NUTRIENTS
&
NUTRIENT CYCLING

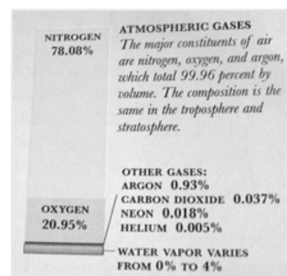
GLOBAL CYCLES
and
HUMAN IMPACT
on
THE ENVIRONMENT

GLOBAL CYCLES

- Nutrient cycling usually viewed from a local perspective
- Biogeochemical cycles from differing ecosystems are often linked
- Gaseous cycles are better viewed from a global perspective

THE GLOBAL OXYGEN CYCLE

- Major supply of free oxygen is in the atmosphere
- Oxygen sources:
  - Photodissociation of water vapor
  - Photosynthesis



THE GLOBAL OXYGEN CYCLE

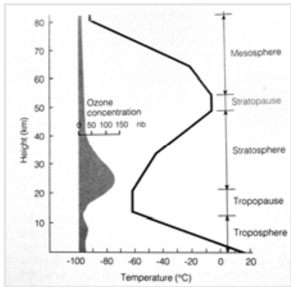
- Oxygen is in a dynamic equilibrium between production by photosynthesis and consumption in respiration
- Involved in oxidation of carbohydrates in <u>respiration</u> releasing energy, CO_2 and water
- Oxygen is extremely reactive and is involved in many nutrient cycles

THE GLOBAL OXYGEN CYCLE

- Oxygen and nitrogen forms nitrates
  - ~3% of oxygen produced by photosynthesis is used to oxidize ammonium in nitrification
- Oxygen in the higher levels of atmosphere reduces to ozone (O_3) in the presence of UV radiation

OZONE

- **Most ozone found in the stratosphere 20-35 km above earth**
- **Ozone absorbs most of the UV radiation**
- **Radiates IR outward**
- **<u>Ozone shields earth from UV radiation</u>**

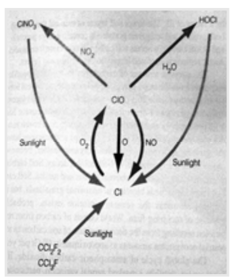


OZONE

- **Ozone maintained by cyclic photolytic reaction:**
  $O_2 + hv \Rightarrow O + O$
  $O + O_2 = O_3$
- **Consumes a large amount of solar energy**
- **Other reactions (oxides of N and H) destroy ozone and maintain a balance between O_2 and O_3**
  - **$NO + O_3 \Rightarrow NO_2 + O_2$**
- **Natural balance in the stratosphere between formation and destruction**

OZONE

- **Catalysts injected into stratosphere have caused a decrease in ozone**
- **Chlorofluorocarbons (CFC), methane (CH_4), nitrous oxide (NO_2)**
- **Ozone layers over both poles are thinning; more UV radiation getting through the atmosphere**



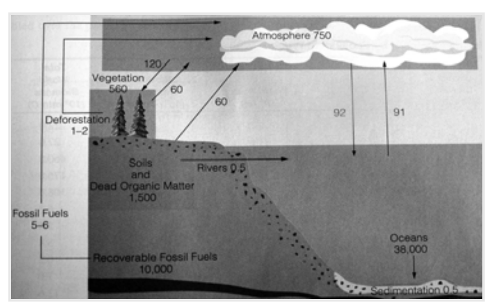
OZONE
Impact on urban and rural trees

- **To determine impact of urban pollution on tree growth planted cottonwoods in and around NYC**
- **City trees thrived, rural trees did not (1/2 biomass)**
- **Why? Ozone – precursors formed in the city but move to rural areas before ozone forms**
- **Nitric oxide (NO) dismantles ozone, but NO low in rural areas so ozone remains longer**
- **Conclusion: urban effects extend well beyond the city**

GLOBAL CARBON CYCLE

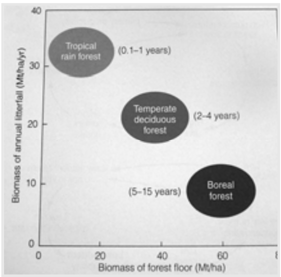
- **Most carbon is buried in sedimentary rock; not actively involved in the global carbon cycle**
- **Oceans contain the majority of the active carbon pool; HCO_3^- and CO_3^-**
- **<u>Uptake</u> of CO_2 by terrestrial ecosystems governed by photosynthesis**
- **<u>Losses</u> of CO_2 from respiration: autotrophs and heterotrophs**

GLOBAL CARBON CYCLE



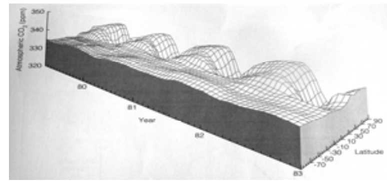
All values in Gt of carbon; exchanges annual

GLOBAL CARBON CYCLE



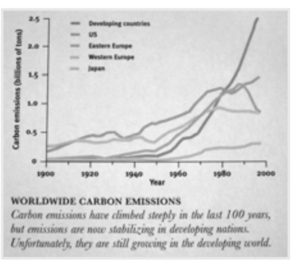
- **Carbon stored in soils and biomass**
- **Three times more in soil than in biomass**
- **Carbon/unit of soil ⇧ from tropics to boreal forests**
- **Low values for tropic – high rate of decomposition**

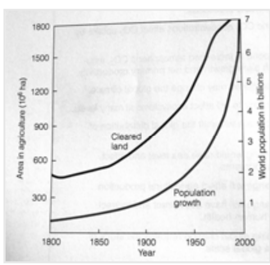
GLOBAL CARBON CYCLE



- **Annual variation in atmospheric carbon dioxide**
- **Fluctuations most prominent in temperate Northern Hemisphere**

GLOBAL CARBON CYCLE





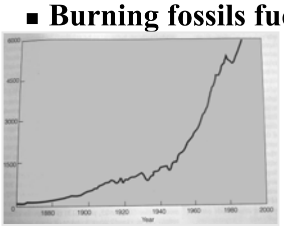
GLOBAL CARBON CYCLE

CO_2 balance among land, sea and atmosphere disturbed by:

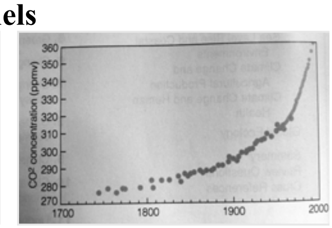
- **Clearing forests:**
  - **Productivity immediately declines**
  - **Soil temperature increases; transpiration decreases**
  - **Rate of decomposition increases with greater return of CO_2 to atmosphere**
  - **Rate of nutrient loss *via* leaching increases**

GLOBAL CARBON CYCLE

- **Burning fossils fuels**



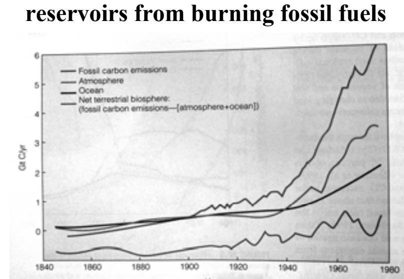
Annual input of CO_2 from fossil fuel burning
(in million Mt Carbon)



Atmospheric CO_2 over 300years

GLOBAL CARBON CYCLE

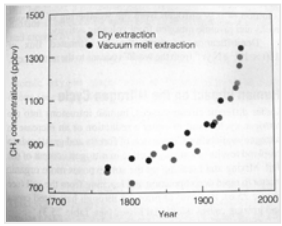
Carbon changes in major global reservoirs from burning fossil fuels



Atmospheric values from observations and ice core analysis

GLOBAL CARBON CYCLE

- Methane (CH_4): ruminant animals, decomposition, industrial gases
- Oxides to water over time (3.2 years)
- Doubled over last 200 years due to increased population, cattle ranching and rice paddies



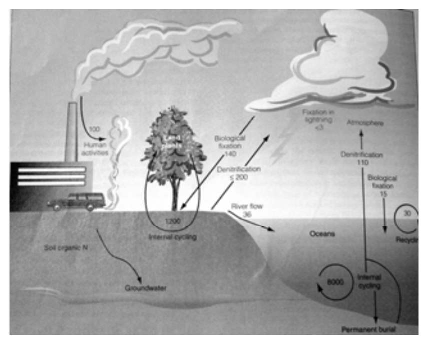
GREENHOUSE GASES

- Absorb long wave and thermal energy
- CO_2 and water vapor principal gases
- Others include:
  - Methane
  - CFCs & HCFCs
  - Nitrous oxide & sulfur dioxide
- Lower in concentration but more effective trapping heat

GREENHOUSE GASES
Effects on Global Climate

- Increase in average global temperature
- Changes not uniform
- Warming greatest during winter and in northern latitudes
- Increased variability in climate
  - More storms and hurricanes
  - Greater snowfall
  - Variable rainfall

GLOBAL NITROGEN CYCLE

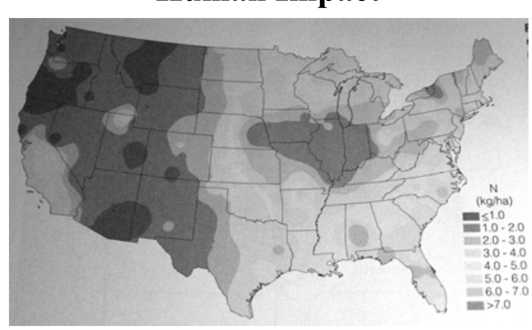


Values = 10^{12}gN/yr

GLOBAL NITROGEN CYCLE
Human Impact

- Major sources automobiles and power plants
- Conversion to cropland results in steady decline of N soil content
- Excessive N may be added *via* commercial fertilizers
  - Extra N leached to groundwater
- Human waste especially from urban sewage treatment

GLOBAL NITROGEN CYCLE
Human Impact

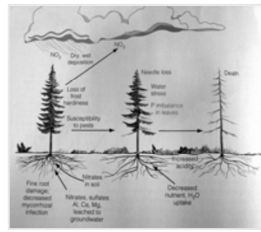


Inorganic N deposition from nitrate and ammonium, 1998

GLOBAL NITROGEN CYCLE
Human Impact

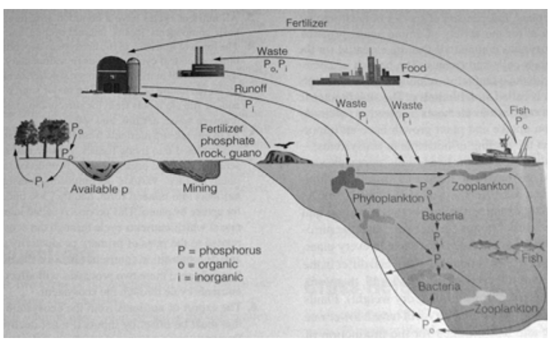
- **Atmospheric pollution from automobiles and power plants**
  - **Nitrogen dioxide produces brownish haze**
  - **Reacts with oxygen and other molecules to form other pollutants**
- **Increased deposition of N leads to Nitrogen saturation and leaching**

GLOBAL NITROGEN CYCLE
Human Impact



- **First response to excess N: increased growth**
- **Decline and dieback in conifer forests**
- **Excess growth exceeds availability of other nutrients**
- **Ammonium levels increase; Al^{3+} released; increased acidity**

GLOBAL PHOSPHORUS CYCLE



GLOBAL PHOSPHORUS CYCLE

- **No significant atmospheric component**
- **Derived from weathering of calcium phosphates - low availability**
- **Internal cycling is the major regulation**
- **Essential in energy transfer and component of nuclear material**

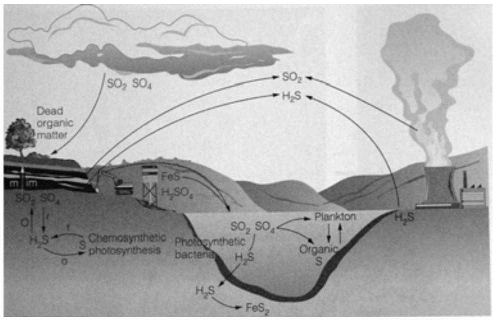
GLOBAL PHOSPHORUS CYCLE

- **Forests on infertile soil cycle P more efficiently than those on moderately fertile soils**
- **Phosphorus –most limiting factor on infertile soils such as the Utisol soil**
- **P Cycle altered by application of fertilizers**
  - **Combines with Ca, Fe and NH_4 to form insoluble salts**
- **Over enrichment (eutrification) of freshwater ecosystems; algae thrive**

GLOBAL SULFUR CYCLE

- **Gaseous phase allows global circulation**
- **Atmosphere contains <u>sulfur dioxide</u>, <u>hydrogen sulfide</u> and <u>sulfate particles</u>**
- **Gases combine with moisture to be recirculated**
- **Terrestrial biogenic sources minor compared to atmosphere**
- **Dimethylsulfide major biogenic source from oceans**

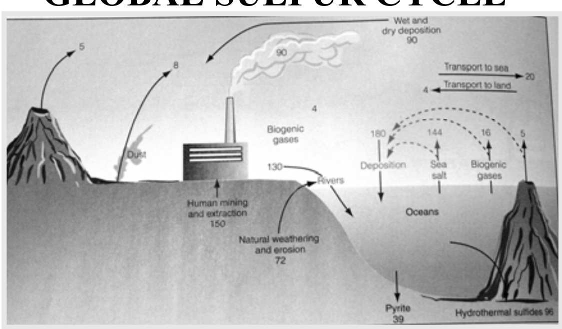
GLOBAL SULFUR CYCLE



GLOBAL SULFUR CYCLE
Human Impact

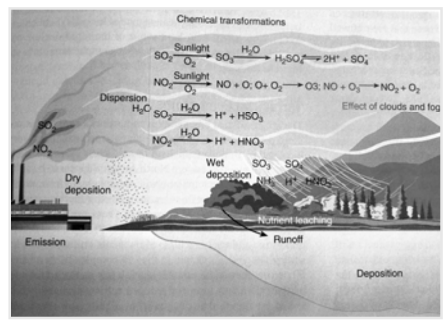
- **Largest source of sulfur gases from industrial activities**
- **Deposited as precipitation and dry fall**
- **Transported *via* air and rivers (>25% of sulfate in rivers from human activities – air pollution, mining, etc.)**

GLOBAL SULFUR CYCLE



Values shown in units of 10^{12} gS/yr

GLOBAL SULFUR CYCLE



ACID DEPOSITION

- **High concentrations of SO_2 associated with respiratory problems, increased rate of asthma**
- **Plants injured or killed –worst during foggy periods**
- **Ferrous sulfide (released during mining) and water yield sulfuric acid and ferrous sulfate**
- **Ferrous sulfate and ferrous hydroxide destroy aquatic life**

ACID DEPOSITION

- **Nitrogen oxide reacts with oxygen and water to produce nitric acid**
- **Precipitate in acid rain, snow and fog**
- **Acidity in eastern N. America and Northern and Central Europe has increased 2-16 times more than areas not subject to industrial fall out.**
- **Annual pH of rain 2.3 to 4.6(normal = 5.6)**

ACID DEPOSITION

- **Acid inputs into <u>aquatic systems</u> release Aluminum, which may the most toxic pollutant**
- **Acid inputs in acidic soil results in increased leaching of nutrients, shrinking of calcium pool, increased solubility of Al and reduced nutrient availability**
- **Acidic fog leaches Ca, Mg, and K from needles/leaves**

OTHER HUMAN IMPACTS

- **<u>Heavy metals</u>: Lead, Cadmium, Mercury**
  - **1° source of lead – leaded gasoline, paint**
  - **Absorbed by plants and move up the food chain**
  - **Lead causes mental retardation, anemia, paralysis**
- **<u>Chlorinated hydrocarbons:</u>**
  - **Highly fat soluble, long half life ~ 20 yrs.**
  - **DDT – banned in US, PCB – toxic waste from sewage and industry**

OTHER HUMAN IMPACTS

- **<u>Radionuclides</u>: fission and non-fission products**
  - **^{90}Sr and ^{137}Cs behave like calcium and follow it in nutrient cycling**
  - **Lichens to caribou to Native Alaskans**
  - **High levels during early nuclear testing and again with the Chernobyl disaster**

SUMMARY

- **Oxygen - a dynamic equilibrium:**
  - **Byproduct of photosynthesis**
  - **Consumed in respiration**
- **Ozone – part of oxygen reservoir**
  - **Blocks much of UV portion of solar radiation**
  - **CFC, No_n, other oxides can destroy ozone**
- **Carbon dioxide uptake governed by photosynthesis**

SUMMARY

- **CO_2 losses from respiration, greatest from microbial decomposers**
- **Increased carbon dioxide output from loss of forests and burning fossil fuels**
- **Clearing forests:**
  - **Productivity immediately declines**
  - **Soil temperature increases; transpiration decreases**
  - **Rate of decomposition increases with greater return of CO_2 to atmosphere**
  - **Rate of nutrient loss *via* leaching increases**

SUMMARY

- **Nitrogen oxides from:**
  - **Automobiles**
  - **Power plants**
  - **Implicated in forest decline**
- **Excessive amounts of nitrates from fertilizer, animal waste, sewage – pollute aquatic systems**
- **Nitrous oxide is reduced by UV light to react with hydrocarbons to produce pollutants**

SUMMARY

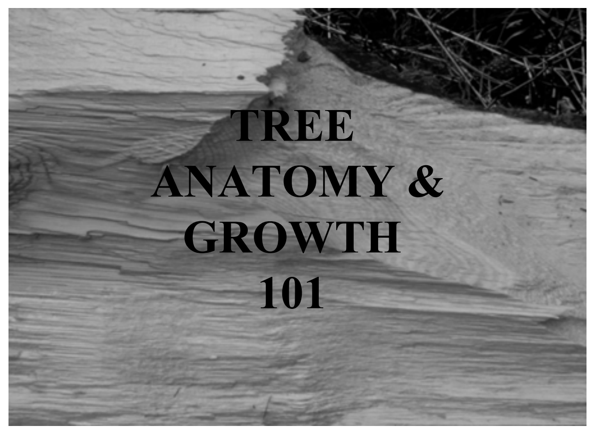
- **Phosphorus has no atmospheric component**
- **Natural source: weathering of Ca phosphate minerals**
- **Transfer to aquatic systems naturally low**
- **Large-scale application of fertilizers and disposal of sewage and wastewater causes large input of P to aquatic systems – algae thrive**

SUMMARY

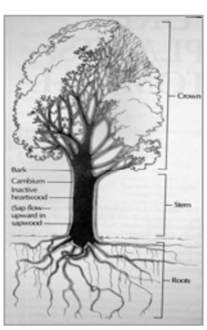
- **Sulfur cycled primarily in gaseous state**
- **<u>Sources</u>: volcanoes, ocean surface, decomposition, combustion of fossil fuels**
- **Sulfur dioxide, released by burning fossil fuel, major pollutant as H_2SO_4**
- **Kills plants, increased respiratory disease**
- **Acid deposition major problem downwind of major industry**

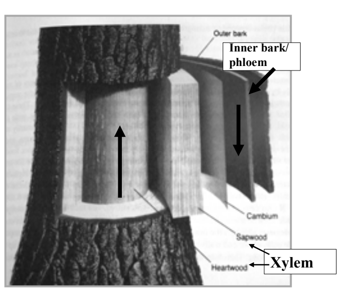
SUMMARY

- **Heavy metals: source – industrial use; serious health problems**
- **Chlorinated hydrocarbons: insect control and industrial uses. Fat soluble and enter food chain harming predaceous animals (reproduction)**
- **Radionuclides: can concentrate in food chain**



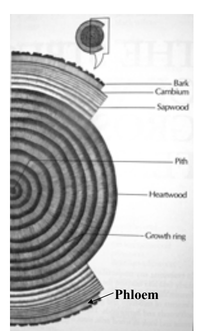
TREE ANATOMY





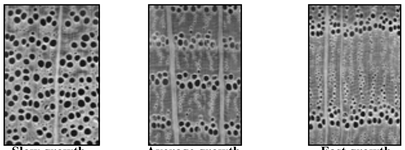
Vertical arrows indicate direction of flow

TREE ANATOMY



- **<u>Bark</u>: outer skin; protective covering**
- **<u>Phloem</u>: inner bark; nutrient flow from leaves**
- **<u>Cambium</u>: meristematic tissue giving rise to diameter growth (secondary growth)**
- **<u>Xylem: (</u>heartwood and sapwood) water conduction; dead tissue**
- **<u>Growth ring</u>: annual increment**

TREE ANATOMY
Growth Rings

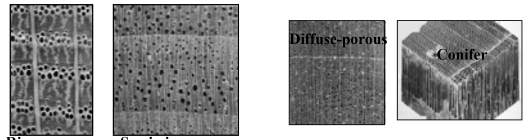


Slow growth Average growth Fast growth

Quercus rubra **(15X)**

- **Dendrochronology: Study of tree rings**
  - **Assess global climate change; variations in temperature and moisture**
  - **Date time of structure of historical ruins**

TREE ANATOMY

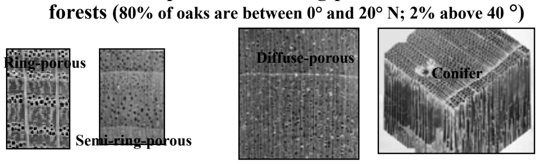


Ring-porous Semi-ring-porous

- **Ring-porous woods (oaks, hickory, ash, elm, walnut):**
  - **Tolerate water deficiency better than others**
  - **Delayed flushing/bud burst – escape early frosts**
  - **Susceptible to freezing and air lock (not boreal)**
  - **Water conducted in youngest rings; susceptible to some disease (chestnut blight; Dutch elm disease)**

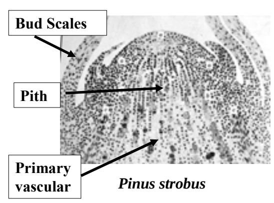
TREE ANATOMY

- **Small xylem cells (conifers and some diffuse-porous trees):**
  - **Resistant to blockage of flow from air lock with freezing**
  - **Root pressure enough to overcome small gaps**
  - **Boreal and alpine trees; no ring-porous trees in boreal forests (80% of oaks are between 0° and 20° N; 2% above 40 °)**

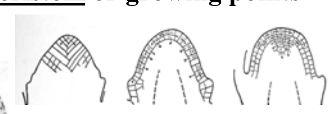


TREE ANATOMY
Growth - Apical

- **<u>Primary Growth</u>: Elongation/ longitudinal growth: <u>Apical meristem</u> or growing points**

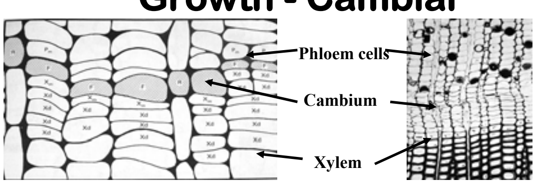


Pinus strobus



Active growth confined to very tips of apical meristem

TREE ANATOMY
Growth - Cambial



- **Cambial activity/cessation triggered by environmental factors: light, heat, moisture, etc.**
- **Stimulated by auxins (growth hormones) produced in expanding buds and growing points**
- **Resumption of activity varies in ring-porous, diffuse-porous and conifers**

TREE ANATOMY
Growth -Cambial

- **Ring-porous trees:**
  - **Resumption of cambial activity at early stage of bud swelling and extends rapidly**
- **Diffuse-porous trees:**
  - **Spread of cambial activity is slow**
- **Conifers:**
  - **Cambial activity begins at the base of buds but pattern of spread not certain, depends on vigor and distribution of old foliage**

STRUCTURE & GROWTH
<u>Primary Growth</u>

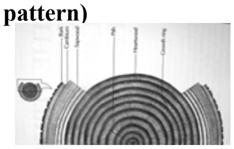
Extension of growing points forming shoots/roots

- **Tree shape determined**
- **Begins with bud break**
- **Triggered by photoperiod, accumulated warmth, moisture**
- **Most elongation occurs when growing space is maximal and risk of frost, desiccation and heat damage are minimal**
- **Time of growth varies with climate, species, local weather**

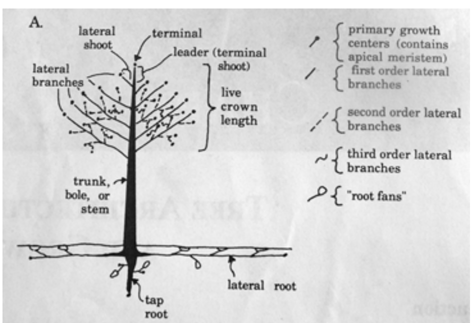
STRUCTURE & GROWTH
<u>Secondary growth</u>

Expansion of stem and root diameter

- **Shoot elongation triggers hormones stimulating secondary growth**
- **Begins later than primary growth**
- **Sensitive to available space**
- **Earlywood / latewood (preformed growth pattern)**



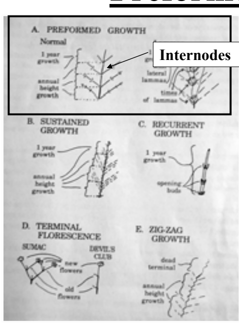
STRUCTURE & GROWTH



STRUCTURE & GROWTH
Shoot development patterns

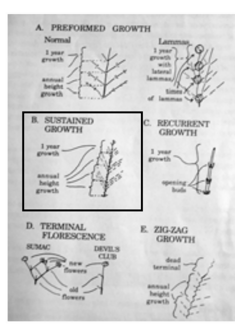
- **Dictate tree's architecture by controlling:**
  - **Branch growth**
  - **Crown shape**
  - **Stem growth**
- **Five growth patterns common to temperate forests of North America**
  - **Preformed growth – Determinate**
  - **Sustained growth- Indeterminate**

STRUCTURE & GROWTH
<u>Preformed (Determinate)</u>



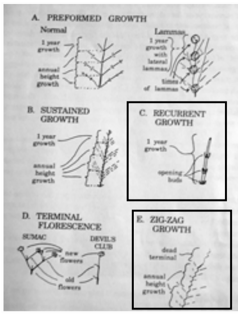
- **Buds formed represent all the tissues for next season; miniature of next stem and leaf**
- **Early, rapid growth**
- **Oaks, true fir, D-fir, hickories, spruce, ash, pines**
- **Terminal and upper laterals develop most vigorously**
- **"Conservative strategy"**

STRUCTURE & GROWTH
<u>Sustained (Indeterminate)</u>



- **Primordia enclosed in winter bud a portion of the potential growth**
- **Not all primordia develop before active shoot growth (site sensitive)**
- **Hemlock, yellow-poplar, red maple, sweetgum**
- **Do NOT expand as rapidly as Preformed type but grow longer time**
- **"Exploitive strategy"**

STRUCTURE & GROWTH
Shoot development patterns



- **Recurrent growth: typical of southern pines**
- **Bud primordia telescoped inside each other**
- **May produce whorls of shoots**
- **Aborted tip or 'zigzag' growth: Each leaf a direct continuation of the branch; distal stem grows at an angle**
- **Typical of birches, redbud, some elm**

STRUCTURE & GROWTH
Shoot development patterns

- **Apical (epinastic) control: the degree to which the terminal leader maintains control over the growth of laterals.**
  - **Strong control – conical tree form**
  - **Weak apical control – rounded form**
- **Apical control import to vertical growth**
- **Phototropism: growth response toward light**

STRUCTURE & GROWTH
Crown Shapes

- **Vary from columnar to almost flat-topped**
- **Epinastic control: The terminal bud controls the length and orientation of lateral branches; determined by growth of central stem and lateral branches**
- **Shapes result from inherent growth form of the species and environmental influences**
- **Columnar crowns found at higher elevations and latitudes**
- **Gradient in shape occurs with latitude; attributed to light absorption**

STRUCTURE & GROWTH
Crown Shapes

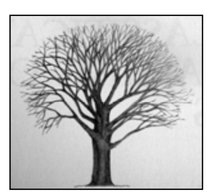
- **Excurrent growth form- strong apical (epinastic) control**
  - **Typical of conifers and some deciduous trees (yellow-poplar and sweet gum)**
  - **Terminal leader in control of growth**

STRUCTURE & GROWTH
Crown Shapes

- **If the terminal is killed in a tree with strong epinastic control, uppermost laterals turn upward**
- **The most vigorous branch will grow straight up and the others resume their horizontal orientation**

STRUCTURE & GROWTH

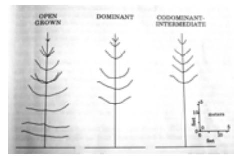
- **Decurrent/ Deliquescent growth form:**
  - **Lateral branches grow nearly as fast as the terminal leader**
  - **Apical control is lost, repeated forking occurs**
  - **Spreading form allows light to reach leaves**



STRUCTURE & GROWTH
Crown Shape Factors
Branch Abrasion

- Occurs when distal branches rub together during windstorms
- Contributes to dominance of trees with strong lateral branches, such as those with strong preformed growth
- May give crowns a sculpted appearance

STRUCTURE & GROWTH
Crown Shapes Factors

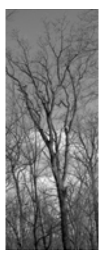


Light - Phototropism

- Each branch must photosynthesize enough to survive and grow
- Lateral growth is reduced in shade and branches die
- Shade determines crown length

STRUCTURE & GROWTH
Crown Shapes Factors
Light

Open-grown White Oak



Forest-grown Chestnut Oak

STRUCTURE & GROWTH
Shade Tolerance

- Shade Tolerance: The ability of a plant to subsist in the shade of other plants
- Shade Tolerance is related to the species' ability to utilize light at low intensity
- Trees are classed as:
  - Tolerant
  - Intermediate
  - Intolerant

STRUCTURE & GROWTH
Shade Tolerance

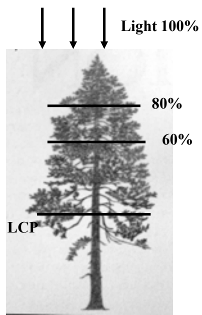
- Light compensation point (LCP): the light intensity at which photosynthesis equals respiration (No net gain or loss of CO_2)
- Shade tolerant species have a lower LCP than do shade intolerant species

STRUCTURE & GROWTH
Shade Tolerance

- Leaves grown under shaded conditions have reduced rates of respiration & thus a reduction in LCP as well as reduced rate of photosynthesis
- As irradiance > LCP photosynthesis increases proportionately if other factors are favorable

STRUCTURE & GROWTH
Shade Tolerance

- When PS < RS eventual death results
- A seedling getting < required light will live for a while on stored carbohydrates in the seed
- Below the LCP natural pruning occurs

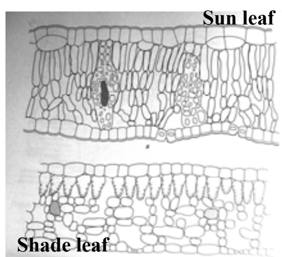


STRUCTURE & GROWTH
Shade Tolerance

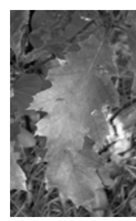
SPECIES	LCP	SHADE TOLERANCE
Ponderosa pine	30.6%	Intolerant
Douglas-fir	13.6%	Intermediate
Red oak	13.3%	Intermediate
White pine	10 %	Intermediate
E. Hemlock	8.0%	Tolerant
American beech	7.5%	Tolerant
Sugar maple	3.5%	Very tolerant

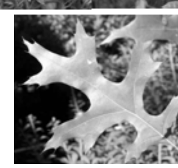
STRUCTURE & GROWTH
Effect of intense light on plants

- Sun leaves: Thicker/ thick walls
- Deep palisade structure
- Sun leaves generally less surface area
- Species specific; understory trees not as striking



STRUCTURE & GROWTH
Shade Tolerance




STRUCTURE & GROWTH
Light

- Light is one of the most variable factors in the forest and one of the few things the forester can influence

STRUCTURE & GROWTH
Roots & Root Growth

STRUCTURE & GROWTH
Roots & Root Growth

- **Functions:**
  - **Firm anchoring of the tree – entire system**
  - **Absorption of water and nutrients – fine non-woody roots**
- **Larger roots:**
  - **Store carbohydrates**
  - **Synthesize organic compounds**
  - **Transport**
  - **Generation of vegetative shoots**

STRUCTURE & GROWTH
Roots & Root Growth

- **Roots of angiosperms more extensive and efficient than of conifers**
- **Roots of conifers have greater ability to extract nutrients from soil**
- **Roots of deciduous trees have extensive and fine root systems to absorb nutrients from decomposition**

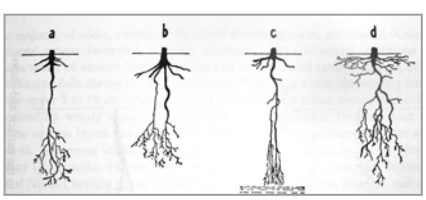
STRUCTURE & GROWTH
Roots & Root Growth

- **Root system includes:**
  - **Framework of large, woody, long-lived roots**
  - **Small, short-lived, non-woody absorbing roots**
  - **Apical meristem at root tips**
- **Tap roots provide early stability; most common on dry and fire prone sites**
- **Tap roots are common in pines and large-seed trees (oaks, hickories, walnuts)**

STRUCTURE & GROWTH
Roots & Root Growth

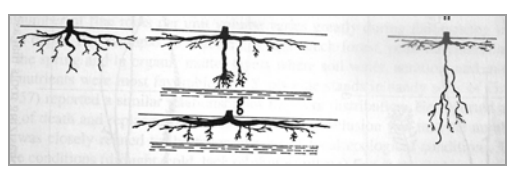
- **Form of root system controlled genetically and influenced by site factors**
- **In wet areas root system is shallow**
  - **Tree susceptible to <u>windthrow</u>**
- **Rooting may be curtailed by quality of the soil**

STRUCTURE & GROWTH
Roots & Root Growth



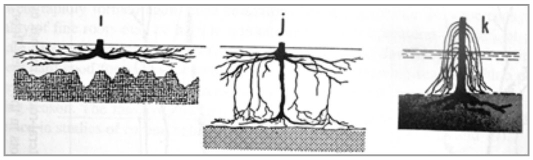
- **Taproots with reduced upper laterals**
- **Found in coarse, sandy soils**

STRUCTURE & GROWTH
Roots & Root Growth



- **Flattened, plate-shaped root system responding to soil type and water**
- **Bimorphic system in leached soils with rich surface**

STRUCTURE & GROWTH
Roots & Root Growth



- "i" - Flatroot in strongly leached soils with raw humus and hardpan below
- "j" – Hardpan below
- "k" – Pneumatophores in tidal lands

STRUCTURE & GROWTH
Roots & Root Growth
Pneumatophores

Bald cypress

Black mangrove

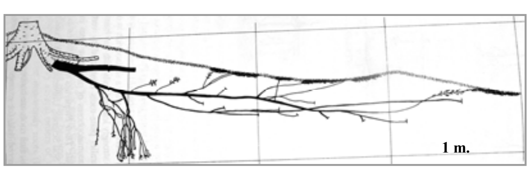
STRUCTURE & GROWTH
Roots & Root Growth

STRUCTURE & GROWTH
Roots & Root Growth

AERIAL ROOTS

- Characteristic of birch
- Seeds germinate on decaying logs, stumps and moss on rocks
- Roots grow downward into the soil

STRUCTURE & GROWTH
Roots & Root Growth



- Fine roots concentrated in upper 10 cm. of soil where aeration, nutrients and water are optimum
- Fine root mortality and generation high

STRUCTURE & GROWTH
Roots & Root Growth

- Lateral spread related to nature of the rooting medium (greater in sandy soil)
- Soil water may be obtained by penetrating deeper (may extend 3 to 10 meters or more)
- Depth is curtailed in saturated soil due to anoxia
- Submerged roots are internally aerated

STRUCTURE & GROWTH
Roots & Root Growth

- **Natural root grafting among members of a species is relatively common**
  - **Union forms between cambial layers of two closely associated roots**
  - **Phloem and xylem connect and allow transport of food, water and pathogens (red pine, American elm)**

SUMMARY

TREE ANATOMY

- **Know & define the parts of the tree: bole/stem, phloem, xylem, cambium, growth ring, earlywood / latewood**
- **Know the difference between ring-porous and diffuse porous wood and the ecological implications of ring structure**
- **Define primary and secondary tree growth**

SUMMARY

- **Define apical merited**
- **Describe the triggering mechanisms for cambial activity**
- **Primary growth begins with bud break, determines tree shape and height, is triggered by environmental factors**
- **Time of growth genetic and environmental**

SUMMARY

- **Secondary growth – expansion of stem and root diameter**
- **Triggered by shoot elongation, later than primary growth, sensitive to available space**
- **Shoot development patterns: (describe and give examples for each)**
  - **Preformed / determinate Sustained / Indeterminate**
  - **Zigzag pattern**

SUMMARY

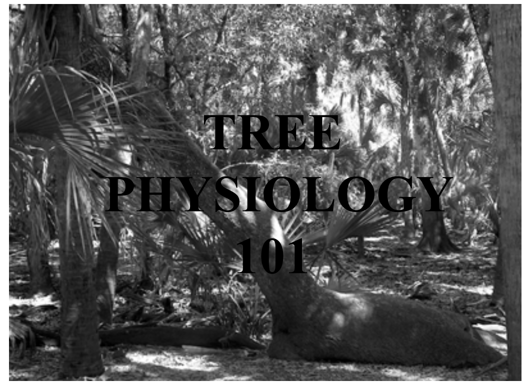
- **Crown shapes:**
  - **Decurrent**
  - **Excurrent**
- **Define epinastic (apical) control**
- **Effect of light on crown shape**
  - **Phototropism**
- **Define shade tolerance and tolerance classes**

SUMMARY

- **Light compensation point**
  - **PS = RS**
- **Natural pruning, fate of seedlings**
- **Sun leaves/ shade leaves**
- **Light is the one variable the forester can manipulate**

SUMMARY

- Roots
  - Purpose and function
- Conifer vs. angiosperm roots
- Triggers for root growth
- Types of roots, fine, tap, large
- Root grafting and its implications



PROCESSES OF TREES

- <u>PHOTOSYNTHESIS</u>
- RESPIRATION
- TRANSPIRATION
- REPRODUCTION
- SEED GERMINATION
- HORMONAL BALANCE

PHOTOSYNTHESIS

- Energy transfer:
  - Carried out in chloroplasts
  - Driven by sunlight as short wave radiation
  - Utilizing 6 moles of water and 6 moles of carbon dioxide
  - Producing 6 moles of oxygen and one moles of carbohydrate

PHOTOSYNTHESIS

$$6CO_2 + 12H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

- Photosynthesis is a complex series of metabolic reactions:
  - Light reaction
  - Dark reaction

PHOTOSYNTHESIS

LIGHT REACTION:

- Chloroplasts contains chlorophyll molecules
- Absorption of a photon raises energy level of the chlorophyll molecule
- Electron energy transferred to another receptor molecule
- High energy ATP and reductant NADPH formed

PHOTOSYNTHESIS

DARK REACTION:

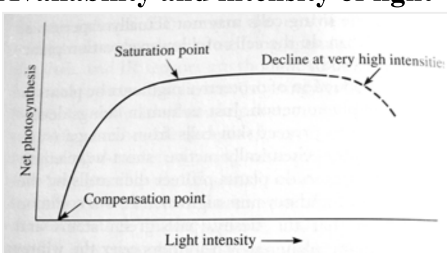
- **CO_2 is incorporated into carbohydrates**
- **Called 'dark reaction' because light is not directly necessary**
- **RuBP (ribulose biphosphate) combines with CO_2**
- **Catalyzed by <u>rubisco</u> (ribulose biphosphate carboxylase-oxygenase) the most abundant enzyme on earth**
- **ATP and NADPH both required for transformation of precursors into simple sugar**

PHOTOSYNTHESIS

- **<u>Gross Photosynthesis</u>: all energy (or Carbon) that is assimilated in PS represents gross primary production (GPP)**
  - **All living organisms require energy for basic metabolic functions**
  - **Provided through oxidation of compounds *via* Respiration**
- **<u>Net Photosynthesis</u>: the energy (or Carbon) remaining after respiration is net primary production (NPP)**
- **NPP = GPP - RS**

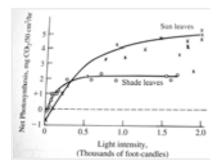
PHOTOSYNTHESIS
FACTORS AFFECTING PS

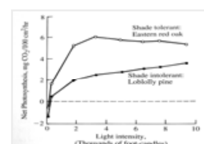
- **Availability and intensity of light**



PHOTOSYNTHESIS
FACTORS AFFECTING PS

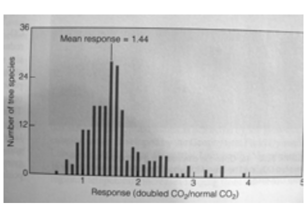
- **Rate of PS varies with species, individuals within a species, and in various parts of a single plant**





PHOTOSYNTHESIS
FACTORS AFFECTING PS

- **Available Carbon Dioxide**

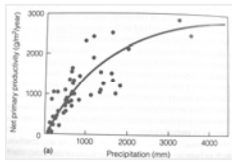


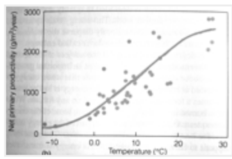
PHOTOSYNTHESIS

- **Productivity is usually measured as the rate at which energy or biomass is produced per unit area per unit time**
- **Expressed as kcal/m^2/yr or g dry wt/m^2/yr**

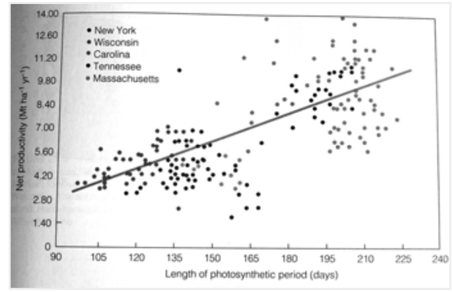
PHOTOSYNTHESIS

- **Primary productivity is a function of rate of PS and leaf area**
- **NPP influenced by annual precipitation and mean daily temperature**





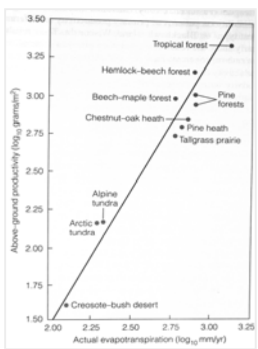
PHOTOSYNTHESIS



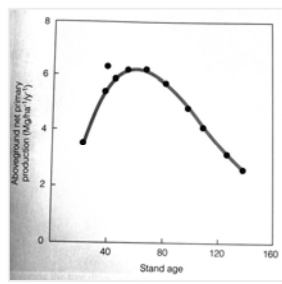
Growing season: length of time when temperatures are sufficiently warm to support PS and NPP

PHOTOSYNTHESIS

- **Productivity dependent on the combination of water availability and temperature (Evapotranspiration)**
- **High temp/low water and low temp/high water result in low NPP**

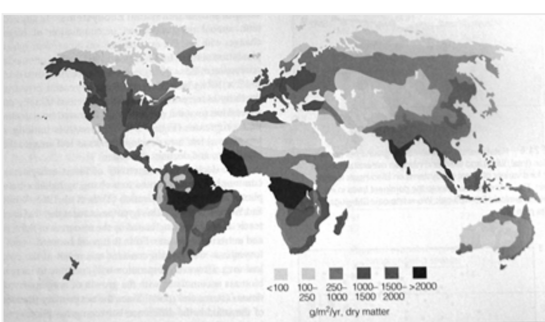


PHOTOSYNTHESIS



- **NPP changes with age**
- **In general, productivity increases during stand development then declines**
- **Decline a combination reduction in PS & RS**

GLOBAL PRODUCTIVITY



PROCESSES OF TREES

- **PHOTOSYNTHESIS**
- **RESPIRATION**
- **TRANSPIRATION**
- **REPRODUCTION**
- **SEED GERMINATION**
- **HORMONAL BALANCE**

RESPIRATION

- **Carried out in mitochondria – dark RS**
- **Does occur in photosynthetic cells**
  @ 5 – 15 % rate of PS
- **Balances the oxygen production of PS**
- **Respiration increases with rising temperature**
- **$(CH_2O)_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$ + ATP**

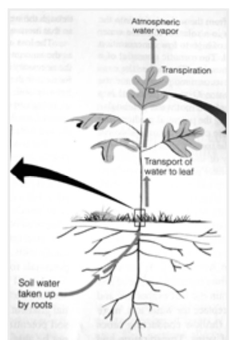
RESPIRATION Types of RS

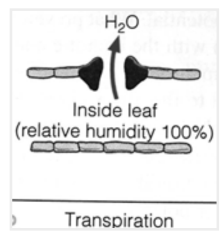
- **Growth and Synthesis –**
  - **Totally dependent upon rate of PS**
  - **Loss of C during plant growth**
- **Maintenance –**
  - **Proportional to dry weight of the living tissue**
  - **Temperature sensitive – doubles for each 10°C ↑**
  - **Strongly influenced by tissue N concentration**
  - **Repair of damaged proteins, membranes, etc.**

PROCESSES OF TREES

- **PHOTOSYNTHESIS**
- **RESPIRATION**
- **<u>TRANSPIRATION</u>**
- **REPRODUCTION**
- **SEED GERMINATION**
- **HORMONAL BALANCE**

TRANSPIRATION





Stomata: dissipate heat and water; take in CO_2

PROCESSES OF TREES

- **PHOTOSYNTHESIS**
- **RESPIRATION**
- **TRANSPIRATION**
- **<u>REPRODUCTION</u>**
- **<u>SEED GERMINATION</u>**
- **HORMONAL BALANCE**

REPRODUCTION (Regeneration)

- **Regeneration includes:**
  - **<u>Sexual Reproduction</u> → fruit & seed → seed bank → seed germination → plant establishment**
  - **<u>Vegetative (asexual) Reproduction</u>**
    - **Stems of existing plants *via* vegetative buds develop clonal sprouts**

REPRODUCTION (Regeneration)

- **<u>Monoecious</u> condition:**
- **Trees that bear both male and female flowers on the same tree**
  - **A tree may be predominantly male or female**
- **<u>Dioecious</u> condition:**
- **Trees bear unisexual male and female flowers on different individuals**
  - **Precludes inbreeding**
  - **Examples: *Acer, Alianthus, Diospryos, Fraxinus, Maclura, Populus, Sassafras***

REPRODUCTION (Regeneration)

- **Angiosperms rarely produce viable self-pollinated seeds; conifers can**
- **Sexual reproduction is the basic mode by which plants:**
  - **maintain populations**
  - **adapt to changing environments**
- **Production of large crops of fruit and seeds depletes nutrient reserves**

REPRODUCTION (Regeneration)

- **Trees progress from <u>juvenile phase</u>, no flowering, to the <u>adult phase</u> when flowering occurs.**
- **Duration of the juvenile phase varies markedly among species.**
- **Juvenile phase also influenced by site conditions and vigor of the plant**

REPRODUCTION (Regeneration)

- **Size and age important predictors of flowering**
- **Flowering triggered by hormonal control**
- **Suppressed trees may never flower**
- **Adult phase first appears at the top of the crown.**
- **Tree species adapt to the environmental conditions of the site where they grow**

REPRODUCTION (Regeneration)

- **Many 'Exploitive' species flower in early spring and disseminate millions of small seeds in four to six weeks that germinate readily**

  (red maple, willows, cottonwood, river birch, silver maple, elms)

REPRODUCTION (Regeneration)

- **Others species develop fruit and medium to large seeds throughout the 2-4 month growing season. (i.e. oaks, hickories)**
- **Disseminate in fall or winter germinating the following spring**
- **In general, the entire reproductive cycle is adapted to the prevailing regime of site factors for a given ecosystem.**

REPRODUCTION (Regeneration)

- **Flower and seed production occur irregularly in natural forest stands.**
- **Fast growing, shade intolerant species tend to have fewer years between large seed crops**
- **Seed production is sensitive to site conditions**
  - **Large dominant trees are the primary seed producers; open grown trees produce large quantities of seed**

REPRODUCTION

Seed dispersal

- **Gravity – local dispersal (40-50 m from parent)**
  - **Heavy seeded trees with very site specific requirements**
- **Wind or water –wide dispersal**
  - **Characteristic of pioneer species**
- **Animals – variable dispersal**
  - **Blue jays and acorns**
- **Timing – immediate to prolonged**

REPRODUCTION

Seed germination

- **Disseminated seeds stored, often in dormant state**
- **Some germinate readily (red maple, silver maple, cottonwood)**
- **To germinate, viable seeds:**
  - **Take in water**
  - **Activate metabolic processes**
  - **Initiate growth of embryo**

REPRODUCTION

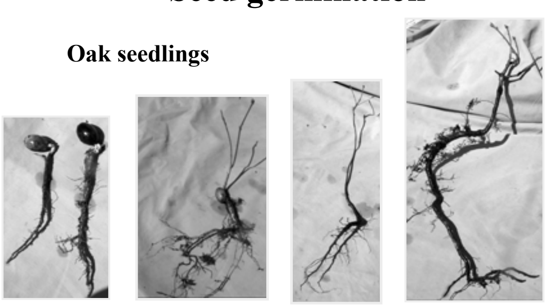
Seed germination

- **'<u>Buried seed strategy</u>': some species require long periods of dormancy, germinating one or more years after dispersal.**
- **Includes many shrubs such as *Ribes, Rhus* and <u>black cherry</u> and <u>yellow-poplar</u>**
- **Some species require sunlight for germination**

REPRODUCTION

Seed germination

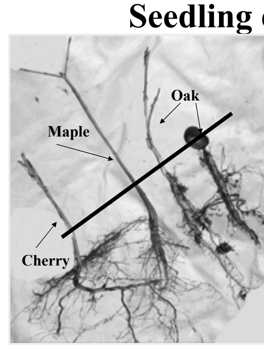
Oak seedlings

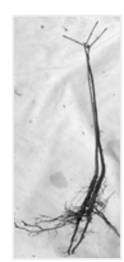


< 1 year　1 year　2 years　3 years

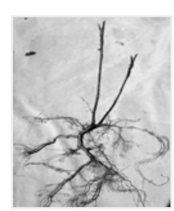
REPRODUCTION

Seedling development





Red maple



Black Cherry

REPRODUCTION (Vegetative reproduction)

- Vegetative or asexual reproduction is clone formation Major mode of spread for aspens
- Growth process where genetically identical stems (ramets) are derived from a sexually produced plant.
- Vegetative growth is reduced by the production of fruit and seed
- In many situations vegetative reproduction is more important for survival

REPRODUCTION (Vegetative reproduction)

- All woody angiosperms can reproduce vegetatively
- Conifers less able to do so
- Enables the tree to survive and expand its spatial coverage
- Meristem from crown, basal stem, root collar, underground roots and rhizomes contributes to vegetative reproduction

REPRODUCTION (Vegetative reproduction)

- Basal stem: new shoots from adventitious buds
- Root: New shoots from adventitious buds on roots; appear as separate growth
- Rhizome: new shoots develop from horizontal underground stems

REPRODUCTION (Vegetative reproduction)


Root collar spouting - Yellow-poplar

REPRODUCTION (Vegetative reproduction)

Red Maple

REPRODUCTION (Vegetative reproduction)

Dogwood

Epicormic sprouting

Red maple

REPRODUCTION (Vegetative reproduction)

- **<u>Runners (stolons):</u> arching branches of shrubs take root when they come in contact with the ground**
- **<u>Fragmentation</u>: broken branches may take root after being buried**
- **<u>Layering</u>: Lower branches of conifers pressed into the soil by snow or woody debris**
- **<u>Tipping</u>: Uprooted tree lying horizontal; branches turn upward and develop into independent trees**

PROCESSES OF TREES

- **PHOTOSYNTHESIS**
- **RESPIRATION**
- **TRANSPIRATION**
- **REPRODUCTION**
- **SEED GERMINATION**
- **<u>HORMONAL BALANCE</u>**

HORMONAL BALANCE

- **<u>Auxins</u>: plant growth hormones**
  Ex: indol-3-acetic acid
- **Auxin effects:**
  - **Growth stimulation**
  - **Differentiation – stimulating cambial activity and meristem activity**
- **Auxin promotes cell elongation**

HORMONAL BALANCE Phototrophism

- **Plants lean toward light**
- **The light decreases auxin activity**
- **Light retards growth by either destroying auxin or blocking auxin transport**
- **On the shaded side growth continues thereby bending the plant toward the light source**

VARIATION/GENETICS

- **A forest tree must have a governing biochemical control mechanism**
- **Environment is integral to development**
- **Features of a tree are determined by environment and genetics**

VARIATION

- **<u>Adaptedness</u>: the ability of organisms to live and reproduce in a given range of environments**
- **<u>Plasticity</u>: the ability to survive and compete in different environments**
- **<u>Genotype</u>: genetic constitution of an individual**
- **<u>Phenotype</u>: the observable properties of an organism produced by the genetic makeup together with environment**

VARIATION

- **Plastic characteristics:**
  - **Size of parts; number of shoots, leaves, and flowers; elongation rates of stems**
- **Nonplastic characteristics (genetically controlled):**
  - **Leaf shape, serration of leaf margin, floral characteristics**

VARIATION
Sources of variation

- **Variation in phenotypes: genotype and environment**
- **Genetic variation:**
  - **Mutation – ultimate source of variation**
  - **Recombination of genes – spreads mutations and gives them maximum variability**
  - **Selection – natural selection based on fitness**
- **Evolution: - Survival of the fittest or those most able to reproduce**

VARIATION
Sources of variation

- **Hybridization: genetic combination between populations that are substantially different**
- **Genecology: study of variation in plant species from an ecologic point of view**
- **Provenance: a geographic race of a species**
  - **Ex loblolly pine**
- **Cline: gradual change or a gradient**

VARIATION
Sources of variation

SUMMARY

- **Photosynthesis (PS) is the process by which autotrophs use the energy of the sun to convert carbon dioxide and water into carbohydrates**
- **Light reaction of PS traps light energy**
- **Dark reaction of PS converts CO_2 into simple sugars**

DISTURBANCE as an ECOSYSTEM PROCESS

DISTURBANCE

- Disturbances:
  - ecosystem processes affecting composition, structure, and function
- Disturbances:
  - change site conditions
  - destroy forest organisms
  - direct the course and rate of vegetation change

DISTURBANCE
Types of disturbances

- Natural disturbances:
  - Earthquakes & Volcanoes
  - Avalanches, Glaciers & Floods
  - Fire & Wind
  - Disease & Insects
- Human disturbances: logging, land clearing, change biota

DISTURBANCE

- Disturbances have temporal and spatial characteristics:
  - Intensity
  - Frequency
  - Spatial extent or scale

DISTURBANCE

- INTENSITY:
  - Measured by the proportion of total biomass killed or removed
    - Magnitude of physical force
    - Characteristics of the affected organism influencing their response to the disturbance
    - Nature of the disturbance

DISTURBANCE

- FREQUENCY:
  - Mean number of disturbances within a given time period.
  - Return interval is the mean time between disturbances
  - High frequency does NOT mean high intensity

DISTURBANCE

- SCALE
  - The size of the area affected determines the impact of the disturbance
  - Range from very small to large scale
    - Death of one tree to vast wildfires
    - Gaps are created when a single tree dies
      - Changes the microclimate
      - Releases understory growth

SOURCES OF DISTURBANCE

SOURCES OF DISTURBANCE
FIRE

- Natural fires – lightning
- Other fires – arson, carelessness, secondary to other disturbances
- Globally, large areas evolved by fire
- Perpetuates forests

SOURCES OF DISTURBANCE
FIRE

- Types of fire:
  - Surface
  - Crown
  - Ground
- Type and behavior depend upon:
  - Fuel, wind, moisture, vegetation

SOURCES OF DISTURBANCE
FIRE

- SURFACE FIRE
  - Most common
  - Feeds on litter layer
  - Converts organic matter to ash
  - Consumes herbaceous matter but not underground plant parts
  - Cambial layer in thin barked trees may be killed

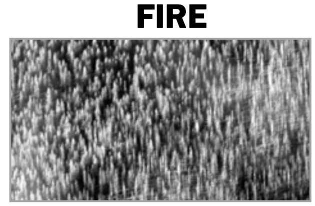
SOURCES OF DISTURBANCE
FIRE

CROWN FIRE: (Wildfire)

High fuel load and high wind; most prevalent in coniferous forests

Kills above ground matter

SOURCES OF DISTURBANCE
FIRE



- Crown fires skip leaving unburned patches
- Develops a mosaic of different stand ages

SOURCES OF DISTURBANCE
FIRE

- GROUND FIRE:
- Consumes organic matter to bedrock
- Prevalent in areas of deep dried out peat or large amount conifer debris
- Flameless with very high temperatures
- Irreversible change

Dolly Sods

SOURCES OF DISTURBANCE
FIRE

- Contributions of fire:
  - Reduces fuel load
  - Stimulates germination – serotiny
  - Stimulates sprouting
  - Prepares seedbed
    - Exposing mineral soil
    - Eliminating competition
    - Thin stands
  - Controls disease and insects

SOURCES OF DISTURBANCE
WIND & ICE

Hurricane Hugo

- Wind shapes canopies
- Affects growth
- Uproots – <u>windthrow</u>
- Mature and diseased trees most vulnerable

SOURCES OF DISTURBANCE
WIND & ICE

- Windthrow
  - Opens canopy - gap
  - Pit and mound formation
  - Exposes mineral soil
  - Brief increase in understory (forage) growth

SOURCES OF DISTURBANCE
WIND & ICE

- Trees weakened by heavy weights are susceptible to damage
- Ice storms – much breakage
- Epiphytes – heavy load pulls tree over

Resurrection fern & grass air plant

SOURCES OF DISTURBANCE
WIND

- Hurricanes: can devastate wide areas
  - Force extends ~ 40 km from center
  - Cause landslides and flooding
  - Major force in maintaining diversity
- Tornadoes: More limited effect
  - Uproot and kill trees in the path
  - Variable in impact

SOURCES OF DISTURBANCE FLOODS

SOURCES OF DISTURBANCE ANIMALS

- Deer – a disturbance
  - Over-browsing has eliminated some species, inhibit regen of oaks
- Cattle – overgrazing
  - Disperse invasive plant seeds
  - Eliminate fire risk
- African elephant – can convert woodland to grassland

SOURCES OF DISTURBANCE HUMAN

- Timber harvesting
  - Depends on harvest methods used
- Agriculture
  - Monocultures
  - Promotes erosion
  - Reduce range of woody plant
- "Development"

SUMMARY

- Disturbance –Any physical force that damages natural systems and results in mortality
- Vary in *Intensity, frequency, spatial scale*
- Large-scale disturbances shape and modify the nature of the system
- Favor some species over others
- Can ensure regeneration of the ssystem

SUMMARY

- Fire is the major natural large-scale disturbance
- Fire is beneficial and adverse disturbance
- Hurricanes, flooding and drought
- Major human-induced disturbances
  - Cultivation
  - Logging
  - Development
  - Surface mining

NUTRIENTS

- Direct factors necessary for autotrophs

('autotrophs' = plants that create their own food source)

√ HEAT OXYGEN

√ LIGHT CARBON DIOXIDE

√WATER MINERAL NUTRIENTS

NUTRIENTS

- Nutrient: a substance required by organisms for normal growth and activity
- Organisms require nutrients in inorganic/mineral form
- Macronutrients: Elements needed in large amounts
- Micronutrients: Elements needed in much smaller amounts

NUTRIENTS

- MACRONUTRIENTS:
  - Carbon, Oxygen, Hydrogen – basic constituents of all organic matter – derived from CO_2 and water
  - Nitrogen (N)– Utilized in fixed form, basis of proteins
  - Calcium (Ca) – essential to root growth, with pectin gives rigidity to cell walls
  - Phosphorus (P)– energy transfer ADP to ATP, component of nuclear material

NUTRIENTS

- MACRONUTRIENTS:
  - Magnesium (Mg) – integral part of chlorophyll
  - Potassium (K)- Formation of sugars and starches
  - Sulfur (S) – basic component of protein
- Above six elements exist in soil

NUTRIENTS

- MICRONUTRIENTS:
  - Include – Copper, Zinc, Iodine, Silica, Selenium, Iron and others
- Micronutrient deficiency causes organism failure as surely as does macronutrient lack

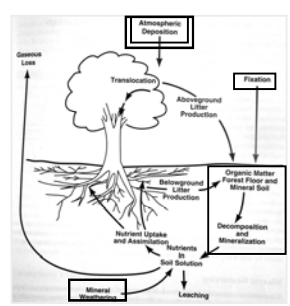
NUTRIENTS

- The maintenance of inorganic nutrients involves recycling of nutrients between the abiotic environment and living organisms – Nutrient cycling or biogeochemical processes
- Nutrient cycles:
  - Gaseous: oxygen, carbon, nitrogen
  - Sedimentary: sulfur, phosphorus

NUTRIENTS

Sources of nutrients:

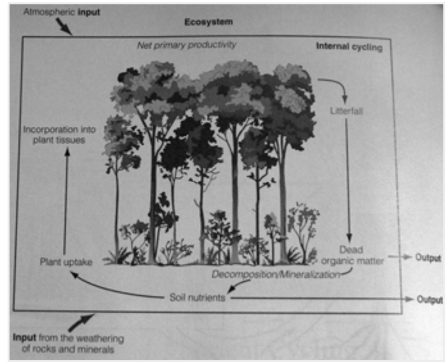
- Weathering of mineral soil
- Nitrogen fixation
- Atmospheric gases
- Precipitation with deposition of atmospheric particles
- Decomposition of organic matter



NUTRIENTS

- **NUTRIENT CYCLING: The movement of nutrients from soil to plant and back to the soil after decomposition**
- **Nutrient cycles involve the chemical exchanges of elements among air, soil, water and living organisms**

NUTRIENT CYCLING



DECOMPOSITION

- **All heterotrophs are decomposers**
- **Digestion breaks down organic matter, alters its structure and releases it as waste**
- **Decomposers: organisms that feed on dead organic material (Microflora)**
  - **Bacteria**
  - **Fungi**
  - **Certain insects (detritivores)**

DECOMPOSITION

- **Bacteria: principal decomposers of animal matter**
- **Fungi: major decomposers of plant material**
- **Both organisms secrete enzymes into tissues to break down the complex organic compounds.**
- **Organic matter may be decomposed by successive groups of microflora**
- **This continues until the original matter is reduced to inorganic nutrients**

DECOMPOSITION

- **Detritivores: invertebrates that fragment dead plant and animal matter includes**
  - **Protozoa, nematodes, mites, springtails, millipedes, worms, etc.**
- **Microbivores: feed on the bacterial and fungal decomposers**
  - **Control abundance and distribution of fungi**

DECOMPOSITION

R = Dead material

F =fragmentation

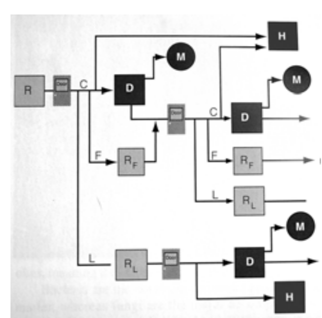
L = leaching

C = breakdown complex to smaller compounds

H = humus

D = resynthesized

M = mineralized

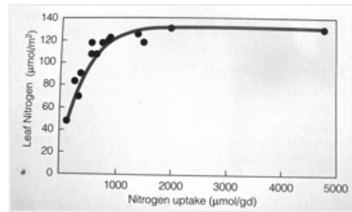


NUTRIENT UPTAKE

- **Factors influencing rate of nutrient uptake**
  - **Demand**
  - **Availability**
- **Rate of uptake most important variable controlling the nutrient content of plants**
- **Rate of uptake is a function of the external concentration of the nutrient**

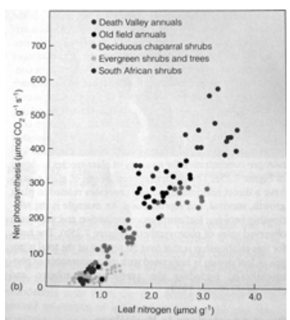
NUTRIENT UPTAKE

- **As nutrient concentration rises uptake rises until reaching a maximum uptake rate**



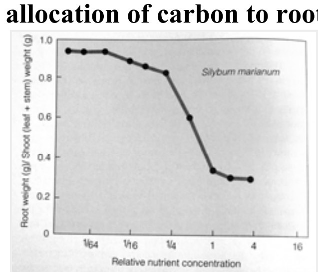
NUTRIENT UPTAKE

- **Nutrient concentrations of plant tissues have direct relationship to key plant processes**
- **Over 50% of total leaf N is associated with photosynthesis**



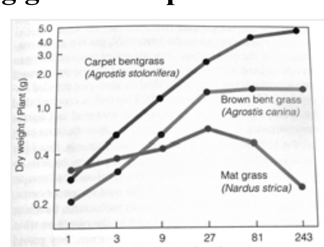
NUTRIENT UPTAKE

- **Adaptation for low nutrient availability: increase allocation of carbon to root growth**



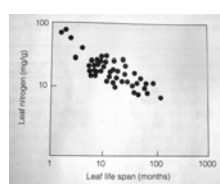
NUTRIENT UPTAKE

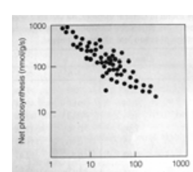
- **Plants adapt to nutrient availability by altering growth response:**



NUTRIENT UPTAKE

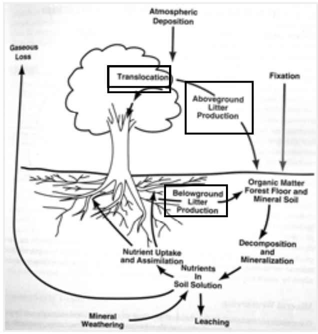
- **Plants adapt to nutrient availability by altering leaf longevity:**





NUTRIENT UPTAKE

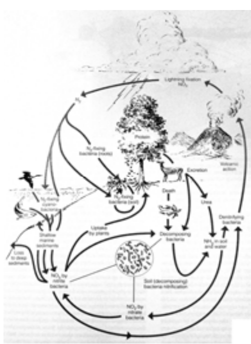
Plant influence on nutrient availability



THE NITROGEN CYCLE

- **N_2 in the atmosphere can not be used by plants; four processes required for complete nitrogen cycle**
- **<u>Fixation</u>**
- **<u>Mineralization/</u> <u>ammonification</u>**
- **<u>Nitrification</u>**
- **<u>Denitrification</u>**

THE NITROGEN CYCLE



NITROGEN FIXATION

- **Fixation done by specific groups of bacteria/fungi (90 % of fixed N)**
  - **Rhizobium bacteria grow in and on the roots of certain terrestrial plant species (legumes and root-nodulated non-legumes)**
  - **Live on carbon from the plant and return nitrogen**
  - **Mycorrhizal fungi**
- **Lightning produces nitrates (high-energy fixation)**

NITROGEN FIXATION

- **Biological fixation produces ammonia (NH_3)**
  - **N_2 split to 2N**
  - **$2N + 3H_2 = 2 NH_3$**
- **High energy fixation produces nitrates**
- **Once available by either form of fixation N is available to plants**
- **Death returns organic compounds to soil**
- **N in these compounds unavailable to plants**

MINERALIZATION

- **Proteins are broken down by decomposers into amino acids**
- **Amino acids oxidized to CO_2, H_2O, NH_3 and energy**
- **Ammonium absorbed directly by roots and incorporated into protein**
- **Some ammonium dissolved and bound in the soil**

NITRIFICATION

- Ammonia oxidized to nitrates and nitrites yielding energy
  - $NH_3 + 1\frac{1}{2}\, O_2 \longrightarrow HNO_2 + H_2 + 165$ kcal
  - $NO_2^- + 1\frac{1}{2}\, O_2 \longrightarrow NO_3^-$
  - Biological process (bacterial)
- Nitrates leach more easily than ammonium
- DENITRIFICATION: nitrates are reduced by certain bacteria to gaseous N to obtain oxygen

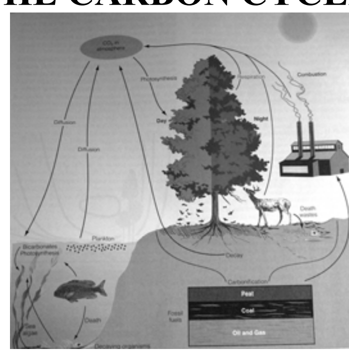
DECOMPOSITION

- Decomposition is breakdown of chemical bonds formed during the development of plant and animal tissue
- Decomposition involves respiration - the release of energy originally fixed by photosynthesis
- Rate of decomposition dependent upon temperature, moisture and litter quality

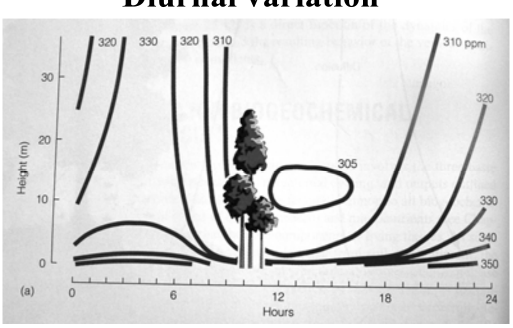
THE CARBON CYCLE

- Carbon: basic constituent of all organic compounds
- Major element in fixation of energy by photosynthesis
- Productivity often measured as grams of carbon fixed/unit area/year
- Source of all fixed carbon is carbon dioxide
  - $6CO_2 + 12\, H_2O \longrightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$

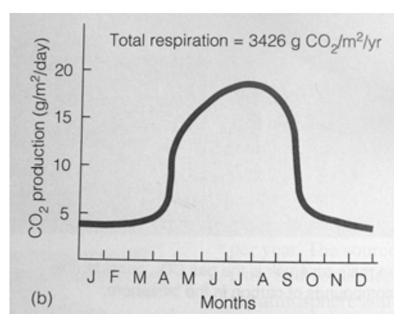
THE CARBON CYCLE



THE CARBON CYCLE
Diurnal variation



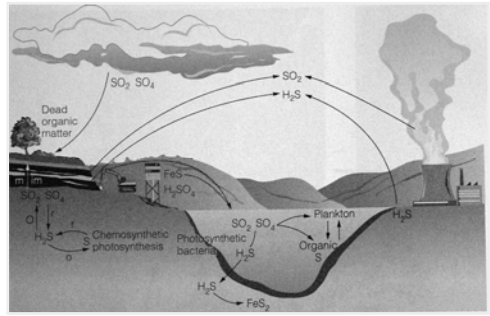
THE CARBON CYCLE
Seasonal variation



THE SULFUR CYCLE

- **Sulfur (S) contained in;**
  - **organic material - coal, oil and peat**
  - **inorganic form - pyrite rocks and sulfur deposits**
- **Released by:**
  - **Weathering**
  - **Erosion**
  - **Decomposition**
  - **Industrial production**

THE SULFUR CYCLE



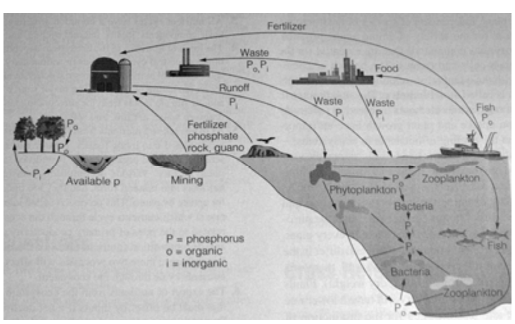
THE SULFUR CYCLE

- **Sulfur in soluble form incorporated into sulfur bearing amino acids**
- **Sulfur utilized as an O_2 receptor in the reduction of carbon dioxide**
- **In the presence of iron and anaerobic conditions will precipitate as FeS_2 – a highly insoluble compound**

THE PHOSPHORUS CYCLE

- **Occurs in minute amounts in the atmosphere and total available amount is small**
- **Source in soil is apatite a phosphate of calcium ($Ca_5(PO_4)_3(F,Cl,OH)$)**
- **Principal sources: rock and natural phosphate deposits**

THE PHOSPHORUS CYCLE



THE PHOSPHORUS CYCLE

- **Essential in energy transfer and component of nuclear material**
- **Phosphorus – low availability**
- **Most limiting factor on infertile soils such as the Utisol**
- **Forests on infertile soil cycle P more efficiently than those on moderately fertile soils**

BIOGEOCHEMICAL CYCLES

- **Major cycles are all linked to each other**
- **All are components of living organisms**
- **Proportions of nutrients involved in various processes are fixed**
- **Limitation of one nutrient can affect the cycling of all others**

SUMMARY

- **Organisms obtain chemical elements essential to growth and development from their environment**
- **Macronutrients: needed in large amounts**
- **Micronutrients: needed in smaller amounts**
- **Nutrients flow from living to nonliving components of the ecosystem in a perpetual cycle**

SUMMARY

- **Types of nutrient cycles:**
  - **Gaseous - atmosphere**
  - **Sedimentary – earth's crust**
- **Availability of essential nutrients depends on nature of the soil**
- **Plant uptake of nutrients incorporated into living tissue**

SUMMARY

- Decomposition returns dead organic material to usable mineral form
- Rate determined by environmental factors
- Carbon cycle tied to energy flow
  - Diurnal and seasonal variation
- Nitrogen cycle – fixation of atmospheric N and decomposition of organic matter to make N available

SUMMARY

- **Phosphorus cycle: wholly sedimentary**
- **Sulfur cycle both gaseous and sedimentary**
  - **Released by weathering and decomposition**
- **All major biogeochemical systems are linked**