



Cambridge University

Botanic Garden

Plant Species and Speciation Trail

In the animal kingdom, a 'species' is often defined as a group of animals which can breed together and produce fertile offspring, but in the plant kingdom things are more complicated. Fertile inter-species hybrids are relatively common, and plants which are sexually infertile can reproduce asexually by rooting stems or sending out suckers. Some plants can even produce seeds without fertilisation, leading to the evolution of what some call 'microspecies'.

This trail takes you on a tour highlighting the processes of speciation, as well as examples of plants used by researchers to investigate how new species arise.

**See an online version of this trail
at www.botanic.cam.ac.uk/speciation**

Plant Species and Speciation

Scientists give names to plants and animals to distinguish them from one another. At first, these names were descriptive – one example being *Rosa sylvestris alba cum rubore, folio glabro* ('pinkish-white woodland rose with hairless leaves') – but as more organisms were discovered, the names started to get even longer and more complicated.

The Swedish botanist Carl Linnaeus realised that these long names were unnecessary: as long as each organism had a unique two-part ('binomial') name. Using his system, the rose above became known as *Rosa canina*. In 1753, he published his *Species Plantarum*, a book containing the binomial names of nearly 6,000 plants.

This binomial name emerges from the system which scientists use today to classify organisms. The classification starts with **domains** – Bacteria, Archaea (organisms which look like bacteria but which have rather different cellular processes), and Eukarya (organisms which have cells with a nucleus). Within the Eukarya, the most well-known **kingdoms** are Plants, Animals and Fungi; within kingdoms the classification continues, with levels of increasing specificity featuring **phylum**, **class**, **order**, **family**, **genus** (plural genera) and **species**. The species name of every organism contains the genus followed by a descriptive 'specific epithet' which distinguishes the species from others in the genus – for example, humans are designated *Homo sapiens* (genus *Homo*, species *Homo sapiens*).

In the animal kingdom, a species is often defined as a group of animals which can breed together and produce fertile offspring. While this is generally the case, there exist relatively rare examples of fertile inter-species crosses in artificial environments.

**See an online version of this trail
at www.botanic.cam.ac.uk/speciation**

In the plant kingdom, matters get much more complicated! Fertile inter-species hybrids are relatively common, and plants which are sexually infertile can reproduce asexually by rooting stems or sending out suckers. Indeed asexual clonal reproduction can also occur through the production of seeds without fertilisation, a phenomenon known as apomixis. It is even possible for a relatively infertile hybrid to produce fertile offspring by crossing with another plant. Today, there are various different definitions of what constitutes 'a species', combining reproductive isolation, ecological niches and DNA evidence, amongst others.

Speciation is characterised by the evolution of barriers to genetic exchange between previously interbreeding populations. Barriers include pollinator preferences and ecogeographic separation. Plants provide many opportunities for studying speciation. Flowering plants are especially rich in species (over 400,000 species described to date), trailing only insects in named species diversity. Much of this diversification has occurred recently, creating spectacular examples of adaptive radiation and of speciation in action.

Although speciation often takes place over long timescales, in plants it can happen in a matter of one or two generations through what is known as 'polyploid hybrid speciation'. This happens when parental plants make mistakes when they create their gametes (analogous to our sperm and eggs). Instead of making gametes with only one copy of each chromosome, they create gametes with two or more, a state called polyploidy. In animals this would usually lead to death of the organism. Polyploidy can drive speciation when the newly arisen polyploid hybridises with another polyploid plant species. This is a relatively common form of speciation in plants and was involved in the evolution of wheat.

New plant species are arising all the time. Climate change and other environmental changes will accelerate speciation rates, but these are unlikely to outpace concurrent extinction rates.

1

Black pine (*Pinus nigra*)

The black pines along the Main Walk were planted under the direction of John Stevens Henslow, founder of this Garden, to illustrate variation within species. Despite being the same species, the black pines which come from warm climates hold their branches erect, while those from cold areas have sloping branches to allow snow to slide off. This limits the load on their branches and ensures the leaves are free to photosynthesise.

This variation within species is a living illustration of Darwin's phrase 'survival of the fittest', which he intended to mean 'better suited to the local environment' rather than in the athletic sense of the word 'fit'. In an early natural population of trees with erect branches there would have existed some trees which by chance had slightly more sloping branches than others. These trees were more fit to survive heavy snow, and their offspring inherited the sloping branches. In the snowy areas, over millions of years, the variant with erect branches died out, and the variant with sloping branches survived.



2

Cut-leaved beech (*Fagus sylvatica* 'Laciniata')

At the western edge of Cory Lodge lawn, within the plantings of catkin-bearing trees of the Fagaceae family, stood a common beech and two variant forms. The common beech had a serious honey fungus infection and sadly needed to be removed in 2026. The variants include this lovely cut-leaved beech, displaying narrow, deeply-cut feathery leaves, and an outstanding weeping beech (*Fagus sylvatica* 'Miltoniensis'). A graft join is clearly visible some 1.5 metres clear of the ground, where the weeping form has been spliced to the rootstock.

These beeches formed an original Henslow planting from the 1840s illustrating variation within species: two examples of mutants (or 'monstrosities', as Henslow would have called them) produced by random and abrupt changes in the genetic code of a common beech. Very occasionally, the tip of a developing branch of the cut-leaved beech can make the reverse change, leading to smooth-edged leaves on one branch and cut-edged leaves on the rest of the tree.



**See an online version of this trail
at www.botanic.cam.ac.uk/speciation**

3

Hau kuahiwi (*Hibiscadelphus distans*)

The geographical isolation of islands means they are often home to species found nowhere else in the world. These species have had time to evolve to suit the ecological niches in which they find themselves, and are referred to as 'endemic', meaning that they are confined to a particular area.



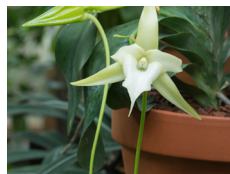
One such species is hau kuahiwi, found only on the island of Kaua'i in Hawaii. Its tube-shaped yellow flowers are about 4cm long, adapted to be pollinated by honeycreepers. Like Darwin's finches, these birds have evolved a range of beak shapes to best make use of various food sources on the islands of Hawaii.

Endemic species face challenges if their environment changes. Europeans accidentally introduced mosquitoes bearing avian 'flu in the 1820s; the disease killed many honeycreepers, affecting the tree's pollination. By the 1980s only two populations of hau kuahiwi remained; one was destroyed in a landslide in 1989, and the other by a storm in 1992. Around ten reintroduced plants exist in the wild.

4

Orchids (Orchidaceae)

The orchid family is the largest family of flowering plants (with about 28,000 species) and is renowned for their many diverse and often bizarre pollination systems and includes the plant from which we obtain vanilla. Orchid flowers have a prominent petal called the labellum, that has been modified in countless ways to attract many different pollinating animals. The pollination of orchids can be influenced by a single mutation. If such a mutation alters the labellum enough, a different pollinator may step in. This results in the new variation becoming functionally reproductively isolated from its parents and it will evolve along its own trajectory. Eventually it will be recognised as a new species and will have evolved without being genetically incompatible with its sister species. This is one of the reasons why it is possible to hybridise different species in the orchid family and produce fertile offspring and also why there are so many hybrids and cultivars, over 100,000 produced by horticulturalists to date.



If you do not wish to keep this booklet,
please return it to the ticket office for others to use.

Plant Species and Special



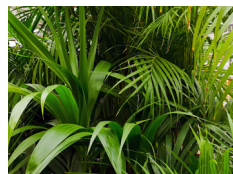
ion



5

Lord Howe Island palms (*Howea* spp.)

Allopatric speciation occurs as a result of genetic divergence caused by geographical isolation: over time one species becomes two due to adaptations to different environments. Populations can also become genetically isolated even without geographic isolation and this is known as sympatric speciation. Two species of *Howea* (*H. belmoreana* and *H. forsteriana*) occur on Lord Howe Island, a small subtropical island of less than 12 km², situated 580 km off the eastern coast of Australia. The island was formed by volcanic activity about 6.9 million years ago. Data on flowering time show that these two species are reproductively isolated with *H. forsteriana* flowering before *H. belmoreana*. Flowering-time differences seem to be directly influenced by substrate-induced physiological changes, where the former species prefers calcarenite, a recent basic sedimentary rock formation that dominates low-lying parts of the island.



6

Monkeyflowers (*Mimulus* spp.)

Despite the striking differences in flower shape, Lewis's monkeyflower (*Mimulus lewisii*) and the scarlet monkeyflower (*M. cardinalis*), are very closely related, indicating that they split into two species relatively recently. The two are found on mountainous slopes, with Lewis's monkeyflower found mainly higher and the other found mainly lower. However, there is a small overlap at about 1400m above sea level.



Experiments have shown that crosses between the two species produce fertile offspring, but these hybrids occur only very rarely in the wild. This can be explained by pollinator specificity: Lewis's monkeyflower is pollinated by bees, while the scarlet monkeyflower is pollinated by hummingbirds. Field experiments have revealed that bees prefer larger, less pigmented flowers, while hummingbirds favour flowers with more pigment and more nectar. Pollinator mediated selection on floral traits is a common mechanism of speciation in plants.

**See an online version of this trail
at www.botanic.cam.ac.uk/speciation**

7 Maize and teosinte (*Zea mays*)

Humans have been directing the process of evolution ever since the first crops were domesticated in the Fertile Crescent of the Middle East over 10,000 years ago. By growing plants, then selecting and breeding from those which have useful features such as a high seed yield or disease resistance, we have been able to shape crops to best suit us.



Teosinte is the wild plant from which maize was domesticated. The two plants have greatly different plant architecture: teosinte has many long branches on which can be found several 'ears' bearing ten grains each, while maize typically has an erect stem bearing two or three ears with several hundred grains each, making it much easier to harvest. Maize and teosinte are classed as different subspecies of the same species (*Zea mays*), but some domesticated crops (including banana and several citrus) are new species bred by humans.

8 Common toadflax (*Linaria vulgaris*)

Also known as 'eggs and bacon', the common toadflax grows in scrubby ground, under hedgerows and in verges, showing spikes of yellow and orange flowers. It is pollinated by insects, whose reward is a sugary nectar, held at the base of a specialised structure called a 'nectar spur' – a long, tapering tube. The length of the spur restricts nectar collection to pollinators with tongues of particular lengths. It is thought to be a 'key innovation' in flowering plants that can lead to rapid speciation, through reproductive isolation due to pollinator specificity.



Given that there are no model plant species that possess a nectar spur, researchers in the Department of Plant Sciences are comparing the well-studied plant snapdragon (*Antirrhinum majus*), which possesses only a nectar pouch (a 'gibba'), with the common toadflax (*Linaria vulgaris*), a related species within the Antirrhineae that possesses a spur. This comparison allows researchers to study nectar spur development.

9

Whitebeams and rowans

(*Sorbus* spp.)

Sorbus species are unusual in that they can produce seed without the need for normal pollination and fertilisation of the flowers (apomixis). As a result, the UK has many endemic *Sorbus* species, which have long intrigued plant taxonomists.

Some believe that they should be recognised as ‘microspecies’, while others contend that they are ‘full’ species. Matters are further complicated by the fact that the microspecies occasionally hybridise sexually, giving rise to further new species or microspecies. On the Isle of Arran, there are unique *Sorbus* taxa resulting from crosses between rowan (*S. aucuparia*) and rock whitebeam (*S. rupicola*). *S. arranensis* is an apomictic hybrid, and *S. pseudofennica* is a backcross (also apomictic) between *S. arranensis* and *S. aucuparia*.

It was our first Director, Humphrey Gilbert Carter, who started the interest here in Cambridge. His student, Warburg, also took a special interest and much of our collection dates from his work in the 1960s.



10

Roses (*Rosa* ‘Cantab’)

There are taxonomic ranks below species (‘infraspecific’) including ‘subspecies’, ‘variety’, ‘form’ and ‘cultivar’. These are plants which are still classified as one species but which have subtle differences, and may even over time evolve into separate species. Subspecies describe geographically isolated variants – for example, the black pines in the Pinetum are *Pinus nigra* ssp. *corsicana*, *Pinus nigra* ssp. *mauretanica* etc.

Cultivars have been selected and cultivated by humans. They are not necessarily true to type – some are hybrids, others are the result of natural variation. Cultivars must be propagated through cuttings or grafting. There are now over 24,000 rose cultivars. Their genealogy was explored by geneticist Charles Hurst from 1922–1947 here in the Botanic Garden. Hurst attempted to disentangle their complex ancestry by crossing rose species and examining the genetics of the resulting hybrids.



See an online version of this trail
at www.botanic.cam.ac.uk/speciation

11

Sweet vernal grass (*Anthoxanthum odoratum*)

Trelogan Mine in Wales was used to produce lead and zinc in the 1800s. The ground near the mine is contaminated with high levels of the two metals, which at high levels are toxic to plants. However, a population of sweet vernal grass has gradually been able to evolve tolerance to the metals, and now grows on the contaminated ground near the mine.



The population of grasses which grows near the mine has shifted its flowering time forward relative to the population of grasses which grows further away. The two populations are becoming reproductively isolated: the earlier-flowering plants pollinate each other before the later-flowering plants are mature. The differences in flowering time are maintained even when seed is taken from the two populations and grown in a garden. This sort of reproductive isolation is a driver of speciation: the variety which grows on metal-laden soil may eventually be deemed to be a new species.

12

Taiwanese trident maple (*Acer buergerianum* var. *formosanum*)

Named for its three-lobed leaves, the trident maple is popular as an ornamental tree, whose leaves mature from rich green in summer to red, yellow and orange in winter.



The Taiwanese trident maple is classified as 'Critically Endangered', with its natural habitat being threatened by land clearance for housing, as well as by logging for timber. It is not alone: a 2016 report by the Royal Botanic Gardens, Kew highlights that 21% of global plant species are currently threatened with extinction. In the face of this crisis, the world's botanic gardens can serve as an insurance policy to safeguard the world's most threatened plant species. Fundamentally, there is no technical reason why plant species should become extinct, given the array of conservation techniques such as seed banking, cultivation, tissue culture, assisted migration, species recovery and ecological restoration. However, once a plant has become locally extinct, reintroduction is difficult and often unsuccessful.

If you do not wish to keep this booklet,
please return it to the ticket office for others to use.

Prof. Beverley Glover and her research group in the Department of Plant Sciences study the evolution and development of floral characteristics that are important in attracting animal pollinators. By understanding how plants build features that attract particular animals, the researchers aim to understand the diversification of the flowering plants. This research informs strategies to protect plant and animal biodiversity, and to optimize pollinator attraction in crops and so help ensure food security.



The research group's work on these topics is underpinned by the living collection of Cambridge University Botanic Garden, of which Beverley is Director.

www.plantsci.cam.ac.uk/research/beverleyglover

**See an online version of this trail
at www.botanic.cam.ac.uk/speciation**