CHAPTER 1

Diversity in the plant world

Summary

In this Chapter the stages in evolution of the diversity of plant life on earth are outlined and the essential characteristics of the most successful land plants summarised, as an introduction to Chapters 2 and 3. The characteristics, origins and occurrence in the garden of 'primitive plants' are then summarised. Finally, flowering land-plant forms, their occurrence in the wild and their value in the garden are presented in tabular form.

Introduction

The most remarkable thing about plants is that they are green (Fig. 1.1), a property that makes it possible for them to generate the energy required to sustain almost the entire living world. To appreciate the significance of this it is necessary first to consider what happens to the average motor car if, like the one in Fig. 1.2, it is neglected for long enough: the bodywork rusts and the non-ferrous components disintegrate and decay. Indeed, it is the usual experience that all inanimate things, left to themselves, eventually reach a state of disorder: buildings crumble, books turn to dust and machines rust. This general tendency is expressed in the second law of thermodynamics, which states, in essence, that in an isolated system the degree of disorder and chaos – the entropy – can only increase.

Creating order out of disorder

When one thinks about living things, however, it is immediately apparent that they are able to create order out of disorder, assembling atoms and molecules to form tissues and bodies of great complexity and sophistication (Fig. 1.1). How is this creation of order out of disorder thermodynamically possible, given that living things, just like inanimate objects, operate according to the laws of physics and chemistry? The answer is that the cells of living things are not isolated systems in a thermodynamic sense, as a motor car is, for they are constantly deriving energy from another, external, source, the sun. It is necessary to go back in time to find out how this came about.

The earth first condensed from dust and ashes about 4540 million years ago, and life must have appeared some time during the first thousand million years of the planet's existence. The molecules that made life possible may have arrived from another planet in, for example, a comet, but current theories suggest they were probably generated here on earth. The earliest life forms were heterotrophic, deriving their organic molecules (those containing carbon) from their surroundings, a legacy from the prebiotic 'soup' of chemicals that was left on the cooling earth after its genesis. These would have provided them with energy and the building blocks for making cells. But as these natural resources were exhausted, a key event was the evolution of the process called photosynthesis, whereby sunlight is harnessed to provide an alternative, external, source of energy (see Chapters 2 and 8).

The study of very old rock formations in Australia has suggested that this may have occurred more than 3600 million years ago, for by that time there were present on the planet simple organisms consisting of single cells or chains of cells that resemble the blue-green Cyanobacteria ('blue-greens') that grow in shallow, stagnant water or as a greenish slime on the surface of marshy soils and wet lawns even today (Fig. 1.3). These primitive organisms were so successful that they have remained virtually unchanged throughout almost the entire course of evolutionary time. The Cyanobacteria possess the ability to capture the electromagnetic radiation of the sun and incorporate it into a chemical

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Figure 1.1 'The most remarkable thing about plants is that they are green.' Entrance to the 'Professor's Garden' at Brantwood, Coniston, Cumbria. Photograph by David S. Ingram.

Figure 1.2 It is the usual experience that inanimate things, left to themselves, like this VW Beetle, eventually reach a state of disorder. In contrast, living things, like the plants of oilseed rape that surround it, are able to create order out of disorder, assembling atoms and molecules to form tissues and bodies of great complexity and sophistication. Photograph by David S. Ingram.

energy source. This is made possible by the presence of light-absorbing pigments that give the blue-greens their characteristic colour, the most significant being the green pigment chlorophyll *a* (see Chapter 2). For the first time in evolutionary history there had appeared on earth autotrophic organisms, which were able to make their own food. The great diversity of plants alive today sprang from these humble beginnings.

The evolution of photosynthesis had another significant consequence. As the number of photosynthetic organisms increased they altered the earth's atmosphere.

Figure 1.3 A chain of cells of the cyanobacterium (blue-green) *Anabaena*. Light microscope photograph by Patrick Echlin.

This is because the most efficient form of photosynthesis, the one employed by most primitive plants, involves the splitting of water molecules (H_2O) to release oxygen (O_2) (see Chapter 2). This increased the oxygen level in the atmosphere, which had two important effects. First, some of the 'new' oxygen in the outer layer of the atmosphere was converted to ozone (O_3), a gas that absorbs the ultraviolet (UV) radiation from sunlight, which is very damaging to living organisms. This meant that organisms could survive in the surface layers of water, and even on land. The current depletion of the ozone layer as a result of human activity is a serious reversal of a critical stage in the evolution of life on earth. Secondly, the increase in the level of oxygen made possible the process of aerobic respiration, whereby carbon molecules formed by photosynthesis are broken down to release energy required for building bodies in far greater quantities than are released by anaerobic respiration, which occurs in the absence of oxygen. It may be speculated that when photosynthesis first began to occur on a very large scale about 2400 million years ago, the resulting substantial quantities of oxygen in the atmosphere and the concomitant increase in the number of aerobic organisms may have caused great extinction event, the massive decline of anaerobic life forms. It must be emphasised, however, that no evidence has yet been found in the fossil record to support such a claim (see also Box 1.1).

Before the atmosphere became enriched by oxygen the only organisms that existed were prokaryotes (Table 1.1), comprising simple cells lacking a nucleus defined by a membrane (see Chapter 2). These first prokaryotes, called Archaea, which translates as 'ancient ones', may still be found in places as diverse

BOX 1.1

Five major extinctions, in each of which more than 50% of all species died out, *are* known from the earth's fossil record. The most catastrophic of these occurred c. 252 million years ago at the end of the Permian period. The causes of this so-called great dying or more correctly, the Permian-Triassic Extinction Event, in which as many as 97% of all genera of living organisms may have been lost, were probably complex. However, one factor is thought to have been the massive proliferation of photosynthetic land plants, leading to a build-up of very substantial quantities of free oxygen in the atmosphere, which in turn triggered catastrophic global environmental change.

Table 1.1 The main groups of photosynthetic organisms mentioned in Chapter 1. There is currently no single agreed system of higher level classification, but a series of competing ones. This table is broadly based on the five-kingdom system; the gymnosperms based on Christenhusz et al.[a], and the flowering plant classification follows the Angiosperm Phylogeny group III system[b]

Domain:	**BACTERIA**
Kingdom:	**Eubacteria**
Division:	Cyanobacteria (blue greens)
Domain:	**EUKARYOTA** (cells with a membrane-bound nucleus)
Kingdom:	**Protoctista** a rank used here for convenience to group a set of related organisms (phytoplankton, green, red and brown algae) defined by exclusion of other groups
Kingdom:	**Viridaeplantae** (also treated as a division)
Division:	**Chlorophyta** (green algae)
Division:	**Charophyta** (charophytes – a type of multicellular green algae)
Subkingdom:	**Embryophyta** (land plants, also treated as a division)
Non-vascular plants	
Division:	**Marchantiophyta** (liverworts)
	Bryophyta (mosses)
	Anthocerotophyta (hornworts)
Vascular plants without seeds	
Division:	**Lycopodiophyta** (club and spike mosses; quillworts)
	Monilophyta (ferns and horsetails)
Vascular plants with seeds	
Division:	**Pinophyta**
Subclass:	*Cycadidae (cycads)
Subclass:	*Ginkgoidae (ginkgo)
Subclass:	*Gnetidae
Subclass:	*Pinidae (conifers)
Division:	**Magnoliophyta** (angiosperms – flowering plants):
Orders(s):	Amborellales/Nymphaeales/Austrobaileyales (e.g. waterlilies)
**Clade:	magnoliids (most traditionally placed in the dicotyledons [dicots])
**Clade:	monocotyledons (monocots; e.g. grasses, palms and orchids)
Order:	Ceratophyllales (e.g. water hornworts)
**Clade:	eudicots (most traditionally placed in the dicots; e.g. daisy, pea and rose)

*Frequently referred to collectively as the gymnosperms.

**Informal names for groups recognised that have no formal botanical rank.

[a]Source: Christenhusz, M.J.M., Reveal, J.L., Farjon, A., Gardner, M.F., Mill, R.R. & Chase, M.W. (2011) A new classification and linear sequence of extant gymnosperms. *Phytotaxa,* **19**, 55–70.

[b]Source: Angiosperm Phylogeny Group (2009) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. *Botanical Journal of the Linnean Society,* **161**(2), 105–21.

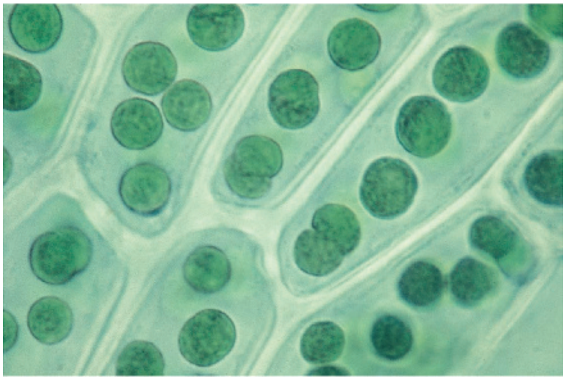

Figure 1.4 Chloroplasts in the cells of a moss leaf. Light microscope photograph by Patrick Echlin.

as hot springs and the human navel. Bacteria, which appeared soon after, are also prokaryotes, and some of these and some of the Archaea are capable of photosynthesis.

The presence of oxygen in the atmosphere also led about 2100–1600 million years ago to the gradual evolution, by natural selection, of eukaryotes (see Chapter 2), whose cells had a clearly defined, membrane-bound nucleus, complex chromosomes and membrane-bound organelles. The latter are subcellular structures with specialised functions. They include mitochondria, where respiration occurs and, in plants, chloroplasts (Fig. 1.4; see also Chapter 2), where photosynthesis occurs. It is probable that organelles such as chloroplasts and mitochondria, which possess their own genetic information in addition to that contained in the nucleus, first evolved as a result of the incorporation of free-living prokaryotes into eukaryotic cells. Thus chloroplasts may have evolved by incorporation of autotrophic cyanobacteria (blue-greens).

Eukaryotic cells, which were well established and diverse by 1 billion years ago, provided the building blocks for the evolution of all complex organisms, from seaweeds and shrimps to oak trees and orangutans.

At first the commonest photosynthetic organisms lived just below the surface of the oceans, but with time the mineral resources of these open waters were depleted by the teeming life within them and organisms began to develop more abundantly near the shores, where the waters were enriched by minerals released by wave action or carried from the land by rivers and streams. The more varied and somewhat harsher environment of the shore gradually led to the evolutionary selection, some 650 million years ago, of complex, multicellular photosynthetic organisms with their tissues differentiated in various ways: anchorage structures to attach them to rocks; flattened structures with a large surface area to volume ratio, to facilitate the collection of light and air for photosynthesis; and primitive conducting systems to enable them to carry the products of photosynthesis from the surface structures to the submerged parts of the plant. The descendants of these organisms are the large seaweeds such as *Laminaria* spp. (kelps) of present day coastlines.

Colonisation of the land

The next critical stage in the evolution of the great diversity of complex plants that were eventually to colonise almost the entire earth was the move from water to land, which occurred some 450 million years ago. The evolution of plants on the seashore and the colonisation of the land did not mean, however, that plant life ceased to exist in open waters. Microscopic plants still occupy the surface waters of oceans, lakes and rivers in vast numbers as the largely unicellular, photosynthetic algae collectively called the phytoplankton. Indeed, these organisms are responsible for almost 50% of the earth's photosynthetic productivity, and are a major sink for carbon dioxide as well as providing the base of the food chain for most of the life in the oceans and in fresh water.

The colonisation of the land by plants was made possible by the evolution, in response to the selection pressures of life out of water, of a number of structural characteristics that are common to all land plants, even today (see Chapters 2 and 3). The terrestrial environment is rich in carbon dioxide and oxygen, and these diffuse more freely in air than in water, so are more readily available on land. Light is also abundant, undimmed by the filtering effect of water, although the infrared component imposes a significant heat load on the organs that absorb it. Finally, mineral ions are readily available in the soil. The remaining requirement is water, and this, together with the heat load from sunlight, are the key limiting factors to life on land.

The most successful of the early land plants, therefore, had roots to provide anchorage and to collect water from the soil. Flattened structures, the leaves, collected the energy of sunlight and with their large surface area to volume ratio were able to maximise this process while providing the shortest possible pathways for the uptake of carbon dioxide for photosynthesis and oxygen for respiration. The evolution of stems provided a means of holding the leaves in the most advantageous position for the collection of sunlight. A conducting system comprised of two parts, the xylem and phloem, provided, respectively, a means of transporting water to the leaves and of conducting sugars and growth substances from the leaves to other parts of the plant. The evolution of secondary thickening, in which the xylem of the stem, branches and roots proliferates to form wood, enabled the development of shrubby plants and trees.

Two further developments prevented potential problems associated with the leaves. Such flattened structures lose water very rapidly and are also subject to a significant heat load from sunlight. The most successful evolutionary response to these selection pressures was a thin, cellular outer skin, the epidermis, covered by a waterproof waxy coating, the cuticle, on the aerial parts of the plant. Such tissues, by preventing the loss of water, had the potential to create two further problems, however: the loss of the cooling effect of the evaporation of water due to the latent heat of vaporisation, and the creation of a barrier to the exchange of carbon dioxide and oxygen for photosynthesis and respiration, respectively. The most successful solution to both problems was the evolution of pores of variable diameter in the cuticle and epidermis. These pores, the stomata, are each surrounded by two specialised cells with the capacity of changing shape and thereby opening and closing the pores, thereby enabling land plants to regulate the loss of water and the uptake of gases (see Chapter 8).

Land plants must grow continuously in order to compete with other plants for the available light, and to mine increasing volumes of soil in the relentless search for nutrients and water. Growth does not occur at random over the whole plant body, however, but is localised in specific regions of cell division and differentiation. These regions are called meristems, the principal ones, apical meristems, being located at the tips of the stems and roots. Subsidiary meristems are involved in, for example, the development and expansion of leaves and in the formation of wood.

The final significant evolutionary steps in the colonisation of the land concerned the development of reproductive structures that were resistant to desiccation and other environmental stresses. The sexual phases (gametophytes) of the life cycle of the first land plants were dependent on water, the female egg cells being fertilised by swimming male gametes. The result was the formation of sporophyte generations producing relatively vulnerable spores, minute propagules not differentiated internally. Later, more successful plants evolved in which the two phases of the life cycle were brought together and the reproductive cells held in protective, multicellular structures. The male gametes of these plants, the pollen grains, were non-motile and desiccation-resistant, being transferred from plant to plant by wind and later by other agents such as insects. Instead of spores, seeds were produced as a result of sexual reproduction. These were structures in which the fertilised embryo was protected from environmental stresses and herbivores by layers of cells that constituted the seed coat. In one of the major groups of seed plants, the gymnosperms (see Table 1.1) the seeds were unprotected. Indeed, the name in translation means 'naked seeds'. The present-day descendants of these plants are the conifers and their relatives. In the second group, the angiosperms (see Table 1.1) the seeds were enclosed in protective layers that constituted the fruit. The present-day descendants of these are the flowering plants. The developing embryo was also provided with a supply of stored food, which meant it could survive unfavourable climatic conditions in a dormant state, rapidly germinating and becoming established as soon as conditions improved.

The seed plants of the present day include the cycads and *Gingko biloba*, both of which retain motile male gametes, the conifers, and the angiosperms, or flowering plants (Table 1.1). It is these that dominate the world's flora and have given rise to the majority of plants grown in gardens. They are thus the main subjects of the rest of this book.

The early stages of the colonisation of the land by plants involved a great diversity of primitive forms, which, although successful at the time, lacked one or more of the suite of characteristics that ultimately made the seed plants the dominant group. The descendants of many of these primitive plants, although less diverse and less successful than their ancestors, still grow on earth today. Their ability to compete with the seed plants is very limited, except in highly specialised habitats. They will, however, be familiar to gardeners as the liverworts, mosses, horsetails and ferns, which grow best in cool, moist and often shady habitats in the garden (see Tables 1.1 and 1.2; see also Figs 1.5, 1.6, 1.7 and 1.8).

Table 1.2 The characteristics of 'primitive' land plants

Group and characteristics	Garden habitats
Algae (Fig. 1.3) An informal grouping of simple organisms ranging from unicellular blue-greens and green plankton to macroscopic colonies or chains of green cells and more complex brown-green and red-green seaweeds. The blue-greens are prokaryotes and the rest eukaryotes. Some blue-greens fix atmospheric nitrogen.	Damp or wet places and in ponds. Blue-greens sometimes form a slime on wet lawns.
Lichens (lichenised fungi) Symbiotic associations of green algae and certain fungi in the Ascomycotina.	Exposed surfaces such as rocks, walls and tree trunks, where neither partner could survive alone.
Liverworts (Marchantiophyta; Figs 1.5 and 1.7) Simple, small, green plants without a cuticle, stomata or lignified xylem. Exhibit alternation of generations in which the haploid gametophyte is the dominant phase with the diploid sporophyte attached to and dependent on it. Male gametes are motile, requiring water for fertilisation. Reproduction is by spores and sometimes by production of multicellular gemmae. There are two types of gametophyte: thallose, comprising a flattish, lobed plate of cells; and leafy, in the form of a small plantlet with rows of thin, flattened leaves on either side of a thin stem and a third row of reduced leaves on the underside; both types have simple rhizoids for attachment.	Thallose types grow in moist, open sites such as shaded paths, and as pot weeds. Leafy types grow among other crowded plants, especially grasses.
Mosses (Bryophyta; Figs 1.6 and 1.7) Simple, small, green plants lacking a cuticle, stomata, lignified xylem and roots. May have specialised cells for conducting water and transporting sugars. Exhibit alternation of generations with the gametophyte being dominant, as in liverworts. Gametophytes are usually in the form of small, leafy plantlets with simple rhizoids for attachment. Male gametes are motile, requiring water for fertilisation. Reproduction is by spores.	Moist, shady places or in boggy ground. Many can survive long periods of desiccation, making it possible for some species to grow on roofs, walls, paths and in lawns.
Ferns and horsetails (Monilophyta; Fig. 1.8) Small to large green plants, sometimes small trees, with a stout rhizome and roots. Possess a cuticle with stomata, lignified xylem and phloem. Exhibit alternation of generations with a relatively large, free-living diploid sporophyte and relatively small, vulnerable, heart-shaped gametophyte (the prothallus) only a few cells thick. Motile male gametes require water for fertilisation. The diploid sporophyte grows out of the prothallus after fertilisation. Sporophyte produces wind-blown spores. At present, the largest forms are the tree ferns. In the geological past, as in the Carboniferous, tree ferns and horsetails grew to great sizes and formed vast forests. The seed habit evolved in some ferns. It is probable that the vulnerability of the gametophyte to desiccation led to the decline of these groups as the seed plants evolved and outcompeted them.	Moist, shady places, especially under trees. Gametophytes require wet conditions but sporophytes can often tolerate some drought. Horsetails, having a stout rhizome, can survive in most conditions.

Communities and the diversity of life forms

Once the first land plants had become established, they spread to occupy almost the entire surface of the earth. Ultimately extensive communities (biomes) of plants and also animals, which had been evolving on land alongside the plants, came into being, their characteristics being largely determined by climate. These biomes were the equivalent of today's deserts, tundra, savannahs, rainforests, and temperate grasslands, forests and woodlands. How these communities evolved is still only poorly

Figure 1.5 The thallose liverwort *Marchantia*. Note the flattened, green gametophytes with male (shaped like umbrellas) and female (shaped like the ribs of an umbrella) structures growing up from them. Male and female structures are found on separate plants. Photograph by David S. Ingram.

Figure 1.6 The leafy, tuft-forming gametophytes of the common garden moss *Bryum*, with horny, flask-shaped sporophytes growing *in situ* on long stalks from the tips of the gametophytes, where sexual reproduction occurred earlier in the life cycle. Photograph by Chris Prior.

Figure 1.7 Liverworts (leafy and flattened), mosses and ferns thrive in the moist dappled shade of the 'Painter's Glade' at Brantwood, Coniston, Cumbria. Photograph by David S. Ingram.

Figure 1.8 Overwintering sporophyte fronds (leaves) of the hard fern (*Blechnum spicant*), a common UK native fern species that grows in abundace in John Ruskin's gardens at Brantwood, Coniston, Cumbria. Photograph by David S. Ingram.

understood. So far, knowledge is largely limited to that arising from studies of the evolution of the individual species that inhabit them, but this can provide no more than a glimpse of the infinitely more complex range of processes and interactions that must have been involved.

The biomes of the present day are made up of smaller communities called ecological systems, or ecosystems (see Chapter 20). These in turn are made up of assemblages of the plants, animals and other living organisms that occupy them, together with their non-living environment. Ecosystems are extremely stable assemblages, although the individuals that occupy them have a defined life span, ranging from a few hours or days in the case of some microorganisms to hundreds or even more than a thousand years in the case of some trees.

The shape, size and form of the individual species of plants in an ecosystem are complementary, so that each has access to the light, water, CO_2 and mineral nutrients required for growth and reproduction. Similarly, flowering, seed set and germination are so timed as to enable each species to grow and reproduce at the time of year most favourable for itself and for the other species, such as insect pollinators, with which it has coevolved. None of this complementarity owes its origins to altruism, of course, but has resulted from competition between species during the evolution of the ecosystem. Indeed, all organisms present in the ecosystem compete for resources, and every organism, no matter how large or small, provides a food source for another organism. By this means, the energy captured by plants from sunlight is passed on in a regulated way throughout the entire ecosystem before being dissipated. Energy from the sun must enter the ecosystem constantly, but all nutrients are cycled through living organisms, eventually being returned to the soil, decomposed by bacteria and fungi, and recycled.

The diversity of biomes, ecosystems and specialised habitats (shaded, exposed, arid, saline, aquatic, cold and montane) within them has led to the evolution among the seed plants of a great diversity of life forms. These are summarised in Tables 1.3 and 1.4, for they have provided horticulturists and plant breeders with the raw material for developing the wide range of plants that grow in gardens today. The subject of garden ecosystems will be considered in Chapters 20 and 21.

The transfer of energy and the cycling of nutrients in an ecosystem involve complex sequences of events, with every organism playing a specific part and with the components of the environment having their role too. Surprisingly, the impacts of climate change have shown

Table 1.3 The diversity of basic types of seed plants

Type	In the wild	In the garden
Annuals		
Usually herbaceous plants that complete their life cycle of germination, growth, flowering and seed set during one growing season, sometimes in only a few weeks.	Opportunistic primary colonisers of disturbed ground or, in arid regions, able to germinate from dormant seeds, flower and set seed again very rapidly following rain at the end of a period of drought.	Weeds in newly cultivated soil (e.g. groundsel, *Senecio vulgaris*). May be used to provide 'instant flowers' (e.g. poppies, *Papaver* spp.) and rapidly maturing vegetables from sown seed (e.g. lettuce, *Lactuca sativa*).
Biennials		
Short-lived herbaceous plants that flower and set seed in the second season following germination. Usually require a trigger, such as low temperature (vernalisation) during winter to induce the formation of flowers. Sometimes have woody flower stalks.	Opportunistic early colonisers of disturbed or bare ground whose life cycle is regulated with precision by the seasons to ensure that flowering occurs at the most favourable time for pollination and seed set.	Weeds in newly cultivated soil (e.g. common foxglove, *Digitalis purpurea*). May be used to provide flowers rapidly, usually early in the growing season (e.g. wallflower, *Erysimum cheiri)*. Spring vegetables, from seed sown during the summer or autumn of previous year (e.g. broccoli, *Brassica oleracea* Italica group). Some biennial vegetables are grown as annuals (e.g. carrot, *Daucus carota*).
Herbaceous perennials		
Plants that continue to grow for more than two seasons. Usually non-woody, but may have woody flower stalks. May require an environmental trigger such as low temperature (vernalisation) to induce flowering. May be evergreen, never dying back, or may die down during unfavourable periods such as summer drought or winter cold, regrowing from a perennial rootstock.	Long-term, highly competitive components of grasslands and other open habitats, including mountain and alpine. Comprise the bulk of the herb layer in scrub, woodlands and forests.	Persistent aggressive weeds in permanent plantings (e.g. willowherbs, *Epilobium* spp.) including lawns (e.g. dandelion, *Taraxacum officinale*). Permanent plantings in a diversity of situations including: lawns (grasses, Poaceae), alpine gardens (e.g. *Lewisia* spp.), herbaceous and mixed borders (e.g. phlox, *Phlox* spp.), underplantings among trees and shrubs (e.g. germanders, *Teucrium* spp.) and herb gardens (e.g. oregano, *Origanum* spp.). Permanent sources of vegetables (e.g. good king Henry, *Chenopodium bonus-henricus*) or fruit (e.g. strawberry, *Fragaria* spp.).

(*Continued*)

Table 1.3 (*Continued*)

Type	In the wild	In the garden
Shrubs		
Woody perennial plants with many branches arising at or close to ground level and lacking an obvious trunk. May be deciduous, losing their leaves during unfavourable periods such as winter cold or summer drought; or evergreen, retaining leaves throughout the year, allowing photosynthesis to occur immediately following the alleviation of unfavourable conditions such as the shade from deciduous trees, winter cold or summer drought. Older evergreen leaves are eventually shed.	Principal and dominant component of scrublands (e.g. Mediterranean-type region or tundra), or alpine regions, or grasslands (e.g. savannah) or as significant understorey components of woodlands and forests of every type in temperate, subtropical and tropical regions.	Provide height, shape, form and flowers in every part of the garden, but especially valuable in mixed borders (e.g. *Weigela* spp.), shrubberies (e.g. mock orange, *Philadelphus* spp.), among trees (e.g. *Rhododendron* spp.), as specimens in lawns (e.g. *Cornus kousa),* in specialised plantings (e.g. *Rosa* spp.), herb gardens (e.g. rosemary, *Rosmarinus officinalis*), and alpine gardens (e.g. dwarf conifers and willows, *Salix* spp.). Permanent sources of fruit in season (e.g. currants, *Ribes* spp.).
Trees		
Woody perennial plants with a single main stem (or sometimes more than one main stem), usually branching well above the ground to form an elevated crown. The distinction between large shrubs and small trees is not clear cut. As with shrubs (see above), may be deciduous or evergreen. May be very long lived (e.g. oaks, *Quercus* spp.) or relatively short lived (e.g. birches, *Betula* spp.).	Dominant and overshadowing component of woodlands and forests in all regions of the world, or may occur as isolated specimens in grasslands such as savannahs or other open situations.	Provide height, shape, form, shade and sometimes flowers in all parts of the garden. There is a great diversity of types including long-lived specimens for large gardens (e.g. beeches, *Fagus* spp.), smaller, less long-lived specimens for smaller gardens (e.g. *Acer* spp.) and flowering types (e.g. *Prunus* spp.). Provide permanent supplies of fruit in season (e.g. apples, *Malus* spp.; cherries and plums, *Prunus* spp.). Seedlings may occur as weeds (e.g. sycamore, *Acer pseudoplatanus*).

Table 1.4 Examples of the diversity of adaptations of the basic types of seed plants. Such adaptations have evolved in response to selection by particular environmental conditions, sometimes extreme. Many adaptations have often evolved in parallel in many different and unrelated species and groups of plants. The great diversity of flower and fruit types is not dealt with here but is referred to in the text, principally in Chapters 2, 3 and 8

In the wild	In the garden (with examples)
Alpines and dwarf plants	
Long-lived herbaceous or frequently woody perennials reduced in size and with other adaptations to withstand the often short growing season, strong winds, free-draining soils and periods of exposure to extremes of heat, cold and desiccation that typify mountainous habitats and northern climates.	Valuable in rock or alpine gardens and containers (dwarf conifers, e.g. *Juniperus* spp.; dwarf broad-leaved shrubs, e.g. *Salix herbacea*; rosette- and mound-forming herbaceous perennials, e.g. *Saxifraga* spp.).
Aquatic and bog plants	
Usually herbaceous perennials adapted to grow in bogs and at the margins of lakes or streams (e.g. *Iris* spp.), or as rooted plants with floating leaves in still water (e.g. water-lilies, *Nymphaea* spp.) or moving water (e.g. water crowfoot, *Ranunculus aquatilis*), or as free-floating plants in still water (e.g. duckweed, *Lemna minor*). Adaptations include stomata on the upper surface of floating leaves only, air-conducting (aerenchyma) cells in submerged plants and mechanisms to trap insects (see 'Insectivorous plants' below).	May be used to provide form, flowers and oxygen in gardens with still or moving water (see left for examples). May occur as weeds in some water gardens (e.g. *Lemna minor*; *Ranunculus aquatilis*).

(*Continued*)

Table 1.4 (*Continued*)

In the wild	In the garden (with examples)
Aromatic plants	
Herbaceous and shrubby forms, sometimes trees, especially from relatively dry climates (e.g. Mediterranean-type), that produce aromatic oils and other chemicals, which may deter herbivores, parasites and pathogens.	Culinary herbs and spices (e.g. mints, *Mentha* spp.; thymes, *Thymus* spp.). May also be used to provide scent as well as form and flowers in non-culinary plantings (e.g. *Eucalyptus* spp.; *Cistus* spp.).
Climbers, vines and scramblers (lianas)	
Plants adapted to gain height, thereby reaching sunlight, in shrublands, woodlands, forests and rocky ground by growing in, on or over other, usually woody, species or rocks. Mechanisms for attaching plants to other species include twining stems (e.g. honeysuckle, *Lonicera* spp.), leaf tendrils (e.g. peas, *Pisum* spp.), branch tendrils (e.g. vines, *Vitis* spp.), twisting petioles (e.g. *Clematis* spp.), hooked thorns (e.g. *Rubus* spp.; *Rosa* spp.) and adventitious roots arising from the stem (e.g. ivies, *Hedera* spp.).	Used in a diversity of situations such as in and through trees and hedges, against walls and fences, and on trellises and pergolas to provide height, cover, form, flowers and fruit. See left for examples. May occur as weeds in permanent plantings (e.g. *Convolvulus* spp.).
Epiphytes	
Usually herbaceous perennial plants adapted to gain height and thereby access to sunlight by growing on other species, usually on the branches of trees and large shrubs. Sometimes occur in temperate regions, but most frequent in tropical and subtropical rain and mist forests, where modified roots (e.g. orchids, Orchidaceae) or the whole plant surface (e.g. Spanish moss, *Tillandsia usneoides*) may absorb water from the atmosphere, or modified rosettes of leaves may collect rainwater in the 'tank' created by the leaf bases (e.g. bromeliads, Bromeliaceae). Minerals are in short supply, and in the absence of soil are absorbed directly from rainwater or from decomposing plant and animal remains trapped by the plants.	Main value in cultivation is as glasshouse plants (especially orchids, Orchidaceae) or as house plants (especially bromeliads, Bromeliaceae; e.g. urn plant, *Aechmea fasciata*)
Geophytes	
Usually herbaceous, sometimes woody species with a perennial, underground structure that remains dormant during unfavourable conditions such as shade from deciduous trees (e.g. spring bulbs and corms), extreme drought or cold (e.g. spring bulbs; *Dahlia* spp.; potatoes, *Solanum tuberosum*).	Used in permanent plantings to provide flowers in winter (e.g. *Cyclamen coum*), spring (e.g. *Narcissus*, *Tulipa* and *Crocus* spp.) and autumn (e.g. *Cyclamen hederifolium*). Or for summer plantings (e.g. *Dahlia* spp.). Or as vegetables (e.g. onion, *Allium cepa*; potatoes) or herbs (e.g. chives, *Allium schoenoprasum*; garlic, *A. tuberosum*). May occur as weeds (e.g. lesser celandine, *Ranunculus ficaria*; couch grass, *Elymus repens*).
Hairy plants	
Mainly herbaceous perennials in which the epidermal cells of the leaf are modified to form hairs arising from the surface. These may be sparse (e.g. hollyhock, *Alcea rosea*) or dense (e.g. lamb's ears, *Stachys byzantina*). Depending on density, the hairs may create turbulence around the leaf, facilitating the uptake of CO_2, or extend the width of the still air layer, thereby reducing transpiration, or may provide protection from excessive sunlight.	Plants with densely hairy leaves often appear silver or white and have value in mixed borders, especially in hot, dry conditions (e.g. lamb's ears, *Stachys byzantina*; *Phlomis* spp.).
Halophytes	
Usually herbaceous or shrubby plants adapted to grow in soils or atmospheres with a high salt content, in deserts, around coasts and in salt marshes. High salt levels restrict water uptake, so adaptations include mechanisms to reduce water loss, including succulence, fleshy leaves, hairy or waxy leaves and sunken stomata. May also possess physiological mechanisms for excreting or excluding salt.	Coastal gardens (e.g. sea kale, *Crambe maritima*; sea lavender, *Limonium* spp.). Often have strong architectural shapes or appear white or silver, and may be valuable in creating special planting effects such as in 'white gardens'.

(*Continued*)

Table 1.4 (*Continued*)

In the wild	In the garden (with examples)
Insectivorous plants	
Plants adapted to grow in positions low in nitrogenous minerals such as peat bogs (e.g. sundew, *Drosera* spp.) or as epiphytes on the branches of trees or shrubs (e.g. pitcher plants, *Nepenthes* spp.) by trapping insects, which are then digested by enzymes. Methods of trapping include: sticky leaves that roll (e.g. butterwort, *Pinguicula vulgaris*); glandular leaf hairs that secrete mucilage (e.g. sundews, *Drosera* spp.); leaves with toothed margins and hinged midribs that snap shut (e.g. Venus flytrap, *Dionaea muscipula*); underwater bladders (e.g. bladderwort, *Utricularia* spp.); and water-filled pitchers (pitcher plant, *Nepenthes* spp.).	Usually only grown as specialised glasshouse plants (e.g. Venus flytrap, pitcher plant) or occasionally in bog gardens (e.g. sundews, butterwort, bladderwort).
Parasitic plants	
Adapted to obtain a supply of carbohydrate from another species. May be completely dependent on the host and lack chlorophyll (holoparasites: e.g. toothworts, *Lathraea* spp.) or partly dependent on the host and having some chlorophyll (hemiparasites: e.g. yellow rattle, *Rhinanthus minor*). May grow beneath the soil, producing only flowers above ground (e.g. toothworts) or among other plants in meadows (e.g. yellow rattle) or as epiphytes (e.g. mistletoe, *Viscum album*).	May have decorative flowers (e.g. the holoparasite, *Lathraea clandestina*), or may have decorative value in trees (e.g. mistletoe) or may be used in meadow plantings to add diversity (e.g. yellow rattle). Sometimes occur as weeds, especially in hot climates.
Resurrection plants	
Plants adapted to grow in arid regions. May dry out and remain dormant for long periods, being induced to grow again by the onset of rain (e.g. rose of Jericho, *Anastatica hierochuntica*).	Of little value but may sometimes be sold as curiosities for use as house plants.
Rosette plants	
Plants in which the stem is reduced in length so that the leaves form a tight rosette, which may be resistant to grazing (e.g. daisy, *Bellis perennis*), desiccation or cold winds (e.g. many alpines; *Primula* spp.). Stems often elongate to form flowers.	A great diversity of garden plants form rosettes, but they are especially valuable in rock and alpine gardens (e.g. *Lewisia* spp.). Also common as lawn weeds (e.g. daisy), where mowing is the equivalent of grazing.
Sclerophylls	
Evergreen perennial plants, shrubs and trees with 'hard' leaves; i.e. thick cuticle and epidermis, with considerable internal support tissues, especially modified and lignified cells. Adapted to grow in arid regions and in Mediterranean-type climates.	Of great value as garden plants in a diversity of situations, especially in the densely populated southeast region of the UK, where lack of water makes it necessary to grow plants that are adapted to dry conditions (e.g. cherry laurel, *Prunus laurocerasus*; Portuguese laurel, *P. lusitania*; holly, *Ilex* spp.; many *Cistus* spp.; bay or true laurel, *Laurus nobilis*; holm oak, *Quercus ilex*; most conifers).
Spiny plants	
Plants, especially shrubs and trees, adapted to resist damage from browsing and grazing mammals by virtue of particular organs being adapted as or reduced to spines, notably leaves (e.g. holly, *Ilex* spp.; members of the Cactaceae) and stem branches (e.g. many *Prunus* spp.; gorse, *Ulex* spp.). Often grow in arid or semi-arid environments. Where leaves are reduced to spines, as in the Cactaceae (cacti), photosynthesis usually occurs in the stem.	May be used in a variety of garden situations (*Prunus* spp.; *Ilex* spp.) or as specialist glasshouse and house plants (Cactaceae).
Succulents	
Plants from arid regions adapted to store water in modified cells in thickened fleshy leaves (e.g. houseleeks, *Sempervivum* spp.) and stems (e.g. many cacti, Cactaceae).	Valuable in rock gardens and on roofs (e.g. houseleeks; *Sedum* spp.), as house plants (e.g. *Kalanchoe* spp.) or as specialised house and glasshouse plants (e.g. cacti).

(*Continued*)

Table 1.4 (*Continued*)

In the wild	In the garden (with examples)
Switch plants	
Shrubs and small trees adapted to dry regions, especially with a Mediterranean-type climate, by having reduced leaves, often lost during very dry periods, and photosynthetic, often winged stems with considerable internal support tissue comprising heavily thickened or lignified cells.	As with sclerophylls, of great value in gardens where water is in short supply (e.g. brooms, *Cytisus* spp.).
Xerophytes	
Herbaceous plants, shrubs and trees adapted to grow in dry conditions (see above: Alpines and dwarf plants, Hairy plants, Resurrection plants, Rosette plants, Sclerophylls, Spiny plants, Succulents and Switch plants).	Of great value in gardens and situations where water is in short supply (see above).

that in many cases ecosystems have a remarkable resilience if change is gradual, and individual species may be replaced by others that are better adapted as temperature and rainfall patterns change. However, the stable ecosystem does lose its stability and enters a period of rapid change if any component is changed suddenly, as when invasive alien species become established or when one or more species are lost. The speed of change will depend very much on the nature and size of the perturbation.

The appearance of humankind on the planet did not occur until about two million years ago. To begin with our ancestors lived as hunter-gatherers, constantly moving from place to place and using the diversity of plant and animal life for food and other purposes wherever they found it. The cultivation of crops in agriculture and horticulture was a very recent development, first occurring only some 12,000 years ago. This was a most significant event, however, for it made it possible for humans to live in settlements – villages, towns and eventually cities. Time brought sophisticated agricultural and horticultural technology, an appreciation of the importance of cultivating plants for aesthetic reasons as well as for providing food and raw materials, and an ever deepening understanding of the scientific principles that underlie plant evolution, growth, development, reproduction and classification.

Time also brought population growth, industry and commerce. The resulting relentless expansion of cities and transport systems, overexploitation of the natural environment, and increasing levels of pollution, especially of the atmosphere and oceans, have led to global environmental change (see Chapter15). Much of this is driven by energy captured by photosynthesis during earlier geological periods and stored in the earth's strata as gas, oil and coal. Global warming, atmospheric ozone depletion, and the catastrophic erosion of biodiversity represent the greatest challenges humankind has ever had to face.

Conclusion

At the heart of every biome and ecosystem is the great diversity of photosynthetic plants and microbes, for these are the only organisms capable of capturing the energy of sunlight and of generating the oxygen required to sustain life. They are also the source of the food and other natural products that sustain human societies and, as every gardener knows, they are among the most beautiful living things on earth. The erosion of biodiversity, the changing climate and other aspects of global environmental change are of great concern. Acquiring an understanding of the scientific basis of plant classification, and how plants evolve, grow and reproduce, not only makes gardening itself more pleasurable, and often more effective, but also engenders a sensitivity to the forces that threaten life on earth and the knowledge required to mitigate their effects through individual and collective action. The chapters that follow provide a first step in the acquisition of such understanding.

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