The Nature of Species

- Concept of species must account for two phenomena:
  - Distinctiveness of species that occur together at a single locality
  - Connection that exists among different populations belonging to the same species
• **Speciation**: process by which new species arise, either by
  – transformation of one species into another,
  – or by the splitting of one ancestral species into two descendant species

• **Sympatric speciation**: differentiation of populations within a common geographic area into species

• Species occurring together are:
  – distinctive entities
  – phenotypically different
  – utilize different parts of habitat
  – behave separately
The Nature of Species

- **Population:** any group of individuals, usually of a single species, occupying a given area at the same time
- Exhibit geographic variation
- **Subspecies:** within a single species, individuals in populations that occur in different areas may be distinct from one another

**Species Criteria**

- common descent
- small distinct groupings
- reproductive community

1) Typological Species Concept
   - type specimen
     - labeled/deposited in museum
     - represent ideal form/morphology of species
     - based on “only” morphological features
     - variation
2) Biological Species Concept
   a) based on Darwinian evolutionary theory
      1937-Dobzhansky: Genetics and the Origin of Species
      1990-inclusion into Great Books of the Western World
      along with Darwin’s The Origin of Species & Descent of Man
   b) natural selection  differential survival & reproduction
   c) stress here on reproductive continuity - genes rather than morphological features
      1982-Mayr defined biological species
      is a reproductive community of populations (reproductively isolated
      from others) that occupies a specific niche in nature
The Biological Species Concept

• Ernst Mayr’s **biological species concept** defines species as…
  “…groups of actually or potentially interbreeding natural populations which are reproductively isolated from other such groups.”

• In short: members of a population mate with each other & produce fertile offspring.
The Biological Species Concept

- **Reproductively isolated**: populations whose members do not mate with each other or who cannot produce fertile offspring
- Reproductive isolating mechanisms (RIM): barriers to successful reproduction
  - Geographic
  - Behavioral
  - Mechanical
  - Ecological
  - Temporal
  - Gamete fusion
  - Postzygotic

<table>
<thead>
<tr>
<th>TABLE 22.1 Reproductive Isolating Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanism</strong></td>
</tr>
<tr>
<td>Geographic isolation</td>
</tr>
<tr>
<td>Ecological isolation</td>
</tr>
<tr>
<td>Behavioral isolation</td>
</tr>
<tr>
<td>Temporal isolation</td>
</tr>
</tbody>
</table>
The Biological Species Concept

- Prezygotic isolating mechanisms prevent the formation of a zygote
  - **Ecological isolation**
    - Utilization of different portions of environment
    - Do not encounter each other
  - Example: lion & tiger
The Biological Species Concept

Lions & tigers ecologically isolated

In captivity lions & tigers can mate & reproduce surviving offspring
Behavioral isolation: species differ in their mating rituals

Biological Species Concept

• Sympatric species avoid mating with members of the wrong species in a variety of ways, including differences in:
  – Visual signals
  – Sound production
  – Chemical signals: **pheromones**
  – Electrical signals: electroreception
Biological Species Concept

- **Temporal isolation**: species reproduce in different seasons or at different times of day
- **Mechanical isolation**: structural differences between species prevent mating
- **Prevention of gamete fusion**: gametes of one species functions poorly with gametes of another species or within reproductive tract of another species
• **Postzygotic isolation** prevents normal development into reproducing adults

• **Hybridization**: mating between two different species with a zygote being formed

• Hybrids often:
  – Do not develop into adults
  – Do not develop into fertile adults

Example: mule
• Criticisms of biological species concept:
  – Interspecific hybridization
  – 50% California plant species, in one study, not well defined by genetic isolation

– Hybridization: common in animals
  • 10% of bird species hybridized in nature
  • Hybrid offspring of Galápagos finches appeared to be at no disadvantage for survival or reproduction
– Reproductive isolation may not be only force for maintaining integrity of species
Ecological Species Concept

Theories & criticisms

- Hybridization: little effect because alleles introduced into one species’ gene pool from other species quickly eliminated by natural selection
- Difficult to apply biological species concept to populations that are geographically separated in nature
- Many organisms: asexual & do not mate

Reproductive Isolation

- **Cladogenesis:** one ancestral species becomes divided into two descendant species
- If species are defined by existence of reproductive isolation, then
  - process of speciation identical to evolution of reproductive isolating mechanisms
Reproductive Isolation

Populations can become geographically isolated

Reproductive Isolation

- Formation of species a continuous process
- Two populations may only be partially reproductively isolated
- If isolating mechanisms have not evolved, then two populations will interbreed freely
- If populations are reproductively isolated, no genetic exchange will occur, two populations will be different species
Intermediate state:
- Hybrids are partly sterile
- Hybrids are not as well adapted to the habitat

- Selection would favor any alleles in parental populations that prevent hybridization
- **Reinforcement:** incomplete isolating mechanisms are reinforced by natural selection until they are completely effective
Reproductive Isolation

- Gene flow may counter speciation
- Reinforcement not inevitable
- Incompletely isolated populations have gene flow
- Hybrids may be inferior but serve as a conduit of genetic exchange
- Two populations will lose their genetic distinctiveness
- A race between complete reproductive isolation evolution & gene flow

Genetic Drift

- Random changes may cause reproductive isolation
  - Genetic drift in small populations
  - Founder effects
  - Population bottlenecks
- Hawaiian Islands: *Drosophila* differ in courtship behavior
  - Changes in courtship behavior between ancestor & descendant population may be the result of founder events
### Genetic Drift

- Given time, any two isolated populations will diverge because of genetic drift
- **Random divergence** may affect traits responsible for reproductive isolation
  - Speciation may occur

### Genetic Drift

- Adaptation can lead to speciation
  - Wet conditions vs dry conditions
  - Natural selection produces a variety of differences in physiological & sensory traits
  - Promotes ecological & behavioral isolation
Genetic Drift

Genetic drift may act on mating behavior

- *Anolis* lizards & dewlap color
  - Ability to see dewlap depends on color & environment
  - Light color: reflects light in dark forest conditions
  - Dark color: more visible in bright glare of open habitats
Geography of Speciation

- Is geographic isolation required for speciation to occur?

- **Sympatric speciation** occurs without geographic isolation
  - Instantaneous speciation through **polyploidy**
    - Individual is reproductively isolated from all other members of its species

---

Geography of Speciation

- **Polyploidy**: individuals that have more than two sets of chromosomes
- Plants with four sets of chromosomes (tetraploids) can survive, but not be fertilized by diploid individuals
Geography of Speciation

- **Allopolyploidy**: two species hybridize
  - Resulting offspring have one copy of chromosomes of each species
  - Infertile: cannot reproduce with either species
  - Can reproduce asexually
  - Can become fertile if chromosomes spontaneously doubled (polyploidy)

Geography of Speciation

- Results in tetraploids that could interbreed
- New species created
- Occurs frequently in plants
- Occurs in insects, fish, salamanders but rare
Alloployploid speciation

- Sympatric speciation may occur over course of multiple generations through disruptive selection
- Two phenotypes would have to evolve reproductive isolating mechanisms
- Two phenotypes could be retained as polymorphism within a single population

Geography of Speciation
Geography of Speciation

• 11 species of cichlid fish occur in Lake Barombi in Cameroon: sympatric speciation
• No within-lake isolation

Species Clusters

• **Adaptive radiations:** closely related species that have recently evolved from a common ancestor by adapting to different parts of the environment
• Occurs
  – in an environment with few other species & many resources
  – Hawaiian & Galápagos Islands
  – Catastrophic event leading to extinction of other species
Species Clusters

Classic model of adaptive radiation on island archipelagoes

1. An ancestral species flies from mainland to colonize one island.
2. The ancestral species spreads to different islands.
3. Populations on different islands evolve to become different species.
4. Species evolve different adaptations in allopatric.
5. Colonization of islands.

Classic model of adaptive radiation on island archipelagoes
Species Clusters

- **Key innovation:** evolves within a species allowing it to use resources or other aspects of the environment previously inaccessible
  - Evolution of lungs in fish
  - Wings in birds and insects
- Allows descendant species to diversify & adapt to new parts of environment

Species Clusters

- **Character displacement:** natural selection in each species favors those individuals that use resources not used by the other species
  - Greater fitness
  - Trait differences in resource use will increase in frequency over time
  - Species will diverge
Species Clusters

- Alternative:
  - Adaptive radiation occurs through repeated instances of sympatric speciation
  - Produces suite of species adapted to different habitats
Adaptive Radiation

Case 1: Hawaiian *Drosophila*

- > 1000 species of *Drosophila* on Hawaiian Islands
- Diversity of morphological & behavioral traits
- Empty habitats resulted in fruit flies that are:
  - Predators
  - Parasites
  - Herbivores
  - Detritivores
  - Nectar eaters

Adaptive Radiation

Case 2: Darwin’s finches

- Ancestors were subjected to different selective pressures
- Geographic isolation on many islands
- Diverse population, some evolved into separate species
- Occupy many different habitats
Adaptive Radiation

- **Ground finches**
  - Feed on seeds: size of bill relates to size of seed they eat

- **Tree finches**
  - All eat insects: one species uses a tool to get insects

- **Vegetarian finch**
  - Eats buds from branches

- **Warbler finches**
  - Eat insects from leaves & branches
Case 3: Lake Victoria cichlid fishes

- Home to > 300 species of cichlid until recently
- Recent radiation: sequencing of cytochrome \( b \) gene -- 2000,000 years ago
- Colonized from Nile River
- Changes in water level encouraged species formation
- Lake dry down 14,000 years ago

Adaptive Radiation

- Cichlids: small, perchlike fishes
- Males very colorful
- Foraging:
  - Mud biters, algae scrapers, leaf chewers, snail crushers, zooplankton eaters, insect eaters, prawn eaters, fish eaters
- Carry a second set of functioning jaws
Adaptive Radiation

- Abrupt extinction in last several decades
- 1950’s Nile perch introduced into lake
- 1990’s 70% cichlids extinct
Case 4: New Zealand alpine buttercups

- Speciation in glacial habitats
- Periodic isolation
- 14 species occupy 5 distinct habitats
  - Snow fields: 2130-2740 m elevation
  - Snowline fringe: 1220-2130 m elevation
  - Stony debris: slopes at 610 to 1830 m
  - Sheltered: 305-1830 m
  - Boggy habitats: 760-1525 m elevation

Adaptive Radiation
Adaptive Radiation

Gradualism: accumulation of small changes

Punctuated equilibrium: long periods of stasis followed by rapid change

Proposed by Niles Eldredge & Stephen Gould in 1972

Stabilizing & oscillating selection responsible for stasis

The Pace of Evolution
The Pace of Evolution

- Ability of species to shift their range could enhance stasis
  - Ice ages
  - Global warming

The Pace of Evolution

- Evolution may include both types of change
  - African mammals: evolved gradually
  - Marine bryozoa: irregular patterns of change
  - Many groups show evidence of both
  - Speciation can occur without substantial phenotypic change
  - Phenotypic change can occur within species in absence of speciation
The Pace of Evolution

Two views of pace of macroevolution

Speciation and Extinction

• Speciation, through time, surpassed extinction
• 5 mass extinctions have occurred
  – Most severe at end of Permian period—96% of all species may have perished
  – End of Cretaceous: dinosaurs went extinct
    • Hypotheses:
      asteroid
      volcanic activity
      disease
Speciation and Extinction

• Consequence of extinction: previously dominant groups may perish, changing course of evolution
• Dinosaurs went extinct, mammals began their radiation
• Rates of speciation after an extinction may take about 10 my
• Takes time for:
  – Ecosystems to recover
  – Processes of speciation & adaptive diversification to begin

Speciation and Extinction

Not all groups of organisms are affected equally during extinctions
Speciation and Extinction

6th extinction underway?
• Estimates:
  – 1/4th of all species will become extinct in near future
  – Rebound in species diversity may be slower than following previous mass extinction events
  • large proportion of the world’s resources will be taken up by human activities

Future of Evolution

Human influences on environment affect evolutionary processes
• Changing patterns of natural selection
• Global climate change: major challenge for many species
• Decreased population sizes will increase likelihood of genetic drift
• Geographic isolation will remove homogenizing effect of gene flow
• Chemicals & radiation could increase mutation rate
The Future of Evolution

Tigers now exist in geographically isolated populations

Future of Evolution

- Humans have introduced species into areas they did not occur
  - Isolated populations: allopatry in speciation process
    - Increase speciation rate
    - Increase extinction rate
- **Human evolutionary future**
  - Natural selection as an engine of evolutionary change
  - Human alteration of our own gene pool