THE EVOLUTION REVOLUTION

Did you know, we share a common ancestor? Four billion years ago — Earth is 4.6 billion years old — a microbe termed 'Luca' or the 'Last Universal Common Ancestor' lived deep underground in hydrothermal vents, turning hydrogen, CO_2 and nitrogen into organic compounds. This was the beginning of all life. Phylogenetics — the study of the tree of life — reveals that with Luca at its base, eukarya, bacteria and archaea formed. Eukarya have cells holding a nucleus, a genetic code and mitochondria enabling metabolism — two billion years ago, eukaryotes created all animals, plants, protozoa and fungi.

Life diversified — humans diverged from apes seven million years ago. The first humans to walk upright emerged 3.2 million years ago. As we developed, using fire to cook, clearing land to farm, decorating caves with art and parchment with words, a brilliant species emerged. But this species remains interlocked with every other being, our lives enabled by bacteria making oxygen, plants creating food, soil microorganisms powering plants and animals and birds transporting seeds. This awareness makes evolution such a revolution — we are not alone. We are one among Earth's gigantic and gifted family.

Today, this tribe faces danger. As humans evolved, we assumed a superiority and grew blinkered by greed — 1750 onwards, the Anthropocene saw industrialisation destroying forests, oceans and ozone. Humans now impact 83% of Earth's land and 66% of its seas while our atmosphere holds the highest ever CO_2 concentrations from fossil fuels. As habitats decline, one million animal and plant species face extinction. Land-based species have declined by 20% while 40% amphibians, 33% corals and 30% marine mammals could be permanently lost.

Wrapped in rhetoric, tinsel and tin, humans may think ourselves invincible — but without these species, there will be no fresh air, clean water, ripe crops or humanity. Solutions are still possible — as Times Evoke's global experts emphasise, recognising the interdependence of all life is key. Multiple adaptations, from reforesting to rewilding and renewable energy, can revive endangered beings. But these involve another revolution in evolution, where humans must adapt to survive. Join Times Evoke in this extraordinary journey, tracking where we came from — and where we must travel.

Photos: iStock

'Insects outnumber all species on Earth — some beetle groups are as old as dinosaurs'

***Brian D. Farrell** teaches evolutionary biology at Harvard University. Speaking to **Srijana Mitra Das** at **Times Evoke**, he discusses how insects evolved over 300 million years and why these are 'Earth's primary engineers':*

What is the core of your research?

■ I study the role of ecological interactions in producing diversity in species — I research if the differences in how species manage in the world produces their diversity or whether it is the reverse. I thus study the intersections between ecology and long-term evolution.

Why is insect biodiversity important?

■ Insects pollinate plants — they are responsible for the food of the world. Insects also recycle perished material. I term insects the principle denizens of Earth because of their key functions and how they are the essential intermediaries between plants and all the vertebrates that depend on these. You could take away all the birds and mammals but Earth would still have productive crops as long as there are insects — they are the primary engineers of our planet.

Insects also outnumber all other species on Earth — of the million and a half known organisms on the planet, over a million are insects. They weigh as much as all the other species put together — they are the majority of Earth's biomass.

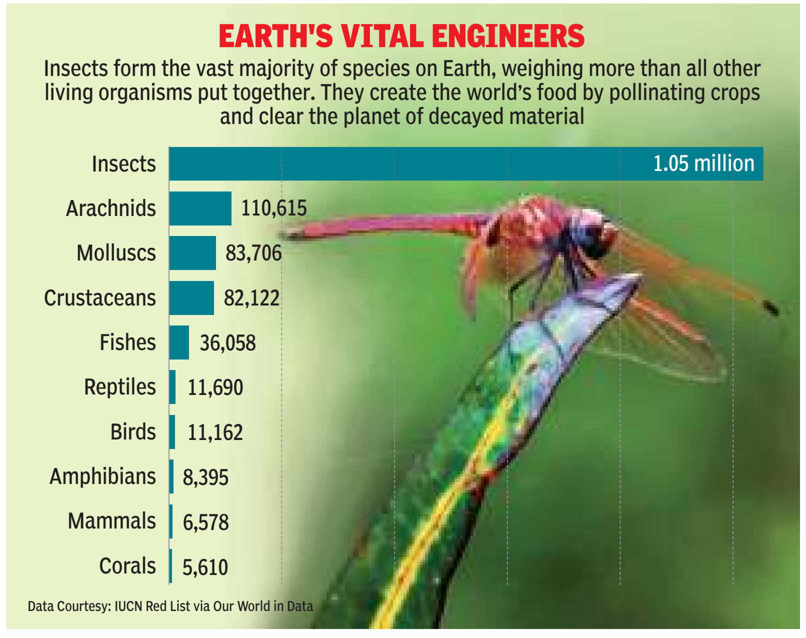
What are some of your findings on beetles and their evolution?

■ Beetles are the largest group of all insects — about one of every four animals is a beetle as are around 30% of all insects. These include parasites, pollinators, plant-consumers, insect-eaters, etc. I study the age of interactions or how long species are associated with each other and how that history is reflected in the interactions we see today — if you were to walk into a forest or a field, could you understand who eats what, which insects proliferate which plants, etc., by studying their current ecology, like how large they are? The answer is no — to understand these ecosystems, you need to understand how old these beings are.

Photo Courtesy: B. Farrell

CAPTURED IN AMBER: The palm beetle Delocrania sp, preserved in amber here, is about 15 million years old — found in the Dominican Republic, while the Delocrania went extinct there, it looks identical to certain beetle species found in Central and South America today

iStock



SLOW & STEADY

In my research, I discovered related insects feed on related kinds of plants. I call such insects, which are much smaller than the things they eat, 'tiny consumers', from beetles to caterpillars, worms to viruses. It turns out they all evolved in similar ways — and they are very slow to change what they eat. One kind of beetle I've worked on feeds only on milkweed. You won't find a mango beetle suddenly consuming pine trees or potato beetles abruptly eating grasses. Certain insects tend to be very conservative in their evolution of new associations.

Now, about twenty years ago, I was working on a group of beetles which feed on pine trees or cycads, which, at 300 million years in age, are among the oldest plants on Earth. I sequenced their DNA and compared their evolutionary history to the plants they eat. I found the beetles that feed on the oldest plants which were around when the dinosaurs were here — pine trees, conifers, cycads — are as old as the plants themselves. They've been feeding on them for two to three hundred million years. So, these insects are like little dinosaurs themselves. This research came out around the same time as Steven Spielberg's 'Jurassic Park' movies and the New York Times presented a two-page spread on this, highlighting how ancient these ecological associations actually are.

I also found how the beetles which made the rare change, from feeding on ancient plants to younger ones, became much more diverse — they produced the majority of species on Earth. So, ecological associations can be very old and conservative but shifts can dramatically alter ecology. Long-term evolutionary history has a profound relationship with ecological interactions we see today.

Working in South American forests, what are some interesting insects you've seen?

■ I've seen fireflies which light up an entire forest at night. There are iridescent Morpho butterflies with blue reflective wings that are bright enough to be seen from space. I've seen five-inch-long plant-eating beetles which consume giant rainforest trees and cicadas which build chimneys of clay upto a foot tall to get them air underground when the floods come.

Have insects evolved special ways of communication as well?

■ In nature, the only thing more important than getting enough to eat is finding a mate — for this, animals compete through singing. Interestingly, when a cicada starts singing, all the other species stop because they simply cannot compete with this loud little being. When singing, the tiny cicada dominates the forest — and, through the march of time, every other species has learnt to wait for its turn.

Are human actions now impacting this extraordinary and ancient world?

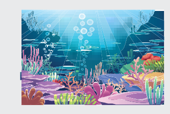
■ There is sizable research on 'insect armageddon' or the disappearance of insects from Earth. Data shows a fraction of insects are around now compared to the numbers forty years ago. This is deeply worrying — if insects were to disappear, we wouldn't know what to do or how to bring them back. Some research highlights neonicotinoide insecticides as causing such damage while others point to light pollution. Insects which have evolved over millions of years are now the first indicator of how much our environment is suffering from human impacts.

Photo Courtesy: B. Farrell

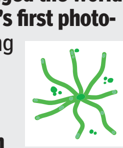
A WISE LITTLE MONARCH: The caterpillar of the Monarch butterfly (Danaus plexippus), found in the USA, has a closely related Indian species, the Common Tiger butterfly — both feed on milkweeds with poisonous latex in their leaves, but the larvae is able to cut the leaf's central vein to drain out the latex, then eating the leaf tips, as shown here

THE TIMES OF EARTH

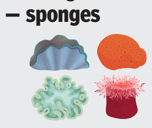
- The earliest life forms were **microbes** that left carbon molecules in rocks **3.7 billion years ago** — these were also preserved in **'stromatolites'** or hard structures 3.5 billion years ago — hence, scientists now study **Earth's rare living stromatolite reefs**



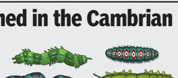
- About **2.4 billion years ago, cyanobacteria changed the world** — these were **Earth's first photosynthesisers**, making food using sunlight and water and releasing oxygen in the **'Great Oxidation Event'**, recorded in seafloor rocks which lost their bands of iron after oxidisation



- **The first animals emerged 800 million years ago — sponges** which consumed particles from water became Earth's first reef builders. About 580 million years ago, the **Ediacaran Period** also saw **seafloor creatures with ribbon and frond-like bodies**



- **Life blossomed in the Cambrian Period 540 million years** — animals developed **hard shells, spines** and **burrowing habits**, thus letting worms and molluscs move to land

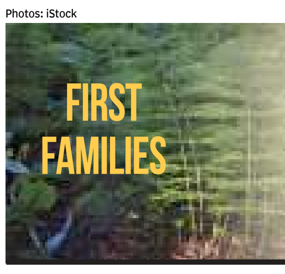


- In **the Triassic Period, 230 million years ago, dinosaurs roamed the world,** which was **a single supercontinent called Pangea** — as this slowly split apart, temperature changes caused horsetails, ferns and massive conifer forests to bloom

- **Mammals now emerged,** the **first humans seen two million years ago**

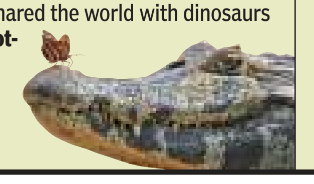
Research: National Geographic, Scientific American, LiveScience, Nature, Smithsonian Magazine, CNN

FIRST FAMILIES



- **Horsetails** are archaic plants resembling weeds, often found growing near streams — their everyday appearance veils an amazing antiquity since **horsetails existed over 350 million years ago.** Often as large as trees during **Earth's Devonian Period,** horsetails reproduce via spores over seeds, which makes them extremely hardy — **much of the world's coal,** which comes from **360-million-year-old Carboniferous deposits,** are **the remnants of horsetails** which, scientists estimate, grew over 100 feet tall

- **Crocodylians** — alligators, gharials and crocodiles — **have existed for 85 million years.** They come from the **crocodylomorpha,** which **originated over 205 million years ago in the Triassic age.** They shared the world with dinosaurs and diversified into many forms, from **the 40-foot-long Sarcosuchus** to the lissom Sebecus. While the species is famously fierce, ecologists find crocodylians also evolved **symbiotic ties with** birds and insects sharing their ecosystems



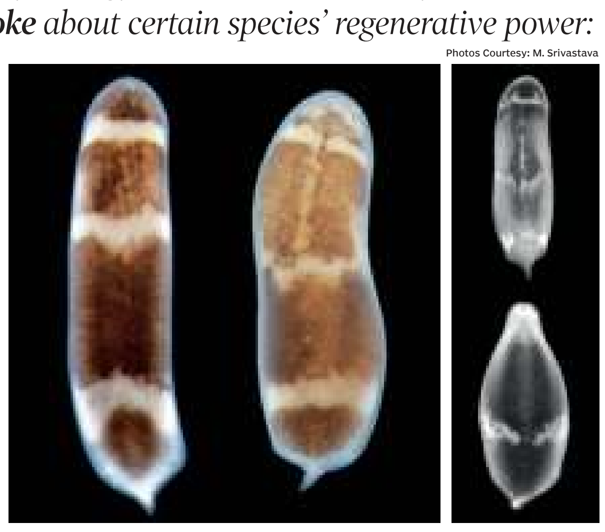
- The **ostrich,** which grows **upto nine feet tall,** is a **ratite** or a **flightless bird,** like the kiwi and emu. Blessed with **multiple stomachs** to help digest food — the toothless ostrich **swallows stones to grind food in its stomachs,** some birds having two pounds of stones within them — **ostrich fossils date back 25 million years.** While this is still the blink of an eye in evolutionary time, the ostrich remains a far older denizen of Earth than humanity

Research: Smithsonian Magazine, National Geographic, Encyclopaedia Britannica

'Evolution gave some acoels the ability to fully regenerate'

***Mansi Srivastava** teaches organismic and evolutionary biology at Harvard University. She tells **Times Evoke** about certain species' regenerative power:*

Photos Courtesy: M. Srivastava



I WILL SURVIVE: The three-banded panther worm (L) is distinctive for its striking look — but it also regroups successfully, with the worm in two sections here (R) regenerating into new worms

Regeneration drives my lab's research. Some animals can get cut into multiple pieces but each piece can then grow into a fully functioning new animal. These animals can make entirely new brains and muscles. However, other animals, like humans, do not regenerate well. So, our research seeks to understand exactly how this ability evolved over time.

It turns out many distantly related animals can regrow very well in a phenomenon we term 'full body regeneration'. We study its evolution, focusing on understanding the molecular and cellular processes that enable this. Our approach is to study how regeneration works in different species and compare these processes.

In my lab, we research worms called acoels, particularly the three-banded panther worm called the Hofstenia miamia. These are marine invertebrates which can regenerate. During my postdoctoral research, people were studying planarian worms which are freshwater animals. Some labs had started to focus on which genes and cells enabled regeneration in planarians. But to study evolution, we need to make comparisons — so, I chose acoels, which are also worms but very distantly related to planarians, last sharing a common ancestor about 550 million years ago.

Importantly, this was the same ancestor humans also emerged from — so, this research helps us understand whether humans could also regenerate well once and whether we somehow lost that capacity along the way. By comparing a planarian and an acoel, we've found there are some shared mechanisms of regeneration — those genes are also present in humans but in us, they can't facilitate regrowth. This

THE WORM TURNS

is an intriguing question. Nature has given certain beings amazing abilities — a planarian worm can be separated into 200 pieces. Each piece will then make all of its tissues, brains and eyes and start functioning like a perfect animal. Some animals have a version called reaggregation where a sponge or hydra can be taken apart, every cell standing on its own in water — over time, these come together and, from a disorganised mass of cells, reconfigure an entire body part. That is a truly incredible process.

There are many species of planarians and acoels on our planet — some can regenerate while others can't. Clearly, this is a very labile or changeable process which we're studying over millions of years. At the moment, this serves basic science. Once we develop a complete understand of how an animal can regenerate, we can envision how this can be applied to human biology.

As evolutionary biologists, we do not believe that humans are more evolved than anybody else. All life on Earth came from a single common ancestral population. My pet dog, a trichoplax and I all came from the same ancestor — and we're all equally evolved.

From modern genomes, we can reconstruct the genomes of ancient animals and from that endeavour, we can count how much sequence change occurred over time. It turns out that like trichoplax, humans are some of the slowest evolving lineages. So, even though we look very different from placozoans, these flat, pancake-shaped animals with only four to six sub-types, our genomes haven't changed as much as that of, say, a fruit fly. We need to move away from this idea of species being more or less evolved. Change occurs and differences emerge but there is no reason to think humans are more developed than other beings — including those who can regenerate.

'Gingkos appeared 200 million years ago — this tree has a grand place in history'

***Sir Peter Crane** researches environmental studies at Yale University and is President of the Oak Spring Garden Foundation. Speaking to **Times Evoke**, he discusses the living gingko tree, which dates back to the dinosaurs:*

The core of my research is to understand the evolution of plant life on Earth over the last 450 million years. This encompasses the origin of plants on land and their diversity in terms of trees, flowering organisms, etc. I also particularly study the gingko tree — this is a remnant of a group of plants which was much more diverse and occurred all over the globe in the past. Today, gingko is represented by just one living species, gingko biloba, native only to a few areas in China. This extraordinary tree provides us with clues about ancient plants which we know only from fossils now.

Gingko is one of five living groups of sea plants. Other plants are much more diverse — cycads and conifers have several hundred species while flowering plants have 4,00,000 living varieties. But gingko has just the one species. It is a bit like the platypus of the plant world — the platypus is a mammal but it lays eggs. The gingko is a forest tree but it retains some reproductive features of ferns, mosses and simpler plants.

A LEAF FROM TIME'S BOOK: An ancient ginkgo leaf found in fossil remains from the Late Paleocene in Almont, North Dakota, USA — this dates to about 58 million years before now

Photos Courtesy: The Oak Spring Garden Foundation (osgf.org) via P. Crane

A HOST OF GOLDEN GINKGO LEAVES: A resplendant ginkgo tree, which once proliferated worldwide, in Tokyo now

We first see gingko-like plants appearing in the fossil record about 200 million years before now. In the distant past, during the Mesozoic era, India was part of a supercontinent which included Australia, Antarctica, Southern Africa and South America. This was when dinosaurs roamed the world and fossil records show gingko plants from India as well. As the continents split apart and climates changed, the diversity of gingko plants began to decline. Upto 20 million years ago, gingko was found in Europe and North America — it's just over the last two million years that it became so restricted in its distribution.

Fascinatingly, the gingko did survive many changes on Earth and today, it has been adopted by people to grow in Beijing, Chicago and London. It is a very effective street tree and is very distinctive horticulturally with its beautiful yellow leaves. Its seeds are eaten in Asia as a nut-like delicacy. So, this plant has both an extraordinary evolutionary and cultural history.

Quite unusually, the gingko has male and female trees — it reproduces by shedding pollen into the air, which reaches a female tree, pollination producing seeds. But gingko also reproduces by sending downward-growing stems from branches which penetrate the ground and send up sucker shoots — this is similar to the banyan tree but the two are not related. A very old and often damaged gingko tree has many of these downward-facing stems, which give rise to more stems coming up from the tree's base. This 'vegetative reproduction' makes the gingko so resilient. Yet, there is the enduring mystery of why this tree almost went extinct over the last one to two million years.

A BRANCH OF HISTORY

Apart from tracing the past, gingko can also help us understand the future. Researchers study the density of breathing pores or stomata on the underside of its leaves — these are the pores through which the plant takes up CO_2 from the air. The theory is, when CO_2 concentrations are high, it needs fewer of these pores per unit area to take in the same CO_2 amount. In the deep past, when we had a much warmer world and high atmospheric CO_2 levels, we tend to see a decrease in the density of those pores. This makes gingko an interesting figure in discussions of future climate models too.

Importantly, the gingko helps us contextualise our place in the order of creation — contemplating this tree, which has been on the planet for over 100 million years, emphasises how we need humility when we think about our own place on Earth. We've heard recently of amazing images from Nasa's James Webb space telescope — rooted on Earth, the gingko tree makes a similar point. Our place in the grand sweep of the universe and its history is relatively small — we should bear that in mind when we think of how to manage our lives and this planet's ecosystems.

IN EARTH'S DIARY: Biologists have long been intrigued by the ancient Ginkgo biloba, an illustration here labeled as 'Salisburia adiantifolia' in Philipp Franz von Siebold and Joseph Gerhard Zuccarini's text 'Flora Japonica'

I've been fortunate to see wonderful gingko trees in China, Korea and Japan, some thousands of years old. But I have a special affinity for one tree in the Royal Botanical Gardens at Kew, London, where I was director. That tree was planted in 1760 — it's stood through so many changes in the world over its 250-year-plus life. For me, it embodies a very precious page of Earth's history.

READERS WRITE

Dear Times Evoke,

Mahesh Rangarajan's observations on the Indian tiger (13th August) were so insightful. Such articles are a revelation and TE gives readers this week after week, making us eagerly await Saturdays!

—K Nehru Patnaik, Visakhapatnam

Mahesh Rangarajan's discussion on the evolution of the Indian mindset regarding tiger conservation was very important. Mining and development projects do pose new challenges now. Yet, there is hope with people actively striving to bring more awareness about ecology, thereby strengthening sustainable development. Thanks, TE, for this beautiful article.

—Ramsha Ali, Kolkata

TOI's Times Evoke is a delight to read as it is always infused with new ideas. On Independence Day weekend, Mahesh Rangarajan took us on an enthralling tour of Indian tigers and their habitats which must be protected from human impacts. This needs new thought and policy and Times Evoke raises exactly such awareness.

—Dr Yogesh Sharad Salphale, Chandrapur

It was such a pleasure reading TE (30th July) on NASA's James Webb mission! This was beautifully explained by famed scientists and the page looked simply stunning!

—Pooja Vaid, New Delhi

Times Evoke truly took us to the beginning of time with its brilliant articles about the evolution of space, planets, stars, etc. The educational and social value of such articles is boundless. Congratulations for TE, TOI!

—TV Kalyankrishnan, Coimbatore

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