Cycle 8: Species and Speciation

What is a species?

New and new species are discovered every year, but there is still no universal species concept that applies to all life. There have been many methods used to identify, define, and classify species:

- Populations with distinctly different traits
- Populations that successfully mate with each other but not other populations
- Populations that have distinct evolutionary histories

How to Define what a Species is

There are several interconnected concepts that can be used to define species:

1. Ecological Species Concept: a species is a group of organisms that are adapted to a particular set of resources (**niche**) in the environment.

2. Morphological Species Concept: a species is a distinct cluster of individuals in phenotypic space (**similar physical characteristics)**, with no intermediates or overlaps with other clusters. In a morphological species concept you can make comparisons using fossils and describe species based on observable traits.

- **Issues:** Variation in phenotypes is not consistent for different species and there is no information about the evolution of the differences you can identify between species. This makes it difficult to distinguish species that look similar.

3. Biological Species Concept: a species is a group of interbreeding populations that are **reproductively isolated** from other groups. In this concept, the collection of alleles can potentially be shared with anyone in the species, but not outside the species. You can also test gene flow by putting individuals from different populations together to see if they successfully mate. You can explain how species have evolved by examinings heritable traits, behaviour, and physiology that lead to reproductive isolation.

- **Issues:** Species boundaries cannot be defined for asexually reproducing organisms. reproductive behaviour cannot be found for extinct organisms. It may also not be possible to test whether individuals can successfully reproduce sexually.

4. Phylogenetic Species Concept: a species is a group of populations with a recent evolutionary history. A phylogenetic species is the smallest group of population that are all more closely related to each other than to anything else. To construct an evolutionary tree, both morphological and genetic information, such as DNA or amino acid sequences, can be utilized through molecular phylogenetics. Ideally, these groups should be monophyletic, meaning they consist of all descendants stemming from a common ancestor. Determining the extent of evolutionary change that defines a species or a group of species is crucial in this process, which can be applied to all organisms given the collection of data. While molecular data is generally not possible from most fossils, it is feasible to obtain molecular data from preserved remains. Species are characterized by individuals that share a recent evolutionary history. It must be decided how much evolutionary change defines a species. This species concept implies reproductive isolation for sexually reproducing organisms, but does to prove it. It can determine how traits have evolved to give rise to new species.

Comparing Populations

When comparing populations, it is essential to use information that matches the organism's true evolutionary history. Shared traits that are homologous and indicative of a true common ancestry are used for this purpose. However, it is important to be cautious of **homoplasies**, which can mislead evolutionary analysis due to convergent evolution. Homoplasies refer to similar traits that have evolved independently and do not share a common ancestry. A classic example is the evolution of wings in insects, birds, and bats, where these structures have evolved separately. To construct a reliable evolutionary tree, it is preferable to utilize information that is evolutionarily conserved, such as conserved DNA sequences of a gene. These traits can provide a more accurate depiction of shared ancestry and the independent evolution of particular properties.

Quick Recap/Quick Points

- Ideally, species are defined with multiple points of evidence such as morphology, behavior, genetics, trees, physiology, and more
- No universal definition of a species that applies equally to all life
    - Many different species concepts with guidelines for different groups of organisms

How does speciation happen?

Many mechanisms can lead to speciation, some of which are biological, some are geographical, while others are environmental. Essentially, all these mechanisms result in restriction to gene flow between organisms in the same species. When gene flow is restricted, differences between populations may evolve, which can lead to a point where they can no longer interbreed. This can occur due to factors such as geographic or environmental variations that impose restrictions on the exchange of genes between populations that were previously categorized as the same species.
Note: speciation mechanisms are defined in the context of the biological species concept as they focus on reproductive barriers.

Reproductive Barriers and Isolation

Reproductive barriers prevent gene flow between populations. These barriers can be categorized into 2 types: prezygotic and postzygotic. Prezygotic barriers occur prior to the formation of a zygote and encompass mechanisms such as differences in meeting, mating behaviors, and fertilization processes, all of which impede the successful fusion of gametes. On the other hand, postzygotic barriers manifest after the formation of a zygote and involve factors like developmental issues and reduced offspring viability, which hinder the survival and reproductive success of hybrid individuals.

Prezygotic Isolation Mechanisms

1. **Ecological isolation** – populations occupy the same geographic region but occupy different habitats, such as one type of crocodile preferring swamps while another prefers lakes. The populations don't interbreed simply because they live in different areas and wouldn't naturally encounter each other.
2. **Behavioral isolation** – signals or behaviors crucial for mating recognition (e.g. courtship rituals, mating displays, or even hormones) are not recognized by individuals from another population.
3. **Temporal isolation** – populations mate at different times, preventing successful interbreeding.
4. **Mechanical isolation** – structural differences that hinder mating between populations. For instance, certain flowers physically/morphologically restrict access to specific pollinators, facilitating pollination with particular species only. More broadly speaking, the reproductive organs between an individual from one population and an individual from another are not anatomically compatible.
5. **Gametic isolation** – incompatibility of gametes, preventing fertilization between populations. Essentially, the gametes aren't able to fuse together into a viable zygote. This can be due to a variety of biological factors, including sperm recognition proteins being unable to recognize the egg.

Postzygotic Isolation Mechanisms

1. **Hybrid inviability** – developing embryo is not viable and fails to reach maturity. Essentially, the gametes do fuse together into a zygote, but the development of that zygote/embryo fails to reach completion and the embryo dies before birth.
2. **Hybrid sterility** – the hybrid offspring may survive, but they are unable to reproduce due to their sterility. This often arises from an odd number of chromosomes, which prevents proper pairing during meiosis, preventing the hybrid from forming viable gametes.
3. **Hybrid breakdown** – the first generation of hybrids can produce viable gametes and offspring, but the second generation exhibits reduced fitness, sterility, or even inviability.

The Relationship between Reproductive Mechanisms and Speciation

These mechanisms are simply the ways in which distinct species are unable to interbreed, resulting in reproductive isolation. The process of creating these distinct species is called speciation, which is where one original species diverges into two distinct lineages which then become two distinct species. There are two types of speciation: sympatric (non-environmental) and allopatric (environmental):

1. Sympatric speciation – the process of speciation occurring without geographic or environmental separation between populations.

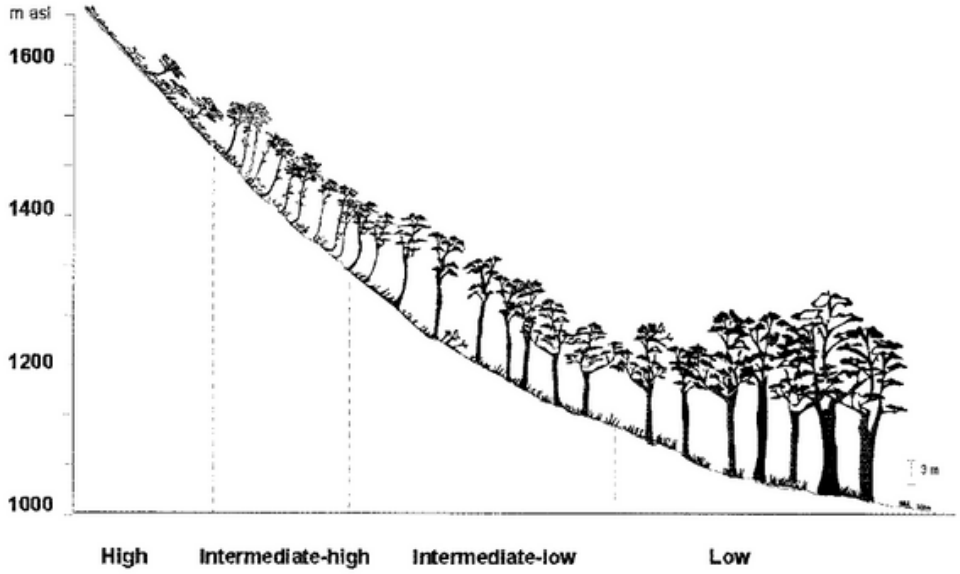
   a. It is characterized by changes in the number of sets of chromosomes, leading to gametic isolation: the gametes of different populations possess varying numbers of chromosomes, preventing successful fertilization.

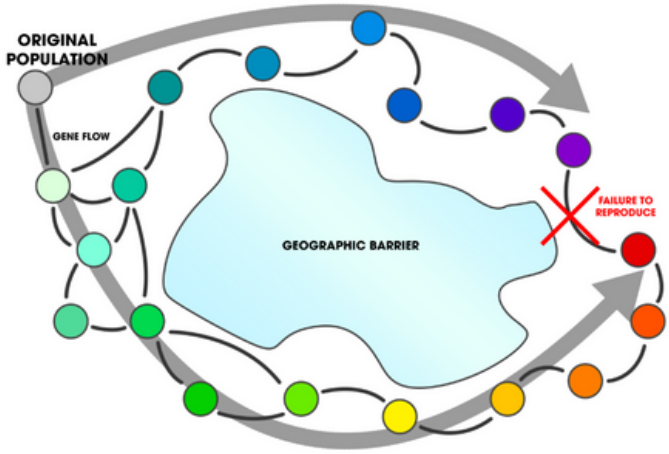
2. Allopatric Speciation – two populations are geographically separated with a physical barrier that individuals cannot cross. For example, squirrels that are on one side of a mountain might not have interacted with squirrels on the other side of the mountain for many generations, leading to the development of distinct physical/biological/behavioral characteristics. Conceptually, allopatric speciation can be related to any prezygotic mechanism that isn't gametic.

a. **Secondary Contact** – occurs when populations that were previously geographically separated come into contact with each other again. In this scenario, the outcome can vary, ranging from resuming interbreeding to partial or complete reproductive isolation. Secondary contact serves as a natural test to assess whether speciation has taken place. If reproductive barriers have evolved, indicating speciation, the two populations will remain reproductively isolated and will not interbreed. On the other hand, fusion of gametes between populations can occur if reproductive barriers have not fully developed or if they have broken down, leading to resumption of interbreeding between the two populations.
b. **Hybrid zone** – the region where individuals from previously separated populations come into contact and interbreed (i.e. secondary contact without fully developed reproductive barriers). However, hybrids in these zones often exhibit reduced fitness and therefore face a heightened risk of extinction. Despite their compromised fitness, hybrids may be better adapted to environments outside the hybrid zone. The fitness of hybrids depends on the extent of accumulated differences that have been in the process of leading to complete reproductive isolation between the populations.
c. **Reinforcement** – a process that occurs after secondary contact between previously isolated populations, leading to accelerated reproductive isolation. When postzygotic barriers exist and hybrids display lower fitness, individuals who do not engage in hybridization are selectively favored. This selective pressure promotes the evolution of prezygotic isolation mechanisms, i.e. reinforcing speciation.

Exceptions to the Reproductive Barriers

1. **Clinal variation** refers to the observable differences in morphology and genetics among populations as they adapt to diverse environmental conditions, such as varying elevations. Despite these differences, all populations exhibiting clinal variation are considered part of the same species because they share alleles across the entire range.
2. **Ring species** are characterized by their ability to recognize the distinct mating calls of different populations. As these populations go around a geographic barrier, they gradually accumulate changes in their traits and behaviors, eventually leading to restrictions in interbreeding with the original population. Despite these reproductive barriers, ring species are still considered a single species with multiple subspecies.





Quick Recap/Quick Points

- Populations do not immediately diverge into separate species
- Barriers to gene flow
  - Reproductive isolating mechanisms (prezygotic, postzygotic)
  - Geographic mechanisms (allopatric, sympatric)
- New alleles, new traits are not shared with other populations
- More differences evolve and accumulate so populations diverge further apart