Chapter 1: An overview

What is a tree?

Everyone knows what a tree is: a large woody thing that provides shade. Oaks, pines and similarly large majestic trees probably come immediately to mind. A stricter, botanical definition is that a tree is any plant with a self-supporting, perennial woody stem (i.e. living for more than one year). The first question that normally comes back at this point is to ask what then is a shrub? To horticulturalists, a 'tree' is defined as having a single stem more than 6 m (20 ft) tall, which branches at some distance above ground, whereas a shrub has multiple stems from the ground and is less than 6 m tall. This is a convenient definition for those writing tree identification books who wish to limit the number of species they must include. In this book, however, shrubs are thought of as being just small trees since they work in exactly the same way as their bigger neighbours. Thus, 'trees' cover the towering giants over 100 m through to the little sprawling alpine willows no more than a few centimetres tall.

Some plants can be clearly excluded from the tree definition. Lianas and other climbers are not self-supporting (although some examples are included in this book), and those plants with woody stems that die down to the ground each year, such as asparagus, do not have a perennial woody stem. Bananas are not trees because they have no wood (the trunk is made from leaf stalks squeezed together). Nor are bamboos trees since they are just hardened grasses even though they can be up to 25 m tall and 25 cm thick (see Box 1.1).

An interesting feature of trees is how unrelated they are. It is generally easy to say whether a plant is an orchid or not because all orchids belong to the same family and share a similarity in structure (especially the flowers). This is true of most plant groups such as grasses and cacti (in their own families) and chrysanthemums (all in the same genus). But the tree habit has evolved in a wide range of plants so there is no other similarity other than being tall with a perennial skeleton. Box 1.1 illustrates how many groups have evolved the tree habit. This is a superb example of 'convergent evolution' where a number of unrelated types of plant have evolved the same answer—height—to the same problem: how to get a good supply of light.

On the whole, this book is concerned with the two biggest groups of trees. These are the **conifers** and their allies, and the **hardwoods** like oak, birch and so on. (As you can see from Box 1.2 the terminology can be confusing, so throughout

Box 1.1 The range of trees found in different plant groups

Ferns (Pteridophytes)	Tree ferns: all in the family Cyatheaceae; rarely branched, no true bark and with a trunk containing woody strands; need frost-free shaded habitats
Conifers and their allies: Gymnosperms. This term means 'naked seeds' (as in gymnasium, where the Greeks exercised naked); the seeds are exposed to the air and can be seen in the cone or fruit without having to cut anything open	Conifers: 600+ species in three families Cupressaceae: cypress, junipers Taxodiaceae: redwoods Pinaceae: pines, spruces, larches, hemlocks, firs, cedars Taxads: *c.* 20 species Taxaceae: yews Ginkgo: 1 species Ginkgoaceae: the ginkgo or maidenhair tree (*Ginkgo biloba*) Cycads: palm-like with stiff leathery leaves Gnetales: a strange group with a few interesting woody plants *Welwitschia mirabilis*: single species in SW Africa *Gnetum*: mostly tropical climbers *Ephedra*: 30+ low shrubs of dry deserts
Flowering plants: Angiosperms. This means hidden seeds: contained inside a fruit	**Dicotyledons** The main group of trees such as oaks, birches, etc. Around 75 of the world's 180 families contain trees **Monocotyledons** A wide-ranging set of trees concentrated in a few families Palmaceae: palms; mostly tropical, a few temperate; nearly 3000 species Agavaceae: dragon trees (*Dracaena* spp.); mostly N. African Pandanaceae: screw pines (*Pandanus* spp.); Old World Tropics. Stilt roots supporting a stout forked trunk

Box 1.1 *(cont.)*

Liliaceae:
aloes (*Aloe* spp.); Southern Africa
yuccas (including the Joshua tree, *Yucca brevifolia*)
cordyline palms (*Cordyline* spp.); Australia and New Zealand
European butcher's brooms (*Ruscus* spp.)
Xanthorrhoeaceae: grass trees (*Xanthorrhoea* spp.); Australia. Short trunk with forked branches and long narrow leaves
Strelitziaceae: traveller's palm (*Ravenala madagascariensis*)

Monocotyledons that are not trees
Musaceae: bananas (*Musa* spp.). The trunk is made from leaf stalks squeezed together
Poaceae: bamboos (e.g. *Dendrocalamus* spp.) are just hardened grasses with no wood

this book we will stick to conifers and hardwoods as shorthand for gymnosperms and dicotyledon angiosperms.) The monocotyledon trees such as palms and dragon trees are mentioned in passing but on the whole they grow in a different way from conifers and hardwoods and the book can only be so long. Purists might indeed argue that since the trunks of these trees contain no real 'wood' (Chapter 3) they are not trees anyway. Tree ferns (Box 1.1) come into the same category.

A short history of trees

Back in the Silurian, over 400 million years ago, the first vascular plants (those with internal plumbing) appeared on the Earth. From these the first trees evolved in the early Devonian around 390 million years ago. Within 100 million years, the coal-producing swamps of the Carboniferous (360–290 million years ago) were dominated by lush forests. We would have recognised the tree ferns from today's forests but the others—giant horsetails and clubmosses—have long since disappeared leaving us just a few small relatives. The horsetails such as *Calamites* were up to 9 m tall and 30 cm in diameter but the clubmosses (notably *Lepidodendron*) must have been magnificent at up to 40 m high and a metre in diameter. In these forests the first primitive conifers appeared and by around 250 million years ago (the late Permian) trees such as cycads, ginkgos and monkey

Box 1.2 Definitions that go with the two main groups of trees

Throughout this book the terms **Conifers** and **Hardwoods** will be used as shorthand for Gymnosperms and Angiosperm trees.

Gymnosperms	**Angiosperms**

As explained in Box 1.1, these are the proper botanical terms but a little hard to digest.

Conifers and their allies	The rest

As you can see from Box 1.1 the gymnosperms include more than just the conifers but they are the major component.

Softwoods	**Hardwoods**

The problem with these descriptive terms (which stem from the timber industry) is that although most gymnosperms *do* produce softer wood, there are many exceptions, and many hardwoods can be physically soft. Yew (*Taxus baccata*, a softwood) produces very dense and hard wood, whereas some Hardwoods, like balsa (*Ochroma pyramidale*), are very soft and easily broken or indented with a fingernail.

Evergreens	**Deciduous trees**

Exceptions can be found here as well. The dawn redwood (*Metasequoia glyptostroboides*), the swamp cypress (*Taxodium distichum*) and larches (*Larix* species), for example, are deciduous gymnosperms. In contrast, European holly (*Ilex aquifoilium*), rhododendrons and many tropical angiosperms are evergreen.

Needle trees	**Broadleaved trees**

Most conifers indeed have needle-shaped leaves but again there are exceptions. The ginkgo tree (*Ginkgo biloba*) and monkey puzzle (*Araucaria araucana*) have definite broad flat leaves (admittedly these trees are easily identified oddities). Cycads, which are primitive gymnosperms, have long divided leaves that resemble those of palms. Some angiosperms have reverted to needle leaves or have largely lost their leaves and use their needle-like branches as leaves, e.g. gorses (*Ulex* spp.) and brooms (*Cytisus* spp.).

puzzles were recognisable: the sort of trees found fossilised in the petrified forest of Arizona. The pines were not far behind, probably evolving around 180–135 million years ago (Jurassic) to share the earth with the dinosaurs.

Conifer domination was long and illustrious but the early hardwoods were diversifying during the early Cretaceous, around 120 million years ago. The hardwoods probably evolved from a now extinct conifer group that had insect-pollinated cones. The magnolias are some of the earliest types of hardwood that we still have around. During the Cretaceous period and into the early Tertiary (65–25 million years ago) the hardwoods underwent a massive expansion, displacing the conifers, undoubtedly helped by the warm humid global climate of the early Tertiary.

At the end of the Permian period, around 250 million years ago, most of the Earth's land masses were squashed together into the old super-continent of Pangaea. By the time the hardwoods had evolved, Pangaea had broken into Laurasia (which gave rise to the northern hemisphere continents) and Gondwanaland (containing what is now Australia, Africa, South America, India and Antarctica), trapping the pines primarily in the northern hemisphere. Laurasia and Gondwanaland themselves broke apart later, which goes some way to explaining why the hardwoods of the northern and southern hemisphere are so different from each other and yet remarkably similar around the globe within a hemisphere.

By 95 million years ago (midway through the Cretaceous period) a number of trees we would recognise today were around: laurels, magnolias, planes, maples, oaks, willows and, within another 20 million years, the palms. When the dinosaurs were disappearing (by 65 million years ago) the hardwoods were dominating the world with the conifers exiled mostly into the high latitudes.

Living fossils

Most of the types of tree we see every day have been around for a long time. Perhaps the most incredible are the growing number of rediscovered 'living fossils': trees known from the fossil record and which were thought to have become extinct and yet have been found hanging on in remote parts of the world. The most famous is the ginkgo (Japanese for 'silver apricot', named after the fruit) or maidenhair tree (*Ginkgo biloba*), a Chinese tree known from the fossil record back about 180 million years—the Jurassic era—and 'rediscovered' in Japan by Europeans in 1690. The dawn redwood (*Metasequoia glyptostroboides*) was similarly refound in 1945 in China, and more recently in 1994 the Wollemi pine (*Wollemia nobilis*, a member of the monkey puzzle family, Araucariaceae) was found growing in Wollemi National Park near Sydney, Australia. In these plants you can see real history (or prehistory) and touch plants that would have been familiar to the dinosaurs!

The value of trees

Over their long history, trees have played an important part in our lives. Trees have been (and still are) sacred to many peoples; oaks were sacred to the European Druids, baobabs (*Adansonia digitata*) to African tribes, the ginkgo (*Ginkgo biloba*) to the Chinese and Japanese, sequoias to North American Indians, and monkey puzzles to the Pehuenche people of Chile. Indeed, many of our words and expressions are derived from a close association with trees. Writing tablets were once made from slivers of beech wood (*Fagus sylvatica*), hence 'beech' is the Anglo-Saxon word for book. Beech is still called 'bok' in Swedish and 'beuk' in Danish. Romans crowned athletes with wreaths of the bay laurel (*Laurus nobilis*); this was extended to poets and scholars in Middle Ages, hence Poet Laureate. Similarly, Roman students were called bachelors from the laurel berry (baccalaureus) leaving us with bachelor degrees (baccalaureate) and, since Roman students were forbidden to marry, unmarried bachelor males.

Despite modern technology, we are still very reliant on wood as a raw material. The world's annual consumption of timber is currently more than 2300 million cubic metres (a well-grown conifer in a European plantation contains around 1–2 m^3 of wood at maturity). This is used for anything from building to paper-making to the creation of chemicals including synthetic rubber. We get a million matchsticks from an average Canadian aspen. Cloth has historically been made from tree bark by the Polynesians and Africans and we can now make rayon from wood. (Incidentally, wooden chopping boards show mild antibacterial properties and so are better than the seemingly more hygienic plastic ones!)

Numerous things we eat and drink come from trees. From the Old World comes citrus fruit, cinnamon (*Cinnamomum verum*), cloves (*Eugenia caryophyllus*), nutmeg (*Myristica fragrans*), coffee (*Coffea arabica* and *C. robusta*), tea (*Camellia sinensis*) and carob (*Ceratonia siliqua*). From the New World we get, among others, papaya (*Carica papaya*), avocado (*Persea americana*), cocoa (*Theobroma cacao*) and the Brazil nut (*Bertholletia excelsa*). There are also oils such as olive oil (*Olea europaea*) and palm oil (*Elaeis guineensis*), the latter from tropical W Africa and used for margarine, candles and soap. The artificial vanilla flavour of cheap ice-cream is a chemical derivative of wood. And cellulose extracted from wood is a common ingredient in instant mashed potato (and disposable nappies). Medicinal compounds from trees are legionary, including quinine (*Cinchona* spp.[1] 'Jesuit's bark' from Peru and Ecuador) used to fight malaria (hence the colonial passion for gin and tonic, a palatable way of taking your bitter quinine medicine). Others are still being discovered: extracts from the ginkgo are currently being advocated for improving blood flow to the brain to improve memory, particularly in those suffering from Alzheimer's disease.

Trees fulfil many other uses. Where would we be without rubber, most of

[1] Throughout this book the abbreviation 'spp.' is used for species.

which comes from one species (*Hevea brasiliensis*)? Or brake linings in our cars (which can be made from lignin extracted from wood)? We can even run our vehicles on wood. One tonne of wood can produce 250 l of petrol; thus 4–5 t would keep a family on the road for a year. In urban areas, trees trap and absorb pollutants, and moderate the climate. It is no wonder that studies have shown trees in urban areas to be a contributor to reducing stress and speeding healing in hospitals. A single mature beech tree can produce enough oxygen for 10 people every year and fix 2 kg of carbon dioxide per hour. New uses are still being found for trees. Genes for a sweet-tasting but low-calorie compound called monellin have been taken from a tropical shrub and put into tomatoes and lettuces to make them sweeter.

In the natural world, trees and shrubs often act as nurse plants, aiding the establishment of other species. An example is seen in the Sonoran desert where most of the big saguaro cacti (*Carnegiea gigantea*) start life in the shade of a tree. Animals can also benefit: cows in the Midlands of Britain (and undoubtedly elsewhere) give more milk when they can shelter behind shrubby hedges. In ecological parlance, woody plants are often 'keystone species', those on which many other plants and animals depend.

Parts of the tree

Before we look at different aspects of trees in detail, we should start with an overview of the whole tree.

A tree lives in basically the same way as any other plant. The leaves produce sugars, which are the fuel used to run the tree and used to make the basic building blocks of cellulose and lignin that form the bulk of a tree (Chapter 2). The sugars are moved through the inner part of the bark to where they are needed around the rest of the tree. Sugars not required for immediate use are stored in the wood of the trunk, branches and roots (Chapter 3). The roots at the other end of the tree (Chapter 4) absorb water and minerals (such as nitrogen, phosphorus and potassium) from the soil. The water and dissolved minerals are pulled up through the wood of the tree to reach the leaves, the main users of water. The minerals are used with the sugars to build essential components of the tree, including the flowers and fruits needed to start the next generation (Chapter 5).

Trees get bigger in two ways. The buds scattered around the tree are the growing points for making existing branches longer or for making new branches (referred to as primary growth; Chapter 3). Once made, the woody skeleton gets fatter (secondary growth) by a thin layer of tissue (the cambium) beneath the bark adding new bark and new wood. In temperate areas where growth stops over winter these new layers are seen as the familiar annual rings in the wood (Chapter 3).

The pattern in which new buds are laid down on a developing branch, and which of these buds grow out and by how much, determines the characteristic shape of each tree (Chapter 7). Incidentally, many monocotyledons, such as palms, have one growing tip only and so inevitably live near the tropics where climate is less likely to kill the point: if that growing point dies, so does the whole tree.

The essential difference between plants, including trees, and an animal is that most animals act as a whole unit (one heart, one set of eyes, one liver acting for the whole animal) whereas plants are modular, made up of similar parts added together, each acting largely independently, each replaceable. Thus a tree can lose and replace a branch or even the whole trunk, which for an animal would be equivalent to, for example, cutting me off at the feet and watching them regrow a new me. This modular organisation of trees makes for some interesting problems and solutions in keeping a woody skeleton going for hundreds and sometimes thousands of years. Generally, the living portion of the tree is a thin skin over a long-dead skeleton, which nevertheless must be preserved from the attentions of fungal rot and animals in a number of ingenious ways (Chapter 9).

The story is not yet complete: we can see how a tree is organised within but it must still interact with its environment. It must start from a seed and do battle against a whole army of animals and fungi, and compete with its neighbouring plants. And since trees are long-lived compared to most other plants, they have some neat tricks for surviving (Chapters 6 and 8).

Chapter 2: Leaves: the food producers

Perhaps the most striking thing about tree leaves is their tremendous diversity in size. The Arctic–alpine snow willow (*Salix nivalis*), which grows around the northern hemisphere, can have leaves just 4 mm long on a sprawling 'tree' no more than a centimetre high (Figure 2.1). Smaller still, the scale needles of some cypresses are nearer a millimetre long. Among the largest of leaves are those of the foxglove tree (*Paulownia tomentosa*), which on coppiced trees can be over half a metre in length and width on a stalk another half metre long. Such large sail-like leaves are in great danger of being torn by the wind (as in the traveller's palm, *Ravenala madagascariensis*; see Figure 2.1) so it is perhaps no surprise that big leaves are usually progressively lobed and divided up into leaflets to form a compound leaf. This can lead to even larger leaves: the Japanese angelica tree (*Aralia elata*) can have leaves well over a metre in length (Figure 2.1). Many palms have feathery leaves over 3 m long and in the raffia palm (*Raphia farinifera*) up to 20 m (65 feet) long on a stalk another 4 m long.

The leaves are the main powerhouse of the tree. Combining carbon dioxide from the air with water taken from the soil they photosynthesise, using the sun's energy to produce sugars and oxygen. These sugars (usually exported from the leaf as sucrose, the sugar we buy in packets) are the real food of a tree. They are used as the energy source to run the tree; they form the raw material of starch and cellulose and, combined with minerals taken from the soil, they allow the creation of all other necessary materials from proteins to fats and oils.

The role of leaves in producing food should not be underestimated. A large apple tree holds 50 000–100 000 leaves, a normal birch tree may average 200 000 leaves and a mature oak can have 700 000 leaves. Even this pales somewhat in comparison with the 5 million leaves reported from mature American elms (*Ulmus americana*). Using these vast numbers of leaves a mature beech (*Fagus sylvatica*) can fix 2 kg of carbon dioxide per hour, producing as a by-product enough oxygen for ten people every year. The world's trees have been estimated to produce 65 000–80 000 million tonnes of dry matter per year, two thirds of the total produced by all land plants.

The make-up of a leaf

Broadleaved trees, as the name suggests, have leaves with a broad leaf blade (or lamina) to catch as much light as possible. This limp, fragile material is permeated

(*a*)

(*b*)

Figure 2.1. (a) Arctic willow (*Salix nivalis*) in the Canadian Rocky Mountains; (b) traveller's palm (*Ravenala madagascariensis*) on Tenerife, the Canary Islands, showing the large sail-like leaves that are readily torn by the wind; (c) a leaf of the Japanese angelica tree (*Aralia elata*) near Vladivostok, Russia (the part above the flower-head is all one bipinnate leaf); and (d) welwitschia (*Welwitschia mirabilis*) in the coastal desert of Namibia (photographed by G. Smith).