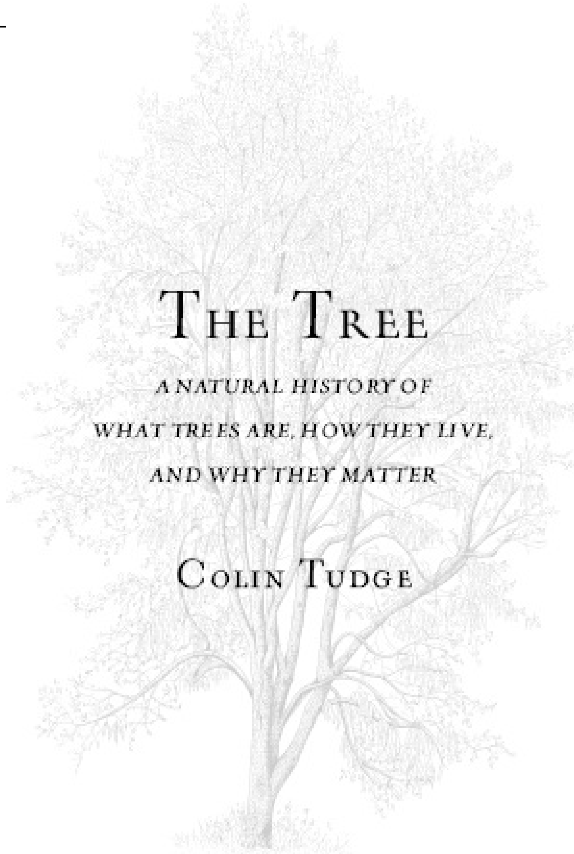
THE TREE

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

Colin Tudge



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To my grandchildren

ILLUSTRATIONS AND FIGURES

Original drawings by Dawn Burford

PREFACE

AT BOSCOBEL IN Shropshire in the English Midlands stands the Royal Oak, where the provisional Ki Charles II is alleged to have hidden from Cromwell's men after the Battle of Worcester, which ende his premature attempt to restore the monarchy. Why not? All this happened only about three and a ha centuries ago (1651) and oaks may live for two or three times as long as that. Robin Hood and h 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 twelf century, and the Major Oak was alive and well at that time. A yew I met in a churchyard in Scotlan has a label suggesting that the young Pontius Pilate may once have sat in its shade "and wonder what the future held." It's an audacious claim. But the tree was there, even if Pilate wasn't—alrea 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 give personal names), with a trunk like a lighthouse, that was four hundred years old when the Maoris fi arrived from Polynesia. For the first nine hundred or so years of Tane Mahuta's life, the moas, relate to ostriches but some of them half again as tall, would have strutted their stuff around its buttress base, threatened only by the commensurately huge but short-winged eagles that threaded their w through the canopy to prey upon them. Now the moas and their attendant eagles are long gone b Tane Mahuta lives on. Many a redwood still standing tall in California was ancient by the tim 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 bein invented writing and so are as old as all of written history. These trees out on their parched hills we already impressively old when Moses led the Israelites out of Egypt, or indeed when Abraham w 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, an there's an extraordinary banyan in Calcutta that would cover a football field. Many are host to s many other creatures that each is a city: as cosmopolitan as Delhi or New York and far more populou than either. Creatures of all kinds may feed on trees, or maraud among their branches. At least, I kno of no arboreal octopuses—but there could be, out in the mangroves. There's many a tree-happy crab the mangroves, as I have seen for myself, and the robbers of the Pacific islands, giant hermit crab come on land (as many crabs do) to feed on coconuts. When the Amazon is in flood—deep enough submerge well-grown trees entirely, over an area not far short of England—the fish feed on fruit an river dolphins race through the upper branches of what should be the canopy, while monkeys hop an swim from crown to crown like ducks. In New Zealand little blue penguins nest in the forest at nig with ground parrots (or at least they do on the sanctuary of Maud Island). In the 1970s, in the crown one fairly modest tree in Panama a scientist from the Smithsonian Institution counted eleven hundre different *species* of beetle—yet he didn't bother with the weevils, although they are beetles too, look closely at the host of creatures that are not beetles, or those that were living in the roots. I onc found myself in an old kapok tree in Costa Rica in which biologists had thus far listed more than fo thousand different species of creatures.

Yet a tree cannot afford simply to serve as someone else's monument and feeding ground. From th moment the seed falls on to the forest floor (or the sand of the savannah, or a fissure in som mountain crag, or a glacier's edge, or a lakeside, or a tropical seashore) to the moment of its fin demise, perhaps a thousand years later, the tree must compete through every second—for wate nutrients, light, and space; and to fend off cold, heat, drought, flood, toxicity, and the host of parasite and predators of all conceivable kinds (from a tree's point of view, squirrels or giraffes ar "predators"). A village or a civilization may choose to make a tree their symbol. The entire nation o 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 d not ~~fight it would be dead. Even when it sheds its leaves to ride out frost or drought, its cells~~ are st busy beneath its armored bark. Were it not so, the leaves could not burst out as they so spectacularl do when the temperate spring or the tropical rains return—or sometimes in advance of the rains, to th delight of camels and goats, which thus may find green fodder in the depths of drought. In many tree too, tropical and temperate, the flowers emerge before the leaves, which keeps the path clear f pollinating winds, bees, or bats. Since there are no leaves to provide nourishment, the flowers must b fed from the tree's reserves in its trunk and roots. The living timber is multipurpose: a prop, a condu a larder.

Flowers, of course (and the cones of conifers), meet life's other demand: not simply to survive an grow but to reproduce. Here, the trees' immobility is a particular drawback. Many trees reproduc without sex, commonly though not exclusively by root suckers, but all trees (to my knowledg practice sex as well. For sex, gamete must meet gamete: sperm and egg in the case of animals an primitive plants, pollen and ovule in the case of conifers and flowering plants. Since many flowers many trees are hermaphroditic (male stamens and female carpels on the same flower), and many tre (like oaks and many conifers) are monoecious (the individual flowers are exclusively male or femal but both kinds occur on the same tree), it may seem easy enough for trees to pollinate themselves. B on the whole they don't. One of the botanical surprises of recent decades (finally proven by genet studies) is the length to which most trees go to avoid self-fertilization. "Outcrossing" is the norm pollination of, and by, other individuals who, of course, are of the same species but preferably are n too similar genetically. To achieve outcrossing, trees must elicit the help of the wind—or bribe o 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 animal though most (like oaks and birches and beeches) are content to use the wind. But in tropical forest where most kinds of trees live, animal pollination is the norm; and because life is competitive, th mechanisms that have evolved for this have become more and more elaborate. Thus for every one the 750 different fig species there is a corresponding specialist wasp species to pollinate it; and eac wasp knows its own fig (although, as recent studies have shown, the relationship between figs an their wasps is not quite so cozy as had been supposed). When the ovules are fertilized and becom seeds, encased in fruits (or some other kind of fruiting body) they must then be dispersed—sometim again by wind but often by another, entirely separate, suite of animal accomplices—birds and fru 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 aft the same things, and most live directly at the expense of others. But it is also, just as inescapabl cooperative. Trees are good competitors. But they are also among the world's most exemplar cooperators, forming a host of mutualistic relationships for one purpose or another with an enormou variety of different creatures, from the bacteria and fungi that help them to feed to the many, man different kinds of animals that help them with different stages of their reproduction. Trees do n seem to be aware, as dogs and monkeys are aware. They do not have brains. But they are sentient their way; they gauge what's going on as much as they need to, and they conduct their affairs a adroitly as any military strategist. Why be "aware" when you can simulate all that awareness bring They surely don't think, as animals do. But they orchestrate their fellow creatures nonetheless. 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—o art, our inventiveness, and presumably much of our deviousness—to our sexuality. We dance ar paint and joke and tell stories to impress potential mates—or such at least was the crude beginning our wits, on which we have built. But pigs and squirrels and elephants are clever too. They also mu attract mates. So why have pigs produced no concert pianists or professors of jurisprudence? Anoth ingredient is needed—one suggested a long time ago by more conservative biologists. Our brains ar our dexterity evolved together: they are an exercise in coevolution. Pigs are clever, but their hands a hoofs: nothing there with which to express their dreams and insights. We, by contrast, can transla our thoughts into action: our artifacts (as Robert Pirsig put the matter in *Zen and the Art of Motorcyc 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 ther But because we have hands (at the end of long, strong, extremely mobile arms), brains did provic 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 th growing brains in turn encouraged more dexterity. But the only reason we have such dexterous hand and whirling arms is that our ancestors had spent eighty million or so years (so some zoologis calculate) in the trees. Arboreal life requires dexterity and hand-eye coordination. Squirrels almo became intellectuals, but not quite. Monkeys and apes came closer—but they stayed up in the tree where they are obliged to squander their fabulous skills just on getting around. Our ancestor somewhere in Africa, came to the ground when the climate dried up and the trees retreated. The learned to walk on two legs (which no other primate or any other mammal of any kind has learned do convincingly), freeing their versatile hands and arms for other purposes. Were it not for th pedigree we would remain as intellectually frustrated as elephants and dolphins sometimes seem be.

Archaeologists speak of the Stone Age, and the Bronze Age and the Iron Age and the Steam Ag and now we have the age of the internal combustion engine and nuclear power and space and IT. B every age has been a Wood Age—ours at least as much as any in the past; and perhaps the decades t come will be even more so. Ice Age Russians made houses from the bones of mammoths, the Inuit us ice, and the people of the Bronze Age Orkneys built remarkable villages, with restaurants ar mausoleums, from slabs of rock. But great architecture demands wood. The ruins that survive fro 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 i construction—and timber roofs and rafters. Wood, in this energy-conscious age, may well begin t 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 lea 500,000 years ago, long before we were as big-brained as we are now. No fuel: no smelting—so n Bronze Age or Iron Age or modern machines. No wood: no ships. No ships: no ocean travel—n human beings in Australia, New Zealand, or any other island that could not be reached simply b hitching a lift on floating vegetation (as many a beast is thought to have done, from rats to monkey and tortoises). No ocean travel: no empires: no modern politics. A woodless world would have ha 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 fo ~~tipping arrows, stunning fish, and killing pests; of resins, varnishes, and industrial oils, glues and~~ dy and paints; of gums of many kinds, including chewing gum; of a host of fibers for the rigging an hawsers of great ships (whether made of wood or not) and for the stuffing of cushions; and of cours perhaps above all these days, for paper. All that, plus a thousand (at least) kinds of fruits and nuts an —in traditional agrarian societies—a surprising amount of fodder for animals, including cattle an 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 ha disappeared after we had hit the ground, we would still be scrabbling like baboons (assuming th baboons had even allowed us to live).

Perhaps this is why we feel so drawn to trees. Groves of redwoods and beeches are often compare to the naves of great cathedrals: the silence; the green, filtered, numinous light. A single banyan, eac with its multitude of trunks, is like a temple or a mosque—a living colonnade. But the metaph should be the other way around. The cathedrals and mosques emulate the trees. The trees are innate holy. Christians with their one omnipotent God may take exception to such pagan musing; but th totaras and the kauris were sacred to the Maoris, and the banyan and the bodhi and the star-flowere temple trees (and many, many others) to Hindus and Buddhists, and the roots of this reverence, on 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 ca the Middle Ages, the Indians, the Chinese, the Jews, and the much underappreciated natural history o all hunter-gatherers and subsistence farmers everywhere. But it was the Christians from the thirteen century onward, with an obvious climax in the seventeenth, who gave us science in a recognizab 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 tha that. The great founders of modern thinking—Galileo, Newton, Leibniz, Descartes, Robert Boyle, th naturalist John Ray—were all devout. For them (as Newton put the matter) science was the proper u of the God-given intellect, the better to appreciate the works of God. Pythagoras, five centuries befo Christ, saw science (as he then construed it) as a divine pursuit. Galileo, Newton, Ray, and the rest sa 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 Pythagoras and Galileo, but I don't think it's too pretentious to aspire at least to drink at the sam 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 th are purely material they must be conserved: our survival depends on them. Most of this boo however, is not about their usefulness but about what they *are:* how they came into being, what kin there are and where they live and why, and how they live, competing and cooperating. The revelation build by the week: how they may live and grow huge on what seems like nothing at all; how they dra prodigious quantities of water from the ground, send it up into the atmosphere, and then (so some hav claimed) may call it in again, by releasing organic compounds that seed fresh clouds; how they spea to one another, warning others downwind that elephants or giraffes are on the prowl; how they mim 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 ar more and more like the world's appointed governors, ultimately controlling all life on land (and in th oceans too, vicariously), but also the key to its survival.

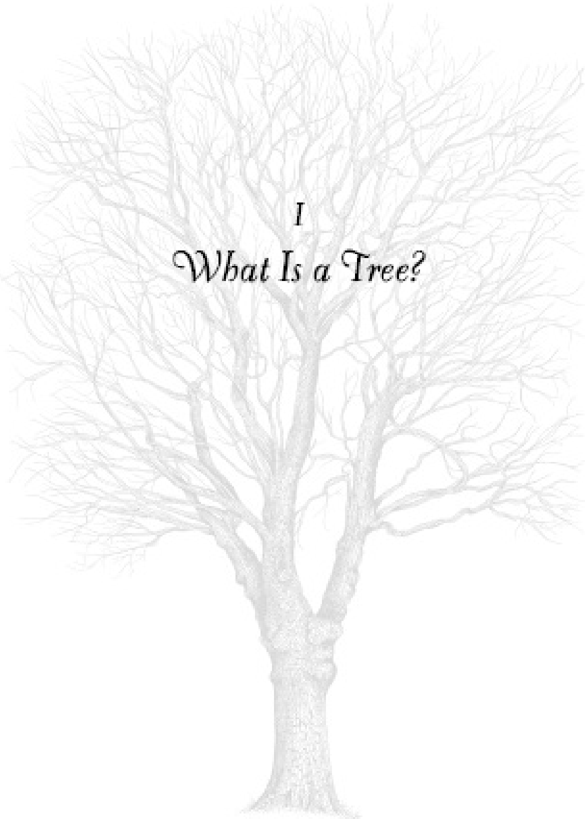
So this book presents science not as it is often presented, as a tribute to human cleverness ar power, but truly in a spirit of reverence. I like the idea (I have found that some people don't, but I d that each of us might aspire to be a connoisseur of nature, and connoisseurship implies a combinatio of knowledge on the one hand and love on the other, each enhancing the other. Conservation—of a living creatures, including trees—has little chance of long-term success without understanding, whic depends in large measure on excellent science. But conservation cannot even get on the agenda unle people care. Caring is an emotional response, to which science has often been presented as th antithesis. In truth, science cannot be done properly without a cool head. Yet when the science is don its primary role (to reverse an adage of Marx's) is not to change the world but to enhanc appreciation. That is the purpose of this book. Science in the service of appreciation, and appreciatio in the service of reverence, which, in the face of wonders that are not of our making, is our only prop 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. Steven and Michael J. Donoghue, (editors), *Plant Systematics*, 2nd ed. (Sunderland, Mass.: Sinau Associates, 2002).

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



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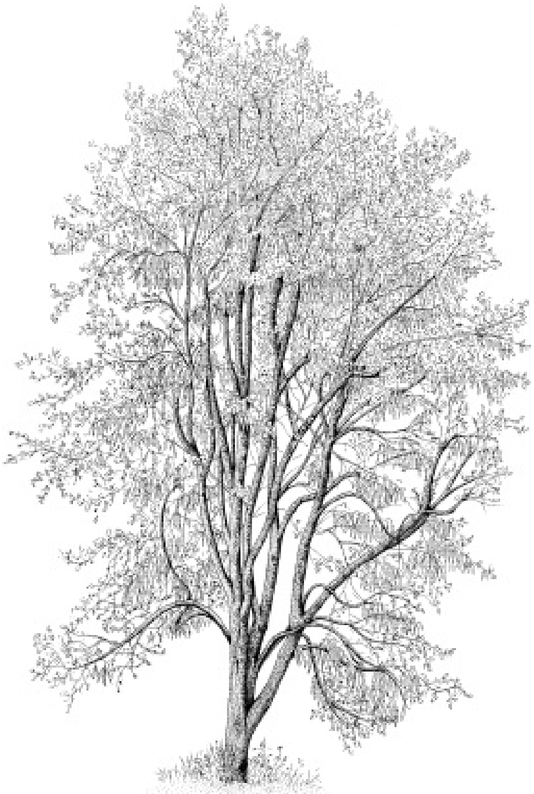
What Is a Tree?



Round-leaved and altogether beautiful: the Judas tree.

1

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 g to the heart of things. Children ask ridiculously simple questions—like “Who made God?”—that hav kept theologians busy for many a century. In such a vein we might innocently inquire, “And wha pray, are trees, that anyone should presume to write a book about them?” And “*Why* do plants gro 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 ca a little “deconstruction.”

What, for a start, is meant by “big”? It’s a relative term, of course, although if we choose we ca put a figure on it—say, a minimum height of five or six meters. There is a case for doing this: if yo are a forester, or are running a nursery, you need some guidelines. But guidelines are not definition 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 a noble tree in a forest or a park, but an acorn that falls in a fissure in some Scottish crag may spend couple of centuries in bonsai mode, never more than a twisted stick. Yet it may turn out acorns that, they should be carried to some fertile field, could again produce magnificence. Is the twisted stick le 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 an oak may often be, but most are perfectly respectable trees. Yet there is one, *Betula nana*, that adapted to the tundra of the north of Scotland and mainland Europe and is very small indeed. Do w 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 alof

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

Then again, many big trees, including some cedars, many a mulberry, and the beautiful blu flowered jacaranda, may grow from ground level with several solid trunks of equal magnitude. Eac 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 Unite States, with their beautiful flaky, yellow, pink, and gray trunks (which add yet more color to th already wondrous hills of California). Rhododendrons tend to have many stems, while madrones a commonly content with one. But the rhododendrons can be just as big and solidly wooden as th madrones. In nature, in short, trees and shrubs are not distinct. Why should they be? Nature was n 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, the should we categorize banana plants? In general shape they resemble palm trees, with a thick centr stem and a whorl of huge leaves at the top. But the stem of the banana plant is not made of wood. I stem is formed largely from the stalks of the leaves, and its strength comes from fibers that are n bound together, as in pines or oaks or eucalypts, to form true timber; its hardness is reinforced, as in cabbage stalk, by the pressure of water in the stem. So botanically the banana plant is a giant herb. B it looks like a tree and competes with trees on their own terms, as a big plant seeking the lig (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 d with one another except that they are all plants. Many plants, in many of those lineages, hav independently essayed the form of the tree. Each achieves treedom in its own way. “Tree” is not distinct category, like “dog” or “horse.” It is just a way of being a plant. The different kinds hav much in common, and it is good and necessary to have some feel for what is essential. But th essences of nature will not be pinned down easily. In the end, *all* definitions of nature are simply f convenience, helping us focus on the particular aspect that we happen to be thinking about at the tim There is no phenomenon in all of nature—whether it’s as simple as “leg” or “stomach” or “leaf” more obviously conceptual like “gene” or “species”—that does not take a variety of forms, and th cannot be looked at from an infinite number of angles; and each angle gives rise to its own definitio A horse cannot be encapsulated, as Charles Dickens’s Thomas Gradgrind insisted in *Hard Times*, as graminivorous quadruped.” There is more to horses than that. The way we define natural thin influences the way we treat them—whether we speak of wildflowers or of weeds, of Mrs. Tittlemou or of vermin. But in the end nature is as nature is, and we must just try with different degrees 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 slig elaboration: "A tree is a big plant with a stick up the middle—or could be, if it grew in the rig circumstances; or is very closely related to other plants that are big and have a stick up the middle; resembles a big plant with a stick up the middle." It is clumsy, but it will have to do. So to the ne 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 endures—until it is melted in some volcano, or dissolved by acid rain. But living things are restles through and through. As soon as some living cell has constructed some protein, as part of its ow fabric, it starts to dismantle it again. This constant self-renewal, powered by an endless intake energy, is called metabolism.

Metabolism—the basic business of staying alive—is half of what living things do. The other half reproduction. It is not vital to reproduce in order to stay alive. Indeed, reproduction involves sacrific reproduction, as we will see later in this book, is often the last fling: many a tree dies after one bout it. But it is essential nonetheless. At least, all creatures that do not reproduce die out. Howev successfully an organism may metabolize, sooner or later time and chance will finish it of Everything dies. Only those that reproduce endure—or, at least, their offspring do. All individuals a 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 different kinds. To some extent they are its rivals, to some extent it needs them—for food, shelte mates, or whatever. Each successful creature, then—each one that survives at all, that is—must com to terms with the others around it.

All of life's requirements—metabolism, reproduction, and the business of getting along with othe —are difficult. Each creature must solve life's problems in its own way. There is no perfect, univers 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. plant that is big like a tree can stretch farther up into the sky, and so capture more of the sun's energ and it can reach farther down into the earth, for water and minerals. This is the upside. But it takes long time to achieve large size, and whether you are an oak tree or an elephant or a human being, t 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 enormou strength: specialist material like wood, and clever architecture. All trees have wood, by definitio (apart from those granted honorary status, like bananas); but as we will see, wood is subtle stuf requiring much chemistry and microgeometry. The many types of trees have essayed ma architectural forms. Ginkgoes and conifers are built from repeats of a single simple module: a straig trunk up the middle with circles or spirals of branches at intervals. In others, like the elm, the lea shoot bends over and the next shoot in line takes over the lead, until it too bends away and the on below that takes over. In yet others (particularly some tropical trees), the branches that grow upwa from the horizontal branches repeat the form of the whole tree—it’s as if a new, miniature forest gre aloft, from the horizontal branches of the giants below. And still others, like oaks or chestnuts, a more free-flowing. There are many basic designs. The point is, though, that such design is *necessar* 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 regular 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 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 them. K-strategists tend to be long-lived and reproduce several times in their life, often at lon intervals. Orangutans, elephants, eagles, and indeed human beings are classic K-strategists. Oth creatures, known as r-strategists, produce an enormous number of offspring. Inevitably, eac individual offspring is small, and so has little chance of survival. But there is safety in number Codfish are noted r-strategists. They produce up to two million eggs at a time. The newly hatched fis live for a while as plankton, floating fairly helplessly—and most perish: they just get eaten. But long as each pair of codfish manage to produce just two surviving offspring in the course of the lives, the lineage of cod will carry on. Despite the enormous prodigality of their reproductive strateg its fantastic wastefulness, codfish are immensely successful—or at least they were until North S fishermen became too technically proficient, or too “competitive,” and disastrously reduced the numbers. Cod live a long time. But many r-strategists, like flies, run through their entire life cycle in few weeks: birth, growth, reproduction, death. Thus populations of flies may rise and fall from ne 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 ma do so repeatedly. A mature oak or beech may produce many millions of seeds in a good year (goo seed years are known as “mast” years), and although they won’t do this every year, they may we have scores or even hundreds of prolific years in the course of their lives. They are r-strategis indeed, in a good year at least as prolific as codfish. Yet many trees—including oaks—produce seed that are large and that do not need to germinate immediately: each has a very good chance of surviva To this extent they are K-strategists too. To combine the advantages of the K- and r-strategies a organism must be truly mighty. Yet there is a downside too: most trees must grow for several year and many must endure for several decades, before they can reproduce at all; and all that time they a vulnerable.

We don’t think of trees as r-strategists, because they are so big and long-lived. Their populations d not boom and bust like those of flies. They cannot, we imagine, leap to take advantage of new created environments as a fly or a mouse may do. Yet once we venture beyond our own pun timescale and take the long view, we see that they can and do do this. Thus when the last ice age ende in the Northern Hemisphere, around ten thousand years ago, the forests of birches and alders that ha been whiling away the time farther south were able virtually to race toward the North Pole in the wal of the retreating glaciers; and they will surely resume their advance as global warming reduces th ~~polar ice still further. By the same token, the huge tropical rain forest of Queensland, in the Souther~~ Hemisphere, has not been there forever, as it may seem. Like the Great Barrier Reef, which stands ju off the Queensland coast and is as long from end to end as Great Britain, the rain forest of Austral grew up only after the last ice age and is a mere ten thousand years old. Macbeth was shocked to se the Great Wood of Birnam shift a few miles across the moor to the Hill of Dunsinane. But if we coul take a time-lapse view of all the world this past few million or tens of millions of years, as cold h followed warm has followed cold, we would see vast and apparently immovable forests flitting ov the surface of the globe like the shadows of clouds.

Thus the advantages of treedom are both manifold and manifest. Big plants can metabolize mo 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 complicated—all that chemistry and architecture—and it is risky, because all the time a tree growing, time and chance and other creatures are working on its downfall. So it is that many oth plants, such as mosses and liverworts, never acquired the means to be big at all; but they have st made a very good living during the past 400 million years, just by sticking to damp and easy place Then again, trees cannot grow where it's too dry or the soil is too thin, and so they leave scope fo many smaller plants that can. So the world's grasslands are vast too, like the savannahs of the dr tropics, the prairies of temperate North America, the pampas of subtropical South America, and th 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 o Brazil. Furthermore, trees are classic keystone species: simply by existing and doing their thing, the create niches where other creatures can live. Hence forests create endless scope for small, quic growing plants—herbs and ramblers—to occupy the ground in between the trees; and a vast variety plants of all kinds (mosses, liverworts, ferns, and many kinds of flowering plants, including man relatives of the arum lily and of the pineapple, some cacti, and most of the orchids) grow on the tre themselves, as epiphytes. Overall, too, there is more room for small plants than for big ones. Whol viable populations of small plants may need only a few square yards, while a population of wild tre that is numerous enough to endure will generally need many acres. So although there are tremendou theoretical advantages in being a tree, the species of trees are outnumbered by nontree plants by abo 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 irritatin 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 specie *Quercus robur*. So is the Scotch pine: *Pinus sylvestris*. A common birch in Europe is *Betula pendul* and so on. What's the problem?

One problem involves how you tell the different kinds apart. Any one species is liable to be high ~~variable, and sometimes different species resemble each other very closely. Sometimes there is~~ mo variation *within* species than there is between species. Or then again: many creatures can be identifi definitively only by their reproductive organs, which in the case of flowering plants (including mo trees) means flowers. But many trees are not in flower at the time you come across them—a particul problem in the tropics, where flowering often seems to be erratic (or perhaps the tree knows when it appropriate to flower, but the biologist does not). Some trees with similar flowers have differe 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 san time. If you want to know what species a particular willow belongs to, you may have to make tw visits.

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

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

Still, there are problems. For example, two apparently different species that look different may fa to interbreed in the wild simply because they live in different places. Bring them together, howeve 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 fro very different areas together, perhaps for the first time in many thousands of years. Among the mo striking examples is the London plane, *Platanus x acerifolia* (the x indicates its hybrid status). It 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 s difficult for many other kinds of tree. It is the offspring of the Oriental plane from southern Europ and Turkey, *Platanus orientalis,* and the sycamore from eastern North America, *Platanus occidentali* and arose, so tradition has it, in the Botanic Garden of Oxford University, in the seventeenth centur An offspring of the first-ever London plane stands in a courtyard in Magdalen College, which is ne to the Botanic Garden. That offspring, now several centuries old, is huge. For those who would b connoisseurs, it is well worth a diversion (assuming the porters will let you in). Of course, once nov trees appear in botanic gardens, botanists and gardeners all over the world flock to get hold of ther 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 thes days, are aligned along chromosomes. Every kind of organism has its characteristic number ar arrangement of chromosomes. Eggs and sperm (or the appropriate cells in ovules and pollen) conta only one set of chromosomes, and are said to be “haploid.” When they fuse in the act of fertilizatio the resulting embryo has two sets of chromosomes and then is said to be “diploid.” Most organism (at least of the most familiar kinds) are diploid: for example, human beings have forty-s chromosomes—twenty-three acquired via the egg of the mother and twenty-three from the sperm the father. Chimpanzees have forty-eight chromosomes, twenty-four from each parent.

Sometimes, however, apparently spontaneously, the chromosome number will double. (Th chromosomes divide in the normal way they do in preparation for cell division, but then the cell fai to divide.) Thus the diploid cell becomes tetraploid, with four sets of chromosomes. This does n apparently happen much in animals (or not, at least, in mammals), but it is extremely common plants. The newly formed tetraploid organism can breed successfully with other tetraploids of its ow kind, but it cannot usually breed successfully with either of its parents. So it forms an instant ne species. Many plants in nature turn out to be tetraploid, and many more tetraploids have bee produced in cultivation. The common potatoes grown in Europe are tetraploid derivatives of diplo potatoes that grow wild (and are cultivated) in the Andes. Many trees, wild and cultivated, a tetraploid. Sometimes the chromosomes of the tetraploid plant double again to produce octoploid These octoploids form new, discrete species—generally unable to interbreed with the tetraplo parents who gave rise to them. “Polyploid” is the general term that describes any organism with mo than two sets of chromosomes. Sometimes the complications become too much even for the plants ar they end up with an odd number of chromosomes (some having been lost among all the cell divisior and matings). Plants with anomalous numbers of chromosomes are said to be “aneuploid.” Aneuploid in animals generally leads to various degrees of disorder; aneuploid animals usually die, and if the live they tend to be compromised at least to some extent. But many plants put up with aneuploid 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 specie sometimes mate to produce fully viable offspring (as the eastern and the western species of *Platan* evidently did). But usually such crosses fail, and often this is because the chromosomes of the tw parents are incompatible. The two different sets of chromosomes might be able to support body cel that work well enough (as in the mule). But even if cells with two different kinds of chromosom succeed this far, they will not necessarily produce sound gametes (eggs and sperm or ovules ar 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 fir diploid parents of different species mating to produce diploid hybrid offspring that are sterile; but th hybrids then double their chromosomes and become tetraploid—and the hybrid tetraploids are fertil This happens a lot among plants, and has produced many, many new plant species, both in the wi and in cultivation. Indeed, the complications seem endless. For instance, a tetraploid plant might ma with a closely related diploid plant to produce a triploid offspring—two sets of chromosomes from th tetraploid parent, and one set from the diploid parent. Triploids are sterile—they cannot produ ~~gametes at all—but they may still form viable plants. Thus the cultivated banana is triploid. Becau~~ it is sterile, its fruits contain no seeds (as wild banana fruits do). So the domestic banana has to b 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 importa 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 th fantastical. But among trees, hundreds of examples of polyploids are now known; the more th botanists look, the more polyploids they find. Some of the polyploids simply represent a doubling (redoubling) of chromosomes within one species. Others are polyploid hybrids. For good measur breeders have produced many hundreds of polyploids by artificial means. (Some chemicals induc polyploidy almost to order.)

Willows, genus *Salix*, provide many fine examples of polyploid trees. There seem to be around fo hundred species—although there must be many more that are still unknown, including an enti phalanx in western China, yet to be properly studied. Some willow species have a haploid number 19 chromosomes, so that the diploids have 38 (2 × 19). But another group of willows has a haplo number of 11 (diploid 22), and the third group has 12 (diploid 24). There doesn't seem to be muc hybridization between willows with different haploid numbers, but there is a great deal hybridization between different species with the same haploid number, and this has produced a who array of polyploids, some with as many as 224 chromosomes. Most of those polyploid hybrids a fertile, and some willows have been bred artificially from combinations of up to fourteen differe species. For good measure, many of the hybrids are all of one sex and reproduce by suckers, so that a the members of such "species" in fact form a clone (of which more later). Thus, the hybrid known *Salix x calodendron* is all female. Many willows, too, both wild and in cultivation, are aneuploid. A in all, identification of the multifarious willows—the diploid types and all their polyploid hybrids— 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 tropica grasslands worldwide that provide such essential shade and fodder for giraffes, camels, gazelles, an the domestic cattle and goats of nomadic pastoralists. *Acacia* is a huge and messy genus, with 1,30 species—which should probably be further subdivided, perhaps into five or more different genera. B that as it may, the basic haploid number of the whole group is 13, so the default diploid number is 2 but there are polyploids with up to 208 chromosomes—sixteen times the haploid number. In some o these, it's clear that the ancestor simply doubled (and then sometimes redoubled) its chromosome 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 11 chromosomes, which means they are octoploid: and there are some aneuploid hybrids in cultivatio In northern Europe, the silver birch, *Betula pendula*, and the downy birch, *B. pubescens*, can look ve similar, and some botanists have suggested that they are the same species. But the silver birch is diploid, with 28 chromosomes, and the downy birch is a tetraploid, with 56. The downy birc presumably arose from the silver birch, but now, following polyploidy, it is very clearly a separa species. Alders, too, show much the same kind of thing. Clearly the variety depends in part on pa hybridization of what had been separate species.

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

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

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

Thus, among apples, all the Cox’s Orange Pippins there have ever been are a clone: cuttings cuttings of cuttings that were taken from the first ever Cox’s Orange Pippin tree that was produc (from a tree grown from a pip, or seed) in the nineteenth century. Cox’s Orange Pippin is only one many hundreds of apple varieties, each with its own special character: Golden Delicious, Braml Jonagold, Arkansas Black, Discovery, and so on and so on. Each of those varieties is simply a clon 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 th wild (as in cultivation) you may find that what you construe to be different “kinds” are inde different species; or they may be different varieties of the same species; or they may be hybrids other pairs of species—hybrids that in the fullness of time may be perfectly capable of hybridizi again with some other, apparently quite separate, species. Then again, you may find two patches aspens (or elms, or willows) that look quite different—and then learn that each patch is simply a clo and that the two clones are really from the same species and might even have arisen from see produced by the same parents. And if you ask a grower or a forester how many kinds of trees there a 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 produc

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 answe~~ 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 pointe out in the nineteenth century, it is impossible to know, in science, whether you know everything ther is to know. However much you know, you can never be sure that nothing has escaped you. With tree there are many good reasons to think that a great deal *has* escaped us. Every so often some high conspicuous tree turns up that either has never been seen before or is known only from fossils and h long been presumed extinct. Two classic examples are discussed in Chapter 5: metasequoia, the daw 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 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 that, to list the species even in relatively small areas of tropical forest; and despite the best efforts legal and illegal loggers, the tropical forest that remains to us is still mercifully vast—so that all Switzerland, for example, could easily be lost in Amazonia. (Amazonia is the forest that surrounds th Amazon River; it occupies the western half of Brazil and extends into Peru, Colombia, Bolivia, an Ecuador. With a total area of more than 1.6 million square miles, it is about a hundred times bigge than Switzerland, which is a mere 16,000 square miles. Amazonia is also about sixteen times bigg 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-conquistador administrators, soldiers, traders, and priests became obsessed with the flora and fauna of tropic America and set out to identify, describe, and collect what was there. Dedicated research expedition were mounted from the eighteenth century on, driven by scholarship and supported by empire an commerce—not least in search of new and valuable crops, of which rubber became the jewel. Th greatest of all the explorers, so many believe, was the German Alexander von Humboldt, wh together with the French physician and amateur botanist Aimé Bonpland, traveled six thousand mile in South America between 1799 and 1804, on foot and by canoe. They collected 12,000 specimens plants, including 3,000 new species, and hence doubled the number known from the Wester Hemisphere. On their return they published the thirty volumes of *Voyage aux régions équinoxiales* von Humboldt’s expense (it cost him his entire fortune), of which von Humboldt wrote twenty-nin volumes and Bonpland contributed just one, although von Humboldt insisted that they share th authorship of the whole. The book was first published in English between 1814 and 1829 in fiv volumes, as *Narrative of Travels to the Equinoctial Regions of the New Continent During the Year 1799–1804*. The great revolutionary Venezuelan general Simón Bolívar (1783–1830) commented th “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 *Narrati*