Speciation

Charles Darwin (1809–1882). Darwin was an English naturalist who first established the theory of organic evolution by natural selection.

The cactus ground-finch (*Geospiza scandens*) from Santa Cruz Island, Galápagos.

What is a species?

- A group of organisms that share certain characteristics.
- In classical taxonomy, a species is defined exclusively on the basis of phenotypic characteristics. If the characters of two groups of organisms are sufficiently different, then the groups are considered to be separate species.
- In genetics and evolution, a species is defined on the basis of shared gene pool. A group of interbreeding, or potentially interbreeding organisms that does not exchange genes with other such groups is considered to be a species.
- Evolutionary geneticists say that each species is **reproductively isolated** from every other species.

Types of reproductive isolation between different species:-

Pre-zygotic Mechanism

Habitat isolation	**Species may occupy different habitats, so that they never come in contact with each other.**
Temporal isolation	Species have different mating or flowering seasons or times of day, or become sexually mature at different times of the year.
Sexual isolation	Sexual attraction between males and females of different animal species is limited due to differences in behavior, physiology or morphology.
Gametic isolation	Gametic transfer takes place, but gametes fail to unite with each other. This can occur because the male and female gametes fail to attract, because they are unable to fuse, or because the male gametes are inviable in the female reproductive tract of another species.

Post-zygotic mechanism

Hybrid inviability	**The egg of one species is fertilized by the sperm from another species, but the fertilized egges fails to develop past early embryonic stages.**
Hybrid sterility	The interspecies hybrid survives, but it is sterile. For example, the mule is a cross between a female horse and a male donkey.
Hybrid breakdown	The F1 interspsecies hybrid is viable and fertile, but succeeding generations become increasingly inviable due to formation of less fit genotypes by genetic recombination.

Speciation

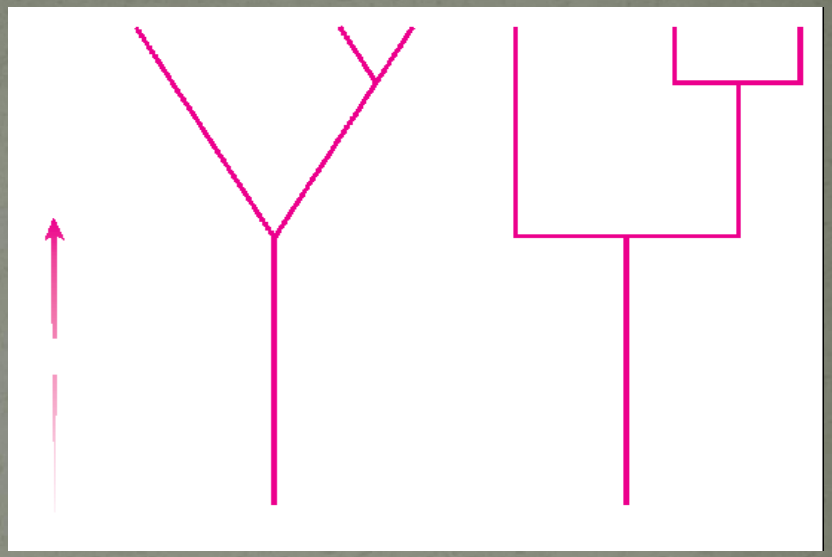
- **Speciation** comes in two different forms.
- It may be the evolution of a population over time until the current population cannot be classified as belonging to the same **species** as the original population. This process is known as **anagenesis,** or **phyletic evolution** (*an* is Latin for without, *genesis* is Latin for birth or creation).
- Speciation may also be the divergence of a population into two distinct forms (species) that exist simultaneously. This branching process is known as **cladogenesis** (*clado* is Greek for branch).

Anagenesis:-

- During anagenesis, characteristics of a species changes due to both neutral evolutionary forces and adaptive forces promoted by natural selection. As a result of natural selection, the new species may be better adapted to survive in its original environment or the environment may have changed so that the new species is better adapted to the new surroundings.

Cladogenesis:-

- Cladogenesis commonly occurs as a budding process in which a single species divides into the original species plus a new species with different characteristics



Diagrammatic interpretation of cladogenesis.

(a) Phyletic gradualism is depicted as a gradual divergence over time.

(b) Punctuated equilibrium is depicted as a rapid divergence of two groups after long periods of no change.

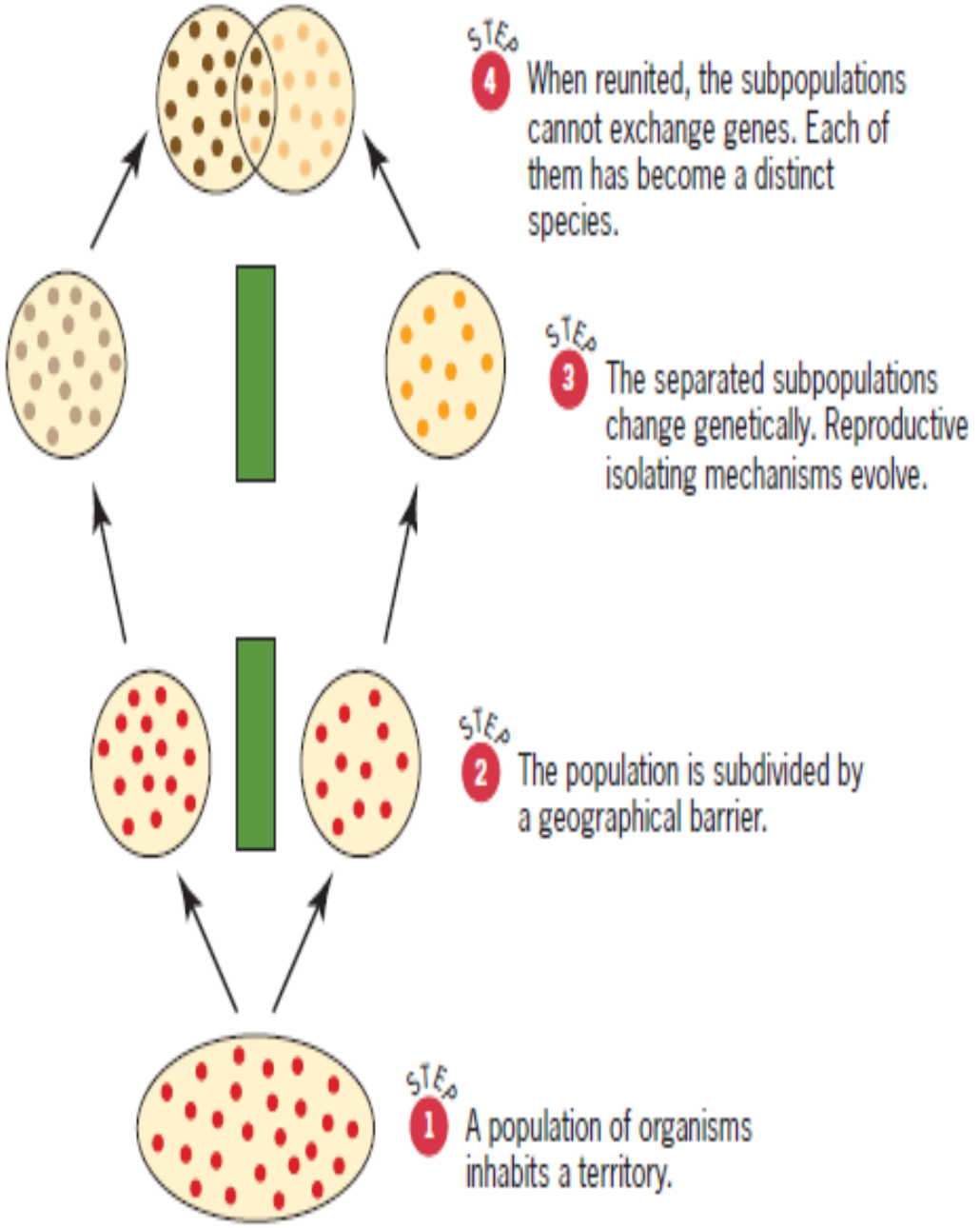
The horizontal axis is some arbitrary measure of species differences.

Divergent evolution:

- The divergence of one species into two or more discrete species is the most common form of speciation.
- Depending on the geographic locations of the evolving population(s), speciation is categorized as –
  - allopatric,
  - Parapatric, or
  - sympatric.

Allopatric Speciation:

- *Allos* = other (greek) *patria* = home land (latin).
- It occurs when members of a species become geographically separated from the other members. It can occur by the geographic subdivision of large populations by geological processes.
- For example, a mountain range may emerge and split a species that occupies the lowland regions. Over time, the accumulation of genetic changes in the two populations led to the formation of two morphologically distinct species.
- Moreover, due to founder effect, which occurs when a small group migrates to a new location that is geographically separated from the main population, allopatric speciation may happen. In this case, migration between the island and the mainland populations is a very infrequent event. In a relatively short time period, the founding population on the island may evolve into a new species.
- Several evolutionary forces may contribute to this rapid evolution.
- Genetic drift may quickly lead to the random fixation of certain alleles and the elimination of the other alleles from the population.
- Another factor is natural selection as environment on an island may differ significantly from the mainland environment.



The process of allopatric speciation.

■ **FIGURE 24.14** Four species of *Drosophila* from the Hawaiian Islands. Starting at the upper left and moving clockwise: *D. heteroneura*, *D. grimshawi*, *D. ornata*, and *D. differens*. These and hundreds of other *Drosophila* species have evolved during the last few million years on the Hawaiian Islands, which are far removed from other land masses in and around the Pacific Ocean.

Effect of Natural Selection on Allopatric Speciation: The concept of Adaptive Peak

- To explain how natural selection may act on the phenotypic effects of many alleles, Sewall Wright developed the concept of adaptive peaks to describe combinations of many alleles that provide an optimal fitness for individuals in a stable environment.

- There are several different combinations of alleles that may lead to highly fit individuals. If a small change occurs in the frequency of alleles at one or a few loci, it will drive the population off an adaptive peak and into a less fit valley; natural selection, though, will tend to push the population back to the original peak.

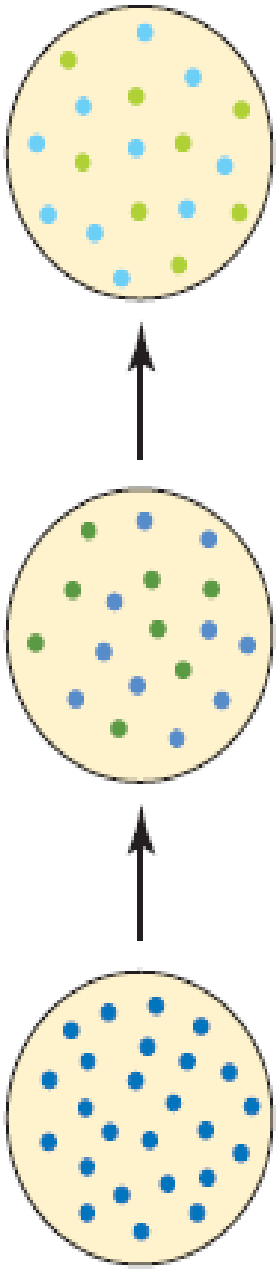
- When a small group migrates to a new environment, the adaptive landscape is likely to be changed. Allele combinations that were highly adaptive in the original environment may be much less so in the new environment. If this occurs, natural selection may lead to a shift toward a new adaptive peak in which the frequencies of many alleles have been changed leading to changes in morphological features of the organism to make it better adapted to its new environment.

Parapatric Speciation:

- *Para* = Beside (Greek)
- Occurs when members of a species are separated only partially or when a species is very sedentary. In these cases, the geographic separation is not complete.
- For example, a mountain range may divide a species into two populations, but with breaks in the range where the two groups are connected physically. In these zones of contact, the members of two populations can interbreed, although infrequently.
- Plants, terrestrial snails and many flightless insects may speciate in a parapatric manner.
- Prior to parapatric speciation, the zones where two populations can interbreed are known as hybrid zones. For speciation to occur, the amount of gene flow within the hybrid zones must become very limited and there must be selection against the offspring produced in the Hybrid zone.

Sympatric Speciation:

- *Sym* = Together (Greek).
- Occurs when a polymorphism, which is the occurrence of alternative phenotypes in the same population, arises within an interbreeding population before a shift to a new niche. This mode of speciation may be common in parasites and phytophagous insects.
- For example, if a polymorphism arises within a parasitic species that allows an individual with a certain genotype to adapt to a new host, this genotype may be the forerunner of a new species. If the parasite not only feeds on the new host but also mates on the new host, a barrier to gene flow arises, although the parasite may be surrounded by other members of its species with the original genotype. Sympatric speciation can thus occur in the middle of a species range rather than at the edges.
- Occurs when members of a species initially occupy the same habitat within the same range.
- In plants, a common way for sympatry to occur is by the formation of polyploids.



STEP 3 Genetic differentiation leads to reproductive isolation between the subpopulations. Each subpopulation becomes a distinct species.

STEP 2 Subpopulations form in the absence of geographical barriers and begin to differentiate genetically.

STEP 1 A population of organisms inhabits a territory.

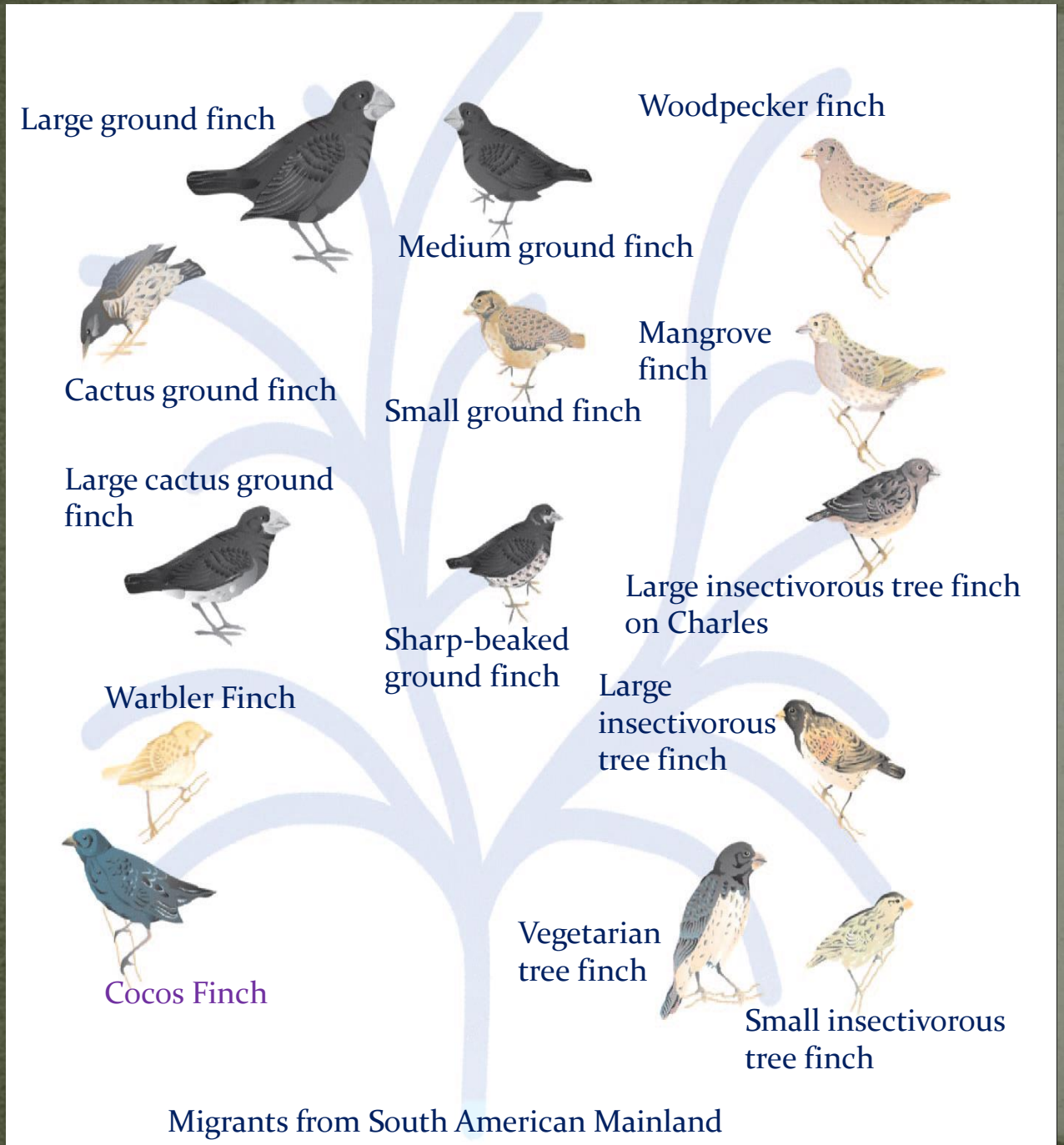
The process of sympatric speciation.

Darwin's Finches: A classic example of Cladogenesis

- An original flock of finches somehow reached the Galápagos Archipelago from South America, 700 miles away, and with time spread to the various islands of the Galápagos Archipelago.

- Given the limited ability of the birds to get from island to island, allopatric speciation took place. On each island, the finch population evolved reproductive isolating mechanisms while evolving to fill certain niches not already filled on the islands.

- For example, in South America, no finches have evolved to be like woodpeckers because many woodpecker species already live there. But the Galápagos Islands, being isolated from South America, have what is called a **depauperate fauna,** a fauna lacking many species found on the mainland. The islands lacked woodpeckers, and a very useful food resource for birds—insects beneath the bark of trees—was going unused. Finches that could make use of this resource would be at an advantage and would thus be favored by natural selection. On one island, a finch did evolve to use this food resource. The woodpecker finch acts like a woodpecker by inserting cactus needles into holes in dead trees to extract insects.



Darwin wrote: "Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends."

Species of Darwin's finches These birds apparently evolved from a single group of migrants from the South American mainland. Isolated on the different islands, the birds evolved to fill many vacant niches.

Phyletic Gradualism Versus Punctuated Equilibrium

- Darwin visualized cladogenesis as a gradual process, which we refer to as **phyletic gradualism** which suggested that each new species evolved continously over long periods of time. Large phenotypic differences that produce the divergence of species are due to accumulation of many small genetic changes.

- However, an alternative view arose in 1972, when N. Eldredge and S. J. Gould suggested that speciation itself, and the morphological changes accompanying speciation, occur rapidly, separated by long periods of time when little change occurs (*stasis*). They called their model **punctuated equilibrium** (periods of stasis punctuated by rapid evolutionary change).

- Allopatric, parapatric, and sympatric speciation mechanisms apply to both punctuated equilibrium and phyletic gradualism. The only major difference between the models is the rate of change, and this can only be discovered from an almost complete fossil record.

- The punctuated equilibrium model has brought much excitement to modern evolutionary biology. We await a time in the near future when we can decide which model has predominated in evolutionary history.