BIO 111 - Principles of Life I: Biomolecules, Genetics and Evolution

(Varsha 2023)

MODULE: EVOLUTIONARY BIOLOGY

Part II – SPECIES CONCEPTS AND SPECIATION

What is a species?

"... I was much struck how entirely vague and arbitrary is the distinction between species and varieties": Darwin 1859.

Exactly what a species is has been debated for a long time, and to this day there is no agreement among biologists

Many *Species Concepts. E.g. Typological Species Concept, Biological Species Concept, Phylogenetic Species Concept, etc*

Typological Species Concept (Carl Linneaus)

'a species is a group of individuals differing from other groups by the possession of constant diagnostic characters'

Each species is thought to have certain characters that are fixed, i.e. do not change over time or across individuals of the same species

Emphasizes morphological differences across species

- Conceptualized before evolution was accepted
- Each species thought to have a set of diagnostic traits
- Based on descriptions of a ‘type’ specimens for a given species
- The ‘holotype’ is the most important type specimen for a species and is kept in a museum/collection

- TSC – does not adequately take into account one of the main principles of evolution: *Variation*
- Variation within populations

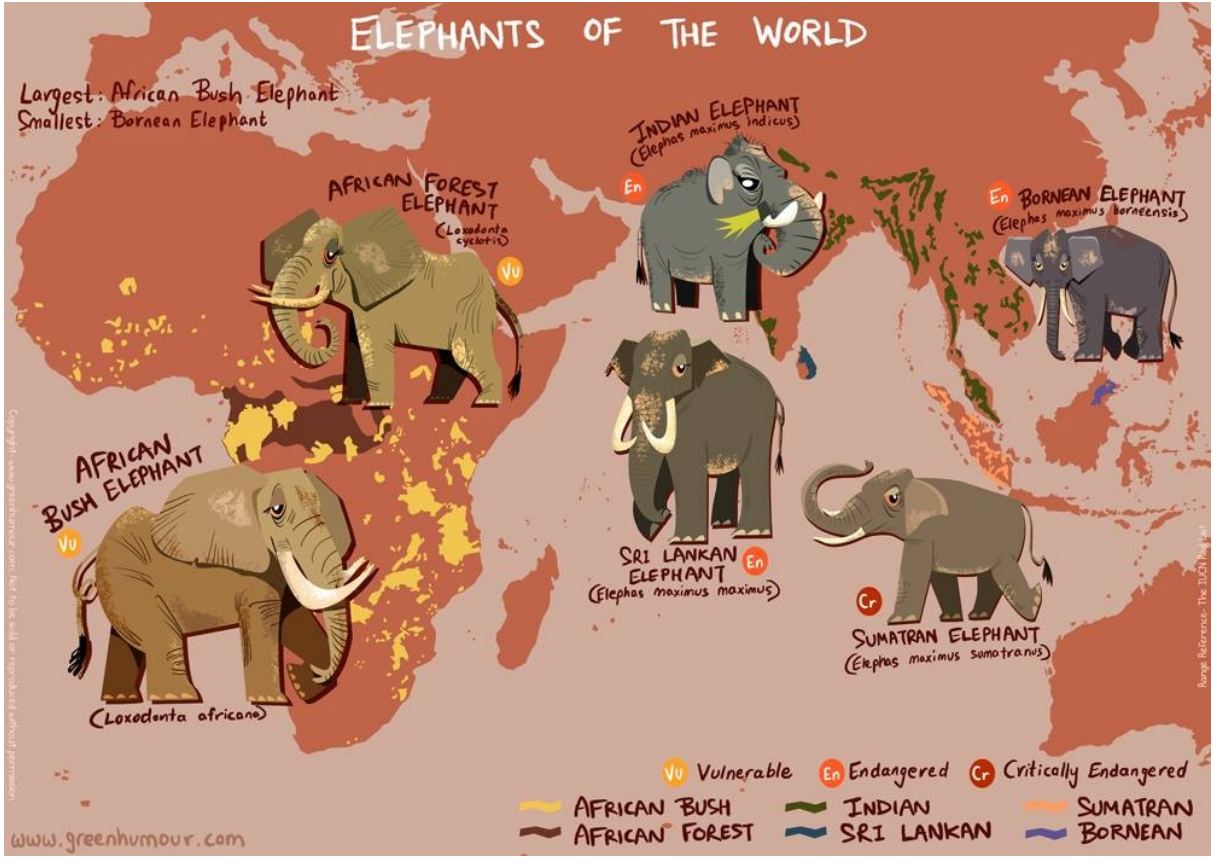
Ladybugs (Coccinellidae)

Image: Jaroslav Vanek/readingevolution.com

Claytonia virginica

Frey 2004 Evolution 58:2426-2437

Geographic variation across populations - often classified as 'subspecies'



Reading exercise

- What are the recognized subspecies of tigers?
- Which of these have gone extinct?

TSC cannot distinguish cryptic or sibling species

Sibling or Cryptic species are two or more species that are almost identical in appearance, but are still reproductively isolated

Biological Species Concept

First conceptualised by John Ray. Ernst Mayr later modified this to the currently popular BSC. He defined species as

"Species are groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups."

A female horse mated to a male donkey can give birth to a.....

Adapted from slides by Neil Buckley

... a mule (which is sterile). Thus, donkeys and horses are separate species.

Adapted from slides by Neil Buckley

Liger

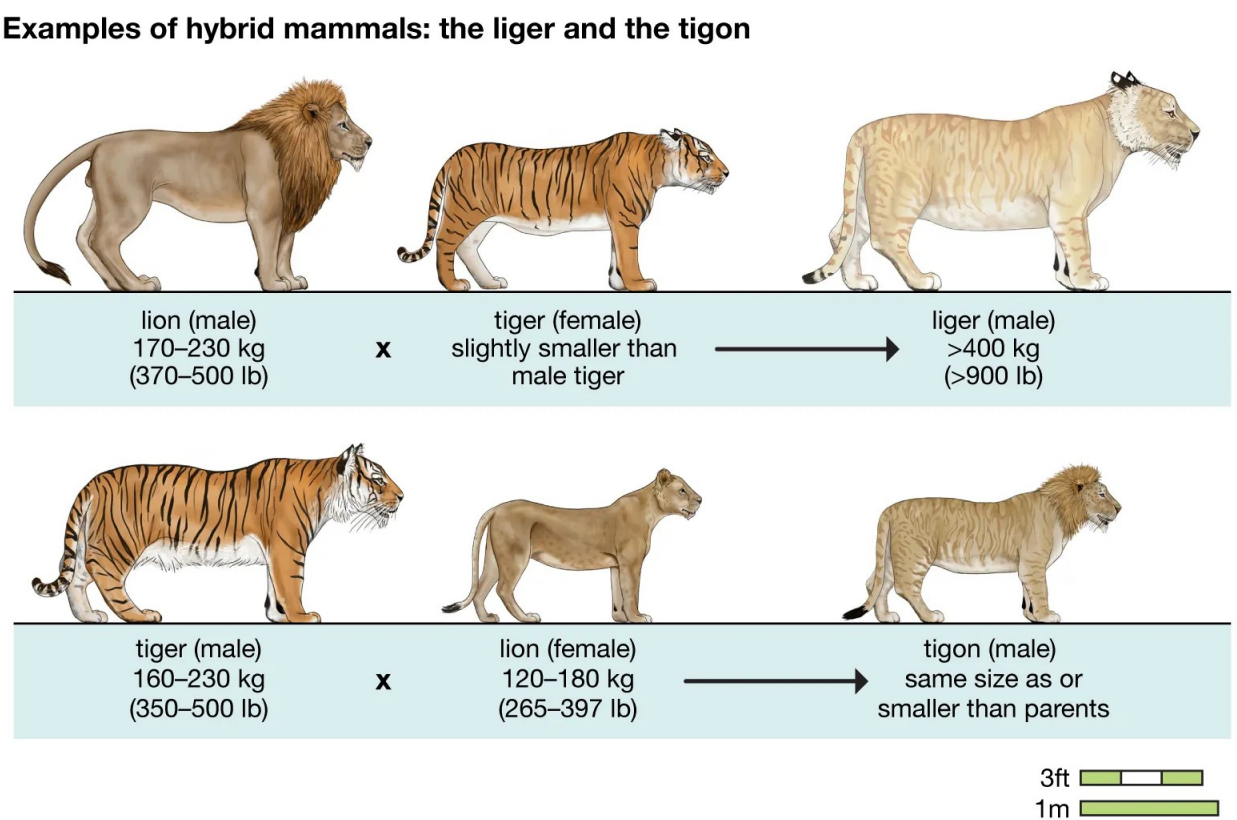


Photo: www.respeitoanatureza.blogspot.in

Widely used in practice, although there are several problems.

1. Not applicable to asexual species. E.g.,

- Prokaryotes
- *Amoeba* & some other protists
- Some animals, plants & fungi

2. The degree of reproductive isolation can vary between species pairs. Fertile hybrids of two species are not rare in some groups - waterfowl, terrestrial plants, freshwater fishes.

- Despite occasional production of fertile hybrids, the species remain distinct (i.e., can be morphologically recognized as different species)

- Remember, in *sibling species* pairs, fertile hybrids may never be produced, but the species look the same. However, here we are talking about species pairs that may be morphologically distinct (separate), but can hybridize occasionally

3. Not easy to assess potential to interbreed, especially in the case of geographically isolated populations

- Many other concepts

- In practice, there is no single concept that works for all groups and all scenarios.

- BSC has become the most popular *operational* concept.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- If two populations regularly hybridize to produce fertile offspring, then it is unlikely that they are morphologically distinct. Therefore, they are usually placed under a single species in practice.
- If two populations are reproductively isolated, they are expected to diverge in morphology and, therefore, become morphologically distinct with time
- Generally, the mechanisms for formation of different types of 'species' (i.e., species according to different concepts) are the same.

SPECIATION

- Process of formation of new species

  i.e. Divergence of ancestor into descendant/daughter species

- Evolution of reproductive isolation (assuming BSC)
  - Prezygotic barriers
  - Postzygotic barriers

Reproductive Isolation

Prezygotic mechanisms (prevent zygote formation):

- Temporal isolation: Reproduce at different seasons or at different times of the day.
- Behavioral isolation: Mating rituals, songs, mating calls
- Mechanical isolation
- Gametic isolation: Sperm-egg or Pollen-ovule incompatibility

Postzygotic Isolation (reduced viability or fertility of hybrids)

Hybrid inviability (or reduced viability)

Embryological arrest: Hybrid embryos often do not develop properly; no viable offspring is created (or offspring viability is reduced).

Hybrid sterility

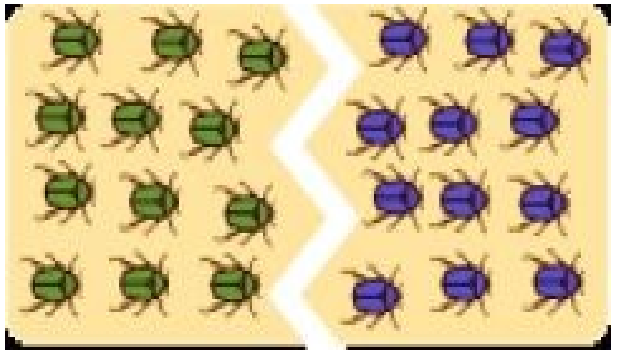
Infertility: Hybrid offspring might grow to viable adults but these are infertile and cannot produce further offspring (Donkey + Horse = Mule; Mule is sterile).

How does reproductive isolation/incompatibility evolve?

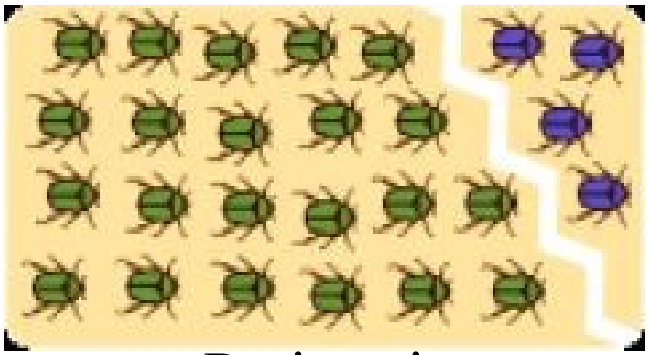
Reproductive incompatibility between two individuals or between two groups of individuals can reduce fitness, and, therefore, should be selected against. If so, how can reproductive incompatibility evolve?

We can identify modes of speciation, based on degree of geographic isolation

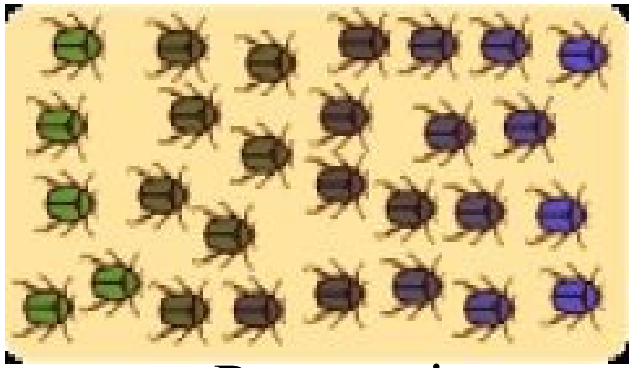
- Allopatric
  - Peripatric
- Parapatric
- Sympatric



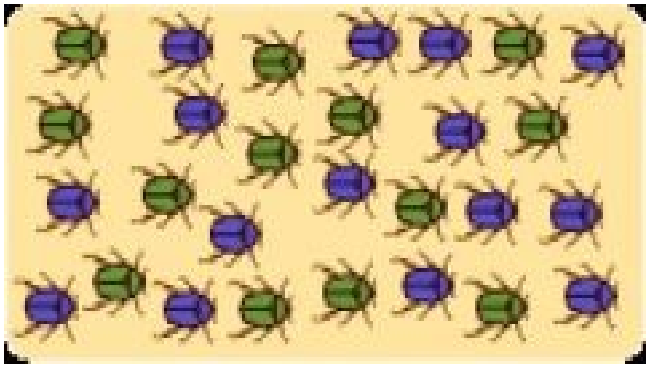
Allopatric



Peripatric



Parapatric



Sympatric

Images from http://evolution.berkeley.edu

Allopatric speciation

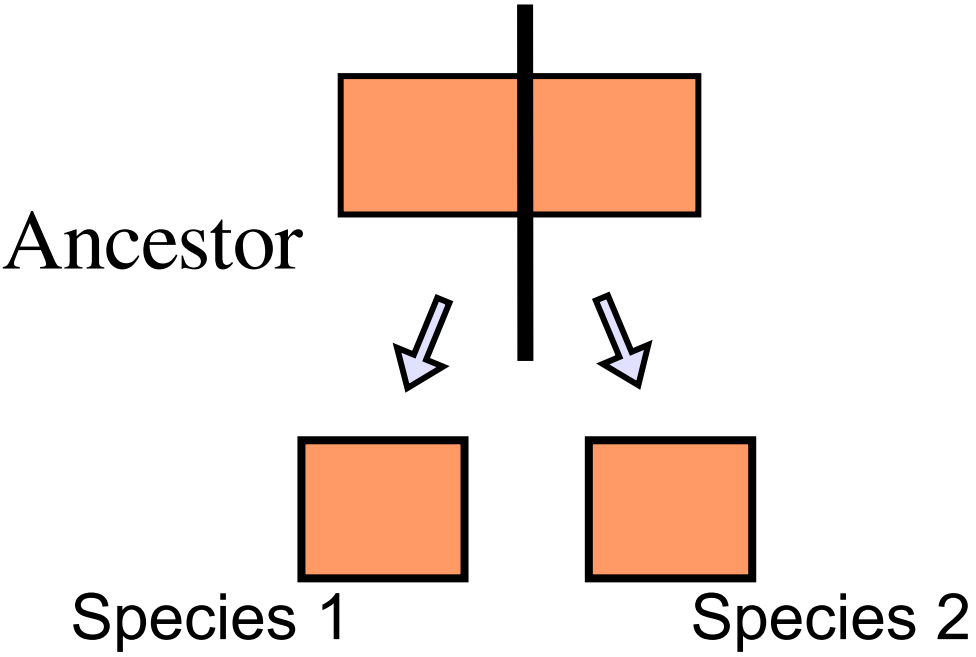
- Two populations are geographically isolated by physical barriers.

- Reproductive isolation occurs in complete geographic isolation (low probability of *gene flow*)
  - Rivers & Oceans
  - Mountain ranges
  - Deserts
  - Land (in case of aquatic organisms)

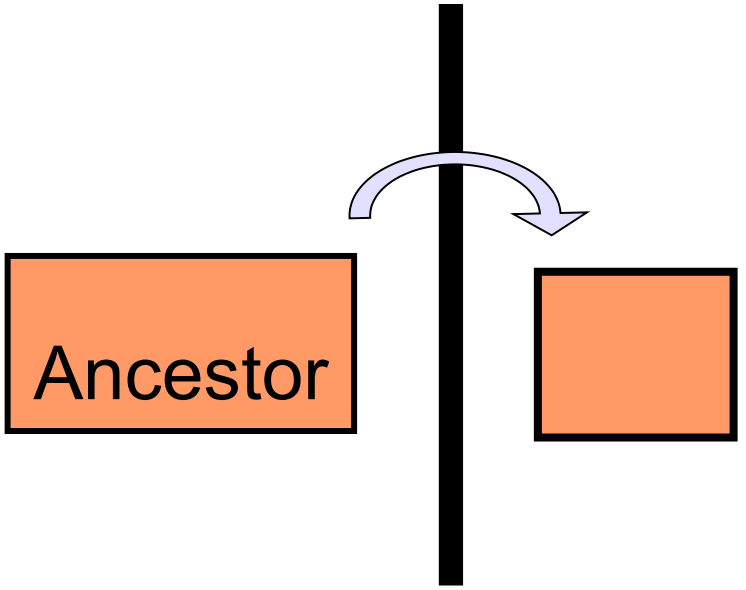
Two ways in which allopatric speciation can occur

1) A new geographic barrier comes up (*vicariant speciation/vicariance*)

2) Some members of a population disperse across a pre-existing barrier to establish a new population (*speciation by dispersal*)



Vicariant speciation



Speciation by dispersal

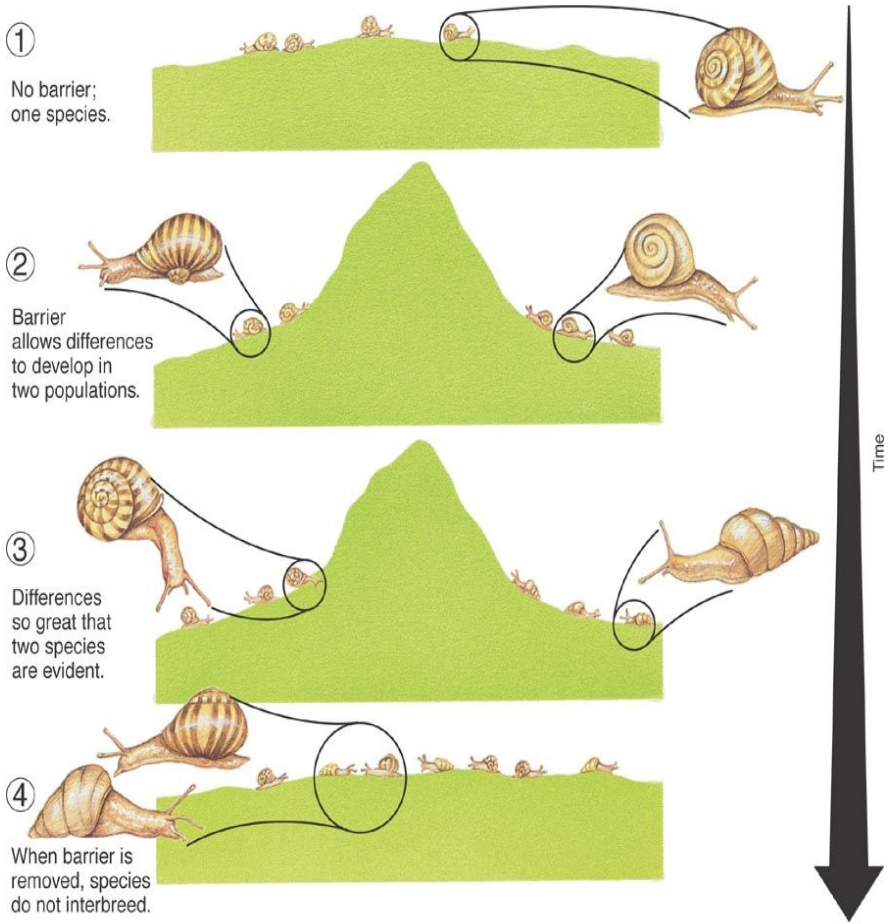
Vicariant speciation

1. A single species

2. A physical (geographic) barrier develops dividing the species

3. The divided populations diverge through the accumulation of genetic and phenotypic differences

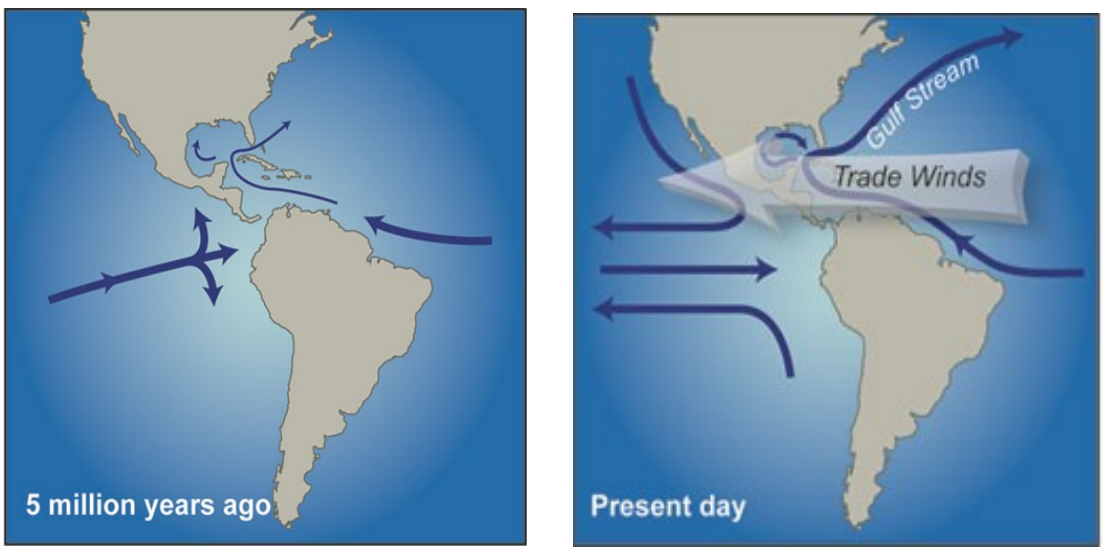
4. The separate populations become so different that, if and when the barrier disappears and they overlap again, interbreeding does not occur



Adapted from slides by James F. Thompson

South and North America isolated for a very long time

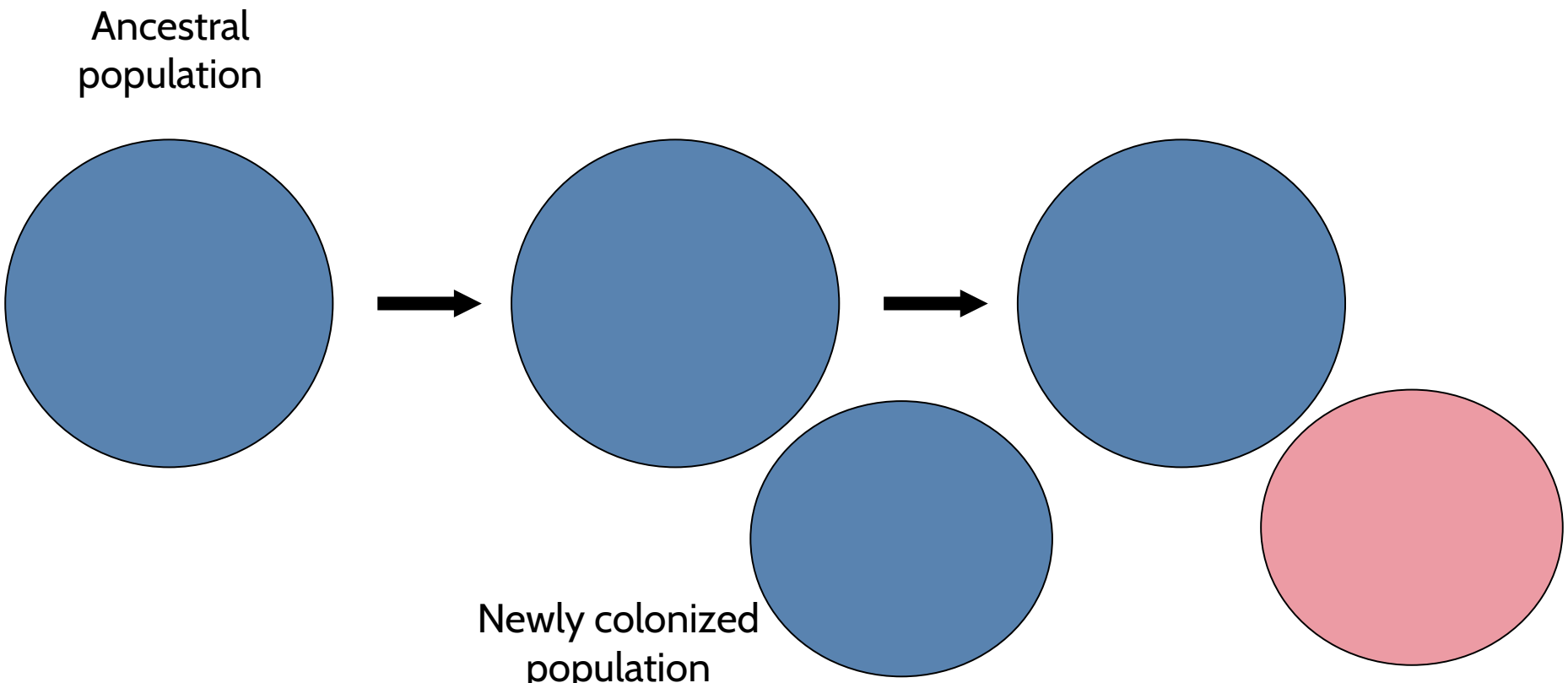
Reconnected 3 mya by the *Isthmus of Panama,* which resulted in vicariant speciation Eg. Snapping shrimps (*Alpheus*)



Images: Taken from slide by John McCall

Speciation by dispersal

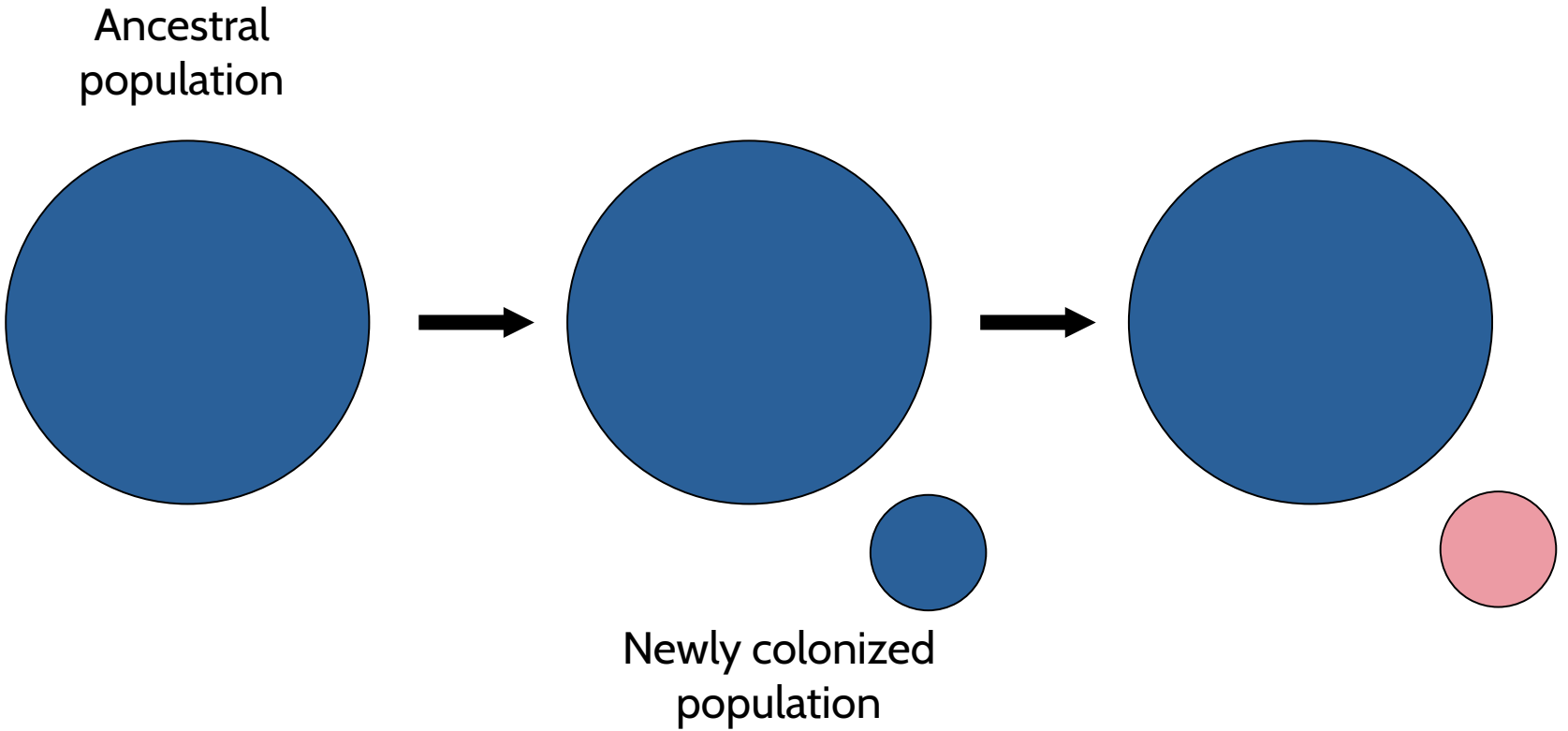
E.g. Dispersal into a new region that establishes a new population



Peripatric speciation

- Similar to allopatric speciation - *low/no gene flow between diverging populations*
- One of the isolated populations has a small population size(i.e, has very few individuals). Hence *Genetic Drift* plays a more important role in peripatric speciation compared to allopatric speciation.
- Can happen both due to vicariance and dispersal

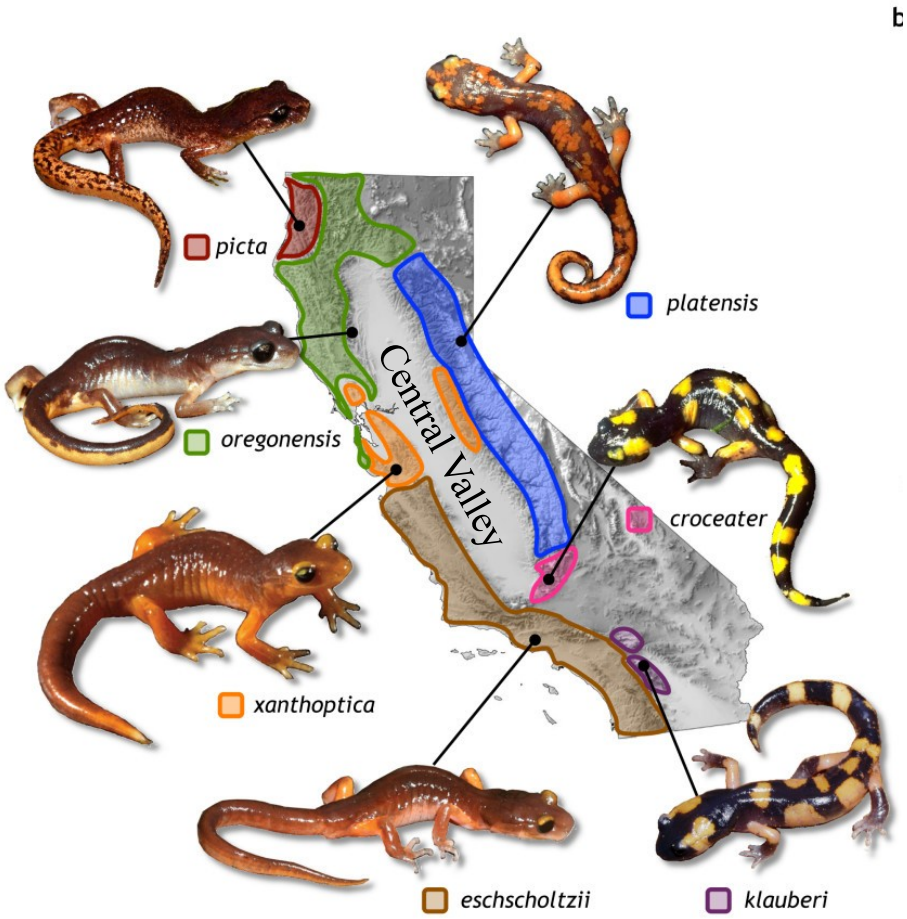
E.g. Colonization of an island from the mainland by very few individuals



Parapatric speciation

Reproductive isolation occurs without complete geographic isolation (*some gene flow*).

E.g. Ring species in *Ensatina* salamanders



Central Valley, California

Source: Pereira *et al* 2011 *BMC Evolutionary Biology* 11: 194

Sympatric speciation

Sympatry – living in the same area

Speciation without geographic isolation

High probability of gene flow between diverging lineages

E.g., Sympatric speciation in the apple maggot fly, *Rhagoletis pomonella*

Two ‘host races’ specializing on different hosts (apple and hawthorn). These ‘host races’ are thought to represent intermediate stages of speciation

Chapter 16 Opener Evolutionary Analysis, 4/e

Illustration: Pearson Prentice Inc

Sympatric speciation due to polyploidization

Polyploidization – production of multiple sets of chromosomes

e.g. A newly formed polyploid is reproductively isolated from the original diploid

Polyploidy formation is common in plants, and is thought to have played an important role in plant speciation