Introduction to Environmental Science

Two types of "global" change
- Pervasive local change (e.g. land-use change, deforestation, pollution)
- Inherently global change (e.g. climate change, ozone depletion)

Globalization and global change
- Fourfold population increase
- Sixteen-fold energy increase
- Ten-fold pesticide increase
- Twenty-fold increase in economic output

Major MEA findings
- 60% of ecosystem services degraded or deteriorating
- Cultivated systems cover ¼ of the globe
- >50% of wetlands destroyed
- 10-30% of mammal, amphibian, bird species threatened with extinction

Natural Resources
- Renewable
- Non-renewable

Purpose of science in society
- Minimize/quantify uncertainty
- Predict outcomes of different actions
- Understand complex adaptive systems

Objectives of the scientific approach
- Explain observed world in terms of generalized principles
- Maximize predictive power (i.e. "If we do x, y will probably result")
- Hypothesis are disproved or not disproved, not proved or not proved

Scientific Methods

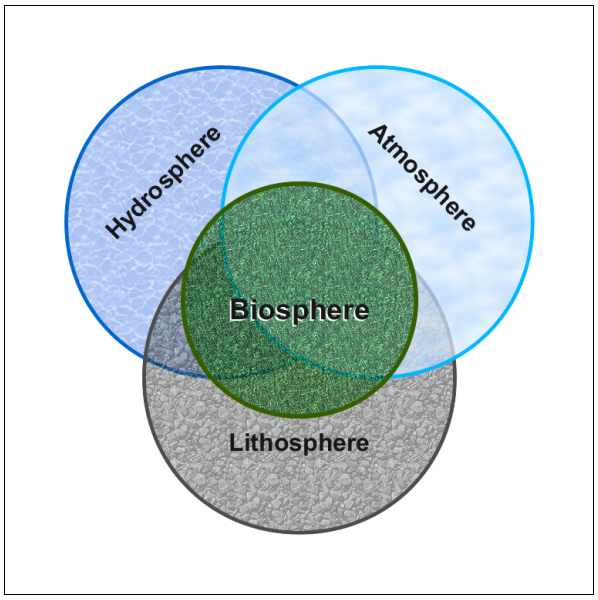
Approaches to scientific knowledge
- Hypothesis formulation and testing
- Empirical generalization
- Systems modeling
- Dialectical analysis
- Historical materialism

General (traditional) scientific method
- Research-->Hypothesis-->Experiment-->Publication
- Multiple hypotheses eventually consolidated into a theory
- Theory consistently confirmed and further developed into a law

Inductive vs. deductive reasoning
Why the traditional method sometimes cannot be used in environmental science (think replication)

The Biosphere

The Biosphere concept
Modern concept developed by Vernadsky
Biosphere – Physical domain of life
Three intersecting spheres:
Lithosphere – outer region of solid rock
Hydrosphere – watery envelope surrounding Earth
Atmosphere – Gaseous envelope surrounding Earth



Four "laws of ecology"
Everything is connected to everything else
Everything must go somewhere
Nature (usually) knows best
There is no such thing as a free lunch (TANSTAFL)

Biosphere and Society

Tragedy of the Commons
Developed by Hardin to advocate:
Coercive population control
Lifeboat ethic
Elimination of food aid
Privatization or restriction of access to common-pool resources

Sustainable development

Sustainable development is development that "meets the needs of the present without compromising the ability of future generations to meet their own needs"

Intra-generational (within the current generation) equity

Inter-generational (across generations) equity

Right now we are failing on both fronts

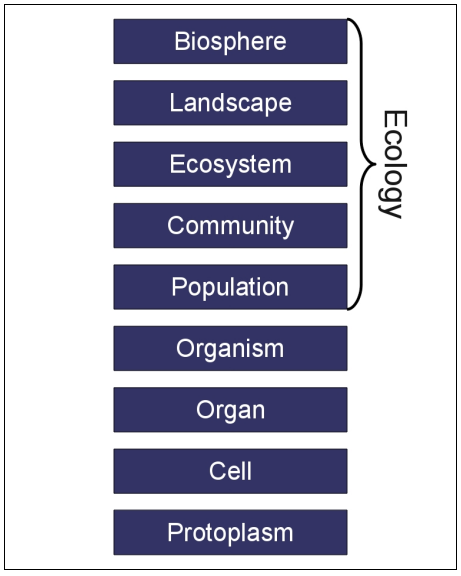
Globally, North produces disproportionate share of waste and consumes a disproportionate share of resources relative to its population

Richest 10% of global population accounts for 54% of total GNI

Within-country disparity, too. In the US, the richest 20% of the population accounts for 85% of the GDP

We haven't even begun to consider any for of inter-specific justice or equity

Biological levels of organization



Energy flows

Energy = ability/capacity to do work

Potential energy

Kinetic energy

Thermodynamics

Earth is a thermodynamically open system, but a materially closed system

First law of thermodynamics: law of the conservation of energy

Second law of thermodynamics: tendency towards entropy

Photosynthesis & Respiration

Photosynthesis: Transformation of radiant energy into chemical energy, accomplished in plants with chlorophyll
- Water + carbon dioxide + radiant energy → gluclose + water + oxygen

Aerobic Respiration: Converts chemical (potential) energy stored by planets into kinetic energy
- Glucose + water + oxygen → energy + carbon dioxide
- Undertaken by animals (regularly) and plants (at night)
- Higher temperatures → more plant respiration
- Anaerobic respiration is also possible

Trophic Levels
- (Primary) Producers
  - Also called autotrophs (as opposed to heterotrophs)
  - Convert inorganic matter into organic molecules
  - Plants, algae, and some bacteria
- Primary Consumers
  - Consume producers, i.e., predators
  - Herbivores
  - Convert plant material into usable substances
- Secondary Consumers
  - Consume primary consumers
  - Carnivores
  - Cannot convert plant material
- Tertiary Consumers
  - Consume secondary consumers (although many may also consume primary consumers)
  - Also carnivores
  - "Top predators"
  - Cannot convert plant material
  - Least efficient in terms of energy flow

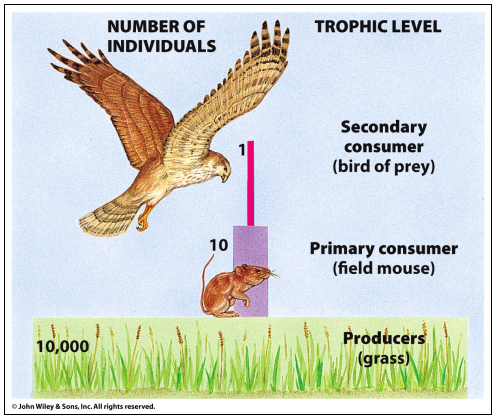
Other trophic interactions
- Omnivores
  - Both primary and secondary/tertiary consumers
  - Can convert plant material
  - Some can be consumed by tertiary consumers
- Detritivores
  - Consume detritus (i.e. inert organic matter)
  - Can convert both plant and animal material
  - Work in conjunction with decomposers
- Decomposers
  - Saprotrophs (and heterotrophs)
  - Break down inert organic matter into forms that can be used again by producers
  - Work in conjunction with (and are sometimes the same as) detritivores

Food Web
- Most organisms rely on multiple food choices

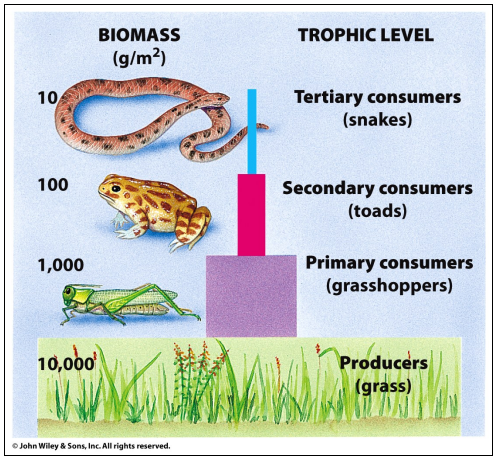
More complex model
More realistic model
Energy still constrained to move in one direction
Energy is dissipated as heat at each juncture

Energy/Matter pyramids

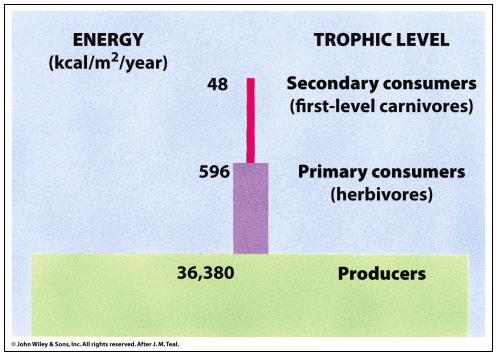
Pyramid of numbers



Pyramid of Biomass



Pyramid of Energy



Primary Productivity

Gross Primary Productivity (GPP) = Rate of energy capture by plants (terrestrial, phytoplankton in aquatic systems) in photosynthesis

Net Primary Productivity (NPP) = GPP – respiration

Human Appropriation of Net Primary Productivity

Community Development

Evolution through natural selection (sensu Darwin)

- Above-replacement reproductive capacity
- Heritability of key traits
- Limits on population growth
- Differential reproductive success

Modern synthesis of evolution

- The gene as the primary transmission mechanism
- Mutation as the primary source of variation
- Coevolution
  - Mutualism may have been responsible for evolution of the cell
- Demographic stochasticity/ecological drift

Taxonomic classification, 8 taxonomic levels:

- Domain
- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species

Dreadful Kings Play Chess On Fancy Golden Stools

Ecological niche

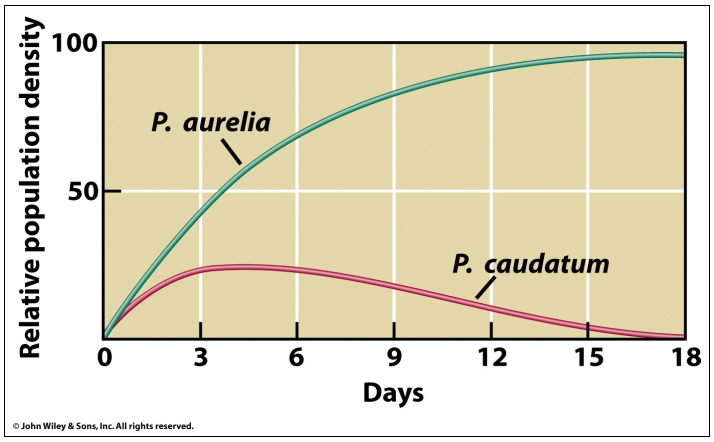
- Multidimensional phase space defined by a species' resource requirements
- Condition actually constraining population size is the limiting factor (less than needed or more than tolerated)
- Niche that a species could theoretically occupy is its fundamental niche
- Actually occupied niche is the realized niche
- Are communities dominated by niche-assembly or dispersal-assembly rules?

Keystone species

Species that significantly affects the rest of the community in disproportion to its relative abundance

Competition

Interspecific vs. intraspecific competition
Traditionally treated as the most important interaction, now recognized as one of many
Competitive exclusion
Resource partitioning
Intermediate disturbance \& non-equilibrium dynamics



Coevolution
Mutualism
Both species benefit from the interaction
Removal of one species has detrimental effect on other
e.g. mycorrhizae
Commensalism
One species benefits, the other is unaffected
Removal of beneficial species has detrimental effect on other, but not vice versa
e.g. epiphytes on tropical trees
Parasitism
One species benefits at the expense of another
Removal of parasitic species has beneficial effect on host
Loss of the host (prior to reproductive cycle) has detrimental effect on parasite
Frequently not fatal, but can weaken host response to other stresses
Parasites that trigger disease and death called pathogens
e.g tapeworm, crown gall bacteria
Predation
One species consumes the other (or most thereof)
Capture prey through pursuit and ambush
Consumers are predators
Coevolution → evolutionary arms race
Deterrence
Impose (or imply) cost on potential predator
Bright, bold coloration frequent
Mimicry by freeloaders
e.g. hornet, cacti, Monarch Butterfly

Predator adapts through physiological or behavioral changes
Avoidance
Avoid detection by potential predator
Cryptic coloration frequent
e.g. Potoo, Walking Stick
Predator adapts through sensory or behavioral changes
First predator to adapt gains an advantage

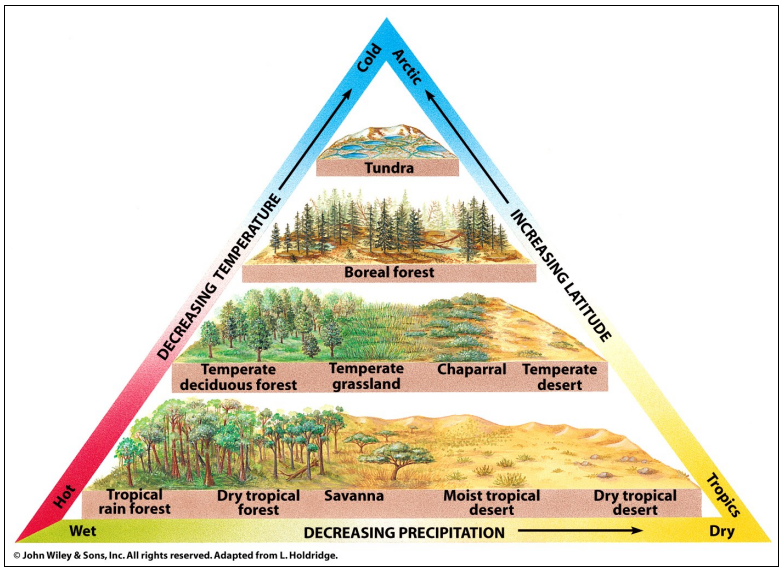
Species richness
Number of species in a community/ecosystem/habitat
Structural complexity
Ecotone/edge effects
Disturbance regime
Environmental stress
Dispersal

Resilience and resistance
Resistance is ability to withstand disturbances
Resilience is ability to recover from disturbances
Together, confer degree of community stability

Primary succession
Occurs on non-vegetated or de-seeded land (e.g., volcanic rock, land exposed by retreating glacier)
Undertaken by pioneer species
Secondary succession
Occurs on de-vegetated or primary successional land
Undertaken by non-pioneer (i.e. established) species

Biomes

Geographic & climatic zonation
Latitude
Temperature
Precipitation

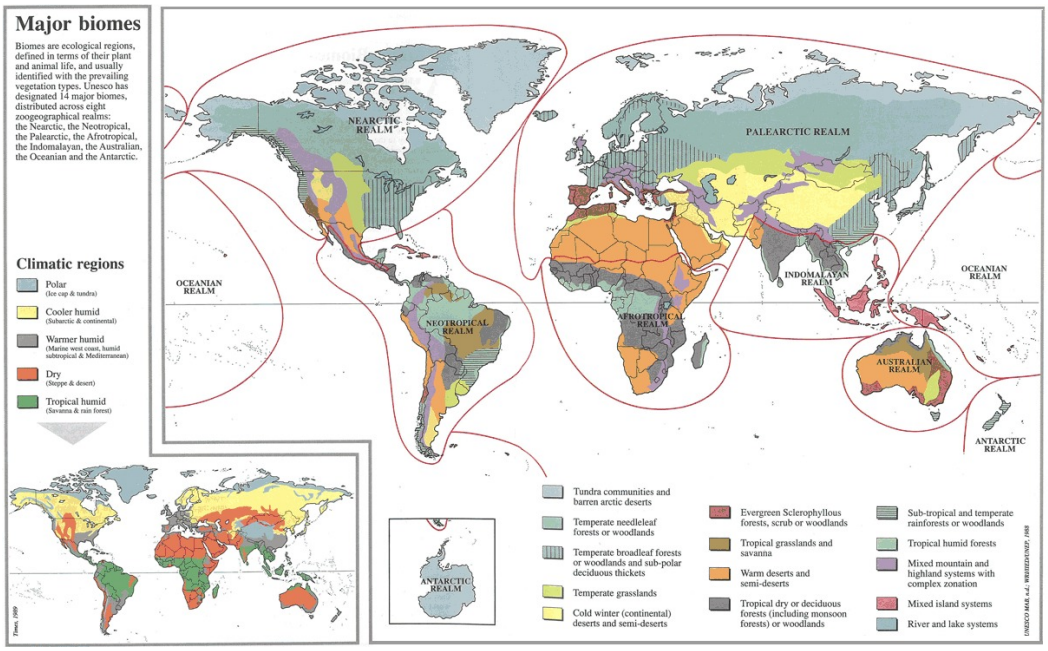


Eight zoogeographical regions

- Afrotropical
- Antarctic
- Australian
- Indomalayan
- Nearctic
- Neotropical
- Oceanian
- Palearctic

Eleven terrestrial biomes

- Tundra (arctic and alpine) – least productive
- Boreal forest
- Temperate rain forest
- Temperate deciduous forest
- Temperate grassland
- Chaparral
- Desert
- Tropical rain forest – most productive terrestrial biome (third most productive among terrestrial and aquatic) by unit-area; most productive terrestrial biome (second most productive among terrestrial and aquatic) by total
- Tropical seasonal forest
- Savanna
- Mixed montane

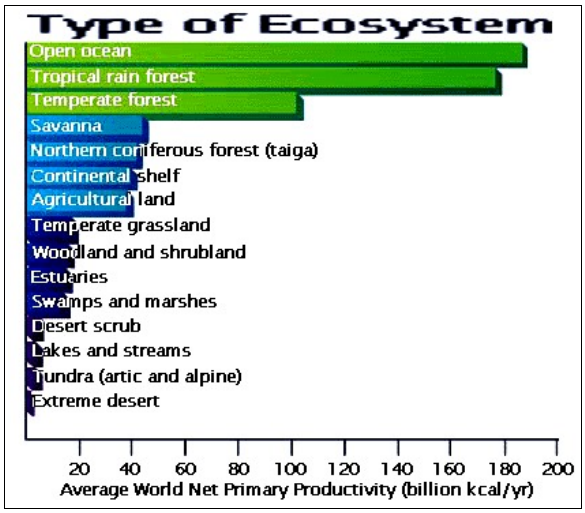


Aquatic ecosystems
- River
- Lake
- Wetland
  - Swamp
  - Marsh
  - Bog
  - Fen
- Estuary – most productive per unit-area due to four factors:
  - Rivers carry terrestrial nutrients into the estuary
  - Tidal action promotes rapid nutrient cycling and waste removal
  - Significant light penetration into shallow water
  - Numerous plants act as primary producers and trap detritus
- Ocean – Largest contribution to total NPP but very low per-unit NPP, contribution due to ocean cover over most of the Earth
  - Intertidal environment
  - Pelagic environment
  - Benthic environment
    - Seagrass bed
    - Kelp forest
    - Coral reef
      - Fringing reef
      - Atoll
      - Barrier reef
  - Threats to oceans
    - Non-point-source pollution

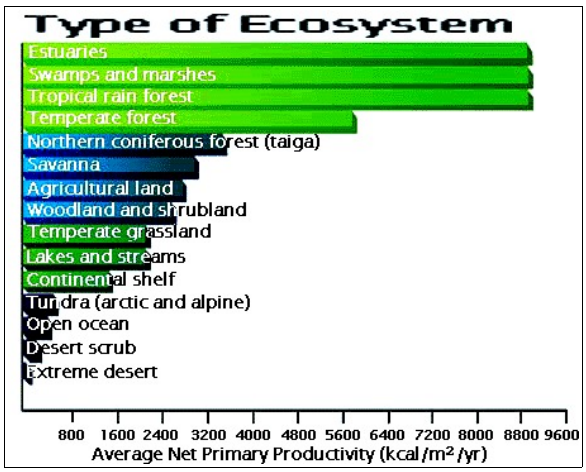
Point-source pollution
Invasive-alien species
Overharvesting
Bycatch
Aquaculture
Coastal development
Habitat destruction
Climate change

NPP Comparisons

Total NPP



NPP per unit-area

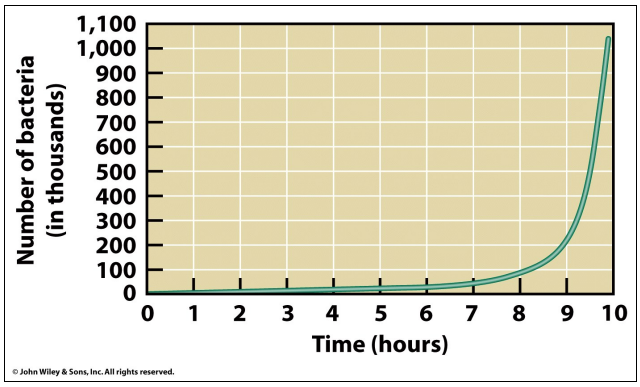


Population Ecology

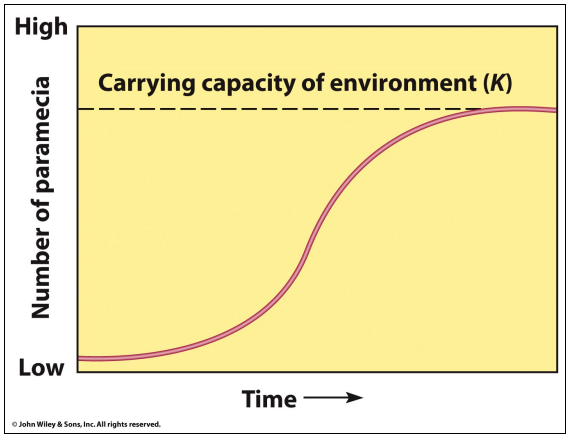
Basic concepts
Population = Number of individuals of a given species in a given area
Population density = Number of individuals per areal unit in a given area
Population change

$$\Delta N = r = B - D + I - E$$

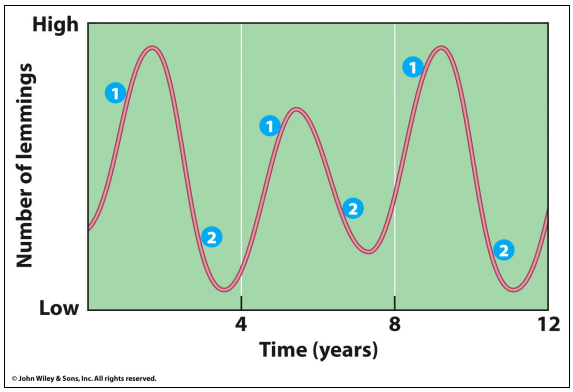
Exponential population growth
J-shaped curve



Logistic population growth
S-shaped curve
Population encounters environmental resistance
Density-dependent
Density-independent
Population eventually stabilizes near *carrying capacity*



Oscillating population
Population peaks near carrying capacity, then crashes, then peaks, then crashes, *ad infinitum*
Peaks and crashes can be caused by density-dependent factors and changes in the carrying capacity
Many real populations exhibit this trend

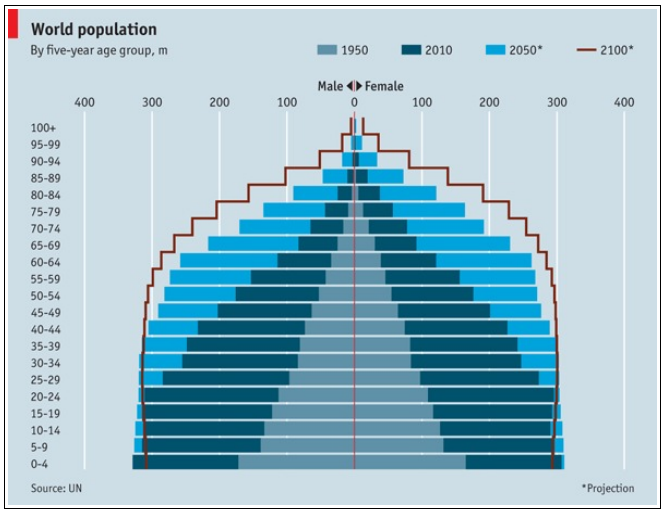


Age-structured population

Future population depends on proportion of population in each age-group, fertility of that age-group, and likelihood of each individual surviving to the next age-group.

Frequently estimated using the Leslie matrix

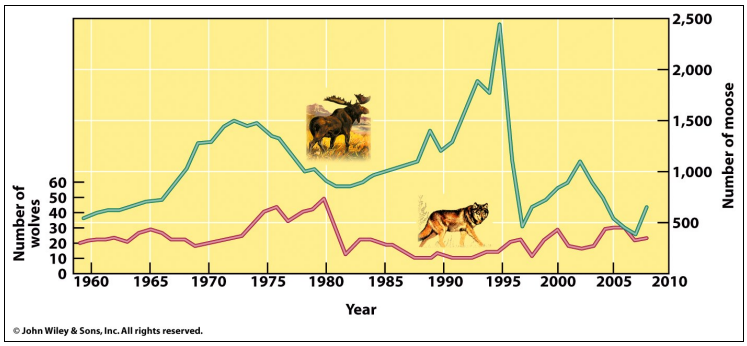
Important in human populations



Predator-prey interactions

Lotka-Volterra model

Each population influences the other; i.e., prey population = food availability for predator, predator population = mortality probability for prey



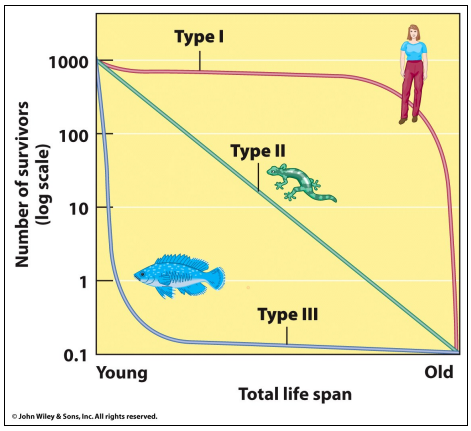
Life History traits

Reproductive strategy

r-selected

K-selected

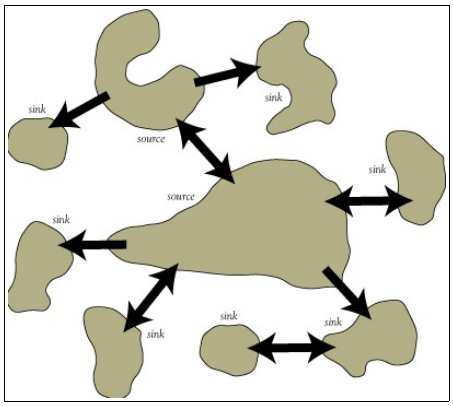
Survivorship probability



Metapopulations

Sink = death rate > birth rate

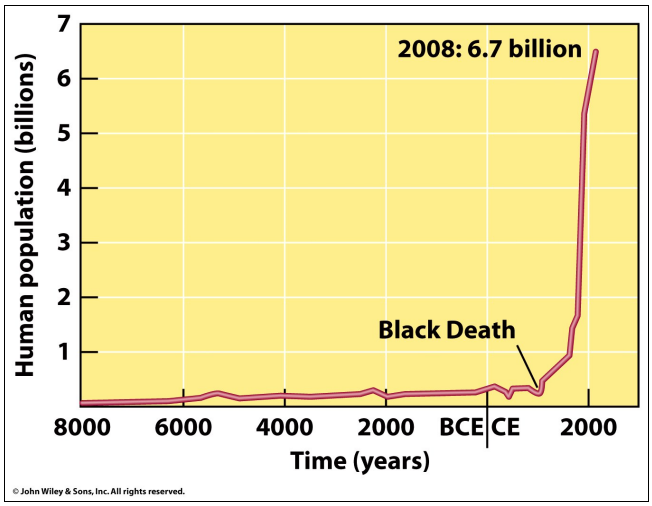
Source = birth rate > death rate



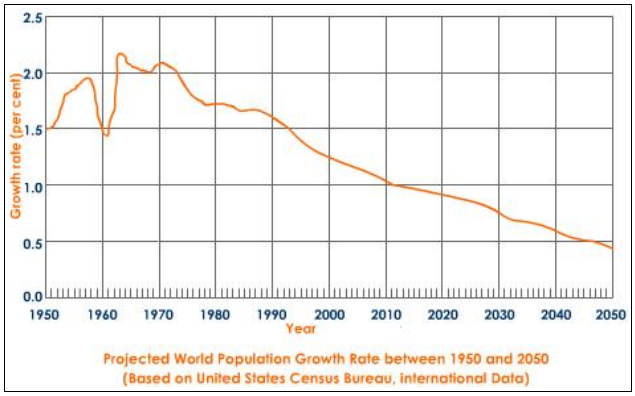
Human population

Perspectives on human population
- Malthus
  - Population increases exponentially, but food production can only increase linearly
  - Poverty is the result of irresponsible breeding by the poor
  - Contraception is unacceptable, as the poor become lazy if they aren't forced by necessity to work
  - The only way to prevent universal famine is to starve the poor
- Hardin
  - Human reproduction continues until carrying capacity reached
  - Poverty and famine in poor countries primarily due to irresponsible governments and citizens
  - Allowing families (and by extension women) to control their own fertility is "intolerable"
  - "Lifeboat ethic" (i.e., "Every man for himself, and the Devil take the hindmost")
  - Food aid causes the poor to breed, and eventually leads to famine
  - Privatize natural resources or have the State restrict access to prevent overexploitation
- Cairo Consensus
  - Switch from coercive to individual-based approach
  - Emphasis on women's rights and empowerment, sexual health, contraception availability, family planning
  - Partnerships with NGOs and human rights organizations
  - "Sustained economic growth," social justice, and ecological sustainability are mutually obtainable goals
- Marx
  - Human reproduction is linked to social mode of production and reproduction
  - Poverty due to wealth accumulation (intra-nationally) and imperial exploitation (inter-nationally)
  - Surplus population produced by land appropriation and replacement of workers with machines
  - Population stabilization much more feasible when wealth and power are shared

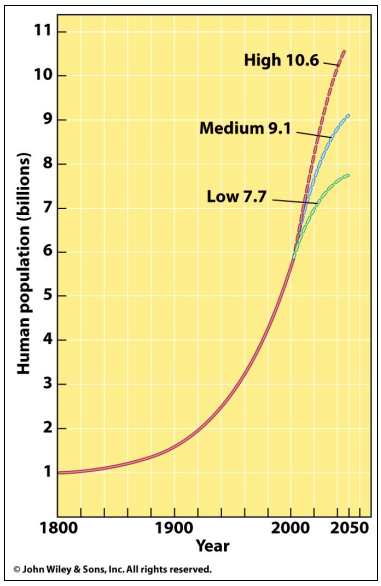
Significant population growth



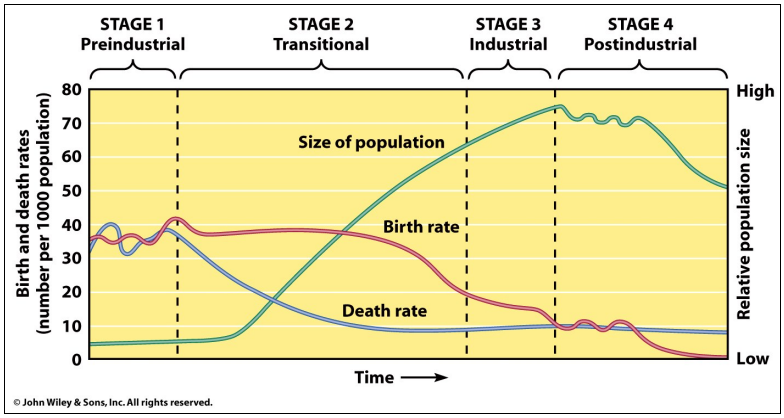
However, rate of growth slowing



Projections call for a leveling mid- to late-twenty-first century



Demographic transition?



How many people can the Earth support? 42?

- Distribution of wealth and commodities
- Average level of wealth or consumption
- Role of technology
- Types of global and national political institutions
- Demographic structure and distribution
- Desired environmental quality and levels of biodiversity
- Whether total population should be stabilized or allowed to oscillate
- Acceptable levels of risk (e.g. Should floodplains be developed?)
- The time-frame being considered