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FROM THE EDITOR

Modern biology owes unpayable debt to Darwin



For any endeavor, identifying the greatest practitioner of all time is almost always contentious. Ask sports fans to select the best baseball player, and you'll get a lot of votes for Babe Ruth, but also some for Ty Cobb, Willie Mays and Ted Williams (surely none for Barry Bonds, though). Football aficionados might

name Jim Brown, Sammy Baugh, Red Grange or Jerry Rice.

Within the sciences, you'll get similar disagreements. Physicists would argue over Isaac Newton and Albert Einstein, with perhaps a few votes for Niels Bohr. Mathematicians would divide their votes among Newton, Archimedes and Carl Gauss.

But then there's biology. The greatest biologist of all time? There's only one answer. Any other vote invalidates the voter as unqualified. It's Darwin.

On the occasion of his 200th birthday (on February 12), the world is celebrating the life and work of the man who made modern biology possible. As geneticist Theodosius Dobzhansky once so aptly proclaimed, "Nothing makes sense in biology except in the light of evolution." No scientist's birthday warrants more hullabaloo and hoopla.

No doubt Darwin himself would be a bit uncomfortable with all the fuss. He would have insisted that the facts he chronicled, and the ideas he articulated to explain them, deserved all the attention — not Darwin himself.

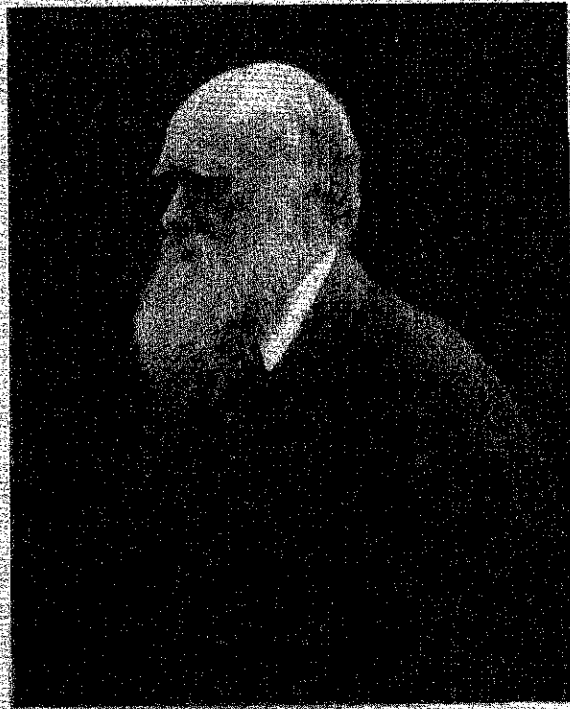
And so in this special issue marking Darwin's birthday, our focus is on the science going on today that descended from Darwin's original work. My account of his life (Page 18) serves merely to introduce our staff's reports on the multifaceted aspects of evolutionary science occupying researchers now, as Rachel Ehrenberg puts it, "in labs, on beaches and in bogs."

Her report (Page 21) assesses some of the refinements in Darwin's work that scientists are still actively formulating, on issues ranging from the rate at which evolution proceeds to the definition of *species*. Tina Hesman Saey then explores (Page 26) the evolutionary frontier on the molecular level, describing experiments tracking evolution in bacteria to shed light on its mechanisms and surprises. Sid Perkins (Page 30) recounts some recent tales told by the fossil record, showing how gaps in that record are far from holes in Darwin's theory, but rather are places to look for intriguing new evidence.

All that leaves much unsaid about the vast diversity and depth of evolutionary biology research today. So longer versions of these features, and additional features on other evolutionary arenas, are available now on the *Science News* website, www.sciencenews.org. All of these reports send the message that Darwin's life is worth celebrating — because the science he started has survived and thrives.

—Tom Siegfried, Editor in Chief

DARWIN *turns* 200



Two centuries ago, modern biology's founding father was born in England. He became the most celebrated scientist of his time, deciphering the records of life's history from creatures extinct and living and thereby explaining the genesis of life's diversity. Today his view of evolution by natural selection forms the core of the scientific study of life, and his mode of thought has earned its own addition to the lexicon of both scientific and popular discourse. Darwinian logic pervades the sciences of life, from the spread of viruses to interactions between and within human cultures, and has infiltrated other arenas as diverse as quantum physics and computer science. Far from a relic in textbooks, Darwinism breathes vitality into biology on a broad spectrum of research frontiers, inviting reflections on the life of, and the science made possible by, Charles Darwin.

In this special section

An opening essay on **Darwin** (Page 18) examines his life and science, followed by **Evolution's Evolution** (Page 21), an account of how Darwin's ideas have changed since the publication of *On the Origin of Species* in 1859; **Molecular Evolution** (Page 26) describes experiments on evolution in bacteria; and **Step-by-step Evolution** (Page 30) reports on recent discoveries helping to fill gaps in the fossil record.

Web edition www.sciencenews.org/darwin

Expanded versions of the articles featured here as well as two additional stories exploring evolutionary science today—**Computing Evolution** and **A Most Private Evolution**—are available on the *Science News* website in a special Darwin anniversary package. **FOR SUBSCRIBERS ONLY:** Downloadable PDF files of the complete Darwin Web edition

American mainland and the nearby Galápagos Islands.

By the time the voyage ended in October 1836, Darwin had amassed a mental catalog of life's diversities and subtleties never before held in one head. It gave him a lot to think about.

Sick at Down Darwin's dispatches to England during the *Beagle* trip made him a scientific celebrity by the time he returned, and he hobnobbed with London's elite. But soon ill health drove him southeast of London to a rural home (known as Down House) near the town of Downe.

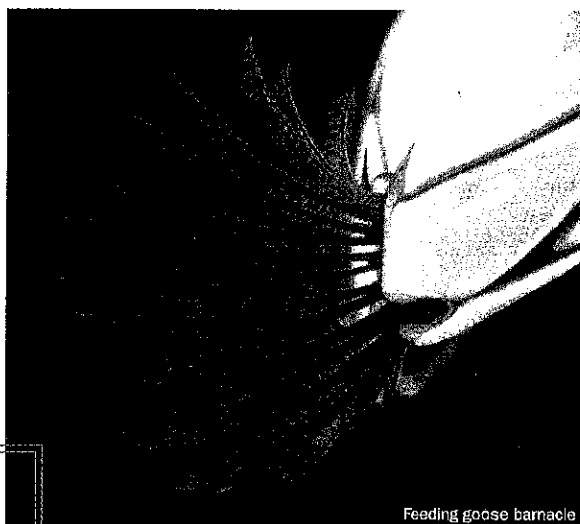
For the rest of his life, Darwin suffered, almost daily, from a mystery illness something akin to repetitive food poisoning. Doctors of his day couldn't help him; modern diagnosticians have speculated on a variety of disorders, ranging from lactose intolerance to Crohn's disease.

Whatever it was, Darwin's illness, a curse to him, perhaps established the circumstances subserving his scientific success. Forced to live in the country, he had no job and few distractions. He could devote his time to investigating nature in his own way. He spent eight years studying every aspect of every species of barnacle, for instance. All that time he also read with a vengeance, compiling and indexing detailed notes from book after book. He read science and philosophy and history and even trashy novels (there should be a law, he said, against unhappy endings). When Darwin opined, he knew what he was talking about, and he knew what everybody else knew, too.

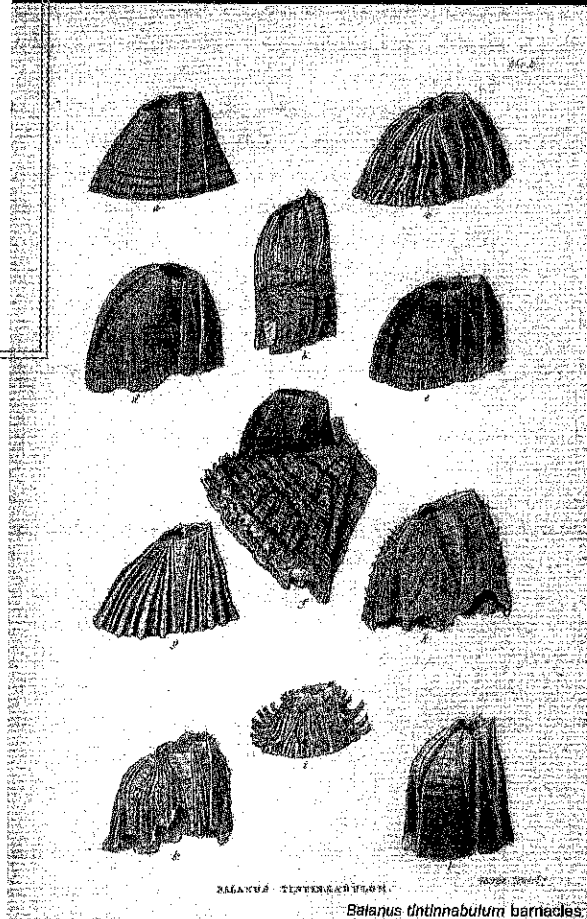
He knew so much that he could often see what others couldn't, and he could also reason about things without wondering whether his suspicions would be supported by observations—he knew what observations had already been made. If they were insufficient, he made his own, growing orchids, breeding pigeons, spying on earthworms.

Of all his reading, the most signal was the 1798 essay on population by Thomas Malthus, which Darwin perused "for amusement" in 1838. About 15 months earlier, Darwin had begun a systematic investigation of "the species question," an issue at biology's foundation. Conventional wisdom held that species had been created individually and were immu-

... the most earthshaking ideas in the history of biological science remained unpublished. Darwin was busy classifying barnacles.



Feeding goose barnacle



Balanus tintinnabulum barnacles

FROM TOP: DAVID SHALE; REPRODUCED WITH PERMISSION FROM JOHN VAN WYHE, ED., THE COMPLETE WORK OF CHARLES DARWIN ONLINE (DARWINONLINE.ORG.UK); TIMELINE: QINGMA/ISTOCKPHOTO; PUBLIPHOTO; PHOTO RESEARCHERS

1.2 bya
First multicellular organisms

Trilobites, common in Cambrian seas

542 to 488 million years ago (mya)
(Cambrian period)
Time of the Cambrian explosion, when diversity of life-forms balloons



488 to 444 mya
(Ordovician period)
Invertebrates—especially arthropods and mollusks—dominate the sea. First land plants appear.

359 to 299 mya
(Carboniferous period)
A time of forests, swamps, seed ferns, mosses, lycops and the origin of the amniote egg. Insects are abundant.



By Tom Siegfried

Charles Darwin was born into a world that today's scientists wouldn't recognize.

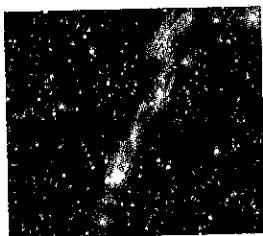
When baby Darwin arrived on February 12, 1809, modern science was also in its infancy. Dalton had just recently articulated the modern theory of the chemical atom, but nobody had any idea what atoms were really like. Physicists had not yet heard of the conservation of energy or any other laws of thermodynamics. Faraday hadn't yet shown how to make electricity from magnetism, and no one had a clue about light's electromagnetic identity. Geology was trapped in an antediluvian paradigm, psychology hadn't been invented yet and biology still seemed, in several key ways, to be infused with religion, resistant to the probes of experiment and reason.

Then came Darwin. By the time he died in 1882, thermodynamics possessed two unbreakable laws, chemistry had been codified in Mendeleev's periodic table, Maxwell had discovered the math merging electricity and magnetism to explain light. Lyell had established uniformitarianism as the basis for geology, Wundt had created the first experimental psychology laboratory, and science had something substantial to say about how life itself got to be the way it was — thanks to Darwin's perspicacious curiosity, intellectual rigor, personal perseverance and power of persuasion.

Superlatives are commonplace in accounts of Darwin's life. "An intellect which had no superior, and with a character which was even nobler than the intellect," wrote Thomas Henry Huxley, Darwin's champion in the original evolution debates. More recently Stephen Jay Gould called Darwin "the Muhammad Ali of biology." But all Ali did was fight. Darwin was more like Willie Mays — he could hit, hit with power, run, field and throw. Translated to science, Darwin could read, reason, experiment, theorize and write — all as well or better than any of his contemporaries. Several sci-

From the beginning...

Milestones in the history of life and evolutionary science



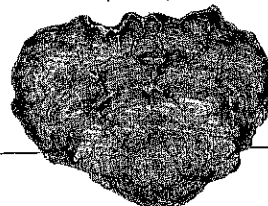
4.6 billion years ago (bya)
Origin of solar system and Earth

By 3.9 bya
Meteorite bombardment of Earth ends. Evidence suggests presence of life.

3.5 bya
Evidence for presence of cyanobacteria, which conduct photosynthesis

2.7 bya
Disputed evidence for presence of eukaryotes, first cells with DNA encased in a membrane-bound nucleus

Stromatolite formed by fossilized cyanobacteria communities



entists before Darwin had expressed the idea of evolution, some even hinting about the role of selection. But none had the wherewithal to perceive the abundance of evidence for evolution, deduce its many nuances, explain its mechanism, foresee and counter the many objections, and articulate it so convincingly to the world.

And even had Darwin never written a word about evolution, he would be remembered today as one of the 19th century's premier botanists, a superb entomologist and prominent geologist. He was a leading authority on carnivorous plants and coral reefs, pigeons and bees, earthworms and orchids, beetles and barnacles (especially barnacles). And yet he was never educated to be a scientist and held no academic position. All he brought to the scientific table was his brain. What a brain.

Woe unto the beetles In his youth, Darwin was an average student but an avid reader. He had an early interest in observing and collecting, mainly beetles and butterflies. ("Woe unto the beetles of South America, woe unto all tropical butterflies," a friend wrote in advance of Darwin's famous sea voyage.) When it came time for higher education, Darwin headed to Edinburgh, a few hundred kilometers north of his birthplace in Shrewsbury, England, to study medicine. Soon discovering that he couldn't stand the sight of blood, Darwin headed back south to Cambridge, to prepare for the clergy, a profession in which blood wouldn't be such a problem.

His heart was not in religion, though, and his Cambridge years exposed him to other intellectual pursuits — lectures on botany, for instance, fieldwork with geologist Adam Sedgwick and friendships cultivated with biologists like John Stevens Henslow. Darwin's interest in science was stirred while reading books by the German savant Alexander von Humboldt and the English astronomer John Herschel, which imbued in him "a burning zeal to add even the most humble contribution to the noble structure of Natural Science," Darwin wrote later.

Henslow was perhaps the first to see in Darwin the makings of an uncommon scientist, and recommended him to serve as naturalist on the exploration voyage of the *Beagle*. During that ship's leisurely circumnavigation of the globe, Darwin spent five years observing the planet's diverse life, its sundry geological formations and rich fossil record of life long gone. Darwin's eye saw more than what met it. He remarked on the variations between fossils and living forms, on the similarities of animals separated by vast distances and on the subtle differences and relationships among organisms on the South

table. Some thinkers, though (including Darwin's grandfather, Erasmus), believed otherwise. While on the *Beagle*, Darwin began to suspect that immutability was not correct (though he was unimpressed by grandpa's book, judging it to have an excessively high ratio of speculation to fact). But the idea of natural selection had not yet entered the grandson's mind.

Malthus helped. Population, unchecked, would grow uncontrollably and run out of resources, he wrote. Scarcity kept populations in check; not all who were born could survive to reproduce. Darwin recognized in this account the "struggle for existence" he had observed in all manner of plants and animals. "It at once struck me that under these circumstances favorable variations would tend to be preserved and unfavorable ones to be destroyed," he wrote in his autobiography. "The result of this would be the formation of new species. Here, then, I had at least got a theory by which to work."

By 1842 he had prepared a rough 35-page outline (in pencil) of his evolutionary ideas, expanded by 1844 to a 230-page manuscript. In a letter to his wife, he allowed that his theory would be "a considerable step in science," if it ever were to be accepted "even by one competent judge." He asked in that letter that she be sure to publish the manuscript if he died before getting around to it himself. He did show it to a couple of colleagues, but otherwise the most earthshaking ideas in the history of biological science remained unpublicized. Darwin was busy classifying barnacles.

By 1854 he had begun spending most of his time on the species question, and in 1856 the geologist Lyell warned him to publish soon, before another naturalist anticipated him. Sure enough, two years later Alfred Russel Wallace, working in Indonesia, arrived at nearly the same notion — that species developed over time as small variations accumulated, with favorable ones enhancing survival. For counsel and comment, Wallace sent his paper to — Darwin.

Dismayed, Darwin sought advice from Lyell. Wallace's idea deserved to be published. Could Darwin now dare publish himself, without appearing to be stealing Wallace's discovery?

Lyell and Henslow brokered a compromise. Wallace's paper would be read to the Linnean Society, and so would an extract of Darwin's 1844 manuscript, at one session, with Lyell and Henslow vouching that they had indeed seen Darwin's work years earlier. Wallace was acknowledged, but Darwin's claim to priority was preserved. That hardly mattered, though. It was Darwin's artful reasoning and marshaling of the evidence that established evolution by natural selection, as presented

in his masterwork, *On the Origin of Species*. Published in 1859, it electrified the scientific and intellectual world, evoking the prejudicial condemnation that afflicts most great new insights, but also filling the open-minded with food for centuries' worth of future biological thought.

A simple solution For so momentous a problem, Darwin's solution seems elegantly simple, although also so subtle that its exposition is often badly mangled. Offspring differ slightly from their parents and each other (descent with modification), making some "fitter" than others in the struggle for existence (survival of the fittest). Over periods of time unimaginably long, the small changes from generation to generation accumulate, mutating one species into others. On smaller scales, over shorter times, such accumulated changes can be seen in various breeds of dogs or pigeons or plants, often induced by the artificial selection of particular traits by human breeders. On evolutionary scales of millions of years, the selection driving the appearance of new species is natural.

Some scientists (such as Huxley) saw the truth in Darwin's views immediately; others came to agree gradually. Many, of course, disagreed bitterly. But most of the "rebuttals" of evolution, even today, merely raise points that Darwin anticipated and countered. Gaps in the fossil record? To be expected, Darwin explained, because the geological record was so imperfect, as if only a few pages remained from only the most recent volume in the entire encyclopedia of the Earth's history.

Today Darwin's original idea has been borrowed by investigators in diverse disciplines, from psychology to computer science. Even in physics, the word "Darwinian" appears in papers on thermodynamics, quantum physics and black holes. Within biology, Darwin's ideas have themselves evolved. Speciation isn't always gradual, change isn't always the result of selection, organisms are not the only units of selection, evolutionists now believe. Darwin foresaw some of these views, and he would have embraced them all — as a man of science willing "to give up any hypothesis, however much beloved ... as soon as facts are shown to be opposed to it," in his words. "If I know myself, I work from a sort of instinct to try to make out truth."

And in the battle to wrest truth from nature, none fought better than Darwin. "He found a great truth," Huxley wrote in Darwin's obituary, "trodden under foot, reviled by bigots, and ridiculed by all the world; he lived long enough to see it, chiefly by his own efforts, irrefragably established in science, inseparably incorporated with the common thoughts of men." 🌀

251 mya

Earth's largest mass extinction event occurs at the end of the Permian period. Most marine and land vertebrate species are wiped out, along with many plants and insects.

251 to 65 mya (Mesozoic era)

This era includes the age of gymnosperms (plants with seeds) and the age of reptiles. Its subdivisions are the Triassic (extinction survivors, including dinosaur ances-

tors, recolonize); the Jurassic (dinosaurs); and the Cretaceous (end of the age of the dinosaurs). First flowering plants appear (130 million to 125 million years ago).

65 mya

Asteroid hits Earth. Mass extinctions of marine life and some terrestrial life, including dinosaurs (ancestors of modern birds). The age of mammals begins.

