Australian National Botanic Gardens

Teachers' Notes

Module 4

Seeds

We acknowledge the Traditional Owners of Country throughout Australia and recognise their continuing connection to land, waters and culture. We pay our respects to their Elders past, present and emerging.

Plant Science Learning Hub

Students need a space to learn that is fun and rewarding. The Australian National Botanic Gardens has developed a Plant Science Learning Hub that aims to inspire and engage students in plant science and the stories surrounding Australian flora. With clear links to the Australian Curriculum for school years four to six, the Plant Science Learning Hub will provide a valuable resource for students and educators.

1. Plant Life Cycles
2. Plant Structure
3. Pollination
4. **Seeds**

This series provides educators with authoritative plant science content that has a uniquely Australian perspective. The Gardens manages globally significant scientific collections of living plants and herbarium specimens of Australian native flora. We provide educational experiences for students from pre-primary to tertiary levels, leveraging our scientific collections, participation in national and international conservation projects and outreach programs to engage the community in valuing, conserving, and appreciating Australia's diverse plant heritage..

Document overview

This document provides educators with supporting notes for the **Seeds** module. It focusses specifically on flowering plants native to Australia.

- Seed banks are collections of seeds that can be natural or made for conservation.
- Securing seeds in conservation seed banks helps to safeguard the biodiversity of the Earth.
- Seed dispersal syndromes describe the physical features that make seeds suited to different methods of dispersal and can be used to hypothesise a plant's method of seed dispersal.
- Certain environmental conditions or events are required to overcome seed dormancy and trigger the process of germination.

Module Learning Objectives

The following learning objectives apply to the Seeds Module.

1. Understand the role of seed banks in conserving plant species.
2. Identify features that assist in different seed dispersal techniques.
3. Explore the anatomy of a seed and discover how they are adapted to different environmental germination triggers.

Each lesson within the lesson plans and the field kits has individual learning intentions appropriate to the activity.

Contents

INTRODUCTION TO SEEDS

Seeds allow flowering plants (**angiosperms**) and non-flowering seed plants (**gymnosperms**) to reproduce. This module focusses on the seeds produced by native Australian angiosperms.

Seeds are the first stage in the life cycle of a flowering plant. The **ovary** of a flower contains **ovules** that are fertilised during pollination. The fertilised ovules develop into seeds and the surrounding ovary grows into a **fruit** or **seedpod** to protect the developing seeds. The seeds are **dispersed** from the parent plant by different methods and may travel individually or within a fruit. For more information on flowers and plant structure check out the **Plant Structure Teachers' Notes** available on the Plant Science Learning Hub.

Seeds and fruits come in a variety of shapes, sizes, textures and colours, as seen in this group of native seeds and fruits.
Images: ©M.Fagg, 2014

Seeds of a Dwarf Cup-flower (*Gnephosis tenuissima*).
Image: B.Clinton©ABRS, 2017

The Australian native seeds: a digital image library project which is supported through funding from the Australian Government's Australian Biological Resources Study (ABRS) Bush Blitz Program.), Scale is in microns.

There is an incredible range in the texture, shape, size and colour of seeds. Orchids (family Orchidaceae) produce the smallest seeds in the world, often appearing to the naked eye as a cloud of dust. The world's smallest seed is just 0.05 millimetres long and belongs to New Caledonia's Jewel Orchid, *Anoectochilus imitans*. Orchid seeds often contain an under-developed **embryo** and little or no food supply (**endosperm**), instead relying on **mycorrhizal fungi** to provide them with nutrients after they germinate. By contrast, the world's largest and heaviest seed grows in the Seychelles Islands, East Africa, and belongs to the Double Coconut (*Lodoicea maldivica*). These enormous seeds grow up to 50 centimetres in diameter, weigh up to 25 kilograms and take up to seven years to mature!

Close up seeds of a *Caladenia* species of orchid.
Image: ©ANBG, 2023

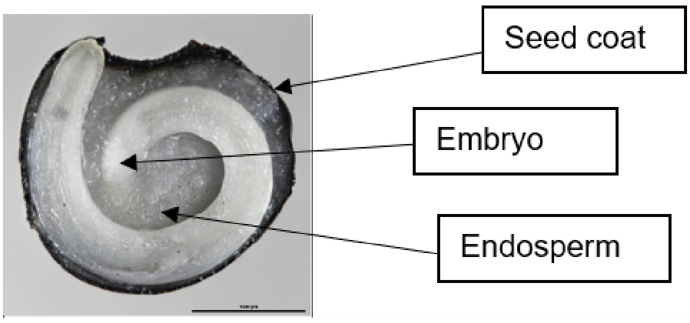
Orchid seeds being processed in a seed bank. Orchids produce the smallest seeds in the world.
Image: ©ANBG, 2023

The Double Coconut (*Lodoicea maldivica*) is the largest and heaviest seed in the world, weighing up to 25 kilograms!
Image: Karelj, Public domain, via Wikimedia Commons

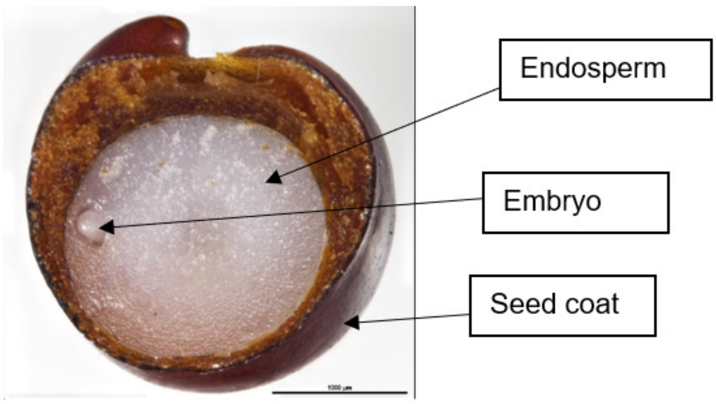
ANATOMY OF A SEED

Most angiosperm seeds have four main structural elements, as described below.

1. The outer **seed coat** protects the embryo from drying out and contains chemicals that detect when conditions are suitable for germination.
2. The **embryo** of the tiny developing plant includes an embryonic root and shoot.
3. The **endosperm** provides food for the embryo before it can produce its own food through **photosynthesis**.
4. One or two **cotyledons** (**first leaves**), which perform variable functions depending on the type of plant. Cotyledons can assist the seedling in establishing itself, transfer nutrition from the endosperm, store food or perform photosynthesis until the **true leaves** grow.



Arthropodium strictum seed.



Cheiranthra cyanea seed

SEED BANKS

Seed banks are collections of stored seeds that can be naturally occurring or man-made. Seed banks act as a 'back-up' storage of seeds, which ensures that plants persist in the environment and do not go extinct. Natural seed banks allow plants to regenerate when all above ground vegetation is lost e.g. after a bushfire. Conservation seed banks allow us to re-grow species in case of extinction. Seed banks store seeds much like financial banks accumulate money, and 'depositing' seeds in the seed bank can act as an investment in the future of the plant species and the ecosystem as a whole.

Conservation seed banks allow us to re-grow species in case of extinction.Image: ©ANBG, 2023

NATURAL SEED BANKS

Seed banks occur naturally in the soil (**geospory**) and in seedpods or cones above the ground (**serotiny**). Seed banks are considered **transient** if the seeds persist for less than one year and **persistent** if seeds remain viable for more than one year. Transient seed banks germinate in response to predictable annual changes, such as the warming temperatures of summer. Persistent seed banks are stored long-term and are often triggered to germinate after an unpredictable large disturbance, such as a bushfire. Seeds accumulate in seed banks over many years and some species can remain viable in the bank for decades before germinating. The long-term viability of seeds in natural seed banks depends on the environmental conditions and the **germination strategies** they use (see ***Germination strategies*** below for more information).

Soil seed banks can contain seeds from many different plants that have accumulated over many years. The density of seeds stored in the soil varies according to the biome and environmental conditions. Shrubby woodlands dominated by *Eucalyptus populnea* in central New South Wales were found to have a soil seed density ranging from 3,200–13,800 seeds per square metre, whereas the *E. marginata* forests of southwest Western Australia were found to have an average density of 767 seeds per square metre.

The soil seed bank can provide a window to understanding the local native species of an area but is often infiltrated by weed seeds as well. Seeds in the soil seed bank wait for a cue to begin germinating, known as a **germination trigger** (see ***Germination triggers*** below for more information).

Eucalyptus marginata forest
Image: ©M.Fagg, 1990

Eucalyptus marginata seed
Image: B.Clinton©ABRS, 2017
The Australian native seeds: a digital image library project which is supported through funding from the Australian Government's Australian Biological Resources Study (ABRS) Bush Blitz Program.

When mature seeds are stored in seedpods or cones attached to a plant they form **aerial seed banks**. Unlike soil seed banks, aerial seed banks are still attached to the parent plant and contain seeds from just one species. Some *Banksia* species store their seeds in this way, waiting for a trigger such as fire to release their seeds.

Banksia robur after burning.
The seeds are visible inside the follicles.
Image: K.Thiele©ANBG, 1987

CONSERVATION SEED BANKS

Conservation seed banks are managed by seed scientists who collect, study and store seeds to safeguard the future of plant species. Successful seed storage relies on maintaining constant temperature, moisture and light levels. Seed banks use temperature controlled, and humidity controlled drying rooms to process seeds collected in the field to ensure they are stable for storage. Large freezers set to sub-zero temperatures are used for the long-term storage of seeds.

Seed scientists around the world investigate the most effective ways of collecting, treating, storing and germinating different seeds. They find the best ways to store seeds, ensuring that they remain **viable** for many years but do not germinate while in storage. Discovering the germination conditions required by thousands of plant species is not a simple task, and sometimes it takes years to 'crack the code' of just one species! To do this, seed scientists check the **fill** and **viability** of the seeds and then trial different **pre-treatment** methods.

Seed banks have the capacity to germinate and reintroduce plants back into the wild or use them for research into future foods or medicines. Up to 40% of global plant species are at risk of becoming extinct due to the impacts of land clearing, invasive species and climate change, so seed banks are crucial to safeguarding the Earth's biodiversity.

Seed fill is a measure of the proportion of outwardly undamaged seeds that have all the internal tissues essential for germination (that is, an intact endosperm and embryo). Seed fill has not often been documented separately to seed viability, as seeds must be filled to be viable (although the converse is not true; that is, not all filled seeds are viable).
Martyn, Amelia J., et al. "Seed Fill, Viability and Germination of NSW Species in the Family Rutaceae." 2013.

The National Seed Bank is located at the Australian National Botanic Gardens.

Image: ©ANBG, 2022

Check seed fill and viability

→ Seed fill: seed samples are x-rayed to determine how many are 'full' (have intact endosperms and embryos).

→ Seed viability: Even when full, seeds might not be viable. Tetrazolium chloride stains live embryos red while non-viable embryos do not stain.

↓

Investigate germination requirements (at least 75% germination success)

→ Germination conditions: mimic what seeds experience in nature.

→ Related species: existing germination protocols for related species are trialled for seeds being investigated; if unsuccessful, other pre-treatments are trialled.

→ Pre-treatments: warm or cold stratification, fire-related (smoke and heat), acid scarification or scalpel chipping, light/dark regimes, constant/alternating temperatures.

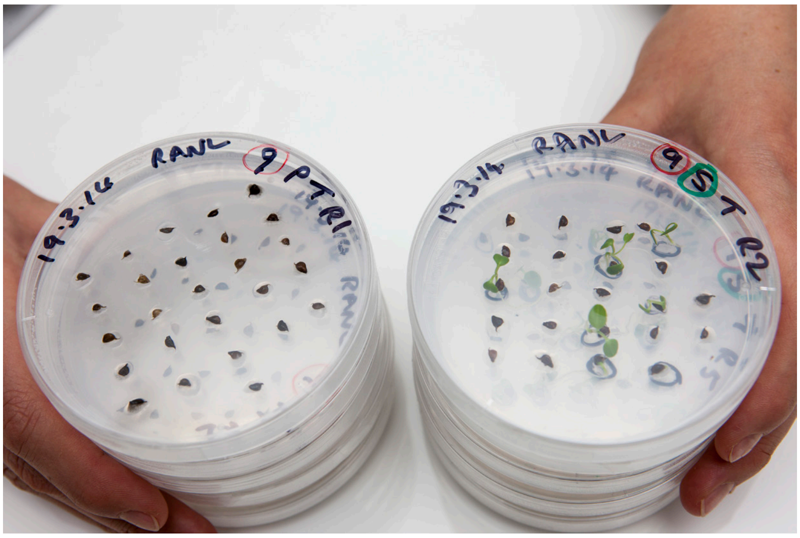
THE NATIONAL SEED BANK

The National Seed Bank

The Gardens' National Seed Bank (NSB) in Canberra plays a critical role in the conservation of native plants on a national and international scale. The NSB has four main functions:

1. **Conservation**: to act as a long-term seed bank, particularly for the storage of rare and threatened flora.
2. **Research**: to conduct research into the biology and ecology of Australian native seed.
3. **Propagation**: to supply seed to produce seedlings for the Gardens' living collections.
4. **Supply**: to supply seed to research organisations through the plant release program.

The NSB has been collecting native seed since the 1960s and houses more than 8,000 individual seed collections, representing more than 4,000 plant taxa and 139 threatened species. The NSB collects seed from target environments including alpine, subalpine and grassland regions near the Australian Capital Territory. Between 2007 and 2012, NSB seed scientists and researchers from the Australian National University (ANU) worked together to 'bank' 451 alpine seed collections from 148 species. The NSB's drying room remains at a constant 15°C and 15% relative humidity and the storage freezers at -21°C. Stored in these conditions, the NSB's seed collections can remain viable for hundreds of years.



Seeds are tested for viability at the National Seed Bank located at the Australian National Botanic Gardens.

Image: ©ANBG, 2022

SEED DISPERSAL

Seed dispersal is the process of a seed being moved away from the parent plant to another location. Seed dispersal can occur via **biotic** (living) or **abiotic** (non-living) methods and be **allochorous** (occurring with help from external **vectors**), or **autochorous** (occurring without assistance).

Dispersing seeds away from the parent plant has several benefits for the seeds, the parent plant and the ecosystem. Most seeds have a better chance of survival the further away from the parent plant they can establish. If seeds fall directly under the parent plant and begin to grow, they usually face high rates of **competition** for sunlight, water and nutrients from other seedlings and from the parent plant itself. This high competition reduces each individual seedling's chance of survival and their ability to thrive but can produce the **fittest** population overall. Moving away from the parent plant can allow seeds to establish in areas where their species has not grown before, potentially leading to an extension of its distribution. However, travelling far away from the parent plant means the seeds may encounter unfavourable growing conditions where they land, presenting a trade-off between lower rates of competition and finding a suitable growing location. In this way, seed dispersal can influence the structure of plant communities and ecosystems.

Seed dispersal syndromes and adaptations

Seeds and fruits come in many different shapes, sizes, colours and textures. Some seeds are dispersed while still inside the fruit, and others are dispersed as a seed alone. Plants have evolved various strategies to disperse their seeds, and often seeds are adapted to assist in their dispersal. This allows us to predict a seed's **dispersal syndrome** based on its shape and characteristics. Common syndromes include dispersal by animals, wind, water, ballistic and gravity, which are discussed in more detail below.

ANIMAL DISPERSAL

Seed dispersal by animals is called **zoochory**. There are three sub-categories of this dispersal syndrome, including:

- **endozoochory**, where an animal disperses seeds by eating and excreting them,
- **epizoochory**, where an animal accidentally disperses seeds that are stuck to their body, and
- **synzoochory**, where animals disperse seeds by collecting and storing (**caching**) them for later use.

Tasty treats

Seeds that undergo **endozoochory** are often brightly coloured and have a tasty coating to attract animals to eat them. The seeds pass through the animal's digestive system and are exposed to their gut flora and digestive fluids before being excreted in their poo. The poo can provide nutrients and act as a fertiliser to assist the seeds to grow.

Being eaten can also act as a **germination trigger** or alleviate dormancy in some seeds. Passing through an animal's gut passage can break **germination inhibitors** such as removing the fruit pulp surrounding a seed, or trigger germination through seed coat **scarification**. Scarification physically damages and weakens the seed coat, allowing the embryo to absorb water and begin to germinate. This process can increase germination capacity and allow seeds to be dispersed further, but the longer a seed remains in an animal's gut the higher its risk of the embryo being damaged and becoming non-viable. Seeds thus face a trade-off between passage time in the gut and dispersal distance.

Emu poo with the seeds of Sandalwood (*Santalum spicatum*). This is an example of Endozoochory.
Image: ©M.Fagg, 2005

Cassowaries

Cassowaries (*Casuarius casuarius*) are a **keystone species** in Queensland's tropical rainforests, meaning that the biodiversity and ecological balance of the rainforest relies on their presence. Cassowaries eat over 238 plant species and disperse their seeds throughout the rainforest, often being referred to as 'rainforest gardeners' for their efforts. Cassowaries eat fruits that are toxic and too large for other animals to consume so over 70 rainforest species rely solely on Cassowaries to disperse their seeds. Sometimes other animals eat the seeds in Cassowary poo and disperse them further.

A sculpture of a cassowary (*Casuarius casuarius*) in a rainforest.

Image: ©M.Fagg, 2020

Mammals

A historically overlooked group of seed dispersers in Australia is our digging mammals. Bilbies (*Macrotis lagotis*), Bettongs (*Bettongia* species) and Bandicoots (*Isoodon* and *Perameles* species) are known to eat fruits and seeds, but limited research has been conducted into their role as seed dispersers. Through their digging activities these mammals can bury seeds and provide favourable sites for their germination. Their scats can contain both viable seeds and mycorrhizal fungi spores, providing a co-dispersal situation that can improve germination outcomes. Many of these mammals are threatened species, so any decline in their populations will be reflected in decreased seed dispersal activity over time.

Bilbies (*Macrotis lagotis*) are important environmental engineers and play a role in seed dispersal of some plant species. Image: State of Queensland, CC BY 4.0, via Wikimedia Commons

A Western Australian study looked at the effects that captive Woylies (*Bettongia penicillata ogilbyi*) and Quenda (*Isoodon fuscivents*) have on the dispersal and germination outcomes of *Acacia acuminata* (Mangart), *Dodonaea viscosa* (Broadleaf Hopbush) and *Gastrolobium calycinum* (York Road Poison) seeds. Less than half of the seeds consumed were retrieved intact from the animals' scat, but of those seeds retrieved whole, the rate of seed viability was very high (see Table 1).

Seed species	Seed viability after consumption (whole seeds only)		Germination capacity after consumption (compared to control)	
	Quenda	Woylie	Quenda	Woylie
Acacia acuminata	100%	80%	No change	No change
Dodonaea viscosa	96%	100%	Lower	No change
Gastrolobium calycinum	97%	87%	Higher	Lower

The outcome of seed viability and germination capacity of three native species after being eaten by Quenda and Woylies.

Source: https://www.nespthreatenedspecies.edu.au/media/4mbgfwbf/4-1-7-seed-dispersal-by-australian-digging-mammals-report_v4.pdf

Comparing the germination capacity of these seeds with controls of the same species showed that seed-animal interactions are not the same in each case. Some seeds benefitted from the digestion process and some seeds had worse outcomes after being eaten. This indicates that not all seeds are adapted for dispersal by digging mammals and some may be adapted to dispersal by only one mammal species. Seeds that showed no change in their germination capacity may not benefit from being digested, instead benefitting from the increased dispersal distance that the mammals can provide for them.

Digging mammals may be effective dispersers of some seeds, but they also have capacity to disperse weed seeds. Their role in seed dispersal will depend on how disturbed their environment is and what species of plants predominate.

Woylies (*Bettongia penicillata ogilbyi*) are also known as Brush-tailed Bettongs and may be important seed dispersers for some plant species.

Image: Calistemon, CC BY-SA 4.0, via Wikimedia Commons

Hitchhikers

Many seeds disperse by sticking to an animal as it brushes past. This is called **epizoochory**, and the seed is usually covered in sharp spines, burrs, hooks or a very sticky substance that helps them attach to fur, feathers or even clothing. Seeds can travel great distances in this way before being dislodged in a new environment.

One such hitchhiking seed is that of *Corymbia torelliana*, or Cadaghi. As the fruits of *C. torelliana* ripen their flesh dries out, leaving only seeds and globs of golden resin inside. The resin attracts Meliponine bees (stingless bees) who use it as a nest construction material. As the bees enter the fruit to collect the resin they encounter the seeds, which attach to the sticky resin and their bodies. The seeds can block structures inside the bees' nest so they try to dislodge as many Cadagi hitchhikers as they can, but those seeds remaining are dispersed along the bees' flight path and at their nest site.

As the fruit of *Corymbia torelliana* ripens it dries out (top and bottom left), leaving the seeds and resin behind (right).
The bees coming to collect the resin are covered in seeds that they then transport away from the parent plant.

Image: ©www.bobthebeeman.com.au

A Meliponine bee transporting the resin from *Corymbia torelliana*.

Image: www.bobthebeeman.com.au

Seed snack packs

Seed dispersal by ants is called **myrmecochory**. Ants are beneficial seed dispersers as they can help seeds to travel up to 180 metres from their parent plant. Across the world 11,000 species of flowering plants and their ant dispersers have developed a **symbiotic myrmecochorous** seed dispersal relationship. The seeds of these plants have a lipid-rich structure called an **elaiosome** that acts as a 'snack pack' reward for the ant who collects it. The ant eats the elaiosome and discards the seed near the entrance of their nest or in an underground midden. Seeds that are dispersed above ground have better germination outcomes than those discarded underground.

Myrmecochory is a globally significant method of seed dispersal that occurs in 334 plant genera and has evolved independently over 100 times. Myrmecochory is especially important to Australian ecosystems, and occurs in 78 native genera, including many in the families Fabaceae, Goodeniaceae and Proteaceae.

The process of removing the elaiosome also performs a kind of **scarification**, where the seed coat is physically damaged. This scarification can occur through the removal of the elaiosome by the ant or by the seed being dragged across the ground. This can allow the embryo inside the seed to access and absorb water and can improve germination outcomes. Some seeds require scarification to germinate, whereas others may die if they are damaged in this way.

Seeds of *Goodenia* species around an ant nest.

Image: ©M.Fagg, 2010

Acacia rhodophloia *Acacia fulva* *Acacia oswaldii*

Wattle (*Acacia* species) with varying elaiosomes. Ants will eat these 'snack packs' and the seeds will undergo scarification in the process.

Images: B.Clinton©ABRS, 2017

The Australian native seeds: a digital image library project which is supported through funding from the Australian Government's Australian Biological Resources Study (ABRS) Bush Blitz Program.), Scale is in microns.

WIND DISPERSAL

Wind Dispersal

Seed dispersal by wind is called **anemochory**. Wind-dispersed seeds have structures such as wings or a parachute (**pappus**) that allow them to be caught by the wind and 'fly' away from their parent plant, as well as slowing their descent so they fall gently to the ground. Wind-dispersed seeds can be classified as gliders, parachutes, helicopters, flutterers or tumbleweeds. Wind-dispersed seeds can be carried long distances away from their parent plant, providing opportunities to colonise new areas and expand their distribution. However, seed dispersal by wind is not very precise and seeds may land anywhere. Some plants with wind-dispersed seed produce hundreds or thousands of seeds to hedge their bets and ensure that some will find suitable growing environments.

Asteraceae (daisy family)

Many species in the plant family Asteraceae (daisies) have wind-dispersed seeds. A well-known example are the non-native dandelions (*Taraxacum* species) that produces distinctive ball-shaped heads of up to 200 seeds each. These seeds have a feathery pappus that acts as a parachute to catch the wind and ensure a gentle ride for the seed. Each seed can travel on the wind up to 100 metres away from the parent plant. There are numerous Australian native plants with similar seeds.

The seeds of a *Microseris lanceolata* will be dispersed by the wind.
Image: A.N.Schmidt-Lebuhn©CANBR, 2012

The seeds of a *Microseris lanceolata*.

Image: B.Clinton©ABRS, 2017

The Australian native seeds: a digital image library project which is supported through funding from the Australian Government's Australian Biological Resources Study (ABRS) Bush Blitz Program.), Scale is in microns

Proteaceae (protea family)

The Proteaceae contains many plant groups that rely on the wind to disperse their seeds. One such Australian **endemic** genus is *Lambertia*, which includes 10 species known commonly as Mountain Devils and Wild Honeysuckles. The seedpods of *Lambertia formosa* (Mountain Devil) contain two small, flat and winged seeds that are suited to dispersal by the wind. Similarly, the seeds of *Lambertia multiflora* (Many-flowered Honeysuckle) are winged and contained in woody seedpods.

Another wind-dispersed member of the Proteaceae is the genus *Telopea* (Waratahs). The number of seeds that each Waratah flower head produces depends on how many individual flowers were fertilised and the seed pods take up to six months to mature. Waratah seeds can 'fly' on the wind as they have a papery appendage that resembles an insect's wing.

Waratah (*Telopea* species) seeds are papery and winged to aid in their dispersal by the wind.

Image: M.Crisp©ANBG, 1984

Image: B.Hall©ANBG, 2018

WATER DISPERSAL

Water dispersal

Seed dispersal by water is called **hydrochory**. Seeds of **terrestrial** plants can be dropped, carried or blown into the water for dispersal, whereas **marine** and **aquatic** plants can release their seeds underwater. Buoyancy is an important trait for water-dispersed seeds, so they are often small, lightweight, fluffy or have air pockets to allow them to float. Water-dispersed seeds can have a thick outer coat to protect them from water infiltration, such as the husk of a coconut (*Cocos nucifera*).

Flooding

Some plant species rely on flood waters to disperse their seeds, and others require flooding for germination success. The River Red Gum (*Eucalyptus camaldulensis*) occurs across Australia and is considered the 'ecological engineer' of Australia's floodplains. The trees provide habitat for birds and mammals, fallen branches provide habitat for arthropods and reptiles. The health of the tree is an indicator of the health of the floodplain ecosystem. River Red Gums require flooding every seven years to stay healthy, but during a drought this often does not occur. After five years without flooding they adapt to use 70% less water, including dropping leaves to minimise water loss through evaporation. Although they can adapt to drought conditions, River Red Gums experiencing drought for 10 years will begin to die. To survive after an extended drought, they require flooding every two years for an eight-year period.

River Red Gum (*Eucalyptus camaldulensis*) seed pods. Image: A.V.Slee©CANBR, 1996

River Red Gum (*Eucalyptus camaldulensis*) seeds. Image: Anon©CANBR

Ocean currents

Plants that grow on tropical beaches are commonly dispersed by water. They often have seeds contained in woody, waterproof seed pods or coverings that allow them to float in salt water for long periods of time. This is true for the coconut (*Cocos nucifera*), which has been successfully germinated after floating on the ocean for 110 days. The seed coat in a coconut is the thin, brown layer between the flesh and the hard outside casing. The embryo is under one of the coconut's three holes (pores), and when it germinates the plant sprouts from one of these pores. The edible parts of the coconut, including the 'water' and flesh, are components of the endosperm.

A coconut (*Cocos nucifera*). The seed coat is the thin, brown layer between the flesh and the hard outside casing. The embryo is under one of the coconut's three holes (pores), the plant sprouts from one of these pores. The edible parts of the coconut, including the 'water' and flesh, are components of the endosperm.
Image: ©J.L.Dowe

The Matchbox Bean (*Entada phaseoloides*) is a vine that grows in Africa, Asia, the Western Pacific and Queensland. Its distinctive seed pods can be up to two metres long and contain seeds that are similar in size to a matchbox (approximately six centimetres long and one centimetre thick). The vines often grow near waterways, so the seeds are adapted for dispersal by water. They are transported from rivers out to the ocean and can remain viable at sea for long periods of time due to their hard, protective casing.

The Matchbox Bean (*Entada phaseoloides*) is a vine that uses water dispersal to spread its seeds. Its seed pods (left) can grow up to two metres long and its seeds (above) up to six centimetres in diameter.

Image: ©CANBR, 1979

The Matchbox Bean (*Entada phaseoloides*) seed.
Image: Muséum de Toulouse, CC BY-SA 4.0, via Wikimedia Commons

Mangroves are shrubs and trees that grow along coastlines around the world. Their life cycle is unusual as many release live **propagules** (seedlings) into the water rather than seeds, making them one of the world's few **viviparous (live-bearing**) plants. Mangrove propagules have an **obligate dispersal period** and an **obligate stranding period** that they must undergo to successfully establish, so still require water to complete their life cycle.

An *Avicennia marina* propagule after it has established itself in the sediment, with its cotyledons visible.

Image: ©M.Fagg, 2014

BALLISTIC DISPERSAL

Seed dispersal by ballistics (explosions) is called **ballochory**. Ballistic dispersal involves the forceful expulsion of seeds from a fruit or seedpod, sometimes accompanied by an audible 'pop' sound. Ballistic seed dispersal is usually the result of pressure building within the cells of the fruit as it dries out. The burst of seeds can happen by itself or be triggered by the movement of wind, water or an animal. Fruits of the Quinine Tree (*Petalostigma triloculare*) explode after drying out, sending seeds up to 2.5 metres away from the parent plant.

Fruits of the Quinine Tree (*Petalostigma triloculare*).
The seeds will explode from the fruit.
Image: ©M.Fagg, 1977

Unlike animals, plants cannot use muscles to throw their seeds away from them. Instead, they have developed clever ways of constructing devices for 'throwing' seeds to explosively disperse them. As the fruits of the Western Australian endemic species *Baxteria australis* dry out, their floral structures contract into a shape resembling a **catapult**. The seeds sit in the catapult ready to be launched, travelling up to one metre away from the parent plant when they are deployed!

Baxteria australis is endemic to south-west Western Australia and releases its seeds via ballistic dispersal. Structures of *B. australis* are shown as follows: (a) flowers, (b) fruit that has split open, (c) catapult mechanism for seed dispersal and (d) seed.

Images: ©Paula J. Rudall & John G. Conran (2012), Systematic Placement of Dasypogonaceae Among Commelinid Monocots: Evidence from Flowers and Fruits, Bot. Rev. 78:398–415. DOI 10.1007/s12229-012-9103-6

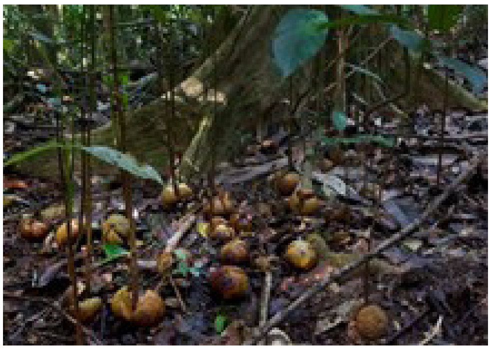
GRAVITY DISPERSAL

Seed dispersal by gravity is called **barochory**. Gravity dispersal occurs most commonly when a parent plant drops their seeds on the ground directly below them. Gravity dispersed seeds often grow in heavy fruits that will not be caught by the wind when falling to the ground. Fruits with a hard outer coating may roll some distance from the parent plant before they release their seeds, whereas softer fruits may break open and scatter their seeds when they hit the ground.

Gravity dispersal helps seeds to grow in suitable habitat, as the parent plant is already growing in the required environmental conditions. The parent plant also benefits by having a colony form around it. Seeds falling directly below the parent plant are subject to high levels of competition for resources from other seedlings and the parent plant. Only the **fittest** seedlings survive this intense competition which helps to create a healthy plant population. Gravity dispersal means seeds grow wherever they land or roll, which can lead to very limited species distributions. This is true for the weird and wonderful rainforest tree *Idiospermum australiense*, known commonly as the Green Dinosaur, which has seeds dispersed by gravity. It exists in small pockets with stable and humid conditions in Queensland's rainforests that cover a total area of only 23 square kilometres.

Green Dinosaur seeds are some of the largest seeds in Australia, weighing more than 200 grams, and are too toxic to be dispersed by animals.

Image: ©J.W. Wrigley, 1999



Green Dinosaur seeds rely on gravity for seed dispersal, which means they grow near the parent plant in small pockets of humid rainforest in northern Queensland. Image: ©Neil Hewitt, Cooper Creek Wilderness, Daintree

DIRECTED DISPERSAL

Directed dispersal describes the disproportionate movement of seeds to favourable growing sites. This is often associated with **zoochory**, as animals travel and transport seeds to different locations selectively. For example, a bird that eats a seed at one location is very likely to poo it out in a similar environment, as that is where it commonly travels. But scientists have found that seeds transported by abiotic methods, such as wind and water, can also undergo directed dispersal. In a wetland environment plants growing in permanently inundated areas released large seeds that sank to the bottom of the body of water and were transported by subsurface currents. These currents only exist in water so the seeds can only move to other inundated areas, providing them with favourable growing conditions. Conversely, plants growing on the waterline produced light seeds that floated on top of the water until they were deposited on a different shoreline. Seeds of plants that grew further away from the water underwent wind dispersal, allowing them to avoid the water altogether and land in a favourably dry area. These wetland species are differently adapted to seed dispersal by water and wind, enabling them to be selectively transported to a location with favourable growing conditions. In this way, directed dispersal can be feature of both **biotic** and **abiotic** methods of seed dispersal.

GERMINATION

Germination is the first stage in the process of a seed becoming a plant. Chemicals contained in the seed coat can be triggered by certain environmental conditions and ensure that the seed only germinates when conditions are favourable. When those conditions are detected the seed coat absorbs water, causing it to crack open and expose the **embryonic** root and shoot inside. This allows the shoot to grow towards the direction of the sunlight and emerge as a seedling, feeding off the **endosperm** until it grows leaves that allow it to produce its own food through **photosynthesis**. Seeds do not necessarily germinate immediately after they have been dispersed, as they have different **germination strategies** and require different **germination triggers**.

Germination strategies

A common **germination strategy** is **dormancy**. The seed remains 'asleep' and cannot germinate until it experiences the right conditions to **alleviate** its dormancy. This strategy allows a seed to delay germination until it can 'sense' that conditions are optimal for seedling growth.

There are different kinds of seed dormancy.

- **Exogenous dormancy** is dictated by conditions outside of the plant embryo and includes physical, mechanical and chemical dormancy.
- **Endogenous dormancy** occurs because of conditions within the embryo and includes physiological, morphological and combined dormancy.

Dormancy is a common germination strategy amongst species that inhabit harsh or unpredictable environments. For example, many alpine species have a dormancy which is only alleviated after exposure to several weeks of cold temperatures. This ensures that seeds germinate after winter when conditions are less harsh. Dormancy prevents seeds from germinating until conditions are suitable not just for germination, but also for a seedling to grow.

While seeds wait to experience the conditions required to alleviate their dormancy they are stored either in the plant itself or in the soil.

- When dormant seeds are stored in the plant it is called **serotiny**, which is observed in some Banksia species. This creates **aerial seed banks** where many seeds are stored in cones or pods above the ground.
- When dormant seeds are stored in soil it is called **geospory**, which is observed in many Australian species. In this case the soil acts as a seed bank, storing seeds from different species together.

Some species of *Banksia* store their seeds in their cones, creating 'aerial seed banks'.
Image: A.Lyne©ANBG, 1993

Alternative germination strategies amongst native alpine species include **non-dormancy**, where germination tends to be immediate, and **staggered germination**, where there are some dormant and some non-dormant seeds produced by a plant, allowing germination to occur at different intervals from the time of dispersal. These different strategies allow plants to hedge their bets in terms of survival in the environmental conditions.

GERMINATION TRIGGERS

Germination triggers are physical or chemical conditions or events that signal to a seed to begin germinating. Different seeds have different germination triggers, such as:

- light levels
- oxygen levels
- soil moisture
- fire/smoke
- scarification or
- temperature.

These are explored in more detail in the following sections.

Light

Some seeds require a change in light levels to germinate, whereas others need light levels to remain stable. The grass *Spinifex hirsutus*, or Hairy Spinifex, helps to stabilise coastal sand dune environments in Western Australia and South Australia. In these dry environments moisture and nutrients are found underground, away from the surface. Hairy Spinifex seeds will only germinate if they experience an extended period without light, as this signals to the seed that it is underground and will have access to the nutrients and moisture it requires.

Spinifex hirsutus helps to stabilise coastal dune environments and germinates in response to darkness. Image: M.Fagg, 1977

Sunlight is also an important germination trigger for rainforest species, as the dense forest canopy limits the amount of sunlight that reaches the plants below. Exposure to light can alleviate the physiological dormancy of some rainforest seeds and trigger germination.

Increased light levels are often associated with an opening in the canopy and therefore an opportunity to grow, such as when a canopy tree falls.

- The space will be filled by plants as quickly as they can grow, competing for the best position in the increased sunlight.
- If the canopy and understorey layers of the rainforest remain intact these seeds may never 'see' additional sunlight and may not be triggered to germinate.

Rainforest plants compete to secure a position with access to sunlight before they even begin to grow. In response to these challenges some rainforest species have evolved the ability to grow on other plants and surfaces rather than in the ground.

- **Epiphytes** (growing on plants) and **lithophytes** (growing on rocks) can live many metres above the ground, providing them with better access to sunlight and certain pollinators than if they were growing at ground level.
- Epiphyte seeds (or spores) take advantage of any surface they can cling to, such as a fork in a tree, a stump where a branch has fallen, a rock or textured bark, and begin to germinate in place.
- Species like the Bird's Nest Fern (*Asplenium nidus*) don't utillise their roots as much as other plants, as they receive water from the rain and nutrients from composting leaf litter that collects amongst their leaves.
- Species like the Sydney Rock Orchid (*Dendrobium speciosum*) produce root mats that bind to each other over rock surfaces and between crevices. Their roots are often covered by a moist layer of ferns and mosses.

This Bird's Nest Fern (*Asplenium nidus*) is an epiphyte.

Image: ©M.Fagg, 2012

Lithophytes like the Sydney Rock Orchid (*Dendrobium speciosum*) can grow on rocks and cliff faces in the rainforest.

Image: ©M.Fagg, 1984

Oxygen

Seeds take in oxygen through their seed coat to undergo **aerobic respiration**. Oxygen is found in pore spaces in the soil so if a seed is buried too deep, or the soil is very compact or wet, there may not be enough pore spaces to meet the seed's oxygen needs. The seeds of flood-irrigated crops like rice can germinate in **anaerobic** conditions as they have a structure called a **coleoptile** that protrudes from the water and acts like a snorkel.

Soil moisture

Mature seeds are often very dry so encountering water can trigger germination. Seeds **imbibe** water through their coat or through a gap that has opened in the coat and use it to convert their endosperm into chemicals that they can use for food. Interestingly, some studies have shown that seeds do not imbibe water as a liquid, but rather as a vapour, and therefore humidity in the seed zone is more important than the environment being wet.

Fire and smoke

Over 400 native Australian plant species, mainly from the fire-prone arid and temperate regions of southern Australia, have seeds that are triggered to germinate after being exposed to smoke or fire. Heat alleviates physical dormancy by breaking the hard seed coat and allowing water uptake. Chemicals from smoke interact with the seed to trigger or speed up germination.

- Once a bushfire has swept through an area it usually removes the groundcover and leaves behind a fertile layer of ash.
- This creates an area that is nutrient-rich, clean and open to sunlight; an ideal environment for seedlings to grow.
- The post-fire environment is so ideal for seedling growth that some species have evolved to only germinate after a fire. These species are termed 'fire ephemerals.' A good example of this is the Pink Flannel Flower (*Actinotus forsythii*).
- *Banksia* seeds are held in the cone of the parent plant. The cone itself is a flower head that has developed from hundreds or thousands of tiny individual flowers grouped together in pairs.
- When pollinated, the flowers grow into a woody seed pod (known as a follicle) with the seed inside. Some *Banksia* species need fire to disperse their seeds. During a fire, the heat can trigger the pods to open and disperse the seeds.
- Some species of Banksia also require one or more rainfall events following the fire to trigger germination.


This *Banksia aemula* cone (left) opened and released its seeds after being exposed to fire. The seeds of *Banksia aemula* (right).

Image: ©M.Fagg, 2014 Image: B.Clinton©CANBR, 2017

The Australian native seeds: a digital image library project which is supported through funding from the Australian Government's Australian Biological Resources Study (ABRS) Bush Blitz Program.), Scale is in microns.

Cold

Many seeds are sensitive to temperature and will only germinate when temperatures stay within a certain range or alternate between cool and warm temperatures. Some forms of physiological dormancy are alleviated by temperature, such as alpine species requiring **cold stratification**. Alpine biomes occur at high elevations above the **tree-line**, where trees cannot grow, and experience snow in the winter. Alpine environments have a very limited distribution in Australia, occurring at approximately 1,850 metres elevation in the Australian Alps (from the ACT to NSW and Victoria), and 700–1,000 metres elevation in the central Tasmanian Alps.

The seeds of many alpine plant species lie dormant in soil before germinating, such as Mountain Hovea, *Hovea montana*, and Alpine Marsh-marigold, *Caltha introloba*.

- Cold stratification is a period of cold temperatures followed by warmer temperatures, usually experienced as the season changes from winter to spring, accompanied by moist soil conditions.
- Waiting for this temperature trigger prevents the seeds from germinating early, such as in late autumn, when they may be exposed to damaging frosts.
- Once their dormancy has been alleviated, many alpine seeds undergo **warm-cued germination**, meaning they germinate in response to the warmer temperatures of spring and summer.
- The increasing light levels and changes between night and day temperatures in spring can also trigger germination.
- Alpine species that grow below the tree-line have a weaker response to cold stratification and warm temperatures than species that grow strictly in the alpine zone above the tree-line.

The seed dormancy of Mountain Hovea, *Hovea montana*, is alleviated by cold stratification and germination occurs in response to warmer temperatures. Image: B.Clinton©CANBR, 2017 The Australian native seeds: a digital image library project which is supported through funding from the Australian Government's Australian Biological Resources Study (ABRS) Bush Blitz Program.), Scale is in microns.

Flowers of the Mountain Hovea (*Hovea montana*).
Image: ©M.Fagg, 2015

Scarification

In some seeds that undergo physical dormancy the seed coat is impermeable to gases so they cannot take in oxygen. These seeds need to be **scarified** before they can take up oxygen and water to trigger germination. **Scarification** can occur when a seed is scratched or eaten by an animal. Often digestive enzymes weaken the seed coat. Some seeds require scarification to trigger germination and are adapted to the digestive tract of particular animal species, such as emus or cassowaries. See previous section: ***Animal dispersal: Cassowaries*** for more information.

Seed pre-treatment

To replicate the conditions required to alleviate dormancy and trigger their germination stored seeds will often need to undergo a form of **pre-treatment**. The method of pre-treatment varies by seed type, but seed scientists, horticulturists and gardeners alike will often use the same method for the same seed species to ensure they will germinate and grow.
Common methods of pre-treatment include:

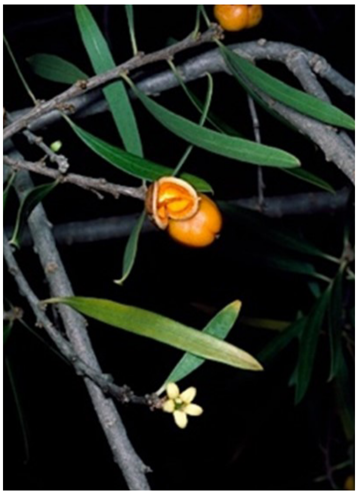
- exposure to smoke
- exposure to fire
- soaking in boiling water
- soaking in room temperature water
- washing in soap or alcohol
- scarring or nicking the seed coat
- exposure to bright light
- exposure to darkness
- exposure to cold or
- exposure to heat.

Australian native pines, *Callitris* species, require a cold stratification pre-treatment of 1–2 weeks in the fridge or 4–12 hours soaking in cool water.

The hard seeds of species of *Acacia*, *Davesia*, *Hardenbergia* and *Kennedia* require soaking and/or scarification pre-treatment to allow germination to occur.

Native saltbushes, such as *Maireana*, *Atriplex* and *Rhagodia* species, require drying before germination can occur. Some species benefit from initial leaching of salt through soaking in water, followed by drying, to facilitate germination.

Pittosporum angustifolium occurs across mainland Australia and is commonly known as Weeping Pittosporum, Native Apricot and Gumby Gumby. The seeds of *P. angustifolium* must be washed in soapy water and then soaked in fresh water to remove the sticky resin that prevents them from germinating. This process needs to be repeated multiple times before the seeds are ready to sow.



The seeds of *Pittosporum angustifolium* have a sticky resin coating that inhibits germination and remains as the seeds dry out. To leach off the resin seeds are pre-treated by repeated washing and soaking.
Image: ©M.Fagg, 1991

Seeds of *Pittosporum angustifolium*.
Image: A.N. Schmidt-Lebuhn©CANBR, 2015

A seed of a *Pittosporum angustifolium*.
Image: B.Clinton©CANBR, 2017
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SUSTAINABLE DEVELOPMENT GOALS

Our education materials support the following Sustainable Development Goals:

- ensure inclusive and quality education for all and promote lifelong learning (SDG 4)
- demonstrate actions that work towards making cities inclusive, safe, resilient and sustainable (SDG 11)
- inform and empower students to preserve our forests and halt biodiversity loss (SDG 15)

CURRICULUM LINKS

The Seeds module provides opportunities for students to engage in the following Australian Curriculum content descriptions **(Version 9.0)**:

Biological Sciences

AC9S5U01 Examine how particular structural features and behaviours of living things enable their survival in specific habitats (Year 5)

AC9S6U01 Investigate the physical conditions of a habitat and analyse how the growth and survival of living things is affected by changing physical conditions (Year 6)

Science as a Human Endeavour

AC9S4H01 Examine how people use data to develop scientific explanations (Year 4)

AC9S4H02 Consider how people use scientific explanations to meet a need or solve a problem (Year 4)

AC9S5H01 Examine why advances in science are often the result of collaboration or build on the work of others (Year 5)

AC9S5H02 Investigate how scientific knowledge is used by individuals and communities to identify problems, consider responses and make decisions (Year 5)

AC9S6H01 Examine why advances in science are often the result of collaboration or build on the work of others (Year 6)

AC9S6H02 Investigate how scientific knowledge is used by individuals and communities to identify problems, consider responses and make decisions (Year 6)

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