

EVOLUTION: THE HIGHLIGHTS

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Biologists have identified approximately 1.6 million species currently living on the face of the earth. Thousands more are named each year in a myriad of scientific journals. Even with all this work, it has been estimated that we have probably identified only 10 to 15 percent of all the species now in existence. Untold numbers are becoming extinct before they are even identified, as is happening in the wake of technological advance through the forests of South America and Indonesia. As impressive as this 'array of diversity' is in our present world, it is even more staggering when we attempt to comprehend all the diverse forms that may have ever existed throughout the history of our planet. Perhaps less than one percent have survived to the present day. The estimated total climbs to 1.6 billion different forms of life (not even close to the national deficit!). These are the products of evolution.

The theory of evolution is ascribed to Darwin, but he never called it that. Darwin referred to it as the "theory of descent with modification." or the "theory of transmutation." The term "evolution" was coined by Charles Bonnet (an 18th century embryologist) to describe the development of the adult form from an embryo. "e" means "out" coupled with "volutio" which means "turning or folding", thus the term "e-volution" literally means an "unfolding" or an "unrolling." A simple working definition of evolution is "the process of change in living populations." Evolutionary Biology, then, is the study of biology as an historical science, or the study of living systems as they change through time. There are two main approaches to the study of the evolution of life: the first approach is through the past, or in other words, by means of the fossil record; the second approach is through the living world around us.

The Geological Time Scale is divided up according to the "ebb and flow" of life forms throughout the earth's 4.5 billion year history. The divisions that we recognize either denote abrupt changes in the rocks themselves or dramatic changes in the fossil assemblages contained in them. The first evidence of life that the rock record yields comes from the Fig Tree Formation of South Africa. The Fig Tree Formation has been radiometrically dated at 3.5 billion years old. The life forms it contains are microscopic, unicellular organisms called bacteria (*Eobacterium iso/atum*). Blue green algae also occur quite early in the fossil record, at 1.9 billion years. The free oxygen in the earth's atmosphere is believed to have originated as a byproduct first of blue-green algal photosynthesis and later from the photosynthesis of more advanced forms of plant life.

The fossil evidence was difficult to interpret in the mid-nineteenth century for an acceptable as well as realistic time scale for geological processes had not been worked out; therefore, it was not possible to establish the ages of fossil remains. Both Darwin and Wallace approached the phenomenon of evolution through the living world. In the following paragraphs I will briefly examine the backgrounds of these two men, and then summarize what Darwin and Wallace perceived on their separate voyages which led them to question the "fixity of species" and to independently formulate the theory of evolution through natural selection.

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As a boy, Darwin's favorite pastimes were hunting and riding. He loved the outdoors and open-air pursuits were much preferred over schooling. Darwin showed little aptitude for scholarly subjects other than science, so his father (Robert Darwin, a well-to-do country physician, as was his distinguished grandfather, Erasmus Darwin) sent him to Edinburgh to carry on the family tradition in the study of medicine. Darwin found the lectures uninteresting and the clinical aspects repulsive. Out of dutiful respect for his father's wishes, however, he stayed on at Edinburgh for two years, but neglected his studies. Instead, he befriended some local naturalists, and spent much of his time with them. When it became abundantly clear that Charles would not become a doctor (as had his older brother Erasmus; Darwin also had four sisters), his father decided that he should study for the ministry. Charles consented, provided it was a country parsonage for which he was destined as this would give him ample opportunity to carry on his outdoor hobbies. So, Charles transferred to Cambridge, where he spent three years studying theology. In 1831, after receiving a Bachelor's degree from Christ's Church College, Darwin received a letter stating that he had been nominated to serve as a ship-board naturalist. Darwin's father perceived the voyage as a worthless diversion, and would not permit him to go. His uncle, Josiah Wedgwood (founder of the Wedgwood pottery works), pleaded young Darwin's case stating "the pursuit of Natural History... is very suitable to a clergyman;" Darwin's father consented.

At the age of 22, Charles Darwin set out on his voyage around the world aboard the H.M.S. Beagle (a refitted 10-gun brig under the command of Captain Hugh FitzRoy). The main purpose of the voyage was to map the coastline of South America. The ship would then circumnavigate the world. FitzRoy made it clear to Darwin, that as part of his duties, he would be expected to help refute the radical new ideas of geology (FitzRoy was referring to estimated ages for the earth that exceeded "theological limits") by gathering as many specimens as he could to "celebrate the wonders of Creation." The voyage would last close to five years (four years and nine months) and served to shape young Darwin's entire career.

Alfred Russel Wallace was the eighth of nine children. His parents were of very modest means, but they shared a "green thumb" and a love for books. As a result of the family's poor financial situation, the children were "farmed out" early as apprentices. Wallace left school at the age of 14 (all told Wallace received seven years of formal education). In school, the abnormally tall, innately shy Wallace excelled in reading and writing. His two most "painful" subjects were Latin and geography (yet he was to become a well-qualified authority in the Latin designations for living things; as for his dread of geography, he was destined to become the first European to penetrate the upper reaches of the Rio Negro, a major tributary of the Amazon, and later to explore the rugged mountains of the interior of New Guinea as well as many of the other islands in the Malay Archipelago.) He was, however, a born student and never shed his enthusiasm for learning. In 1845, after saving a modest sum of 100 pounds while employed as a surveyor for the railroad (in that same year Darwin inherited 40,000 pounds from his father's estate), Wallace and a close friend (Henry Walter Bates)

decided to use the money to fund an expedition to the Amazon. The region was poorly known and the pair figured that their initial expense would be offset by the money they would make selling natural history collections. Wallace was bewildered and enthused by the diversity he saw and wondered how it (diversity) came about in nature. He spent a total of four years in the "green inferno" of the Amazon forests. Unfortunately, enroute to England the ship he was on burned at sea (along with much of his collection). In 1854, Wallace arrived in the Malay Archipelago; he would spend the next 7 years among the islands. During that time, he wrote over two dozen scientific papers, one of which contained the essence of the theory of evolution through natural selection.

Darwin began his "systematic enquiry" upon his return home in 1836. During his voyage, Darwin began to question the overwhelming diversity of living things. Just as the earth's landscape was gradually altered through vast expanses of time (he read Lyell's *Principles of Geology* while on the trip) was it possible that plants and animals had been changed through time? He sought explanations that would integrate what he had learned on his voyage round the world. Darwin labored away on his "species work" for 22 years. He might have withheld his view on the transmutation of species from the British public even longer had not his hand been forced by Alfred Russel Wallace. In 1858, Wallace sent Darwin an essay of his to review. To Darwin's shock, it contained the essence of his own "species work." Wallace independently arrived at the conclusion that species were mutable, and that natural selection was the principal mechanism. Wallace had written his version over the span of three days, while suffering from the ill effects of a bout of malaria! Papers by Darwin and Wallace were read before the Linnean Society of London on the 1st of July 1858. A little over one year later, Darwin's magnum opus appeared in print. It had a resounding Victorian title, *On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life*, but was an abstract of a large work Darwin had in mind.

The first edition of *The Origin of Species...* amounted to 1250 copies and was sold out on the first day (24 Nov. 1859). It was great success not only scientifically, but commercially as well. New printings were called for in rapid succession: 1859 (2nd), 1861, 1866, 1869, and 1872 (6th). Darwin's Origin actually contains two theories: (1) the theory of evolution; (2) the theory of evolution by natural selection.

The facts that Darwin collected in support of the theory of evolution can be grouped into a small number of categories. These are: (1) comparative anatomy, (2) embryology, (3) variability of domestic plants and animals, (4) biogeography, (5) paleontology. Within the realm of comparative anatomy, Darwin noted the existence of homologous structures (features that are similar in development and construction, but have different functions like the hand of man, a bird's feathered wing, the front flipper of a whale, and the membranous wing of a bat) and pointed out that these structural similarities suggest a common ancestry. He observed that very young embryos of fishes, amphibians, birds and mammals are strikingly similar

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(they all possess a dorsal tubular nerve cord, pharyngeal gill slits, and a postanal tail). These embryological similarities (there are others) also suggest a common ancestry. There are a few examples that come to mind that demonstrate that evolutionary change can occur within a relatively short time; this is notable in the plants and animals that have come under the influence of man. Darwin remarked at length on breeds of pigeons; his discourse on pouters, tumblers, barbs, carriers, runts, Jacobins, fantails, laughers, trumpeters, and turbits are but vaguely familiar to many of us. To make this point more palatable, I suggest that you take a trip to the nearest fruit and vegetable market. While there gather the following items in your cart: cabbage, kohlrabi, broccoli, cauliflower, brussels sprouts, and kale. They differ distinctly in appearance, but all are varieties of a plant in the mustard family called *Brassica oleracea*. The original wild type (which is most similar to kale in appearance) was cultivated in the eastern Mediterranean region for only a few centuries. These variations within a species, provide additional evidence for the plasticity of species, and support the theory of evolution. The field of biogeography emphasizes historical events of migration and extinction, and attempts to elucidate and qualify the factors responsible for both present and past distributions of organisms on the face of the earth. Darwin noted that South American animals, regardless of whether they came from hot or cold regions, were more similar to each other than to other animals from similar climatic regimes elsewhere. The discipline of paleontology delves into the morphology, paleogeographic distribution, and paleoecological and systematic relationships of fossil organisms. Darwin recognized that the fossils from South America more closely resembled living South American forms than any other fossils known at the time.

As for the second theory contained in *The Origin of Species* (the essence of which was presented in Wallace's treatise entitled *On the Tendency of Varieties to Depart Indefinitely from the Original Type*, the logic of the theory of evolution by natural selection can be summarized as follows:

- (1) Variation exists among individual members of a species and some of these differences are inherited.
- (2) In each generation, more offspring are produced than survive to reproduce. Those individuals that survive and breed determine the nature of the next generation.
- (3) Those individuals with variations best adapted for survival in a particular environment contribute proportionately more offspring to the next generation.
- (4) Over long period of time, this process of differential survival and reproduction will lead to divergence between organisms in different environments. Ultimately, this leads to the development of separate species.

In succeeding editions of *The Origin of Species* Darwin carefully answered many of the objections levelled at both theories. Two of these objections were especially difficult to rebuff at the time because Darwin lacked

critical data. The first had to do with the age of the earth; the second concerned the perpetuation of favorable traits. The geological time scale was not established, and many still considered the age of earth to be no more than several thousand years old. Evolution through natural selection was perceived as a slow and gradual process, requiring vast tracts of time. The "theological limit" (6000 B.C. as established in Cuvier's "great compromise"; Archbishop Ussher tabulated the age of post-Adamite generations and proclaimed that the earth was created in 4004 B.C.) was not viewed as a sufficient amount of time in which to produce the bewildering variety of forms that man was rapidly discovering co-inhabited the earth. The belief that species were immutable productions was firmly grounded in religious dogma, and supported by the dominant view of our earth's history compressed into a time frame of less than 10,000 years.

Darwin had established that 300 million years had elapsed since the last part of the Mesozoic era. Although that estimate is now believed to be too high (deposits proximal to the Jurassic-Cretaceous boundary have been radiometrically dated at 135 to 5 million years), the order of magnitude is correct. Lord Kelvin (a notable physicist of the 19th century) based his estimates on the rate of cooling of the earth through time and on the age of the sun. These estimates were by far the most influential because they were based on "precise physical measurements" that demand few assumptions. At the time, they seemed irrefutable, and were accepted widely. An apparent thermal gradient (established by temperatures taken in deep mines which showed a fairly uniform increase in temperature with depth) indicated that heat was flowing from a hot interior to the cool outer portion of the crust where it eventually escapes into the atmosphere. Kelvin regarded this phenomenon as the dissipation of heat from an originally molten condition, and calculated (based on the present rate of heat flow) that the earth's crust formed about 25 million years ago. This apparent time of crystallization of the earth's crust established the maximum possible age of life as we know it. Regarding the age of the sun, Kelvin reasoned that the persistent loss of so much heat energy by radiation must gradually lower its temperature. He concluded on the best grounds then available that the sun has probably illuminated the earth for only a few tens of millions of years. A million years ago, according to Kelvin, the sun was providing the earth with significantly more energy than it is now; in a few million years it will be providing the earth with much less. We know that 10¹⁰ more light and heat would destroy us, and so would 10¹⁰ less. Approximate uniform solar energy is thus essential to the continuity of life on earth. This argument, like that concerning the earth's thermal history, portrayed the planet as a substantially different place to live in times past than it is now. Kelvin concluded (1897) that the earth had probably been habitable for 20-40 million years.

Evolution through natural selection is a two step process: first comes the production of genetic variability; secondly, you have the ordering of variability (Le. those organisms better suited to the prevailing environment have a greater probability of surviving). Darwin and his contemporaries

knew almost nothing of the source of genetic variability and of how new characters are inherited. The notions of blending inheritance and of the inheritance of acquired characteristics were popular concepts in Darwin's day (these concepts were derived from casual observations, for there was no accepted method of analyzing heredity before 19(0). One critic (Fleming Jenkin, 1867) simply suggested that a favorable characteristic appearing spontaneously in an individual would be progressively swamped out (by blending inheritance) and, ultimately, obliterated in any population in which it occurred. According to the concept of blending inheritance, when a better-adapted individual mated with a normal one, the favorable traits would be diminished in the offspring, and when these, in turn, mated with normal individuals, these traits would be further "diluted". Thus, in succeeding generations favorable traits would not persist. Darwin's uncertainty concerning the source and the inheritance of the genetic variability, the substance that supplies the raw material for natural selection, left a major hole in his argument.

Later, that gap in knowledge was filled by the science of genetics. In 1865 (within 6 years of *The Origin of Species*, Gregor Mendel published his theory of particulate inheritance. He had concluded, from his experiments on pea plants, that the hereditary material did not blend; inheritance was particulate. The factors carrying heredity information are discrete units transmitted by each parent to the offspring, preserved uncontaminated (i.e. no blending) and resorted in each generation. Darwin never knew of Mendel's findings, which were largely ignored until they were "rediscovered" in the early 1900s. Later, the "discrete units of inheritance" which Mendel referred to were called genes, and genes were found to be located on chromosomes within each cell.

From 1900 to 1930, two large groups of scientists held opposing views on the subject of the origin of species. One faction (the Mendelian geneticists) believed that new species arise suddenly, by saltation (macro-mutational events), and the other camp (the evolutionary gradualists or naturalists) maintained that new species arise gradually, through the accumulation of small heritable changes. These opposing views were reconciled in the modern synthetic theory of evolution which amplified the Darwin-Wallace theory of evolution by natural selection in light of: (1) the chromosomal theory of heredity; (2) the discoveries of population geneticists (i.e. "populations evolve, not individuals," thus rejecting the concept of the inheritance of acquired characteristics); (3) the biological concept of species (i.e., a species is a group of interbreeding natural populations reproductively isolated from other such groups).

The modern synthetic theory of evolution has stood as the organizing principle of biology for over the past four decades. Evolutionary biologists continue to investigate the manner(s) in which new species arise and change through time. Currently, there are two theories: the theory of gradualism, and the theory of punctuated equilibria. Supporting evidence exists for both models. The controversy between gradualists and punctuationists has sparked a renewed interest in the theoretical approach to evolutionary processes.

The theory of evolution through natural selection has changed man's view of the world and of himself. Since the time of Plato (?427-347 B.C) the dominant view was that the world consisted of a limited number of unvarying essences; the visible world's variable manifestations were but incomplete, imprecise reflections of these "eide." The Scala Naturae ("ladder of life") of Aristotle was a static hierarchy with varying degrees of "perfection." Theological doctrine was tightly interwoven into this classical framework. During the latter half of the 19th and early part of the 20th century the "fixity of species" paradigm gradually gave way to one of "evolution." With this a revolutionary change in our perception of biological diversity occurred.

It has been said, "Evolution is the common source of unity and diversity. " Evolution is the broadest unifying principle of biology. A notable geneticist (Theodosius Dobzhansky) once stated, "Nothing in the biological sciences makes sense except in the light of evolution." The diversity of life forms is the result of divergent evolution from a common ancestor over the span of billions of years. When the theory of evolution through natural selection was presented more than a century ago, the molecular, hereditary, and cellular mechanisms that underlie such a process were unknown. Today we know that these mechanisms support the picture of an evolutionary process that builds diversity while retaining unity.

The key to life on earth is diversity! What one organism needs to sustain life, others produce. It is this diversity of needs and products that perpetuates the cycling of the essential elements of life throughout the biosphere. A stable ecological system is built on a complex web of resource production and consumption by its members. In any ecological community, no two species have exactly the same combination of needs and products. Thus, biotic diversity arose through evolution not as the result of random or passive change, but as a result of natural forces originating, selecting, and perpetuating novel life forms that would exploit a previously unexploited combinations of resources!

Darwin perceived the magnitude of organismal interrelationship, and in the closing sentences of *The Origin of Species* wrote,

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and so dependent upon each other in so complex a manner, have all been produced by the laws acting around us. These laws, taken in the largest sense, being growth, reproduction, inheritance, variability, a ratio of increase so high as to lead to a struggle for life, and as a consequence to natural selection, entailing divergence of character and the extinction of less-improved forms. Thus, from the war of nature, from famine and death, ... the

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production of the higher animals directly follows. There is a grandeur in this view of life, ... and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved. "