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The theory of evolution: 150 years afterwards

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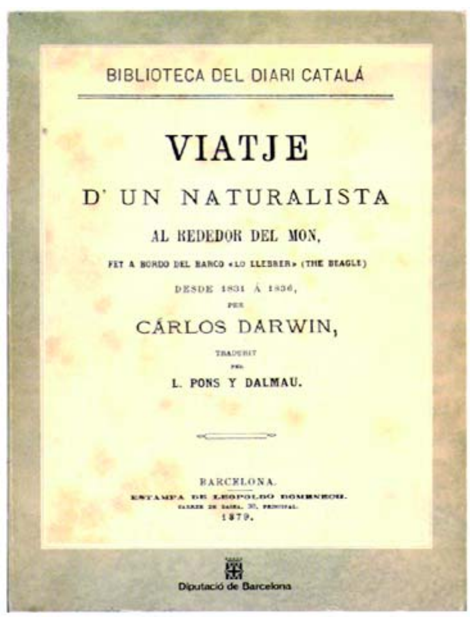
Darwin's theory of evolution: a fundamental shift in human thinking

Shifts in prevailing scientific paradigms are not easily accepted. Partly this is because most academics are better at looking at the constituent elements of problems than at seeing the connexions between them and understanding how the resulting system works. The publication of *On the Origin of Species* on November 24, 1859 [2] by Charles Darwin (1809–1882) marked a fundamental shift in human thinking, one of the most significant in the intellectual history of the human species.

Until the eighteenth century, few had challenged the timescale of Earth history set out in the *Book of Genesis*. Gradually this came under challenge, not least from Georges Cuvier (1769–1832) and Jean-Baptiste Lamarck (1744–1829), but it was James Hutton (1726–1797) that first described in detail the immensity of Earth history in which he saw no "vestige of a beginning" and "no prospect of an end." Then came Charles Lyell's (1797–1875) great work in the 1830s, and gradual acceptance of deep time with what it implied. Nonetheless resistance continued. As Thomas Henry Huxley (1825–1895) once said, the path of geological speculation was long blocked by a thorny barrier carrying the notice: "No Thoroughfare. By Order of Moses."

More recently we have seen the fundamental shift in thinking caused by the theory of the plate tectonics. Again this was fiercely resisted, and Alfred Wegener (1880–1930), who first identified plate movement through continental drift, died before his ideas were generally accepted. Another more recent example is the introduction of Gaia theory, or Earth Systems Science, which describes, in the words of James Lovelock and Lynn Margulis in 1974 [4]: "The evolution of a tightly coupled system whose constituents are the biota and their natural environment, which comprises the atmosphere, the oceans and the surface rocks."



Source: Omnis cellula

Fig. 1. Cover of the book *Viatje d'un naturalista al rededor del mon, fet a bordo del barco "Lo Llebrer"* (*The Beagle*), by Charles Darwin, published in Catalan in Barcelona in 1879.

The genesis of evolutionary ideas

Darwin himself inherited the mindset of his age, and this is evident in the work that led to the publication of *The Voyage of the Beagle* (Fig. 1). He was influenced by the ideas of his grandfather Erasmus Darwin (1731–1802) and especially by those of Thomas Malthus (1766–1834), who in 1803 set out the principle that population growth would sooner or later outstrip the growth of resources, with the eventual result of overpopulation and insufficient supply. On his return from his expedition on the *Beagle*, which lasted almost five years (from December, 27, 1831 to October 2, 1836), Darwin had the time and financial independence to pursue his researches as he so wished. He may have been

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influenced by Robert Chambers' anonymous work of 1844, in which Chambers proposed a universal law of development not unlike the eventual theory of evolution by natural selection (only the 12th edition, posthumous, published in 1884, revealed the author's name). The trouble was that Chambers' book, *The Vestiges of the Natural History of Creation*, contained bad things as well as good ones, and although widely read was scarcely regarded as serious scholarship. For his part, Darwin was aware from the beginning that his ideas about evolution would be highly controversial, and he undertook a programme of detailed work on barnacles, climbing plants, beetles, and in the end worms, to establish his thesis beyond reasonable criticism. When he eventually produced *On the Origin of Species*, he admitted that it was like committing murder.

Darwin was precipitated into publication because Alfred Russel Wallace (1823–1913) had come up with similar ideas, and had written to Darwin in 1856 to explain some of his thinking. In February 1858, Wallace completed his work on the subject, and sent a letter to Darwin. In a meeting at the Linnean Society in London in July that year, Darwin's and Wallace's papers were first made public, even though no one took any notice [3]. The publication of *On the Origin of Species* the following year not only changed the direction of human thinking about life on Earth, but also arose criticism and controversy, which expanded beyond the scientific community both in Britain and abroad (Fig. 2).

Accuracy of Darwin's theory

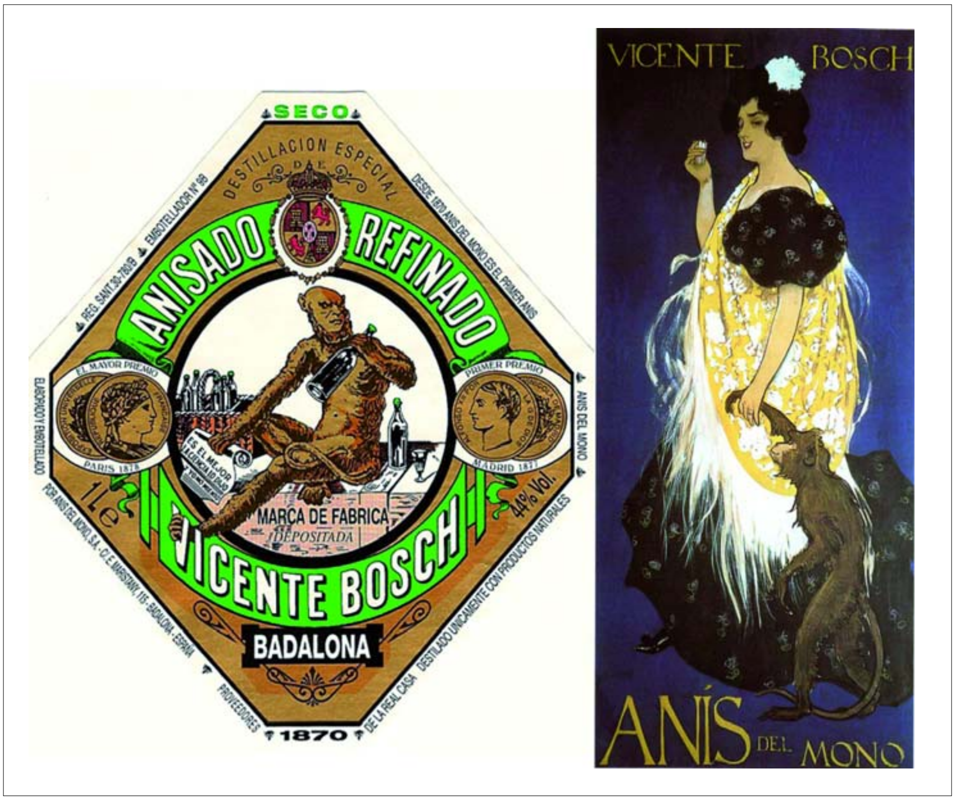
From the current perspective, it seems almost extraordinary how much Darwin (and Wallace in some respects) got right. In their works, there was the theory of natural selection itself; there was the notion that, however diversified species might become over thousands or millions of years, they came from a single stock or tree; there was recognition of selective extinction of species in different circumstances, thereby showing living organisms as a patchwork of possible forms; there was the need for deep time in which evolution could take place (although how much deep time remained a matter of controversy); there was the dispersal of species related to their geographical circumstances (later well illustrated by plate tectonics); there was the role of sexual selection to cause differentiation between the sexes; there was recognition of the co-evolution of species and what Darwin called "the economy of nature" or the biological processes we now describe as ecology; and last there was the gradual evolution of living organisms similar to the gradual character of geological change over time. In this scenario, the role of an interventionist and capricious God in creating species from time to time, and of course maintaining them, was unnecessary. When the early geologists found such species as marine reptile fossils, the conventional wisdom then was that if only they looked hard enough they would find them alive somewhere else on Earth.

Darwin did not and could not possibly know many aspects of biology that research has revealed throughout the last 150 years. Nevertheless, what has been learnt since, in particular about the mechanisms of mutation and genetic inheritance arising from the work of Mendel and his successors, fits amazingly well with Darwin's original thesis. Thus the discovery of DNA and the identification of the human genome, and more recently the discovery of jumping genes, or transposons, between very different species. There has also been modification of Darwin's ideas about selection by bringing in cooperation between species, and what has been called symbiogenesis (or the evolutionary effects of mutual dependence between organisms). Then there are the vagaries of evolution. How organic structures that play a given role evolve and eventually play another one: for example how gills for fish eventually become bones for the human ear. All this enriches the theory of evolution rather than qualifies it. Darwin was truly an extraordinary pioneer, and every word he wrote has lasting value.

There was particular opposition to Darwin's conception of deep time. Although many people abandoned biblical chronology, the age of the Earth remained a matter of high controversy. By the time that Darwin died in 1882 and Huxley in 1895, the conventional view remained that the cooling of the Earth did not permit an age of more than 100 million years. Lord Kelvin (William Thomson, 1824–1907), one of the scientific sages of that epoch, maintained that it was closer to 24 million years. It was not until the discovery of radioactivity by Antoine Henri Becquerel in 1896, and its application to the age of the Earth by Ernest Rutherford in 1904, that the immensity of deep time could be accepted. Nowadays the age of the Earth is roughly estimated to be 4550 million years, as it was established by Clair Patterson in 1956 [1]. The timing of the beginning of life is still in controversy, it might have taken place around 900 million years later.

The enduring character of change

The character of change, as outlined by Lyell and his successors, was also matter of controversy, with those who believed in uniformitarianism and others in catastrophism. The truth lies between them. In the second half of the twentieth century,



Source: Int. Microbiol. (left); MNAC, Barcelona (right)

Fig. 2. Label of Catalan anisette *Anís del Mono* (literally, Monkey's Anisette) that reproduces a figure half ape half human holding a piece of paper that says: "It is the best. Science said it, and I am not lying." There has been much controversy about the meaning of the animal represented in the label. Vicente Bosch, owner of the distillery where the anisette was produced, might have wanted to homage Darwin and his theory of evolution. However, there is also the hypothesis of Bosch trying to ridicule Darwin and science, and the face of the ape would represent that of Darwin. The figure of the "monkey" became very popular, and the anisette was a sheer success in its time, and many decades after. The already famous painter Ramon Casas (1866–1932), a friend of Picasso and other painters in Barcelona in those times, won a contest to choose the best poster to advertise the anisette.

Stephen Jay Gould (1941–2002) introduced the idea of punctuated equilibrium in which gradual change could be punctuated by episodes in which evolution of species moved rapidly in response to a variety of ecological circumstances. In addition, there seemed to be contradiction between the second law of thermodynamics and entropy on one side, and the increasing complexity and elaboration of species on the other. Once it had been accepted that the second law of thermodynamics only operated within closed systems and that entropy carried the implication of dispersal rather than disappearance of energy, this objection lost its force.

The enduring character of change is an essential element in Darwin's theory of evolution (Fig. 3). This goes back to Heraclitus and the early Greek philosophers. Just as the environment changes, so do living organisms and the relationships between them. This brings me to a few words about Gaia theory, which in many ways supplements our understanding of evolution. As was well said in a Declaration at a Conference of the fourth International Global Research Programme at Amsterdam in July 2001: "The Earth system behaves as a single, self-regulating system, comprised of physical, chemical, biological and human components. The interactions and feedbacks between the component parts are complex and exhibit multi-scale temporal and spatial variability." As was also said in the Declaration, "[t]he nature of changes now occurring simultaneously in the Earth system, their magnitudes and rates of change are unprecedented. The Earth is currently operating in a no-analogue state."

The robustness of Gaia over 3600 million years is both impressive and reassuring. She has survived the great extinctions from outside the Earth, and the great catastrophes from within it. This has required a remarkable resilience whereby physical and biological mechanisms have adapted to new circumstances. Regarding humans, we are no more than a small, be it immodest, part of Gaia. Only in the last tick of the clock of geological time did humans make their appearance, and only in the last fraction of it did they make any impact on the Earth system as a whole.

Only now do we know how vulnerable our little planet is to human depredations. A periodical visitor from outer space would find more change in the last 200 years than in the preceding 2000, and more change in the last 20 years than in the preceding 200. The association between humans and their environment, including the micro-world in and around them, has changed at every change of human evolution: from vegetarians to meat eaters, from hunter gatherers to farmers, and from country to city dwellers. But the most radical divide started at the beginning of the industrial revolution in Britain in the late eighteenth century. Until then the effects of human activity had been local, or at worse regional, rather than global, as they are now.

Impact of human activities on the evolution of life

All the civilizations of the past pushed evolution in different directions by clearing land for cultivation, introducing plants and animals from elsewhere, and causing a variety of changes. Modern industrial societies have caused disturbances of various categories, which are interlinked and will have an impact also in the future evolution of life on Earth. Let us see a few of them:

Population increase. Human population has risen from around 1000 million at the time of Malthus, at the end of the eighteenth century, to over 2000 million in 1930, and is now close to 7000 million. Currently it is increasing by over 80 million people every year. More than half of them live in cities, which are themselves like organisms drawing in resources and emitting wastes.

Lack of resources. More humans need more space and more resources. Soil degradation is widespread, and deserts are advancing. Such degradation is currently estimated to affect some 10% of the world's current agricultural area. Although more and more land, whatever its quality, is used for human purposes, increase in food supplies has not kept pace with increasing population. Application of biotechnology, itself with some dubious aspects, can never hope to meet likely shortfalls. In the meantime industrial contamination of various kinds has greatly increased. To run our complex societies, we need copious amounts of energy, at present overwhelmingly derived from dwindling resources of fossil fuels laid down hundreds of millions of years ago.

Increasing wastes and pollution. Overpopulation leads also to mounting problems of waste disposal, including the toxic products of industry. In addition, there has been increasing pollution of water, both fresh and salt. No resource is in greater demand than fresh water, whose demand doubles every 21 years, and seems to be accelerating. The chemistry of the atmosphere has also changed due to human activities. Acidification from industry has affected wide areas of both land and sea. Greenhouse gases are increasing at a rate which is already changing the average world temperature, with big resulting variations in climate and local weather as well as sea levels. Carbon levels in the atmosphere are now the highest in the last 650,000 years, and keep rising. We face not only climate change but also climate destabilization.

Loss of biodiversity. Humans are causing extinctions of other organisms at many times the normal rate. Indeed the rate of extinction is reminiscent of what happened when the dinosaurs came to an end some 65 million years ago. Yet we remain ignorant of our own ignorance. The rising damage to the natural services on which we, like all species, depend is immeasurable. There is no conceivable substitute for such services. At present there is a creeping impoverishment of the biosphere. Then what about the effects on humans themselves? How much is human nature or behaviour a product of evolutionary change or of the learned environment?

What kind of evolution?

In his book *The Meaning of the 21st Century*, James Martin has distinguished what he has described as primary, secondary and tertiary evolution. He suggests that: "[p]rimary evolution is the mutation and natural selection of species—a glacially slow process […] Secondary evolution refers to an intelligent species learning how to create its own form of evolution. It invents an artificial world of machines, chemical plants, software, computer networks, transport, manufacturing processes and so on. It learns how to manipulate DNA […] Tertiary evolution refers to something which is just beginning on Earth. An intelligent species learns to automate evolution itself."

The idea of automated evolution represents a vast acceleration of change. James Martin writes that with the machines we envisage today, it could be a billion times faster: "Furthermore it will be incomparably more efficient. Darwinian evolution is described as being random, purposeless, dumb and Godless. Automated evolution is targeted, purposeful, intelligent, and has humans directing it and changing its fitness functions on the basis of results. In

Fig. 3. Darwin's finches. Contribution of naturalist illustrator Carles Puche to the Darwin Year 2009.

Darwinian evolution, the algorithm stays the same. In automated evolution, researchers will be constantly looking for better techniques and better theory. The techniques of evolvability will themselves evolve."

In his fantasy *The Time Machine* in 1895, H.G. Wells (1866–1946) foresaw a genetic division of humanity into Eloi (or the master class) and Morlocks (or the servant class) in perpetual struggle against each other. At present we do not have to go so far. On the one hand, humans may thereby be liberated from many current drudgeries. Soon houses may be able to clean themselves, robots may produce meals on demand, cars may drive under remote instruction, and evolution of desirable characteristics could even be automated. All this seems unimaginable when so many still have to trudge miles to collect fuelwood and water. On the other hand, humans could well become dangerously vulnerable to technological breakdown, and thereby lose an essential measure of self-sufficiency. Already dependence on computers to run our complex systems, and reliance on electronic information transfer, are having alarming effects.

The future is around the corner

For the longer term I hesitate to speculate. Are we a degenerate species because we have contrived that so many of us survive, thereby frustrating the processes of natural selection? Or can we safely proceed with secondary and even tertiary evolution?

Peter Ward once wrote: "The future stretches before us not as one long dark tunnel but as a series of vignettes of variable clarity, like a long avenue punctuated by street lights of differing luminosity." Cities will rise and fall. Tectonic plate movement will shift the relationship between land and sea. Changes in oxygen levels in the atmosphere may affect the viability of current forms of life. In any case plant and animal species will continue to change in shape and function. Humans may be no exception. Given the evolutionary significance of our brains and the current hazards of childbirth, we might imagine a sort of human marsupial in which women gave birth earlier in the reproductive process, and developed a kind of pouch.

Supposing our species fell victim to some natural disaster, as other species have so often done in the past, I wonder how long it would take for the Earth to recover from the human impact. How soon would our cities fall apart, the soils regenerate, the animals and plants we have favoured find a more normal place in the natural environment, the waters and seas become clearer, the chemistry of the air return to what it was before we polluted it? Driven by evolution, life itself, from the bottom of the seas to the top of the atmosphere, is so robust that the human experience could become no more than a short and certainly peculiar episode in the history of life on Earth. As the 17th century philosopher Thomas Hobbes said, as he approached death, "I am about to take my last voyage, a great leap in the dark." That is true of all living species, not least ourselves, now and for ever.

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