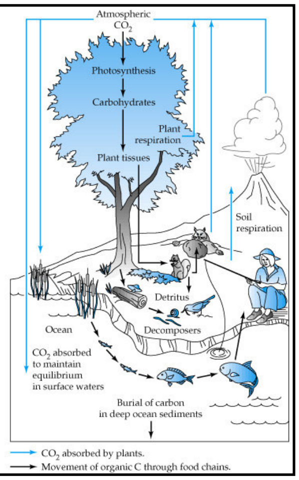
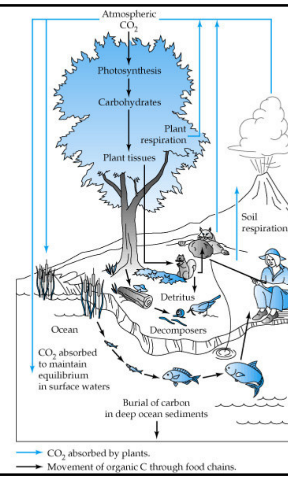
Carbon cycle

- $CO_2 + H_2O \rightarrow CH_2O + O_2$
- Carbohydrates used for
  - Respiration
  - Add biomass
  - Supply upper trophic levels
- Ultimate energy supply for all ecosystems

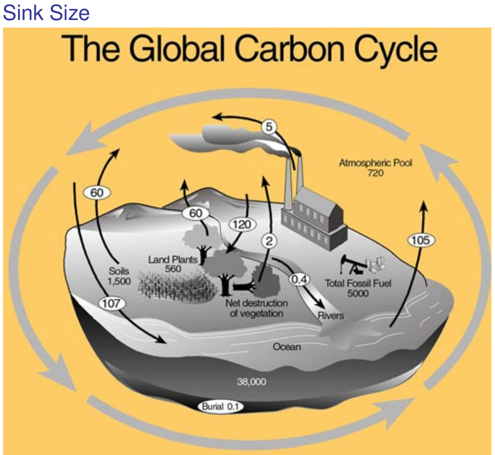


Carbon cycle

- Carbon Sinks
  - Ocean
  - Atmosphere
  - Plant biomass
  - Animal biomass
  - Sediment
  - Detritus
- Climate change implications

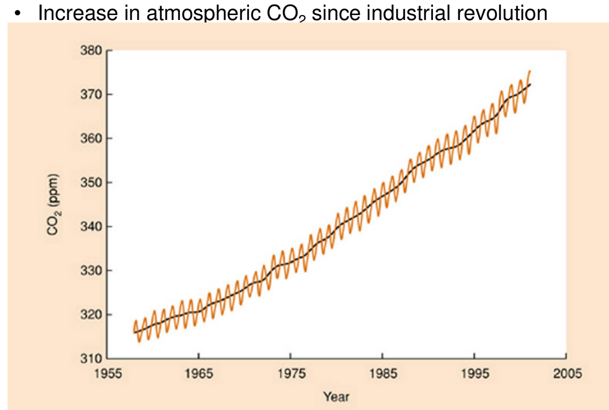


Global Sink Size



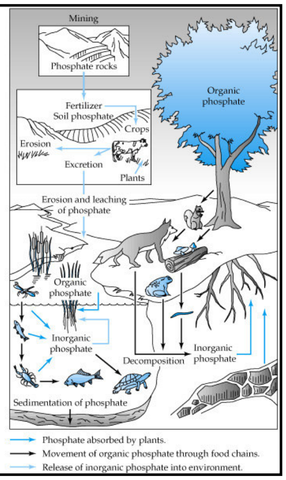
Carbon cycle and fossil fuels

- Increase in atmospheric CO_2 since industrial revolution



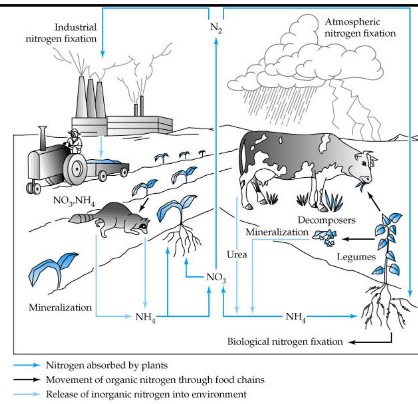
Phosphorus Cycle

- Necessary for protein production
- Inorganic P (PO_4) taken up by plants
- Plant-fungi mutualism increases uptake
- Organic P moves through foodweb, animal and decomposers release inorganic P
- Freshwater ecosystems often P limited
- Sediments are P sinks
- Weathering of soil provides some P



Nitrogen Cycle

- Most common element in atmosphere
- Few organisms can fix N_2
- Fixed N often limiting in terrestrial systems

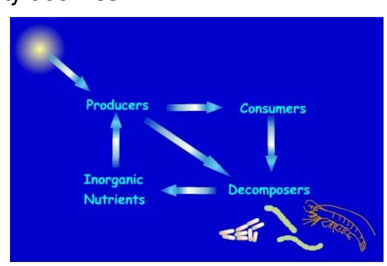


Nitrogen cycle

- $N_2H_4CO + H_2O \rightarrow 2NH_3 + CO_2$
- $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$
- $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$
- Most animals produce ammonia (NH_3) or urea (N_2H_4CO) as nitrogenous waste
- Plants can only use ammonium (NH_4) or nitrite (NO_3)
- Nitrifying bacteria (Nitrosomonas and Nitrobacter) – convert amonium, nitrate (NO_2) to nitrite (NO_3)
- Denitrifying bacteria complete the cycle $NO_3 \rightarrow N_2$

Decomposers

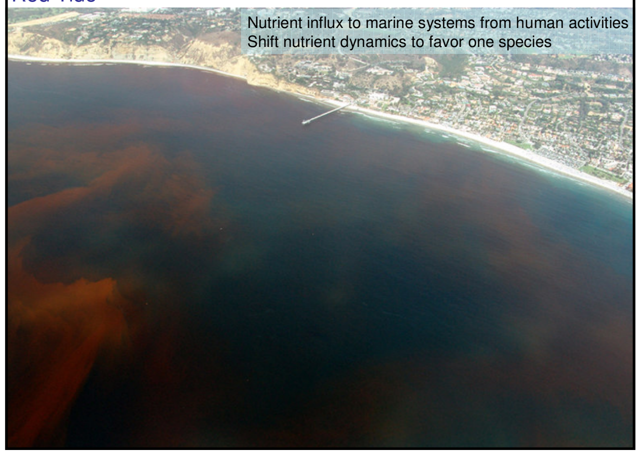
- All nutrient cycles rely on decomposers to process waste, make nutrients available again.
- Without decomposers – residence times increase, organic matter accumulates, nutrient availability declines



Fertilizers

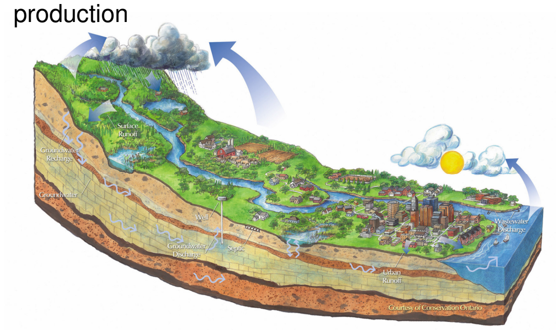
- Primary productivity often limited by a single nutrient
- Boost nutrient availability in a limited area to increase productivity
- N-P-K ratio

Red Tide



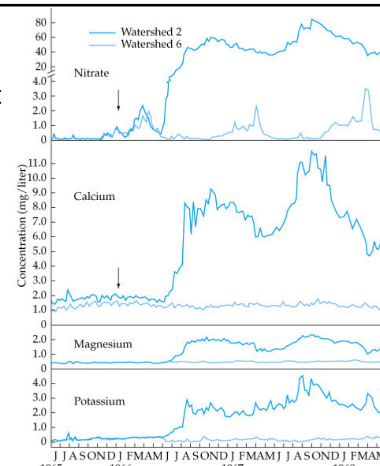
Nutrient export and ecosystem function

- Ecosystems are not closed systems, but usually have balanced nutrient import/export
- Disturbances can change dynamic and alter production



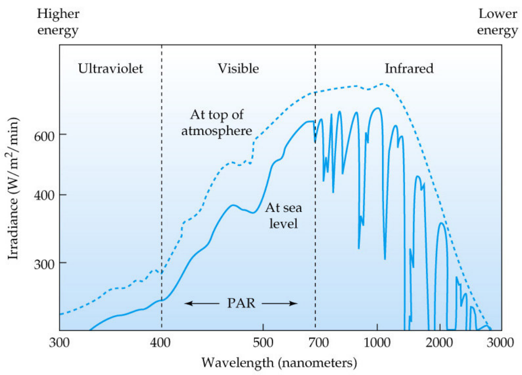
Deforestation

- Increased erosion
- Increased nutrient export
- Decreased nutrient content in soils
- Decreased productivity
- Nutrient increase in aquatic system, freshwater and marine

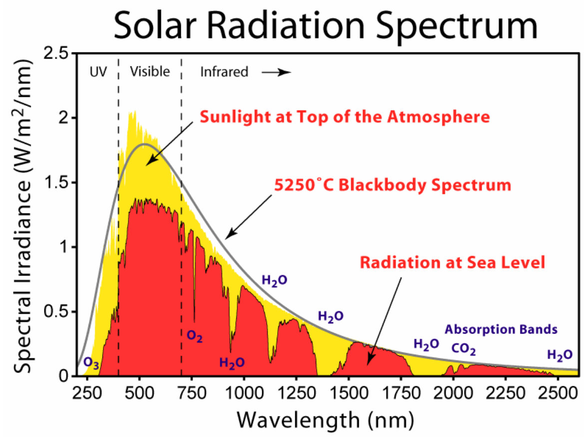


Energetics

- All ecosystem energy is ultimately solar



Specific wavelength absorption by atmospheric components

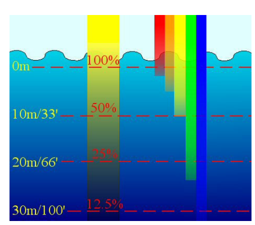


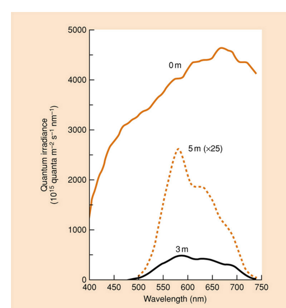
Primary Productivity

- Primary productivity – amount of energy or biomass produced by photosynthesis in an ecosystem.
  - Autotrophs - Plants, bacteria and photosynthetic protists (algae)
  - Measured as biomass or energy (calories)
  - Serves as food for all non-photosynthetic life (heterotrophs)
  - Mixotrophs – can switch between auto and heterotrophic.
- $CO_2 + H_2O \rightarrow CH_2O + O_2$

Water absorption of wavelengths

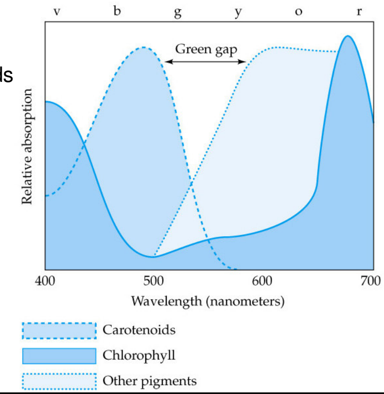
- Blue and green penetrate well
- Red and orange are absorbed quickly





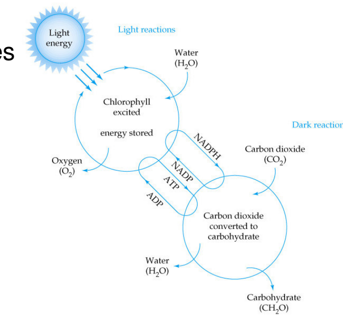
Photosynthetically Active Radiation (PAR)

- Wavelengths used for photosynthesis
- Chlorophyll – violet and red
- Secondary compounds absorb yellow and orange
  - Carotenoids
  - Xanthophyl
  - Phycobillin
- Nothing efficiently uses green



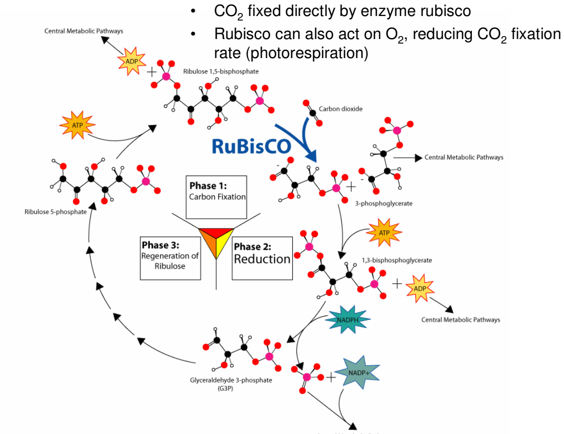
Photosynthesis

- Light reactions
  - Chlorophyll captures light energy
  - Water split, O_2 released
- Dark reactions
  - Atmospheric CO_2 converted to carbohydrates



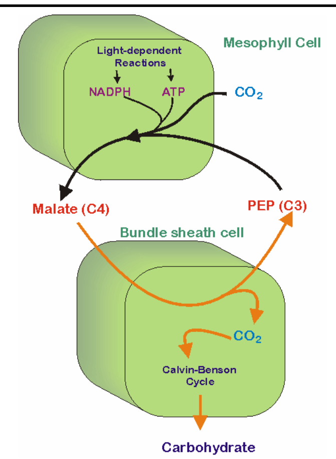
C3 carbon fixation

- CO_2 taken directly from air
- CO_2 fixed directly by enzyme rubisco
- Rubisco can also act on O_2, reducing CO_2 fixation rate (photorespiration)



C4 carbon fixation

- C3 pathway restricted to deeper portion of leaf
- CO_2 stored in malate (C4), stomata open less
- Dark reactions pull CO_2 from malate, fix it to carbohydrates
- Dark reactions similar to C3. except for source of C
- Minimize photorespiration
- Less nitrogen required (less rubisco)



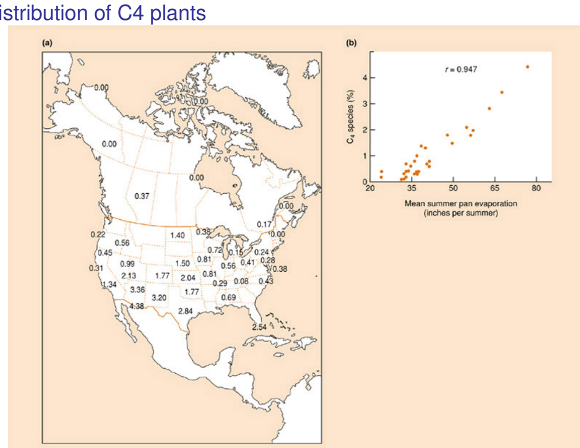
CAM photosynthesis

- Crassulacean acid metabolism (CAM)
- Desert adapted plants
- Modified C4
- Stomata open at night only, store C in malic acid
- Thick cuticle on leaves
- Water storage helps deal with malic acid
- No photorespiration

C3 C4 CAM overview

- C3
  - Most plants
  - Need stomata open to complete cycle with CO_2.
  - When stomata closed, use O_2 through photorespiration
  - 18 ATP used to synthesize one glucose, up to half of the energy from light reaction spent in photorespiration
- C4
  - More efficient CO_2 uptake, stomata not open as long
  - Each CO_2 is fixed twice
  - Advantageous in dry, hot, or CO_2 limiting conditions
  - 30 ATP used to synthesize one glucose, photorespiration minimized
- CAM
  - Similar to C4
  - Photorespiration avoided

Distribution of C4 plants



Products of Photosynthesis

- Carbohydrates wind up in one of three places
  - Used immediately in respiration
  - Stored and used later in respiration
  - Used to build plant biomass – ultimately used later in repiration

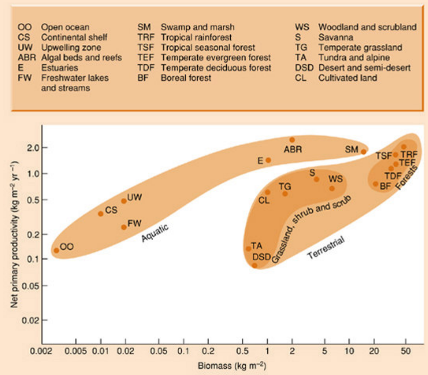
- Carbon fixed by photosynthesis is all ultimately used for respiration
  - Carbon cycle
  - Plant biomass as a carbon sink

Primary production efficiency

- What percentage of solar energy is converted to usable energy in carbohydrates?
  - Limited wavelengths used
  - Energy spent during process or respiration (30%)
  - 1-2% on land 3-4% for algae
  - Solar constant 1366 watts/m^2
  - Efficient solar panels = 15%

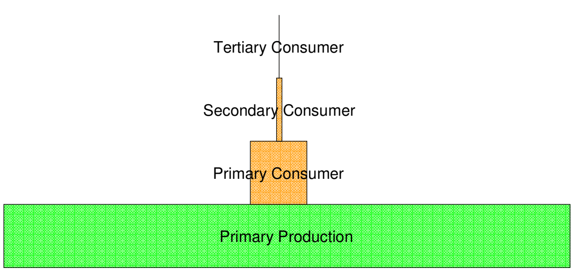
Light, moisture, nutrients and CO_2 as resources

- All are "food", photosynthetic organisms compete for them. One is often limiting.



Eltonian Pyramid

- Primary production determines energy available for herbivores (primary consumers)
- Lindeman efficiency = proportion of total energy passed from one trophic level to the next.
- 10% efficiency is typical



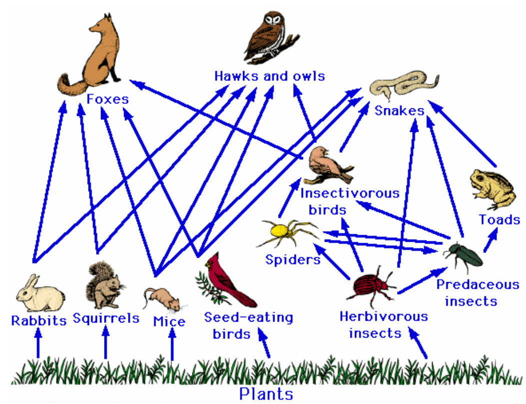
Why so inefficient?

- First law of thermodynamics – conservation of energy
- Second law of thermodynamics – quality of energy declines as it is transferred from one state to the next
- Entropy – systems naturally progress towards a state of disorder. At every level, a higher portion of the energy exists in a disordered state.
- Most energy "lost" as kinetic energy or heat

Primary producer – herbivore inefficiency

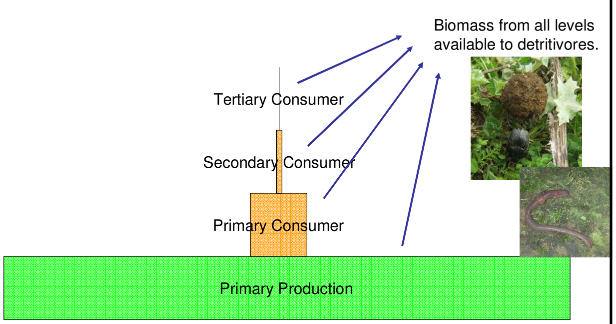
- Plant defenses
  - Physical
    - Spines, silica
  - Chemical
    - Alkaloids, Terpenoids, tannins, nicotine, caffeine
  - Low food quality
- Similar to other predator-prey relationships
- Coevolved, “evolutionary cat and mouse”

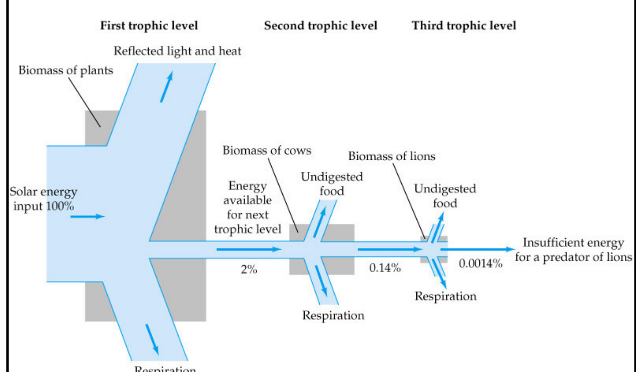
Simple terrestrial tropic levels

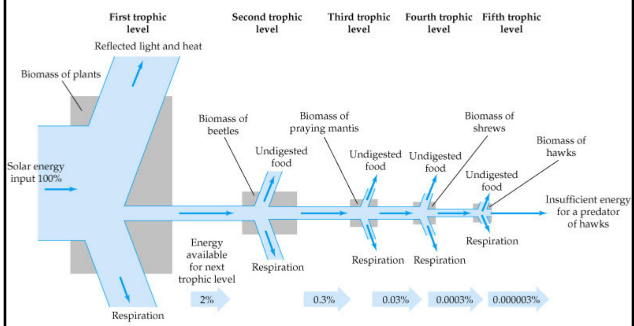


Eltonian Pyramid

- All ecosystems should be dominated (biomass or energy) by primary producers, then by decomposers.







More energy in and/or greater efficiency should result in more trophic levels.

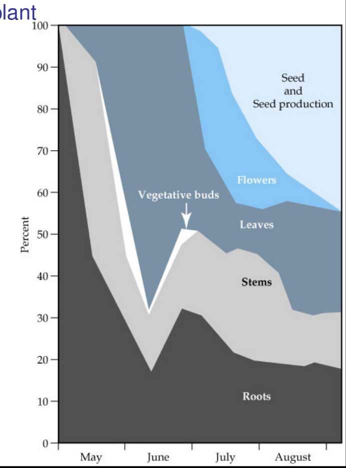
Exploitation Efficiency

- Proportion of available energy at a lower level ingested by a consumer level. Not Lindeman efficiency which uses total energy at two levels.
- Typically 20-60% - Why not higher or lower?
- Assimilation efficiency – how efficiently an organism converts ingested energy into biomass accessible at the next level.
  - Minimize loss due to kinnetic and heat loss

Organism Energy Budget

- Calories ingested used for:
  - Growth
  - Storage
  - Maintenance
  - Reproduction
- Organism (plant/animal/bacteria…) will allocate energy to maximize fitness.
- Energy allocated to growth and storage will determine what an individual makes available to next tropic level
- Reproductive allocation contributes indirectly
- Allocation will change over life history

Energy allocation for annual plant

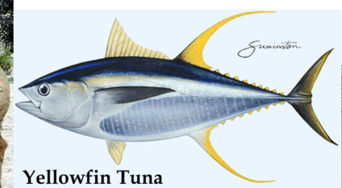


Endotherms vs. Ectotherms

- Endotherms
  - Generate body heat, maintain constant body temp
  - + active over a wide range of temperatures
  - - up to 30% of energy spent heating body
  - - low assimilation efficiency
- Ectotherms
  - + more efficient under ideal conditions
  - - restricted range of temperatures
  - + high assimilation efficiency
- For a given level of productivity, expect greater endotherm biomass.

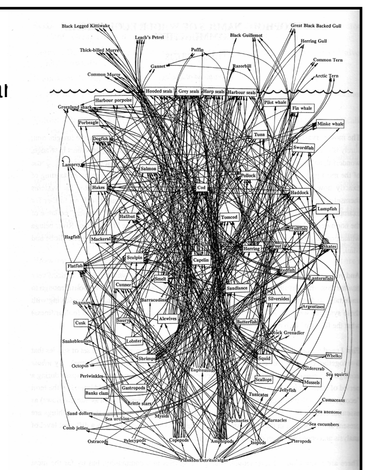
Endotherm vs. Ectotherm thermoregulation

- Not “warm blooded” or “cold blooded”
- Endotherms control body temperature physiologically, ectotherms behaviorally
- Most biological reactions very temperature sensitive. Endo vs. ectotherm presents a significant tradeoff



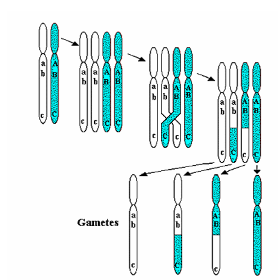
Realistic Food Web

- Actual ecosystems ar very complex
- Trophic levels not always distinct
- Food web is more realistic view



Life History and the Evolution of Sex

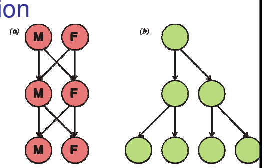
- Sexual Reproduction
  - Two sexes, each produce a gamete
  - Offspring are genetically distinct from parents, each parent has ~50% alleles in common
- Asexual reproduction
  - No sexes
  - Offspring are clones of parent
- Parthenogenesis
  - All female species, clone through egg laying



Crossing-over and recombination during meiosis

Fitness costs of sexual reproduction

- Each individual needs to account for more than 2 offspring for populations to increase
- Only half of a parents genetic material used
- Cost of recombination – unknowns introduced from combining two genomes
- Cost of mating behavior (injury, courtship, territory defense)
- Cost of mating structures (attract predators, energetically expensive displays)



Evolution of Sex

- Vast majority of organisms reproduce sexually…why?
- Must be a benefit to counter costs
- Enhances genetic diversity
- Clones tend to be of average fitness
- Increasing genetic variability produces a wider array of phenotypes – more likely to produce "superfit" individual.