KEYWORDS: Galápagos, “mystery of mysteries,” adaptive changes, hybridization, change in the living world

Photo: James Hayward

Fernandina is the youngest island of the Galápagos Archipelago and consists of a single volcano, La Cumbre, pictured here at sunset. Situated as it is directly over the Galápagos Hotspot, La Cumbre is the most active volcano in the archipelago. The most recent eruptions occurred in 2009, 2018, and 2020. Note the relatively fresh lava and sparse vegetation.

Mystery IN THE GALÁPAGOS

BY JAMES L. HAYWARD

As we take our first steps into Galápagos National Park, we enter another world. A land iguana greets us as we enter the walkway. Marine iguanas, seafaring dragons, dive for algae in the nearby surf. Penguins stand like bowling pins along the seaside rocks. Flightless cormorants stump their way along rocky shores. Giant tortoises lug their ponderous frames through the vegetated uplands. Four types of mockingbird dart rock-to-tree-to-sand in a search for tasty morsels. More than a dozen species of finches flit about in habitats high and low. Sunflower trees tower over all else in the highlands. These and scores of other species are found nowhere else on the planet.

Over the next eight days our group of sixteen friends will visit eleven of the nineteen main islands of the Galápagos Archipelago. This is my third visit here. I first toured these islands in 2006. Struck by the stark beauty and bizarre wildlife, I vowed to come back. Five years later I did just that with two Andrews University graduate students and a science instructor from Colegio Adventista del Ecuador. We studied the behavioral ecology of marine iguanas and flightless cormorants at Cabo Douglas on the island of Fernandina, where these animals live free of human interference. Yet another ten years and I'm back again. We board an 88-foot catamaran, the *Archipel I*. Comfortable accommodations, good food, a gracious crew, a knowledgeable guide, and a cadre of kindred spirits will make this a delightful voyage of discovery.

Few places inspire contemplation of change better than the Galápagos Archipelago. Questions about this place are legion: How and when did the islands form? Where did the original colonizers come from? How did they get here? Why are so many of the plants and animals here endemic (found nowhere else)? How come some of the endemic forms split into multiple species? Are new species forming here today? In short, *Why do we find all these unique organisms now, when in the past there was nothing here but the sea?* After visiting these islands in 1835, Charles Darwin acknowledged this query with a perceptive observation: "[I]n both space and time, we seem to be brought somewhat near to that great fact—that mystery of mysteries—the first appearance of new beings on this earth."[1]

To get at the root of Darwin's "mystery of mysteries," we must first consider the archipelago's fiery origins—life, after all, happens at the surface of a dynamic planet. The Galápagos Archipelago is young by geologic standards, much younger than the South American continent six hundred miles to the east. The archipelago is moving atop the Nazca Tectonic Plate over the Galápagos Hotspot.

Photo: James Hayward

Bottlenose dolphins (*Tursiops truncatus*) commonly swim alongside ships sailing through Galápagos waters. Dolphins are particularly fond of the cooler, highly productive waters that bathe the westernmost islands.

Photo: James Hayward

Aa ("ah-ah") lava at Cabo Douglas, Fernadina. The base of the La Cumbre volcano can be seen in the background mist.

Intermittently, searing magma from the hotspot burns through the plate to form volcanic islands.

Currently, the Galápagos Hotspot stirs beneath the westernmost islands of Fernandina and Isabela. Because the Nazca Plate slides from west to east over this point, the oldest Galápagos islands occur in the east, whereas the youngest occur in the west, where the volcanoes remain active. Radiometric ages for the emergence from the sea of the various islands range from two and five million years for the eastern islands to less than seven hundred thousand years for the westernmost island of Fernandina. Radiometric ages, however, are unnecessary for us to perceive the relative ages of these islands; the far greater extent of erosion we observe on the eastern islands in contrast to the sterile, fresh aa (pronounced "ah-ah") lava we stumble over on the western islands reveals the temporal sequence with unequivocal clarity.[2]

An ever-changing geology is not the only physical feature undergirding the ongoing pageant of life on the Galápagos Archipelago. Ocean currents determine the archipelago's mild climate. The Humboldt Current and the Peru Offshore Current bring cool, nutrient-rich water north along the South American coast before veering westward and converging to form the South Equatorial Current which, in turn, envelops the Galápagos. These cool waters not only nourish the archipelago's marine inhabitants but also cool and lower the humidity of the air above. The Equatorial Undercurrent, a submarine current that flows eastward from the central Pacific, brings cool water to the western islands, water in which whales, dolphins, and fish flourish. The complex confluence of these currents, along with prevailing winds, creates two

Photo: James Hayward

A pair of Galápagos penguins stands on a rock at the edge of Elizabeth Bay, Isabela. Members of this species are the only penguins with a range that extends north of the equator.

main Galápagos seasons: a warm, moist season from January to April, and a cool, foggy season from June to November; December and May function as transition periods. We are visiting in mid-August during the cool, foggy season, or the *garúa*.[3]

We are beginning to understand how all the remarkable endemic life forms in the Galápagos came to be—Darwin's mystery of mysteries. Almost two centuries past Darwin's visit, we possess a battery of tools and a vastly more complete data set than he had on which to build and test theories about how life unfolded here.

The first thing to recognize is that all organisms on this relatively young archipelago came from related plants and animals elsewhere. Genetic analysis has shown that the archipelago's endemic organisms are ancestrally linked to relatives living in Central and South America. Giant Galápagos tortoises, for example, are most closely related to Chaco tortoises from Argentina and Paraguay; the finches are genetically linked to birds called grassquits of Central and South America; and land and marine iguanas are relatives of spinytail iguanas, also from Central and South America.[4]

How did the original immigrants get here? Mangrove seeds most certainly rode the currents from South America. Clumps of vegetation—even whole mini-islands with standing trees—sometimes break away from riparian and coastal habitats and are released into the sea. These floating clumps of terrestrial life have been seen drifting far away from coastal areas. If by chance such clumps docked alongside a newly formed Galápagos island, hitchhiker seeds, propagules, and animals could have set up life. This is the most likely origin for the ancestors of many of the endemic plants, lizards, snakes, iguanas, and insects that reside here.

Tortoises are buoyant and can float and swim for many days in ocean currents without food or fresh water. Alternately, the first tortoise may have been transported here on one of the floating islands. A pregnant female or tortoise pair is all that would be needed to initiate a founder population of these animals. By contrast, birds often get carried by strong winds to places not of their choosing. Birders call such misplaced birds "vagrants" or "accidentals," which occur often enough that many regional field guides include such anomalies in their listings. This "blown-off-course" explanation is the most likely reason for the ancestors of today's Galápagos finches and mockingbirds.[5]

Although we have some pretty good hunches, we will never know for sure how each ancestor of the endemic plants and animals got here—but got here they did. Explaining how they might have arrived, however, is only part of the puzzle. The more intriguing question concerns how they changed from the organisms they once were to the organisms we see today.

Some endemic species, like the four species of mockingbirds, are very similar to ancestral forms on the mainland. Others are dramatically different. Take, for example, marine iguanas, descendants of mainland lizards. Not only did these animals change structurally, with the development of vertically compressed tails for swimming, flattened faces for scaping algae from underwater rocks, denser bones that provide ballast for underwater feeding, long claws for pulling themselves along the algae-covered rocks while feeding, they also changed physiologically and behaviorally. Marine iguanas are the only lizards that feed in the sea. When feeding, they take in salt water. The excess salt is forcefully excreted by salt glands in the nasal cavities.[6] As we watch the hundreds of marine iguanas hauled out at Punta Espinosa on Fernandina, several of them sneeze out the salty fluid with a hearty hiss.

Due to ocean currents from the polar south, the waters surrounding the Galápagos Islands are many degrees cooler than the optimal temperature range for the poikilothermic iguanas. Our research in 2011 showed that these animals enter the sea to feed when their body temperatures are high and the tide height is low, and they haul out on the beach under the opposite conditions, behavior dramatically different from that of their exclusively terrestrial ancestors.[7]

These adaptive changes, along with those of many other island inhabitants, are due to alterations in genetic composition. Alterations in genetic composition, in turn, are due to a variety of factors, some of which we understand, while others are yet to be discovered.[8]

The first understood factor is *isolation* of the founding island populations from the mainland populations. Isolation prohibits the swamping out of genetic changes that might occur due to processes described below and allows founding populations to follow their own independent paths.

Mutation, a random process, occurs in several forms, including changes in the sequence of nucleotides that make up the genes, breakage of chromosomes, reattachment of chromosome pieces to other parts of the genome, and the duplication of chromosomes. Mutations create genetic variability in populations. It is sometimes said that mutations are usually harmful and thus could not lead to positive consequences to organisms. Most mutations are, indeed, either harmful or benign, but given the vast number of mutations that occur in all populations, it is not surprising that occasional positive ones appear.

Genetic drift involves random fluctuations in gene frequencies and have the most impact on small populations. Founder populations, like those that landed on the Galápagos, contain only small fractions of the genetic variability found in parent populations. Just by chance, some genes in these small populations will disappear if individuals carrying them fail to reproduce. Favorable mutations occur as well. Gene loss or gain results in significant changes in gene frequencies in small populations, changes that would hardly make a dent in large populations.

Natural selection, a decidedly non-random process, happens when individuals with advantageous genes in a particular environment produce more viable offspring than other individuals in the population. Natural selection thus increases the frequency of helpful traits. Different environments select for different traits, and pioneer organisms reaching the Galápagos Islands faced dramatically different environmental circumstances than in their homeland. Consequently, selection pressure on these pioneers would have been a powerful agent of change.

Photo: James Hayward

An early morning view from Bachas Beach, Santa Cruz, the location of the final excursion on our eight-day tour. The tiny island of Daphne Major, site of a famous, long-term study of adaptation and hybridization among Darwin's finches, appears in the distance, as does the *Archipel* I.

Over the past few decades, we have begun to recognize the significant role that *hybridization* plays in both plant and animal speciation. In 1981, researchers on the tiny island of Daphne Major noticed the presence of a new, male finch larger than others living there. Not only was it larger, but it sang a different song from any Galápagos finch. The researchers called the new arrival "Big Bird." Genetic work confirmed that Big Bird was a hybrid from the island of Española, some sixty miles distant. Big Bird successfully mated with at least six of the smaller finch residents on Daphne Major, and the unions produced fertile offspring. Finch offspring learn the song of their fathers, so Big Bird's offspring learned his unique song and were attracted to it. Thus, his offspring bred with one another and with Big Bird himself. The result was a new population of finches which were morphologically different and reproductively isolated from the original resident population. In short, a new species was formed.[9]

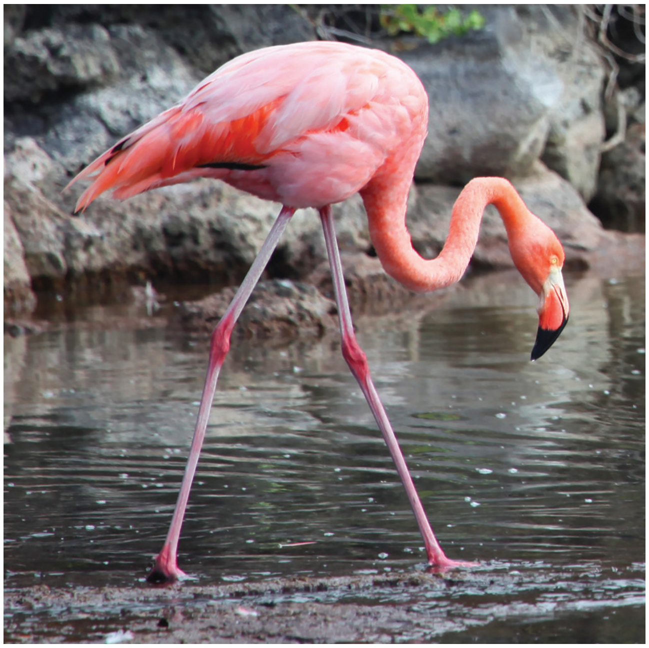
Photos: James Hayward

Currently, eighteen species of "Darwin's finches" are recognized. They are distinguished by their beaks, which are highly adapted for feeding on various types of food, and their body sizes. The three species pictured here illustrate some of the beak diversity in the group. The top photo depicts a female vegetarian finch (*Platyspiza crassirostris*), which feeds primarily on buds, leaves, flowers, and fruit, and also uses its beak to tear through tree bark to feed on the cambium and phloem underneath. The lower left photo shows a small ground finch (*Geospiza fuliginosa*), which feeds on small seeds and tortoise ectoparasites. The lower right photo is of a male common cactus finch (*Geospiza scandens*), which eats the flowers and seeds of the prickly pear cactus.

Geographic isolation, mutation, drift, natural selection, and hybridization are well-studied factors that likely promoted the origin of endemic species on the Galápagos Islands. Less-studied factors also may have been involved. *Horizontal gene transfer*, for example, occurs when genes from one type of organism are shuttled into another type by plasmids, viruses, or by other means. Horizontal gene transfer happens commonly in microorganisms but is also known to occur in plants and animals.[10] *Heterochrony* involves changes in the timing of the development of body parts one to another and in relation to the timing of sexual development. Dramatic shifts in adult body form can occur as, for example, when sexual development is gradually accelerated over the generations so that eventually sexually mature adults look like the juveniles of their ancestors.[11]

Change has been a good thing for the residents of the Galápagos. The plants and animals live in different environments than their ancestors, and adaptive change has allowed them to thrive in this new environment. The ability to adapt and to change into new species is, without doubt, one of the most remarkable features of life, but we still have much to learn about how this happens. Studying mechanisms of change remains an active area of research. Suffice it to say that new species originated here in the past and continue to originate here today.

Currently known genetic mechanisms seem adequate to transform land iguanas into marine iguanas, to produce cormorants that have lost the ability to fly, and to accomplish all the other adaptive feats we observe here. These changes must have taken place after the Galápagos Islands emerged from beneath the sea, from less than a million years ago for the western islands, and as much as five million years ago for the eastern islands. Given this amount of time, it seems highly likely that genetic changes of this magnitude could occur. This conclusion, however, leaves a question hanging. Are the mechanisms of genetic change described above sufficient to produce life in all its glorious diversity and stunning complexity? That question is not answered by the animal and plant life in the Galápagos, and given the limitations of our present knowledge, it may well continue to be unanswerable for a very long time. To be a theist is to believe in a God who



Greater flamingos (*Phoenicopterus ruber*) feed with their siphon-like bills in the ponds and lagoons of several islands.

Photos: James Hayward

Galápagos sea lions (*Zalophus wollebacki*) are the largest, most abundant, and most playful mammals that live in the archipelago.

creates. How that happened and when that happened is still shrouded in mystery.

Medieval Christians envisioned a fixed hierarchy of created things. At the base of the hierarchy were rocks, followed by plants, lower animals, higher animals, humans, cherubim, seraphim, Christ, then God the Father. This Great Chain of Being, or *scala naturae,* was held sacred as God's perfect created order. New species were not allowed, nor were extinctions.[12]

During the 1700s, Carolus Linnaeus rejected this linear organization of life. Instead, he believed that God had created nested hierarchies of species within genera, genera within families, families within orders, and so on.[13] A century later, Charles Darwin agreed with Linnaeus about nested hierarchies, but, based on empirical data, he believed that members of nested groups were linked by common ancestry, just like the younger branches of a tree are linked to older branches. In other words, new species had developed from earlier ones.[14] Many Christians were not happy with Darwin's conclusion because it countered their belief in the unchangeable perfection of God's creation. Even Darwin himself found his conclusion disturbing. He famously wrote to a friend that his admission of species change was like "confessing a murder."[15]

We humans are constitutively conservative. We are mighty comfortable with the status quo; we reflexively buck change. Yet change happens all the time, both around us and within us—the universe expands, black holes collide, supernovae explode, tectonic plates shift, mountains rise, volcanoes erupt, winds stir, and the seasons come and go. The most remarkable change of all is our own physical journey from fertilized egg to childhood to adulthood to death and all the psychological changes that go with it.[16]

Twenty-five hundred years ago, the Greek philosopher Heraclitus taught his doctrine of universal flux, the view that everything undergoes constant change. His teaching could not have been more perceptive.[17]

Adaptive change benefited endemic species in the Galápagos for generations. But generally the process of adaptation is too slow to accommodate the burgeoning forces of human interference and rapacity, including the introduction of invasive species, habitat destruction, overfishing, and climate change. Endemic species live perilously close to extinction on these islands. Several Galápagos endemics already have been lost. Lonesome George, the last of his tortoise ilk from Pinta Island, died in 2012. The Floreana mockingbird is now extinct on Floreana, although tiny, relict populations live on two nearby islets. Other species are threatened—only sixteen hundred flightless cormorants, four hundred lava gulls, and one hundred mangrove finches remain, the only representatives of their species.

Efforts by the Galápagos National Park, Galápagos Conservation Trust, Galápagos Conservancy, Galápagos Conservation Action, the Charles Darwin Foundation and Research Station, and others, help push back the threat of extinction—an uphill battle involving careful planning, concerted action, and advanced technology. Progress is being made, although it remains to be seen how effective these efforts will be in the long run, especially in the face of human overpopulation and climate change. We shudder to think of losing this unique natural laboratory of change, one that has taught us so much.

An instructive example of a conservation effort here is the attempt to save the mangrove finch, the most critically endangered of all Galápagos life forms. Mangrove finches formerly lived on both Fernandina and Isabela, but the Fernandina population has now been extirpated. Remaining members of this species live in a couple of patches of mangrove swamps along the western coast of Isabela. Here they are plagued by two invasive species: black rats, brought here centuries ago by ships, and avian vampire flies, accidentally introduced in the 1960s. Rats prey on the eggs and chicks, and fly larvae kill chicks by sucking out their blood. Poisoning rats in finch nesting areas has helped, as has fumigation of nests with a fly-killing insecticide. Mangrove finch nestlings have been successfully reared and released by the Charles Darwin Research Station, and, during the breeding season, experts closely monitor nests in the field. Plans are underway to introduce a parasitic wasp which would find and kill fly larvae. Despite these intense efforts, the future of the species remains in question; the tiny population teeters on the edge of reproductive sustainability.[18]

Photo: James Hayward

Flightless cormorants are among the weirdest, most comical, birds on earth. They are endemic to the Galápagos Islands, where they live in small colonies scattered along the Fernandina and Isabela coastlines. Note the aquamarine eyes, stubby wings, and oversized legs and feet. This pair at Cabo Douglas, Fernandina, is engaged in what seems like a choreographed dance accompanied by twisted necks and unbirdlike grunts.

Are conservation efforts like this worth it? The answer depends on one's values. For many of us the answer is yes. The natural world is our home. It cradles life in all its manifold diversity. It is the gift that sustains us, inspires us, and renews us. Mangrove finches, along with all living things, are citizens of the planet, fellow members of the creation—our sisters and brothers.

As we disembark one last time from the *Archipel* I, our minds resonate with the experiences of the last eight days. We have romped with sea lions, photographed feeding flamingos, hiked through lava tubes, swum with white-tipped sharks, boated through mangrove swamps, spied on sea turtles, snorkeled with multicolored fish, toured a tortoise breeding center, shared rocky shores with marine iguanas, gawked at a now stuffed Lonesome George, savored Galápagos chocolate, and conversed about everything from personality types to biblical interpretation. Moreover, we have become more cognizant of the challenges faced by life and find ourselves more inspired to foster the well-being of living forms here and elsewhere. Behind all this inspiration and beauty, however, it is the mystery of change that drew us here, motivates our questions, and makes us ponder life's meaning and history.

Change, we have learned, even large-scale change, need not shock or worry us. It is woven into the very fabric of the universe, part of an ongoing creation. More than any place on earth, the Galápagos Archipelago has taught us the value and necessity of change in the living world.

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