**Video Tutorial 1.1: Genetic Analysis of the Galapagos Finches**

From 1831 to 1836, Charles Darwin travelled the world aboard the HMS Beagle, making many observations about the plants and animals that he encountered. Darwin's observations of birds on the Galapagos and Cocos Islands off the coast of South America are particularly well-known.

Fifteen species of finches live on the Galapagos and Cocos Islands. These birds have been grouped into species based on beak size and shape, feeding habits, and breeding behavior. As Darwin originally suggested, the many types of finches living on these islands are believed to have evolved from a common ancestor species that arrived from mainland South America, as shown in the tree here.

The original population of finches probably arrived in the Galapagos Islands about 2 million years ago, and then competed for the limited resources available on each of the Islands, which differ in size, habitat, and ecology. As in any population, there were variations in traits and behaviors within the original bird population, so different types of finches were able to colonize and survive in each habitat. Over time, due to natural changes in the genetic material of the finches, further divergence in traits between groups of birds occurred.

One easily visible trait that varied between the groups of birds was beak shape. Some birds had blunt beaks, while other had pointed beaks. The shape of the beak affects the bird's ability to eat certain types of food – for example, birds with blunt beaks could break open large seeds, while those with pointed beaks could capture and eat small insects. Birds with certain types of beaks were more likely to survive and reproduce in specific habitats that had predominantly one or the other food source. As additional genetic variation occured, birds with different beak shapes became separate species and no longer interbred. This is an example of natural selection; organisms diverge into separate species as they become specialized to eat certain food types or survive in specific habitats.

What are the underlying causes of the physical differences seen among these finches? Let's think about how the morphology or appearance of the birds is related to their DNA . DNA is the molecule that stores information in cells and serves as the blueprint for building an organism. The genetic information, or genotype, would dictate the structure and function of each finch and would be transmitted from one generation to another as the birds reproduce.

Since the genome of an organism – all of its DNA – encodes genes that determine its appearance and behavior, we would expect that birds with blunt beaks would have different DNA sequences than those with pointed beaks. By comparing the genomes of birds with different types of beaks, we might even be able to determine which parts of the DNA – which specific genes – would cause a bird to develop one kind of beak or another.

How might such a study be done? One team of biologists compared the DNA of the 15 species of finches found in the Galapagos, trying to distinguish sequences that were similar and sequences that varied among groups of birds. As you can imagine, there are many differences in the DNA sequences between birds of separate species, but there are also differences within the same species, as individuals are not identical. Is



© P Meneely, R Dawes Hoang, I N Okeke, K Heston 2017

it possible to find particular sequences in the DNA that would account for changes in beak shape in the finches?

The biologists focused on species that were closely related, but had differently shaped beaks. This way they were less likely to identify variation in the DNA that contributed to other differences between the birds. This approach allowed the scientists to find previously unknown genes that influence beak shape. As you can see in this figure, differences in DNA sequence in Region C of the genome did not associate with beak shape, while differences in sequence in Region D did. In this example, birds with pointed beaks had the sequence represented by the green block, while those with blunt beaks had the sequence represented by the blue block.

Altogether, the team of biologists found 15 regions of the genome that fit this pattern of variation and thus were good candidates for genes affecting beak shape. Of these regions, six were known to be involved in craniofacial development, so would be likely to affect the way the beak is shaped. The one region that was most strongly associated with beak shape included a gene called ALX1.

The ALX1 gene plays a role in turning on other genes, some of which are necessary for normal craniofacial development in vertebrates. Additional research on AXL1 will shed more light on its function, the genes it controls, and how it may affect beak shape in finches.

Researchers have identified other genes, including BMP4, a growth factor, and HMGA2, which affects bird size, as possible contributors to the size and shape of the finch beaks. The details of how these genes affect beak shape remain elusive, so studies on the finch genome continue.

Other interesting information has emerged from genome sequencing studies. Comparisons of the genomes of Darwin's finches elucidate differences between morphology-based trees and those based on the DNA sequences of related species. You can see evidence for this when you compare a tree created by traditional methods of species classification with one created from DNA sequences. In the tree based on morphology, the sharp-beaked ground finches - the species shown in red – occupy one branch, but in the tree derived from DNA sequence data, these sharp-beaked ground finches now appear in different branches of the tree. Genome sequencing can reveal evolutionary relationships at the DNA level that were not evident from observation alone.

The kind of study outlined here highlights the relationship and interconnectedness of evolution, genomes and genetics. The ability of organisms to survive in specific environments can be traced to differences in their DNA.

We need to think about evolution, genomes and genetics across scales, from DNA molecules to the genes that they comprise, which are organized into chromosomes and direct the development of the structure of the bird itself. Changes in DNA sequences affect the physical appearance and behavior of organisms. Understanding the relationships between genes, genomes and organisms is central to understanding genetics and evolution - and to understanding modern biology.



© P Meneely, R Dawes Hoang, I N Okeke, K Heston 2017

References:

Lamichhaney S, Han F, Berglund J, Wang C, Almén MS, Webster MT, Grant BR, Grant PR, Andersson L. 2016. A beak size locus in Darwin's finches facilitated character displacement during a drought. Science. 22 Apr 2016:470-474.

Lamichhaney S, Berglund J, Almén MS, Maqbool K, Grabherr M, Martinez-Barrio A, Promerová M, Rubin CJ, Wang C, Zamani N, Grant BR, Grant PR, Webster MT, Andersson L. 2015. Evolution of Darwin's finches and their beaks revealed by genome sequencing. Nature 518: 371-375.



© P Meneely, R Dawes Hoang, I N Okeke, K Heston 2017