ECOLOGY

Relationships of Organisms to Their Environment

Levels of Organization

Biosphere - Where life exists on Earth
Ecosystem - Interacting unit of biotic communities and abiotic environments
Community - Assemblage of interacting organisms in one environment
Population - Group of individuals of the same species in one environment ⇑ ⇑

Organism - Individual organisms *Scope of Ecology*

Organ System - Group of different organs working together
Organ - Group of different tissues working together
Tissue - Group of cells working together
Cell - Basic functional unit of organism
Organelle - Cell structures with specific functions
Molecule - Group of atoms

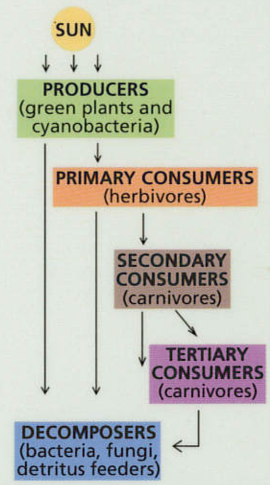
The Ecosystem

A Functional Unit in Ecology

A. **Trophic structure**
1. Autotrophs: Use either photosynthesis or chemosynthesis
2. Heterotrophs: Use food molecules produced by autotrophs

B. **Major components**
1. Abiotic portions
   a. Inorganic and organic substances
   b. Environment
2. Biotic portions
3. Producers (autotrophs)
4. Consumers (phagotrophs)
   a. Primary: Feed on producers (herbivores)
   b. Secondary: Feed on primary consumers (carnivores or predators)
   c. Tertiary: Top carnivore or predator
   d. Omnivore: Feed on plants, animals, etc.
   e. Parasites: Feed directly on prey by living with host
   f. Decomposers: Mainly fungi and bacteria (saprotrophs)
   g. Detritivores: Consume detritus: Waste products or bits of dead tissue
      i. Primary detritivore: Feed directly on detritus
      ii. Secondary detritivore: Feed on primary detritivores

Trophic Levels & Energy Transfers



Classification of Ecosystems

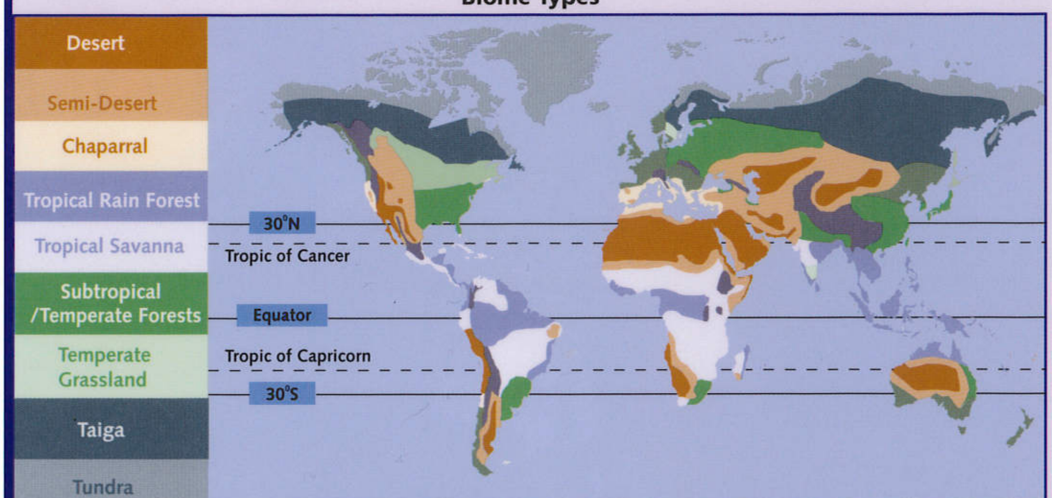
A. **Biomes**: Major types of floral and faunal assemblages of ecosystems based on temperature and rainfall amounts

B. **Terrestrial biomes**
1. Tundra: Primarily grasses and mosses
   a. "Permafrost" or permanently frozen soil prevents tree growth
   b. Occurs in arctic and alpine (tops of mountains) areas
2. Coniferous forests (taiga): Evergreen forests
3. Temperate deciduous forests: Trees and shrubs that shed leaves in fall, becoming dormant during winter months
4. Temperate grasslands: Rainfall allows for grasses and a few trees
5. Tropical grasslands (savannas): Rainfall interrupted by prolonged dry seasons, limiting tree growth
6. Chaparral: Mild, wet winters and long, dry and hot summers
7. Desert: Less than 25 cm rainfall per year
8. Tropical rain forests: May exceed 200 cm of rainfall per year - promotes lush tree and shrub growth; areas with pronounced wet/dry seasons may have tropical deciduous trees
9. The different biomes that occur at different latitudes can also occur on a smaller scale along the elevation gradient of tall mountains

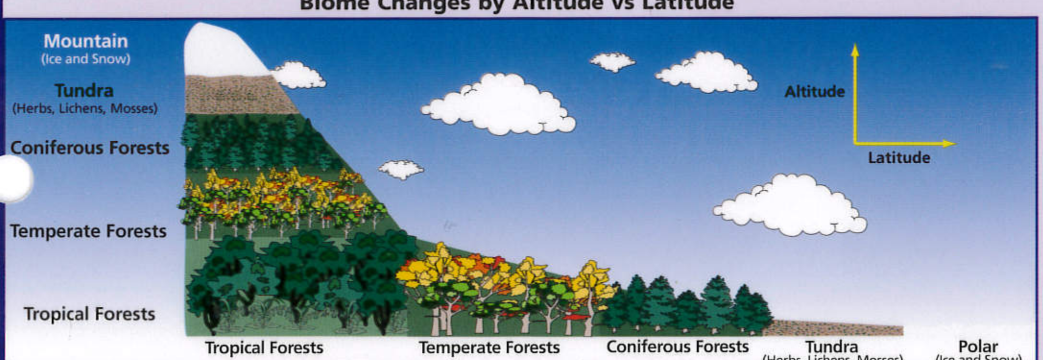
C. **Aquatic biomes**
1. **Freshwater**
   a. Standing water (lentic): Lakes and ponds
   b. Running water (lotic): Rivers and streams
   c. Wetlands: Swamps and marshes
2. **Marine**
   a. Coastal zone: Estuaries, wetlands including salt marshes, intertidal and coral reefs
   b. Open sea (pelagic)
   c. Open sea (benthic): Hydrothermal vent communities

D. Ecotones: Transition between two biomes or ecosystems

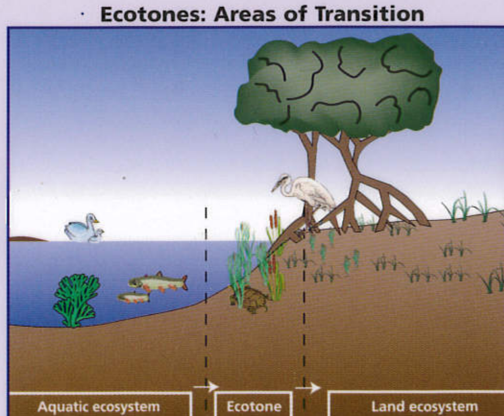
Biome Types



Biome Changes by Altitude vs Latitude



Ecotones: Areas of Transition

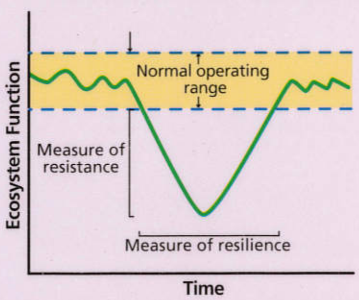


Stability of Ecosystems

A. **Resistance stability**: Ability of ecosystem to resist disturbances (perturbations) and maintain its structure/function

B. **Resilience stability:** Ability of ecosystem to recover quickly after a disturbance

Resistance & Resilience Stability



1. Stable environment: ↑ Resistance associated with ↓ resilient organisms (e.g., redwood forests are resistant to fire, but if burned, take a very long time to recover)
2. Unstable environment: ↑ Resilience associated with ↓ resistant organisms (e.g., grasslands are easily burned, but recovery is very rapid)

Energy Capture in an Ecosystem

Concept of Productivity

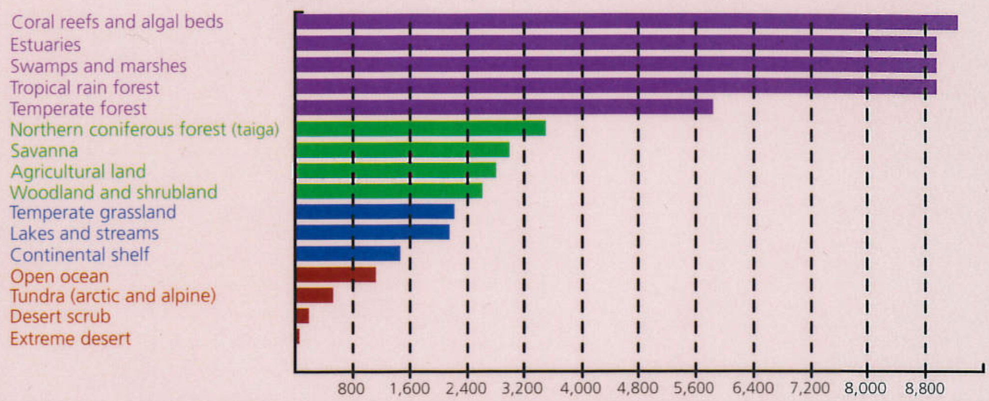
A. **Primary Productivity**

1. *Gross Primary Productivity* (GPP): Total biomass produced, including the energy autotrophs used for respiration (i.e., own metabolic needs)
2. *Net Primary Productivity* (NPP): Biomass available as food for consumers

GPP = NPP + Respiration
NPP = GPP - Respiration
Respiration = GPP - NPP

B. **Secondary Productivity:** Biomass produced by consumers

Average Net Primary Productivity (kcal/m²/yr)

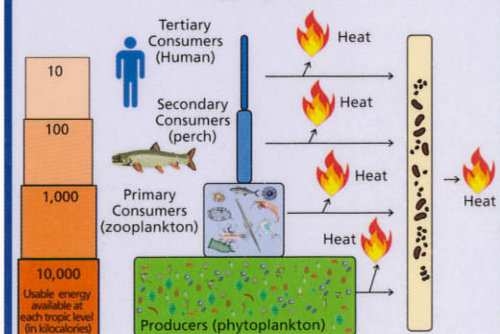


Energy Flow in Ecosystems

A. Laws of Thermodynamics

1. 1st Law: **Conservation of energy**: Energy can neither be created nor destroyed, but can be converted from one form to another
2. 2nd Law: **Law of entropy**: In any energy conversion, less usable energy will be available after each conversion due to heat loss; matter tends to become less organized and more random (a condition called *entropy*)

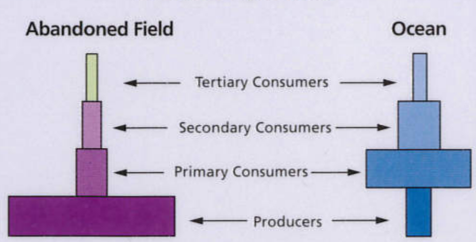
Energy Pyramids



B. **Ecological pyramids** show how ecosystems work:

1. Energy pyramid: Can never be inverted because of laws of thermodynamics
2. Biomass pyramid: Can occasionally be inverted
3. Numbers pyramid: Can occasionally be inverted

Biomass Pyramids



Food Chains & Webs

A. **Food chain**: Shows the transfer of energy between trophic levels from producers to consumers (see figures of ecological pyramids)

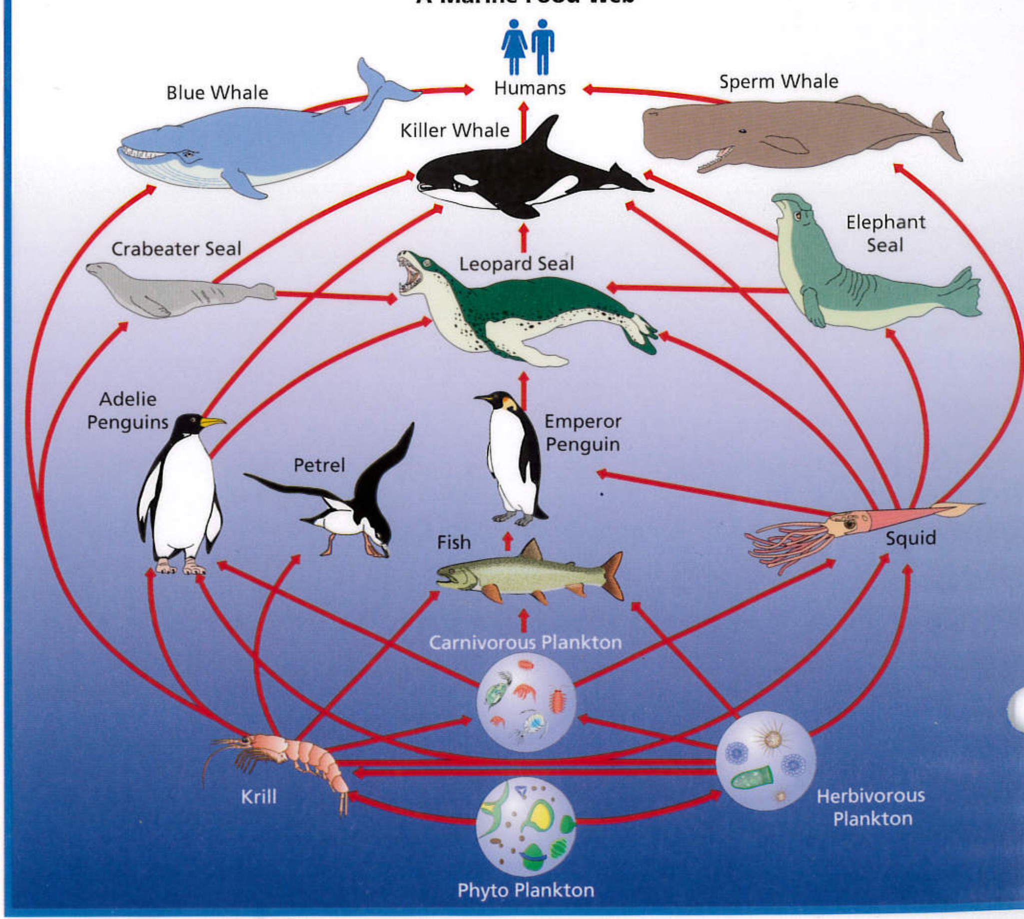
1. Grazing food chain: Starts with plants and goes to grazing herbivores onto carnivores and eventually to decomposers
2. Detritus food chain: Starts with plants to decomposers to detritivores

B. **Food web**: Shows the feeding relationships of who eats whom in an ecosystem

C. **Keystone species:** Species which if removed would have the greatest impact on an ecosystem

D. **Biological magnification:** Accumulation of toxins as food is transferred from one trophic level to the next in a food web; concentrations can be millions of times greater because of huge amounts of biomass necessary to support biomass at higher trophic levels

A Marine Food Web

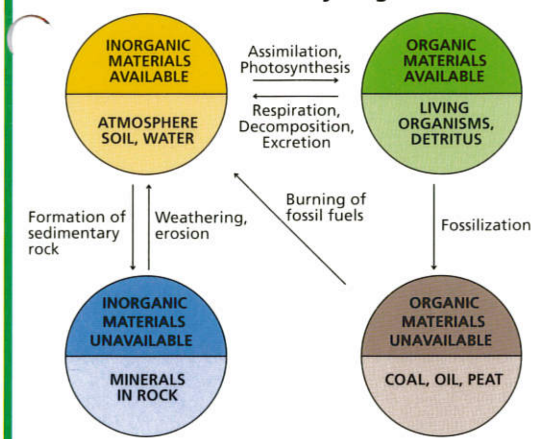


Nutrient Cycling in Ecosystems

"Message from Nature - Recycle"

A. Most nutrients move between four basic compartments

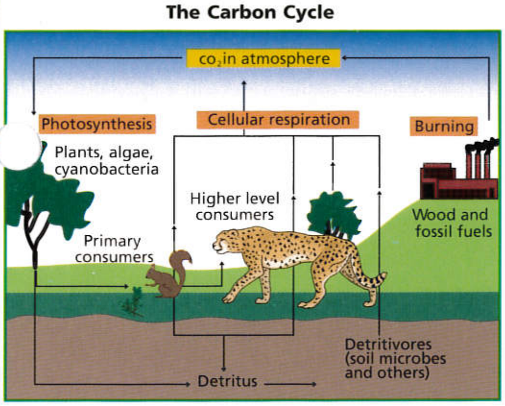
Nutrient Cycling



B. Selected examples

1. **Carbon cycle**
   a. CO_2 in the atmosphere and oceans is cycled relatively quickly
   b. Greenhouse effect & global warming
   c. Carbon dioxide and other gases (e.g., methane, nitrous oxide, chlorofluorocarbons) shield the escape of some heat from solar radiation, thus warming the Earth

The Carbon Cycle



   d. Major sources of excess carbon dioxide:
      i. Fossil fuel combustion
      ii. Deforestation
      iii. Warming oceans hold less carbon dioxide
   e. Some solutions
   f. Carbon distribution in tropical *versus* temperate terrestrial regions
      i. Tropics: > 75% in vegetation, < 25% in soil
      ii. Temperate: < 50% in vegetation, > 50% in soil
      iii. Thus, deforested tropical regions do not sustain agricultural crops for more than a few years before nutrients are depleted
      iv. Temperate regions can sustain crops for many years because most nutrients are locked in the soil; for this reason, most present-day human populations have developed in temperate regions that can "feed the people"
2. **Water cycle**
   a. More water evaporates from the sea than returns to it by rainfall
   b. Less water evaporates from land than returns to it by rainfall
   c. Overall, water is in balance between the land and sea
3. **Nitrogen cycle**
   a. Organisms use nitrogen in proteins (amino acids), ATP, DNA and RNA
   b. N_2 gas makes up nearly 80% of air
   c. Most organisms can only use the following forms: NH_3, NO_2 & NO_3
   d. N_2 converted/fixed into usable form two ways:
      i. Electro- or photo-chemically
      ii. Biologically using the special enzyme nitrogenase (bacteria, cyanobacteria & fungi)
   e. Nitrifying bacteria convert nitrogen into less toxic forms for
      i. *Nitrosomonas* $NH_3 \rightarrow NO_2$
      ii. *Nitrobacter* $NO_2 \rightarrow NO_3$
   f. Denitrifying bacteria help complete the cycle by returning nitrogen to its most common forms: NO_2 & $NO_3 \rightarrow N_2$, N_2O
4. **Phosphorus cycle**
   a. Organisms use phosphorus in major energy macromolecules (e.g., ATP, DNA, RNA), cell membranes (e.g., phospholipids), and skeletons (e.g., bones, teeth)
   b. Phosphate (PO_4^{3-}) is used to synthesize organic molecules
   c. Phosphorus, through erosion/weathering, leaches into water
   d. Algae (and plants in general) acutely respond to excess levels of phosphorus, which can lead to eutrophication in aquatic systems where algal blooms can become so thick that mass die offs of plants and animals can occur
   e. Consumers eat plants (and algae) to move phosphorus through the ecosystem
   f. Decomposition and excretion complete the cycling of phosphorus
5. **Sulfur cycle**
   a. Organisms use sulfur primarily in the synthesis of amino acids
   b. Hydrogen sulfide (H_2S) is involved in chemosynthesis by certain microbes (e.g., hydrothermal vent communities)
   c. Excess H_2S in the atmosphere (from burning fossil fuels, volcanic eruptions, etc.) can be oxidized to sulfur dioxide (SO_2), which combines with water vapor to form sulfuric (H_2SO_4) "acid rain" conditions; especially devastating to aquatic communities and some forested areas

C. **Nutrient cycling adaptations in tropical forests**

1. Nutrient reservoir is primarily in the biomass of the plants, which must quickly take up nutrients before they are washed away by rainfall
2. Root mats that are shallow and broad
   a. Recover nutrients quickly – before leaching
   b. Inhibit denitrifying bacteria – less N_2 loss to air
3. Mycorrhizal fungi (see Symbiosis, p. 5): Trap nutrients in plant roots; minimize leaching
4. Leaf structure/function
   a. Thick, waxy cuticles retard water (nutrient) loss
   b. Long, pointed leaf tips drain off rain water quickly; reduces leaching of nutrients
   c. Leaves usually permanent, throughout the year
5. Algae & lichens
   a. Obtain nutrients from rainfall, some may be available immediately for use by leaves
   b. Lichens may fix nitrogen
6. Thick bark: Inhibits nutrient loss from trees

D. **Nutrient cycling adaptations in temperate forests**

1. Nutrient reservoir is primarily in the soil, which is subjected to much less rainfall; nutrient cycling is slower and steady nutrient levels easier to maintain
2. Deep root systems help absorb nutrients from enriched soils
3. Leaf structure/function
   a. Broad (in angiosperms), to maximize exposure to limited sunlight
   b. Deciduous, losing leaves in minimum growing conditions (e.g., winter), which also returns nutrients to soil
4. Mycorrhizal fungi, although present, not as critical compared to tropical systems

E. **Nutrient cycling in grasslands**

1. Grazers (i.e., herbivores), and their subsequent fecal production, recycle nutrients to soil
2. Fire, which may be common because of extended dry periods and relatively low rainfall levels (compared to forested areas), helps recycle nutrients and inhibit succession (see **Ecological Succession**, p. 6)

F. **Nutrient cycling in tundras**

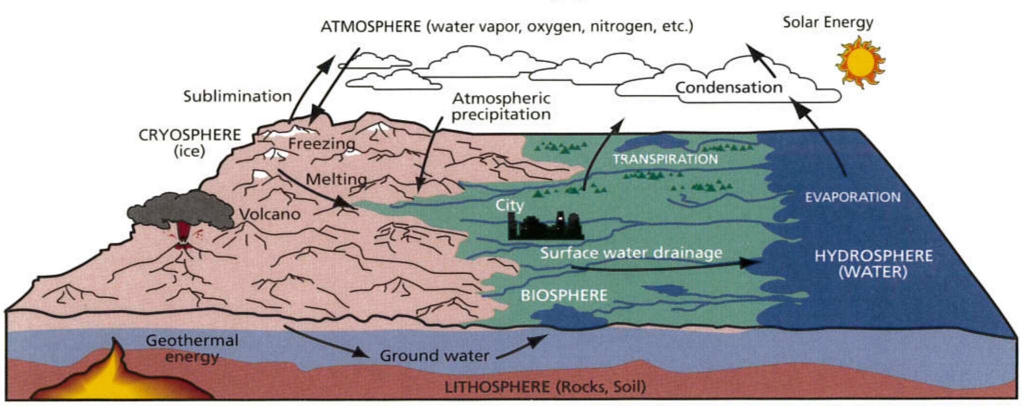
1. Short growing seasons and permafrost conditions make nutrient cycling very slow
2. Most primary production goes to decomposers, such as fungi and bacteria

G. **Nutrient cycling in deserts**: Extremely harsh environment where primary productivity is constrained by very low rainfall; little decomposition, extremely low nutrient cycling rates

H. **Nutrient cycling in oceans**

1. Mostly nutrient-impoverished environment; however, because of its large volume, nutrient cycling and primary productivity significant to the biosphere
2. Neritic (near the continent) areas, estuaries, mangrove forests, and coral reefs are nutrient-enriched areas

The Water Cycle

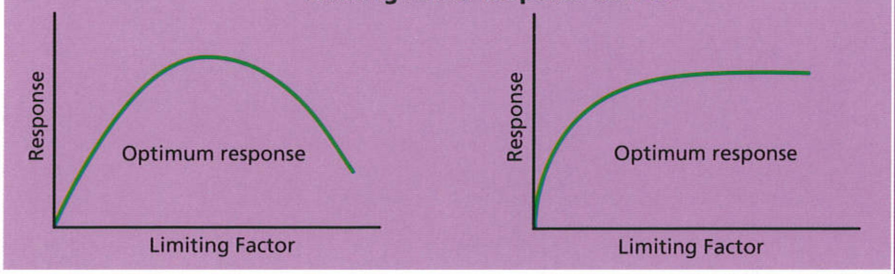


Limiting Factors & the Physical Environment

A. Too much or too little of an abiotic factor can be detrimental to an organism and potentially the ecosystem

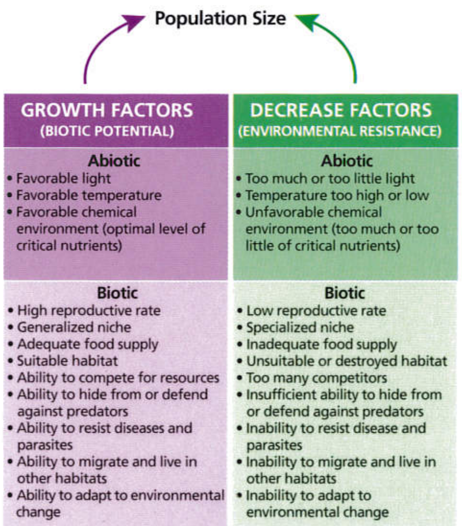
B. Activity curves
   1. Saturation: Beyond a certain level, there is no change in activity; suggests maintaining minimal level of factor is most important
   2. Optimum: Limited range for optimal activity e.g., Stenohaline *vs* Euryhaline: Narrow *vs* wide range of salt tolerance

Limiting Factor Response Curves



Population Dynamics in Communities

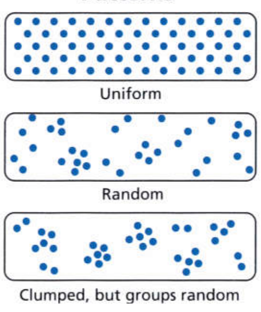
Factors Affecting Population Size



A. **Density**: Number of individuals in a given area

B. **Dispersion patterns**
   1. Uniform: Competition may force individuals to be relatively evenly spaced into territories
   2. Random: Rare because resources are not usually random
   3. Clumped: Most common as resources; are usually patchy

Density Distribution Patterns



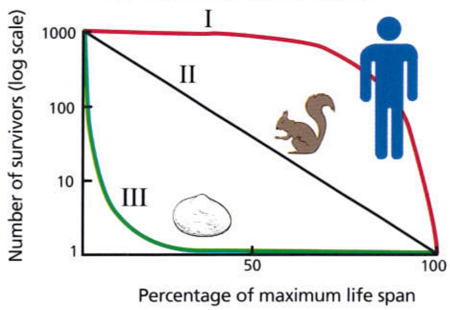
C. **Natality**: Ability to increase in numbers
   1. Maximum natality: Theoretical maximum rate of increase in new individuals
   2. Ecological natality: Actual production of new individuals under environmental conditions

D. **Mortality: Death of individuals**
   1. Minimum mortality: Deaths related to physiological longevity (e.g., old age)
   2. Ecological mortality: Deaths related to ecological longevity (e.g., predation)

E. **Survivorship Curves**
   1. I - Highly convex: High survivorship until old age
   2. II - Intermediate: Constant survivorship
   3. III - Highly concave: Low survivorship of young, high for adults

F. **Dispersion**: Movement into (immigration) or away from (emigration) an environment

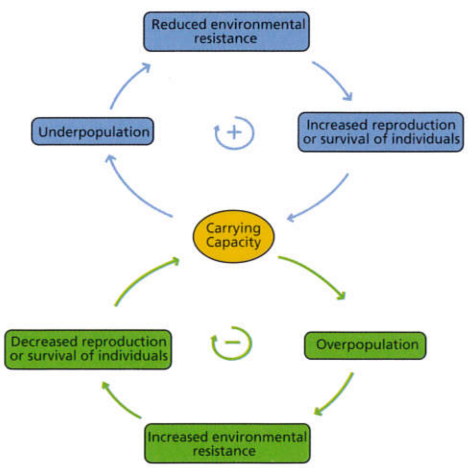
Survivorship Curve Types



G. **Biotic potential**: Inherent ability for a species to be successful

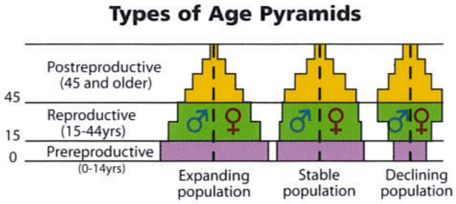
H. **Carrying capacity**: Maximum population size for a specified area

Factors Affecting Carrying Capacity



I. **Age distribution**: Ratios of various age groups

Types of Age Pyramids

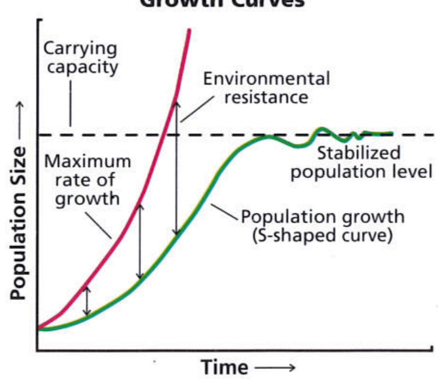


J. **Growth form**: How population growth increases
   1. Symbols: ΔN = Change in number of individuals in population, Δt = Change in time
   2. Growth Rate → $\Delta N/\Delta t$ = Average rate of change in population per time
   3. Specific Growth Rate → $\Delta N/N\Delta t$ = Average rate of change in population per time per organism
   4. "*Substitute **d** (a differential calculus term) for* **Δ**"
      a. Instantaneous Growth Rate → dN/dt = Rate of change in population per time at a particular instant
      b. Instantaneous Specific Growth Rate → dN/Ndt = Rate of change per time per organisms at a particular instant
      c. "Any estimate of growth must consider birth rates and death rates": $dN/Ndt = r = b - d$
         r = Instantaneous coefficient of population growth
         b = Instantaneous specific birth rate
         d = Instantaneous specific death rate
   5. Intrinsic Rate of Natural Increase *or* Biotic Potential of a Population: $r_{max} = b_{max} - d_{min}$
      a. Biotic potential growth rate curves can be graphed by using the following equation: $dN/dt = rN$
      b. When plotted, the curve is shaped like a ***J*** and characterizes exponential growth

K. **Carrying capacity**:
   1. Environmental resistance prevents populations from increasing at their biotic potential indefinitely
   2. Thus, population sizes are limited within an ecosystem

K = maximum value of "N" because of environmental resistance or carrying capacity
K - N = Additional individuals environment can support
K - N/K = Fraction of "K" still available for population growth

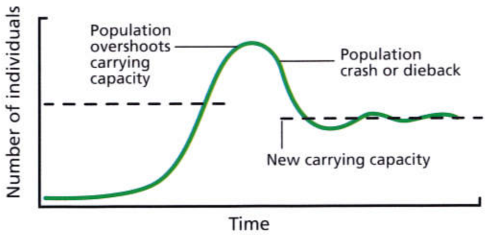
J-shaped & S-shaped Population Growth Curves



   3. Growth curves with carrying capacity factored in can be graphed using the following modified equation: $dN/dt = rN(K - N/K)$
      a. When plotted, the curve is shaped like an ***S*** and characterizes logistic growth
      b. Exponential growth can lead to population crashes if the carrying capacity is reached too quickly

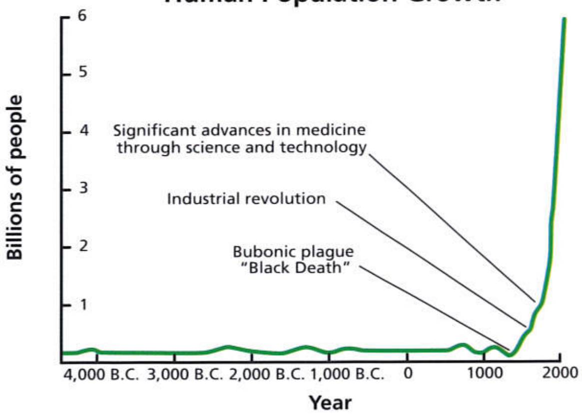
Population Dynamics in Communities Cont.

Population Crash from J-shaped Growth



c. Human population growth is increasing exponentially
   i. Over one million new humans are born every 4 days; the carrying capacity of the Earth may be 10-20 billion humans
   ii. Human population may reach 12 billion by 2050
   iii. *"Will there be a catastrophic population crash? Or will the human population stabilize without overshooting the carrying capacity?"*

Human Population Growth



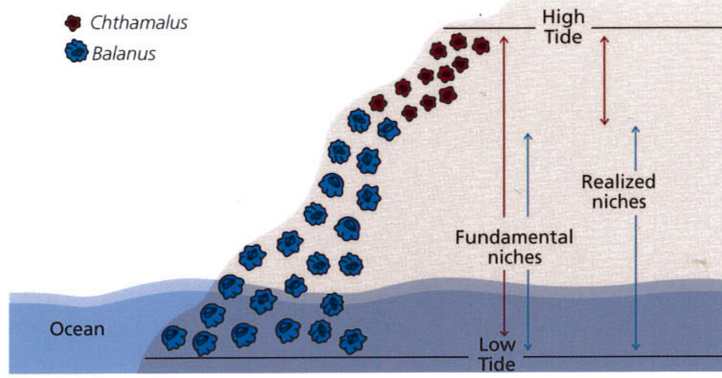
L. Different reproductive strategies exist in populations to maximize biotic potential
   1. **R-strategy**: Maximum reproductive rate (r) with minimum parental care
   2. **K-strategy**: Lower reproductive rates because population densities are near the carrying capacity (K); parental care maximized to ensure survival of offspring

Characteristics Associated with r & K selection

CHARACTERISTIC	*r*-SELECTED POPULATIONS	*K*-SELECTED POPULATIONS
Maturation time	Short	Long
Lifespan	Short	Long
Death rate	Often high	Usually low
Number of offspring produced per reproductive episode	Many	Few
Number of reproductions per lifetime	Usually one	Often several
Timing of first reproduction	Early in life	Late in life
Size of offspring or eggs	Small	Large
Parental care	None	Often extensive

M. Population maintenance after growth has been achieved:
   1. **Density-independent control**: Abiotic factors: e.g., weather, natural disturbances
   2. **Density-dependent control**
      a. Biotic factors: e.g., competition, disease, predation, parasitism
      b. Ecological niche: Functional status of a species within the ecosystem
      c. Fundamental niche: Resources a species could use ideally
      d. Realized niche: Resources a species actually can use
      e. Competition: Can limit resources available to species
         i. Participants:
            a. Intraspecific: Individuals of the same species
            b. Interspecific: Individuals of different species
         ii. Types
            a. Interference: Directly fighting over resources (e.g., males competing for females)
            b. Exploitation: Use of similar resources (e.g., different species feed on same food source)
      f. Competitive exclusion principle: Two or more species that overlap geographically (i.e., *sympatric*) cannot occupy the same niche (*allopatric* species live in different areas and do not interact)

Interspecific Competition Affecting Actual (Realized) Niche Size of Barnacles



         i. Resource partitioning: Habitat/resource is divided into subunits or microhabitats that minimize competition
            a. Spatial RP: Dividing physical space into subunits
            b. Temporal RP: Using same habitat at different times (e.g., diurnal/nocturnal partitioning)
         ii. Character displacement: Similar, sympatric species tend to have greater differences than similar allopatric species

N. Interactions among species have various outcomes, not all of which are negative for both species

Types of Ecological Interactions

		Effect on Organism 2		
		Benefit	***Harm***	***No Effect***
Effect on Organism 1	***Benefit***	Mutualism	Predation or parasitism	Commensalism
	Harm	Predation or parasitism	Competition	Amensalism
	No Effect	Commensalism	Amensalism	—

1. **Symbiosis**: Those associations involving organisms living directly in/on each other
   a. All organisms are involved in symbiosis and thus is a major factor in ecosystem communities
   b. Three symbiotic types involving the **host** organism (usually larger) and the **symbiont** (usually smaller):
      i. **Mutualism:** Both partners benefit
      ii. **Commensalism:** One partner benefits while the other is unaffected
      iii. **Parasitism:** One partner benefits while the other is harmed
   c. Symbiosis sub-subcategories:
      i. **Phoresis:** One symbiont transports the other
      ii. **Inquilinism:** Different organisms sharing a common home
      iii. **Endosymbionts:** Live within cells
      iv. **Ectosymbiont:** Live outside cells
   d. **Obligate symbionts:** One or both partners must live in the association for survival; ex: Termites are able to digest cellulose because of symbionts in their gut
   e. **Facultative symbionts:** One or both partners can survive outside the association
   f. Some selected, significant symbioses
      i. **Mycorrhizae:** Plant-fungus association, possessed by at least 80% of all plants to help get nutrients from the soil

Population Dynamics in Communities Cont.

ii. **Serial Endosymbiosis Theory (SET):** Three types of eukaryotic organelles: mitochondria, plastids, and undulipodia (cilia & flagella); may have originated as free-living bacteria that invaded a host cell

iii. ***Rhizobium*/legumes:** Bacillus bacteria live in soil where legume plants grow and becomes incorporated into tissue structures called **nodules**, which provide a plant with nearly all its nitrogen needs through nitrogen fixation

iv. **Coral/zooxanthellae:** Dinoflagellate algae live intracellularly in vacuoles of gastrodermis of coral tissues; they assist in $CaCO_3$ production and provide food to the corals; allows corals to live in nutrient-poor waters

2. **Predation** (consumption of animals) **& herbivory** (consumption of plants)
   a. Importance affected by:
      i. Prey characteristics
         - Ability of prey to defend itself
         - Ability of prey to escape detection
         - Possible prey densities w/o predators
         - Possible prey dispersal w/o predators
      ii. Predator characteristics
         - Attack properties of predator
         - Fecundity of predator
         - Functional response of predator
      iii. Prey defense
         - **Animals**
            - **Aposematic coloration:** Warning coloration/patterns that other animals learn to avoid through experience because the prey has some innate defense that could harm the prey (e.g., toxic taste, venom)
            - **Camouflage:** Adaptations making it difficult to detect prey using **cryptic coloration**
            - **Disruptive coloration:** Coloration/patterns used to break up the outline of the prey organism
            - **Countershading** uses light/dark pigmentation to match background illumination levels

              Ex: Many aquatic animals have light bottom halves but dark top halves; a predator from above will see a dark background, while this same predator below the prey sees a lighter background - the prey may be difficult to distinguish from the respective backgrounds

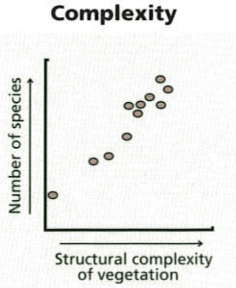
Countershading

            - **Mimicry:** Adaptations making a prey organism (mimic) look similar in structure and form to other species (model) thereby increasing survival rates of mimic
            - **Batesian mimicry** involves a harmless mimic looking similar to a harmful mode; mimic may be avoided by predators that recognize the generalized patterns as a harmful prey
            - **Mullerian mimicry** involves several species that all look similar and are all harmful; thus, the predators learn to avoid all species with the same pattern
         - **Plants**
            - **Secondary compounds** produced by many plants can deter grazers
            - **Plant morphology** involves physical adaptations, such as spines, that deter grazers
            - **Anti-herbivore mutalisms** involve insects (usually ants) that protect the plant from herbivores in return for food rewards from the host plant
            - **Below-ground nutrient storage** is used by many plants to survive heavy grazing on above-ground plant parts

Community Structure

A. Communities vary in species composition
   1. **Species dominance**: Numerical abundance is not the only criterion necessary for such designation (e.g., small understory trees in a forest may be more numerous, but the relatively few larger trees that determine the light levels filtering through are the "dominant" species)

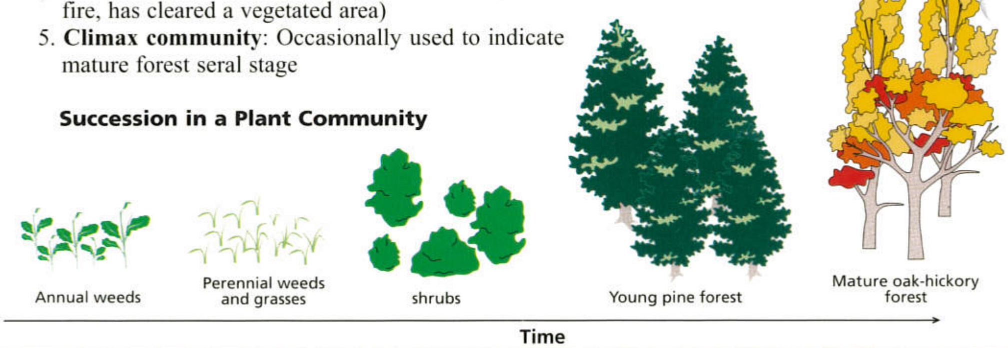
Species Richness Generally Increases with Habitat Complexity



   2. **Keystone species**: Organisms that play a critical role in maintaining the integrity of the community (not always easily determined)
   3. **Species diversity = Biodiversity**
      a. Species richness: Number of species; usually higher in complex habitats
      b. Relative abundance: Number of individuals of one species compared to the total for all species

B. **Ecological succession**: Changes in the composition and function of communities
   1. **Seral stage**: Each stage in the succession process; may be short-term (months to several years), or long-term (decades)
   2. **Pioneer species**: Early successional species
   3. **Primary succession**: Community development on a site previously unoccupied (e.g., volcanic rock)
   4. **Secondary succession:** Community development on a site previously occupied by a community (e.g., disturbance, such as fire, has cleared a vegetated area)
   5. **Climax community**: Occasionally used to indicate mature forest seral stage

Succession in a Plant Community



Community Characteristics at Different Seral Successional Stages

Characteristic	Initial seral stages	Final seral stages
Community Function		
Net primary productivity	High	Low
Food webs/chains	Simple, plant-herbivore	Complex, high decomposition
Nutrient cycling efficiency	Low	High
Energy use efficiency	Low	High
Community Structure		
Plant size	Small	Large
Species diversity	Low (r-selection high)	High (K-selection high)
Trophic structure	Producers dominant	Producers, heterotrophs
Ecological niches	Very few and general	Abundant and specialized

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