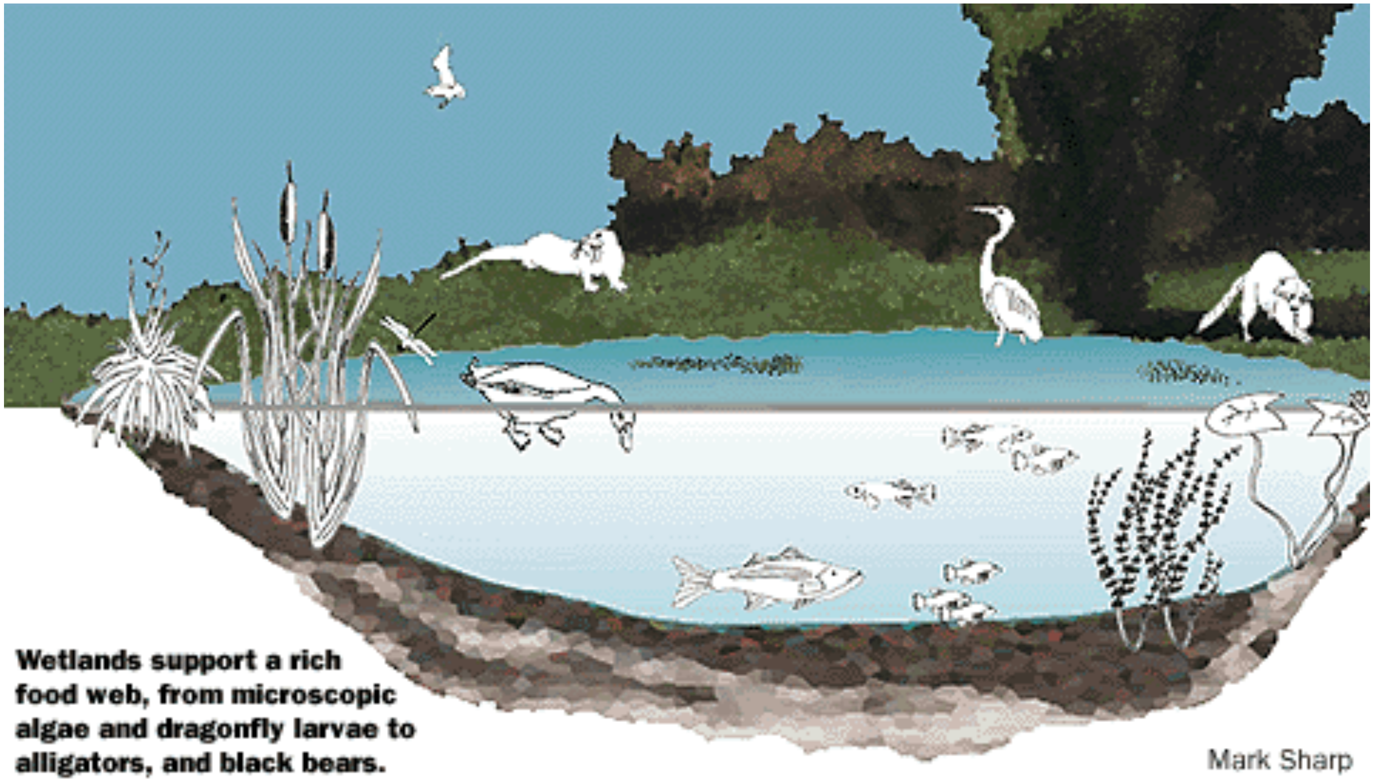


Evolved from terrestrial plants

- What makes growing in aquatic environments different than in terrestrial environments?

Aquatic Plant Zones





http://upload.wikimedia.org/wikipedia/commons/6/6d/Food_web.gif

Tradeoffs between a terrestrial and aquatic existence

Varies based on plant characteristics (e.g., growth form) and location (e.g., plant zone)

Adaptations to a water environment

1. Fluctuating water levels
2. Limited oxygen
3. Limited light
4. Limited carbon dioxide
5. Difficulty obtaining nutrients
6. Reproduction difficult

On the Plus Side……

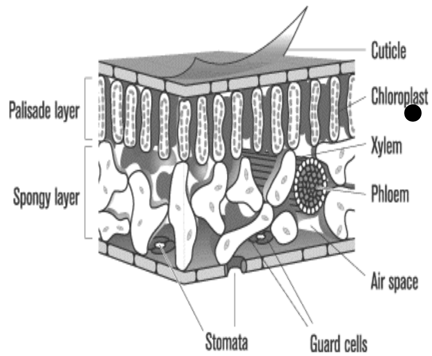
Water –

- Insulation – high specific heat buffers sudden or radical shifts in air temperature
- Support – water’s high density provides support for plants
- Light – less light available to plants, but water buffers radical shifts in light

Save energy on:

- Temperature regulation
- Structural support

Harder or Easier?
Problems plants have to solve



- Photosynthesis requires specialized cell structures
  - T: Chloroplasts mostly in the middle layer of cells in a leaf. A?
- Photosynthesis requires efficient light harvesting
  - T: Thin leaves, wide, but need structural support. A?

- Photosynthesis requires a way to exchange gasses BUT prevent loss of excessive water
  - T: Stomata mostly on underside of leaf. A?
- Photosynthesis requires a water supply
  - T: Obtain from soil. A?

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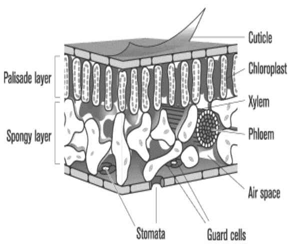
Problems plants have to solve



Plants require inorganic nutrients

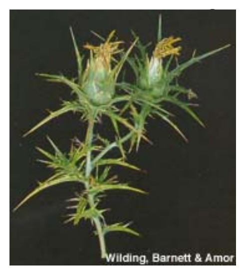
- T: Mine from soil and transport up plant. A?

Respiration requires oxygen

- T: Plentiful in air. A?

Stationary plants need ways to reproduce

- T: Wind, insects, etc. A?



Plants have to cope with physical forces and biological dangers

- T: Wind, floods, drought, cold; herbivory, competition. A?

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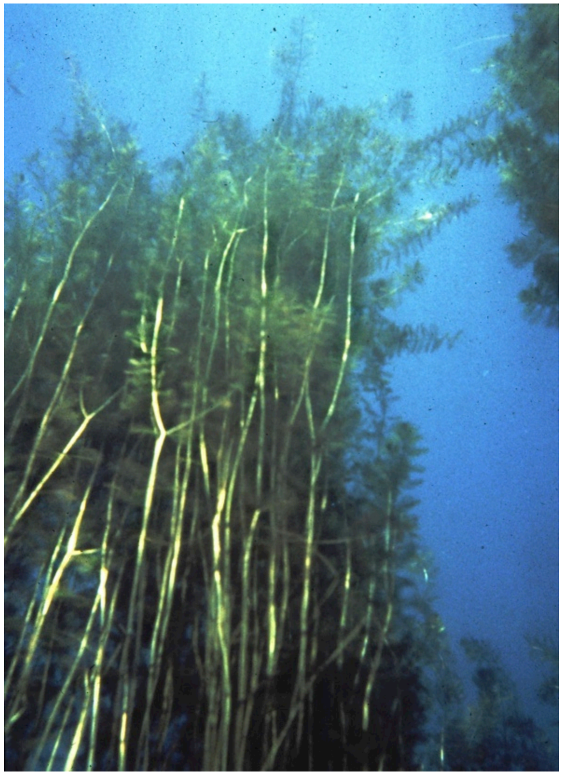
1. Adaptations to fluctuating water levels

- Heterophylly
  - Survive under dry or submerged conditions
  - Emergent leaves ovate, elliptic or rounded – why?
  - Longer, ribbon-like submerged leaves – why?
- Ability to adapt rapidly
  - Costly in energy and nutrients
    - Harms competitive ability with terrestrial plants
- Seed banks

2. Problem – Obtaining Oxygen

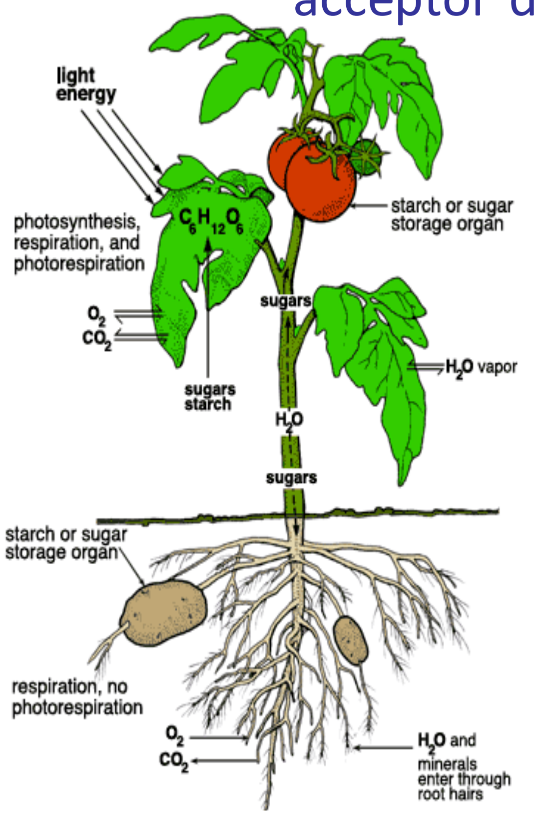
- Aquatic plants need to:
  - Sequester oxygen
  - Tolerate low oxygen levels
  - Cope with toxic byproducts of anoxic and hypoxic sediments



Limited oxygen

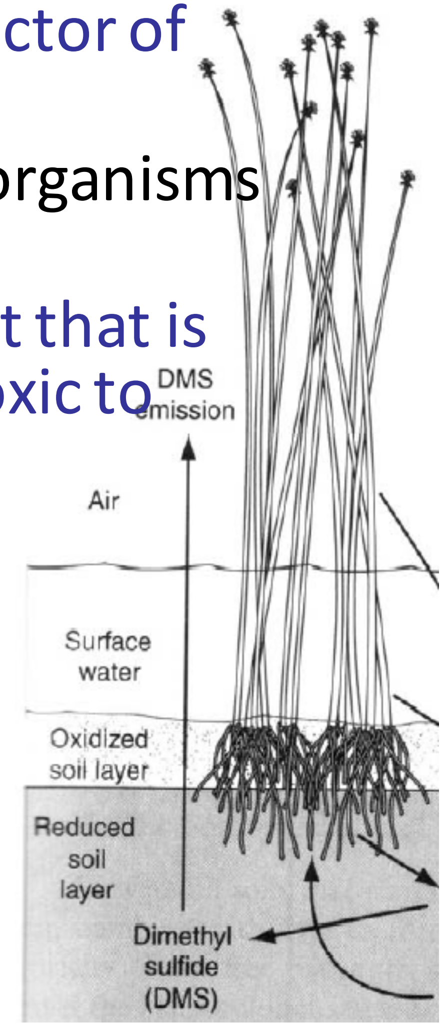
Upland soils

- Plant roots -- same oxygen levels as atmosphere (21%)
- Soil microorganisms aerobic
  - O_2 as terminal electron acceptor during respiration



Wetland or aquatic soils

- Sediment pore spaces filled with water
  - Rate of oxygen diffusion reduced by factor of 10,000
- Sediment microorganisms anaerobic
  - Create habitat that is stressful or toxic to plants

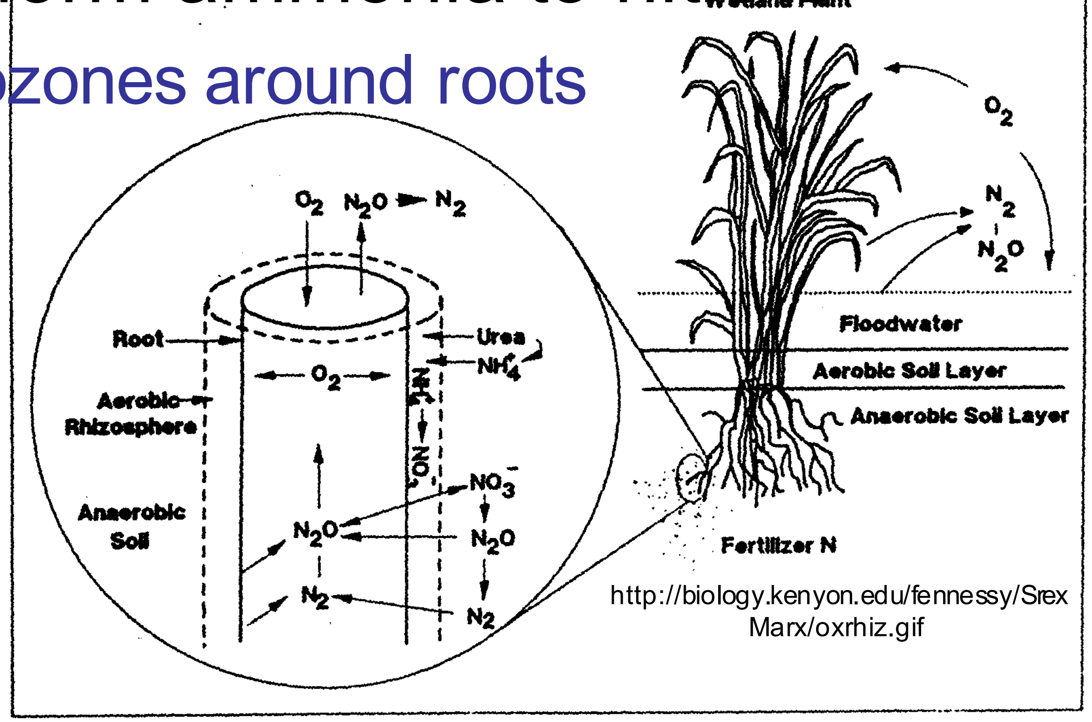


Strategies for limited oxygen: Radial oxygen loss

- Some wetland plants can create aerobic conditions in anoxic sediments through radial oxygen loss into the rhizosphere.
  - Oxygen channeled to roots leaked to surroundings through diffusion
  - Increases sediment redox potential in root zone
  - Submerged plants tend to do less of it
- Driven by diffusion – loss higher under most reducing conditions

Strategies for limited oxygen: Radial oxygen loss

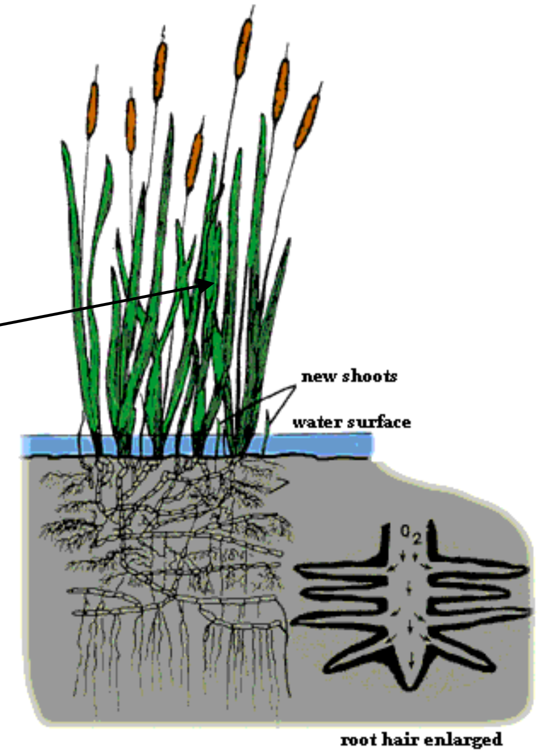
- Depletes root oxygen but may help plants by
  - Oxidizing potentially toxic compounds (e.g., sulfide)
- Oxygen in rhizosphere used by nitrifying bacteria can transform ammonia to nitrate
  - Oxygenated microzones around roots



http://biology.kenyon.edu/fennessy/SrexMarx/oxrhiz.gif

Strategies for limited oxygen: Structural Adaptations: Roots

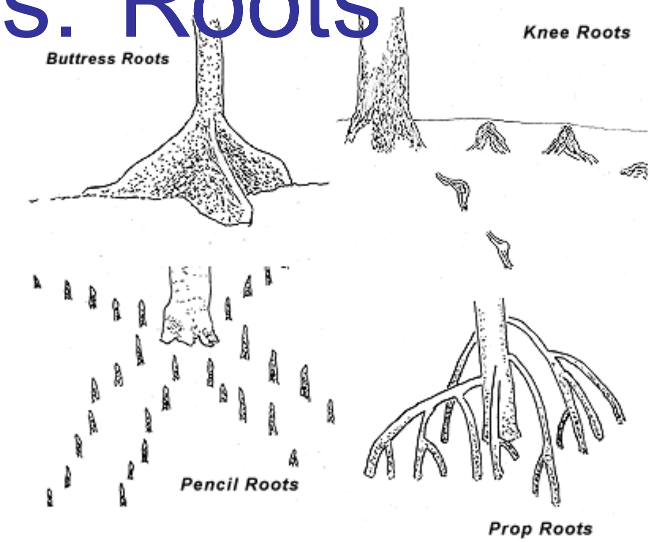
- Adventitious roots
  - Form from non-root tissue within days of flooding.
  - New roots replace roots killed by anoxia
  - Aid in water and nutrient uptake
  - Herbaceous and woody species



- Shallow roots
  - Wetland species tend to develop shallower root systems when flooded.
  - Surface and subsurface roots are above soil or in oxygenated portion of soil.
  - Uprooted trees – indicator of continuous soil saturation

Strategies for limited oxygen: Structural Adaptations: Roots

- Pneumatophores – Modified erect roots that grow upward from roots of some tree species (mangrove, cypress).
  - Cypress "knees"
    - Do not help aerate roots
    - Important role in CO_2 exchange
  - Mangrove pneumatophores, root knees and plank roots
    - Do play role in aeration - ~40% of root system is gas space
- Prop roots and drop roots – develop from stems or branches and drop into soil
  - Mangroves
    - Provide stability
    - Improve aeration



www.wettropics.gov.au/ pa/pa_images

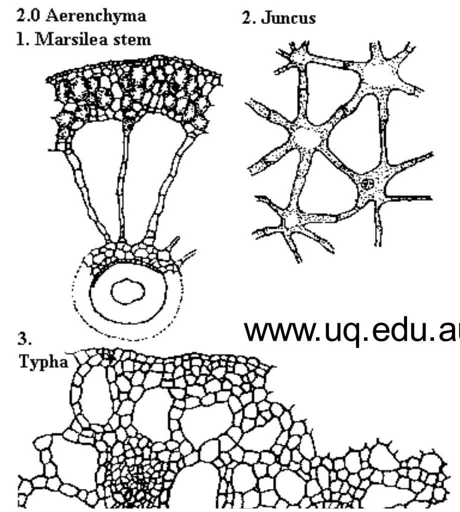
Black Mangrove pneumatophores

http://www.sfrc.ufl.edu/4H/Other_Resources/Contest/Highlighted_Ecosystem/MangroveEnvfac.htm

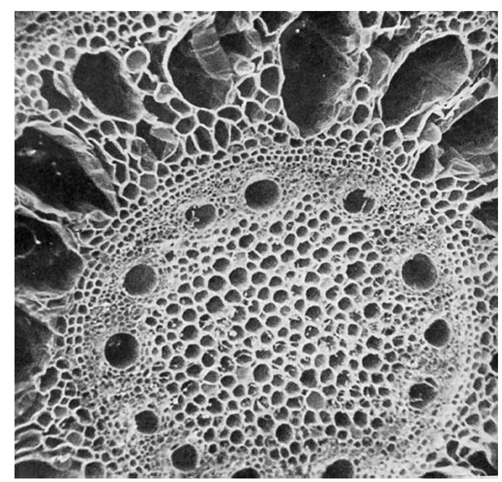
Strategies for limited oxygen: **Structural adaptations**

- Make it easier to move oxygen through the plant
  - **Aerenchyma** – special tissues
  - Rapid gas exchange pathway: diffusion through porous tissues.
    - In some species, air space extends from leaves to roots (e.g., Spartina).
    - Cattails – ½ leaf volume is gas storage. Internal concentration of carbon dioxide is up to 18 times great than atm.

Lacunae = gas-filled spaces



www.uq.edu.au



http://www.sfrc.ufl.edu/4H/Other_Resources/Contest/Highlighted_Ecosystem/aerenchyma1.jpg

Strategies for limited oxygen: Stem adaptations

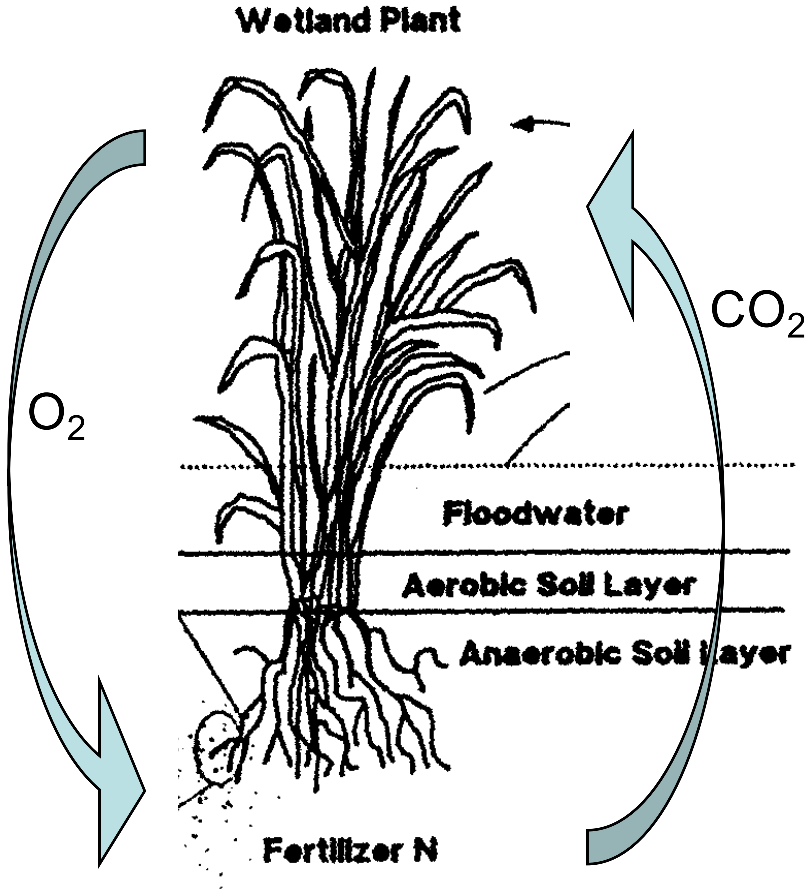
- Rapid underwater shoot extension & stem elongation in response to flooding
  - Access to light, oxygen, and CO_2
  - Happens when normally exposed leaves are submerged
  - Early season stem elongation
- Stem buoyancy
  - Formation of aerenchyma
    - Aerenchyma allow submerged plants to remain upright and form canopies.
  - Floating-leaves - use water for support – saves energy on structural tissue

www.lucidcentral.org/ keys/appw/nonkey/images

www.plant-identification.co.uk

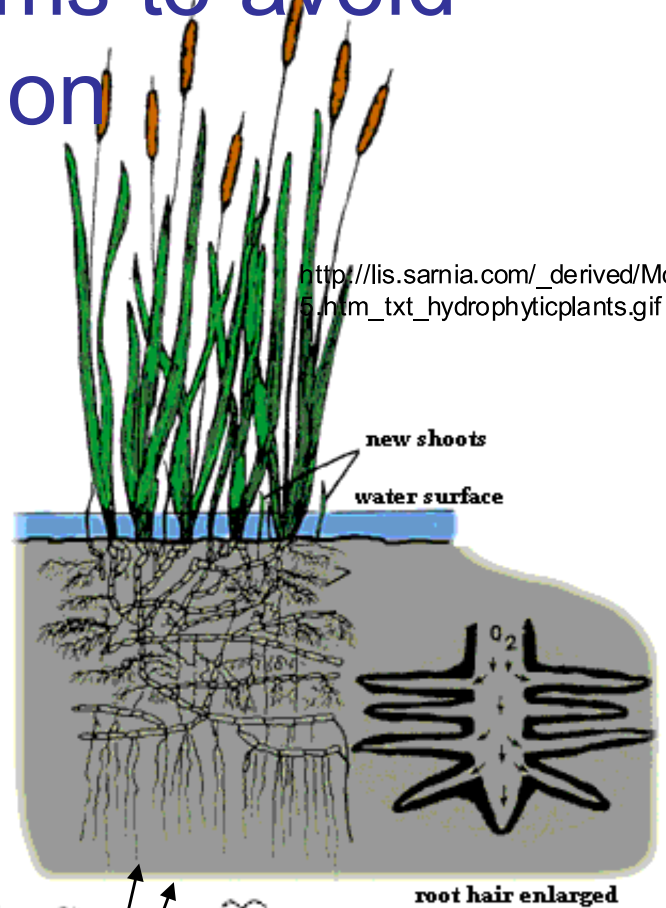
Strategies for limited oxygen: Aerenchyma

- Allow O_2 to travel to roots by diffusion, effectively aerating roots.
- More reduced the conditions, more porous the plant tissue

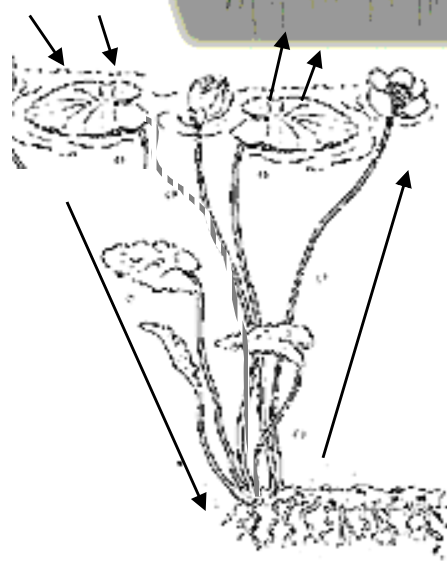


Gas Transport Mechanisms to avoid oxygen deprivation

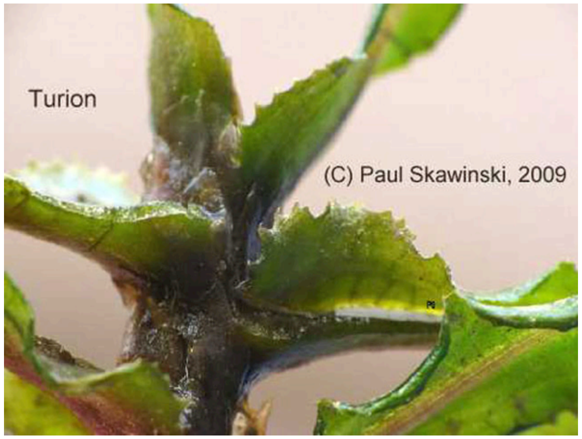
- Passive molecular diffusion
  - Primary mechanism
  - Oxygen usually higher in aerial parts of plant than roots
  - *Phragmites australis* stems 20.7%, rhizomes 3.6%
- Pressurized ventilation
  - Air into stomata of younger leaves (smaller pores – support pressure gradients), down to rhizomes, up stems of older leaves, and out
  - Driven by temperature and water vapor pressure differences between inside of leaves and air
  - *Nuphar lutea*
  - Rhizomes get oxygen!



http://lis.sarnia.com/_derived/MonoL5.htm_txt_hydrophyticplants.gif



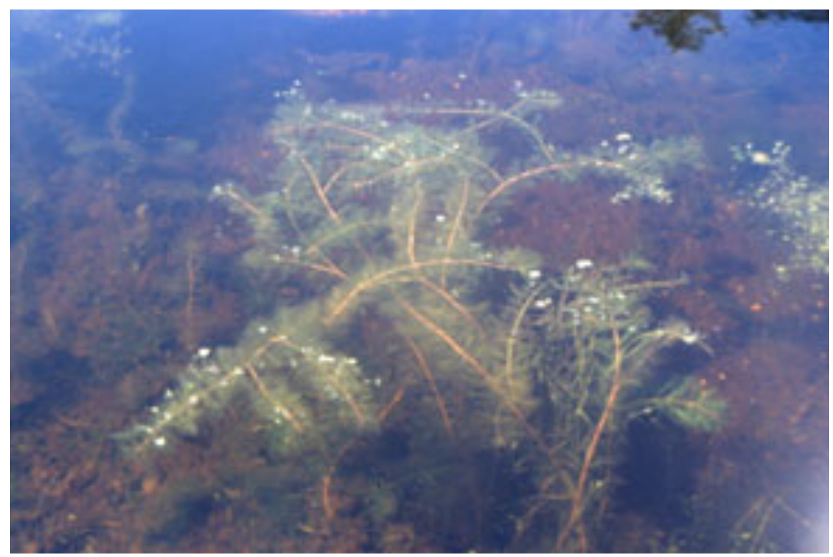
Strategies for limited oxygen: Avoidance of anoxia



- Avoid anoxia in time and space
  - Time active growth or seedling establishment to avoid flooding
    - Reduce metabolism in winter to avoid oxygen deprivation
    - E.g., tulip tree can survive flooding, except in spring when actively growing
  - Reproduce by seed dispersal to new areas
- Reach oxygen-rich atmosphere quickly
  - Avoid low oxygen periods, then grow very quickly using <u>stored</u> carbon and nutrients
    - Overwintering carbohydrate-rich structures survive anoxic sediments until plant reaches water surface
      - (e.g., turions, bulbs, rhizomes)
- (Alter environment around roots)

Submerged plants have it especially tough!

- Limited by light and carbon
- CO_2 (primary form of inorganic carbon for photosynthesis) diffuses ~10,000 times more slowly in water than in air
  - Submerged plants can use bicarbonate ions for photosynthesis
  - Some can use inorganic carbon from the sediments



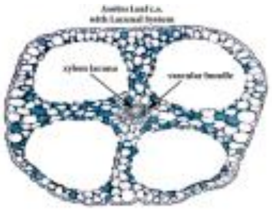
3. Strategies for limited light: Adaptations

- Make it easy to absorb the light
  - Chloroplasts on leaf surface rather than in mesophyll
  - Higher chlorophyll concentration (higher photosynthetic rate at low light
- Increase surface area exposed to light
  - Leaves ribbon like or highly dissected (high surface area to volume ratio
    - Also helps get dissolved gases into plant inner tissues as do wavy-edged leaves

- Grow toward the light
  - Apical growth (from tip of stalk) allows concentration of leaves at water surface
    - Also can outcompete other plants by getting all the goods (E.g., *Myriophyllum spicatum)*
- Start REALLY early
    - E.g., Curly leaf pondweed (*Potamogeton crispus*)

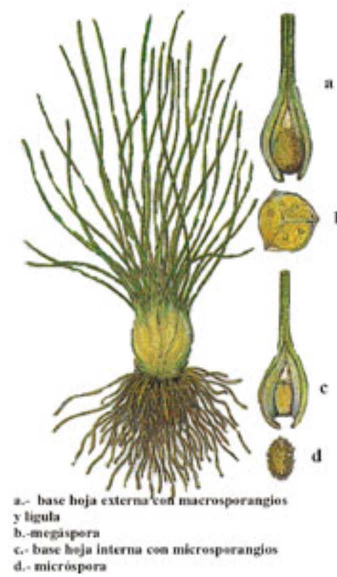
4. Strategies for limited carbon dioxide:

- Same characteristics that help with light and oxygen
- Use bicarbonate when CO_2 limited
  - Plants that can use either carbon dioxide or bicarbonate have more habitats available to them
- Aquatic acid metabolism
  - Assimilate carbon dioxide at night when more plentiful
    - Get CO_2 at night by diffusion, tie up into carboxyl group of organic acid, and decarboxylate the next day, releasing CO_2 for photosynthesis



Limited carbon dioxide:

- Aerenchyma transport
  - Recycle respired carbon dioxide within aerenchyma and use in photosynthesis
  - See this in soft water lakes with low carbon (e.g., *Isoetes*)
  - Maintain internal CO_2 pressures higher than external pressures
- Sediment-derived CO_2
  - Can be up to 90 % of carbon uptake in some submerged species
- Diffusive Boundary Layer – submerged plants have no stomata – get by with molecular diffusion



5. Strategies for limited nutrients: Adaptations

- Obtaining nutrients
  - Mychorrhizal associations
  - Nitrogen fixation
  - Carnivory
- Conserving nutrients
  - Nutrient translocation
  - Evergreen leaves

Limited Nutrients: Obtaining nutrients

- Mychorrhizal associations – symbiotic fungi
  - Increase plant ability to capture water, phosphorus, nitrogen, potassium
  - Plant provides carbohydrates to fungi
  - More mycorrhizal infection in areas with low phosphorus and more oxidized soils
- Nitrogen fixation
  - N_2-fixing bacteria get energy from plant
  - Plant gets added N
    - Found in aquatic legumes, *Alnus, Myrica,* some mangroves probably get nitrogen from cyanobacteria

Limited Nutrients: Obtaining nutrients

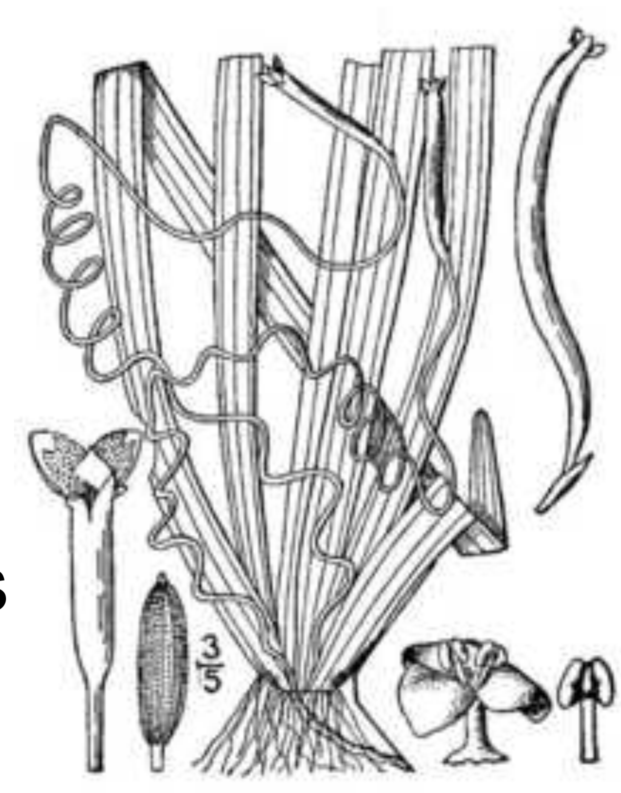
- Carnivory
  - Many species in nutrient poor peatlands
  - Types of traps
    - Pitfall (pitcher plant – *Sarracenia*)
    - Lobster pot
    - Passive adhesive
    - Active adhesive (sundew – *Drosera*)
    - Bladder trap (bladderwort – *Utricularia*)
    - Snap trap (Venus' flytrap – *Dionaea)*
  - *Utricularia* found in wide range of nutrient regimes. Why?
  - Facultative carnivory – cost of maintaining structures versus benefits of additional nutrients

Limited Nutrients: Conserving nutrients

- Nutrient translocation
  - At end of active growing season
    - Move nutrients and carbohydrates from aboveground tissues to belowground ones such as roots, rhizomes, tubers, bulbs
    - Store as source of energy for next growing season's initial growth
      - E.g., Pond cypress – foliar nitrogen 3x higher in spring than fall
- Evergreen leaves
  - Ericaceae (e.g., blueberries) – low nutrient peatlands
    - Retain their leaves for 2 years

6. Aquatic Plant Reproduction

- Really good at reproducing asexually
  - Fragmentation
  - Rhizomes
  - Stolons (above the sediments)
- Submerged plants have to reproduce underwater
- Cool, but few examples of sexual reproduction in submerged plants
  - *Vallisneria*



Adaptations to herbivory

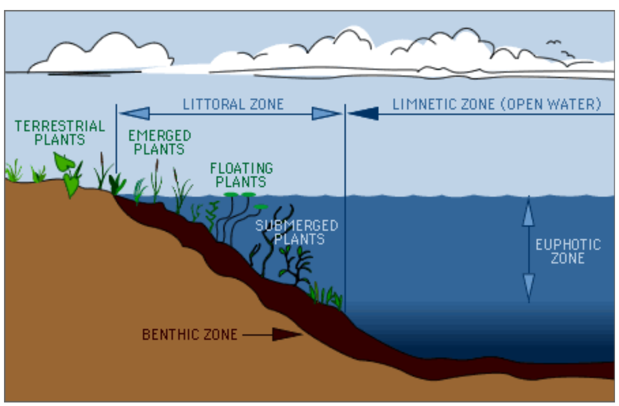
- Chemical defenses
  - Many wetland plants produce secondary metabolites that are unpalatable to herbivores
  - Plants that live a long time tend to use chemical defenses more
    - Cost/benefits?
  - Nymphaceae – produce alkaloids that are toxic to many invertebrates
- Structural defenses
  - Thorns, hairy leaves, leathery leaves

Aquatic environment

- Evolution of:
  - Specialized tissues and processes, e.g., aerenchyma (tissue with intercellular air spaces), & diffusion of oxygen from roots to sediments.
  - Life history changes (timing of seed production, vegetative reproduction)
  - Phenotypic plasticity in response to changing environmental conditions.

Types of Wetland Plants: Emergents

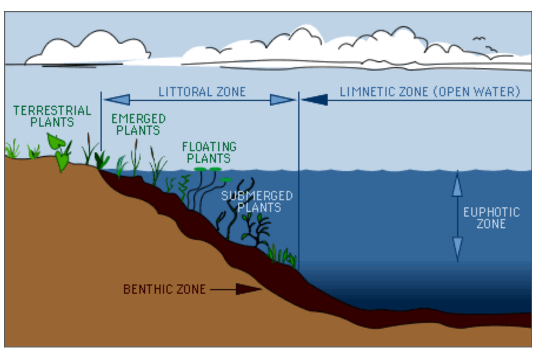
- Root in soil, with aerial leaves, stems, reproductive organs
- CO_2, O_2 from air
- Nutrients from soil/ sediment.



www.nccoastalmanagement.net/ Handbook/section2.htm

Types: Floating Leaved

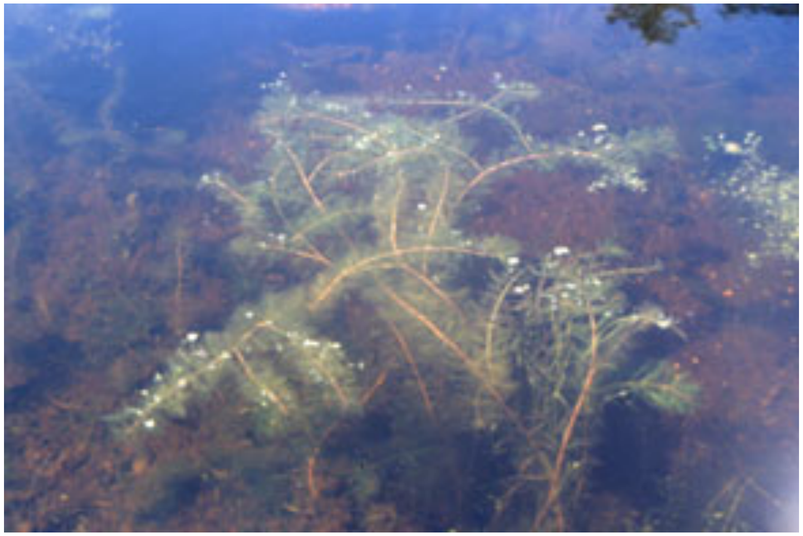
- Floating leaf shape – most circular, oval or cordate (why?)
  - Leathery texture resistant to herbivory and wetting
- Long flexible petiole – no supportive tissue
- Stomata on aerial side.
- May have heterophylly

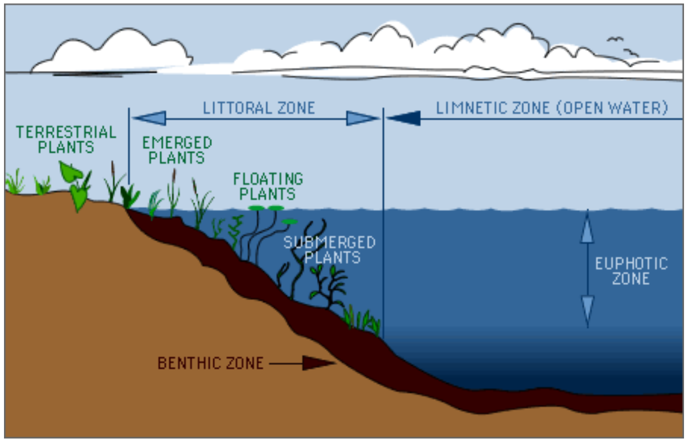


Ranunculus peltatus
http://www.zum.de/stueber/lindman/167.jpg

Types: Submergent

- Photosynthetic tissues are underwater.
- Stems and leaves are soft (no lignin); either elongate, ribbon-like, highly divided, or wavy-edged
- Take up DO and inorganic carbon from water column.
- Majority of nutrients and some inorganic carbon from sediments (some from water column).
- Examples: *Vallisneria* (water celery), *Utricularia, Myriophyllum, Potamogeton* (pondweed).





www.biosurvey.ou.edu

Questions?