The Origin of Species: The Beak of the Finch

hhmi | BioInteractive

Film Guide
Educator Materials

OVERVIEW

The Beak of the Finch is one of three films in HHMI's Origin of Species collection. Naturalists from Charles Darwin to E. O. Wilson have marveled at the incredible number and diversity of species on Earth. Understanding why there are so many species on our planet is an active area of current research. This film follows Princeton University biologists Peter and Rosemary Grant as they study the finches endemic to the Galápagos Islands. Their work, conducted over the course of four decades, shows how geography and ecology can both drive the evolution of new species.

Darwin's finches. Charles Darwin brought the finches living on the Galápagos Islands to scientists' attention following his famed voyage on HMS *Beagle*. Thirteen distinct species of Galápagos finches are adapted to living in different habitats and eating different diets. One of the most striking differences among species is the shape and size of their beaks. (Photos courtesy of John van de Graaff.)

KEY CONCEPTS

A. Habitats and ecological niches are constantly changing; even entire ecosystems change over time. New species can arise as populations adapt to changes and new opportunities in the environment.

B. Newly formed islands provide many new habitats for species to occupy. In the Galápagos Islands, a single ancestral population of finches has given rise to 13 separate species, each adapted to different habitats and niches.

C. An adaptation is a structure or function that confers greater ability to survive and reproduce in a particular environment.

D. When two groups within one species become geographically isolated—separated by a physical barrier, such as a river, canyon, or mountain range—genetic changes in one group will not be shared with members of the other, and vice versa. Over many generations, the two groups diverge as their traits change in different ways.

E. For two groups to become distinct species, traits must change in ways that will keep members of each group reproductively isolated, meaning that they will not mate or produce fertile offspring with members of the other group even if they come to be in the same geographic location.

F. Evolutionary change can occur rapidly, in only a few generations, if there is genetic variation among individuals in a population and if natural selection acting on this variation is strong. However, major change, such as the origin of new species, often takes many thousands of generations.

CURRICULUM CONNECTIONS

Standards	Curriculum Connection
NGSS (2013)	LS2.A, LS3.B, LS4.B, LS4.C
AP Bio (2015)	1.A.1, 1.A.2, 1.A.4, 1.B.2, 1.C.1, 1.C.2
IB Bio (2016)	5.1, 5.4, C.1
AP Env Sci (2013)	II.C
IB Env Systems and Societies (2017)	3.2
Common Core (2010)	ELA.RST.9-12.4, WHST.6-12.9, MP2
Vision and Change (2009)	CC1, CC5

PRIOR KNOWLEDGE

Students should

- have a basic understanding of natural selection, evolution, and adaptation;
- be familiar with the concept that organisms occupy specific niches in their environments; and
- know that genes and their respective traits are inherited and that some traits provide organisms with a greater chance to survive and reproduce.

PAUSE POINTS

The film may be viewed in its entirety or paused at specific points to review content with students. The table below lists suggested pause points, indicating the beginning and end times in minutes in the film.

	Begin	End	Content Description	Review Questions
1	0:00	5:36	• The 13 species of finches in the Galápagos have different beaks adapted to different diets. • DNA evidence indicates that the Galápagos finch species are all more related to one another than any one is to a species on the mainland; they all evolved from one ancestral species.	• What evidence did scientists use to determine that all 13 species of finches on the Galápagos have one common ancestor?
2	5:37	11:08	• Traits like the size and shape of beaks can change when the environment and thus the food supply changes. • Habitats and ecological niches are constantly changing. • In 1977, as a result of drought, large seeds were abundant and birds with large, strong beaks had a competitive advantage. Over generations, the average beak depth changed. • In 1983, abundant precipitation allowed vines to flourish. During the 1985 drought, smaller seeds were more abundant, so that birds with smaller beaks had a competitive advantage, survived well, and their offspring had smaller beaks. • Evolutionary change can occur rapidly, in only a few generations, if there is genetic variation among individuals in a population and if natural selection acting on this variation is strong.	• How did the population of medium ground finches on the island of Daphne Major change as a result of environmental changes? • Does evolution happen quickly or slowly?
3	11:09	15:45	• Species are defined as populations whose members do not interbreed with members of other populations. Reproductive isolation can result in speciation. • Song and appearance both played a role in keeping members of different species from mating with each other. • It is likely that a finch species arrived on one island from	• What is the definition of a species? • What two characteristics played a role in reproductively isolating ground finches? • How did one ancestral

			the mainland, then as descendants populated other islands, their traits changed over time. If the changes included traits in mating, they became distinct species.	population give rise to many species, each with different adaptations?

BACKGROUND

During Charles Darwin's journey on HMS *Beagle* from 1831 to 1836, he spent five weeks on the Galápagos Islands in 1835. Although his visit was short, the observations Darwin made and what he concluded about how evolution works made his trip one of the most famous events in the history of science.

When Darwin first encountered the finches, he collected and categorized them into three distinct groups: blackbirds, wrens, and finches. After he returned to England, he presented his specimens to one of Britain's leading ornithologists, John Gould. Gould identified all the birds as belonging to a single group, based on their anatomy and colorings, rather than several groups as Darwin had thought. Darwin was struck by the fact that although the birds were all finches according to Gould, the sizes and shapes of their beaks were remarkably different, as different as those of birds from different taxonomic groups on various continents. In a particularly evocative phrase in his book *The Voyage of the Beagle*, 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."

His discovery of the finches, along with other evidence he had gathered during his voyage, all pointed toward one conclusion: All the various species were not created in their current forms but have instead evolved through natural, undirected processes. Darwin famously took many years to publish his ideas about how species form and his theory of evolution through natural selection. *On the Origin of Species* was published in 1858—only after Darwin received a letter from Alfred Russel Wallace independently outlining the same ideas. (See the related short film *The Origin of Species: The Making of a Theory*.)

Fast-forward to 1973, over 100 years after Darwin wrote his revolutionary ideas, when Peter and Rosemary Grant traveled to the Galápagos Islands for the first time to study variability among finches within and among populations. By then, the theory of evolution was no longer questioned by scientists but accepted as a central unifying principle in biology. However, biologists were continuing to investigate and ask questions about the processes that drive evolutionary change. For example, what roles do competition, genetics, and the environment play? How do these factors work together to produce the variety of species in existence today as well as those we have discovered in the fossil record? Forty years of research on the Galápagos finches has helped provide some of the answers.

Islands Are Natural Laboratories

To gain insights on particular research questions, researchers generally try to limit the number of variables being considered. For that reason, studies in speciation often focus on groups of species that are closely related and living in relatively contained, isolated habitats, such as islands.

The Grants' studies of speciation have focused on the finches living on the Galápagos Islands. These islands sit on the equator in the Pacific Ocean 973 km west of Ecuador, South America. The distance between the mainland and the closest island in the Galápagos makes it unlikely for mainland species of plants or animals to colonize the islands. However, given enough time, some mainland species will make the journey. Flying animals like birds, bats, and insects can, on rare occasions, move from the mainland to ocean islands and from island to island, even if these are separated by large distances. This can happen, for example, when birds are blown off course by a storm. Flying animals can accidentally carry seeds with them—for example, in mud on their feet—which can germinate and grow to form their own populations. Large seeds, like coconuts, can float to the islands on their own and germinate there.

The Galápagos Islands are not only remote but they are also geologically young. They are volcanic islands that began rising from the seafloor between 4 million and 5 million years ago. Some of the first islands to emerge are now back under water due to erosion and subsidence. The current islands have been above the ocean surface for about 3 million years or less. Thus, the species found on the Galápagos Islands today are relatively few, and most have only existed there for less than 3 million years. Scientists can study how these species evolved in a relatively short period of time in a new environment that is largely undisturbed by human activities. In addition, on the smaller islands, like Daphne Major, scientists can potentially study entire populations of animals living on those islands for many generations. For all these reasons, islands can function like natural laboratories.

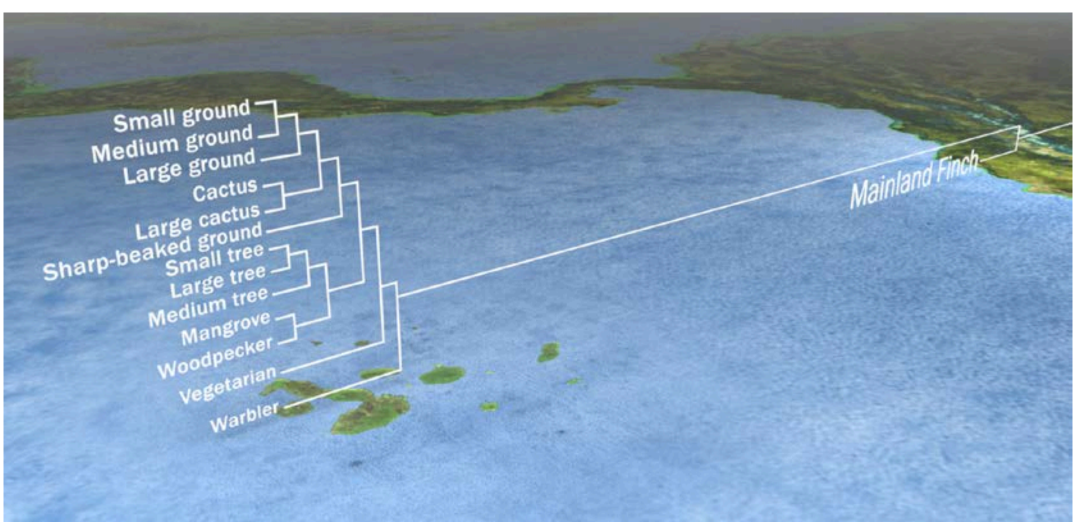
Evolution of the Galápagos Finches

When the Grants began their study, they didn't know whether the Galápagos finches arose from a single species or from two or more that came to the islands independently. At one extreme, if each Galápagos species came separately from the mainland, then each of the 13 Galápagos species living on the islands today should be more closely related to a species on the mainland than to another Galápagos species.

One way to study evolutionary relationships among species is to compare DNA sequences. When the Grants looked at genetic data from mainland birds and compared those to genetic data from the Galápagos finches, they discovered that a single mainland species, the grassquit, is the closest living relative of all the finches. This discovery was not compatible with a multiple-origins hypothesis. The ancestral species to all of the finches on the Galápagos had likely been a seed-eating species like the grassquit that arrived on the islands around 2 million years ago.

The first group of finches likely arrived on one of the Galápagos Islands and over time diversified into different species of birds. The original founding population has gone extinct, and probably other species have as well. The 13 species that inhabit the islands today are the result of 2 million years of evolution.

When the first ancestral population of finches arrived on the islands, many of the potential ecological niches were still available because the islands were young and there was little, if any, competition for resources. As different populations of finches occupied these niches, they evolved adaptations that enabled them to survive in the different habitats. Thus, in a relatively short period of time, many different species of finches evolved from a single ancestral population, a process called adaptive radiation.



Finch phylogenetic tree. Comparisons of DNA sequences revealed the evolutionary relationships among finch species. The data showed that all finch species living in the Galápagos Islands today are more closely related to one another than to any species of birds on the mainland, suggesting that they originated from a common ancestor.

Today, 13 species of finches live on the islands of the Galápagos archipelago and an additional one on Cocos Island, an uninhabited island off the coast of Costa Rica located about 720 km north of the Galápagos Islands. This rapid radiation of finch species would not have occurred in an environment in which all the ecological niches were already occupied.

As illustrated by the phylogenetic tree in the figure above, when the founding population diverged into two descendants, one of the descendants evolved into the warbler finch and the other descendant gave rise to all the other finch species. The warbler finch is the only insect-eating Galápagos finch that can catch insects while in flight. Thousands of years later, the finch population diverged and one descendent led to the vegetarian finch and the other to the ancestor of the remaining finch species. The vegetarian finch is aptly named because its diet is mainly made up of fruits, flower buds, and blossoms. The final two groups that later formed branches of their own on the Galápagos finch family tree are the insect-eating tree finches and the seed-eating ground finches, which also include the cactus finches.

One trait which is highly diverse among the Galápagos finch species is the size and shape of the beak. For example, the cactus finch (*Geospiza scandens*) has a long, pointed beak capable of probing and opening cactus fruits to eat the seeds. It also eats the pollen and nectar of the cactus flowers. With its shorter, blunter beak, the medium ground finch (*Geospiza fortis*) can only eat cactus seeds once fruits fall to the ground or are opened by cactus finches. However, it can also crack open some larger and sturdier species of seeds that the cactus finch cannot open.

Table 1. The Galápagos Finches

Scientific Name	English Name	Approximate weight (grams)
Geospiza fuliginosa	Small ground finch	14
Geospiza fortis	Medium ground finch	20
Geospiza magnirostris	Large ground finch	34
Geospiza difficilis	Sharp-beaked ground finch	20
Geospiza scandens	Cactus finch	21
Geospiza conirostris	Large cactus finch	28
Camarhynchus parvulus	Small tree finch	13
Camarhynchus pauper	Medium tree finch	16
Camarhynchus psittacula	Large tree finch	18
Camarhynchus pallidus	Woodpecker finch	20
Camarhynchus heliobates	Mangrove finch	18
Platyspiza crassirostris	Vegetarian finch	35
Certhidea olivacea	Warbler finch	8

Adaptation and Speciation

Most of the Grants' research has focused on the medium ground finch and the cactus finch, both on the island of Daphne Major. By observing these birds year after year for four decades, they have shown that as the environment changes so too do the traits of the birds.

The film shows that when the island of Daphne Major experienced an extreme drought in 1977, food quickly became scarce. Medium ground finches have stout beaks that are ideal for picking up seeds from the ground, but beak sizes vary greatly within medium ground finch populations. When seeds were plentiful, there were many different seed sizes and all the medium ground finches had enough to eat. But after the drought, the smaller, soft seeds from cactuses and other plants were eaten until hardly any remained. The smaller medium ground finches with smaller beaks ran out of food and began dying. Finches that were larger and had larger beaks could still forage on the larger, harder seeds of a plant called caltrop. These birds had a survival advantage, but even they struggled to handle these seeds, which are covered in sharp spines. Around 1,200 medium ground finches were alive at the beginning of the drought, but fewer than 200 survived, a loss of 85%. Most of the survivors were larger and had larger beaks. (Although the film only mentions the medium ground finches, 60% of the cactus finches on Daphne Major also died.) The larger-beaked medium ground finches that survived reproduced in the year after the drought.

The island of Daphne Major. Daphne Major is one of the smallest (approximately a quarter of a mile in diameter) and least accessible islands in the Galápagos archipelago. It is not, and has never been, permanently inhabited by humans. (Photo courtesy of John van de Graaff.)

The Grants discovered that the next year, the offspring of surviving medium ground finch individuals had beaks similar in size to those of their parents, showing that the beak size trait is strongly heritable. The average beak size of the birds in the new post-drought population was 4% larger. Four percent is a big change in such a short time and is consistent with the interpretation that beak size is an inherited trait that has a strong influence on the survival of an individual finch.

The Grants are among the few scientists to have directly witnessed and measured evolutionary changes taking place in real time. But how do changes like the ones they observed lead to new species? To begin to answer that question, an additional ingredient—reproductive isolation—must be considered. A broad definition of a species is a group of interbreeding individuals who are reproductively, and thus genetically, isolated from other groups. When populations of finches initially occupied different habitats on the same Galápagos island, breeding among all the finches was likely common, allowing for genetic exchange among them. However, as populations became more isolated on different islands, breeding between members from two different populations became increasingly rare. The genetic changes responsible for changes in beak size and shape, in body size, and in feeding ecology became less likely to be shared among the different populations. These changes were also accompanied by changes in the songs the birds sing.

The Grants have shown that enough differences in song and appearance will keep two finch species from interbreeding, and thus keep them genetically isolated from each other, even if they are living in the same general area. When the time comes to choose a mate, finches do so largely on the basis of appearance and song. Galápagos finches learn their species' song during a very short sensitive period early in life, usually from their fathers, and retain that song for life. In the course of speciation, changes in song in a population provide a behavioral barrier to the exchange of genes with other populations. Once this barrier is in place, genetic differences can accumulate in different populations even if they are living in the same geographical location. Eventually these changes become so numerous that members of one population will not be able to produce fertile offspring with members of another population. They will have become distinct species.

Current Galápagos finch species tend to keep to themselves, but some are still capable of exchanging genes. In rare instances, the Grants have shown that a cactus finch might mate with a medium ground finch on Daphne Major and produce fertile offspring. This might happen, for example, when a male finch learns the wrong song from a neighbor. Hybrids can survive and reproduce under some circumstances, specifically if there is a rich supply of intermediate-size seeds suitable for birds with intermediate-size beaks.

DISCUSSION POINTS

- In an upper level biology course, students may learn about allopatric, parapatric, and sympatric speciation. These are the three major mechanisms for speciation described in textbooks. Allopatric speciation takes place when two populations are completely geographically isolated from each other and no gene flow occurs between them. Genetic changes in one population are never shared with the other population. When the founding population of seed-eating birds arrived on the early-forming Galápagos Islands, it became isolated from its mainland population. However, allopatric speciation does not explain the origin of all new species. For example, in parapatric speciation, genes occasional flow between two populations that have adjacent geographic ranges. Genes may still flow intermittently between populations of finches on nearby islands, but it is rare. In sympatric speciation, gene flow is common because the two populations live in the same geographic area but occupy different parts of the same habitat. When speciation occurs in sympatric populations, one or more traits that are responsible for interbreeding are selected against. Such traits may include ones that affect appearance, the ability to tolerate certain environmental extremes, or the timing of reproduction for the two populations (e.g., spring or summer). In the case of the Galápagos finches, most researchers think that species originally formed following geographic isolation (or in allopatry). They then remained distinct species primarily due to behavioral isolating mechanisms that kept members of different species separate if and when they came into contact.
- The film's narrator explains that a species is defined as a group of organisms whose members do not breed with members of other groups. This is often called the biological species concept, first introduced by evolutionary biologist Ernst Mayr, and is the definition most often taught to students. This concept emphasizes reproductive isolation. However, because the ability to mate and produce hybrid offspring is often difficult to test, biologists focus on size, shape, and color to group individuals into distinct species.
- The narrator of the film reveals that the average beak depth of the medium ground finches increased by over 4% from the time the 1977 drought began until after it ended. This change is nearly undetectable to the human eye. However, stress to students that for a bird who is already close to starving and whose only means to get food is to pick up seeds, maneuver them so they are positioned correctly, and crack them open, even a 4% larger beak may mean the difference between life and death. Perhaps have students imagine that their only route to survival is being able to pick up a basketball by palming it with one hand. Fingers that are 4% to 6% longer than average could be quite an advantage. You might also consider doing a nut-cracking demonstration with a couple of different-sized pliers to show how even small amounts of mechanical advantage can have a huge impact. Also point out to students that 4% is an average number. Individuals with beaks that are 1% smaller are at a small disadvantage, whereas those with beaks 8% or 10% smaller are at a strong disadvantage. Survival is probabilistic; the probability of survival for birds with beaks that are 10% or more smaller than the average is extremely low, whereas for birds with beak sizes near the average the probability is high and even higher for those with above-average beak sizes.
- Students might be confused as to whether the changes in beak size described as a result of the drought provide an example of speciation. The medium ground finches that survived the drought and their offspring, which inherited larger beaks, are still all medium ground finches. These changes in beak size represent adaptations in response to natural selection. If changes like these occur over thousands of generations and for different traits, including traits involved in reproductive isolation, then a population might be on the path to becoming a new species.

- It is important to help students understand that the frequency and tempo of speciation vary over evolutionary history. Generally, fewer new species evolve when environmental conditions are constant. Rapidly changing conditions and disruptive environmental events can spur more rapid speciation. The so-called Cambrian Explosion is an example of relatively fast and extravagant speciation of animals, as is the speciation that occurred after major extinction events associated with environmental change in the Mesozoic and Permian. The Galápagos finches are a good example of an adaptive radiation that occurred recently and over a relatively short period of time. The fact that adaptive changes have been directly observed by the Grants gives us insights into how natural selection can contribute to the process of speciation.
- Stress to students that the Galápagos Islands make for an ideal place to study evolutionary processes like natural selection and adaptive radiation because they are geologically young, remote, and relatively undisturbed. Evidence of adaptive evolution can be found among other island species. For example, the honeycreepers of the Hawaiian Islands have evolved in much the same way as the Galápagos finches, but the Hawaiian Islands have been inhabited by humans for thousands of years and habitats have been altered extensively by human activities and by species introduced to the islands by humans. These factors make studying the honeycreepers more challenging than studying the finches of the Galápagos.
- Students may ask whether there are examples of adaptive radiation beyond the Galápagos finches. Indeed, several other examples of adaptive radiation have been studied. The African cichlids are one of the most striking ones. The cichlids are a diverse group of freshwater fish, some of which live in lakes and rivers in western Africa. In the last 10 million years, the African cichlids have evolved into over 2,000 different species. Scientists have proposed three major stages in the adaptive radiation of the cichlids. In the first stage, cichlid species diverged in using very different habitats, just as tree and ground finches have diverged. In the second stage, just like the changes in beak shape among the finches, mouth shape diverged among the cichlid species adapting to eating different types of food. In the last stage, divergence occurs in signals used in species recognition, usually the color of the males. This sexual selection by female choice drives changes in the appearance of the fish. This last mechanism is similar to mate choice in the finches, which is dependent on the overall body shape of a potential mate and the song the male sings. Another example of adaptive radiation are the *Anolis* lizards. Have your students watch the related short film *The Origin of Species: Lizards in an Evolutionary Tree* and ask them to name the similarities and differences between the finches and anoles.

STUDENT HANDOUT

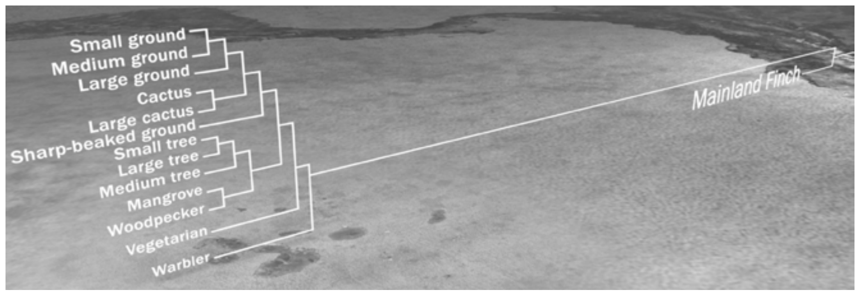
We designed the student handout as a learning assessment that probes students' understanding of the key concepts addressed in the film, which can be used to assess students' prior knowledge before watching the film or to guide students as they watch the film. We encourage you to choose the use that best fits your learning objectives and your students' needs. Moreover, because the vocabulary and concepts are complex, we encourage you to modify the handout as needed (e.g., reducing the number of questions, explaining complicated vocabulary for English learner students).

ANSWER KEY

1. (Key Concept B) Which is the most likely explanation for the presence of 13 different finch species on the Galápagos Islands today?
    a. Many years ago, several different species of birds migrated to the islands and the 13 finch species that currently live there are the only species that survived.
    b. ***Many years ago, a small population of a single bird species migrated to the islands and evolved into the 13 species that live on the islands today.***
    c. Each of the 13 species has migrated to the islands at different times over the years.
    d. A single bird species migrated to one island at around the time of Charles Darwin's voyage to the Galápagos and then migrated to all 13 islands.

2. (Key Concept C) Different finch species have beaks of different shapes and sizes. These different beak structures are evidence of
   a. different finch species adapting to different environments over many generations.
   b. different finch species with different beak structures coming to the Galápagos Islands from the mainland.
   c. different finch populations being evolutionarily related.
   d. individual birds changing their beak characteristics so that they could feed efficiently.

3. (Key Concept B) Examine the phylogenetic tree of the 13 finch species below. Which of the following statements is a correct interpretation of the phylogenetic tree in the illustration?



   a. The sharp-beaked ground finch is more closely related to the small tree finch than either species is to the cactus finch.
   b. The warbler finch is the common ancestor to all the finch species that exist today in the Galápagos Islands.
   c. All the Galápagos finches are more closely related to one another than they are to mainland finch species.
   d. The 13 finch species evolved in sequence; the warbler finch is the oldest species and the small ground finch is the most recent species to evolve.

4. (Key Concept D) Which experimental data from the film provide the best evidence that the cactus finch and the medium ground finch on Daphne Major are distinct species?
   a. Many more medium ground finches than cactus finches died in response to the drought.
   b. Cactus finch and medium ground finch males attempted to breed only with females of their own species.
   c. The cactus finch and medium ground finch feed on different types of food.
   d. Medium ground finch and cactus finch females have different markings and feather color.

5. (Key Concept A) Imagine you are studying a population of finches on one of the Galápagos Islands. You have been recording many of the birds' physical traits, including the length of both wings. You observe that for 80% of individuals measured, the length of the left wing is not significantly different from the length of the right wing (in other words, they are symmetrical). But for about 20% of birds measured, the wing lengths are asymmetrical. This distribution is true from generation to generation. Suddenly, a rare 5-day windstorm takes over the island. After the storm, you spend the next several days netting each bird on the island that survived the storm. You discover that 85% of the birds with symmetrical wings survived the storm, whereas only 5% of the birds with asymmetrical wings did.
   a. Propose a hypothesis to explain this observation.

   A complete answer to this question should include the explanation that the birds with symmetrical wings may have been better at flying during the windstorm, perhaps to find food or shelter, while the birds with asymmetrical wings may not have been able to maneuver as well in the strong wind or may have expended more energy to make the same maneuvers in the wind as the birds with symmetrical wings made.

   b. If such storms become increasingly common due to changes in climate, how might you expect the population to change over time with respect to wing symmetry?

   Student answers might include that the distribution of symmetrical to asymmetrical will change so that close to 100% of birds will have symmetrical wingspans.

6. (Key Concept E) Which of the five statements below describe(s) geographically isolated populations? Select the appropriate answer, a–d.
    i. The two populations live on different islands.
    ii. One population breeds in late spring and the other population breeds in late summer.
    iii. One population eats mostly small, soft seeds and the other population eats mostly large, hard seeds.
    iv. The males of one population have different mating calls than the males of the other population.
    v. The females of the two populations look the same.

    a. ***statement i only***
    b. statements i and iv only
    c. statements ii, iii, and v only
    d. statement iv only

7. (Key Concept F) Which of the five observations below provide(s) evidence that two populations are likely experiencing reproductive isolation and that there is little if any genetic exchange between them? Select the appropriate answer, a–d.
    i. The two populations live on different islands.
    ii. One population breeds in late spring and the other population breeds in late summer.
    iii. One population eats mostly small, soft seeds and the other population eats mostly large, hard seeds.
    iv. The males of one population sing different songs than the males of the other population.
    v. The females of the two populations look the same.

    a. statement i only
    b. statements iii and v only
    c. ***statements i, ii, and iv only***
    d. statements ii and iv only

8. (Key Concept F) How did the Grants test their hypothesis that differences in birds' songs can keep finches from breeding with members of other species?
    a. They watched which birds were mating with each other and listened for the songs the birds were singing.
    b. They recorded birds singing on the island of Daphne Major for an entire breeding season to see which type of song was used more often by each species.
    c. ***They played the songs of medium ground finches and cactus finches through a loudspeaker at different times, when individuals from both species were present, to see which species responded to each song.***
    d. They played the song of the medium ground finch to medium ground finch males through a loudspeaker to see if they would respond; they then played the song of the cactus finch to cactus finch males to see if they would respond.

9. (Key Concept F) Explain the evidence presented in the film for your answer in question #8 above.
    a. ***Males only came to the loudspeaker when the song of their own species was being played***.
    b. The type of song used more often during the breeding season was also the song sung by the most abundant species.
    c. During mating, birds sang the song of their own species.

10. (Key Concept G) Figure 1 shows the beak depths of 200 medium ground finches on Daphne Major before a severe drought began on the island. This is a normal sample of a population of medium ground finches, similar to measured samples from previous years. During wet years, all types of seeds are abundant. The medium ground finch prefers to eat small, soft seeds that are easy to crush. However, during droughts, when small seeds are not as abundant, they also eat the larger seeds on the island.

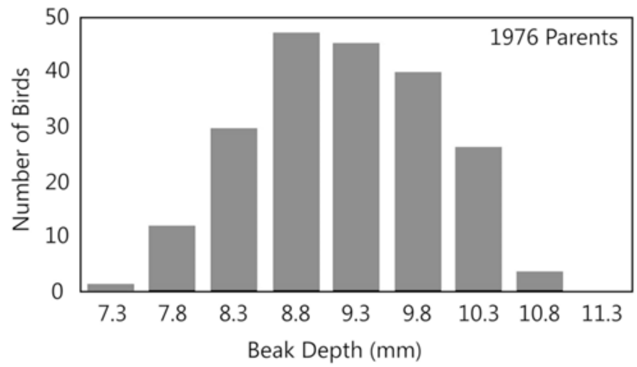


Figure 1. Beak sizes of a sample of 200 medium ground finches living on Daphne Major in 1976.

   a. Make two or three observations about the distribution of beak depth measurements in this sample of 200 medium ground finches.

   The shape of the distribution is like a bell curve (some students may describe it as a hill or arc) where most of the measurements are in the middle and only a few birds' beak measurements are at the extremes.

   b. What is the most common beak depth of the finches living on Daphne Major in 1976? ***8.8 mm***

   c. What is the range of beak depths in this group of medium ground finches? ***7.3–10.8 mm***

11. (Key Concept G) Figure 2 shows the same graph as in Figure 1 but with the birds that survived the drought shown by black bars.

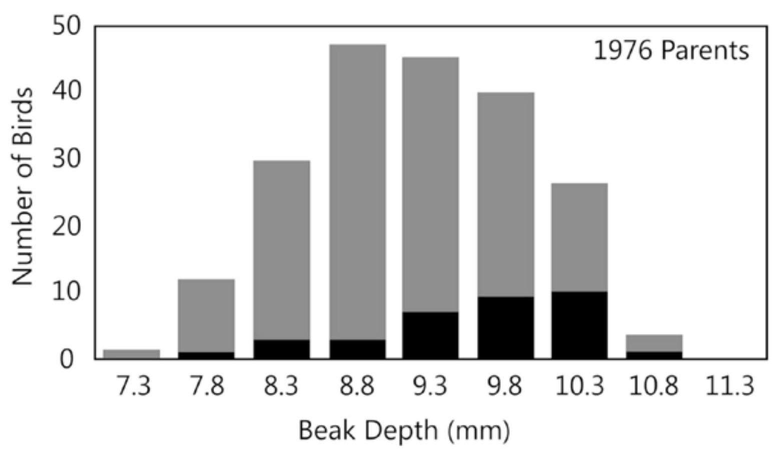


Figure 2. Beak sizes of medium ground finches living on Daphne Major in 1976 (gray bars) and of the finches that survived the drought of 1977 (black bars).

   a. Approximately what percentage of birds with the most common beak depth in 1976 (your answer to question #10b) survived the drought? ***5%***

   b. Compare the original group of medium ground finches (gray bars) to the group of survivors (black bars). List two observations you can make based on the data provided in the graph. Consider both the number of birds and beak characteristics.

   The original population was much larger, with over 200 individuals, with the most common beak depth being 8.8 mm. The survivor population consisted of fewer than 40 individuals, with the most common beak depth being 10.3 mm.

   c. Provide one possible explanation for the change in bird numbers and beak characteristics.

   Many birds died because they could not crack open the large seeds. Those with larger beak depths were more successful in cracking open the larger seeds and as a result survived.

12. (Key Concept G) The graph in Figure 3 represents the beak sizes of the offspring of the birds that survived the drought of 1977. (The survivors were represented by the black bars in Figure 2, and this graph shows the beak depth distribution of their offspring in 1978.)

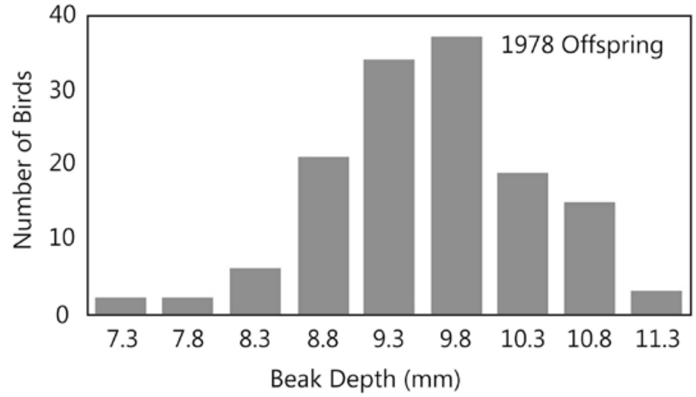


Figure 3. Beak sizes of the offspring of the medium ground finches that survived the drought of 1977.

Identify and describe similarities and differences between this group of medium ground finches and the following groups:

a. the sample of 200 medium ground finches measured in 1976 (Figure 1).
The number of individuals has increased to close to the number of birds present in the population before the drought. However, the most common beak depth has increased from 8.8 mm to 9.8 mm.

b. the sample of medium ground finches that survived the drought of 1977 (Figure 2 black bars).
The number of offspring is greater than the number of parents that produced them. However, the most common beak depth is not quite as large as the parent beak depth, and the range of beak depths is greater than that of the parents.

13. Explain the observed change in beak characteristics using the following concepts in your answer: competition, survival of the fittest, inheritance.

During the drought, competition for the scarce small seeds was intense. Many could not compete successfully and died. Birds with larger beak depths were able to feed more successfully on larger seeds that birds with small beak depths could not crack open. The larger beak depth gave those birds a selective advantage, and they were able to survive. When the survivors reproduced, their offspring inherited the trait for larger beak depth.

REFERENCES

Darwin, C. 1867. Letter. In F. Burkhardt, D. M. Porter, S. A. Dean, S. Evans, S. Innes, A. M. Pearn, A. Sclater, and P. White, Eds. 2006. *The correspondence of Charles Darwin: volume 15, 1867*. Cambridge University Press, Cambridge, U.K.

Grant, P. R., and B. R. Grant. 2008. *How and Why Species Multiply*. Princeton University Press, Princeton, New Jersey.

Kocher, T. D. 2004. Adaptive evolution and explosive speciation: the cichlid fish model. *Nature Reviews Genetics* 5:288-298.

Weiner, J. 1994. *The Beak of the Finch*. Alfred A. Knopf, Inc., New York.

AUTHORS

Paul Strode, PhD, Fairview High School, Boulder, Colorado, and Laura Bonetta, PhD, HHMI; quiz by Paul Strode and Mary Colvard, Cobleskill-Richmondville High School (retired), Deposit, New York

Edited by Laura Bonetta, PhD, and Dennis Liu, PhD, HHMI, and Ann Brokaw, Rocky River High School, OH; Susan Dodge

Illustrations by Fabian de Kok Mercado

Reviewed by Peter Grant, PhD, and Rosemary Grant, PhD, Princeton University; Jonathan Losos, PhD, Harvard University

Field tested by Nancy Bates, The Young Women's Leadership School Bronx; Susan Campbell, Brentwood High School; Moira Chadzutko, St. John the Baptist Diocesan High School; Noreen Kohler, Phoenix Academy; Kirsten Landry, Regis Jesuit High School; Katie Lodes, St. Joseph's Academy; Ioana Paunescu, International Community High School; Patricia Richards, Walter Johnson High School; Kimberly Snook, Haslett High School; Jessica Ullrich, Brentwood High School