Evolution 1B

1. Introduction

What are species, exactly? Defining and recognising a species has been a controversial issue for a long time. There are many definitions for the concept of species. There is no universal species concept – one that applies to all organisms. Instead, scientists have been proposing different species concepts for years, and each is based on slightly different biological reasoning. Species concepts do not only define what a species is, but by defining what a species is, they also clarify what speciation is.

2. Learning Outcomes

(h) Explain the various concepts of the species (biological, ecological, morphological, genetic and phylogenetic concepts)
(j) Explain how new species are formed with respect to geographical isolation (allopatric speciation) and behavioural or physiological isolation within the same geographical location (sympatric speciation)

3. References

Campbell, N.A. and Reece, J.B. (2008). Biology, 9th edition. Pearson.

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4. Concepts of Species

Biological species concept

A species is a group of organisms capable of **interbreeding** and producing **fertile, viable offspring**. Organisms of the same species are **reproductively isolated** from those of a different species. (Note: For most purposes, the biological species concept is used.)

Advantage:
To determine if organisms are of the same species, they can be studied to see if they can interbreed and produce fertile, viable offspring.

Limitation:
1) This definition of species cannot be applied to **asexually reproducing organisms** and **extinct species** whose breeding behaviour cannot be observed in nature.
2) In plants, two different species can mate and give rise to viable hybrids offspring that are potentially fertile because they are capable of polyploidy. Polyploidy is rare in animals.

Genetic species concept

A species is a group of **genetically compatible interbreeding** organisms in a **natural population** that is **genetically isolated** from other such groups. Organisms in a species have sufficient similarity in their DNA sequences and share the same number of chromosomes.

The focus on **genetic isolation** rather than **reproductive isolation** distinguishes the Genetic Species Concept from the Biological Species Concept.

Genetic isolation results as 2 genomes diverge to the point that they are genetically distinct and evolve independently of each other. e.g. genetic changes that lead to behavioural changes or changes in pheromones and odors associated with species recognition.

Genetic isolation maintains the integrity of gene pools in the natural population, but if the 2 sister species are mated deliberately or incidentally, fertile viable offspring may be possible. There are instances where a species has achieved genetic isolation but not reproductive isolation. e.g. two related species, mule deer and white-tailed deer have distinctive morphology, mating behaviour and habitat preference. While they keep mostly to themselves, occasional interspecific mating and captive breeding resulted in fertile hybrids. Genetic isolation is achieved as the 2 species have genetically determined mechanisms in place to prevent or minimize breeding but reproductive isolation has not been achieved because if a fertilization event occurs, fertile offspring is still possible. Two reproductively isolated species, however, will always be genetically isolated.

Advantage:
The genetic species concept uses genetic data from mitochondrial and nuclear DNA to identify species and species boundaries and helps to deduce evolutionary relationships.

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Limitation:
Technology required to study the DNA sequences is currently quite expensive and not accessible to everyone. However, the cost is reducing rapidly and its use has become more widespread recently.

Ecological species concept

A species is a group of organisms **sharing the same ecological niche**.

Niche refers to both the place where an organism lives and its interactions with the environment, i.e. the roles that an organism plays in its habitat (predator, prey, primary producer or consumer, decomposer etc).

Advantage:
Every organism has a niche.

Limitation:
1) This definition cannot be applied to **unrelated species that occupy similar niche**. e.g. the striped possum, a marsupial mammal from Australia and the aye-aye a placental mammal from Madagascar.
2) Furthermore, many animals are elusive and determining their niches can be **time-consuming and difficult.**

Morphological species concept

A species is a group of organisms sharing **similar body shape** and other **structural features.**

Advantage:
Every organism has morphological features that can be easily studied as long as you have a specimen.

Limitation:
1) This definition makes it difficult to determine the **degree of difference** that is required to indicate **separate species** as well as **what structural features** should be used to **distinguish the differences**.
2) Some organisms may be **superficially similar** but have **different evolutionary origins** e.g. the marsupial mole from Australia and the placental mole from Africa.

Marsupial "mole" **Placental mole**

Fig. 1: marsupial mole versus placental mole.

Phylogenetic species concept

Notes to self

A species is the **smallest group of organisms** that **share** a **most recent common ancestor** and can be distinguished from other such groups. The phylogenetic history of a species can be obtained by comparing **homologous morphological structures and/or homologous molecular sequences**, with those of other organisms.

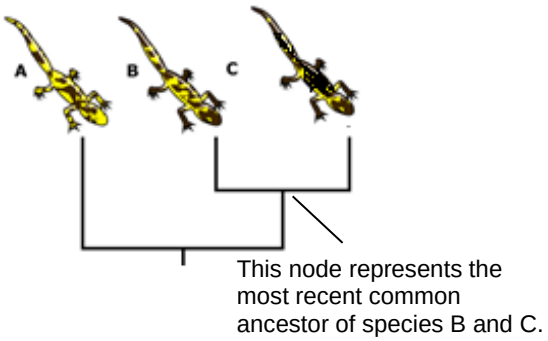


Fig. 2: Phylogenetic tree. A diagram that depicts the lines of evolutionary descent of different species from a common ancestor.

Advantage:

1) Using this definition to classify species will **avoid mistakenly classifying organisms based on superficial morphological similarities** as the characteristics that are compared are based on **common ancestry/homology**.
2) To determine the phylogeny, genetic, DNA sequences, amino acid sequences, morphological, fossil evidence, hybridization(mating) studies are conducted, so **phylogenetic concept** of the species **potentially** presents the **most accurate representation of a species**.
3) It has the added advantage of **providing accurate historical information** about the speciation event that the biological concept of a species cannot.

Limitation:

It is difficult to come up with an accurate phylogenetic tree as multiple evidences need to be gathered and processed. This means that the accuracy of the phylogenetic tree is dependent on the availability, diversity and accuracy of the source data. If for instance, DNA evidence was not used, the phylogenetic tree may not be that reliable.

5. Speciation

Notes to self

Speciation is a process by which **one or more new species arise** from a previously **existing species**.

Disruption of gene flow is required for speciation to occur.

Recall:
Gene flow is the **transfer of alleles from one population to another**, due to the **movement** of fertile individuals or their gametes. If members of a population migrate and **interbreed** with members of another population 2, **gene flow has occurred**.
e.g. an animal arriving from a different population may bring in new alleles to the new population, or pollen grains blown across vast distances, will fertilize the plants of the destination population. The extent of gene flow depends on geographical proximity, number of individuals involved, extent of interbreeding and environmental harshness.

Disruption of gene flow is required for speciation to occur, and this occurs via **isolating mechanisms** (e.g. **geographical isolation**, **behavioural isolation** and **physiological isolation**).

Speciation can occur in two main ways – **allopatric speciation** and **sympatric speciation** (Fig. 3). Both depend on **disruption of gene flow between populations of the existing species** via an isolating mechanism.

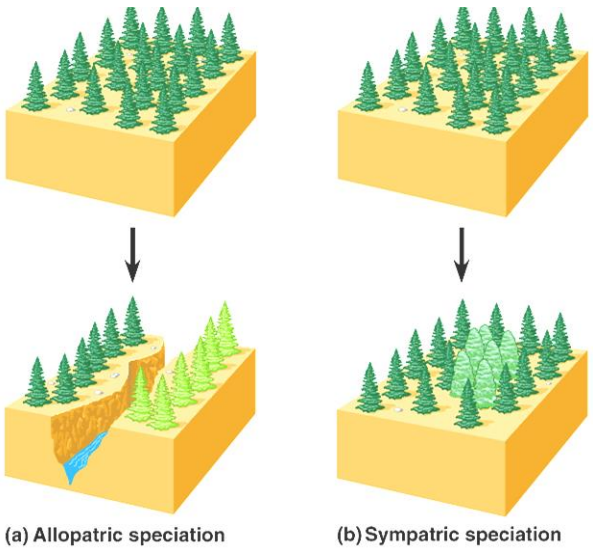


Fig. 3. Allopatric speciation is formation of new species in populations that are geographically isolated from one another. In **sympatric speciation,** speciation occurs in populations that live in the same geographical area.

Allopatric speciation	Sympatric speciation
A population in one geographic area ↓ Members are **<u>geographically-isolated</u>** due to a **<u>physical barrier</u>**. For example, geologic changes, like the formation of a deep canyon over time, will result in geographically-isolated sub-populations. ↓ **Gene flow** is **disrupted.** ↓ **Evolutionary changes occurring independently** within each sub-population. i.e. **different genetic changes** from **accumulation of mutations**, as well as changes in allele frequencies through **genetic drift** and **natural selection** occurred within each sub-population. ↓ Over time, **new species** form**.**	A population in one geographic area ↓ Members are **<u>not geographically-isolated</u>**, but are either **<u>physiologically isolated</u>** or **<u>behaviourally isolated</u>**. A **<u>reproductive barrier emerges</u>** that isolates a subset of a population from the remainder of the population in the same area. For example, some birds in a population may develop a new bird call and only mate amongst themselves. ↓ **Gene flow** is **disrupted**. ↓ **Evolutionary changes occurring independently** within each sub-population. i.e. **different genetic changes** from **accumulation of mutations**, as well as changes in allele frequencies through **genetic drift** and **natural selection** occurred within each sub-population. ↓ Over time, **new species** form.

Table 1. Comparison between allopatric speciation and sympatric speciation.

Geographical Isolation & Allopatric Speciation

Notes to self

Geographical isolation is where a **physical barrier** blocks migration of individuals, thereby **blocking gene flow** between populations in the two different areas.

How geographical isolation can lead to speciation

Example 1: Porkfish

An **ancestral fish population** was **split into two sub-populations** by the formation of the Isthmus of Panama about 3.5 million years ago.

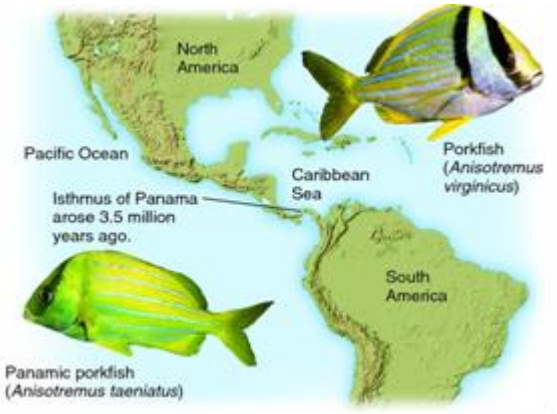


Fig.4. Geographical isolation occurred due to formation of a barrier, the Isthmus of Panama.

This **physical barrier disrupted gene flow** between the two sub-populations.

The divided sub-populations were exposed to **different environments** and thus **different selection pressures.**

Since there was **variation within the populations, favourable** characteristics were **selected for** and **unfavourable** characteristics were **selected against**, resulting in **changes in allele frequencies**.

Thus **evolutionary changes** occurred **independently** within each sub-population, i.e. **different genetic changes** from **accumulation of mutations**, as well as changes in allele frequencies through **genetic drift** and **natural selection** occurred within each sub-population.

Over hundreds and thousands of successive generations, each sub-population became **genetically distinct species**. These species are **reproductively isolated** and **unable to interbreed to form fertile, viable offspring**.

The **Caribbean porkfish** (*Anisotremus virginicus*) is found in the Caribbean sea, whereas the **Panamic porkfish** (*Anisotremus taeniatus*) is found in the Pacific ocean (Fig.4.).

Example 2: Finches

Notes to self

An **ancestral population** of Darwin's finches strayed from the **South American mainland** of Ecuador to one of the **Galápagos Islands**. They then **colonized other islands/parts of the islands**.

The sub-populations were **geographically isolated** in the various islands/parts of the islands and did not interbreed. Hence **gene flow was disrupted**.

The divided populations were exposed to **different environments** in the different islands and thus were under **different selection pressures.**

Since there was **variation within the populations, favourable** characteristics were **selected for** and **unfavourable** characteristics were **selected against resulting in changes in allele frequencies**.

Thus **evolutionary changes** occurred **independently** within each sub-population i.e. **different genetic changes** from **accumulation of mutations**, as well as changes in allele frequencies through **genetic drift** and **natural selection** occurred within each sub-population.

Over hundreds and thousands of successive generations, each sub-population became **genetically distinct species**. These species are **reproductively isolated** and **unable to interbreed to form fertile, viable offspring**.

There are now at least **13 species** of **finches** on the Galápagos Islands, each filling a different niche on different islands/parts of the islands.

This kind of evolutionary pattern in which there is a **rapid increase in the number of species** produced from a common ancestor upon introduction into new environments is known as **adaptive radiation**.

Fig.5. Ancestral population of finches flew from the South American mainland to the Galápagos Islands.

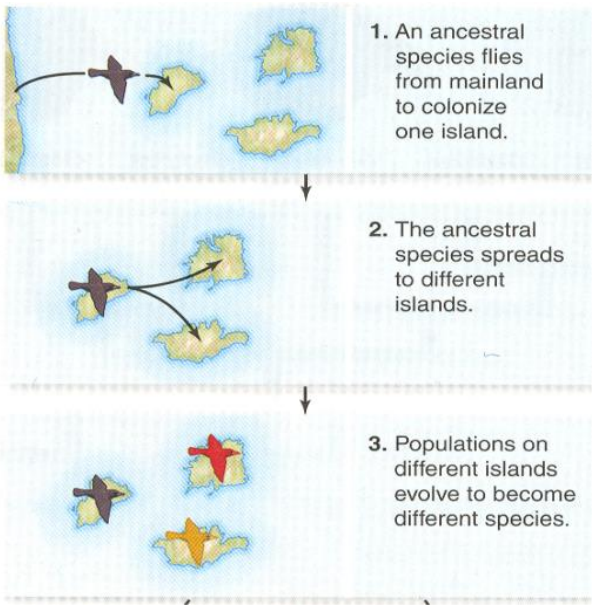


Fig.6. Adaptive radiation on island archipelagos.

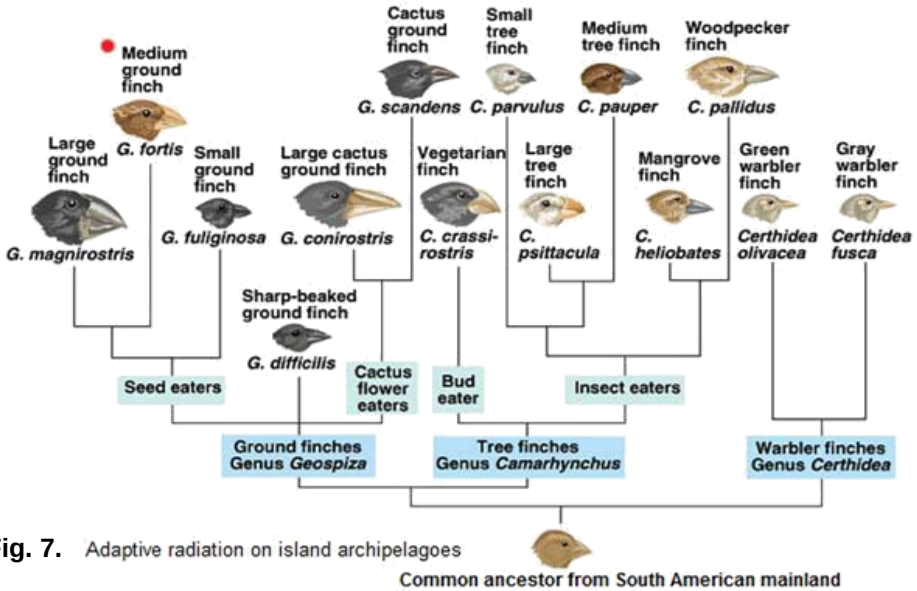


Fig. 7. Adaptive radiation on island archipelagoes

Physiological Isolation, Behavioural Isolation & Sympatric Speciation

Physiological isolation is where mating between individuals of different sub-populations existing in the same geographical area is not possible, due to unique physiology (internal functions) or behavioural differences.

The physiological or behavioural difference serves as a **reproductive barrier**, thereby **blocking gene flow** between sub-population existing in the same area.

How physiological isolation could have led to speciation

Example 1: Palms on Lord Howe Island

An **ancestral palm** grew on Lord Howe Island off the coast of Australia. The island had **two soil types** in close proximity to each other - the older **volcanic soil** and the younger **calcareous soils**. When the palms that normally grew on volcanic soil started to grow on calcareous soil, a conspicuous **flowering time difference** may have arisen as a **physiological response** to growing on a different soil.

This **prevented the interbreeding** between the two sub-populations of palms growing in the two types of soil **although they were in close proximity** (Fig. 8).

This **disruption of gene flow** resulted in **evolutionary changes occurring independently** within each sub- population. i.e. **different genetic changes** from **accumulation of mutations**, as well as changes in allele frequencies through **genetic drift** and **natural selection** occurred within each sub-population.

Since there was **variation within the population, favourable** characteristics were **selected for** and **unfavourable** characteristics were **selected against** in the 2 different environments.

Notes to self

Over hundreds and thousands of successive generations each sub-population became **genetically distinct species**, *Howea forsteriana* and *Howea belmoreana*. These two species are **reproductively isolated** and **unable to interbreed to form fertile, viable offspring**.

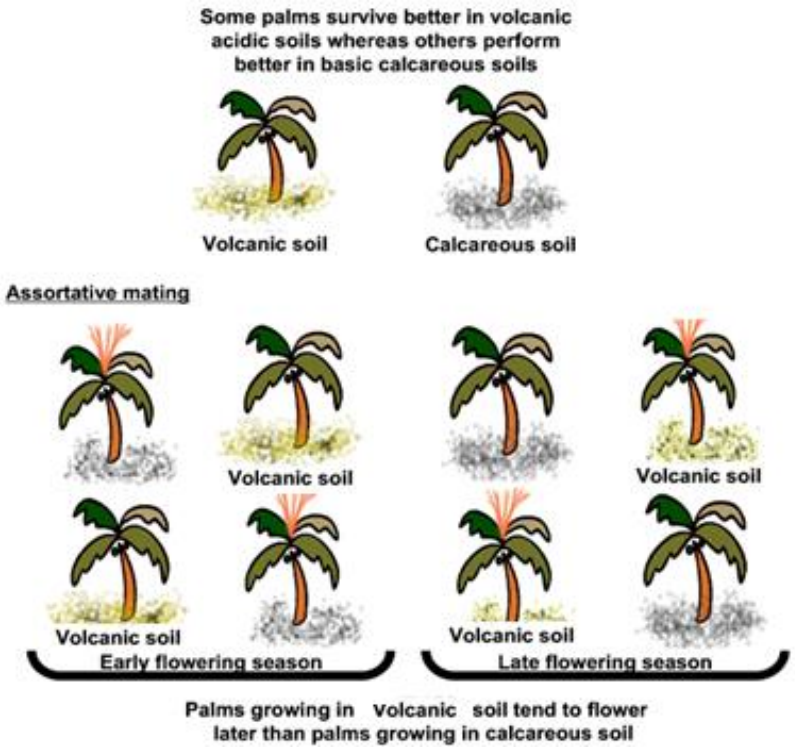


Fig.8.
Palms growing in calcareous soil have an early flowering season while palms growing in volcanic soil have a late flowering season (left).

Example 2: Eastern & Western Meadowlark

In an ancestral population of meadowlark, **some members** of the population **developed a new call**.

Over many generations, the new bird **call became more distinct**. Birds began to distinguish between the two calls and tended to **mate preferentially with the members with the same call**.

This **disruption of gene flow** resulted in **evolutionary changes occurring independently** within each sub-population. i.e. **different genetic changes** from **accumulation of mutations**, as well as changes in allele frequencies through **genetic drift** and **natural selection** occurred within each sub-population.

Over hundreds and thousands of successive generations each sub-population became **genetically distinct species**, **eastern meadowlark** (*Sturnella magna*) and the **western meadowlark** (*Sturnella neglecta*) (Fig.9). These two species are **reproductively isolated** and **unable to interbreed to form fertile, viable offspring**.

Their **differences in songs** enable meadowlarks to recognize potential mates as members of their own species even though both species are **nearly identical in shape, colouration and habitat** and their **ranges overlap** in the central United States.

Notes to self

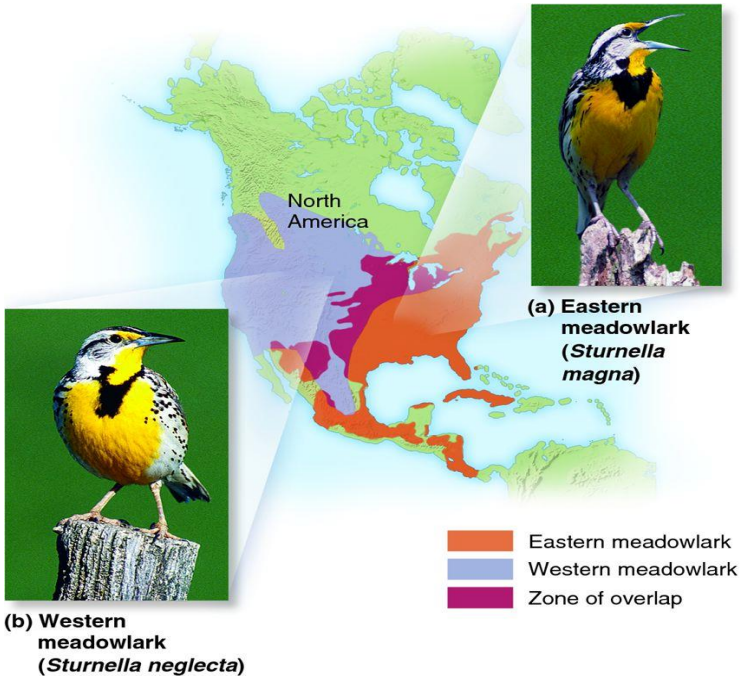
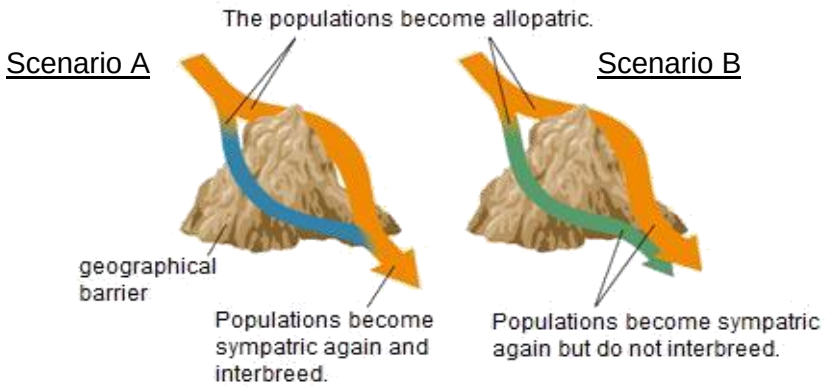


Fig.9. Similarity between different species. The eastern meadowlark (*Sturnella magna,* left) and the western meadowlark (*Sturnella neglecta,* right) have similar body shapes and colorations. However interspecies mating does not occur due to differences in their songs. For many years they were thought to be the same species. When biologists discovered that the Western meadowlark was a different species, it was given the species name *neglecta* to reflect the long delay in its recognition.

Q: Explain if speciation has occurred in scenario A or B?



Reproductive barriers

Notes to self

The emergence of a reproductive barrier can lead to sympatric speciation (Table.1). This is because the reproductive barrier (e.g. a new bird call) can isolate a subset of the population from the rest of the population. The resulting two sub-populations can then undergo evolutionary changes independently of each other and so after many generations form two different species in the same geographical area.

Reproductive barriers also **prevent different species from interbreeding,** that is, they keep different species **reproductively isolated**.

Reproductive barriers can be classified into (Fig. 10):
(1) **prezygotic mechanism** (prevents mating or fertilisation)
(2) **postzygotic mechanism** (causes zygote fatality or prevents hybrids from developing into fertile adults).

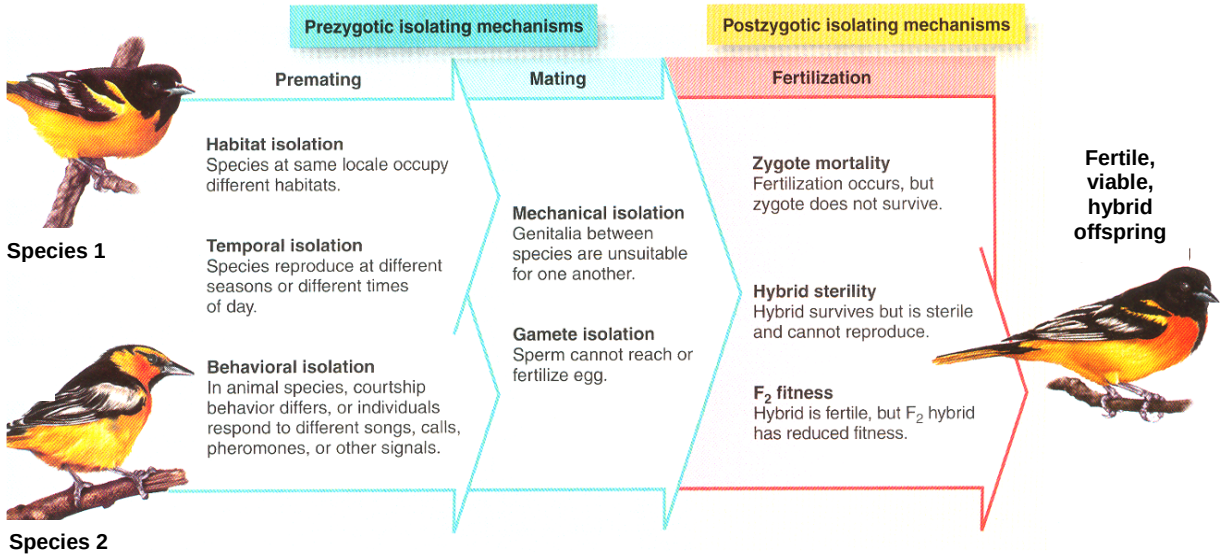


Fig.10. Prezygotic and postzygotic reproductive barriers. The barriers prevent interbreeding between species 1 and 2 to give fertile, viable offspring.