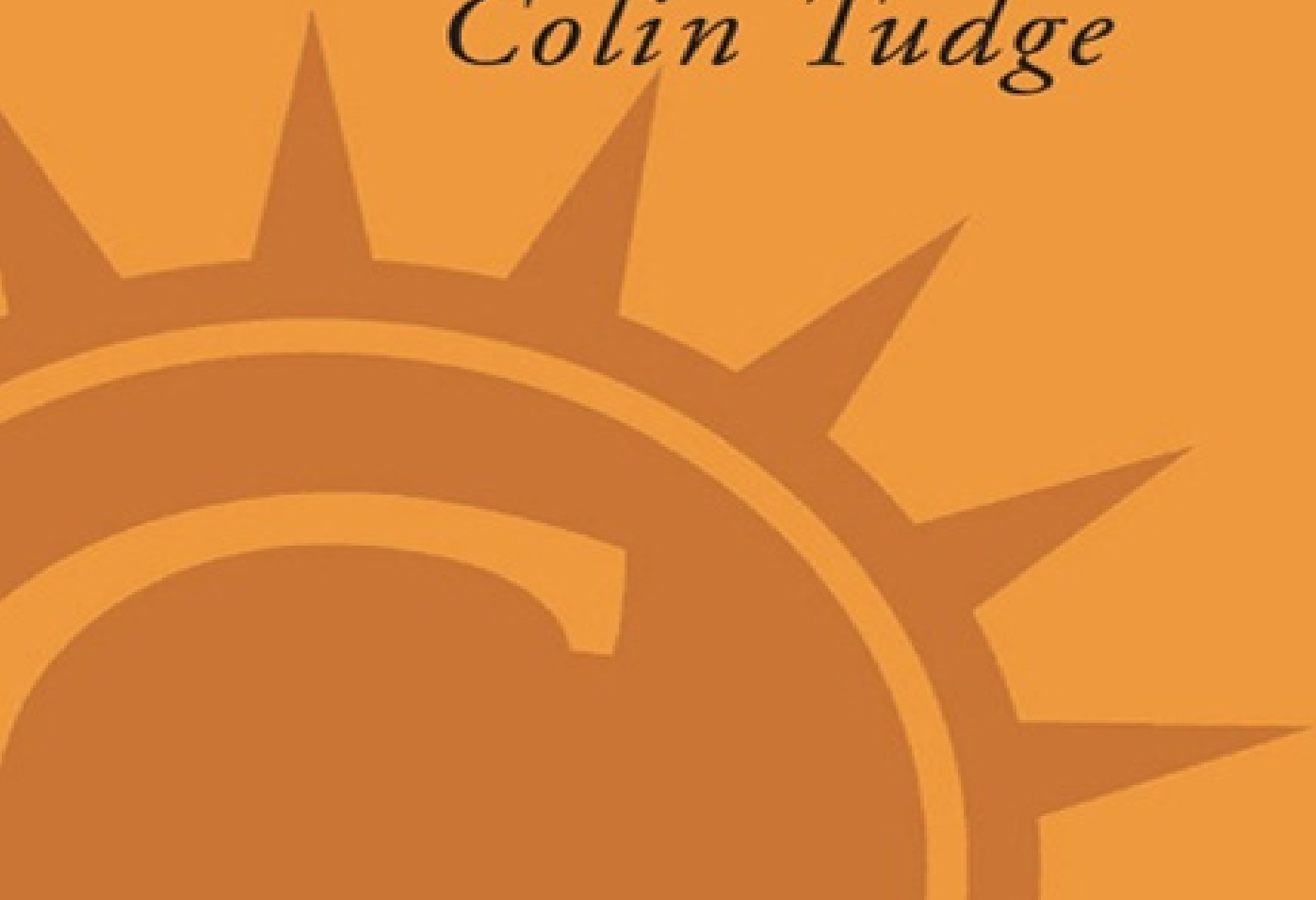
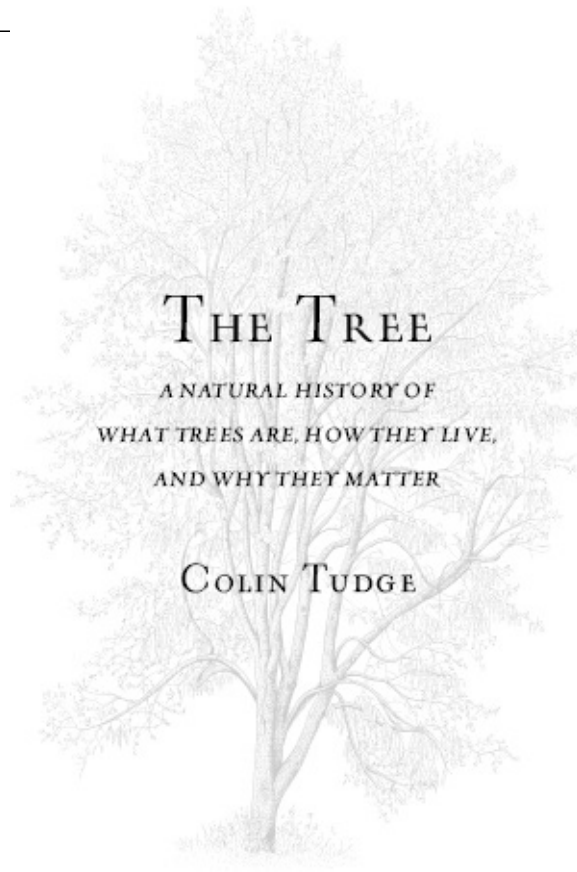


THE TREE

A Natural History of What Trees Are,
How They Live, and Why They Matter

Colin Tudge





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Original drawings by Dawn Burford

PREFACE

AT BOSCOBEL IN Shropshire in the English Midlands stands the Royal Oak, where the provisional King Charles II is alleged to have hidden from Cromwell's men after the Battle of Worcester, which ended his premature attempt to restore the monarchy. Why not? All this happened only about three and a half centuries ago (1651) and oaks may live for two or three times as long as that. Robin Hood and his Merry Men are said to have feasted beneath the Major Oak in Sherwood Forest in Nottinghamshire—and so they might have, for if they existed at all it was in the time of Richard I, in the late twelfth century, and the Major Oak was alive and well at that time. A yew I met in a churchyard in Scotland has a label suggesting that the young Pontius Pilate may once have sat in its shade “and wondered what the future held.” It's an audacious claim. But the tree was there, even if Pilate wasn't—already some centuries old at the time of Christ.

There's a kauri tree in New Zealand called Tane Mahuta (the oldest and biggest kauris are given personal names), with a trunk like a lighthouse, that was four hundred years old when the Maoris first arrived from Polynesia. For the first nine hundred or so years of Tane Mahuta's life, the moas, related to ostriches but some of them half again as tall, would have strutted their stuff around its buttressed base, threatened only by the commensurately huge but short-winged eagles that threaded their way through the canopy to prey upon them. Now the moas and their attendant eagles are long gone but Tane Mahuta lives on. Many a redwood still standing tall in California was ancient by the time Columbus first made Europe aware that the Americas existed. Yet the redwoods are stripling compared to some of California's pines, which germinated at about the time that human beings invented writing and so are as old as all of written history. These trees out on their parched hills were already impressively old when Moses led the Israelites out of Egypt, or indeed when Abraham was born. So it is that some living trees have seen the rise and fall of entire civilizations.



Trees inspire: the Buddha received enlightenment under a peepul tree.

Some redwoods, Douglas firs, and eucalypts are as tall as a perfectly respectable skyscraper, and there's an extraordinary banyan in Calcutta that would cover a football field. Many are host to so many other creatures that each is a city: as cosmopolitan as Delhi or New York and far more populous than either. Creatures of all kinds may feed on trees, or maraud among their branches. At least, I know of no arboreal octopuses—but there could be, out in the mangroves. There's many a tree-happy crab in the mangroves, as I have seen for myself, and the robbers of the Pacific islands, giant hermit crabs, come on land (as many crabs do) to feed on coconuts. When the Amazon is in flood—deep enough to submerge well-grown trees entirely, over an area not far short of England—the fish feed on fruit and river dolphins race through the upper branches of what should be the canopy, while monkeys hop and swim from crown to crown like ducks. In New Zealand little blue penguins nest in the forest at night with ground parrots (or at least they do on the sanctuary of Maud Island). In the 1970s, in the crown of one fairly modest tree in Panama a scientist from the Smithsonian Institution counted eleven hundred different *species* of beetle—yet he didn't bother with the weevils, although they are beetles too, so I look closely at the host of creatures that are not beetles, or those that were living in the roots. I once found myself in an old kapok tree in Costa Rica in which biologists had thus far listed more than four thousand different species of creatures.

Yet a tree cannot afford simply to serve as someone else's monument and feeding ground. From the moment the seed falls on to the forest floor (or the sand of the savannah, or a fissure in some mountain crag, or a glacier's edge, or a lakeside, or a tropical seashore) to the moment of its final demise, perhaps a thousand years later, the tree must compete through every second—for water, nutrients, light, and space; and to fend off cold, heat, drought, flood, toxicity, and the host of parasites and predators of all conceivable kinds (from a tree's point of view, squirrels or giraffes are "predators"). A village or a civilization may choose to make a tree their symbol. The entire nation of Brazil is named after a tree—for brazilwood was known to Europeans before the country was. B

however we may choose to ennoble it, the tree must fight its corner, a creature like all the rest. If it does not fight it would be dead. Even when it sheds its leaves to ride out frost or drought, its cells are still busy beneath its armored bark. Were it not so, the leaves could not burst out as they so spectacularly do when the temperate spring or the tropical rains return—or sometimes in advance of the rains, to the delight of camels and goats, which thus may find green fodder in the depths of drought. In many trees, too, tropical and temperate, the flowers emerge before the leaves, which keeps the path clear for the pollinating winds, bees, or bats. Since there are no leaves to provide nourishment, the flowers must be fed from the tree's reserves in its trunk and roots. The living timber is multipurpose: a prop, a conductor, a larder.

Flowers, of course (and the cones of conifers), meet life's other demand: not simply to survive and grow but to reproduce. Here, the trees' immobility is a particular drawback. Many trees reproduce without sex, commonly though not exclusively by root suckers, but all trees (to my knowledge) practice sex as well. For sex, gamete must meet gamete: sperm and egg in the case of animals and primitive plants, pollen and ovule in the case of conifers and flowering plants. Since many flowers on many trees are hermaphroditic (male stamens and female carpels on the same flower), and many trees (like oaks and many conifers) are monoecious (the individual flowers are exclusively male or female but both kinds occur on the same tree), it may seem easy enough for trees to pollinate themselves. But on the whole they don't. One of the botanical surprises of recent decades (finally proven by genetic studies) is the length to which most trees go to avoid self-fertilization. "Outcrossing" is the norm: pollenation of, and by, other individuals who, of course, are of the same species but preferably are not too similar genetically. To achieve outcrossing, trees must elicit the help of the wind—or bribe or otherwise coerce a variety of animals, from flies and beetles and bees to birds and bats—to carry the pollen for them. Some temperate trees (like apples and horse chestnuts) are pollinated by animals, though most (like oaks and birches and beeches) are content to use the wind. But in tropical forests where most kinds of trees live, animal pollination is the norm; and because life is competitive, the mechanisms that have evolved for this have become more and more elaborate. Thus for every one of the 750 different fig species there is a corresponding specialist wasp species to pollinate it; and each wasp knows its own fig (although, as recent studies have shown, the relationship between figs and their wasps is not quite so cozy as had been supposed). When the ovules are fertilized and become seeds, encased in fruits (or some other kind of fruiting body) they must then be dispersed—sometimes again by wind but often by another, entirely separate, suite of animal accomplices—birds and fruit bats and rodents and orangutans, whose help must again be actively co-opted.

Thus life is perforce competitive: hordes of creatures of thousands of different kinds are all after the same things, and most live directly at the expense of others. But it is also, just as inescapably cooperative. Trees are good competitors. But they are also among the world's most exemplary cooperators, forming a host of mutualistic relationships for one purpose or another with an enormous variety of different creatures, from the bacteria and fungi that help them to feed to the many, many different kinds of animals that help them with different stages of their reproduction. Trees do not seem to be aware, as dogs and monkeys are aware. They do not have brains. But they are sentient in their way; they gauge what's going on as much as they need to, and they conduct their affairs as adroitly as any military strategist. Why be "aware" when you can simulate all that awareness brings? They surely don't think, as animals do. But they orchestrate their fellow creatures nonetheless. A forest is a forest because it has trees in it, not because it may have sloths and toucans or squirrels

chimpanzees. The trees are the prime players and the animals are the dependents.

The human debt to trees is absolute. Modern evolutionary theory has it that we owe our brains—our art, our inventiveness, and presumably much of our deviousness—to our sexuality. We dance and paint and joke and tell stories to impress potential mates—or such at least was the crude beginning of our wits, on which we have built. But pigs and squirrels and elephants are clever too. They also must attract mates. So why have pigs produced no concert pianists or professors of jurisprudence? Another ingredient is needed—one suggested a long time ago by more conservative biologists. Our brains and our dexterity evolved together: they are an exercise in coevolution. Pigs are clever, but their hands are hoofs: nothing there with which to express their dreams and insights. We, by contrast, can translate our thoughts into action: our artifacts (as Robert Pirsig put the matter in *Zen and the Art of Motorcycle Maintenance*) are ideas in space. Brains are expensive organs (they require a huge amount of energy) so unless they produced some immediate payoff, natural selection would have selected against them. But because we have hands (at the end of long, strong, extremely mobile arms), brains did provide payoffs, manifest not least in a thousand kinds of tools with which to effect further manipulation. Hands provided the encouragement, the selective pressure, to make our brains even brainier; and the growing brains in turn encouraged more dexterity. But the only reason we have such dexterous hands and whirling arms is that our ancestors had spent eighty million or so years (so some zoologists calculate) in the trees. Arboreal life requires dexterity and hand-eye coordination. Squirrels almost became intellectuals, but not quite. Monkeys and apes came closer—but they stayed up in the trees where they are obliged to squander their fabulous skills just on getting around. Our ancestors somewhere in Africa, came to the ground when the climate dried up and the trees retreated. They learned to walk on two legs (which no other primate or any other mammal of any kind has learned to do convincingly), freeing their versatile hands and arms for other purposes. Were it not for the pedigree we would remain as intellectually frustrated as elephants and dolphins sometimes seem to be.

Archaeologists speak of the Stone Age, and the Bronze Age and the Iron Age and the Steam Age and now we have the age of the internal combustion engine and nuclear power and space and IT. But every age has been a Wood Age—ours at least as much as any in the past; and perhaps the decades to come will be even more so. Ice Age Russians made houses from the bones of mammoths, the Inuit used ice, and the people of the Bronze Age Orkneys built remarkable villages, with restaurants and mausoleums, from slabs of rock. But great architecture demands wood. The ruins that survive from classical times are all of stone, but that's only because wood rots. Architecture in stone and brick evolved from timber architecture, and needed wooden-handled tools and wooden scaffold for its construction—and timber roofs and rafters. Wood, in this energy-conscious age, may well begin to replace all or some of the steel used in the grandest buildings.

Wood was the first serious fuel, too—and human beings clearly learned the use of fire at least 500,000 years ago, long before we were as big-brained as we are now. No fuel: no smelting—so no Bronze Age or Iron Age or modern machines. No wood: no ships. No ships: no ocean travel—no human beings in Australia, New Zealand, or any other island that could not be reached simply by hitching a lift on floating vegetation (as many a beast is thought to have done, from rats to monkeys and tortoises). No ocean travel: no empires: no modern politics. A woodless world would have had advantages. But we could also say no wood: no civilization.

Yet timber is not the end of it. Trees are the source of drugs, unguents, incense, and poisons for tipping arrows, stunning fish, and killing pests; of resins, varnishes, and industrial oils, glues and dyes and paints; of gums of many kinds, including chewing gum; of a host of fibers for the rigging and hawsers of great ships (whether made of wood or not) and for the stuffing of cushions; and of course, perhaps above all these days, for paper. All that, plus a thousand (at least) kinds of fruits and nuts and—in traditional agrarian societies—a surprising amount of fodder for animals, including cattle and sheep, which most of us assume live primarily on grass. As a final bonus, the wooden husks of many tree fruit make instant household pots and drums and ornaments.

In short, without trees our species would not have come into being at all. And if trees had disappeared after we had hit the ground, we would still be scrabbling like baboons (assuming the baboons had even allowed us to live).

Perhaps this is why we feel so drawn to trees. Groves of redwoods and beeches are often compared to the naves of great cathedrals: the silence; the green, filtered, numinous light. A single banyan, each with its multitude of trunks, is like a temple or a mosque—a living colonnade. But the metaphor should be the other way around. The cathedrals and mosques emulate the trees. The trees are innately holy. Christians with their one omnipotent God may take exception to such pagan musing; but the totaras and the kauris were sacred to the Maoris, and the banyan and the bodhi and the star-flowered temple trees (and many, many others) to Hindus and Buddhists, and the roots of this reverence, one feels, run back not simply to the enlightenment of Buddha as he sat beneath a peepul, or bo, tree (528 B.C., tradition has it) but to the birth of humanity itself.

Yet Christianity did give rise to modern science. The roots of science run far back in time and from all directions—from the Babylonians, the Greeks, many great Arab scholars in what Europeans call the Middle Ages, the Indians, the Chinese, the Jews, and the much underappreciated natural history of all hunter-gatherers and subsistence farmers everywhere. But it was the Christians from the thirteenth century onward, with an obvious climax in the seventeenth, who gave us science in a recognizable modern form. The birth of modern science is often portrayed by secular philosophers as the “triumph of “rationality” over religious “superstition.” It was, however, much more subtle and interesting than that. The great founders of modern thinking—Galileo, Newton, Leibniz, Descartes, Robert Boyle, the naturalist John Ray—were all devout. For them (as Newton put the matter) science was the proper use of the God-given intellect, the better to appreciate the works of God. Pythagoras, five centuries before Christ, saw science (as he then construed it) as a divine pursuit. Galileo, Newton, Ray, and the rest saw their researches as a form of reverence.

This book is written in that same spirit. Of course, I don't claim to walk on the same plane as Pythagoras and Galileo, but I don't think it's too pretentious to aspire at least to drink at the same spring. This book is mainly about the science of trees—what modern research is telling us about them. The last chapter is about the uses we make of them, and what they do for us, and why for reasons that are purely material they must be conserved: our survival depends on them. Most of this book, however, is not about their usefulness but about what they *are*: how they came into being, what kinds there are and where they live and why, and how they live, competing and cooperating. The revelations build by the week: how they may live and grow huge on what seems like nothing at all; how they draw prodigious quantities of water from the ground, send it up into the atmosphere, and then (so some have claimed) may call it in again, by releasing organic compounds that seed fresh clouds; how they speak

to one another, warning others downwind that elephants or giraffes are on the prowl; how they mimic the pheromones of predatory insects, to summon them to feed upon the insects that are eating the leaves. Every week the insights grow more fantastical—trees seem less and less like monuments and more and more like the world’s appointed governors, ultimately controlling all life on land (and in the oceans too, vicariously), but also the key to its survival.

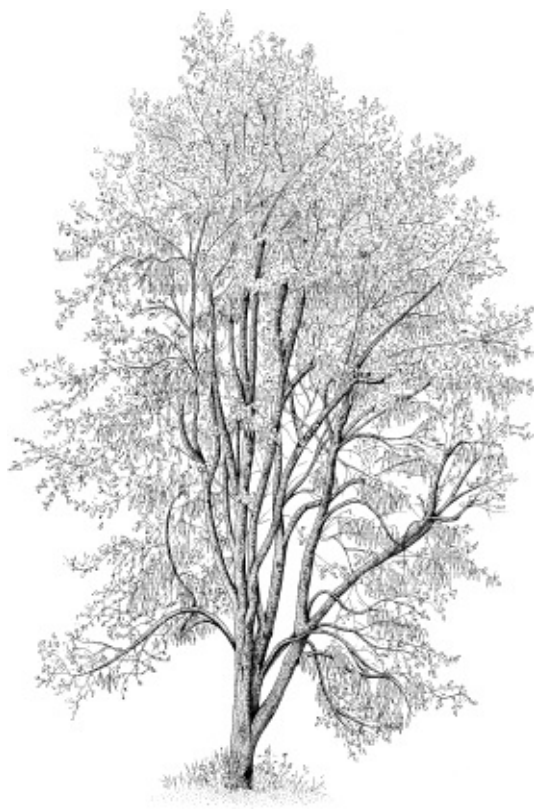
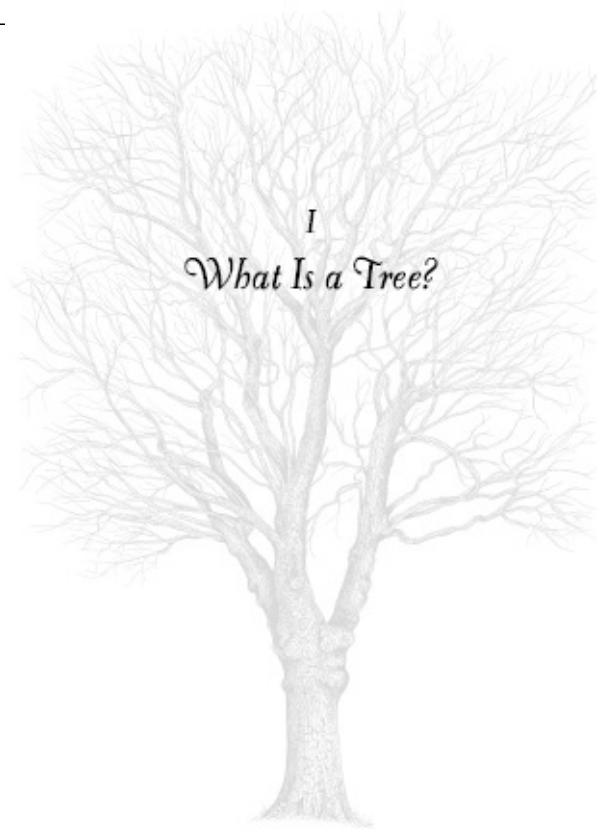
So this book presents science not as it is often presented, as a tribute to human cleverness and power, but truly in a spirit of reverence. I like the idea (I have found that some people don’t, but I do) that each of us might aspire to be a connoisseur of nature, and connoisseurship implies a combination of knowledge on the one hand and love on the other, each enhancing the other. Conservation—of all living creatures, including trees—has little chance of long-term success without understanding, which depends in large measure on excellent science. But conservation cannot even get on the agenda unless people care. Caring is an emotional response, to which science has often been presented as the antithesis. In truth, science cannot be done properly without a cool head. Yet when the science is done its primary role (to reverse an adage of Marx’s) is not to change the world but to enhance appreciation. That is the purpose of this book. Science in the service of appreciation, and appreciation in the service of reverence, which, in the face of wonders that are not of our making, is our only proper response.

AUTHOR’S NOTE

The following abbreviations have been used throughout the text:

“Judd” refers to Walter S. Judd, Christopher S. Campbell, Elizabeth A. Kellogg, Peter F. Stevens, and Michael J. Donoghue, (editors), *Plant Systematics*, 2nd ed. (Sunderland, Mass.: Sinauer Associates, 2002).

“Heywood” refers to V. H. Heywood, ed., *Flowering Plants of the World* (Oxford: Oxford University Press, 1978).



Round-leaved and altogether beautiful: the Judas tree.

Trees in Mind: Simple Questions with Complicated Answers

“**I** NEVER STOPPED THINKING like a child,” said Einstein. Neither should any of us. It’s the way to go to the heart of things. Children ask ridiculously simple questions—like “Who made God?”—that have kept theologians busy for many a century. In such a vein we might innocently inquire, “And what do we pray for, are trees, that anyone should presume to write a book about them?” And “Why do plants grow into trees?” And “How many kinds are there?” Childish stuff, but it will serve to mark out the ground

WHAT IS A TREE?

A tree is a big plant with a stick up the middle.

Everybody knows that. But that statement as it stands requires what modern philosophers would call a little “deconstruction.”

What, for a start, is meant by “big”? It’s a relative term, of course, although if we choose we can put a figure on it—say, a minimum height of five or six meters. There is a case for doing this: if you are a forester, or are running a nursery, you need some guidelines. But guidelines are not definitions. They are ways of helping practical people do practical things. They do not—and are not intended to—capture what Aristotle would have called the essence of nature.

For many trees grow big when conditions are favorable, and stay small when they are not. An oak is a noble tree in a forest or a park, but an acorn that falls in a fissure in some Scottish crag may spend a couple of centuries in bonsai mode, never more than a twisted stick. Yet it may turn out acorns that, if they should be carried to some fertile field, could again produce magnificence. Is the twisted stick less of an oak because it fell on stony ground? And if it remains an oak, is it not still a tree? Then again—different kind of case—the world’s many kinds of birches form the genus *Betula*. None are as huge as an oak may often be, but most are perfectly respectable trees. Yet there is one, *Betula nana*, that is adapted to the tundra of the north of Scotland and mainland Europe and is very small indeed. Do we say that all birches are trees except for the tough little *Betula nana*? Or do we say it’s a dwarf tree?

What of the stick that runs up the middle, the “trunk,” which holds the “crown” of the tree aloft

Should there be just one, a solitary pillar, or are several allowed? Many a gardener and forester have insisted that plants with a lot of supporting sticks should be called shrubs. Again, for practical purposes such distinctions can be useful. If Alice's Queen of Hearts had instructed her long-suffering gardeners to plant her an arboretum and they'd come up with a shrubbery, their heads would surely have come off. But wild nature is not so easily pinned down. In the Cerrado of Brazil—the vast, dry forest, about the size of France, in the middle of the country to the south and east of Amazonia's rain forest—there are trees that form bona fide, big, one-trunked trees when they grow along the banks of the occasional rivers but become multistemmed, short shrubs where it's drier. The shrub is not merely stunted, like the oak in the rock. It is a discrete life-form. Many organisms exhibit what biologists call “polymorphism,” meaning “many forms.” Many kinds of fish, for example, have dwarf forms and full-size forms; some butterflies and snails are highly variable. Here we see a polymorphic tree—one form for the forest, another for the open ground.

Then again, many big trees, including some cedars, many a mulberry, and the beautiful blue-flowered jacaranda, may grow from ground level with several solid trunks of equal magnitude. Each may be as big as a respectable oak. Are they trees or big shrubs? The family of the heather, Ericaceae, also includes the rhododendrons from the Himalayas and the madrone trees of the United States, with their beautiful flaky, yellow, pink, and gray trunks (which add yet more color to the already wondrous hills of California). Rhododendrons tend to have many stems, while madrones are commonly content with one. But the rhododendrons can be just as big and solidly wooden as the madrones. In nature, in short, trees and shrubs are not distinct. Why should they be? Nature was not designed to make life easy for biologists.

Must the central stick be of wood? That, after all, is what we generally mean by “stick.” How, then, should we categorize banana plants? In general shape they resemble palm trees, with a thick central stem and a whorl of huge leaves at the top. But the stem of the banana plant is not made of wood. Its stem is formed largely from the stalks of the leaves, and its strength comes from fibers that are not bound together, as in pines or oaks or eucalypts, to form true timber; its hardness is reinforced, as in a cabbage stalk, by the pressure of water in the stem. So botanically the banana plant is a giant herb. But it looks like a tree and competes with trees on their own terms, as a big plant seeking the light (although, like the trees of cacao and tea and coffee, the banana prefers a little shade).

In fact, there are many lineages of trees—quite separate evolutionary lines that have nothing to do with one another except that they are all plants. Many plants, in many of those lineages, have independently essayed the form of the tree. Each achieves treedom in its own way. “Tree” is not a distinct category, like “dog” or “horse.” It is just a way of being a plant. The different kinds have much in common, and it is good and necessary to have some feel for what is essential. But the essences of nature will not be pinned down easily. In the end, *all* definitions of nature are simply for convenience, helping us focus on the particular aspect that we happen to be thinking about at the time. There is no phenomenon in all of nature—whether it's as simple as “leg” or “stomach” or “leaf” or more obviously conceptual like “gene” or “species”—that does not take a variety of forms, and that cannot be looked at from an infinite number of angles; and each angle gives rise to its own definition. A horse cannot be encapsulated, as Charles Dickens's Thomas Gradgrind insisted in *Hard Times*, as “a graminivorous quadruped.” There is more to horses than that. The way we define natural things influences the way we treat them—whether we speak of wildflowers or of weeds, of Mrs. Tittlemouse

or of vermin. But in the end nature is as nature is, and we must just try with different degrees of feebleness, and for our own purposes, to make what sense of it we can.

For the purposes of this book, the child's definition of "tree" will serve—albeit with slight elaboration: "A tree is a big plant with a stick up the middle—or could be, if it grew in the right circumstances; or is very closely related to other plants that are big and have a stick up the middle; or resembles a big plant with a stick up the middle." It is clumsy, but it will have to do. So to the next childish question.

WHY BE A TREE?

A nonliving thing is passive. The atoms of which a stone is composed sit there for as long as it endures—until it is melted in some volcano, or dissolved by acid rain. But living things are restless through and through. As soon as some living cell has constructed some protein, as part of its own fabric, it starts to dismantle it again. This constant self-renewal, powered by an endless intake of energy, is called metabolism.

Metabolism—the basic business of staying alive—is half of what living things do. The other half is reproduction. It is not vital to reproduce in order to stay alive. Indeed, reproduction involves sacrifice. Reproduction, as we will see later in this book, is often the last fling: many a tree dies after one bout of it. But it is essential nonetheless. At least, all creatures that do not reproduce die out. However successfully an organism may metabolize, sooner or later time and chance will finish it off. Everything dies. Only those that reproduce endure—or, at least, their offspring do. All individuals are part of lineages, offspring after offspring after offspring.

But then, too, each creature finds itself in the company of other creatures, of its own kind and of different kinds. To some extent they are its rivals, to some extent it needs them—for food, shelter, mates, or whatever. Each successful creature, then—each one that survives at all, that is—must come to terms with the others around it.

All of life's requirements—metabolism, reproduction, and the business of getting along with others—are difficult. Each creature must solve life's problems in its own way. There is no perfect, universal life strategy. Each has its own advantages and drawbacks.

So it can pay a creature to be very small; or it can pay to be big. Each mode has its pros and cons. A plant that is big like a tree can stretch farther up into the sky, and so capture more of the sun's energy, and it can reach farther down into the earth, for water and minerals. This is the upside. But it takes a long time to achieve large size, and whether you are an oak tree or an elephant or a human being, the longer you take to develop the more likely you are to be killed before you reproduce.

Being big is difficult, too. To hold a ton of leaves aloft in the sun and air requires enormous strength: specialist material like wood, and clever architecture. All trees have wood, by definition (apart from those granted honorary status, like bananas); but as we will see, wood is subtle stuff requiring much chemistry and microgeometry. The many types of trees have essayed many

architectural forms. Ginkgoes and conifers are built from repeats of a single simple module: a straight trunk up the middle with circles or spirals of branches at intervals. In others, like the elm, the lead shoot bends over and the next shoot in line takes over the lead, until it too bends away and the one below that takes over. In yet others (particularly some tropical trees), the branches that grow upward from the horizontal branches repeat the form of the whole tree—it's as if a new, miniature forest grew aloft, from the horizontal branches of the giants below. And still others, like oaks or chestnuts, are more free-flowing. There are many basic designs. The point is, though, that such design is *necessary*. Being big requires a lot of engineering as well as a lot of chemistry, and it takes a long time to put in place. But the bigger trees grow, the more they are vulnerable to wind—and tropical storms regularly cut swaths as big as Los Angeles through the world's rain forests.

For the purposes of reproduction, most creatures pursue one of two main strategies. Some, known as K-strategists, produce just a few offspring at a time, which in general are large at the time of the birth to give them a good chance in life; after they are born, typically, the parents take good care of them. K-strategists tend to be long-lived and reproduce several times in their life, often at long intervals. Orangutans, elephants, eagles, and indeed human beings are classic K-strategists. Other creatures, known as r-strategists, produce an enormous number of offspring. Inevitably, each individual offspring is small, and so has little chance of survival. But there is safety in numbers. Codfish are noted r-strategists. They produce up to two million eggs at a time. The newly hatched fish live for a while as plankton, floating fairly helplessly—and most perish: they just get eaten. But as long as each pair of codfish manage to produce just two surviving offspring in the course of their lives, the lineage of cod will carry on. Despite the enormous prodigality of their reproductive strategy and its fantastic wastefulness, codfish are immensely successful—or at least they were until North Sea fishermen became too technically proficient, or too “competitive,” and disastrously reduced their numbers. Cod live a long time. But many r-strategists, like flies, run through their entire life cycle in a few weeks: birth, growth, reproduction, death. Thus populations of flies may rise and fall from near zero to plague proportions in what seems like no time at all.

Trees seem to get the best of both worlds. Many—most—produce huge numbers of seeds and make do so repeatedly. A mature oak or beech may produce many millions of seeds in a good year (good seed years are known as “mast” years), and although they won't do this every year, they may well have scores or even hundreds of prolific years in the course of their lives. They are r-strategists; indeed, in a good year at least as prolific as codfish. Yet many trees—including oaks—produce seeds that are large and that do not need to germinate immediately: each has a very good chance of survival. To this extent they are K-strategists too. To combine the advantages of the K- and r-strategies an organism must be truly mighty. Yet there is a downside too: most trees must grow for several years and many must endure for several decades, before they can reproduce at all; and all that time they are vulnerable.

We don't think of trees as r-strategists, because they are so big and long-lived. Their populations do not boom and bust like those of flies. They cannot, we imagine, leap to take advantage of newly created environments as a fly or a mouse may do. Yet once we venture beyond our own puny timescale and take the long view, we see that they can and do do this. Thus when the last ice age ended in the Northern Hemisphere, around ten thousand years ago, the forests of birches and alders that had been whiling away the time farther south were able virtually to race toward the North Pole in the wake

of the retreating glaciers; and they will surely resume their advance as global warming reduces the polar ice still further. By the same token, the huge tropical rain forest of Queensland, in the Southern Hemisphere, has not been there forever, as it may seem. Like the Great Barrier Reef, which stands just off the Queensland coast and is as long from end to end as Great Britain, the rain forest of Australia grew up only after the last ice age and is a mere ten thousand years old. Macbeth was shocked to see the Great Wood of Birnam shift a few miles across the moor to the Hill of Dunsinane. But if we could take a time-lapse view of all the world this past few million or tens of millions of years, as cold has followed warm has followed cold, we would see vast and apparently immovable forests flitting over the surface of the globe like the shadows of clouds.

Thus the advantages of treedom are both manifold and manifest. Big plants can metabolize more effectively because they command so much earth and sky; and they can produce literally tons of seed to be scattered far and wide. Small wonder that a third of all land is covered in forest. But being big is complicated—all that chemistry and architecture—and it is risky, because all the time a tree is growing, time and chance and other creatures are working on its downfall. So it is that many other plants, such as mosses and liverworts, never acquired the means to be big at all; but they have still made a very good living during the past 400 million years, just by sticking to damp and easy places. Then again, trees cannot grow where it's too dry or the soil is too thin, and so they leave scope for many smaller plants that can. So the world's grasslands are vast too, like the savannahs of the dry tropics, the prairies of temperate North America, the pampas of subtropical South America, and the steppes of Asia. These grasslands at best have scattered trees, though they grade into open woodland—many small trees but with big, mainly grassy spaces in between, as in the dry, tropical Cerrado of Brazil. Furthermore, trees are classic keystone species: simply by existing and doing their thing, they create niches where other creatures can live. Hence forests create endless scope for small, quick-growing plants—herbs and ramblers—to occupy the ground in between the trees; and a vast variety of plants of all kinds (mosses, liverworts, ferns, and many kinds of flowering plants, including many relatives of the arum lily and of the pineapple, some cacti, and most of the orchids) grow on the trees themselves, as epiphytes. Overall, too, there is more room for small plants than for big ones. Whole viable populations of small plants may need only a few square yards, while a population of wild tree that is numerous enough to endure will generally need many acres. So although there are tremendous theoretical advantages in being a tree, the species of trees are outnumbered by nontree plants by about five to one. The nontrees live in places where trees cannot—and in the niches created by trees.

So now to the third childish question.

HOW MANY KINDS OF TREES ARE THERE?

A simple question indeed—but of course there are complications. To begin with, as the more irritating kind of philosopher would say, “It depends what you mean by *kind*.”

In this context, “kind” most obviously means “species.” The common English oak is a species, *Quercus robur*. So is the Scotch pine: *Pinus sylvestris*. A common birch in Europe is *Betula pendula* and so on. What's the problem?

One problem involves how you tell the different kinds apart. Any one species is liable to be highly variable, and sometimes different species resemble each other very closely. Sometimes there is more variation *within* species than there is between species. Or then again: many creatures can be identified definitively only by their reproductive organs, which in the case of flowering plants (including most trees) means flowers. But many trees are not in flower at the time you come across them—a particular problem in the tropics, where flowering often seems to be erratic (or perhaps the tree knows when it is appropriate to flower, but the biologist does not). Some trees with similar flowers have different leaves, and both may be needed to make the identification. Willows, however, tend to produce the flowers before they produce leaves—so you never find flowers and leaves on the same tree at the same time. If you want to know what species a particular willow belongs to, you may have to make two visits.

But biologists do not define species purely in terms of what they look like. Much more fundamental, they very reasonably feel, is who mates with whom. If different individuals breed together, then it is reasonable to declare that they are of the same species. *Betula pendula* will happily breed with another *Betula pendula*, but not with *Quercus robur*. So they are different lineages of creatures, living separate lives. Easy.

Still, there are snags. Many species can and do interbreed with other species, and so form hybrids. The example that everyone knows is the mule: the issue of a male donkey and a mare. But horses and donkeys seem to be very different kinds of animals. If they can breed together, doesn't this mean they are of the same species? No—for although the mule is a powerful animal and stubborn, as cowboys were wont to complain, it is nonetheless sexually sterile. Strong though it is, it is not, as a biologist would say, "viable." So we can extend our definition slightly: "Two or more individuals can be considered to be of the same species if they can mate together to produce *fully viable* offspring." "Fully viable" implies sexual potency; it also implies that the offspring should be able to compete successfully in the wild. There are some hybrids (for example, among frogs) that are sexually fertile yet generally fail in the wild, unable to compete with either of their parent species. Again, it is reasonable to rank the parent types as separate species, since the hybrids they produce between them are (relative) failures.

Still, there are problems. For example, two apparently different species that look different may fail to interbreed in the wild simply because they live in different places. Bring them together, however, and they may interbreed perfectly happily. Trees provide scores of examples, among oaks, willow poplars, and many more. Many hybrids have arisen in gardens, where human beings bring plants from very different areas together, perhaps for the first time in many thousands of years. Among the most striking examples is the London plane, *Platanus x acerifolia* (the x indicates its hybrid status). It is tremendously successful in temperate cities everywhere. Because it sheds its outer bark (as eucalyptus or a madrone does), it gets rid of all the soot and other pollutants that can make life difficult for many other kinds of tree. It is the offspring of the Oriental plane from southern Europe and Turkey, *Platanus orientalis*, and the sycamore from eastern North America, *Platanus occidentalis*, and arose, so tradition has it, in the Botanic Garden of Oxford University, in the seventeenth century. An offspring of the first-ever London plane stands in a courtyard in Magdalen College, which is next to the Botanic Garden. That offspring, now several centuries old, is huge. For those who would be connoisseurs, it is well worth a diversion (assuming the porters will let you in). Of course, once now

trees appear in botanic gardens, botanists and gardeners all over the world flock to get hold of them. The London plane flourishes everywhere in the temperate world because it resists pollution so well—not least in the native countries of its parent species, in Asia and the United States.

Then there is the extremely important phenomenon of polyploidy. Genes, as everyone knows these days, are aligned along chromosomes. Every kind of organism has its characteristic number and arrangement of chromosomes. Eggs and sperm (or the appropriate cells in ovules and pollen) contain only one set of chromosomes, and are said to be “haploid.” When they fuse in the act of fertilization, the resulting embryo has two sets of chromosomes and then is said to be “diploid.” Most organisms (at least of the most familiar kinds) are diploid: for example, human beings have forty-six chromosomes—twenty-three acquired via the egg of the mother and twenty-three from the sperm of the father. Chimpanzees have forty-eight chromosomes, twenty-four from each parent.

Sometimes, however, apparently spontaneously, the chromosome number will double. (The chromosomes divide in the normal way they do in preparation for cell division, but then the cell fails to divide.) Thus the diploid cell becomes tetraploid, with four sets of chromosomes. This does not apparently happen much in animals (or not, at least, in mammals), but it is extremely common in plants. The newly formed tetraploid organism can breed successfully with other tetraploids of its own kind, but it cannot usually breed successfully with either of its parents. So it forms an instant new species. Many plants in nature turn out to be tetraploid, and many more tetraploids have been produced in cultivation. The common potatoes grown in Europe are tetraploid derivatives of diploid potatoes that grow wild (and are cultivated) in the Andes. Many trees, wild and cultivated, are tetraploid. Sometimes the chromosomes of the tetraploid plant double again to produce octoploids. These octoploids form new, discrete species—generally unable to interbreed with the tetraploid parents who gave rise to them. “Polyploid” is the general term that describes any organism with more than two sets of chromosomes. Sometimes the complications become too much even for the plants and they end up with an odd number of chromosomes (some having been lost among all the cell divisions and matings). Plants with anomalous numbers of chromosomes are said to be “aneuploid.” Aneuploidy in animals generally leads to various degrees of disorder; aneuploid animals usually die, and if they live they tend to be compromised at least to some extent. But many plants put up with aneuploidy. Sugarcane is aneuploid; but that doesn’t stop it from being an extremely vigorous, major crop.

There is one further complication. As we have noted, diploid organisms that are of different species sometimes mate to produce fully viable offspring (as the eastern and the western species of *Platanus* evidently did). But usually such crosses fail, and often this is because the chromosomes of the two parents are incompatible. The two different sets of chromosomes might be able to support body cells that work well enough (as in the mule). But even if cells with two different kinds of chromosomes succeed this far, they will not necessarily produce sound gametes (eggs and sperm or ovules and pollen), because this requires close cooperation between the chromosomes.

Yet if a hybrid organism doubles its chromosomes, it often *can* produce viable gametes. So we find diploid parents of different species mating to produce diploid hybrid offspring that are sterile; but the hybrids then double their chromosomes and become tetraploid—and the hybrid tetraploids are fertile. This happens a lot among plants, and has produced many, many new plant species, both in the wild and in cultivation. Indeed, the complications seem endless. For instance, a tetraploid plant might mate with a closely related diploid plant to produce a triploid offspring—two sets of chromosomes from the

tetraploid parent, and one set from the diploid parent. Triploids are sterile—they cannot produce gametes at all—but they may still form viable plants. Thus the cultivated banana is triploid. Because it is sterile, its fruits contain no seeds (as wild banana fruits do). So the domestic banana has to be reproduced vegetatively, by planting cuttings. In other cases, though, triploid hybrids double the chromosomes to become hexaploid (with six sets of chromosomes). The most famous and important hexaploid organism of all is bread wheat (as opposed to pasta wheat, which is tetraploid).

If you have been brought up with animals and are innocent of botany, you may find all this fantastical. But among trees, hundreds of examples of polyploids are now known; the more the botanists look, the more polyploids they find. Some of the polyploids simply represent a doubling (or redoubling) of chromosomes within one species. Others are polyploid hybrids. For good measure, breeders have produced many hundreds of polyploids by artificial means. (Some chemicals induce polyploidy almost to order.)

Willows, genus *Salix*, provide many fine examples of polyploid trees. There seem to be around four hundred species—although there must be many more that are still unknown, including an entire phalanx in western China, yet to be properly studied. Some willow species have a haploid number of 19 chromosomes, so that the diploids have 38 (2×19). But another group of willows has a haploid number of 11 (diploid 22), and the third group has 12 (diploid 24). There doesn't seem to be much hybridization between willows with different haploid numbers, but there is a great deal of hybridization between different species with the same haploid number, and this has produced a whole array of polyploids, some with as many as 224 chromosomes. Most of those polyploid hybrids are fertile, and some willows have been bred artificially from combinations of up to fourteen different species. For good measure, many of the hybrids are all of one sex and reproduce by suckers, so that all the members of such "species" in fact form a clone (of which more later). Thus, the hybrid known as *Salix x calodendron* is all female. Many willows, too, both wild and in cultivation, are aneuploid. All in all, identification of the multifarious willows—the diploid types and all their polyploid hybrids—is a nightmare (even when they are not tucked away on some remote Chinese hillside).

Acacias show a similar picture. Acacias are those lovely, lonely, sprawling trees of tropical grasslands worldwide that provide such essential shade and fodder for giraffes, camels, gazelles, and the domestic cattle and goats of nomadic pastoralists. *Acacia* is a huge and messy genus, with 1,300 species—which should probably be further subdivided, perhaps into five or more different genera. Even that as it may, the basic haploid number of the whole group is 13, so the default diploid number is 26, but there are polyploids with up to 208 chromosomes—sixteen times the haploid number. In some of these, it's clear that the ancestor simply doubled (and then sometimes redoubled) its chromosome number. Other acacias arose as polyploid hybrids.

In birches, the haploid number is 14, so the diploid number is 28—but some species have up to 112 chromosomes, which means they are octoploid: and there are some aneuploid hybrids in cultivation. In northern Europe, the silver birch, *Betula pendula*, and the downy birch, *B. pubescens*, can look very similar, and some botanists have suggested that they are the same species. But the silver birch is a diploid, with 28 chromosomes, and the downy birch is a tetraploid, with 56. The downy birch presumably arose from the silver birch, but now, following polyploidy, it is very clearly a separate species. Alders, too, show much the same kind of thing. Clearly the variety depends in part on past hybridization of what had been separate species.

~~How many more species of trees will turn out to be hybrids or polyploids or fertile polyploid hybrids? Another century or so of serious study will throw a great deal more light. Science takes time~~

There is one final set of complications. If different populations of trees become isolated one from another, eventually they may evolve into separate species. But in the shorter term, the separate populations may remain similar enough to breed easily together—that is, they are still the same species—and yet become genetically distinct to some extent, and may look different. Then biologists say that the two populations are different “races” or “varieties” of the same species; and if the variety is really distinct, they may call it a “subspecies.” In Great Britain, varieties of plants that arise through informal selection on traditional farms are called “landraces.” Domestic varieties of plants that have been produced through formal breeding programs are called “cultivars,” for cultivated variety (and domestic races of animals are called “breeds”).

Sometimes, both in the wild and in domestication, “variety” simply means a subset of the species. Among domestic crops, the different varieties of runner beans are of this kind: subsets of the runner bean species as a whole, but breeding sexually (by seed) and genetically still diverse. Many plants, however, also reproduce vegetatively as well, by means of bulbs or tubers—or, as with many trees, by suckers from the stem or roots. A tree produced vegetatively in the wild may remain attached to its parent so that parent and offspring together form an entire copse (as in English elms or groves of giant redwoods). Indeed, the parent tree and the offspring that grow from its suckers may cover many acres, as with the aspens of Canada. Growers and foresters often reproduce their favored trees by cutting, which of course they separate from the parent. Whether they are separated from the parent or remain attached, all the offspring that are produced vegetatively are genetically identical with one another and with their parent (who, of course, is a single parent). All the offspring are then said to be “clones” of one another and of the parent; and the whole genetically identical group is collectively called a clone.

Thus, among apples, all the Cox’s Orange Pippins there have ever been are a clone: cuttings or cuttings of cuttings that were taken from the first ever Cox’s Orange Pippin tree that was produced (from a tree grown from a pip, or seed) in the nineteenth century. Cox’s Orange Pippin is only one of many hundreds of apple varieties, each with its own special character: Golden Delicious, Bramley, Jonagold, Arkansas Black, Discovery, and so on and so on. Each of those varieties is simply a clone. All belong to a single species, *Malus domestica*.

So how do we answer the very simple question “How many kinds of trees are there?” Well, in the wild (as in cultivation) you may find that what you construe to be different “kinds” are indeed different species; or they may be different varieties of the same species; or they may be hybrids of other pairs of species—hybrids that in the fullness of time may be perfectly capable of hybridizing again with some other, apparently quite separate, species. Then again, you may find two patches of aspens (or elms, or willows) that look quite different—and then learn that each patch is simply a clone and that the two clones are really from the same species and might even have arisen from seeds produced by the same parents. And if you ask a grower or a forester how many kinds of trees there are, he or she may well suggest that the number is virtually infinite, since growers regard each of the cultivars as distinct and know that there could be as many different kinds as breeders care to produce.

So let us be more specific and ask, with what surely is irreducible simplicity, “How many *species* trees are there?” At this point the biologists must surely stop prevaricating and provide a clear answer. But the only honest answer is: “Nobody knows.”

STILL COUNTING

In truth, we can never know for sure how many species of tree there are. As John Stuart Mill pointed out in the nineteenth century, it is impossible to know, in science, whether you know everything there is to know. However much you know, you can never be sure that nothing has escaped you. With trees there are many good reasons to think that a great deal *has* escaped us. Every so often some high and conspicuous tree turns up that either has never been seen before or is known only from fossils and has long been presumed extinct. Two classic examples are discussed in Chapter 5: metasequoia, the dawn redwood, and *Wollemia nobilis*, regrettably dubbed the Wollemi pine.

But there is also a practical reason for ignorance. Most kinds of trees, like at least 90 percent of organisms of all kinds, live in tropical forests, and tropical forests are very difficult to study—large because there are so many trees in the way. It requires hundreds of person-years, and heroic years at that, to list the species even in relatively small areas of tropical forest; and despite the best efforts of legal and illegal loggers, the tropical forest that remains to us is still mercifully vast—so that all of Switzerland, for example, could easily be lost in Amazonia. (Amazonia is the forest that surrounds the Amazon River; it occupies the western half of Brazil and extends into Peru, Colombia, Bolivia, and Ecuador. With a total area of more than 1.6 million square miles, it is about a hundred times bigger than Switzerland, which is a mere 16,000 square miles. Amazonia is also about sixteen times bigger than the United Kingdom, which is around 94,000 square miles.)

So it is that from the sixteenth century onward a succession of naturalists-cum-conquistadors, administrators, soldiers, traders, and priests became obsessed with the flora and fauna of tropical America and set out to identify, describe, and collect what was there. Dedicated research expeditions were mounted from the eighteenth century on, driven by scholarship and supported by empire and commerce—not least in search of new and valuable crops, of which rubber became the jewel. The greatest of all the explorers, so many believe, was the German Alexander von Humboldt, who together with the French physician and amateur botanist Aimé Bonpland, traveled six thousand miles in South America between 1799 and 1804, on foot and by canoe. They collected 12,000 specimens of plants, including 3,000 new species, and hence doubled the number known from the Western Hemisphere. On their return they published the thirty volumes of *Voyage aux régions équinoxiales* at von Humboldt’s expense (it cost him his entire fortune), of which von Humboldt wrote twenty-nine volumes and Bonpland contributed just one, although von Humboldt insisted that they share the authorship of the whole. The book was first published in English between 1814 and 1829 in five volumes, as *Narrative of Travels to the Equinoctial Regions of the New Continent During the Years 1799–1804*. The great revolutionary Venezuelan general Simón Bolívar (1783–1830) commented that “Baron Humboldt did more for the Americas than all the conquistadores.”

The young Charles Darwin loved von Humboldt’s writings and in the 1830s carried the *Narrative*

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