Cambridge University
Botanic Garden

Evolution of Plants Trail



Plants originated in freshwater pools and streams around 470 million years ago, and have a long and complex evolutionary history.

This trail identifies some of the closest living relatives to the earliest land plants and progresses through time to more modern groups, in an evolutionary sequence.

See an online version of this trail at www.botanic.cam.ac.uk/plant-evolution

Evolution of Plants

This trail will introduce you to a selection of plants through evolutionary time, starting with freshwater green algae closely related to land plants. Moving onto land, you will then see living relatives of the early land plants, which have no internal pipework to transport water; they live in damp, shady places.

Around 425 million years ago, plants evolved the ability to transport water, meaning they could grow larger and develop more complex structures. The development of leaves allowed for increased photosynthesis, and seeds enabled survival through conditions unfavourable for the plant itself.

Flowering plants evolved around 140 million years ago, and are the most diverse group in today's plant kingdom. An evolutionary trend to more specialised flowers has been linked to an increase in diversity of pollinating insects.

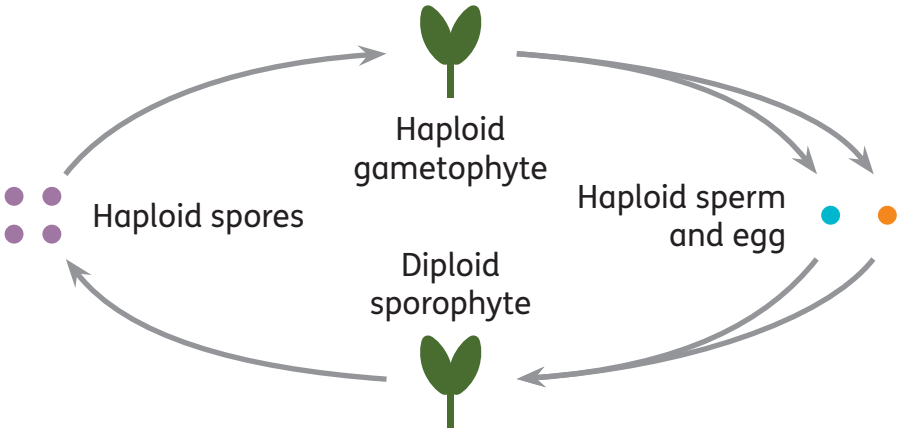
This trail supports the University of Cambridge first-year Natural Sciences lecture series in plant evolution.

Details of the steps necessary for plants to conquer the land, including the key innovations of each of the land plant groups, can be found in the interpretation boards on the Rising Path by the Systematic Beds.

The life cycle of plants

Animals have two copies of each chromosome in all but a few specialised cells; this is referred to as 'diploid'. Having one copy of each chromosome per cell is referred to as 'haploid'.

The visible growth of algae such as *Chara* is haploid. The haploid stage of a plant's life is known as the 'gametophyte', and eventually produces haploid gametes: sperm and eggs.



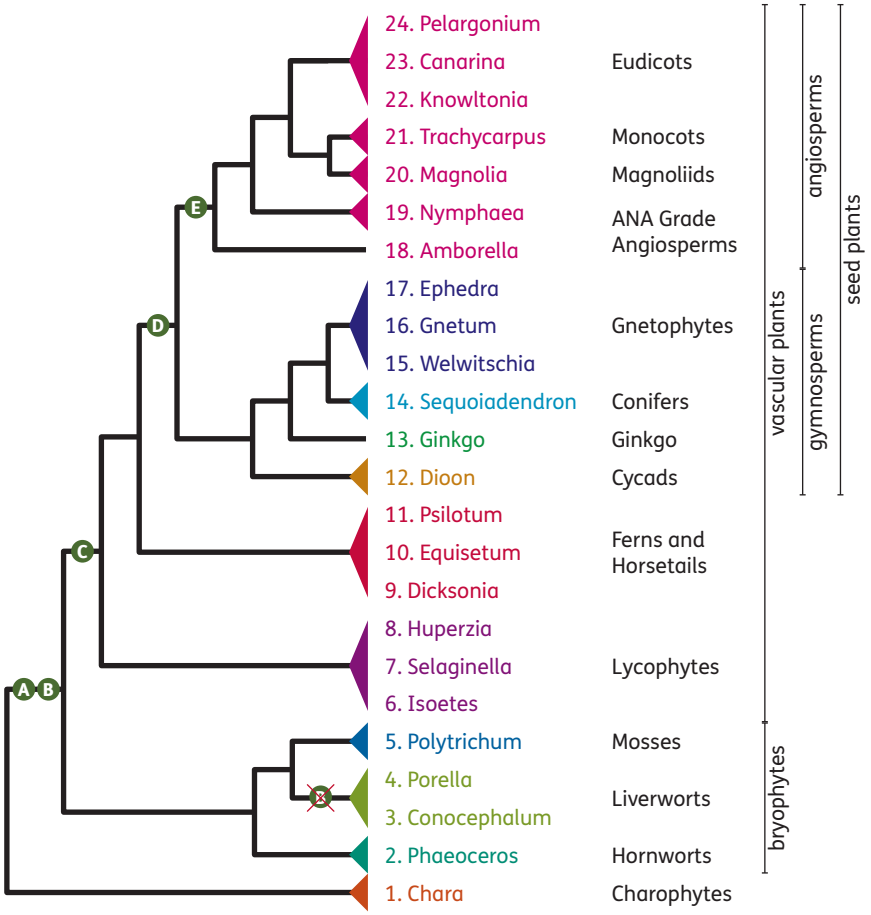
The life cycle of plants, known as 'alternation of generations'. Depending on the plant, sporophytes and gametophytes range in size from very few cells to complex organisms.

These fuse to form a diploid zygote; this diploid stage is known as the 'sporophyte'. In *Chara*, the sporophyte immediately divides to form haploid spores, which then develop into new haploid gametophyte plants.

Like *Chara*, the largest phase in the life of a bryophyte is the haploid gametophyte. However, their diploid sporophytes grow to be more complex than a single cell, being patches (in *Conocephalum*), or small structures (in *Porella* and mosses) which grow on the surface of the gametophyte.

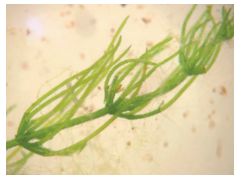
From the lycophytes onward, the dominant phase of life is the sporophyte. These sporophytes are vascular, meaning they can transport water and nutrients around the plant. This innovation has allowed the expansion in size of plants from the small, feathery spikemosses to the enormous trees visible in the Garden. In these vascular plants, the gametophyte still exists, but has been reduced to around a few hundred cells (in the case of the ferns and horsetails), or even smaller (just a handful of cells in the seed plants).

The Plant Tree of Life



- **A** Living on land; multicellular gametophyte and sporophyte stages; waxy cuticle
- **B** Stomatal pores for gas exchange
- **C** Sporophytic branching; water-conducting tissues; roots
- **D** Seeds
- **E** Flowers

1 *Chara vulgaris* (Stonewort)



The alga *Chara* has a gametophyte-dominant lifecycle, and the fertilised eggs are retained on the parent plant, giving protection and food. *Chara* is found in fresh water. Branches are borne in whorls, appearing in clusters around the stem. It feels rough because of calcium salt deposits on the cell wall, hence the common name 'stonewort'.

2 *Phaeoceros laevis* (Smooth hornwort)



The smooth, flattened part of the hornwort is gametophytic; the horn-like structures are the sporophytes, which feature stomata and, unusually, grow from a basal meristem, rather than from the tip. Gametophytes have one lens-shaped chloroplast per cell.

3 *Conocephalum conicum* (Snakeskin liverwort)



Thalloid liverworts (including *Marchantia*) have a flattened gametophytic body, or 'thallus', which develops small egg- or sperm-producing structures. The air chambers in *C. conicum* are clearly visible, separated by dark furrows, with a whitish air pore at the centre of each chamber.

4 *Porella platyphylla* (Leafy liverwort)



Leafy liverworts have gametophytic shoots with two or three rows of veinless leaves. The sporophytes are non-photosynthetic and grow upwards, mainly by cell expansion. *P. platyphylla* is extremely tolerant of drought and, like other liverworts, contains membrane-bound oil bodies.

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Evolution of Plants

For clarity, only a portion of the Garden map is displayed here; ask at the ticket office for a map showing the whole site.



Plants are colour coded into broad groupings; a key to the colours used can be found on the Plant Tree of Life.

*The species listed in the trail do not flower all year round, so the trail label may have been moved to another species which is in flower.

5 *Homalothecium sericeum* (Silky wall feather-moss)



Moss gametophytes have spirals of veined leaves. The sporophytes are partially photosynthetic and have stomata. Plants are either male or female. The photosynthetic layer on the top of the leaf is several cells thick, arranged in rows called lamellae. Moss sporophytes are sometimes branched, and hold a spore-containing capsule.

6 *Isoetes lacustris* (Quillwort)



Isoetes is closely related to plants that made most of our coal. It has underground corms, organs with a unique 'fuzzy morphology' which are both root- and shoot-like. Sacs at the bottom of each quill-like leaf produce large female and small male spores. *Isoetes* is usually found among stones at the bottom of clear ponds.

7 *Selaginella canaliculata* (Spike moss)



Selaginella has microphylls: tiny, single-veined leaves with an independent evolutionary origin to leaves in ferns and seed plants. It can drop small plantlets from fronds to reproduce asexually; spores form on specialised reproductive branches. Despite the name, it is not a moss, but a lycophyte.

8 *Huperzia* spp. (Club moss)



Lycophytes such as *Huperzia* have sporophyte-dominant life cycles. Fossils are first evident in rocks originating 400 million years ago. Spores are produced at the base of small, club-shaped leaves; these spores are tetrahedral, and as a powder are highly flammable. Despite the name, it is not a moss, but a lycophyte.

9 *Dicksonia antarctica* (Tree fern)



Ferns first arose around 350 million years ago. They have tiny thalloid gametophytes, and large, persistent sporophytes. Tree ferns look similar to the fossil ancestors of living seed plants. The 'trunk' of the fern is formed from the remains of old branches, and the rhizomes grow down through this. *Dicksonia antarctica* is native to Eastern Australia.

10 *Equisetum hyemale* (Rough horsetail)



Equisetum belongs to an ancient plant group closely related to ferns. The tiny spines around the stem evolved from much larger leaves by reduction. The stems have ridges containing silica, which gives the plant a rough feel. It spreads aggressively via underground runners.

11 *Psilotum nudum* (Whisk fern)



Psilotum looks very like some of the earliest leafless vascular plant fossils found in Devonian Rhynie Chert deposits. It is, however, a fern, and these similarities are due to convergent evolution. It lacks roots and is epiphytic, deriving water and nutrients from air, rain and debris around it.

12 *Dioon edule* (Cycad)



Cycads are gymnosperms that were common around 200 million years ago. Their large woody reproductive cones bear ovules that are open to the air and are pollinated by beetles. The eggs in the female cone of *Dioon* are produced in pairs, giving the genus its name (meaning 'two-egged'). It is native to Mexico, and is near threatened.

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13 *Ginkgo biloba* (Maidenhair tree)



Ginkgo trees have leaves similar to those found in some 300-million-year-old fossils. Unlike many gymnosperms, the leaves have wide blades with veins that fan out from their base. Long thought extinct, it is now known in the wild at two patches in China. Fertilisation of ovules occurs via motile sperm, as in cycads and ferns.

14 *Sequoiadendron giganteum* (Giant redwood)



Giant redwoods are the only surviving species in the genus. They are the largest living plants and reproduce from male and female cones at the shoot tips. The bark may be a metre thick at the base of the trunk, and provides protection from fire damage; cones normally open immediately after a fire.

15 *Welwitschia mirabilis*



Welwitschia is a gnetophyte with a tree habit. The underground trunk generates strap-like leaves that grow continually from the base, and which can reach more than 4m in length. Male and female cones develop on separate plants; it is insect pollinated. Individual plants can live for several centuries.

16 *Gnetum gnemon*



Gnetum leaves have a midrib and branched veins, which look similar to (but evolved independently from) those in flowering plants. The gametes are borne in 'strobili', often mistaken for flowers. *Gnetum gnemon* is native to Indonesia and can be eaten in a variety of ways.

17 *Ephedra viridis* (Green ephedra)



Ephedra is a gnetophyte shrub with tiny, scale-like leaves. It reproduces from small cone-like structures that initiate in leaf axils and (on female plants) grow red, berry-like fruits. Its dried branches are a source of the stimulant ephedrine. It can grow to a large, tangled clump approximately a metre in height.

18 *Amborella trichopoda*



Amborellales (along with Nymphaeales and Austrobaileyales) form the 'ANA grade' of early diverging flowering plants. *A. trichopoda* is a shrub with flowers that are small and lack petals. The plant either produces male or female flowers, but can switch from one to the other in different seasons. Sex organs are arranged spirally around shoot tips.

19 Nymphaeales spp. (Water lily)



Nymphaeales fossil records date back to around 130 million years ago. Their large flowers with multiple unspecialised parts represent the floral pattern of the earliest flowering plants. The flowers are beetle pollinated, and spiral around male stamens and female carpels.

20 *Magnolia grandiflora*



Instead of a distinct calyx and corolla, the Magnoliaceae have tepals. As seen in many primitive fossilised angiosperms, their stamens and pistils are arranged in spirals. The pollen has a single pore from which the pollen tube emerges. Flowers are showy, lemon scented and extremely tough; they are pollinated by beetles.

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21 *Trachycarpus fortunei* (Windmill palm)



Palms belong to a major group of flowering plants, the monocots, in which floral organs are arranged in tight whorls of three. Monocot leaves are generally long, with parallel veins. Monocots lack cambium, so they cannot grow in diameter along with height. Palm flowers are beetle or fly pollinated.

22 *Banksia* spp.



Eudicots are a second major group of flowering plants. They have 'tricolpate' pollen grains with three grooves along their polar axis. *Banksia* is an example of a basal eudicot in the *Protea* family; its flower spikes are sometimes called 'cones' (though incorrectly, as they are not conifers). Other basal eudicots include buttercup and sycamore.

23 *Cheirolophus canariensis*



The Asterid group of eudicots is recently derived, and features ornate flowers with organs fused into tubes. Approximately 1/3 of all flowering plants (around 80,000 species) are Asterids, including nightshades, daisies, morning glory, mint and snapdragon. Note that a daisy capitulum comprises many closely packed flowers.

24 *Pelargonium fruticosum*



The Rosid group of eudicots comprise about 25% of angiosperms, and they show great diversity in many characteristics relating to morphology and ecology. The Rosids originated around 100–125 million years ago, and include beans, squashes, pelargoniums, mallows, many British trees including birch and oak, and the plant scientist's workhorse, *Arabidopsis*.

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