Adaptive radiation: Darwin Finches
Core course: ZOOL3014
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Macroevolution

Factors of large evolutionary changes (Macroevolution)

Macroevolutionary studies focus on change that occurs at or above the level of species

This is in contrast with microevolution, which refers to smaller evolutionary changes (typically described as changes in allele frequencies) within a species or population

Adaptive radiation

The term adaptive radiation was coined by H.F. Osborn (1902)

Adaptive radiation is the process through which a single ancestor is evolved into multiple descendants with a great variety of adaptations to different niches

It is the diversification of a dominant evolutionary group into a large number of subsidiary types adapted to more restrictive modes of life (different adaptive zones) within the range of the larger group

According to George Gaylord Simpson (1940, 1953), adaptive radiation is the rapid proliferation of new taxa (species) from a single ancestral group

Certain authors of evolution biology such as Savage (1969),Stanley (1979) and Volpe (1985) have used an entirely new term macroevolution for the Osborn's law of adaptive radiation

Adaptive radiations are best exemplified in closely related groups that have evolved in a relatively short time

A striking example is the radiation, beginning in the Paleogene Period (beginning 66 million years ago), of basal mammalian stock into forms adapted to-

Running
Leaping
Climbing
Swimming, and
Flying

Other examples include Australian marsupials, cichlid fish, and Darwin's finches (also known as Galapagos finches)

Many examples of speciation by adaptive radiation are found in archipelagoes removed from the mainland

In addition to the Galapagos Islands, the Hawaiian archipelago, with its several volcanic islands and relatively small total land area, hosts an astounding number of plant and animal species that are endemic; that is, they have evolved there and are found nowhere else

More than 90 percent of the native species of Hawaiian flowering plants, land molluscs, birds, and insects are endemic

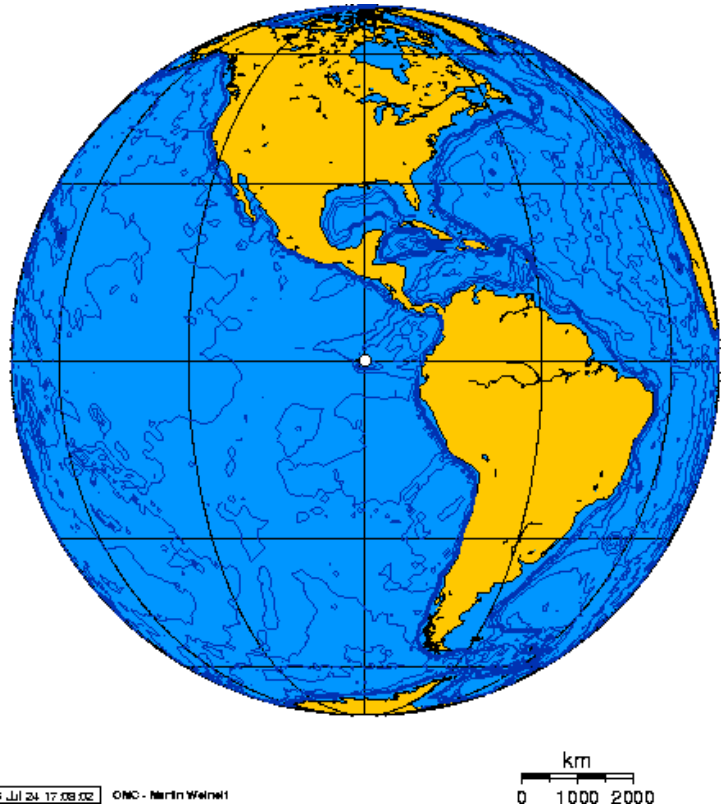
Adaptive radiation in Darwin's finches

The Galapagos Islands

Located approximately 1000 km from the coast of Ecuador, South America

This is just a little closer than the distance between Chicago and Philadelphia.

- **Mostly ground between the two U.S. cities.**
- **Mostly deep water between the Galapagos Islands and the coast of South America.**



The islands are a natural laboratory, nature's test-tube and one in which evolution can be observed

Terrestrial species on these islands won't have many relatives nearby

Neighboring islands will have close relatives

New terrestrial species won't arrive on these islands from the South American mainland very often

Most of the island species have had plenty of time to differentiate from their nearest living relatives

Endemics

The species isn't found anywhere else

The species has very specific habitat requirements

The species needs to be protected otherwise the end is imminent or species may extinct

Among the kind of animals found here and nowhere else:

1 penguin species

1 giant tortoise species

1 marine iguana species

7 species of lava lizard

14 species of sea cucumber

1 species of sea lion

1 species of hawk

several species each of mockingbirds, doves, owls, flycatchers, and yellow warblers

Role of Gene flow

Gene flow between species has played a prominent role throughout the evolutionary history of the Darwin's finches

There is a trace of hybridization between a warbler finch and the common ancestor of tree and ground finches that must have occurred about a million year ago

Little *gene flow* between the islands and the mainland

Limited gene flow means:

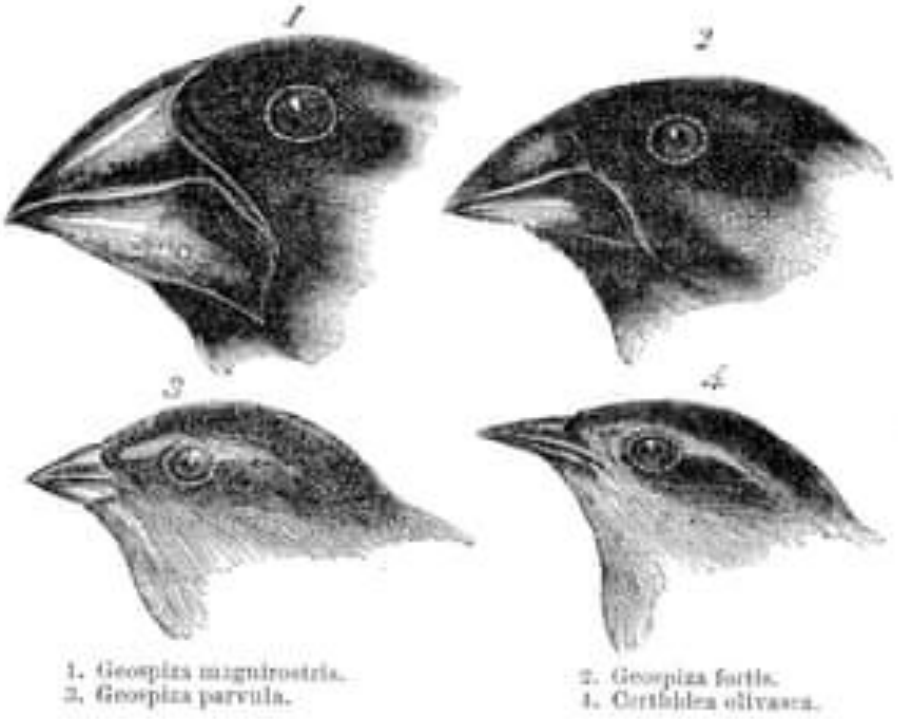
Birds rarely move between the mainland and the islands

Birds on the island have the same genes as birds on the mainland

Birds on the mainland won't evolve, but birds on the islands might

The Finches

The tool-using woodpecker finch probes a branch with a cactus spine on Plaza Island, Galápagos Islands, Ecuador



Four of the species of finch observed by Darwin on the Galápagos Islands, showing variation of beak

Darwin's finches

Darwin's finches, named after Charles Darwin, are small land birds, 13 of which are endemic to the Galapagos Islands

The 14th finch is the Cocos finch which is found on Cocos island, Costa Rica

They are not actually true finches – they belong to the tanager family

It is thought that their ancestor, and closest known relative, is the dull-coloured grassquit, which is found on mainland South America

Once the original grassquits arrived at Galapagos, they diversified and adapted to the different environments found on the Islands, eventually becoming different species

They famously evolved to have different beaks which are suited to different food types such as large seeds and invertebrates, allowing them to occupy different niches

The 13 finch species include:

6 species of ground finches

3 species of tree finches

1 woodpecker finch

1 vegetarian finch

1 mangrove finch

1 Coco Island finch

A warbler finch that looks more like a warbler than a finch (one of the tree finches)

The woodpecker finch actually uses cactus spines to dig grubs out of branches!

The most conspicuous difference among the species are in the sizes and shapes of the beak, which are correlated with marked differences in feeding habits

The ancestral finch was a ground-dwelling, seed-eating finch

After the burst of speciation in the Galapagos, a total of 14 species exist:

ground-dwelling seed-eaters
some living on cactuses and eating seeds
some living in trees and eating seeds and
species of tree-dwelling insect-eaters

These 14 species belong to 4 genera:

Geospiza
Camarhynchus
Certhidea and
Pinaroloxias

The finches found in Galapagos are:

Green warbler finch (*Certhidea olivacea*). Vulnerable. Until 2008, it was thought that this was the same species as the grey warbler finch

Grey warbler finch (*Certhidea fusca*). Least Concern. These finches are found mostly on smaller, drier islands

Mangrove finch (*Geospiza heliobates*). Critically Endangered. These rare finches are only found in a small area on Isabela

Woodpecker finch (*Geospiza pallida*). Vulnerable. This finch is well-known for its use of tools. It can use a twig, stick or cactus spine to dislodge invertebrates from trees

Large tree finch (*Geospiza psittacula*). Vulnerable. This species has a large, powerful bill with a thick base and is found on a number of the islands

Medium tree finch (*Geospiza pauper*). Critically Endangered. This finch is only found in the highlands of Floreana

Small tree finch (*Geospiza parvula*). Least Concern. These finches are small and have distinctive short, curved beaks which they use to mostly feed on insects

Large ground finch (*Geospiza magnirostris*). Least Concern. The largest of Darwin's finches both in size and beak size. They have large, short beaks for cracking large seeds and nuts

Medium ground finch (*Geospiza fortis*). Least Concern. These finches are found on a number of the islands and feed mainly on seeds

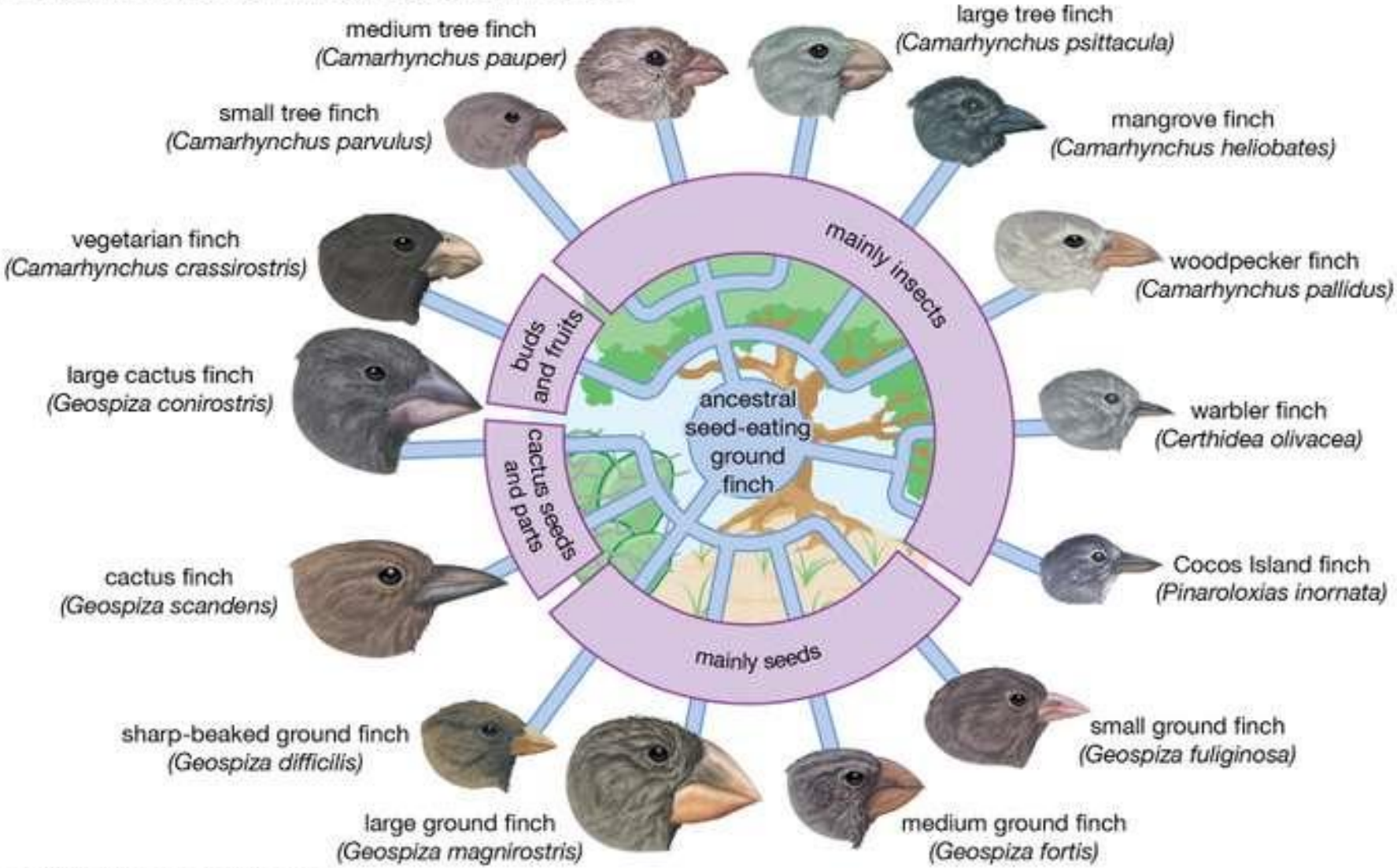
Small ground finch (*Geospiza fuliginosa*). Least Concern. One of the most common species of finch, found throughout the Islands

Large cactus finch (*Geospiza conirostris*). Least Concern. This finch is one of the most variable of the finches in appearance and they feed on a range of foods including *Opuntia* cacti

Common cactus finch (*Geospiza scandens*). **Least Concern. As their name suggests, they feed mostly on Opuntia cacti. When the *Opuntia* are in flower, the finches feed almost exclusively on pollen and nectar. During other times of the year, they will feed on *Opuntia* seeds and fruit. They will also feed on a range of other vegetative foods and invertebrates**

Sharp-beaked ground finch (*Geospiza difficilis*). **Least Concern. Although most populations feed mainly on seeds, those finches found on the small and remote islands of Wolf and Darwin often drink the blood of large seabirds, such as boobies. This has given them an alternative name – vampire finch**

Adaptive radiation in Galapagos finches



Adaptive radiation in Darwin Finches

With their diversity of bill sizes and shapes, each species has adapted to a specific type of food:

ground-finch (*Geospiza*) has a thick beak adapted to feeding on a variety of crunchy seeds and arthropods

warbler finch (*Certhidea olivacea*) developed a slender, pointy bill to catch tasty insects hiding between the foliage

woodpecker finch (*Camarhynchus pallidus*) even uses twigs or cactus spines to pry arthropods out of treeholes

The Galápagos finches are seen as a classic example of an adaptive radiation, the rapid evolution of ecologically different species from a common ancestor

Comparisons of anatomical features of the Galápagos finches, as well as modern molecular techniques, show they are indeed more closely related to each other than to any other species

Origin and ancestry of Darwin's Finches

This means they form a monophyletic group, a group of organisms all descended from one ancestral species

Based on the accumulated differences that occurred in their DNA over time (a way of estimating when species split from each other), the ancestral flock likely reached the Galápagos about 2-3m years ago (Grant and Grant, 2008)

Oldest known fossil remains of Galápagos finches come from the Holocene period (the last 10,000 years) (Steadman et al, 1991)

These fossils are from two species of ground-finches, *Geospiza nebulosi* and *G. magnirostris*, that are still living on the islands today

Blue-back grassquit *Volatinia jacarina*, a small tropical bird common throughout much of Central and South America, was the most likely direct ancestor of the Galápagos finches

Later studies using mitochondrial DNA and found that another species of grassquit, *Tiaris obscura*, was the most likely ancestral species, Sato et al. (2001)

This species originated in Central America, but spread into South America as the Isthmus of Panama, the land bridge between North and South America, formed around 3m years ago

From South America, it made its way to the archipelago

Based on similarities in morphology as well as behaviour, that the Galápagos finches are more closely related to Caribbean species of *Tiaris* or the Saint Lucia black finch *Melanospiza richardsoni* (Baptista and Trail, 1988)

This possibility of a Caribbean origin of the Galápagos finches was also corroborated by a recent analysis (Funk and Burns, 2018)

In this analysis, the majority of species most closely related to the Galápagos finches were found to have their ancestral range in the Caribbean

However, the analysis was not conclusive, and there remains an equal probability of a Caribbean origin or a South American mainland origin to the Darwin's finch radiation

A Caribbean origin of the Galápagos finches seems counterintuitive, as the nearest mainland from the Galápagos is South America, but dispersal does not always follow a straight line

This is nicely demonstrated by the finch that inhabits nearby Cocos Island, *Pinaroloxias inornata*

Although this island is closer to the mainland than the Galápagos Islands themselves, genetic research has shown that the Cocos Island finch descended from a Galápagos species, not a mainland one (Grant and Grant, 2008)

Adaptive radiation in Darwin's finches

Darwin's finches, inhabiting the Galápagos archipelago and Cocos island, constitute an iconic model for studies of speciation and adaptive evolution

Darwin's finches are a classical example of an adaptive radiation

Their common ancestor arrived on the Galapagos about two million years ago

During the time that has passed the Darwin's finches have evolved into 14 recognized species differing in body size, beak shape, song and feeding behaviour

Changes in the size and form of the beak have enabled different species to utilize different food resources such us insects, seeds, nectar from cactus flowers as well as blood from iguanas, all driven by Darwinian selection

A few million years ago, one species of finch migrated to the rocky Galapagos from the mainland of Central or South America

From this one migrant species would come many -- at least 13 species of finch evolving from the single ancestor

This process in which one species gives rise to multiple species that exploit different niches is called adaptive radiation

The ecological niches exert the selection pressures that push the populations in various directions

On various islands, finch species have become adapted for different diets: seeds, insects, flowers, the blood of seabirds, and leaves

The ancestral finch was a ground-dwelling, seed-eating finch

After the burst of speciation in the Galapagos, a total of 14 species would exist:

3 species of ground-dwelling seed-eaters

3 others living on cactuses and eating seeds

1 living in trees and eating seeds

7 species of tree-dwelling insect-eaters

Involves the interplay of complex forces (such as isolation, competition, adaptation, etc.) leading to adaptive radiation at the species level

Evolution of Darwin's finches and their beaks revealed by genome sequencing

Lamichhaney *et. al.* 2015, Nature, 518: 371-375

Interspecies hybridization has played a critical role in the evolution of the finches, and has contributed to maintaining their genetic diversity

The most striking phenotypic diversity among the Darwin's finches is the variation in the size and shape of the beaks

Genetic basis for variation in beak shape

The team investigated the genetic basis for variation in beak shape by comparing two species with blunt beaks and two species with pointed beaks

Fifteen regions of the genome stood out as being very different in this contrast, and as many as six of these contained genes that previously have been associated with craniofacial and/or beak development

"The most exciting and significant finding was that genetic variation in the ALX1 gene is associated with variation in beak shape not only between species of Darwin's finches but also among individuals of one of them, the medium ground finch

Beak shape in the medium ground finch has undergone a rapid evolution in response to environmental changes

Hybridization mixes the different variants of an important gene, ALX1

The ALX1 gene codes for a transcription factor with a crucial role for normal craniofacial development in vertebrates, and mutations that inactivate this gene cause severe birth defects including frontonasal dysplasia in humans

-"This is an interesting example where mild mutations in a gene that is critical for normal development leads to phenotypic evolution