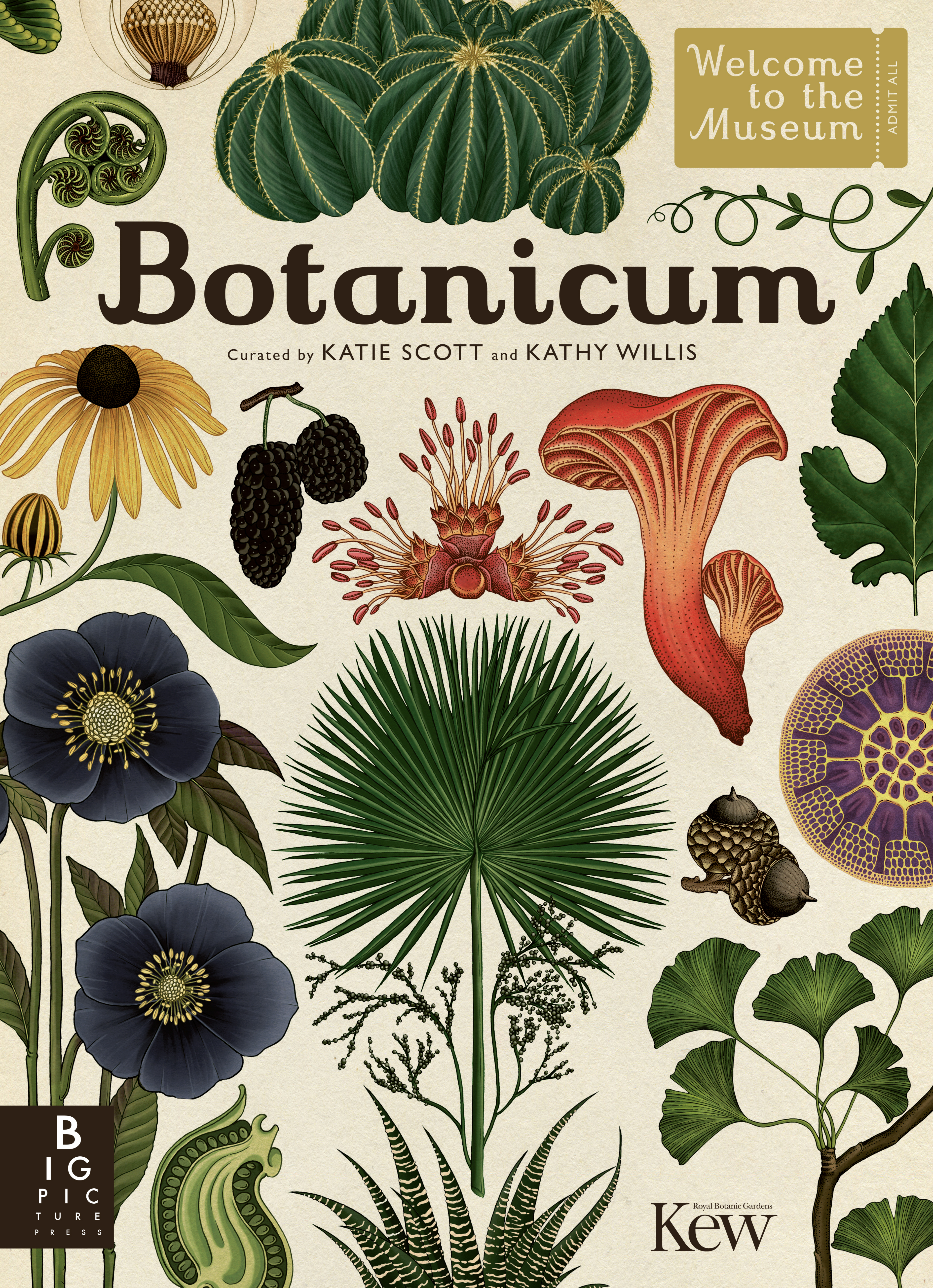


Welcome to the Museum

ADMIT ALL

Botanicum

Curated by KATIE SCOTT and KATHY WILLIS

BIG PICTURE PRESS

Royal Botanic Gardens Kew

Entrance

Welcome to Botanicum

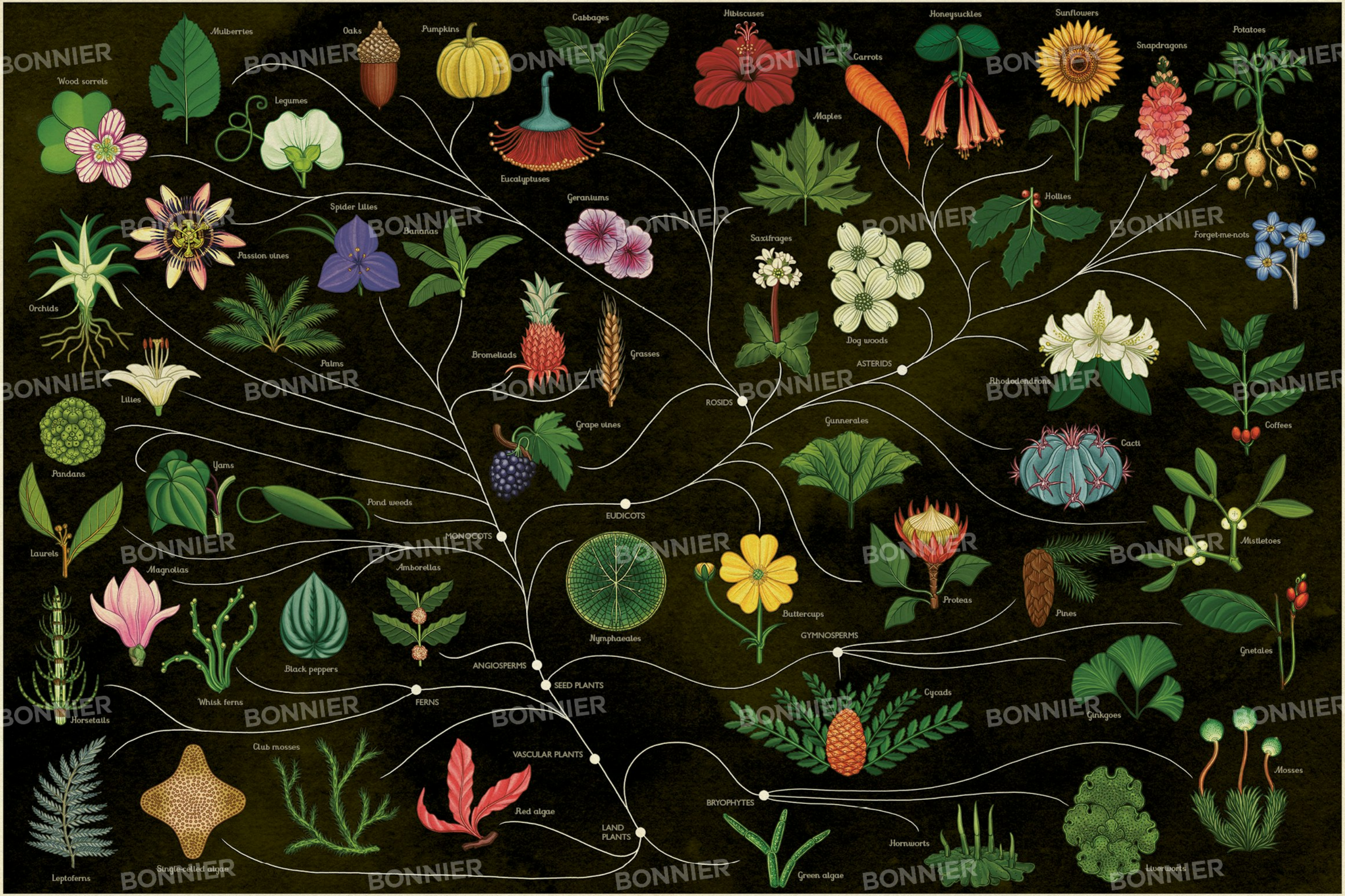
This is no ordinary museum. Imagine if you could wander through every field, wood, tropical rainforest and flower glade in the world. Think what it would be like if you could see the most beautiful, exotic and weird plants all at once. Have you ever wondered what you would see if you could stroll back in time, to the beginnings of life on Earth? You can, in the pages of *Botanicum*.

Tour the galleries and learn how plants have been around many millions of years longer than us. Find out about plants that have changed over time, and about others that have stayed the same. Stroll through our exhibitions and discover the many different life forms of plants.

Look carefully – some of what you see here you can also find in your garden or local park. Many of the plants in our galleries are also in the kitchen cupboard – did you know you eat plants from the grass family, probably every day?

You will learn some fascinating science, such as why some plants are green and others are not. How some plants live in water, and others are suspended in mid-air, not connected to the ground at all. And how some plants feed on flesh. Plants give us some of our biggest, smallest, oldest and smelliest forms of life on Earth.

Enter *Botanicum* and discover the strange and wonderful kingdom of plants, in all its colourful, surprising majesty.


Mulberries
Oaks
Pumpkins
Cabbages
Hibiscuses
Honeysuckles
Sunflowers
Potatoes
Wood sorrels
Legumes
Eucalyptuses
Carrots
Snapdragons
Maples
Hollies
Passion vines
Spider lilies
Bananas
Geraniums
Saxifrages
Forget-me-nots
Orchids
Bromeliads
Grasses
Dog woods
Palms
ASTERIDS
Lilies
ROSIDS
Rhododendrons
Grape vines
Gunnerales
Coffees
Pandans
Yams
Cacti
Pond weeds
EUDICOTS
Laurels
MONOCOTS
Mistletoes
Magnolias
Amborellas
Nymphaeales
Buttercups
Proteas
Pines
Black peppers
GYMNOSPERMS
Gnetales
ANGIOSPERMS
SEED PLANTS
Whisk ferns
FERNS
Cycads
Horsetails
Ginkgoes
Club mosses
VASCULAR PLANTS
Mosses
Red algae
BRYOPHYTES
LAND PLANTS
Hornworts
Leptoferns
Single-celled algae
Green algae
Liverworts

The Tree of Life

The Tree of Life is well named. It looks like the spreading branches of many types of tree and other woody plants. It shows in a simple form how plants have evolved, with the most recent at the very top of the tree.

It gives some small idea of the enormous range and diversity of plant life. The earliest plants appeared on Earth around 3.8 billion years ago. These were the algae. Algae are often small, simple plants with no leaves or roots, many of which can only survive in aquatic environments. More complex plants started to evolve and colonise the land from around 470 million years ago – the bryophytes, which we know as mosses, liverworts and hornworts.

Ferns were the earliest plants to gain height. This was through the addition of a chemical called lignin in their cell walls. This enabled them to grow taller and straighter than the bryophytes and they also developed tubes for transporting water and minerals around the plant. However, like bryophytes, ferns still reproduced by spores.

The first seed plants, which appeared in the fossil record around 350 million years ago, had their seeds held in cones – these plants are called gymnosperms. They were followed around 140 million years ago by angiosperms – plants that have seed that develops within a fruit when flowers are successfully fertilised. Seeds have several advantages over spores, including better protection and bigger stores of nutrients, which give the germinating plant an important head start.

Flowering plants then diverged into two major branches known as the monocots (including orchids, palms and grasses) and eudicots (including buttercups, oaks and sunflowers). From here came the huge and fascinating variety of plant life as we know it – from the tiny to the towering and from beautiful flowers to blooms that look like bees or smell like rotting flesh.

The journey goes on. Not only are scientists continuing to discover new plant species every year (almost every day), but plants are continuing to evolve in response to changing conditions and new challenges. The story has just begun.

Botanicum

To Charlotte and Donald – for their part in nurturing my love of plants – K.S.
For all budding plant and fungal scientists – K.W.

BIG PICTURE PRESS

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Welcome to the Museum
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Botanicum

Illustrated by KATIE SCOTT

Written by KATHY WILLIS

BPP

Algae

Earth was formed around 4600 million years ago. Within 800 million years, fossil evidence indicates the presence of the first plants on Earth; the algae. Algae range in size from single cells to giant seaweeds. The features that link them together as a distinctive plant group are that, although they use sunlight and carbon dioxide from the air to make food (a process called photosynthesis), they don't have roots, stems or leaves and they lack a layer of cells surrounding their reproductive cells.

Algae are most commonly found in water, with different species adapted to live in freshwater and saltwater environments. Some species live on land, often in inaccessible locations like rocky crevasses in the highest mountains or buried in the soils of the deepest valleys. This fondness for living in out-of-the-way places, and their often very small size, makes it difficult to count how many different types of algae there are on the planet. Estimates vary hugely – from 36,000 to 10 million species. Algae are split into 12 groups or algal divisions, called phyla. The three most successful and abundant are red algae, green algae and diatoms.

Key to plate

1: ***Amphitetras antediluviana***
Width: 0.125mm
This is a marine micro-alga called a diatom. Diatoms are often tiny, and usually single-celled. They are important because they are incredibly good at photosynthesis and play an important role in regulating the amount of carbon dioxide in the air.

2: **Fossil segment of red algae**
Bangiomorpha pubescens
Length: 0.225mm
This fossil filament was found in sediments from Arctic Canada and has been dated to around 1.2 billion years ago. It shows characteristic disc-shaped cells surrounded by a sheath, which are features also seen in the filaments of modern-day red algae.

3: **Fossil segment of green algae**
Cladophora sp.
Length: 0.075mm
Cladophora are one of the earliest recognisable green algae in the fossil record and are very similar in shape to their modern counterparts. They have been found in fossil deposits dating to around 800 million years ago. These green algae were the precursor to all land plants.

4: ***Lyrella hennedyi var. neapolitana***
Length: 0.06mm
This marine diatom is called *lyrella* because it looks a bit like the musical instrument, the lyre.

5: ***Rhaphoneis amphiceros***
Length: 0.06mm
This is often found attached to sand grains in shallow marine waters.

6: ***Acetabularia acetabulum***
Height: 0.5–10cm
This green alga is found in subtropical marine waters and, although it is a single-celled organism, it is very large in size and has a complicated structure. It has a lower section resembling roots, which anchor the plant to rocks and a long stalk with umbrella-like structures at the end.

7: ***Red seaweed***
Bangia sp.
Height: 6cm
The earliest red alga in the fossil record is similar to the modern-day algae, red seaweed, in the algae family Bangiophyceae. This marine algae has long red filaments.

8: ***Pediastrum simplex***
Width: 0.06mm
This green alga has its cells arranged in a distinctive genetically determined shape, known as a coenobial colon. It resembles a flattened star.

9: ***Licmophora flabellata***
Height: 0.5mm
Found in shallow marine environments such as estuaries, this diatom has distinctive fans and branching stalks. A sticky substance is secreted from the base of the main stalk to enable this diatom to attach itself to rocks.

10: ***Asterolampra decora***
Width: 0.08mm
A round- and saucer-shaped marine diatom most commonly found in tropical waters.

11: ***Micrasterias rotata***
Width: 0.18mm
This is a single-celled, fresh-water green alga that is often found in acidic peatland environments. These algae are usually highly symmetrical in shape.

12: ***Asterolampra vulgaris***
Width: 0.08mm
Another marine diatom in the Asterolampra family (see plate 10) but distinguished by its different patterning.

Preface

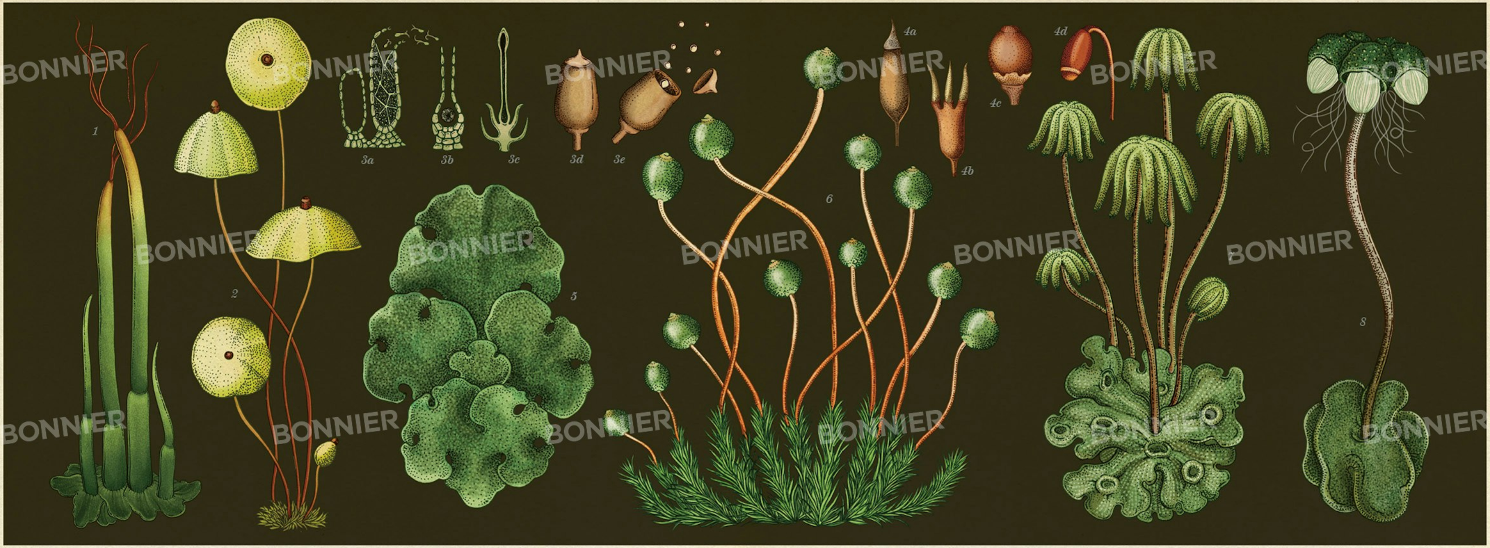
Plants are everywhere. They live on almost every surface on Earth, from the highest mountains to the lowest valleys, from the coldest and driest environments to some of the hottest and wettest places on our planet.

Vast numbers live in water – in oceans, lakes, rivers and swamps – in conditions ranging from extreme salinity (saltiness) to fresh, freezing, fast-flowing rivers. The smallest plants are tiny, single-celled microscopic organisms, less than 0.001mm across. They are so small that you'd need about 100 of them to make up the size of a grain of sand. The tallest are huge trees, towering up to 80m; as tall as a 20-storey building.

Nobody knows for certain how many species of plants there are. So far, scientists have counted about 425,000, but more are being discovered every day. There are clear patterns as to where on Earth plants thrive best, and the conditions they need. In the hot, wet tropics, for example, there are over 80 species of tree to each hectare: at the cold, arid North and South Poles there are fewer than eight. Understanding these patterns of plant diversity is crucial to preserving all other forms of life on Earth, including us. Because without plants there would be no humans. Plants create and regulate the air we breathe, and they provide us with food, medicines, textiles to make our clothes and materials to build our homes. So how do they do it? How did all this happen? How did Earth reach the diversity and variety of plant life we see around us today? What did the first plants look like? When did the first forests form? When did plants first produce flowers? What are the biggest, smallest, weirdest, rarest, ugliest and smelliest plants on Earth? Wander through this museum and all will be revealed.

Royal Botanic Gardens Kew

Professor Kathy Willis
Royal Botanic Gardens, Kew



Bryophytes

Plants started to move out of their watery environment and live on land from around 470 million years ago. These earliest land plants evolved from green algae and were similar to present-day liverworts, hornworts and mosses, which are collectively known as bryophytes. Bryophytes have none of the firm tissue (vascular tissue) that enabled later plants to stand upright. This makes bryophytes soft to the touch, and also unable to grow beyond about 50cm in height. They have root-like structures called rhizoids that allow them to capture nutrients from the soil, and a rather unusual reproductive cycle that involves alternating between two different life forms, a leafy (vegetative) form called a gametophyte and a form that disperses spores called a sporophyte. The leafy form is most commonly seen growing in moist, damp environments. In this form, the plant has male and female organs, which sometimes grow on the same plant and sometimes on separate plants.

The female organs are called archegonia and are bottle-shaped. The male organs are called antheridia and are oval-shaped. Spermatozoids are released from the male organs to fertilise the egg cells in the bottle-shaped female organs. The female egg, once fertilised is called a zygote and grows to produce a second, different, life form called a sporophyte. Spores are produced in the sporophyte and once ripe, they are released into the soil to grow into the leafy form (the gametophyte) and the process starts all over again.

Key to plate

1: **Smooth hornwort**
Phaeoceros laevis
Height: 5cm

2: **Yellow moose dung-moss**
Splachnum luteum
Height: sporophyte 15cm
The sporophyte has a bright yellow parasol-like structure. Insects, rather than wind, disperse the spores.

3: **Reproductive cycle of moss**
a) Male antheridium releasing spermatozoids b) Female archegonium containing egg c) Once the egg is fertilised a zygote grows d) The mature sporophyte at the top of the moss plant e) Spores are released. They will grow into gametophytes and the process will begin again.

4: **Moss capsules**
Capsule height: 2–4mm
a) *Climacium dendroides* b) *Tetraphis pellucida* c) *Sphagnum palustre*
d) *Plagiomnium cuspidatum*
These are the spore-bearing capsules, which have special hoods to protect the spores inside.

5: **Crescent-cup liverwort**
Lunularia cruciata
Width: thallus (plant body) 12mm

6: **Stiff apple moss**
Bartramia ithyphylla
Height: shoots up to 4cm

7: **Umbrella liverwort**
Marchantia polymorpha
Length: thallus (plant body) 4–6cm; female receptacles 20–45mm

8: ***Asterella australis***
Length: thallus (plant body) 4cm

Fungi and Lichens

Two groups of organisms were vital in helping plants gain a hold on dry land around 470–400 million years ago – fungi and lichens.

There's an important point to note here – although this is a book about plants, fungi are not plants. They don't make food by photosynthesis, don't have roots and they reproduce with spores. They are included here because they were historically treated as plants, and because they are involved in the functioning of plant ecosystems: they help to break down plant litter and animal remains in soil, ensuring that there are sufficient nutrients for plants to take up for growth. Fungi are also an important food source for animals and humans. Yeast, for example, which is a fungus, is an essential ingredient in bread and beer. At the same time, fungi are also responsible for some of the most toxic poisons and most dangerous diseases of both humans and animals. Many fungi are highly poisonous and should never be touched or eaten when found growing in the wild.

Lichens are not plants either. They are a collaboration between a fungal element and photosynthesising algae. The organic acid released from rock-inhabiting lichens is thought to have been important for breaking down rocks to make soil in the earliest land environments.

Lichens are also able to survive in harsh places with extreme climates, an ability that would have been essential for early life on land. Species of lichen are found on rocks growing at the top of the highest mountains and in the hottest and coldest deserts. Some even produce their own sunscreen in the form of sun-protecting pigments. Production of the pigments is triggered by high levels of sunlight and this enables these lichens to grow in open environments with little or no shade.

Key to plate

1: **Bird's nest fungus**
Cyathus striatus
Diameter: 1cm
These tiny fungi hold their spores in disc-shaped packets resembling eggs in a nest, and raindrops cause these 'eggs' to spring out and disperse.

2: **Red *Marasmius***
Marasmius haematocephalus
Height: 2–3cm
These small, umbrella-like fungi play an important role in recycling the litter layer on forest floors.

3: **Pixie-cup lichen**
Cladonia chlorophaea
Height: 1–4cm
These lichens produce stalked cups which bear the fruiting structures. In European folklore these tiny cups are thought to be used by pixies or wood fairies to sip the morning dew.

4: **Leathery goblet**
Cymatoderma elegans
Height: 15cm
The cap of this fungus opens to a wide funnel and can often be found containing water, hence its name.

5: **Veiled lady**
Phallus indusiatus
Height: 25cm
This distinctive fungus has been used for centuries as a charm in folklore and traditional medicine.

6: **Enokitake mushroom**
Flammulina velutipes (cultivated form)
Height: 10cm
Commonly used in east Asian cooking, this mushroom is cultivated in a carbon dioxide-rich environment to create long, thin stems.

7: **Turkeytail fungus**
Trametes versicolor
Diameter: 4–10cm
So-named because its radiating growth resembles the fanned tails of turkeys.

8: **Golden shield lichen**
Xanthoria parietina
Diameter: up to 10cm
This lichen is bright yellow-orange in sunny places but a dull green when in the shade because it makes its own sunscreen in the form of a sun-protecting pigment.

9: **Fly agaric**
Amanita muscaria
Diameter: 8–20cm
This toadstool is often represented in fairy stories. Its toxic chemicals cause hallucinations.

10: **Lane Cove waxcap**
Hygrocybe lanecovensis
Height: up to 5cm
An endangered fungus, first collected in 1998 and known from a single parkland in Sydney, Australia.

Club Mosses, Horsetails and Whisk Ferns

The common names we use for plants are sometimes not an accurate reflection of scientific definitions. Club mosses, for example, are not actually mosses, in fact they are vascular plants. This means that they contain a well-developed system of specialised cells, known as vascular bundles, which allow the plants to grow upright and much taller than bryophytes, which lack a vascular system (see pages 10–11). Horsetails and whisk ferns also contain vascular strands.

These three groups of plants, which reproduce by spores, have ancient lineages and are often referred to as 'living fossils' because there are fossil remains dating from 400–370 million years ago that are very similar in structure to the club mosses, horsetails and whisk ferns we see growing today, but with one important difference: the present-day plants are small herbs – usually less that 1m in height. By comparison, their ancestors were giants. Horsetail and lycophyte trees (related to club mosses), towering up to 40m in height, dominated the early Carboniferous landscapes (see pages 18–19). The giant tree-forms of these plants met the fate of most species of life on Earth – extinction, out-competed by better adapted rivals so that all we are now left with are the miniature forms that were able to survive.

Key to plate

1: **Club moss**
Selaginella lepidophylla
Height: 10cm
Club mosses have small, scale-like leaves wrapped all around their stems.

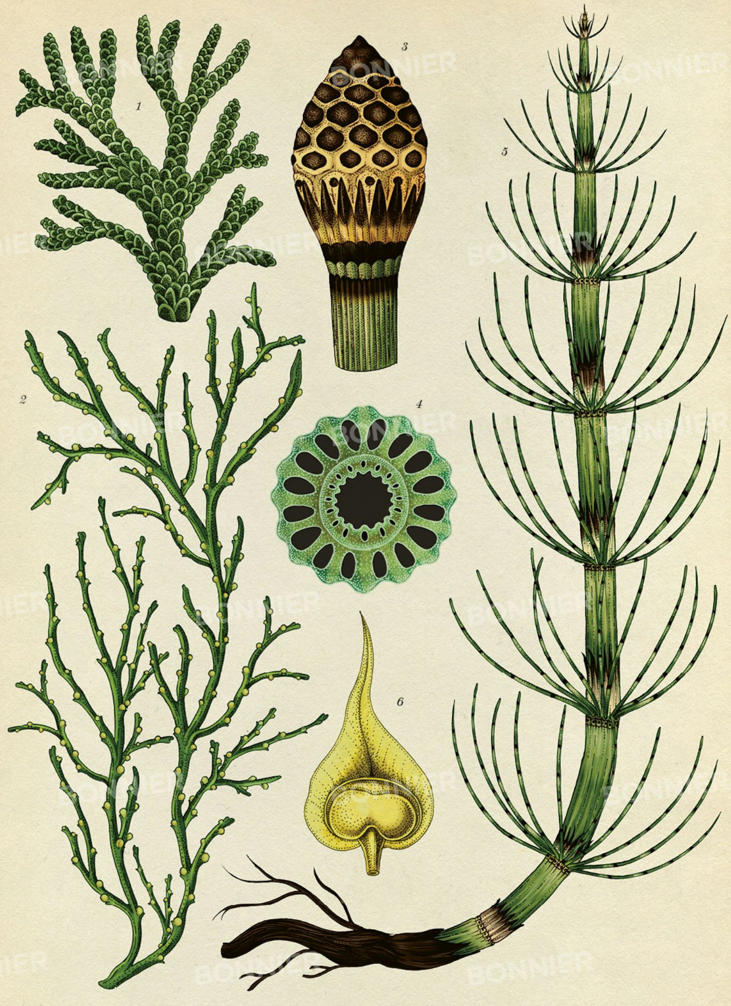
2: **Whisk fern**
Psilotum complanatum
Height: up to 75cm
This species of whisk fern is usually found hanging from the trunks of trees in tropical regions. It does not have roots or leaves but it has small scales on the stem.

3: **Horsetail**
Equisetum hyemale
Cone height: 1cm
Cone
The spores of horsetails come from sporangia, which are produced at the margin of polygonal structures grouped into a 'cone'. These cones are usually situated at the apex (top) of the plant.

4: **Field horsetail**
Equisetum arvense
Diameter: 3–5mm
Section through stem
This section through a young horsetail stem shows how vascular bundles (the round circular sections) extend up through the whole plant stem. These woody strands allow the upward movement of water and sap throughout the plant.

5: **Field horsetail**
Equisetum arvense
Height: 20–50cm
The vegetative shoots of field horsetails have whorled branches and look feathery. The actual leaves are small, papery, and fused into a sheath on the stem. The cones that contain the spores are found on pale, fertile shoots, which grow before the bigger green vegetative ones. Field horsetails grow in damp or wet places.

6: **Sporophyll of a club moss**
Lycopodium clavatum
Sporophyll length: 2–2.5mm
Sporophylls are tiny leaves that bear the sporangia (spore-production centres).



Ferns

Ferns are found in a huge variety of environments across the globe. Mostly they prefer moist, shady environments, but there are species found in hot, dry deserts, underwater, and floating on top of ponds and rivers. They take many different forms, from upright plants with roots that grow in the soil, to epiphytic forms (meaning plants that grow on other plants, usually trees) with their 'roots' waving freely in the air and gaining moisture and nutrients from rain and debris. Some ferns also grow as vines. All ferns are herbaceous, which means that none contain the woody material that forms the central parts of tree trunks (known as the secondary xylem). Despite this, some fern species do still grow to the height of trees. These ferns have a stem containing a central core filled with pith surrounded by strands of vascular tissue. This forms a rigid cylinder, or 'trunk' and a structure which can move water, sugars and nutrients around the plant. These tree-form ferns dominated the Carboniferous forests of 350 million years ago (see pages 18–19), and could reach 10m in height. Tree ferns are still with us today.

Another distinctive characteristic of ferns is a reproductive cycle that involves two different forms of the same plant, alternating between the generations. Ripe spores are released from the underside of the leaves. These grow into small plants, called gametophytes (also part of bryophyte reproduction, see pages 10–11), which look quite unlike their ferny parent. Usually, the gametophyte is a tiny, flat, green, scale-like growth, just a few centimetres long and rarely seen. When this plant matures, it produces male and female organs. These then produce offspring, which grow into the same ferny form as their grandparents, the plant we would readily recognise as a fern, known as a sporophyte. This form then produces spores on the underside of its leaves, and the cycle continues.

Key to plate

1: **East Indian holly fern**
Arachniodes aristata
Pinnule (leaflet) length: 1.5cm
The underside of a leafy pinnule showing the disc-like structures (called sori), in which the spores are produced. The sori are protected by a white membrane called indusium.

2: **Stag's horn fern**
Platycerium superbum
Length of fronds: up to 2m
This species develops two kinds of fronds: rounder and thicker base fronds, which protect the roots and collect detritus to create a soil for the epiphytic plant; and foliage fronds, which look like a stag's antlers and bear the spores.

3: **Maidenhair fern**
Adiantum capillus-veneris
Height: up to 30cm
Stem with fronds
This plant can hang from vertical surfaces or grow upright from horizontal ones.

4: ***Polypodium verrucosum***
Length of fronds: up to 1m
Fronds
The fronds of this species have uniform rows of bumps (its name means 'warty') on the upper surface which are pits holding the spores.

5: **Silver tree fern**
Cyathea dealbata
Height: up to 10m
Unfurling frond
This is one of the large tree ferns of the tropics and subtropics. The fronds have characteristic silvery undersides. Almost all ferns have their fronds tightly coiled into a spiral called a fern crozier before they unfurl.

6: **Deer fern**
Blechnum spicant
Fertile frond length: up to 70cm
This fern has two types of fronds – sterile fronds, which are evergreen; and seasonal, fertile fronds which are usually grouped in the plant's centre.

7: **Sporangium**
Diameter: < 1mm
This 'spore vessel', is a structure found on all ferns, gathered into clusters called sori and producing large numbers of spores. Sporangia are pale first and darken as the spores mature. When the spores are well developed, and if the external conditions are suitable, the sporangia rip wide apart and release the spores.

8: **Section through leaf bearing sporangia**
Section diameter: 3mm
The sporangia, where spores are produced, radiate out from a receptacle around the vein. The vein appears darker on the illustration.

Environment: Carboniferous Forests

The transition from the first, small, herbaceous land plants to massive trees 40–50m high, happened over 90 million years, between 389–299 million years ago. By the end of this period, known as the Carboniferous period, the Earth was covered with dense forests of thick-trunked trees, up to 1m in diameter. Many of the trees appear to have been giant versions of the herbaceous plants from which they evolved. They included huge lycophyte trees (related to club mosses) giant horsetails and very large tree ferns. None of them had flowers, and many still reproduced by spores. But these earliest forests also gave us the first trees that reproduced by seeds. Their seeds were produced in simple cones, very like the ones seen on conifer trees today.

If you'd had a map of the Earth 350 million years ago, it would have looked very different from today. The landmasses that later formed our continents were all in different places. South Africa and South America were at the South Pole, and most of the continental plates that now form Europe, China and Australia, were at the Equator. Forests responded to the climates associated with their locations. The tropical belt – warm, wet and seasonal – was covered in swamp forests of lycophytes and seed ferns, which relished the sweaty humidity and pools of standing water. When these trees died, they fell over, became waterlogged and sank. Over millions of years they became compacted and fossilised into coal. In drier forests, outside the tropical belt, giant horsetails and early seed-ferns dominated alongside lycophyte trees that were much shorter than their tropical cousins. Scientists think their smaller size was an adaptation to make them more resistant to drought.

Key to plate

1: **Gilboa tree**
Eospermatopteris
Height: 8m
The Gilboa is the earliest known fossil tree. It is 385 million years old and was found in fossil deposits in New York. Its trunk had a crown of leafless branches at the top. The plant probably photosynthesised through its trunk. Some of the tree's branches contained sporangia at their end and these contained the spores. The tree achieved great height by having long roots to anchor it to the ground.

2: **Cordaites trees**
Height: up to 30m
Cordaites trees occupied a large range of habitats from mangroves to drier uplands. Their most important feature was the fact that they reproduced by seeds and had cones similar in structure to a present-day conifer tree.

3: ***Lepidodendron* tree**
Height: up to 35m
The upper part of the trunk of this tree was branched many times to form a dense crown of simple leaves that grew directly from the stem (i.e. with no leaf stalk). This type of leaf attachment resulted in a triangular shape on the stem when the leaf fell off, resulting in a beautifully patterned trunk.

4: **Tree fern**
Psaronius
Height: up to 10m
Fossil remains of this tree are often found in coal deposits because it grew in the Carboniferous swamps. It was one of the largest tree ferns to grow during this time. It had large fronds for leaves, similar to those of ferns.

5: **Seed-fern trees**
Medullosa noei
Height: up to 10m
This tree had fern-like leaves, spirally arranged around the stem but it reproduced by seeds. The seeds looked very similar to present-day cycad seeds, suggesting a close evolutionary relationship.

6: ***Archaeopteris* tree**
Height: 9m
This was a major tree in Carboniferous and Devonian (the period before the Carboniferous) landscapes and is thought to be an ancestor to all seed plants because it had stems with wood similar to that found in conifers; however, it still reproduced by spores.

BOTANICUM

Gallery 2

Trees

Conifers

Conifers make up around 30% of the world's forests and can survive in some of the coldest and most hostile places on Earth. Most of them are easily identified by their simple, often needle-like leaves and distinctive cones. Many are also evergreen and don't lose their leaves in winter. Less immediately obvious is that conifers don't have flowers. Instead they have more simple organs for making seeds, called cones.

All conifer trees have two sorts of cones – male and female. Some species have these on the same tree, others have separate male and female trees. Male cones are usually small and produce multiple grains of yellow pollen. The female cone is made up of woody interlocking scales. Once fertilised by pollen released from the male cone, it starts to grow, sometimes to a very large size (like the *Araucaria* cone, for example, which is the size of a football). This process takes from a few months to a year. During the process, the female cone remains green and tightly closed with gluey resin keeping it shut. When mature, the cone turns brown, the scales separate, and seeds are released to be dispersed by wind or animals.

Conifers use a number of external triggers to determine when to release the mature seed: temperature, or sometimes fire, tells the plant that the ground has been cleared, creating plenty of space for its seed to grow.

Key to plate

1: **Chinese golden larch**
Pseudolarix amabilis
Height: 40–50m
Seed cone and shoot
This deciduous conifer loses its needles during cold and dry weather. It has male and female reproductive organs on the same plant. Male pollen stalks are around 1–2cm and female cones around 4–7cm long.

2: **Bald cypress**
Taxodium distichum
Height: 40–45m
Female cone
This tree is dominant in river flood plains and swamps in the south-eastern United States.

3: **Hinoki cypress**
Chamaecyparis obtusa
Height: 40–50m
Female cone
This tree has small, eight-scaled cones. Wood from this tree has been used for centuries in its native Japan for the construction of traditional buildings.

4: **Korean fir**
Abies koreana
Height: 10–18m
Female cone and leaves
Native to the mountains of Korea, this tree has dark green needle-like leaves and blue or purple cones.

5: **Scots pine**
Pinus sylvestris
Pollen grain diameter: 0.06mm
a) pollen grain b) male cone
Conifer pollen often has distinctive air-bladders which allow it to be carried on the wind, creating great yellow 'clouds' over the forest. This method of dispersal allows the pollen to travel huge distances by air or water. Pine pollen has been found trapped in the ice at the North Pole, many thousands of miles from the nearest tree.

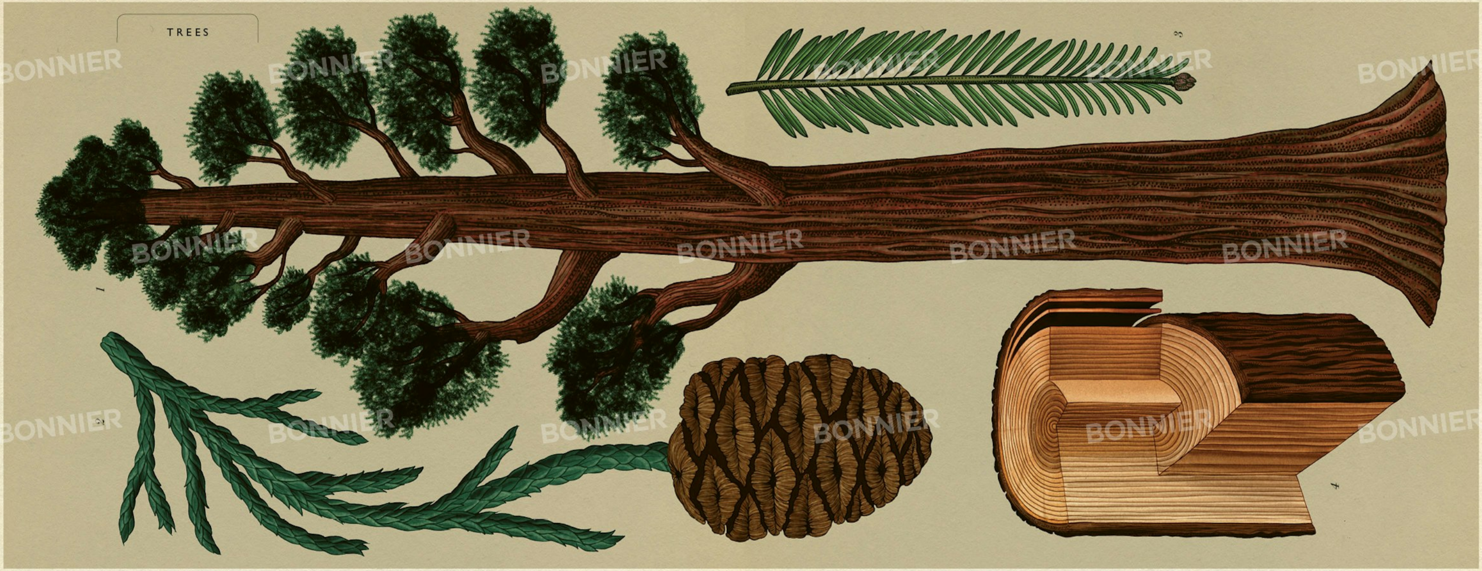
6: **Chilean podocarp**
Podocarpus nubigenus
Height: 35m
Leaves and seeds
This tree grows in the temperate rainforest of southern Chile. It only develops one seed with a juicy, swollen stalk to make it look and taste like a fruit. This attracts birds for dispersal.

7: **European silver fir**
Abies alba
Height: 60m
a) seed scales b) bract

8: **Monkey puzzle**
Araucaria araucana
Height: 50m
Shoot with leaves and male cones
This tree is native to southwest Argentina and southern and central Chile. It was given its name by an observer who thought that monkeys wouldn't be able to climb its spiky branches.

9: **Cedar of Lebanon**
Cedrus libani
Height: up to 40m
Female cone
Lebanon, in the Middle East, has a picture of this cedar on its flag and the tree is named after Mount Lebanon, where it can be found. The largest populations, however, are in the Taurus Mountains of southern Turkey. The tree produces large cones, 8–12cm long.

10: **Loblolly pine**
Pinus taeda
Height: 25–33m
Female cone, branch and leaves
This is the most important and widely cultivated timber species in the southern United States.



The Giant Sequoia

Giant sequoias (*Sequoiadendron giganteum*) are record breakers. They are the tallest trees on the planet, some growing to over 80m. Their trunks can be up to 11m in diameter, meaning it takes sixteen adults holding hands to reach around one. They live for a long time, with many individual trees surviving for more than 2000 years. Fossil records indicate that sequoias have been around for a large part of Earth's history – 100 million years. These giants are genuine 'living fossils'.

Sequoias are conifers. Like all conifers, they reproduce with cones. Male and female cones are carried on the same tree. These cones are small (especially compared to the size of the tree!) – about 5–7cm long – and grow at the ends of branches. Sequoias are well adapted to their environment. Thick bark (up to 50–60cm thick) and foliage high above the ground provide protection from fire.

The trees' great height requires physical adaptations. Sequoia roots spread out for up to 30m beyond the tree, intertwining with other tree roots to provide anchorage for the huge trunk, but not penetrating very deep into the ground. The speed at which this tree grows when young is nothing short of phenomenal. In Italy, a young tree reached a height of 22m in just 17 years.

Key to plate

Giant sequoia
Sequoiadendron giganteum
Height: up to 80m

***1:* Tree**
This tree is native to California in the United States and is found on the western slopes of the Sierra Nevada mountain range, where it occurs in about 75 distinct groves in the forest.

***2:* Female cone**
Length: 5–7cm
Because sequoia cones grow high up the tree, this makes them almost impossible to see and count, but one tree is thought to produce as many as 11,000 cones a year.

***3:* Leaves**
As well as enabling the tree to photosynthesise, sequoia leaves have an important role in water retention. Sequoias have no leaves on the lower part of the trunk, only high up where the leaves can absorb and retain atmospheric moisture. The leaf surface absorbs water like a sponge, storing it for use by the uppermost part of the tree.

***4:* Wood and bark**
Sequoia wood and bark are surprisingly soft and light, making them flexible and less likely to collapse under their own weight or in high winds. They move hundreds of litres of water around their huge frames each day, causing the trunk to swell and contract during each daily cycle.

The Ginkgo

Ginkgoes are beautiful trees. Their flowing, elegant leaves have given them their nickname, maidenhairs. They grace the parks and streets of cities all over the world, partly because of their handsome looks, but also because they appear to be fairly resistant to the extremes of weather and pollution found in cities. In the wild, ginkgoes occur naturally in some parts of China.

Wild or cultivated, the ginkgoes we see today belong to only one species, *Ginkgo biloba*. This tree represents the end of an evolutionary line. Around 250 million years ago there were numerous different types of ginkgoes growing all over the world. All have now died out, apart from *Ginkgo biloba*. *Ginkgo biloba* seems not to have changed its appearance that much in those 250 million years. The modern leaf appears to be identical in shape and form to examples found in the fossil record and ginkgoes are often called a 'living fossil'.

The leaves of ginkgoes look like fans, both in shape and in the pattern of parallel veins on their underside. Ginkgoes are deciduous, losing their leaves when the weather becomes cold. They grow 30–40m in height. Like conifers, they are gymnosperms, and evolved before flowering plants and thus have male and female reproductive structures on their stalks instead of flowers. Male and female *Ginkgo biloba* trees are different and separate. Female trees have ovules or seeds, which also grow from the base of the leaf axis, on stalks called peduncles, with one seed on each stalk.

Key to plate

Maidenhair tree
Ginkgo biloba
Height: 40m

1: **Leaves and ovules on branch of female tree**
Ginkgo biloba is native to China. They can live for a very long time and the oldest recorded individual is thought to be 3500 years old. What appear to be plum-like fruits are actually naked seeds. Although they may look appetising, they emit a terrible stench like vomit. Ginkgo seeds are probably adapted to be dispersed by carrion-eating dinosaurs, which would explain the unsavoury smell.

2: **Catkins from male tree**
Male trees have catkin-like structures, which grow in pairs at the base of the leaf axis and bear distinctive pollen grains. These are wind dispersed.

Temperate Trees

Temperate trees are found in mid-latitude parts of the globe between the polar regions and the tropics. In these regions, summers are warm and wet and winters cold and dry. The trees that grow here have to be able to withstand different kinds of climate and periods of rapid change.

One of the most significant seasonal changes in temperate regions is the number of hours of sunlight. There is less sunlight in autumn and winter, and therefore less opportunity for trees to photosynthesise. Many temperate trees react by shedding their leaves. These are known as deciduous trees, and the process is called leaf abscission. Trees will also shed their leaves if conditions become unusually dry, because most water loss from a plant is through its leaves. Shedding its leaves saves the tree water. It also accounts for the colours of temperate woodlands in autumn. Because the leaves are no longer required to photosynthesise, they lose their chlorophyll, the green pigment used for photosynthesis. This means that other colours in the leaf become apparent, producing the glorious displays of reds, browns and golds seen in the vast forests of New England in the United States, Hokkaido in Japan and in similar temperate regions all over the world.

Shedding leaves has another advantage, too. Most temperate trees have large, flat leaves (very different to the needle-like leaves seen on conifers) attached to the branches by a small stem called a petiole. This makes them excellent for capturing energy when the sun is shining, but it also makes the tree vulnerable to damage when it snows, because the leaves tend to trap the snow, making the branch heavy and likely to break.

Temperate trees shed their leaves by growing a layer of cells between the leaf stalk and the branch, which separates stalk from branch and causes the leaf to fall to the ground. A hormone called auxin controls this process. The vast majority of temperate trees (including all those on this page) are angiosperms (flowering plants) that evolved late – between 150–80 million years ago. This is almost 150 million years later than the conifers.

Key to plate

1: **Sycamore**
Acer pseudoplatanus
Height: up to 35m
a) bud b) seed
This tree is native in the mountains of central Europe and perhaps also Scotland; elsewhere it has been introduced.

2: **White mulberry tree**
Morus alba
Height: Over 20m
a) leaves b) fruit
This species is native to China and is the main food source for silk worms.

3: **English oak**
Quercus robur
Height: 36m
a) leaf b) acorn
These trees occur almost all over Europe.

4: **English elm**
Ulmus procera
Height: 36m
a) seed b) flower

5: **Common beech**
Fagus sylvatica
Height: 40m
a) seed pod b) leaf

6: **Sweet chestnut**
Castanea sativa
Height: 35m
a) leaf b) seed

7: **Scarlet oak**
Quercus coccinea
Height: 21m
a) leaf b) acorns

8: **Silver birch**
Betula pendula
Height: 30m
a) male catkin b) scale from female catkin c) female flower d) male flower

9: **Broadleaf maple**
Acer macrophyllum
Height: 15–30m
Leaf

10: **Japanese maple**
Acer palmatum
Height: 8m
Leaf

Tropical Trees

The tropics are the regions to the north and south of the Equator and have a distinctive climate. The temperature is, on average, 20–25°C throughout the year, and the daylight hours are the same all year round. Some parts also experience large amounts of rainfall providing very wet environments. Because growth in tropical forests is not affected by pronounced changes in day length and temperature, many species don't have growth rings apparent inside their tree trunks – unlike trees from temperate regions (see giant sequoia, see page 25). The bark of tropical trees is thin (often less than 10mm thick), smooth and pale in colour.

There are many different shapes and sizes of tree in the tropics. Their form is largely determined by local variations in temperature and rainfall. In the wettest parts of the tropics, in the Amazon rainforest for example, trees are tall (often 30m or more), evergreen (because they can photosynthesise efficiently all year round) and have little protection against cold or drought (because they don't need it).

In order to stay upright, the tallest tropical trees need good anchorage, so they have evolved a spectacular kind of above-ground rooting system called 'buttresses' (like flying buttresses on a Gothic cathedral) that spread out from the main trunk, often leaving gaps big enough for humans to walk through. Other tropical trees have thinner 'stilt' roots sprouting higher up the trunk, making the tree look like it is walking on stilts. In the wettest parts of the tropics, many leaves have a 'drip tip', which allows water to drain quickly from the leaf's surface. Leaves are usually thick, large (up to 13cm long), and elliptical in shape.

In the drier parts of the tropics, in the Caatingas in tropical South America, for example, where there is a dry season for several months of the year, tropical trees rarely exceed 10m in height and tend to be deciduous, losing their leaves during the dry season. These trees also have very deep roots to cope with the intervals of drought.

Key to plate

1: **Cannonball tree**
Couroupita guianensis
Height: 23m
Flowers and buds on stem
Native to the Guianas in South America, this tree has complex, waxy flowers that are beautifully scented and grow directly on the bark of the trunk. Its fruits look like rusty cannonballs hanging in clusters.

2: **Rubber tree**
Hevea brasiliensis
Height: up to 40m
a) leaves b) seed pod
Native to Brazil (parts of the Amazon basin and Mato Grosso) and the Guianas region of north-eastern South America. The milky latex of *Hevea brasiliensis* is the raw material for natural rubber. Each fruit of the rubber tree contains three seeds.

3: **Ackee**
Blighia sapida
Height: up to 30m
a) Section through fruit b) fruit and leaves on stem
Although this tree is native to tropical West Africa, it is widespread in Jamaica and is the defining ingredient in Jamaica's national dish 'ackee and saltfish'. The brightly coloured fruits contain three large black seeds, each bearing a yellowish-white appendage (aril). This aril, which has the texture of scrambled egg, is the only edible part of this poisonous fruit and even this only becomes edible after the fruit has opened by itself (i.e. is fully ripe). If the aril is eaten too early, people will get what is known as 'Jamaican vomiting sickness'.

4: **Indian banyan tree**
Ficus benghalensis
Height: up to 30m
Leaves on stem
Native to India and Pakistan, the banyan is a type of strangling fig. It begins life growing on other trees and eventually envelopes them completely. Aerial roots hang down from the branches and these become trunks. The leaves are leathery, 20–40cm long and the fruit (figs) 1–2cm in diameter.

Fruit Trees

Humans have always eaten fruit: as well as 5000-year-old oil palm kernals (see pages 44–45) archaeologists have found 4500-year-old banana remains in human settlements in Africa, and the United Kingdom has many Bronze Age sites containing 4000-year-old cherry stones. This long history emphasises its practicality as a food source – most fruits can be eaten straight off the tree.

But why is it important to plants? Why do they produce fruits? Why do they need to make these tasty morsels hang and drop from their branches? The answer is reproduction. All fruits carry the plant's seed. Sometimes the seed is enclosed within the fleshy part of the fruit, as in apples and pears. In other cases the seed is attached to the outside of the fruit, as with soft fruits like blackberries and strawberries. Other soft fruits have one, larger seed in the form of a stone, like cherries and peaches. In others, flesh and seeds are both encased by a firm skin, typically those from a hot climate where exposed flesh would dry out, like citrus fruits, pineapples and bananas.

The flesh of a fruit is tasty and nutritious. There are good evolutionary reasons for this. Many plants rely on animals and birds to disperse their seed. By enclosing them in juicy fruit the plant gets its seed nibbled by peckish passers-by, who then pass it through their digestive systems and deposit it, suitably fertilised, in a fresh growing environment some distance away.

But fruit isn't just what's in your fruit bowl or your fruit salad. Coffee comes from a fruit, and so does cacao, which gives us chocolate. These delicacies have given humans not just sustenance and social relaxation, but also a history of conquest and trade.

Key to plate

1: **Cacao**
Theobroma cacao
Height: 8m
a) section through fruit b) flower
The fruit of cacao is a thick-walled pod that contains lots of large seeds embedded in a sweet-tasting pulp. The fermented and dried seeds are ground up to yield cocoa powder, which is used to make chocolate. The edible properties of *Theobroma cacao* were discovered over 2000 years ago by the people of Central America.

2: **Coffee**
Coffea arabica
Height: 8m
a) section through fruit b) flower
c) leaves and fruits
Coffee is one of the world's favourite drinks, one of the most important commercial crop-plants, and the second most valuable international commodity; Arabica coffee is considered to produce the finest coffee beans. This plant is native to northeast tropical Africa and possibly east tropical Africa. The small red drupes (fruits with an outer fleshy part containing a hard seed) seen on the coffee plant contain two 'beans' (stones each containing a single seed).

3: **Cashew**
Anacardium occidentale
Height: 14m
Leaves and fruits
This tropical evergreen tree originally came from north-eastern Brazil. The fruit of the cashew nut looks like a pear with something hard and kidney-shaped attached at the top. The pear-shaped fleshy part, called the 'cashew apple', is, in fact, the swollen stalk of the fruit. The hard kidney-shaped part of the fruit contains the seed, which we call a 'cashew nut'.

4: **Banana**
Musa acuminata
Height: 15m
Flower
Musa acuminata is the wild ancestor of the cultivated banana. Thousands of years of domestication have produced a delicious edible fruit. The yellow variety known as the Cavendish, which populates supermarket shelves, represents just a small proportion of global production.

5: **Peach**
Prunus persica
Height: up to 10m
Cut open fruit, and leaf
Peaches are drupes. Each peach contains a stone with one seed inside.

6: **Durian**
Durio zibethinus
Height: up to 30m
Cut open fruit, and flowers
The very large, heavy and spiky fruits of the durian tree contain a number of very big seeds that are entirely wrapped in an edible aril (a seed appendage). When fully ripe, the delicious aril has the texture of thick custard cream. Although most Europeans find the smell of the durian disagreeable, in Asia it is the 'king of fruits'.

Ornamental Shrubs

From the seventeenth century, collecting beautiful plants from all over the world to show in private and public gardens became an important component of European trade. Wealthy individuals competed with each other by paying professional plant hunters to scour the world looking for new discoveries. They built themselves increasingly elaborate hothouses and glasshouses to show off their finds, which included everything from delicate orchids (see pages 72–75) to giant waterlilies (see pages 84–85). But there was also a vigorous trade in plants for the garden. In Holland in the 1630s, inflated prices for the coveted 'Viceroy' tulip led to the first recorded financial market collapse, and in some regions of the world where plants were collected, environments were depleted of their native species by plant hunters, some to the point of extinction.

Because ornamental trees and shrubs need to grow outside all year round, a key objective for the plant hunter was to find types that can tolerate the cold and damp of northern European winters. For this reason, many ornamental shrubs we consider common today, come from regions with similar temperatures to parts of Europe. The majority originate from the Sino-Himalaya region of China, with Central America and eastern North America the next most common regions.

Key to plate

1: **Fuchsia**
Fuchsia triphylla
Height: 30cm–1m
Leaves and flowers
This small shrub originates from Haiti and the Dominican Republic and is one of over 110 species of fuchsias found in gardens the world over. It has very attractive flowers which bloom from early spring to late autumn.

2: **Southern magnolia**
Magnolia grandiflora
Height: up to 25m
Vertical section through flower
This large, evergreen magnolia tree is native to the south-eastern United States. It has large, white, fragrant flowers up to 30cm in diameter. The timber from this tree is hard and is often used to make furniture.

3: **King protea or Cape artichoke**
Protea cynaroides
Height: up to 2m
Flower
This is a sparsely branched evergreen shrub with leathery leaves. It has bowl-shaped flowerheads 15–30cm across, covered with red to pink or cream triangular bracts (not in fact petals but modified leaves). It is inside this 'bowl-shape' that many long flowers are massed together in the centre. This is the national flower of South Africa and has a natural distribution in temperate South Africa.

4: **Chinese or saucer magnolia**
Magnolia x soulangeana
Height: up to 6m
Flowers and buds on branch
This magnolia is a small, deciduous shrub with large white, pink or purple, goblet-shaped flowers up to 25cm, and is a popular garden hybrid produced from two natural species from China.

Environment: Rainforests

Rainforests are a rich and fascinating environment. They develop in places where every month is wet (with 100mm of rainfall or more) and where there are high temperatures of 18°C or more all year round. Globally there are three main blocks of rainforest: in Central and South America, in central Africa and southeast Asia. Permanently wet and permanently warm, rainforests provide such a fertile growing environment that many different kinds of plants have learnt to live alongside (and often underneath) each other. These plants have different strategies for sharing the abundant natural resources – some are tall and thin, spreading thick canopies high above the ground to catch the sun; others cling on to another plant; others creep along the ground in the dark, drawing nutrients from the rich, damp, soil.

The tallest rainforest trees stick high out of the canopy. These are known as emergents, and include elegant giants like the Brazil nut tree, which can grow to 50m in height and is one of the tallest trees in the Amazon rainforest. Emergent trees typically have slim trunks, which mean they are light, and produce branches and leaves only at the top.

Beneath the emergents is the canopy layer, often evergreen or semi-evergreen, where plants grow close together, giving a dense, consistent layer of vegetation. This can look like rolling, grassy hills when seen from above.

Below this is the understory. This is where plants grow that can photosynthesise effectively from the limited sunlight that penetrates the canopy. In the understory you will find vines, creepers and epiphytes (plants that grow on other plants), huge spreading ferns, swamp-dwellers like mangroves, and fungi, which flourish in the organically-rich soil.

The number and variety of species in rainforests is staggering. On one hectare in Ecuador, every other tree was found to be of a different species. In 80 hectares of the Rio Palenque forest there are 1030 species: by contrast, there are 1380 seed plant species in the whole of the British Isles.

The rainforest is a dynamic system, constantly changing and regenerating. When a big tree dies it crashes to the ground, opening up a huge gap in the canopy and the groundcover. Sunlight streams in, and life begins again. The fallen trunk then becomes a world in itself, providing a habitat for all sorts of plants and animals as it rots.

BOTANICUM

Gallery 3

Palms and Cycads

Cycads

When you first see a cycad you might be forgiven for thinking it was a palm tree. The long, frond-like leaves emerging like a crown from the top of the trunk give these plants a distinctly palm-like appearance. In fact, they are much older than the palm family. They evolved around 318 million years ago, probably from seed-ferns. This makes cycads the most ancient lineage of living seed plants.

Unlike palms, cycads do not flower and bear their reproductive organs in cones. In this respect they are similar to conifers and ginkgoes (and are classified as gymnosperms – see pages 22–27). Cycads have a long, cylindrical trunk and usually no branches. Leaves grow directly from the top of the trunk, and typically fall off as the tree gets older, leaving a diamond pattern on the stem and a crown of leaves at the top.

Today, there are around 300 species of cycads. They are found in a wide range of environments from the tropics and subtropics to warm temperate regions. All cycads live for a long time, some for more than 1000 years. There are separate male and female plants, the male cycads bearing cones that contain pollen, the females producing cones containing ovules that later become seeds.

Cycads were long thought to be pollinated by the wind, like conifers. However, studies now suggest that the vast majority, if not all, are actually pollinated by small beetles called weevils. Cycad seeds are large and have a fleshy outer coat, a tempting treat for a wide range of birds, rodents and bats. These animals help disperse seeds quickly – a useful trick as the seeds don't live very long and are vulnerable to drying out.

Key to plate

1: **Eastern Cape giant cycad**
Encephalartos altensteinii
Height: 6m
The Eastern Cape giant cycad comes from South Africa, is very long-lived and slow growing (as slow as 2.5cm per year), and is popular as an ornamental plant. In the wild it is found near the coast in habitats ranging from open shrubland on steep rocky slopes to closed evergreen forest in valleys.

2: ***Encephalartos ferox***
Height: 1m
Leaf
This species has bright, orange-red cones. The very large female cones consist of many densely packed cone scales, each of which bears two large seeds. This widespread species occurs in northern KwaZulu Natal province of South Africa and southern Mozambique. It grows at low elevations between 20 and 100m.

3: **Marlboro blue cycad**
Cycas angulata
Height: 2–9m
Maturing seeds on the female plant
Unlike most cycads, *Cycas* produces round seeds rather than condensed, compacted cones on the female plant. This Australian cycad produces distinctive, glossy blue-green leaves between 100–140cm long.

4: **Fern palm or sago palm**
Cycas revoluta
Height: 1–3m
Leaf
This is a species of cycad that is widely distributed throughout Japan and in the coastal Fujian Province of China. Although *Cycas revoluta* is often called the 'sago palm', and is sometimes processed for sago, the source of most cultivated sago is the true sago palm, *Metroxylon sagu* which is an actual palm rather than a cycad.

Palms

Palms are one of the most important flowering plant families in the world. There are more than 2600 different species. They include record-breakers like the plant with the longest leaves (the raffia palm: 25m long and 3m wide), the largest seed (coco de mer palm: seed up to 30cm long and weighing 18kg) and the largest flower clusters (talipot palm: flower clusters are 8m long with multiple clusters containing as many as 24 million flowers on a branched stalk). Palms also contribute some of the most valuable crops to the world economy, including coconuts, dates, betel nuts and palm oil (see pages 44–45).

Palms live in tropical and subtropical regions throughout the world. The greatest number of different species, however, occur in tropical rainforests. Unlike the similar-looking cycads, palms are flowering plants. They evolved relatively recently, around 100 million years ago, and diversified in the earliest tropical rainforests.

Palms are recognisable by the large, evergreen leaves that emerge from the top of the trunk. The leaves are either fan-shaped or feather-shaped, and are usually arranged in a spiral at the top of the stem. The leaves have a feature unique among flowering plants: they emerge from the centre of the crown like a sword. This 'sword leaf' then expands to reveal a broad, folded surface, which then splits apart into leaflets.

The flowers of the palm are quite inconspicuous, but if you look closely, you will see that they are intricate and varied in their structure. In the past, wind was thought to be responsible for pollination in palms, but we now know that insects such as bees, beetles, weevils and flies do most of the work.

Key to plate

1: **Bacaba**
Oenocarpus distichus
Height: 10m
This tall palm is native to the southern Amazon region. It has long pinnate (made up of many leaflets) leaves, which are arranged in a single flat plane. The fruits are used to prepare a drink called bacaba wine. Edible oil can also be extracted from its fruit.

2: **Coco de mer**
Lodoicea maldivica
Height: up to 34m
Seed
This palm has some of the longest leaves (up to 10m) and the largest and heaviest seeds of any plant in the world. Its enormous seeds which usually have 2 lobes can weigh 18kg and be 30cm in diameter.

3: **Coconut**
Cocos nucifera
Height: up to 30m
Fruit
The fruit (20–30cm long) is a fibrous drupe, not a true 'nut'. It has three layers; a thick, fibrous mesocarp surrounding a hard endocarp (the shell of the 'nut') and inside this the white flesh of the endosperm, which is the part humans eat. It is 12–15mm thick and is hollow.

4: **Bottle palm**
Hyophorbe lagenicaulis
Height: 3–4m
This little dwarf palm has a solitary grey trunk which bulges near the base, leading to the name bottle palm. It has a small crown of 4–8 feather-like leaves, which grow to around 3m in length. This palm is native to Round Island, Mauritius, where it has recently been rescued from the brink of extinction.

5: **Dwarf palmetto**
Sabal minor
Height: 1m
Leaf and fruits
This small, fan-leaved species is one of the most cold-tolerant palms. It was used as an important traditional medicine by the Houma American Indians, who dug the small roots to treat multiple ailments. The juice was rubbed on the eyes to alleviate soreness, while a mixture of the dried roots taken internally corrected high blood pressure and relieved kidney problems. This palm is native to the southern United States.

The Oil Palm

The oil from the African oil palm tree (*Elaeis guineensis*) is found in biscuits, cakes, soaps, lipstick and many other everyday products throughout the world. Once the oil has been extracted, waste products from the seeds can be used as fertiliser, as fuel for vehicles and even for road building. Archaeological evidence suggests that our ancestors valued the oil palm too; palm nuts dating back 5000 years have been found on many archaeological digs in western Africa.

In the wild, the oil palm tree grows on the margins of humid forest and along watercourses in drier areas in West and Southwest Africa. Each tree has a single stem, which can grow up to 20m tall. Leaves are similarly large – often 3–5m long. A young tree may have 30 new leaves each year, an older palm about 20.

The fruit grows in large bunches, taking five to six months to reach maturity after pollination. The flesh and seed kernel are both rich in the precious oil.

Oil palms have been extensively planted and form an important crop in many parts of Southeast Asia, Africa and South America. In fact, some plantations in Southeast Asia are so vast they can be seen from space. Managing an industry on this global scale brings challenges to the local environment, and the areas where the trees grow best include some of the world's most biodiverse and important tropical rainforest. Much rainforest has been cut down to clear the land for palm cultivation with devastating consequences for local plants and animals, which are being driven to extinction.

But there is a willingness to address this issue. Many of the companies that trade and use the oil palm worldwide have now joined together in a group called the Round Table in Sustainable Palm Oil. The aim is to ensure that the crop is grown in a sustainable way that does as little damage as possible to tropical rainforest, both now and in the future.

Key to plate

Oil palm
Elaeis guineensis
Height: up to 20m

1: **a) b) c) d) Fruit variously whole and in section**
Length: 2–5cm long
The fruit is black to orange depending on the stage of ripeness, and weighs 10–30g. The fruit flesh consists of 30–60% palm oil. The endocarp (or shell) surrounds the seed (or kernel), which contains kernel oil.

2: **Male inflorescence (clustered flowers on a stalk)**
Length: 35–40cm

3: **Habit (showing the growth and appearance of the plant)**
Leaf length: 3–5m

4: **Male flower**
a) flower b) section through flower
Length: 15–25mm
There are 400–1500 flowers on each branch in the male inflorescence.

5: **Female inflorescence (clustered flowers on a stalk)**
Length: 35–40cm

BOTANICUM

Gallery 4

Herbaceous Plants

Flower Structure

Flowers are nature's way of showing off. Their dazzling variety of colours, shapes, sizes and smells is surely one of nature's greatest achievements. The reason plants invest so much flamboyant energy in their flowers lies in their function – it's all to do with reproduction.

Flowers contain the male organs that make pollen and the female organs that contain the egg-bearing ovules. Once fertilised by pollen, the ovules develop into seeds. A new plant then grows from this seed and the next generation of plants emerges. Some plants have male and female organs on the same flower – others have separate male and female flowers. Plants have evolved a remarkable array of different ways to get the male pollen into the female ovary, and the physical characteristics of a flower tell us how each plant does this.

Plants that use animals for pollination have many ways to lure them in. There are seven main groups of animal pollinators: beetles, flies, bees, butterflies, moths, birds and bats. Beetles have poor colour vision, a good sense of smell and large bodies. Flowers pollinated by beetles are therefore often plain in colour, large to support a hefty visitor and highly scented. Butterflies, on the other hand, have long tongues and good colour vision. Flowers pollinated by butterflies are usually bright, have a flat lip to act as a landing platform, and a deep tube which the butterfly reaches into with its long tongue to get nectar. Nectar is a sugary liquid that provides a treat for the pollinator and which also uses its smell to guide the animal to the right place. The flower's pollen then gets stuck to the animal and is carried to the next flower where it fertilises the female organs.

Other plants, grasses for example, are pollinated by wind. Their flowers do not need colour and scent, because they don't have to attract animals. Flowers of these plants are usually green, like the rest of the plant, and have small petals, or none. These plants need their flowers to grow at the top so that the pollen can blow away freely.

Key to plate

1: **Creeping buttercup**
Ranunculus repens
Height: up to 30cm
a) Section through seed. Each seed contains a small embryo embedded in endosperm. b) Section through flower c) Stamen – this is the male reproductive part of the flower consisting of a stalk (or filament) which holds the pollen-producing structure (anther) at the top.
The buttercup is a radially symmetrical flower – so it is possible to draw many lines of symmetry on the face of the flowers. Buttercups are pollinated by insects.

2: **Rye grass**
Lolium perenne
Height: 30–60cm
a) Section through flower
b) Flower clusters (spikelets) on stem
This wind-pollinated plant holds its flowers at the top, well above the leaves. The stamens, which hold the pollen in the anthers, are long and exposed to the wind.

3. **Snapdragon**
Antirrhinum majus
Height: up to 30cm
a) Stamen b) Vertical section through ovary c) Section through ovary d) Section through flower showing petal and stamens e) Vertical section through flower
Antirrhinum is a bilaterally symmetrical flower – so it is only possible to draw a single line of symmetry on it. It has four different petal shapes: an upper lip, two sides and a lower lip. This structure creates a sort of tube that the pollinator – a bee – has to force its way inside to reach the nectar. This means that the bee will stand on the flower in a particular position and that pollen placement on the body of the bee will always be in the same area – a very efficient pollination system.

Wild Flowers

Flowering plants that grow without being either planted or altered by human hands are known as wild flowers.

Wild flowers are herbaceous plants. This means that they lack a woody stem that remains above ground all year round. Instead, once they have flowered and shed their seeds, the stem withers and falls over, eventually getting mulched back into the soil. There are three kinds of herbaceous plants: annuals, biennials and perennials. Annuals live, bloom and die in the space of a single season. In order to carry on their species to the next generation, they produce large quantities of seeds, which survive in the soil over winter or dry seasons, and germinate the following year or when the weather improves (for example in the brief rainy season in deserts – resulting in a 'desert in bloom'). Biennials and herbaceous perennials both leave a living part of themselves below ground, which then grows and flowers in the spring.

The difference between biennials and perennials is length of life. Biennials will only flower once, during the plant's second year of life, while perennials will go on flowering every year. The part of the plant that remains below ground varies: in some cases it's a bulb (like crocuses and tulips, see pages 54–55), in others a stem specially thickened to grow below ground (like ginger, see pages 56–57).

Wild flowers are completely reliant upon nature to disperse their seeds. Annuals only disperse and produce seeds once in their life cycle, so it is essential that they maximise their opportunities to do so. Many wild flowers produce vast numbers of seeds to give them the best shot at survival. Many have come up with cunning ways of spreading their seeds. Dandelions, for example, use little feathery parachutes to carry the seeds far away on a breath of wind. Poppies carry their seeds in a case that dries out and then bursts, showering seeds as far away from the parent plant as possible.

Key to plate

1: **Black-eyed Susan**
Rudbeckia hirta
Height: 30cm–1m

2: **Common poppy**
Papaver rhoeas
Height: up to 60cm

3: **Germander Speedwell**
Veronica chamaedrys
Height: up to 30cm

4: **Wild columbine**
Aquilegia canadensis
Height: 60cm

5: **Dandelion**
Taraxacum officinale
Height: up to 30cm
Fruiting head diameter: 2.5–7.5cm
a) flower head b) unopened fruiting head c) fruiting head d) fruiting heads after seed dispersal by wind. One head has four remaining seeds and their 'parachutes'.
Dandelions look like they have one, large yellow flower, but they actually have lots of very small flowers collected together into a composite flower head. Each single flower in a head is called a floret.

6: **Common harebell**
Campanula rotundifolia
Height: 10–30cm

7: **Japanese anemone**
Anemone hupehensis
Height: 30cm–1m

8: **Montbretia**
Crocosmia x crocosmiiflora
Height: 30cm–1m

Cultivated Flowers

People realised a long time ago that plants could be cultivated to help cure illnesses. Medieval doctors believed that plants healed the bit of the body they most looked like: black-eyed daisies were thought to be good for disorders of the eye and broccoli was used to treat diseases of the lungs. Many plants are still cultivated for their medicinal properties (though with a rather greater reliance on scientific evidence!). For example, opium poppies are used to produce two vital painkillers, morphine and codeine. Unfortunately, they are also cultivated to produce heroin, a treacherously addictive drug. This handsome poppy may be the world's most contentious flower.

Other flowers are cultivated for food. The sunflower gives us tasty seeds which, as well as being eaten whole, can be pressed to release a versatile and flavoursome oil, used in salads, cooking, making margarine and much more thanks to their high proportion of unsaturated fatty acids. Sunflower oil has other uses too, including as biofuel (fuel made from plants or other organic matter as opposed to fossil fuels such as oil and coal), in soap making, and as a drying oil for paint. The seed cases can also be put to good use after the oil has been extracted, for example mixed with soyabean meal to make a protein-rich livestock food. Ground sunflower seeds have also long been used as an alternative to wheat flour in making bread, for example by Native American peoples.

Some flowers are grown for their smell. Roses and lavender were first introduced into northern Europe by the Romans. Both are used in the perfume industry – lavender was first cultivated as a scent by the ancient Greeks. Less well-known is that the iris is also grown for its scent. To make this, an iris's rooting structure – known as a rhizome – needs to be stored for three years. When taken out of storage and squeezed, it exudes a distinctive, butter-coloured oil called orris, which smells of violets. Orris also has the unusual property of making other scents smell stronger.

Many plants, of course, are grown simply because they look nice. Flowers have been collected from all over the world and cultivated because people enjoy transplanting a dash of colour or a hint of the exotic into a garden. Hellebores are from the Balkans, the Middle East and China. They have become a favourite with gardeners for their palette of colours, and because they flower in both winter and spring.

Key to plate

1: **Hellebore or Lenten rose**
Helleborus sp. hybrid
Height: 30cm

2: **Common sunflower**
Helianthus annuus
Height: up to 3m
Flower diameter: 10–50cm

3: **Opium poppy**
Papaver somniferum
Height: up to 60cm
Seed heads

4: **Bearded iris 'Old Black Magic'**
Iris × germanica hybrid
Height: 60–90cm

Bulbs

If you cut open an onion, you will see many different layers of fleshy material and, right in the middle, a pointed shoot. The outer layer is encased by a thin, paper-like skin. At the base are small, stringy roots. It is a tightly-wrapped food parcel, a way of ensuring that the plant survives from one year to the next during periods of drought or cold.

The onion is a bulb. A bulb is an underground shoot surrounded by modified leaves (the layers). It will only grow if it is pointing upwards in the ground. When the weather gets bad the plant effectively goes into a kind of hibernation, or dormancy. The part of the plant sticking up above the ground dies. When the weather warms up or the rains arrive, the shoot grows through the bulb, up through the soil and out of the earth. The first snowdrops, bluebells, crocuses and daffodils poking their heads above ground are a familiar sign of spring in temperate regions, and these shoots are soon followed by their abundant flowers.

But even though these plants produce bulbs (and can often survive for years in this form), they still reproduce with seeds. Seeds develop from the fertilised flowers and are dispersed in the usual variety of ways. This is a slow process – it takes up to five years for a mature daffodil plant to develop from a seed because the plant puts most of its energy into growing the bulb in the first few years.

Plants with fleshy underground parts have been used for food and flavouring for thousands of years. There is archaeological evidence to indicate that onions, for example, were cultivated in ancient Egypt. Garlic is another bulb that has a long history in food and medicine: 1500-year-old garlic bulbs were found in the tomb of the Egyptian pharoah, Tutankhamun, and garlic is mentioned in the Bible, the Qur'an, and in many other ancient Egyptian, Greek, Indian and Chinese texts.

Another bulbous plant with a long history in human food is the crocus. In this case, however, it is not the bulb but the stigmas that are used. Their reddy-orange colour is potent and valuable both as a spice for cooking and as a powerful dye for clothes and is more commonly known as saffron. Pound for pound, saffron is the most expensive traded foodstuff in the world. The ancients appreciated its value: the Minoans of Crete grew and traded saffron from around 1550 BC.

Rather more common, but equally precious in their way, are the humble daffodil and tulip. The tulip has an unwelcome claim to fame. It was the source of the world's first financial crash in Holland in the 1630s. At this time, individual bulbs were traded for the price of four oxen, eight pigs, twelve sheep or a thousand pounds of cheese.

Key to plate

1: **Saffron crocus**
Crocus sativus
Height: 7–15cm
a) Vertical section through capsule showing developing seeds b) Stamen consisting of filament and anther c) Stigmas d) Entire plant

2: **Garlic**
Allium sativum
Height: 30–45cm
a) Stem and bud b) Flower c) Section through bulb d) Bulb and stem

3: **Tulip**
Tulipa
Height: 15–75cm

4: **Red onion**
Allium cepa
Height: 75cm–1.8m
a) Bulb b) Vertical section through bulb

Below-ground Edible Plants

Plants have many ways of preserving life below ground during cold and dry seasons. Root vegetables, rhizomes and tubers, are examples of this. All provide a way for the plant to store starches, proteins and nutrients to provide energy for regrowth during the next growing season. Many food crops are provided by these below-ground storage organs, including the world's fourth most important global food source, the potato, which is a tuber.

Root vegetables include tasty delicacies like carrots, turnips, swedes, parsnips, mangelwurzels, black salsify and radish. Below ground, they grow as a swollen root, and can worm themselves into all sorts of shapes. Leaves grow directly from the above-ground shoulder of this tap root, and there is little or no above-ground stem, only leaves.

By contrast with root vegetables, rhizomes and tubers grow from leafy plants with above-ground stems. Potato plants are leafy, branched, green plants with small white flowers. Plants that grow rhizomes and tubers also grow the normal kind of root. Rhizomes often form unusual shapes, such as the knobbly underground part of ginger, and are actually roots merged together, usually growing vertically downwards in the soil. The word 'rhizome' derives from the ancient Greek for 'mass of roots'.

Tubers give us potatoes, sweet potatoes, carrots, oca, yams and turnips. A tuber is a short, thick, round stem or root that grows underground, usually as an offshoot from the main stem of the plant. Tubers contain all the necessary parts to produce a new plant. If you leave a potato in a kitchen drawer for too long, for example, it will sprout.

One other category of 'below ground' food deserves a mention – peanuts or groundnuts. Peanuts are not nuts. They are the seeds of a plant in the pea family (Legumes). Peanut flowers grow in clusters on the stems, just above ground. After they are fertilised, a short stalk at the base of the ovary forms, pushing the seed down into the soil, where it develops into a mature peanut pod.

Key to plate

1: **Potato**
Solanum tuberosum
Plant height: up to 1m

2: **Winged yam**
Dioscorea alata
Tuber diameter: around 6cm
Tuber cut horizontally
Tubers of winged yam were domesticated in Southeast Asia or the Pacific but are now eaten in many tropical countries.

3: **Beetroot**
Beta vulgaris
Plant height: up to 2m in flower
Root diameter: around 10cm
Root cut horizontally

4: **Oca**
Oxalis tuberosa
Tuber length: up to 8cm
Tuber
Oca is a crop plant that originated from the Andes in South America.

5: **Radish**
Raphanus sativus
Root length: 2cm–1m
The radish is an edible root vegetable that was domesticated in Europe in pre-Roman times.

6: **Carrot**
Daucus carota
Root length: 14–25cm

7: **Black salsify**
Scorzonera hispanica
Root length: 20cm–1m

8: **Turnip**
Brassica rapa
Root diameter: 5–20cm
Root

9: **Peanut**
Arachis hypogaea
Stem height: up to 70cm
'Pod' length: 3–7cm

10: **Ginger**
Zingiber officinale
Shoot height: up to 1.2m
The spicy rhizome of ginger is used in food and medicine. It comes from Asia.

Vines and Creepers

Some herbaceous plants have stems that can barely support their own weight. Instead, they get their structural support from the things around them. These include other plants (usually trees), rocks, and even buildings. The plant drapes itself around and across the supporting structure and climbs towards the sun, spreading its leaves as it goes.

The stems of vines are flexible to allow the pulling and twisting needed to grow in any direction dictated by the supporting structure. They have evolved a set of special features to attach themselves to these structures. One of these is the tendril, a kind of specialised shoot, leaf or even flower, which can search out a likely-looking place to climb and then wrap itself around it. Tendrils often grow like a coiled spring and undergo a 360° clockwise or anti-clockwise movement every day. This enables them to seek out possibilities for a new supporting structures as they grow.

Other vines use 'adventitious roots', specially adapted roots that grow from the stem and cling to other plants or other surfaces. Many herbaceous vines also have thorns or hooked branches that can grab onto a nearby structure. If herbaceous vines can't find a suitable support structure, they grow horizontally along the ground. These are known as creepers or scramblers.

Key to plate

1: **Purple passionflower**
Passiflora edulis
Height: 2–2.5m
Bud, fruit, leaves and flower on vine
A fast-growing vine with a magnificent large (diameter up to 10cm), purple-and-white flower that boasts four yellow anthers containing pollen, and an upright sticky yellow stigma. The fruit is similar to a pumpkin or a cucumber. Inside the thick, leathery rind lie many seeds embedded in a delicious-tasting, juicy pulp. The pulp consists of the arils, which surround each seed like a sock.

2: **Hops**
Humulus lupulus
Height: up to 6m
Fruit on vine
Hops are probably best known for their flowers (sometimes also referred to as seed cones, because of their shape), which are used as the main flavouring ingredient in beer. The earliest evidence of hops used in making beer dates from the ninth century AD.

3: **Garden pea**
Pisum sativum
Height: 3m
Pod containing seeds
The pea is one of the most nutritious of the Legume family. It is cultivated mainly for its edible seeds (the peas), which are rich in protein, vitamins and minerals. Archaeological evidence found in the Fertile Crescent (the area around modern Israel and Jordan and the Tigris and Euphrates Rivers), indicates that people have been cultivating peas since 8000 BC. The peas in the pea pod are the seeds of the fruit. Each seed consists of a seed coat surrounding an embryo with two large and thick cotyledons (embryonic leaves). That's why peas fall into two halves when you open them, just like a peanut. The two halves of a pea or a peanut seed are the two cotyledons.

4: **Pumpkin**
Cucurbita pepo
Height: 70cm
The pumpkin is one of the oldest domesticated plants. Archaeological sites in northern Mexico have revealed fragments dated 7000–5500 BC, and in the southwestern United States to AD 610. An integral part of the squash, beans and maize diet of Native American peoples before the arrival of European settlers in the fifteenth century, it is still an important crop in these regions.

5: **Sponge gourd**
Luffa aegyptiaca
Fruit length: up to 61cm long
Fruits, leaf and tendrils on vine
The sponge gourd is in the cucumber family (Cucurbitaceae). The fruit of the sponge gourd is a popular delicacy in China and Vietnam, but in western Europe and the United States, it is probably best known for a completely different use – scrubbing your back in the bath. The luffa (or loofah) fruit is very fibrous when ripe. Remove the flesh, and you have an excellent scrubbing sponge.

6: **Laurel dodder or 'Devil's tresses'**
Cassytha ciliolata
Length: vine scrambles up and over trees and can form dense mats of stems up to 5m in height
a) vine and fruits b) Vertical section through fruit
This is a parasitic vine (see pages 86–87). This means that it not only uses another plant for support, it also exploits it as a source of nutrition. Laurel dodder produces small, red, fleshy fruits around 1cm in diameter that are eaten by birds and sometimes humans.

Environment:
Alpine Plants

Alpine plants don't just grow in the Alps. They can survive anywhere in the world with the right conditions. These include: very low temperatures, often below 0°C for months at a time, but often covered by a blanket of snow; dryness; high levels of ultra-violet radiation; and a very short growing season (often less than three months of the year). These conditions present alpine plants with three big challenges to their survival.

First, in the highest areas where plants grow, there is usually very little soil, and what there is can be loose and rocky. Plants have to find a way to anchor themselves in this environment. The creeping avens (*Geum reptans*) forms long runners that grow over the top of the stony soil and tie down (locally immobilise) the loose soil, or scree. Another way plants anchor themselves is to form a dense cushion of growth in the cracks of rocks (for example purple saxifrage, *Saxifraga oppositifolia*). These cushions protect the roots, and insulate the plant against the cold.

The second challenge is the harsh climate, in particular the frequent alternation of freeze and thaw. This is a challenge for young plants, and demands special germination strategies. One of these is the process known as vivipary: seeds germinate while still attached to the mother plant, allowing each generation to protect the next until it reaches maturity. This produces a tufty appearance, common in alpine grasses such as *Poa alpina*. Another way plants protect themselves from the cold is to have part of their structure permanently underground, with an above-ground part that only shows when the weather is suitable. Common moonwort (*Botrychium lunaria*), an alpine fern, is an example of this.

The third challenge for these plants is that the growing season is short, and pollinators are rare. Ways of dealing with this include early flowering, large flowers, and self-pollination. The alpine snowbell (*Soldanella alpina*), for example, is among the first species to emerge after winter so it can use the earliest pollinators without competition. The stemless gentian (*Gentiana acaulis*), by contrast, puts its energies into producing a large flower. This makes it attractive to bumble-bees (which are good at living in cold places because of their size). Other alpine plants self-pollinate. The long-flowered primrose (*Primula halleri*) is pollinated by hawkmoths, which visit infrequently, so the primrose can pollinate itself in their absence.

Key to plate

1: **Alpine meadow grass**
Poa alpina
Height: 15cm

2: **Creeping Avens**
Geum reptans
Height: 10cm

3: **Alpine snowbell**
Soldanella alpina
Height: 10cm

4: **Long-flowered primrose**
Primula halleri
Height: 20cm

5: **Common moonwort**
Botrychium lunaria
Height: 10cm

6: **Purple saxifrage**
Saxifraga oppositifolia
Height: 4cm

7: **Stemless gentian**
Gentiana acaulis
Height:10cm

BOTANICUM

Gallery 5

Grasses, Cattails, Sedges and Rushes

Grasses

The grass family (Poaceae) contains over 10,000 species, including some of the most important plants for humans. Three grasses – maize, wheat and rice (see pages 66–67) – account for over 50% of the world's food. Grasses grow almost everywhere, from the tropics to the cold polar regions. For example, there are only two species of flowering plant in the Antarctic and one of them is a grass (*Deschampsia antarctica*). It is estimated that more than 25% of the world's surface is covered with grass – a remarkable fact considering that grasses are one of the most recent groups of plants to evolve. The first evidence of grass in the fossil record appears around 60 million years ago, about the same time as the first appearance of many hoofed mammals including horses.

Grasses are mostly herbaceous and have long, narrow leaves and hollow, jointed stems. They can grow very tall, like bamboos, or almost flat to the ground. Many grasses spread by growing horizontal underground stems called rhizomes. The above-ground stems are called stolons. New grass shoots can emerge from either stolons or rhizomes. Unlike many plants, the growing point is not at the tip of the grass but near its base or even below ground. This means that grasses are able to withstand grazing, burning and heavy pounding in public parks and sports pitches without damage to the growing point. Many grasses can survive drought because their extensive root systems store large amounts of food.

Key to plate

1: **Taiwan giant bamboo**
Dendrocalamus latiflorus
a) flowers b) leaves c) stem
Height: 14–25m
This giant species of bamboo grows throughout China and eastern Asia. It is found in dense clumps in tropical and subtropical environments. Its light, hollow stems are useful for all sorts of things including timber for building, water pipes, furniture and even musical instruments. One giant panda can eat between 12–38kg of bamboo shoots every day.

2: **Pink muhlygrass**
Muhlenbergia capillaris
Height and spread: 60–90cm
Flowers on stems
Often known as pink hair grass, this plant grows across the United States from Massachusetts in the north to Florida and Texas in the south, and all across the prairies.

3: **Blue grama or mosquito grass**
Chondrosum gracile
Height: 15–50cm
Flowers on stem
This grass gets its common name, mosquito grass, from its distinctive arrangement of seed spikes. These hang down from one side of the flowering stem and look like mosquito larvae. It grows in the plains and open rocky woodlands of the western United States.

4: **Purple moor-grass**
Molinia caerulea
Height: 30cm–1m
Stem diameter: 2–3mm
Section through stem

5: **Red fescue**
Festuca rubra
Height 2–20cm
a) Junction between a leaf blade (above) and leaf sheath surrounding the stem (below) b) stem
This grass is found in gardens, lawns, parks and sports pitches throughout the Western hemisphere. It spreads by long, horizontal, underground shoots called rhizomes. Some of these have been estimated to be up to 250m long and over 400 years old.

6: **Bermuda grass**
Cynodon dactylon
Height: up to 25cm
Seeds at the top of a stem
Not all grasses are beneficial. This one is listed as one of the most damaging weeds to agriculture and the environment in the world. Originally from Africa, it grows very fast and can rapidly take over new areas with dense mats of growth that can stifle everything else.

7: **Sugar cane**
Saccharum officinarum
Height: 3–6m
a) stem b) flowers
Sugar cane probably originated in New Guinea. Christopher Columbus introduced it into the Americas from Europe on his second expedition (1493–1496). Sugar cane provides around 70% of the world's sugar and is grown mainly in tropical but also some subtropical areas. India and Brazil produce about half the world's cane sugar.

Crops

More than half the world's food comes from the seeds of just three crops – the edible cereal grains maize, wheat and rice. All are members of the grass family. Maize or corn (*Zea mays*) is Earth's most produced crop by volume at over a billion metric tonnes per year. It is a staple human food, and even more is used as biofuel and to feed farm animals. All this derived from a single domestication event in the Tehuacán Valley in Mexico, about 9000 years ago. This early crop was a small, scrubby plant, a sub-species known as *Zea mays* ssp. *parviglumis*. Cultivation spread through Central and South America. The Aztecs prized corn so highly that it had its own god, Centeotl. Between 1000 and 500 years ago it became established in what is now the south-eastern United States. Explorers brought it to Europe from the late fifteenth century.

The wheat we know today was first cultivated around 10,000 years ago, in the eastern Mediterranean. The evolution of modern wheat was part luck, part design. The first wheats grown for food were Einkorn (*Triticum monococcum*) and Emmer wheat (*Triticum dicoccon*). Emmer wheat is a naturally-occurring combination (hybridisation) of two species of grass. When Emmer hybridised further with goat wheat (*Aegilops tauschii*), farmers had a high-yield, high-protein variety – modern bread wheat (*Triticum aestivum*).

Asian rice (*Oryza sativa*) probably originated in Southeast Asia. Its wild ancestor, *Oryza rufipogon*, still grows there today. Records of domesticated rice in southern China have been found dating back to around 6000 BC. Other members of the grass family that give us grains are barley, millet, oats, and many others.

Key to plate

1: Teosintes
Zea mays ssp. *parviglumis*
Height: 50cm–1m
This is thought to be the wild crop relative of *Zea mays*. It has no cob.

2: Maize
Zea mays
Height: 3–12m
The tall stem of *Zea mays* carries both male and female reproductive parts. The male part is at the top of the plant in the form of hair-like tassels, the female about halfway down, surrounded by several layers of leaves, commonly called husks. Once fertilised, this female part develops into the familiar cob (15–25cm in length), which we eat. It contains about 600 fruits, or kernels.

3: Goat wheat
Aegilops tauschii
Height: 30cm
The flowers of this grass are small and hidden inside green modified leaves called lemma and palea. Every lemma has a bristle 1–4cm long on its end called an awn with a rough surface which attaches itself to passing animals so the grain can spread.

4: Emmer wheat
Triticum dicoccon
Height: up to 1.5m
The name *dicoccon* refers to the fact that this species produces two grains inside every spikelet or unit of flowering structure. An ear of wheat is made up of spikelets packed together with modified leaves to protect the developing grains.

5: Bread wheat
Triticum aestivum
Height: 65cm–1m
Bread wheat produces 2–4 grains in every spikelet, so it has better productivity than emmer wheat. Some varieties have awns (bristles) and some do not.

6: Rice
Oryza sativa
Height: up to 5m
Rice produces grains, the central part of which (the endocarp), provide a staple food for millions of people. It grows with its roots in deep water.

7: Oats
Avena sativa
Height: 40cm–1.8m
This member of the grass family produces hanging clusters of flowering structures surrounded by modified leaves called glumes. The structures are easier to see than in other members of the grass family because the spikelets are larger at 2.2–2.7cm long.

8: Pearl millet
Pennisetum glaucum
Height: 1.5–3m
This crop is particularly popular in drought-affected areas of India and Africa.

Cattails, Sedges and Rushes

In ponds and wetlands all over the world, you will see a distinctive group of plants growing at the edge of the water. These are cattails, sedges and rushes. They are all tall and look a bit like big grass, but despite apparent similarities, these elegant pond-dwellers are not grasses and nor are they related to each other.

Cattails belong to the Typhaceae family. They are also known as reed mace or bulrushes (confusingly, however, they are not rushes). These evocative names all refer to the sausage-like structure towards the top of the growing stem, which is about 30cm long and 4cm thick. This is hundreds of tiny flowers packed tightly together. Above this, on a spike, is the male part of the plant, containing the pollen. When the tiny seeds are mature, the top part of the plant turns into cotton fluff, which carries the seeds away on the wind.

Sedges are in a plant family called Cyperaceae. An important thing that distinguishes sedges from grasses is their stems. Grasses have long, cylindrical, hollow stems (see pages 64–65). In contrast, sedges have triangular-shaped stems filled with a sticky substance called pith.

Humans have used sedges for thousands of years for food, fuel and making paper. Several species of Cyperaceae produce edible tubers, for example the delicately-flavoured Chinese water chestnut (*Eleocharis dulcis*). The most celebrated member of the sedge family, however, is probably papyrus (*Cyperus papyrus*), which the ancient Egyptians learnt to fashion into paper and a firm, flexible outer skin for boats.

Rushes belong to the Juncaceae family. They have distinctive flowers, scale-like in appearance, made up of three petals and three sepals (leaf-like structures that protect the flower bud) arranged alternately in a symmetrical ring (called tepals). It is one of very few flowers in nature that is brown. Rushes have long, hairless cylindrical stem-like leaves, and a round hollow stem.

Key to plate

1: **Cattail**
Typha latifolia
Height: up to 2.5m
a) flower head b) cut-away stem
Cattails have been used in some parts of the world to decontaminate waterways because they can absorb pollutants without dying.

2: **Papyrus**
Cyperus papyrus
Height: up to 5m
a) leaves and flowers b) cut-away stem
This fast-growing sedge is native to Africa but is cultivated widely. Papyrus, a paper-like material made from the pith in the stem of the plant, was first manufactured in Egypt as far back as the fourth millennium BC. To make papyrus, the outer part of the stem is first removed and the pith inside is cut into strips. These are then lined up side by side on a hard surface, and other strips are placed on top at right angles, creating two layers. These are then hammered into a single sheet, which is dried and flattened with heavy stones and then polished to make a smooth paper-like material.

3: **Heath rush**
Juncus squarrosus
Height: up to 50cm
a) Stigma branches (above), style and ovary (below) b) flower c) stem and flowers
A rush that grows on wet, peaty heath and moorland.

Gallery 6

Orchids and Bromeliads

Orchids

Orchids provide some striking statistics. There are around 28,000 species, making Orchidaceae the largest family of herbaceous flowering plants in the world. Typically, each species will be highly localised and adapted very precisely to its particular circumstances. They grow across the world and in a variety of habitats, from the dark floor of the rainforest to the tall tops of tropical trees.

Over half of orchids are epiphytes. These are commonly known as 'air plants' because they get their support from another plant and grow high up in its branches with their roots sticking into the air. The roots absorb the necessary water and nutrients from mist, moisture, dust and debris that swirl around and collect on them in the tree tops. Ground-dwelling orchids can often adapt to unappealing environments like boggy marshlands.

Orchids are the actors of the plant world, and the weird and varied shapes of the flowers reflect many highly specialised pollination systems. Many mimic the insects that pollinate them and these adaptations are deliberate ploys to attract a pollinator. The insect is lured with what looks like the promise of an encounter with an insect of the opposite sex. The bee orchid (*Ophrys apifera*), is an example of this.

Other orchids take a more direct approach, and some, such as *Catasetum fimbriatum* even have mechanisms for shooting pollen at their pollinator. Crickets and even hummingbirds are also pollinators of orchids.

Orchids' shape, colour and smell have made them prize exhibits in glasshouses and as houseplants for centuries. In the 1800s plant hunters drove many of the rarest species close to extinction. Most plants are now cultivated from seed. However, wild orchids are still endangered because of the small numbers of individual plants in each species.

Key to plate

1: *Cattleya aclandiae*
Height: 20–25cm
Flower
This species is native to Bahia in Brazil. Its sweet smell attracts large bees that expect to find nectar, even though none is present.

2: *Catasetum fimbriatum*
Height: 61–76cm
Flowers on stem
This species of orchid shoots its pollen at bees: the flower has two small hairs close to its lip, which act as a trigger when the bee knocks into them.

3: Vanilla
Vanilla pompona
Height: up to 15.5m
Flowers, buds and leaf
Humans actually eat some orchids. The vanilla pod comes from the vanilla bean, which is the cured unripe fruit of this orchid. Up to 75% of the world's vanilla comes from *Vanilla planifolia*, grown in Madagascar, the Comores and Réunion, although the species is native to Mexico.

4: Umbrella orchid
Trichosalpinx rotundata
Height: 5–8cm
Leaf and flowers
The tiny flowers of this Central American orchid are produced on the underside of the round leaf, which, like a miniature umbrella, protects the flies that pollinate it from the frequent rains.

5: Bee orchid
Ophrys apifera
Height: 25–38cm
Flowers on stem
Ophrys apifera has furry brown-and-yellow stripes, like a female bee. The male bee is easily fooled by this, and tries to mate with it. He then flies away with his head covered in pollen, to try his luck on the next flower. The technique is known as pseudo-copulation.

6: Rothschild slipper orchid
Paphiopedilum rothschildianum
Height: 51–76cm. Twice as tall in flower
This species grows only on the lower slopes of Mount Kinabalu in Borneo.

7: Vampire orchid
Dracula vampira
Height: 20–30cm
Flower
This frightening looking native of Ecuador is pollinated by small, mushroom-eating gnats (flies). It produces a fragrance that mimicks the smell of a mushroom, deceiving the gnats as they wander around the flower looking for food.

8: *Masdevallia stumpflei*
Height: 10–17cm. Twice as tall in flower
Flower
This species, thought to be native to Peru, was only discovered in 1979, growing in a greenhouse in Germany. It has never been found in the wild.

The Christmas Star Orchid

This beautiful white orchid (*Angraecum sesquipedale*) comes from Madagascar. It grows up to 1m high and is epiphytic, growing off tree trunks. It has narrow leathery leaves around 30cm in length and large white flowers with petals around 7–9cm in length. It holds its nectar in a nectar spur, a long, elongated hollow tube (up to 30cm in length) extending behind the flower, accessible only to its long-tongued pollinator.

This is an enigmatic beauty with a fascinating past. It was discovered in Madagascar by a French explorer who brought it back to the Jardin des Plantes in Paris in 1802. Later, some flowers were sent to the Royal Botanic Gardens at Kew. Kew's director, Joseph Hooker, displayed some of his new acquisitions proudly in his splendid glasshouse, and, in 1862, sent a few to his friend the naturalist Charles Darwin, most famous today for his theory of evolution. Darwin was intrigued: "I have just received such a Box full with the astounding *Angraecum sesquipedale* with a nectary a foot long. Good Heavens what insect can suck it?" he wrote to Hooker. There must, thought Darwin, be an unknown species of insect with a tongue almost a foot long. Not for the first time, people thought Darwin was, to put it politely, being a little fanciful. But in 1903, more than four decades later, he was proved right. A new species of hawkmoth was discovered (*Xanthopan morganii* ssp. *praedicta*) that has a tongue long enough to reach into the nectar spur of the Christmas star orchid. Eventually, after patient observation, it was observed in the wild doing exactly that!

Key to plate

1: **The Christmas star orchid**
Angraecum sesquipedale
Height: up to 1m
Nectar spur: up to 30cm long

2: ***Xanthopan morganii* ssp. *praedicta***
The hawkmoth pollinator of *Angraecum sesquipedale*. Its tongue is a similar length to the orchid's nectar spur.

Bromeliads

The Bromeliad family is found almost exclusively in North and South America. Only one species of bromeliad is known to grow wild outside of America, *Pitcairnia feliciana*. It lives in western Africa. Nearly 3000 different species exist in almost every environment in the Americas, from rainforests to dry zones in the tropics, and from mountainside cloud forests to arid deserts. Remarkably, it is believed that all bromeliads evolved around the same time, between 60–30 million years ago.

Bromeliads grow as a rosette of leaves, usually without a stem, a unique and striking feature. In some species, known as tank bromeliads, these stiff overlapping leaves are capable of holding rainwater in their centre, giving the plant a source of moisture in the dry season. This creates a damp, well-protected ecosystem for tree frogs, snails, flatworms, tiny crabs, salamanders, algae and insect larvae.

The leaves of bromeliads tend to be patterned – stripy, spotty or banded – in a variety of rich colours such as white, cream, yellow, purple, red, silver, maroon or black. As well as showy leaves, bromeliads also have very pretty and brightly coloured flowers. These usually grow on spikes. Some of these spikes stick up straight out of the leaf rosette, up to 10m high. Others are droopy, hanging down lower than the plant itself. Over half of bromeliads grow as epiphytes, anchoring themselves to other plants, often on the branches of trees. Hundreds of individual bromeliad plants have been seen growing on a single branch of a tropical tree, and these branches can easily break under the weight. Other species of bromeliad grow on the ground, with their roots in the soil. Others are saxicolous, meaning that they grow on rocks.

Bromeliads were well known to the Inca, Aztec and Maya peoples, who used them for food, fibre and ceremonies. But they only appeared in Europe when Christopher Columbus unloaded a particularly tasty variety from his ship when he got back from his second visit to the New World in 1496. This delicacy was the pineapple (*Ananas comosus*). Within 50 years it had become highly prized amongst the rich of Europe. It long remained a treat for only the wealthy, however, because of the cost of cultivating it in heated glasshouses.

Key to plate

1: **Red pineapple**
Ananas bracteatus
Plant height: 1.2m
Fruit

2: **Common pineapple**
Ananas comosus
Plant height: 1–2m
Fruit
The pineapple is the only member of the Bromeliaceae family that is still economically important. A pineapple is not a simple fruit but consists of a whole bunch of fruits melted together into one large, fleshy structure.
In tropical America, where pineapples are native, tapirs love to eat the fruits of wild pineapples and help disperse their seeds. Cultivated pineapples are bred to be seedless.

3: ***Puya berteroniana***
Height: 3m
Flowers

4: **King of bromeliads**
Vriesea hieroglyphica
Height: 60cm
Leaf length: up to 1m

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Gallery 7

Adapting to Environments

Succulents and Cacti

The term 'succulents' refers to plants that have a set of features that allow them to live in some of the driest environments on Earth. These features include specialised plant tissues, which absorb and hold moisture so that photosynthesis (which needs water) can still occur even during droughts. Succulents also tend to have tough coverings on the stem to support the weight of the stored water. The leaves are thick and leathery to the touch, with a wax-like whitish covering that helps to reduce water loss from evaporation and damage to leaves from the fierce sun. Some succulents have long white hairs to protect them from the sunlight and, just as importantly, from the sub-zero desert nights.

During a drought, succulents are sometimes the only green things that grow. Naturally, this makes them tempting to hungry herbivores. They have evolved several strategies to counter this. Some have a bitter taste, while others have sharp, prickly spines. Perhaps the most extraordinary method of defence is camouflage – stone plants look like pebbles, until they burst into flower, producing a showy bloom like a big daisy.

Cacti have many of the adaptations listed above but instead of leaves they have sharp spines, which are in fact a highly modified form of a leaf. This means that in cacti all of the photosynthesis is carried out in the stem. As well as being a highly effective defence against herbivores, the spines also break up the air flow around the plant, reducing water loss from evaporation.

Key to plate

1: **Zebra cactus**
Haworthia attenuata
Height: up to 50cm
These small cacti have distinctive, triangular-shaped leaves and a white pattern like zebra stripes. Native to Southern Africa.

2: **Barrel cacti**
Parodia magnifica
Height: 7–15cm
Barrel cacti usually grow in clumps with all the plants facing in the same direction, hence their nickname 'compass cacti'.

3: **Jelly bean plant**
Sedum pachyphyllum
Height: up to 25cm
Leaves on stem
The leaves look like jelly beans but unfortunately are not edible. The round shape of the leaves (like string-of-pearls, plate 4) helps reduce the amount of sunlight absorbed by the leaf. This plant is native to Mexico.

4: **String-of-pearls**
Senecio rowleyanus
Length of trailing stems: up to 90cm
Leaves on vine
This succulent is a member of the daisy family (Asteraceae). Each 'pearl' is a leaf in the vine, which grows in the desert of South Africa.

5: **Prickly pear**
Opuntia engelmannii
Height: 3m
Prickly pears produce delicious, sweet fruit. The large, flat pads are the plant stems, and the sharp spines are modified leaves. Prickly pears are the most wide-ranging cacti, and occur throughout South America and as far north as Canada.

6: **African milk tree**
Euphorbia trigona
Height: up to 2.7m
Euphorbias and cacti look very similar but are not related. This plant is a euphorbia from Central Africa. It has a dark green upright stem shaped into a series of ridges. Thorns approximately 5mm long grow in pairs on two of the ridges and between the two thorns, small drop-shaped leaves grow.

7: **Crow's claw cactus**
Ferocactus latispinus
Height: up to 30cm
A species of barrel cactus native to Mexico, with spines 4–5cm long.

8: **Stone plants**
Lithops hookeri
Height: up to 5cm
Stone plants are succulents camouflaged as pebbles. They grow partially buried in the ground and are native to Namibia and South Africa.

9: ***Echeveria laui***
Height: up to 15cm
a) sprouting leaf b) entire plant
The blueish colour of the leaves is due to pigments that help the plant control the sunlight absorbed for photosynthesis. This plant is covered in a layer of powdery wax which protects the succulent tissue beneath. It is native to Mexico.

Aquatic Plants

Aquatic plants grow in water or soil that is permanently wet. They include many plants we have met in previous galleries: algae, mosses, liverworts, hornworts, club mosses, horsetails and many ferns, all of which reproduce without flowers; and cattails, sedges and rushes, which have their roots in water, and do reproduce with flowers. But there is another group of flowering aquatic plants with a very unusual ability – they grow entirely underwater, or partially below the water with just the leaves and flowers on the surface.

Water is denser than air, so these aquatic plants get more support from their environment than land plants. They have less firm tissue, and flexible stems that can move with the water. They also have air-filled cavities to give buoyancy and leaves with little or none of the waxy covering other plants use to minimise water loss through evaporation. Permanently submerged leaves tend to be long, thin and divided many times, which offers less resistance to water currents and presents more surface area for absorbing carbon dioxide. Leaves that float tend to be round and smooth, also offering less resistance to water currents – and have long stalks that move up and down if the water level changes. Specialised air pockets called lacunae give added buoyancy.

Flowers can be produced underwater or on or above the surface. Above-surface flowers tend to be pollinated by wind or insects. Those below the surface disperse their pollen by water. This is not reliable, since pollen can be swept away, so most aquatic plants reproduce asexually as well, by growing rhizomes in the soil beneath the lake that then send up new shoots a little way from the parent plant. Eventually these detach and a new plant is created, genetically identical to its parent.

Key to plate

1: **Water lettuce**
Pistia stratiotes
Height: 15cm
This lives in most subtropical fresh waterways. Its free-floating roots are well adapted to absorbing nutrients from flowing water.

2: **Paddle weed**
Halophila ovalis
Leaf length: up to 2.5cm
Leaves and stem
This saltwater seagrass lives in mudflats and sandbanks around reefs, estuaries and deltas. Its meadow-like growth provides an ideal grazing ground for the marine mammal the dugong, giving the plant its other name, dugong grass.

3: **White water snowflake**
Nymphoides indica
Leaf diameter: 5cm
a) flower b) leaves
These flowers grow above the water. The 'snowflake' gets its name from the delicate hair-like growths on the petals. *Nymphoides* are also known as 'floating heart' plants.

4: **Common eelgrass**
Zostera marina
Leaf length: usually 20–50cm but sometimes up to 2m
A seagrass, also known as seawrack. It can live in cooler waters around ocean coasts, and has become the most widespread marine flowering plant in the northern hemisphere, growing around Europe and North America, and the Arctic. It is the only seagrass found in Iceland.

5: **Aquatic primrose**
Hottonia inflata
Height: 30–60cm
This is a freshwater aquatic, growing in swamps and ditches in parts of the United States. It is particularly fond of ponds excavated and dammed by beavers, which provide stable water levels. It has a basal root which burrows into the mud at the bottom of the pond, and feathery roots which float free in the water.

The Amazon Water Lily

The Amazon water lily, *Victoria amazonica*, is a giant – a waterborne plant with huge leaves that grow to over 2.5m across. It fascinated and intrigued the first Europeans who saw it, including Robert Schomburgk, who found what he described as this "vegetable wonder" in South America in 1837. Schomburgk was determined to bring a specimen back to show the Royal Geographical Society in London, but the leaf was bigger than his canoe. Undaunted, he packed a bud and a small piece of leaf into a barrel full of salt water and set off back down the river to get his finds onto the ship bound for England. It was Schomburgk's idea to name the discovery after the then Princess Victoria, who had become queen by the time he returned home.

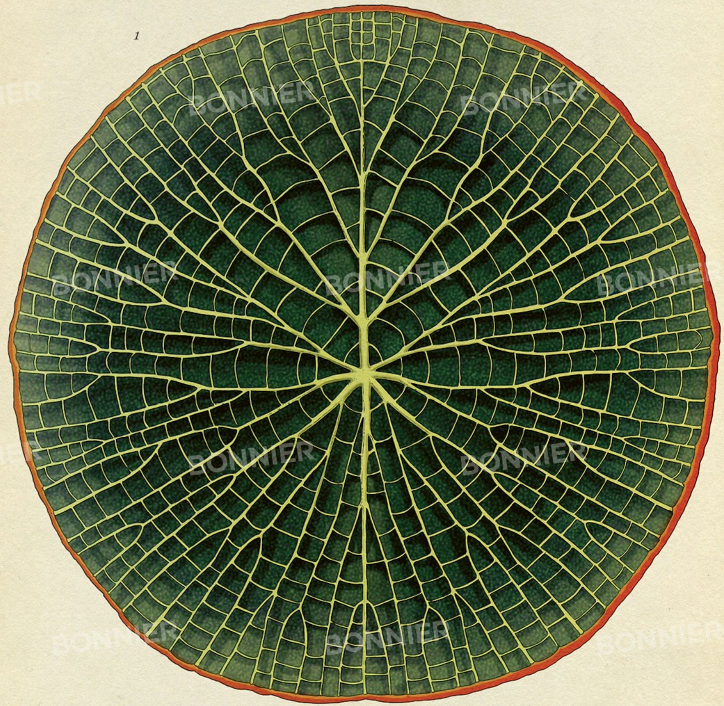
England, of course, has a very different climate to South America. Botanists and gardeners there tried to get water lily seeds to germinate and grow, but couldn't. Two rivals in particular went head to head – Joseph Paxton, head gardener at the Duke of Devonshire's Chatsworth estate in Derbyshire, and William Hooker, the Director at Kew. Hooker was the first to grow plants from seed but Paxton realised that he needed some way of creating an environment similar to the Amazonian jungle to get them to flower, so he built a glasshouse and won the race. "My Lord Duke, Victoria has Shewn Flower!" he wrote in triumph to his employer in 1846. "...no account can give a fair idea of the grandeur of its appearance". Paxton went on to become the leading architect-designer of glasshouses in England, possibly the world. He was fascinated by the system of natural ribs used by the plant to give strength to the leaves, and copied it in glass and iron – most notably in the Crystal Palace, built for London's Great Exhibition of 1851.

The leaves of the giant Amazon water lily first appear as spiny heads poking up through the water but expand rapidly across the pond, growing at a rate of up to half a metre a day. They have a red underside with an incredible network of ribs that are covered in many sharp spines. The spines are a defence mechanism against the eating of the leaves by fish and Amazonian manatees. Air trapped in the spaces between the ribs enables the leaves to float. The enormous white flowers smell of pineapple, open in the evening, and give off heat to attract beetles to pollinate them, after which they turn a pale pink and close for the night.

Key to plate

1: Amazon water lily
Victoria amazonica
Width: up to 2.5m
Leaf

The leaves of the Amazon water lily are so buoyant that they can easily support the weight of a small child of up to 45kg – something Paxton proved by getting his young daughter to lie down on a tin tray on a leaf.



Parasitic Plants

All plants need food, water and nutrients. Most get their own from sun, rain and soil. Some, however, use other plants to do it for them. These are called parasitic plants. Some become entirely reliant upon another plant. In other cases, the parasitic plant relies on another plant for some things but continues to make its own food as well.

A parasitic plant taps the resources of its unwilling host via a modified root called a haustorium. The haustorium produces a special glue to fix itself to the root or shoot of the host plant. It then penetrates the wall of the host plant and links up with the host plant's vascular system. Once in place, the haustorium acts as a pipeline, taking water and nutrients directly from the host into the parasite plant.

The process of attachment to a host plant starts when a parasitic plant's seed germinates. Parasitic plants usually produce many small seeds. These are dispersed into the soil or directly onto the host stem, usually via bird droppings. The seeds pick up a chemical signal, which tells them they have landed near a suitable host, and they begin to germinate and the haustorium starts to grow as a root. Once the haustorium is plugged in, the plant host provides the vital ingredients for growth and the mature parasite plant develops, often with leaves and flowers.

Some parasitic plants have an extremely unusual feature – they're not green. This is because their host does their photosynthesising for them, so they lose their chlorophyll, the green pigment necessary for photosynthesis.

Key to plate

1: **Stinking corpse flower**
Rafflesia arnoldii
Diameter: up to 1m
Flower
This flower has two notable claims to fame. The first is that it produces the largest individual flower on Earth. The other is that it stinks. The smell is similar to rotting flesh. This plant is often found growing on the bark of trees and vines in the grape family (Vitaceae) in the rainforests of Borneo and Sumatra. The plant is mostly hidden within the host plant (known as an endoparasite) until the flower breaks through its bark.

2: **Mistletoe**
Viscum album
Height: up to 1m
Leaves and stems with fruit
As well as being a Christmas favourite, mistletoe is an example of a parasitic plant that grows mostly on the surface of the host plant (known as an epiparasite). Mistletoe is found growing on trees and shrubs in wooded habitats, from the tropics to temperate regions. It depends on its host for water and mineral nutrients but photosynthesises to create its own carbohydrates, so keeps its green stems and leaves. Mistletoes can sometimes become so abundant that they cause a serious problem for their host.

3: **Asiatic witchweed**
Striga asiatica
Height: 15–30cm
Flowers, leaves and stems
This parasitic weed has wreaked havoc in agricultural fields in many parts of the semi-arid regions of Africa, India and the United States. It threatens important crop species, including corn, rice and sugar cane (see pages 64–67). It drops its seeds into the soil, where they react to a chemical signal from the host plant by developing the haustorium to tap into its water and nutrients. When the seedlings emerge from below ground they produce leaves and flowers, so the parasite appears to be growing happily alongside the host. In fact, below ground, it is sucking away its vital nutrients.

4: **European dodder**
Cuscuta europaea
Flower head diameter: 6mm
Stem, flowers and buds
European dodder causes significant damage to crops. It is a parasitic vine found throughout the northern hemisphere, and it is a serious weed. Its stems twine around the shoots and leaves of host plants, choking them. Because it relies on its host for photosynthesis it has tiny leaves and almost no chlorophyll, so the stems are not green but a vivid orange.

Carnivorous Plants

These fascinating plants catch and eat live prey – mostly insects, though some also feed on spiders, small crabs, mites and small single-cell organisms called protozoans. Their taste for flesh comes from their need for nitrogen. All plants need nitrogen to make chlorophyll (the green pigment used in photosynthesis) and proteins. Carnivorous plants tend to dwell in boggy or other acidic environments with little nitrogen, so they need to get it from a different source. They produce special chemicals that digest and then release the nitrogen from a victim. But they have to catch their prey first. Carnivorous plants have two main ways of doing this: passive and active traps.

Passive traps don't involve any active movement by the plant. The prey is lured by the sweet smell of nectar. It then finds itself trapped. There are several different ways a plant does this. One is by sticking the visitor's feet and body to the leaf with a kind of glue produced by hairs on the leaf's surface. Once stuck, the prey is then digested by chemicals secreted by other hairs on the leaf. Another way is to tip the prey in a pitfall trap. These plants grow modified leaves that look like small cauldrons, and are filled with digestive chemicals. The sloping upper part is waxy: the victim slips, loses its footing, and in it goes. Downward-pointing hairs or slippery scales then stop it getting out again.

Active traps involve movement. There are two main types of active trap. The first is a leaf that looks half-folded, like an open book. This leaf has up to six very sensitive trigger hairs on each half. If an insect triggers more than two hairs, it snaps shut, trapping the prey. Digestion of the victim usually takes between 3–5 days. Another form of active trap uses suction. This suits carnivorous plants that live in ponds and lakes. A modified leaf traps air underwater by growing into a bladder shape. It has a kind of trapdoor on one side, triggered by sensitive hairs. When the hairs are tickled by passing prey, the trapdoor springs open, sucking water and the prey inside the bladder.

Key to plate

1: **Common bladderwort**
Utricularia vulgaris ssp. *macrorhiza*
Length: up to 2m
a) flower b) stem and bladder traps
This plant grows in ponds and traps water creatures, such as water fleas. Each plant has thousands of traps, but no roots. Traps are usually only 3mm long, but some species have traps 1.2cm long and can catch tadpoles.

2: **Common sundew**
Drosera rotundifolia
Height: 20cm
Leaf
This plant is now rarely seen since so many bogs have been drained. Once struggling flies are stuck to the leaves the red, stalked glands push them into the centre where they are suffocated by liquid and their inner parts converted to a nutritious soup, absorbed by the leaf. Most of the 200 species are found in western Australia.

3: **Portuguese dewy sundew**
Drosophyllum lusitanicum
Height: 40cm
Leaves
This rare shrub grows near the western part of the Mediterranean Sea in cork oak woodlands.

4: **Rajah pitcher plant**
Nepenthes rajah
Height: up to 3m
Pitcher and leaf
The rajah pitcher plant has the largest pitchers of all – the size of a rugby ball – and is reputed to trap rats. It grows only on Mt Kinabalu, the tallest mountain in Borneo, and on one mountain nearby.

5: **Cobra pitcher plant**
Darlingtonia californica
Height: 40–85cm
The cobra pitcher plant grows in the Sierra Nevada mountains of California. Flies landing on the red tongue follow a nectar trail to a hole underneath the domed, windowed 'head'. When they fly up towards the light coming through this head, they are trapped.

6: **Venus fly trap**
Dionaea muscipula
Leaf diameter: 20cm
There is only one species of Venus fly trap, which is found in the wild only in bogs near Wilmington in the United States. They usually trap and digest flies, but small frogs are sometimes caught.

7: **Common butterwort**
Pinguicula vulgaris
Height: 15cm
The leaves of this plant attract, trap and digest midges and mosquitoes. Around 80 species of butterwort are known from Europe, North America, Asia, but most are in Mexico. Added to milk, the leaves separate it into curds (used to make butter) and whey.

Environment: Mangrove Forests

Mangrove forests are made up by trees and shrubs that grow in tropical and subtropical salt water between the high- and low-tide mark. They occur where flat, fertile tropical land meets the ocean – around 25° either side of the Equator in Central and South America, the Caribbean, the eastern and western coasts of Africa, Southeast Asia and the northern coasts of Australia. Mangrove swamps are hot, wet and inhospitable. They often share their territory with saltwater crocodiles and mosquitoes.

Mangroves have a number of adaptations to deal with their harsh environment. Because the soil in swamps is salty, mangrove roots are largely impermeable, so they can limit the amount of saltwater getting in. Some roots, for example in the red mangrove tree (*Rhizophora mangle*), are impregnated with a substance called suberin, which acts as an extremely effective salt filter.

The swamp floors of mangrove environments also contain very little oxygen, which the underground tissue of plants needs for respiration (a chemical reaction to get energy needed to live). This means that the mangrove root system needs to take up oxygen from the atmosphere. Some swamp-dwellers, like the red mangrove, have stilt roots which can absorb oxygen directly from the air through pores in their bark called lenticels. Others, like the black mangrove (*Avicennia germinans*) have special roots called pneumatophores, which stick straight up into the air, allowing them to take in oxygen like a scuba-diver's breathing-tube.

Perhaps mangroves' most remarkable adaptation is the way they protect the next generation. Most aquatic plants disperse their seed by allowing it to float in the water and germinate when it finds land. Mangrove swamps are too harsh an environment for this, so the seed, once fertilised, germinates while still attached to the parent, either inside the fruit, or out through its side. The seedling, called a propagule, will then detach itself and drop into the water where it can survive for up to a year before taking root.

The dense, far-reaching root systems of mature mangrove forests offer protection from storms and tidal surges, because they are adapted to absorb and dissipate energy from water. They also provide a vital habitat for oysters, crabs and other species. Unfortunately, they also make ideal shrimp farms and up to 20% of the world's mangrove forests appear to have been lost between 1980 and 2010 (as much as 35% in some areas), much to farming.

Key to plate

1: Black Mangrove
Avicennia germinans
Height: 3m

2: Sundari Tree
Heritiera fomes
Height: 25m

3: Nipa Palm
Nypa fruticans
Height: 9m

4: Loop-root mangrove
Rhizophora mucronata
Height: 35m

5: Red Mangrove
Rhizophora mangle
Height: 20m

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ARKive
A compendium of life on Earth from Wildscreen, a UK-based conservation organisation.
www.arkive.org

Botanical Society of Britain and Ireland
Advances the study and enjoyment of wild plants and supports their conservation in Britain and Ireland.
www.bsbi.org.uk/

British Bryological Society
Information and resources for the study of UK mosses and liverworts.
rbg-web2.rbge.org.uk/bbs/bbs.htm

British Mycological Society
Enter the world of fungal biology research, conservation and education.
www.britmycolsoc.org.uk/

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www.growwilduk.com/

The Linnean Society
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www.linnean.org/

Plantlife
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www.theplantlist.org/

Royal Botanic Gardens, Kew
Learn about Kew's scientists' work across the globe including detailed profiles of 400 species. For over 250 years science and conservation work at Kew has helped to discover and describe the world's plant and fungal diversity, safeguarding plant life for our future and promoting the sustainable use of plants.
www.kew.org
www.kew.org/science-conservation

Royal Horticultural Society
The world's leading gardening charity providing information and events on horticulture.
www.rhs.org.uk/

The Woodland Trust
Explore the British woodlands.
www.woodlandtrust.org.uk/

Data Resources
Online access to Kew's key botanical and mycological resources, databases and collections.
www.kew.org/kew-science/people-and-data/resources-and-databases