(1.) Reproduction

- Methods of Reproduction
  - Sexual reproduction
    - Meiosis, gamete formation, and fertilization
    - Offspring show genetic variation
  - Asexual reproduction
    - Single parent produces offspring
    - Offspring are genetically identical

- Asexual Reproduction
  - Spontaneous fission
    - Animals split or cut in two can regenerate new tissues to become two clones
  - Propagation
    - Plant cuttings or broken-off segments (vegetative propagules) propagate new clones
  - Parthenogenesis
    - Ovum develops without fertilization by male
    - Environmentally controlled/induced
  - Budding
    - Individuals bud off clones
    - Rare in animals (e.g. sea anemones, sponges)
    - Common in plants (rhizomes or “runners”)

- Types of Sexual Reproduction
  - Separate male and female individuals
    - Most animals
    - Dioecious plant species have male and female flowers on separate individuals
      - e.g. holly trees, stinging nettle
  - Simultaneous Hermaphrodites
    - Animals with both male and female organs (e.g. earthworms and snails)
    - Plants with bisexual flowers containing both stamen and pistil. e.g. lilies
    - Monoecious plants have male and female flowers on the same individual;
  - Sequential Hermaphrodites
    - Animals and plants that change sex due to age or environmental cues such as population sex ratio
    - Protogynous - start as females
    - Protandrous start as males

- Plant Life Cycle Origins
  - Terrestrial plants evolved from green algae
  - Ancestral plants life cycle is similar to that of green algae
  - Other similarities:
    - Same pigments, chemical make-up, genetics
Evolutionary Trend
  o Evolution of Plants
    o Nonvascular plants
      ▪ Bryophytes (mosses, hornworts)
    o Vascular plants
      ▪ Seedless (ferns, horsetails)
      ▪ Seed-bearing (conifers, flowering plants)
  o Seed-Bearing Vascular Plants
    ▪ Gymnosperms arose first
      ▪ Cycads, Ginkgos, Gnetophytes, Conifers
    ▪ Angiosperms arose later
      ▪ Monocots, Dicots

Two Types of Spores
  o Microspores
    ▪ Develop into pollen grains
    ▪ Immature male gametophyte
  o Megaspores
    ▪ Develop on sporophyte in ovule
    ▪ Female gametophyte
  o Pollination

Gymnosperms
  o Plants with “naked seeds”
  o Seeds don’t form inside an ovary

Pine Cones
  o Clusters of woody scales bearing ovules
  o Megaspores develop into female gametophyte
  o Male cones
    ▪ Microspores become pollen grains are not woody

Life Cycles
  o Senescence:
    ▪ Phase from maturity to death of plant or parts of plant
  o Dormancy:
    ▪ Seasonal response to environmental change
    ▪ Growth stops, metabolism idles
    ▪ Ends with return to favorable conditions
  o Vernalization:
    ▪ Low temperature stimulation of flowering

Animal Reproduction and Dispersal
  o External Fertilization
    ▪ Sessile aquatic organisms release gametes into water (broadcast spawning)
    ▪ No energy spent on finding and competing for partner
    ▪ Energy spent on copious gamete production
    ▪ High number of offspring, low survival rate
  o Internal Fertilization
- Common to many types of animals (aquatic, terrestrial, invertebrates and vertebrates)
- More effective fertilization
- Fewer offspring, higher survival rate

❖ Bearing Offspring:
  - Oviparity (Egg laying)
  - Ovuliparity: fertilization is external (arthropods, fishes, most frogs)
  - Oviparity: fertilization is internal, the female lays zygotes as eggs with important vitellus (typically birds)
  - Ovo-viviparity: oviparity with retention of zygotes in the female’s body or in the male’s body, but there are no trophic interactions between zygote and parents.
    - In sea horse, zygotes are retained in the male’s ventral "marsupium".
    - In the frog Rhinoderma darwinii, the zygotes develop in the vocal sac.
    - In the frog Rheobatrachus, zygotes develop in the stomach.
  - Viviparity (Live Bearing)
    - Histotrophic viviparity: the zygotes develop in the female’s oviducts, but find their nutrients by oophagy or adelphophagy (intra-uterine cannibalism in some sharks)
    - Hemotrophic viviparity: nutrients are provided by the female, often through some form of placenta as in most mammals

❖ Embryonic Development
  - Direct development
    - Individuals develop into adult-like juveniles
  - Indirect development
    - Individuals go through several larval stages before attaining adult form

❖ Cost of Sexual Reproduction
  - Specialized cells and structures must be formed
  - Special courtship and parental behaviors can be costly
  - Nurturing developing offspring, either in egg or body, requires resources (usually from mother)

❖ Reproductive Costs
  - Organisms Budget Time and Energy to Reproduction
    - Reproductive effort - time and energy allocated to reproduction
    - The more energy an organism allocates to reproduction, the less it can allocate for growth and maintenance
      - Terrestrial isopod
      - Douglas-fir tree
  - The amount of energy invested in reproduction varies for different individuals
    - Investment in reproduction includes production, care, and nourishment of offspring
An individual’s fitness is determined by the number of offspring that survive to reproduce

- Trade-offs
  - Number and size of offspring
    - Seed size and number of seeds produced per plant
    - Seed size and probability of seedling survival
    - Expected reproductive success in wet versus dry environments

- Species Differ in the Timing of Reproduction
  - Semelparity is the mode of reproduction in which an organism expends all of its energy in one suicidal act of reproduction
    - The life span of semelparous species varies from several days (some insects) to decades (cicada, bamboo)
  - Iteroparity is the mode of reproduction in which an organism produces fewer young at one time and repeats reproduction throughout its lifetime
  - There are trade-offs associated with early versus late reproduction
  - Vertebrates, perennial plants, shrubs, and trees

- Parental Investment Depends on the Number and Size of Young
  - There is an inverse relationship between the number of offspring produced and the parental investment that each receives
  - Large numbers of offspring
    - Are produced by organisms that inhabit disturbed sites, unpredictable environments, or environments where parental care is impossible
    - Increase the chances that some young will survive
  - Parents that produce few young can expend more energy on each young
    - Altricial young are born or hatched in a helpless condition and require considerable parental care (e.g., mice)
    - Precocial young emerge from the womb ready to move about and forage for themselves (e.g., ungulate mammals)
  - The degree of parental care varies widely
  - Parental care is best developed among social insects (e.g., bees)

- Fecundity Depends on Age and Size
  - The number of offspring produced varies with the age and size of the parent
  - Many plants and ectothermic (coldblooded) animals exhibit indeterminate growth and do not have a characteristic adult size
    - These continue to grow throughout their adult life
  - Perennial plants delay flowering until they reach a sufficiently large size
  - Many biennial plants delay flowering until environmental conditions become more favorable
  - The difference in annual plant size is related to the number of seeds produced
  - Production of offspring increases with fish size (which increases with age)
  - The number of eggs produced by loggerhead sea turtles is constrained by body size
- There is a positive relationship between body size and number of young produced by female big-handed crabs

- **Environmental Conditions Influence the Evolution of Life History Characteristics**
  - Two habitat types relating to variability in time
    - Those that are variable in time and are short-lived
    - Those that are relatively stable, long-lived, and constant
  - This dichotomy was used by R. MacArthur, E.O. Wilson, and E. Pianka to develop the concept of r- and K-selection
  - Species adapted to variable or stable environments will differ in life history traits
  - r-strategists are typically short-lived and inhabit unstable/unpredictable environments that can cause catastrophic mortality
    - High reproductive rates, rapid development, small body size, large number of offspring, minimal parental care
    - Resources are rarely limiting
  - K-strategists are competitive species with stable populations of long-lived individuals
    - Delayed and repeated reproduction, larger body size, slower development, produce few young
  - Mortality is related to density

(2.) **Natural Selection**

- **Darwin’s four postulates:**
  - Individuals within species are variable in traits
  - Some of these variations (traits) are passed on to offspring (that is, these traits are heritable)
  - In every generation, more offspring are produced than can survive due to limits of the environment
  - Individuals with “better” variations (traits) have greater survival and reproduction. They are *naturally selected*.

- **Natural Selection (Darwin’s Conclusion)**
  - Natural selection for various traits among individuals of a population affects which individuals survive and reproduce in each generation
  - Process results in adaptation to the environment (increases fitness)

- **Adaptation**
  - Some heritable aspect of form, function, or behavior that improves the odds for surviving and reproducing
  - Environment specific
  - Outcome of natural selection

- **Populations Evolve**
  - Biological evolution changes populations, not individuals
  - Traits in a population vary among individuals
  - Evolution: change in the frequency of traits

- **The Gene Pool**
  - All the genes in a population
  - Genetic resource that is shared (in theory) by all members of population
Variation in Phenotype
- Each gene in gene pool may have two or more alleles
- Individuals inherit different allele combinations leading to variation in phenotype
- Offspring inherit genes, not phenotypes

What Determines Alleles in a New Individual?
- Mutation
- Crossing over at meiosis I
- Independent assortment
- Fertilization
- Change in chromosome number or structure

Genetic Equilibrium
- Allele frequencies at a locus are not changing
- Population is not evolving
- Five Conditions of Genetic Equilibrium
  - No mutation
  - Random mating
  - Gene doesn’t affect survival or reproduction
  - Large population
  - No immigration/emigration

(3.) Microevolution
- Microevolutionary Processes
  - Drive a population away from genetic equilibrium
  - Small-scale changes in allele frequencies brought about by
    - Natural selection
    - Gene flow
    - Genetic drift

Gene Mutations
- Infrequent but inevitable
- Each gene has own mutation rate
- Lethal mutations
- Neutral mutations
- Advantageous mutations

Polymorphism
- Variability in form within or among populations of same species

Results of Natural Selection
- Three possible outcomes:
  - A shift in the range of values for a given trait in some direction
  - Stabilization of an existing range of values
  - Disruption of an existing range of values
Directional Selection
- Allele frequencies shift in consistent direction over time
  - Speed in grasshoppers

Pinpointing the Target of Selection
- Populations of rock pocket mice have fur that matches the rocks on which they live
  - Black basalt: dark fur
  - Tawny granite: light fur
- DNA comparisons show that the two populations differ in Mclr gene sequence

Pesticide Resistance
- Pesticides kill susceptible insects
- Resistant insects survive and reproduce
- If resistance has heritable basis, it becomes more common with each generation

Antibiotic Resistance
- Antibiotics first came into use in the 1940s
- Overuse has led to increase in resistant forms
- Most susceptible cells died out, while resistant forms multiplied

Stabilizing Selection
- Intermediate forms are favored and extremes are eliminated
  - Human Birth Weight

Disruptive Selection
- Happens when forms at both ends of the range of variation are favored
- Intermediate forms are selected against
  - African Finches
    - Selection favors birds with very large or very small bill
    - Birds with intermediate-sized bill are less effective feeders

Sexual Selection
- Selection favors certain secondary sexual characteristics
- Through nonrandom mating, alleles for preferred traits increase
- Leads to increased sexual dimorphism
  - Sexual selection common in birds

- **Balanced Polymorphism**
  - Polymorphism: “having many forms”
  - Occurs when two or more alleles are maintained at frequencies greater than 1 percent
    - Sickle-Cell Trait: Heterozygote Advantage
    - Allele HbS causes sickle-cell anemia when heterozygous
    - Heterozygotes are more resistant to malaria than homozygotes

- **Genetic Drift**
  - Random change in allele frequencies brought about by chance
  - Effect is most pronounced in small populations
  - Sampling error: fewer times an event occurs, greater the variance in outcome
  - Genetic Drift: Small Populations
    - Frequency of b+ allele
  - Genetic Drift: Large Populations
    - Frequency of b+ allele

- **Bottleneck**
  - A severe reduction in population size
  - Causes pronounced drift
  - Example
    - Elephant seal population hunted down to just 20 individuals
    - Population rebounded to 30,000
    - Electrophoresis revealed there is now no allele variation at 24 genes

- **Founder Effect**
  - Effect of drift when a small number of individuals starts a new population
  - By chance, allele frequencies of founders may not be same as those in original population
  - Effect is pronounced on isolated islands

- **Inbreeding**
  - Nonrandom mating between related individuals
  - Leads to increased homozygosity
  - Can lower fitness when deleterious recessive alleles are expressed

- **Gene Flow**
  - Physical flow of alleles into a population
  - Tends to keep the gene pools of populations similar
Counters the differences that arise from mutation, natural selection, and genetic drift

- Gene Flow Example
  - Blue jay carries acorn between oak populations

Evolutionary Patterns, Rates, and Trends

- **Macroevo1ution**
  - Major patterns and trends among lineages
  - Rates of change in geologic time

- **Comparative Morphology**
  - Comparing body forms and structures of major lineages
  - Guiding principle:
    - When it comes to introducing change in morphology, evolution tends to follow the path of least resistance
  - **Morphological Divergence**
    - Change from body form of a common ancestor
    - Produces homologous structures
  - **Morphological Convergence**
    - Individuals of different lineages evolve in similar ways under similar environmental pressures
    - Produces analogous structures that serve similar functions

- **Comparative Development**
  - Each animal or plant proceeds through a series of changes in form
  - Similarities in these stages may be clues to evolutionary relationships
  - Mutations that disrupt a key stage of development are selected against
  - **Altering Developmental Programs**
    - Some mutations shift a step in a way that natural selection favors
    - Small changes at key steps may bring about major differences

- **Molecular Evidence**
  - Biochemical traits shared by species show how closely they are related
  - Can compare DNA, RNA, or proteins
  - **Comparing Proteins**
    - Compare amino acid sequence of proteins produced by the same gene
      - Human cytochrome c (a protein)
        - Identical amino acids in chimpanzee protein
        - Chicken protein differs by 18 amino acids
        - Yeast protein differs by 56
      - Sequence Conservation
        - Cytochrome c functions in electron transport
        - Deficits in this vital protein would be lethal
        - Some sequences are identical in wheat, yeast, and primates
  - **Nucleic Acid Comparison**
    - Use single-stranded DNA or RNA
    - Hybrid molecules are created, then heated
    - The more heat required to break hybrid, the more closely related the species
  - **Molecular Clock**
• Assumption: “Ticks” (neutral mutations) occur at a constant rate
• Count the number of differences to estimate time of divergence

❖ Biological Species Concept
  ➢ “Species are groups of interbreeding natural populations that are reproductively isolated from other such groups.” -Ernst Mayr

❖ Variable Morphology
  ➢ Reproductive isolation can cause genetic divergence leading to new species

❖ Genetic Divergence
  ➢ Gradual accumulation of differences in the gene pools of populations
  ➢ Natural selection, genetic drift, and mutation can contribute to divergence
  ➢ Gene flow counters divergence

❖ Reproductive Isolation
  ➢ Cornerstone of the biological species concept
  ➢ Speciation is the attainment of reproductive isolation
  ➢ Reproductive isolation arises as a by-product of genetic change
    • Reproductive Isolating Mechanisms
      • Prevent pollination or mating
      • Block fertilization or embryonic development
      • Cause offspring to be weak or sterile
  ➢ Prezygotic Isolation
    • Mechanical isolation
      • Wasp and zebra orchid
    • Temporal isolation
      • Cicada
    • Behavioral isolation
      • Albatrosses
    • Ecological isolation
      • Populations residing in different ecosystems
    • Gametic mortality
      • Mutation driven gamete incompetence or incompatibility
  ➢ Postzygotic Mechanisms
    • Early death
    • Sterility
    • Low survival rates
Models for Speciation

- **Allopatric Speciation**
  - Speciation in geographically isolated populations
  - Some sort of barrier arises and prevents gene flow
  - Effectiveness of barrier varies with species
  - Extensive Divergence Prevents Inbreeding
  - Species separated by geographic barriers will diverge genetically
  - If divergence is great enough it will prevent inbreeding even if the barrier later disappears
    - Archipelagos
      - Island chains some distance from continents
        - Galapagos Islands
        - Hawaiian Islands
          - Colonization of islands followed by genetic divergence sets the stage for speciation
          - Adaptive radiations:
            - Honeycreepers: in absence of other bird species, they radiated to fill numerous niches

- **Speciation without a Barrier**
  - **Sympatric speciation**
    - Species forms within the home range of the parent species
    - Sympatric Speciation in African Cichlids
      - Studies of fish species in two lakes
      - Species in each lake are most likely descended from single ancestor
      - No barriers within either lake
        - Feeding preferences localize species in different parts of lake
    - **Speciation by Polyploidy**
      - Change in chromosome number
        - (3n, 4n, etc.)
      - Offspring with altered chromosome number cannot breed with parent population
      - Common mechanism of speciation in flowering plants
  - **Parapatric speciation**
    - Neighboring populations become distinct species while maintaining contact along a common border