TIMES evoke

THE WORLD IS A GARDEN

Once upon a time, Earth consisted only of water — and greenery. About 500 million years ago, plant life began with pond froth and liverworts, flowerless, spore-producing plants — these proliferated into mosses, ferns, flowers, even trees that towered 20-feet tall. It was no coincidence that the growth of such plant life occurred alongside organisms — the Cambrian explosion unfolded when jellyfish, worms and molluscs prepared Earth's stage for more complex life. Scientists link this burst to plants — they caused a lowering of carbon dioxide (CO_2), a rise in oxygen, reduced temperatures, stable soil and a balanced water cycle.

Plants themselves proliferated, becoming 82.4% of Earth's total biomass — humans are 0.01%. The World Checklist of Vascular Plants, which includes flowering species, seed plants, ferns, clubmosses, etc., categorises 1,422,515 known kinds. Their antiquity is awe-inspiring — orchids are over 83 million years old (humans appeared six million years ago), present when dinosaurs roamed the world. The 24,000-plus species of grasses evolved 120 million years ago, spreading outwards from a common ancestor. As they travelled, plants evolved adaptations to survive and scientifically precise balances with drivers like temperature, rain, animals, fungi, even arching oceans and rising mountains shaping their lives. As they grew, plant abilities to support others also grew, making Earth a garden of life.

This faces severe threats today. The Kew Gardens Report on the State of the World's Plants and Fungi (2023) finds three out of four plant species under existential pressure — 45% of flowering plants, which includes food crops, face extinction. This now coincides with a larger planetary catastrophe, manifest in rising CO_2, warming temperatures, unbalanced precipitation and eroding soils. These conditions are both caused by plant loss — and further threaten their survival. The FAO finds forests provide habitats to 80% amphibian species, 75% bird species and 68% mammal groups — as we hack into plants, we lose much more. However, as Times Evoke's global experts emphasise, there are solutions. The foremost is learning about the foundational role plants play, which is the basis to preserving them. Viewing Earth as a garden might seem quizzical but it is an existential need now, considering the world's vegetation holds over 1,200 billion tonnes of carbon which unknowing activity could release. Join Times Evoke in understanding plants — and saving our garden of life.

'The fossil record shows how plants shaped Earth — they sculpted ecosystems from rivers to rain'

C. Kevin Boyce *is Professor of Earth and Planetary Sciences at Stanford University. Speaking to* ***Srijana Mitra Das*** *at* ***Times Evoke****, he discusses how plants have formed the world we know:*

What is the core of your research?

■ I'm interested in the evolution of life on land that occurred over the last 400 to 500 million years. The real foundation of that is known from the plant and fungal fossil records — these provide insights into the biology and physiology of organisms. You can use these to study how those also changed. That relates then to other disciplines like studying how the biota affects climate, the carbon cycle, plant productivity, etc., seen over time.

Can you share your findings on the evolution of leaf vein density and why this event is so important?

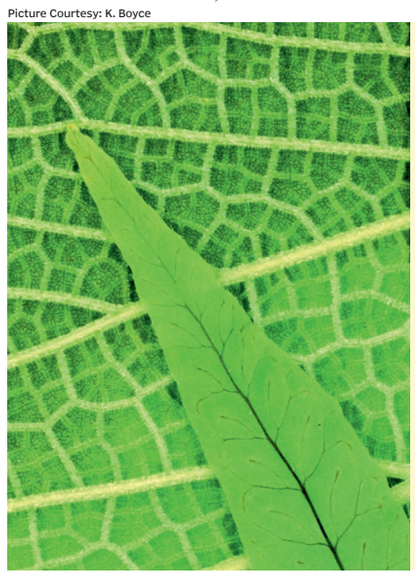
■ Leaf veins move water — this transfer is essential to what plants try to accomplish because in order to do photosynthesis, carbon dioxide (CO_2) is brought in past the pores in a leaf to then be fixed as a sugar. As that is being done, water is lost in the opposite direction though — so, the more water you can reuse, the more CO_2 you can take in and the more photosynthesis you can do. The density of veins (image, R) is very tightly correlated with how much water a leaf can afford to lose. As water moves through a plant, it does so through pipes assigned to this, so there is very low resistance. But as water moves through a leaf, it has to pass through leaf pipes and tissues which are not designed for such transport — anything that shortens that distance lowers the resistance overall. The more veins you have, the shorter that distance becomes. So, the plant can move more water — and do more photosynthesis.

How did this, as you describe it, 'put rain in the rainforests'?

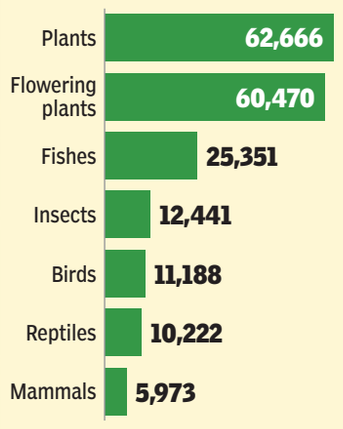
■ As we can see these veins in plant fossils, we can look at this whole process through time and track how it changed — through the last 400 million years, the density of veins was very stable. But this increased dramatically in the flowering plant lineage that evolved about 120 million years ago — so, in the modern world, which is dominated by flowering plants, much more water is lost by these. This is called transpiration or the process by which water is brought up from the ground and released into the atmosphere. Now, in a tropical rainforest, about half the rain which falls there actually comes from the rainforest itself. It is recycled by plants as it falls out of the sky — they put it right back up there.

Prior to the evolution of this specific lineage of flowering plants, you would not have had that kind of recycling which takes place in the modern world.

Picture Courtesy: K. Boyce



WHAT COULD EVAPORATE: A flowering plant (under), 45% species at risk, has 10 times the veins of a fern (top)



Data Courtesy: IUCN & Our World in Data

DEEP ROOTS

What is 'the long-term carbon cycle'?

■ We all learn a bit about the carbon cycle in school when we study soils, the oceans, tractors, factories, etc. — this is the short-term carbon cycle. There are many changes that go on very rapidly there. It's a really fast turnover — but it's not that much when you think, for instance, of how much carbon is stored in limestone rocks or coal and such large geological reservoirs. The carbon cycle we are changing as the human species is the short-term carbon cycle. But if you think about longer geological time, over millions of years, there are very different exchanges with how much CO_2 has come out of volcanoes, how much coal has been deposited, etc. These matter over the longer term — and plant fossils show us these changes as well.

Do flowering plant fossils also offer insights about climate change?

■ Yes. These are the primary ways to know about CO_2 and the atmosphere through time. I've mentioned how the density of pores found on leaves is tied to how much CO_2 there is in the atmosphere — if there is less CO_2, you have more pores on leaves to compensate. These are key ways we know about such dynamics. Such fossils also reflect broader mechanistic ways plants influenced climate — they illuminate how plants are both a record and shaper of climate change over time.

How did the evolution of Palaeozoic land plants create 'meandering rivers'?

■ The existence of complex large plants on land shapes how water moves across a surface — as larger plants evolved, they stabilised riverbanks and impacted how sediment flowed across a landscape. In the modern world, since land plants evolved over the last quarter-million years or so, there's been a tendency to retain sediment on land — if you go back to a world before such plants, sediments would have been washed out into the oceans. Rivers stabilised with plants as levees built up on their sides. During floods, those got breached — sediments thus went laterally into the plains on the sides of the rivers and were held on land. So, there was a big change in where sediments got stored, before and after such plants evolved.

What is the most fascinating plant fossil you've studied so far?

■ My personal favourite is the real oddball fossil, something you look at and there is nothing like it, so you have to go back to first principles and think, what could this organism be doing? How did it interact with its environment? Was it receiving more or less light? Was it capable of greater gas exchange? Could it be photosynthetic?

All my favourite fossils are from very early on in the record — there are extremely tiny earlier fossils, just millimetres high, which make you wonder how they could have functioned at all. There is also what is possibly a giant fungal fossil (image, lower L) called Prototaxites — this was around 20 feet in height while the highest contemporary trees over 400 million years ago were just a couple of feet tall. Even within the domain of plants which have modern descendants, there are giant tree fossils like copses that are millions of years old and look like Dr Seuss' trees — it makes you wonder how on Earth they could do photosynthesis, grow and hold themselves up? Yet, they did.

Why is palaeobotany needed to understand our current world?

■ Our world today is a very small little bubble within the range of things that have happened. Any such aspect of understanding our world is predicated on understanding what happened before. Modern climate change is a small fraction of the range of things that have happened in the past — we have been much warmer and much colder earlier. Understanding such fluxes and that range is important. Even at the level of studying the modern biota — and thereby, life — we need to see that these too changed over thousands of years. Any study of modern ecology must differentiate between what might be noise or perturbation in the system versus possible longer-term characteristics — we need that context of history to understand the world we live in now.

Picture Courtesy: Kevin Boyce

OF FOSSIL RECORDS: Prototaxites trunks are composed of small interwoven tubes

iStock

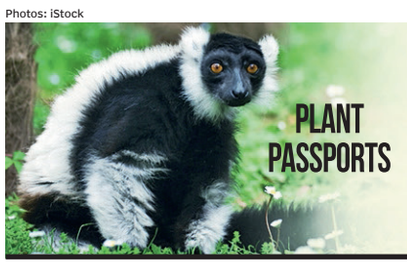
BANKED ON: Modern rivers evolved due to the plant life which stabilised riverbanks

FACTS ABOUT FLORA

- Scientists have divided the massive world of plants into two broad categories — the term **'growth form'** refers to their **overall appearance or habits while 'life form'** means their **buds** or **the vegetative ways through which plants survive in harsh or unfavourable conditions**
- **Trees** tower over all others on Earth — these **tall, perennially woody plants, with a trademark single, self-supporting trunk, compose 16% growth forms on the planet.** However, **shrubs**, perennially woody plants which are much smaller than trees, dominate — these are **28% of growth forms** on Earth
- Yet, the biggest surprise comes from **herbs, little plants sans woody stems, which compose 32%! Epiphytes** also hang around — these grow non-parasitically on other plants, **producing aerial roots**, composing 7% of growth forms
- Among life forms, **hemicryptophytes like grasses and dandelions reign at 24%** — these have **overwintering buds at or just below soil level** while **geophytes**, plants like ginger, legumes, etc., which survive tough conditions by developing **underground storage mechanisms**, compose **11%**
- Around **21% life forms consist of phanerophyte plants** or perennial beings like conifers, palms and cycads that **bear buds high above Earth's surface** — these plants literally arch ever higher to explore more of this wondrous world

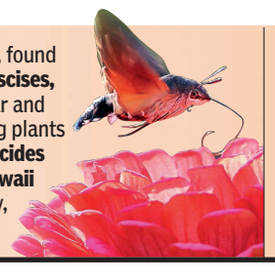
Research: IUCN, FAO, Kew Gardens Report on State of the World's Plants and Fungi 2023, Encyclopaedia Britannica

Photos: iStock



PLANT PASSPORTS

● Birds and bees help plants move — but the **black-and-white ruffed lemur is Earth's largest pollinator!** Lemurs **eat 130 fruit species**, reaching in with hands and tongues, pollen getting stuck on their fur too and moving. **Found only in Madagascar**, lemurs **pollinate 40-feet-high Traveler's trees**, climbing these nimbly — today, **95% lemur species face extinction**, their state also worrying many a tree



● Plants travel with **hummingbird hawk-moths**, found from **Portugal to Japan.** These have **long proboscises, straw-like tongues** with which they drink nectar and pick pollen — **they then fly over oceans**, helping plants move. They now face **climate change and pesticides** — once, the **Fabulous Green Sphinx Moth of Hawaii** was the **Vulcan palm's** natural pollinator. Today, it's gone, leaving this critically endangered

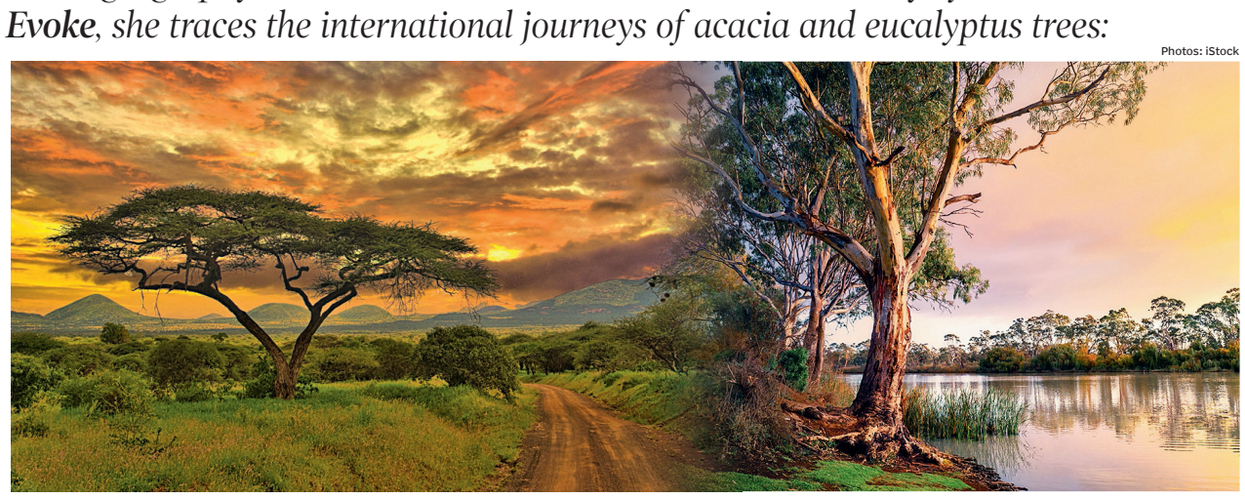
● **Tapirs**, hoofed mammals, live in tropical forests, grasslands and swamps in **Malaysia and the New World.** Upto 8 feet long, tapirs have **fleshy trunks to pluck fruit, depositing seeds in paths they tread.** Millions of years old, fossil records show the species was widespread — today, with **habitat loss and hunting**, tapirs, linked to horses and rhinos, face a highly reduced range, **also shrinking how their plant friends travel**

Research: Smithsonian Magazine, Lemur Centre Duke University, National Geographic, BBC, IUCN

'From timber to temperance, humans sought diverse solutions from plants — thus, acacias reached India'

Haripriya Rangan *teaches geography and environmental sciences at the University of Melbourne. Speaking to* ***Times Evoke****, she traces the international journeys of acacia and eucalyptus trees:*

Photos: iStock



DOWN UNDER TO WORLD OVER: Acacias (L) and eucalyptus (R) were once found only in Australia. Moved globally, these species also evolved

Plants have complex histories of moving through time. There are the natural modes of movement which include water, wind and seed dispersal via birds and animals. There are interesting nuances there too — some plants, for instance, put out seeds which are sticky, so animals and birds going past them find these stuck to themselves and thus, the seeds arrive and settle somewhere else.

But there is also the intricate involvement of human beings with how plants have travelled the Earth. One of the best-known journeys is the huge 'biological expansion of Europe'. This concept was envisioned by the historian Alfred Crosby who outlined how colonising Europeans didn't just conquer places by force — they also travelled as biological agents, carrying both diseases and other animals with them, like cattle, horses, etc. They used these to help them establish control in the New World. On the other hand, Europeans were also constantly looking for various valuable plants and other commodities which they could take back home. These encompassed spices to medicinal herbs and exotic flowering varieties. As they encountered indigenous communities and ecosystems, they began to identify economically valuable plants alongside unusual species which their kings and queens would like to own as symbols of status.

Thus, seafaring traders, merchants, missionaries, etc., helped these botanical beings move vast distances to Europe. They were planted in monasteries, royal gardens, etc., and studied closely. Later, when commercial uses were found for them, this entire process expanded — maize was brought across from the New World to Europe. Tomatoes, today an integral part of Italian cooking, were brought to Europe too as were chillies. As humans moved, so did plants but their travels frequently reflected growing colonial and commercial expansion.

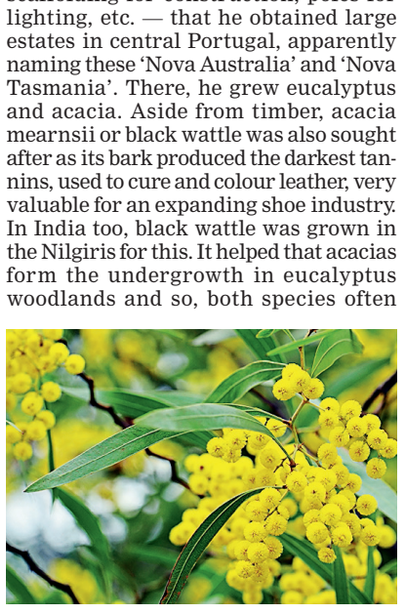
Interestingly, 'Neo-Australia' was created thus — just as plants from the New World were brought to the Old World or Europe, Asia, Africa, etc., transforming those landscapes, cuisines and cultures, there was a great deal of interest in moving economically valuable plants from Australia outwards. Eucalyptus and acacias were two major tree species which Europeans felt were very useful, particularly for economic purposes and land reclamation work — so, there was a very active effort during the 18th century to identify and transport these. From 1788 onwards, voyagers like Captain Cook travelled with botanical experts and other scientists on expeditions, maintaining herbariums on their ships where plants would be kept and managed. In the 18th and 19th centuries, as Australia was getting colonised, a special effort was made to take eucalyptus and acacia species to Europe to grow in dedicated botanical gardens. Then, European powers felt the need to plant these over larger areas. Eucalyptus was brought by the British to India in the early 1800s and planted particularly in the Nilgiris — Ooty was identified as a place Europeans could get land in and become settlers and coffee and tea planters. They realised they needed more wood to provide them fuel and so, they brought acacias across to India for this.

BRANCHING OUT

Other powers were also studying eucalyptus and acacias carefully. In the 1500s, Portugal was a huge seafaring nation which expanded its imperial reach swiftly. But by the 1600s, they had been beaten by the Dutch and then, the English. Their power shrank and they became economically backward during the Industrial era. In the 19th century, Portuguese foresters, looking at Britain's industrialisation, decided that to grow like that, they needed more timber — eucalyptus and acacias were fast-growing species providing this. So, they imported these seeds, often exchanged by European botanical experts mingling at special conferences. Ferdinand von Mueller, a German who established the Melbourne Botanic Gardens, was a huge promoter of Australian eucalyptus and acacias and would prescribe these widely — thus, these plants began to grow from California to the Mediterranean's dry climate.

The Portuguese also began to import and plant these. William Tait, the son of an English port wine merchant based in Porto, was a great plant enthusiast who had corresponded with naturalists like Charles Darwin. He was so committed to the idea of forestry being the driving force for industrialisation — if you had timber, you could have railways, factories, scaffolding for construction, poles for lighting, etc. — that he obtained large estates in central Portugal, apparently naming these 'Nova Australia' and 'Nova Tasmania'. There, he grew eucalyptus and acacia. Aside from timber, acacia mearnsii or black wattle was also sought after as its bark produced the darkest tannins, used to cure and colour leather, very valuable for an expanding shoe industry. In India too, black wattle was grown in the Nilgiris for this. It helped that acacias form the undergrowth in eucalyptus woodlands and so, both species often moved and settled together. Eventually, Portugal became the world's biggest supplier of eucalyptus wood for the pulp and paper industries, which emerged from these trees.

OFFERING RE-LEAF: Eucalyptus provides oils and other natural aids valued medicinally



SOME SUN IN WINTER: Acacia farnesiana produces golden flowers in chilly climes

People found other reasons also to transport these plants. In northern Africa, around French-occupied Algeria in particular, French settlers felt eucalyptus could suck out the water from what they called 'insalubrious' or disease-causing swamps, ending the miasma or conditions of sickness borne from damp thereby. In southern Africa, eucalyptus varieties were planted to stabilise soils facing erosion. Settlers and expansionists did numerous scientific studies to see which plant species would work well in new regions, aiming to improve land for economic value or extract gainful products like timber, tannin, medicinal oils, etc., from these. Plants often resonated with deeper human needs — in California, promoters of eucalyptus also formed groups like Temperance Societies which often used this to encourage people to stop drinking alcohol. 'Neo-Australias' thus spread with these now-iconic varieties.

The stories of plants, their stability and moving, reflects how curious humans are. We are interested in a wide variety of things and when we find plants that can reflect these interests, we carry them with us, giving them new meaning. Acacias came from central America to Europe and became the basis of a perfume industry in France — Grasse in southern France cultivated these on a plantation scale. The species has a beautifully fragrant flower — they found they could boil it down and get the essence out. They then discovered Australian acacias also grew well and were less laborious to harvest and so, they began planting these. The acacias yielded commercial gains — and a bit more. They produce stunning yellow flowers during autumn and winter — so, the French began 'mimosa festivals', celebrating 'winter sunshine', as they termed these blossoms. In India, acacia farnesiana-based perfume is also produced in Kannauj today.

Plants thus represent different things — from capturing power to terra firma, establishing taxes to using their medicinal aid, plants have been valued enough for humans to transport them from one end of the world to the other. Entire societies changed dramatically — often for the gains hidden in a delicate flower.

READERS WRITE

Dear Times Evoke,

Peter Gleick's interview (28th October) on the many lives of water succinctly encapsulated humanity's journey with using this essential resource. Gleick artfully intertwined history and science, offering a compelling narrative. His views served as a call to action, urging readers to foster a more sustainable future by understanding the significance of water. Thank you for a beautiful feature, TE!

— Gita Nair, Jaipur

TE's interview with Peter Gleick was very thought-provoking, with the good news that people really care about water. It is true that many have learnt to manage it much better. Nowadays, people consume limited amounts per day, helping to preserve more. For sustainability, we should encourage FBCCA or Family-Based Climate Change Action.

— Dr D. Lakshmanan, Fmr. Principal Scientist, CAIR CLRI, Chennai

Thank you for the excellent conversation with Peter Gleick. Water is an inextricable part of life and its role in human growth is prodigious. Our species' greed at the cost of all ecosystems is having a catastrophic impact on this. It can even cause epidemics. We must make timely amends.

— Rajarao Kumar, Bengaluru

Peter Gleick was extremely informative. We are destroying water resources, constructing over them, allowing huge extractions, polluting lakes, etc., causing floods and droughts. Thanks to TOI's TE which creates in-depth awareness about water's importance. Keep it up!

— Srinivasan V., Trichy

I'm pursuing an MSc in EVS. TE's articles are very interesting and helpful to me. It would be great if you could also add a little corner for students that guides us about careers in this field. Thanks, TE!

— Kaushik Samanta, Howrah

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