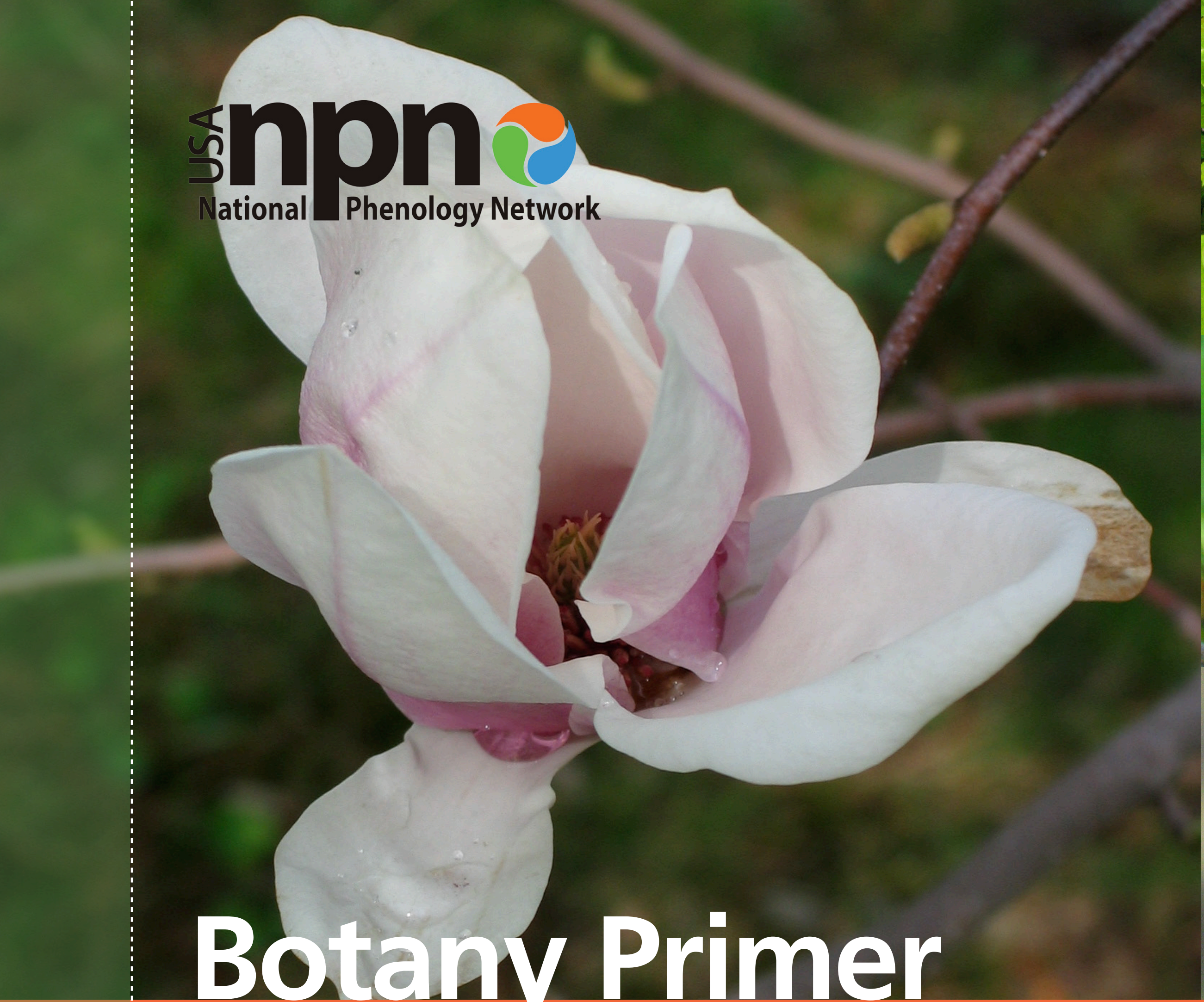
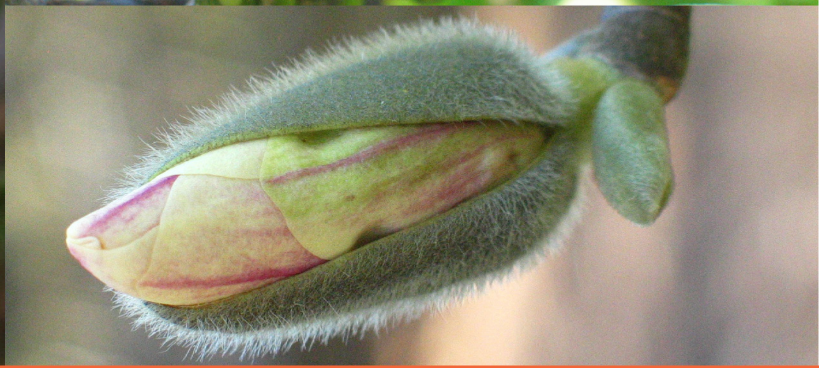
USA npn
National Phenology Network





Botany Primer

Understanding Botany for *Nature's Notebook*

USA-NPN Education & Engagement Series 2015-001 April 2015

nn.usanpn.org

nature's notebook
A project of the USA-NPN

Botany Primer

Understanding Botany for *Nature's Notebook*

USA-NPN Education & Engagement Series 2015-001 April 2015

Suggested citation: Guertin, P., Barnett, L., Denny, E.G. , Schaffer, S.N. 2015. USA National Phenology Network Botany Primer. USA-NPN Education and Engagement Series 2015-001. www.usanpn.org.

TABLE OF CONTENTS

BOTANY PRIMER

How to use this manual

Participants in the USA National Phenology Network's (USA-NPN) *Nature's Notebook* (*NN*) program select and observe species from a large list of plant and animal species. This national effort to collect standardized ground observations of the phenological phases—or observable life cycle stages—of species by researchers, natural resources managers, students and volunteers, supports a wide range of scientific applications and management decisions routinely made by citizens and professionals. High quality data is vital to this effort and this guide is meant to acclimate participants to information referenced within the *Nature's Notebook* program.

The botanical information covered in this document will help observers make reliable plant observations. Along with basic botany, the *phenology* vocabulary used here is meant to complement the names used for the *Nature's Notebook* plant phenophases (those words are quoted in "*italicized red type*"). Botanical terminology is defined at the end of this primer; those terms are in *italicized green type* the first time they are used on a page.

***Nature's Notebook* Nugget**—The USA National Phenology Network (USA-NPN) has selected plant species for observation that have been recommended by a scientific panels, suggested by historic efforts, or requested by partners that focus on specific species. The botanical subject matter covered within this publication generally focuses on the plant types and species included in USA-NPN's *Nature's Notebook.* There may be more plant groups with which you are familiar that are not covered in this document.

Botany Primer

INTRODUCTION

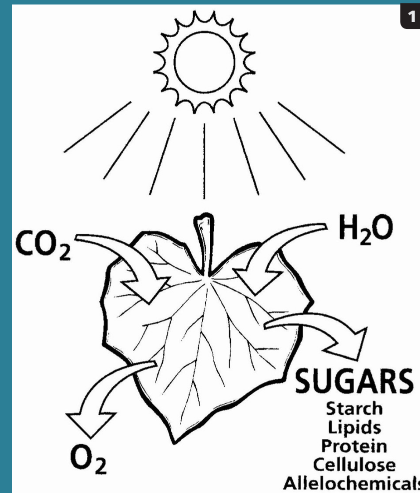
Having a basic understanding of the variety of plants in the natural world, their structures, reproductive processes and life cycles is necessary to making accurate phenology observations.

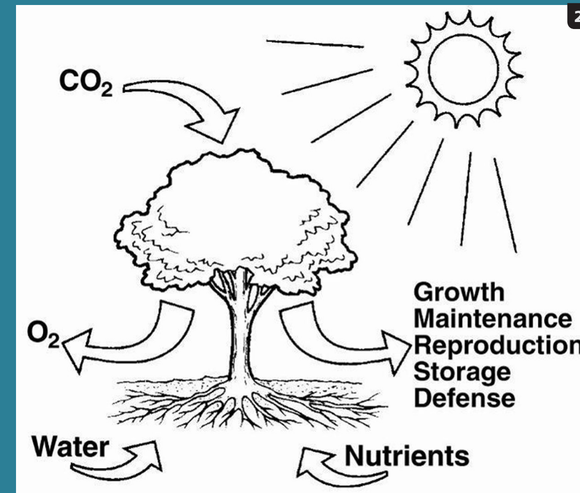
ABOUT A PLANT'S LIFE

As with all of life, a plant needs energy to grow and change. A plant's ability to feed itself, through *photosynthesis*, enables it to produce the chemical and physical components necessary for growth, maintenance, storage, defense (because, of course, it can't run from predators), and to reproduce so the species is successful.

A plant species' anatomy and physiology are fine-tuned to its ecological niche, and support an individual's ability to grow, defend, and survive in its place. For example, in grasslands—which includes many grazing animals within the ecological system, plant species need to be resilient. The anatomy of a grass plant allows it to be munched to the ground without preventing it from resprouting, growing, or reproducing (if you mow a lawn, you are acting like a grazer). Trees, on the other hand, would not be able to withstand grazing in the same way as grasses. For this reason, we mow around young tree seedlings planted in lawns. However, trees have their own unique set of adaptations that enable them to thrive in their own particular ecological niche.

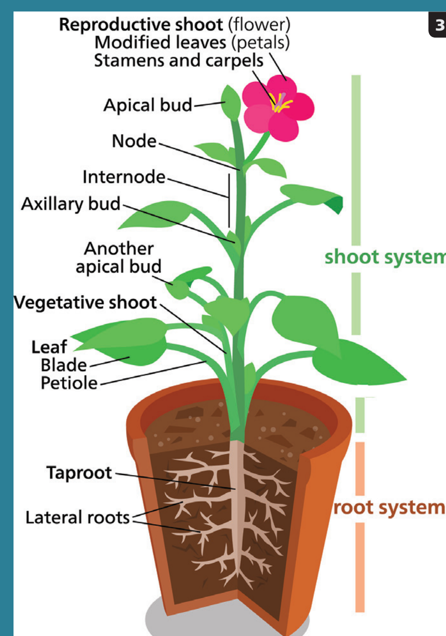
A plant's life



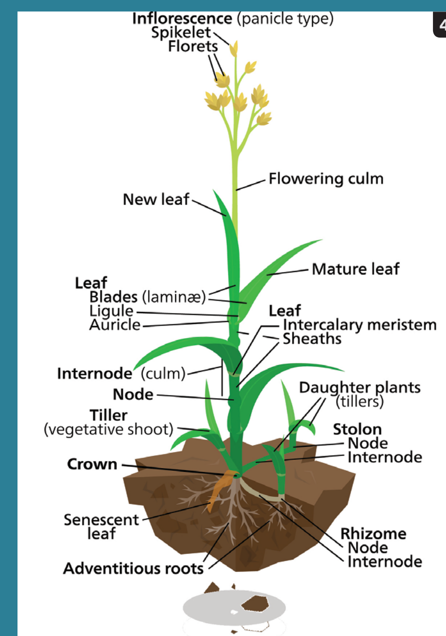


Unlike humans, plants generate their own food—they are *autotrophic*—and the method they use is photosynthesis: the process within the plant by which carbon dioxide and water is converted to sugars and oxygen using energy provided by the sun's radiation.

General anatomy



A broadleaf plant



A grass plant

ABOUT A PLANT'S LIFE (continued)

Each plant organ has a specific role in a functioning plant which varies in importance throughout the plant's vegetative and reproductive stages of life. Depending on the stage of the life cycle the plant is in, plant organs carry out a variety of important functions.

Vegetative organs
The vegetative organs of the plant support all of the functions that enable the plant to take up and release water and gases (such as oxygen and carbon dioxide), make food (by *photosynthesis*), create energy (by respiration), transport water and nutrients, grow, support its stature, and enable and support the reproductive effort.

- ❖ *Roots*—anchor and support the plant; absorb water and nutrients from the soil; store food; and in some plants roots can enable propagation or regeneration
- ❖ *Stems*—support the plant, the buds and leaves; store food; within the stem, the *vascular* network carries water and nutrients throughout the plant; its bark or "skin" or *epidermis* protects from dehydration, disease, and some predators
- ❖ *Leaves or needles*—capture sunlight to make food in the chemical process of photosynthesis; store energy; exchange gases; regulate water movement (causing pull from roots, preventing water loss, and releasing water vapor (*transpiration*))

Reproductive organs
The reproductive organs of the plant enable the plant to produce its offspring so that the entire species continues to survive, evolve and adapt.

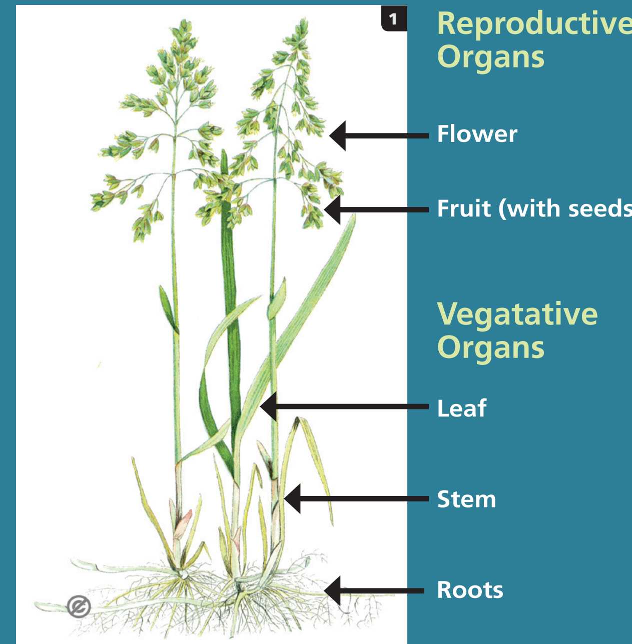
- ❖ *Flowers or cones*—the plant organs that facilitate and support reproduction; attract pollinators (if the species is not *wind–pollinated*)
- ❖ *Fruits and seeds*—are not organs, but are the outcome of successful reproduction, enabling continuation of the species; each species typically has unique traits, and mechanisms for dispersing seeds

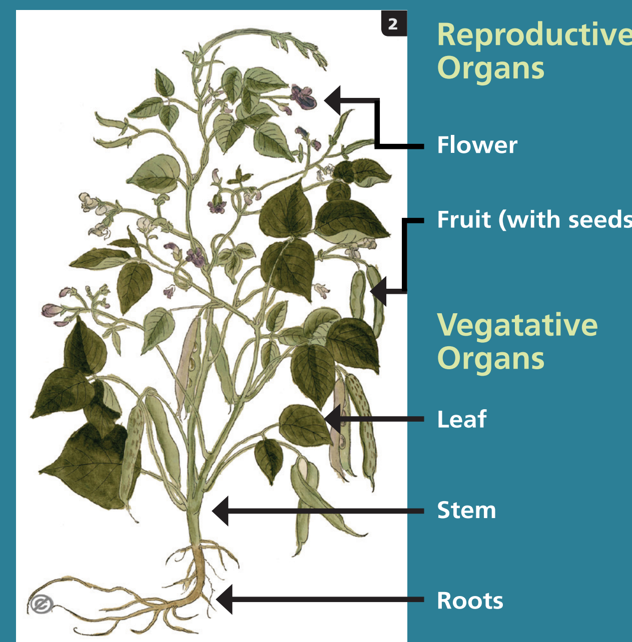
A bit more info….

An overlap of structure and function can occur when the roots sprout leaf buds or a stem node that is touching the soil generates roots and then sprouts leaves, enabling the plant to generate new individual plants without flowering (*asexual* or *vegetative reproduction*). Plants have the rare ability to generate new organs from another, thus giving it additional flexibility when adaptation to change is needed. Plant stems may begin growing roots when a cutting is taken, or stems begin to develop from roots in some species. In this way, structure and function sometimes overlap. The new plant will have the same genetic makeup as the original parent mother plant that it came from.

Variation is the norm. There are a vast array of shapes, sizes, and types of roots, stems, leaves or needles, flowers or cones, fruits and seeds—each type uniquely suited to the plant species' niche in its environment, be it adaption to wet conditions, dry conditions, hot or cold, wind, high solar radiation, leaf–or seed–eating predators... you name it! The variation is nearly endless… and ever evolving.

Plant organs





ABOUT PLANT SPECIES VARIATION

Plant species are present in amazing variety. A vast spectrum of sizes, shapes, functions and life strategies exist (think of the minute (<1 mm) *aquatic* duckweed in contrast to the forest giants—redwoods and sequoia). And, as individual plant species are studied and research continues, scientists find that plant shape and size reflects adaptations that support a species' ability to survive in a particular *biome* or climatic zone.

Although plants share fundamental similarities, members of this kingdom differ greatly. These differences enable botanists and *taxonomists* to categorize them into "types" that can be examined in overview. They can be grouped as:

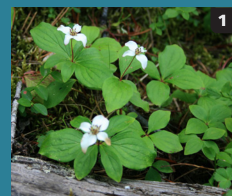
- *vascular* versus *non-vascular* plants
- *gymnosperm* versus *angiosperm*
- *monocotyledon* versus *dicotyledon*
- *annual* versus *perennial*
- *deciduous* versus *evergreen*

For each bullet above, each plant species can be placed into one of the two groups. USA-NPN happens to use the last bullet item to catergorize *Nature's Notebook's* plants into phenological functional groups. For more information on the *Nature's Notebook* plant functional groups, refer to the USA-NPN Phenophase Primer, due out in Spring of 2016. There are numerous ways to group and organize the nearly 300,000 plant species so that we can better understand their relationships!

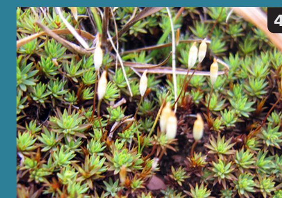
***Nature's Notebook* Nugget**—The "deciduous versus evergreen" dichotomy separates plants based on the biological strategy that a species uses for survival and reproductive success. *Nature's Notebook's* goes a step further and separates the plants into more finely defined groups, such as deciduous broad-leaved plants, deciduous conifers, drought-deciduous, evergreen, semi-evergreen, and so on.

Vascular plants versus non-vascular plants

Plants can be divided into two categories on the basis of the presence or absence of a vascular system. Plants with a vascular system are able to transport water, nutrients and food. A vascular plant has a more recently evolved cell organization for transporting water and products of *photosynthesis* within the plant, allowing vascular plants to evolve to be larger, overall, than non-vascular plants.



Vascular plants




Non-vascular plants

Gymnosperm versus angiosperm

Gymnosperms are an ancient group of plants that do not have flowers, have unique reproductive processes, and produce *seeds* that are naked—that is, the seeds are not enclosed in a fruit. Most often they are surrounded in hard cones or fleshy coverings which can appear to be fruit-like. An angiosperm is a flowering plant that has a more recently evolved reproductive process and its seeds are enclosed within a fruit. Some fruits are dry, some are fleshy, and some cone-like (yet the cone anatomy differs from that of a gymnosperm).

Gymnosperm


Angiosperm

Monocotyledon versus dicotyledon

Both of these categories belong to angiosperm (flowering) plants, but differ in their general appearance (*morphology*), anatomy, and perennial growth. The term "*cotyledon*" refers to the plant's seed leaf, and in *monocotyledons* only one seed leaf is present at germination, whereas in *dicotyledons* two seed leaves emerge from the seed at germination. Other differences are the patterns of their vascular tissue within the plant, how the veins are structured in their leaves, stems, and roots, and the general number of flower parts of their flowers.

Monocotyledon (monocot)

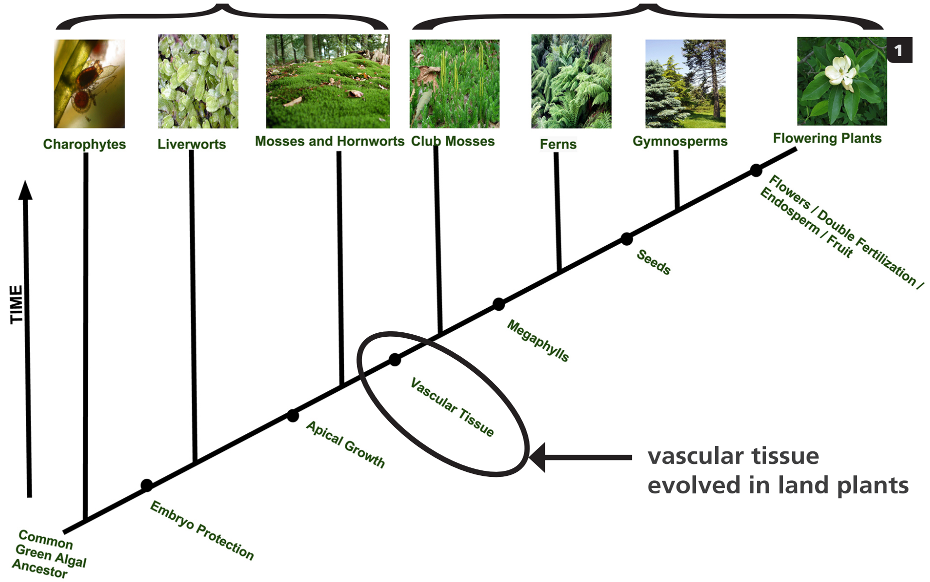
Dicotyledon (dicot)

VASCULAR VS. NON-VASCULAR

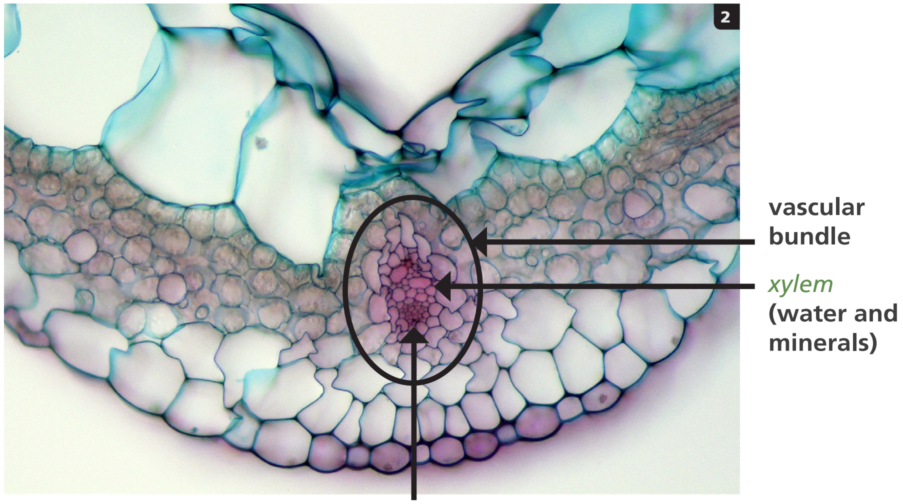
Vascular plants include the *conifers* and other *gymnosperms* like gingko, and ferns, club and spike mosses, horsetails, and all the flowering plants (including grasses). Vascular refers to the tube-like network of tissue (vascular tissue) in the plant that distributes water, nutrients and food throughout the plant.

Non-vascular plants are more ancient in development than vascular plants. Non-vascular plants include mosses, liverworts, hornworts, and algae. They are the first land plants (true plants) that began to evolve.

Non-vascular plants / Vascular plants



Leaf cross-section of the midvein (vascular tissue)



A bit more info….

In short, vascular plants have a complex network of vascular tissue—the plant's veins—and nearly all vascular plants have "true" roots, stems and leaves. The plant's water and nutrients are drawn up into the plant through special tube-like cells called the xylem. And sugars or food (created during *photosynthesis*) are transported down and throughout the plant by other tube-like cells called the phloem. Movement through the plant is enabled by the special shape of the cells and driven by *active transport* (which uses a cell's energy to power movement) within the plant cells. Vascular plants can be very large (some 300 feet tall) and can live far from a water source. The more ancient seedless vascular plants reproduce by *spores* (ferns, horsetails, club and spike mosses, quillworts) while the vascular seed plants reproduce by *seeds*.

A non-vascular plant does not have a tissue network to carry water, nor does it have true roots, stems or leaves (despite having plant structures that may look like leaves). Water moves through the plant by *osmosis*, and nutrients move by *diffusion*. In other words, water soaks into the plant, then moves from one cell to another (and gravity limits how high water can move). Food is carried in the water throughout the plant. Non-vascular plants can not be very tall or large because all parts of the plant need to be close to the source of water—and this means that the non-vascular plant species live in moist areas or in water. Also, they reproduce by spores—which need water to disperse and transport them for successful reproduction.

FLOWERING VS. NON–FLOWERING PLANTS

Being a "*seed* plant" means that the product of the reproductive process is a seed (in contrast, more ancient plants which lack seeds must rely on male and female airborne spores and then the joining of gametes to successfully reproduce). A seed is a multicellular unit containing the new embryonic plant, nourishment to nurture the new plant, and protection, enhancing the seed's survival and also the species' survival.

This grouping of plants (seed plants) includes both the more ancient non-flowering plants (*gymnosperms*) and the more recently evolved flowering plants (*angiosperms*). Whether or not a seed plant has flowers defines how its reproductive products, or seeds, are packaged. Flowers are relatively complex structures having an *ovary* that encases the *ovules* (the future seeds), and the ovary develops into a fruit that encases the developing seeds, protecting them and enhancing dispersal of the mature seeds.

Flowers have a vast array of beautiful forms and, unlike the gymnosperms, a flower can support and protect both the female and male reproductive structures in a single flower or unit.

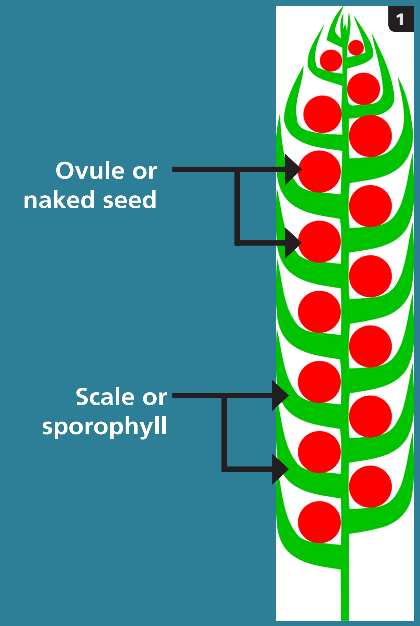
Gymnosperms, being more ancient in development than flowering plants, do not have flowers (or ovaries), but very simple reproductive structures having either male or female reproductive organs. The female part of the plant consists of an uncovered ovule (or "*naked seed*") supported on a structure called a "*scale*" or *sporophyll*. At maturity, there is no fruit to surround the seeds; although some species have fleshy, fruit-like tissue generated from other sources. Other naked seed types may develop a wing and reside in a hard protective structure (like a pinecone) until they are released.

In general, gymnosperm seeds are dispersed by wind and gravity, which are short-distance dispersal methods. In contrast, flowering plants have fruit to cover and protect their seeds—which aids not only in greater protection, but in more effective long-distance dispersal methods to cross the surrounding landscape by animals or water.

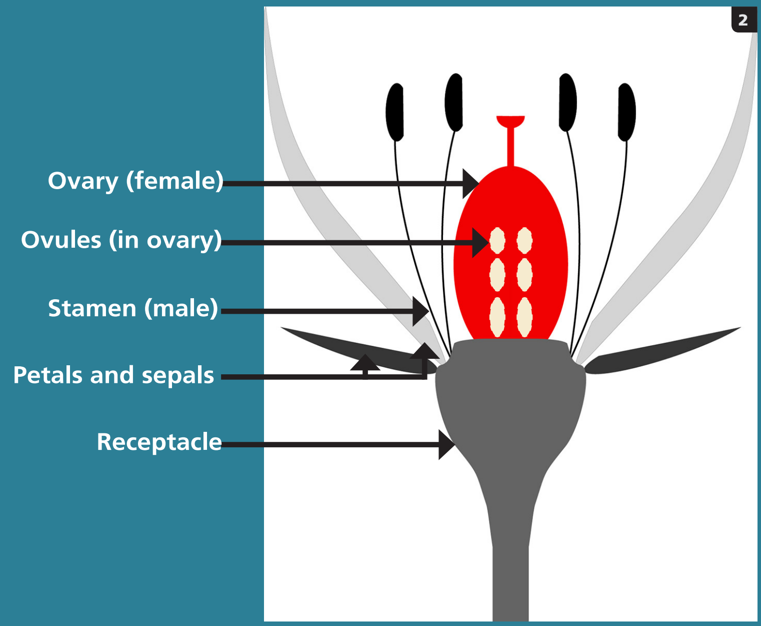
A bit more info....

For a more detailed description of the differences between flowers and gymnosperm structures and their reproductive differences, look for the pages later in this document that cover these subjects individually (Flowers and Inflorescences section starting on page 42 and Reproduction and Fruits starting on page 50).

Gymnosperm strobilus (such as female seed cone)



Angiosperm flower (such as a lily, rose or apple flower)



MONOCOTS VS. DICOTS—
THE SEED'S COTYLEDONS

Another important category of differences between the *gymnosperms* and the *angiosperms* is based on the first leaves, called seed leaves or *cotyledons*, that emerge from a germinating seedling. For the flowering plants, there are two categories: *monocotyledons* (one seed leaf) and *dicotyledons* (two seed leaves). Gymnosperms are multi–cotyledonous and have between two and 24 seed leaves.

Nature's Notebook Nugget—When seeds germinate, the seedling stem uses energy stored in the seed leaves and begins to elongate and push or pull the cotyledons above the soil surface. Often the cotyledons have a unique shape, generally looking very different from a species' "true" leaves. The first true leaves—those leaves having the characteristic shape of the mature leaves of the species—often are the second set of leaves to emerge on the seedling stem. They appear above the cotyledons on the stem, and are tiny versions of the mature leaves. If you are watching for the "*initial growth*" phenophase of seedlings, getting to know the species will help you to identify the first true leaves correctly. ***As an observer, if you see that the cotyledons have emerged above the soil surface, and the first true leaves have not yet emerged or have emerged but have not yet unfolded, this is called the "initial growth" phenophase for the seedling.*** Some species' cotyledons, especially those of monocots, are unusual and remain below the soil surface—for those species the first leaves to be seen above the soil surface are the plant's "true" leaves.

A bit more info....

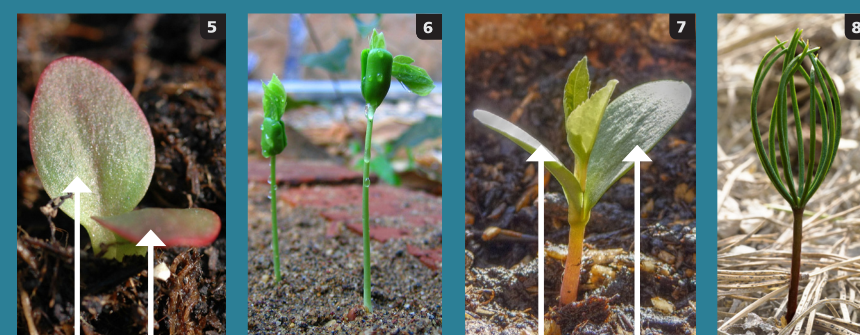
Monocot plants include, but are not limited to, grasses, lilies and all their relatives, palms, agaves and yuccas. One identifying characteristic of monocotyledons is reproductive parts that occur in threes, or multiples of three (like three *carpels* within the lily's *pistil* and the six *stamens* that surround the pistil). Dicot plants comprise most of the other plants you are familiar with in your yard, like roses, forsythia, violets, raspberries, tomatoes, melons, dandelions, sunflowers, cacti, maple trees (and oak, willow, birch, and elm trees) to name a few plant families and examples. Their reproductive parts generally occur in fours or fives, or multiples of four or five; for example, a flower that has four *petals*, four *sepals*, four stamens, a pistil—sometimes having four carpels. The number of reproductive parts is specific to a plant species, and can be used to help identify a species.

Monocotyledon germination

1. Ground level
2. *Coleoptile*
3. *Epicotyl*
4. Adventidious roots
5. *Seed* remnants —cotyledon hidden here
6. Seminal roots

Cotyledons of a monocot can be above the soil but are often below ground

Dicotyledon germination



Cotyledons of a dicot in "*initial growth*" phenophase

Cotyledons of a dicot around not-yet-unfolded true leaves in "*initial growth*" phenophase

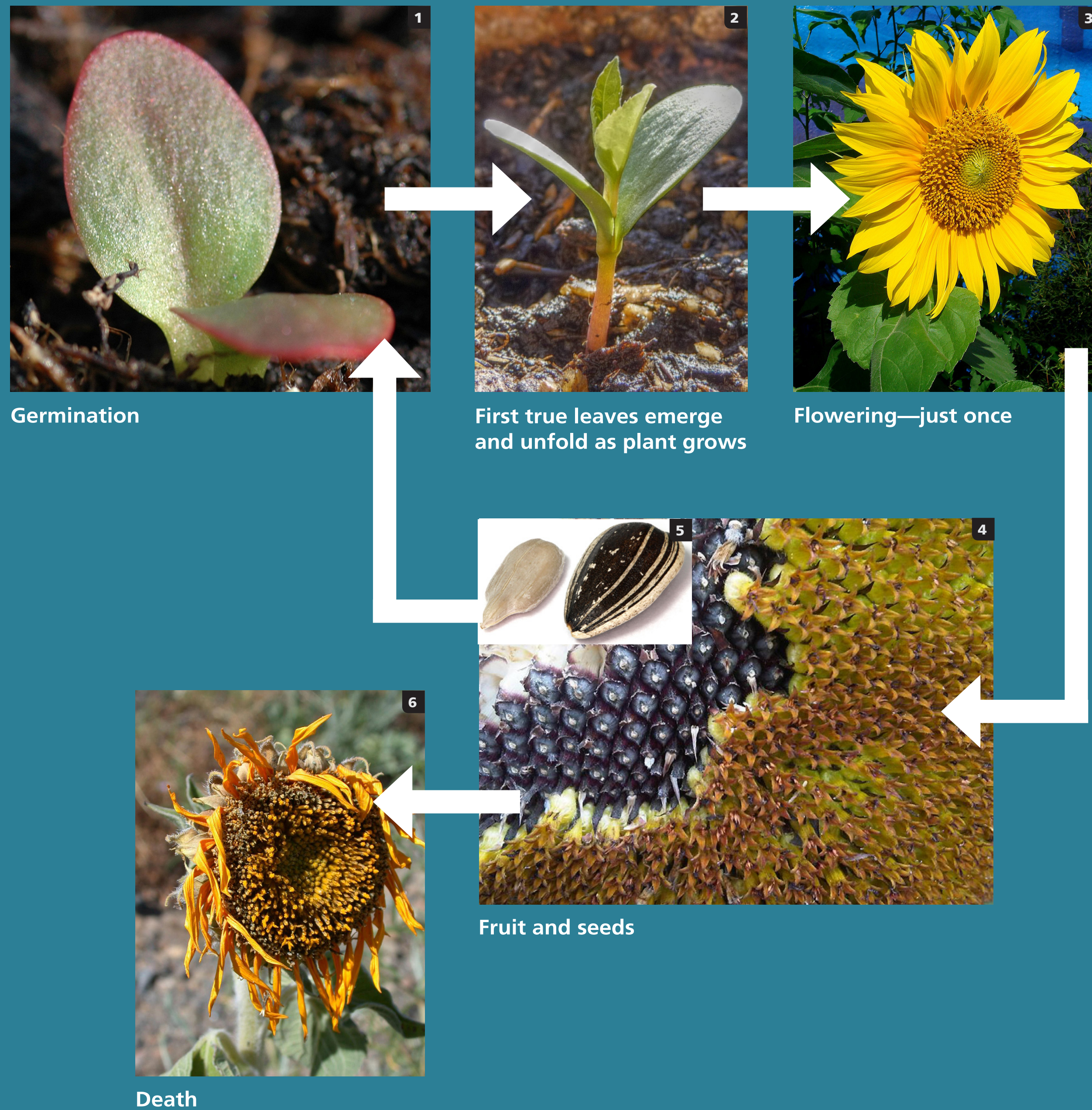
Cotyledons of a dicot in "*leaves*" phenophase, true leaves have unfolded

Gymnosperm germination in "*initial growth*" phenophase

ABOUT PLANT LIFE CYCLES

Plants are also categorized by the number of growing seasons they require to complete a life cycle and their general life span. The cycle starts with *seed* germination or new seasonal growth, continues with the accumulation of plant *biomass*, and ends with seed production. Some plant species complete a cycle in one or two years and then die. Others may take several years to reach reproductive maturity and then repeat this cycle annually and die after hundreds of years. With plant species that repeat many cycles, a cycle may include losing leaves or dying back to the ground, and then leafing out again or resprouting annually. The basic life cycle types are: *annuals, biennials, herbaceous perennials* and woody perennials.

Annual or biennial life cycle



ABOUT PLANT LIFE CYCLES
(continued)

❖ Annuals complete a life cycle in one growing season and die.

❖ Biennials complete a life cycle in two growing seasons, generally flowering and reproducing in their second year, then die.

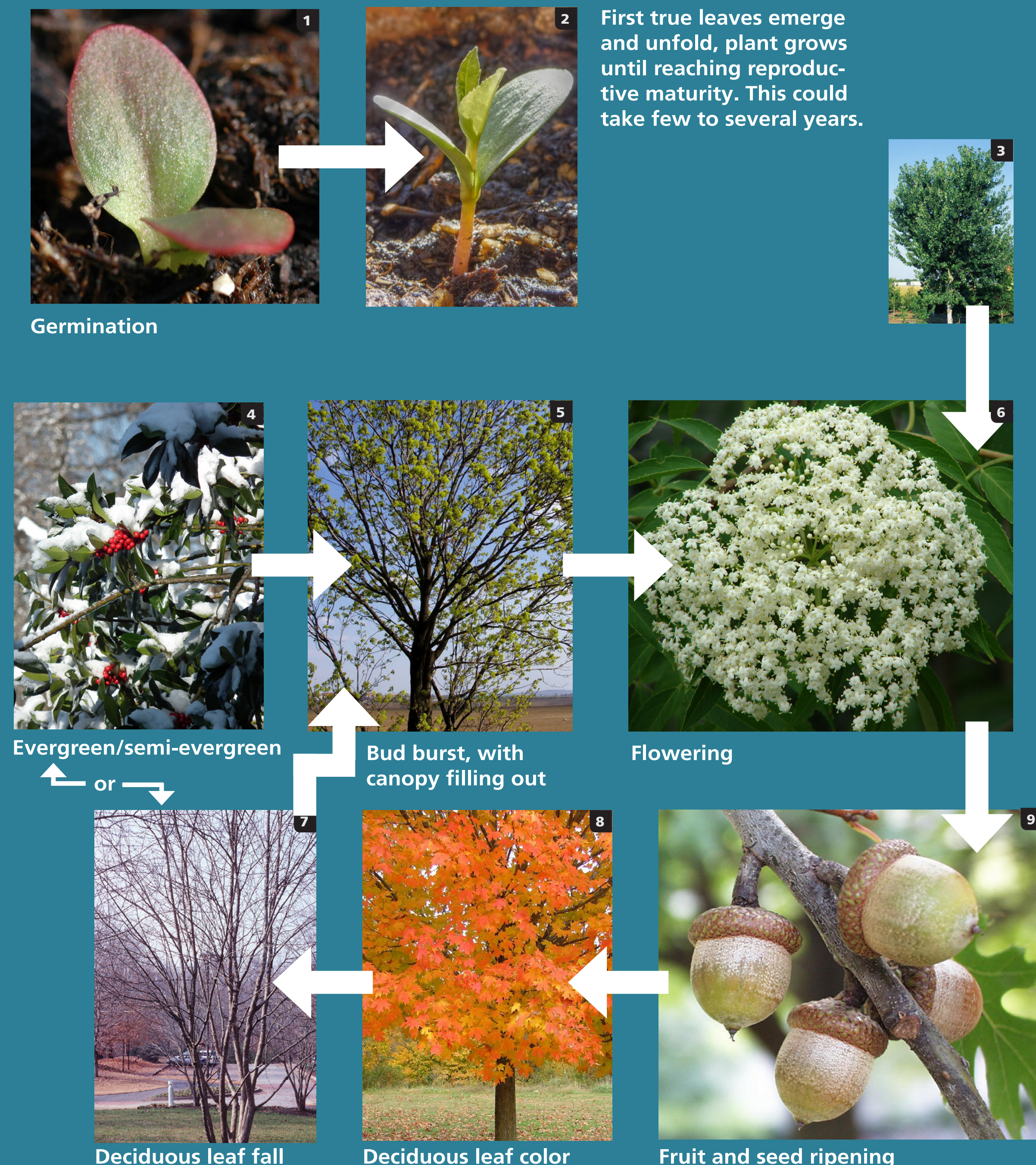
❖ Herbaceous perennials die back to resprout the next growing season, reproducing again—then repeating the cycle.

❖ Woody perennials can be:
- ❖ *deciduous* (dropping leaves or needles during *dormancy*)
- ❖ *semi–evergreen*
- ❖ *evergreen*

A bit more info....

From these very basic categories, some variation can occur. Some plants are perennial but also *monocarpic* (that is—reproducing just once and then the plant dies). They are not annual or biennial (which live only a season or two and reproduce once before dying). When the plant finally does flower, which can take many years, the plant then dies soon after, having accomplished its task of reproducing and producing seeds, and regenerating the species.

Perennial life cycle



ABOUT PLANT VARIATIONS

Some of the other ways that plant species differ is by form, leaf lifespan (by plant type: *evergreen, deciduous*, *semi–deciduous*, *succulent*), its preferred *substrate* for nutrient acquisition and support (where its roots prefer to grow), and how it obtains its nutrients from the environment.

Plant form speaks to the structural characteristics of a species—its architecture, and its woodiness or *herbaceous*ness (for example, a fern, grass, tree, shrub, vine, forb). No matter what form it takes, it might have leaves that are: evergreen—persistent and alive, staying on the plant through the winter or into the next growing season or longer; deciduous—dropping from the plant at the end of a growing season; semi–deciduous—semi–persistent and generally staying on the plant and dropping from the plant when under stress; or succulent—thicker and fleshier, and able to retain water while stressed. Each leaf type supports a life strategy that best suits a species' biology and ecology. Consider a species' roots—they will characteristically prefer a particular substrate: that is, to have its roots in soil, the crevices of rocks, in water or muck, or even balancing in the crook of a tree high in its canopy (*epiphytic*). In addition to these traits there will be a distinct process of how it feeds itself. Does it make all of its own food by photosynthesis (*autotrophic*), or does it invade and steal food from other plants (*parasitic*), or does it get its nutrients from the dead debris of organisms or plants (*saprophytic*)? Given all the possible combinations of traits, it is no wonder the plant world offers so much variation!

A bit more info....

Each species has a unique set of traits. Each trait supports the plant species' strategy to continue its success as a species in the environment in which it evolved. Within any ecosystem and plant community there will be a variety of plant types having a different mix of traits, filling every different ecosystem niche available. Take for example, the forest floor's tiny lily that leafs out in early spring, grows and flowers before the trees put on their canopy of leaves; a niche not only of a specific space (the understory), but of time (early in the spring when there is no shade) so its leaves can capture sunlight and photosynthesize at the rate needed to support successful reproduction. It also occurs at a time when adjacent plants are dormant, thus limiting competition for water and nutrients.

Plant life form

Tree

Shrub

Forb

Vine

Grass

Fern

Biological strategy

Deciduous

Evergreen

Succulent

Substrate preference

Soil-bound

Epiphytic

Aquatic

Nutrient acquisition

Autotrophic

Parasitic

Saprophytic

ABOUT PLANT REPRODUCTION

Plants have several ways to regenerate—to ensure that they successfully survive and continue as a species.

Sexual reproduction occurs when a set of chromosomes combines with another set of chromosomes. Sexual reproduction yields a *seed* which can then germinate, grow, and reproduce. The mixing of genes promotes new adaptations to local change and disease, and can provide the traits that allow for an increase in a species' distribution.

Asexual reproduction (sometimes called *vegetative propagation*) results in a new plant's chromosomes or genes being identical to the mother parent plant. There are many natural and human-derived methods to achieve asexual reproduction in plants. Some plant species produce *clones* of themselves by natural *layering*, *grafting*, or from buds that become *suckers*, *bulblets*, *offsets*, or *plantlets*. Aspen groves are often clones—new plants sprouting from their underground roots until a whole grove of trees stand together. Because they are genetically alike, they typically behave in concert with each other, such as the timing and color intensity of leaf change in autumn.

Nature's Notebook has a "Cloned Plants Project" in which observations are taken by participants on several ornamental plant clones. Because individual plants of cloned species typically behave similarly—responding to stimuli in identical ways—observations recorded on many individuals of the same clone, located in sites across very different regions of the U.S., enable researchers to compare behavior across large regions to identify patterns. See About Plant Cloning on page 17.

Sexual reproduction **By seed**

ABOUT PLANT REPRODUCTION
(continued)

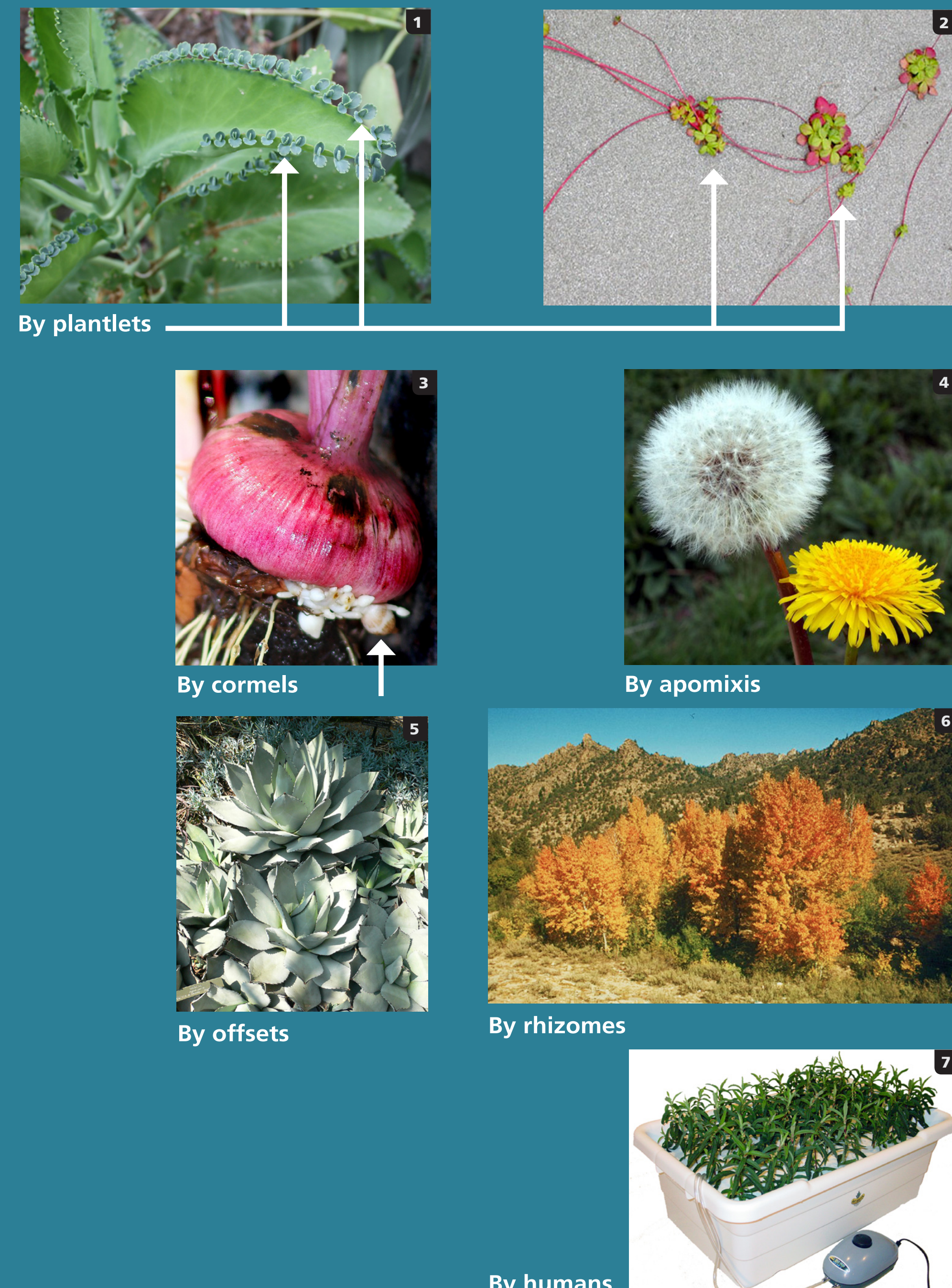
There are plant species that can generate genetically identical (asexual) *seeds* (a process called *apomixis*)—although there are different mechanisms, the outcome is the same—the new plant is a clone. Generally, these plant species also produce sexual seeds—a bit of "bet hedging"or extra measure of caution to ensure the species is able to reproduce and adapt successfully. An example is dandelion seeds which don't require the sperm from *pollen* to produce seed. Often, unless you are familiar with a plant species' natural history, you would not be able tell that the offspring are genetically identical without testing.

In nature, many plant species rely only on sexual reproduction to continue their species. Yet, a large number of plant species use multiple strategies to reproduce, producing both seeds that are sexual and, or seeds that are asexual, and by producing buds that can become *clones* of themselves.

A bit more info....

Humans have manipulated plant reproduction for thousands of years. We breed plants that feed us and our animals, serve as medicines, serve our industries, and we love to garden and add beauty to our surroundings. Often, to do this, we go out into the wild lands and choose exceptional plants to further breed or clone. Many of our favorite plants are clones of wild plants or wild stock that is bred, and then cloned, to satisfy our needs. If you have ever taken a cutting from a favorite plant and then encouraged it to develop roots and planted it, then you have produced a cloned plant.

Asexual reproduction: "cloned plants"



ABOUT PLANT CLONING

When an individual plant within a species has been identified as having unique attributes that can improve or enhance human lives (like a high–protein plant, a large–fruited, sweet–tasting plant, a disease–resistant plant, a drought–resistant vegetable, or an unusually beautiful flower), it is a challenge to keep those attributes available before the plant dies. The attributes change through time by sexual recombination for the resultant offspring, and can be lost. Cloning is one propagation method that many species can tolerate; it can be initiated with individual cells in a sterile environment, or by using larger cuttings from a plant. The cloned plants, which are one genetic variant within the species (and their gene pool), generally will behave and respond in exactly the same way to stimuli—temperature, precipitation, light.

Nature's Notebook Nugget—The USA National Phenology Network, *Cloned Plants Project* asks observers to watch individual plants of a lilac (*Syringa* x *chinensis* 'Red Rothomagensis') and dogwood (*Cornus florida* 'Appalachian Spring') because the clones respond to the environment predictably—leafing out, developing flower buds, and flowering at the same time as their sister clones when conditions are the same. If the timing of their phenological events differs, it is predictably due to differences in local environmental conditions. Comparisons can be made and general patterns can be identified across landscapes, such as where areas are warmer or cooler during a given time period. We can identify an area that is changing in climate over time by the response of the cloned plants living in the area.

Historically, *Nature's Notebook* asked participants to observe a cloned honeysuckle variety. However, it has been found that the cloned honeysuckle can be invasive in some areas of our country, potentially displacing native plants if it spreads into wild areas. As a result, cloned honeysuckle plant monitoring via the USA-NPN has been discontinued. However, the USA-NPN only accepts observations from participants having existing cloned honeysuckle plants on their property since those are already part of the larger dataset. Planting of new cloned honeysuckle individuals is strongly discouraged.

Cloned plants

Cloned lilac

Cloned honeysuckle

Cloned dogwood

Botany Primer

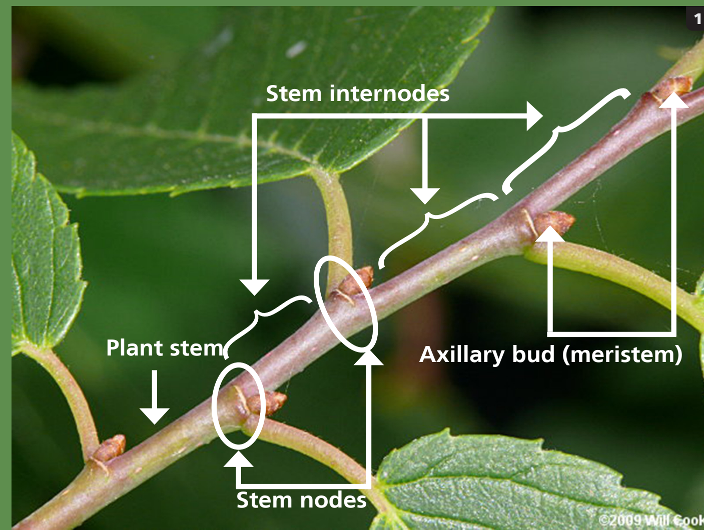
STEMS AND BUDS

Stems and buds, along with their arrangement, are useful for plant species identification. Understanding these structures are also is useful for understanding and knowing what to look for when examining an individual plant for new growth at the start of the plant's growth cycle.

ABOUT STEMS AND VARIATION

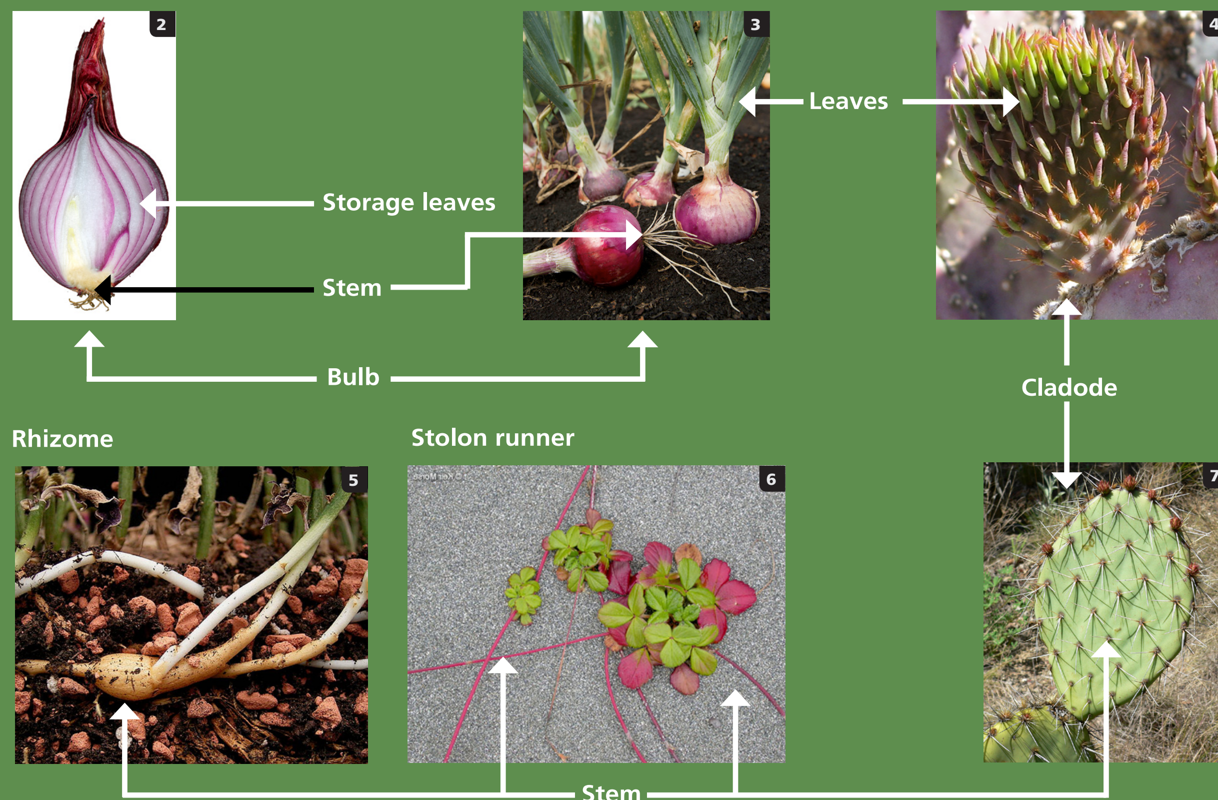
Generally plant stems support the above-ground plant, although sometimes they take on other forms and can occur below ground. Stem tissue supports the plant's leaves, buds, and the continuous root-to-leaf *vascular* system—including *xylem* to transport water and minerals, *phloem* to transport the products or food generated by *photosynthesis*, and *cambium* to produce more xylem and phloem as the stem grows in girth. Stems can be very short or long, *herbaceous*, *succulent* or woody; flexible or rigid. Some plant parts categorized as stem tissue might surprise you; they have the structure and function of a stem even though they don't look like what is typically called a stem (such as a potato *tuber*, or an onion or tulip *bulb)*. Also, "runners" (*stolons*) are stem tissue; they are found on strawberry plants, grasses, and many other plants. Even some root-like parts—called *rhizomes*—are stem tissue, and they function as stems, not roots (in fact, roots can form at their nodes). Another variation is a *cladode*—a flattened stem that looks like a leaf and photosynthesizes (such as a cactus prickly pear pad).

Modified stems are found above ground and below the soil surface. Above ground types of stems include *spurs* (or *short shoots*), stolons, *tendrils*, and cladodes. Below ground stem variations include rhizomes, bulbs and *corms*, and tubers (not to be confused with *tuberous roots*—a swollen root having a nutrient storage function and no stem nodes).



A bit more info....

A node contains the area on a stem where buds of leaves or needles, flowers or cones, and stems or branches are initiated and develop. It is an area of cellular activity (via *meristem tissue*) where growth typically occurs. The stem node area directly above where a leaf is attached—in the bottom of the "V" shape—is called the leaf *axil* (at times the leaf may be missing, its attachment point is still usually recognizable by a leaf scar). The section between each node is called an *internode*.



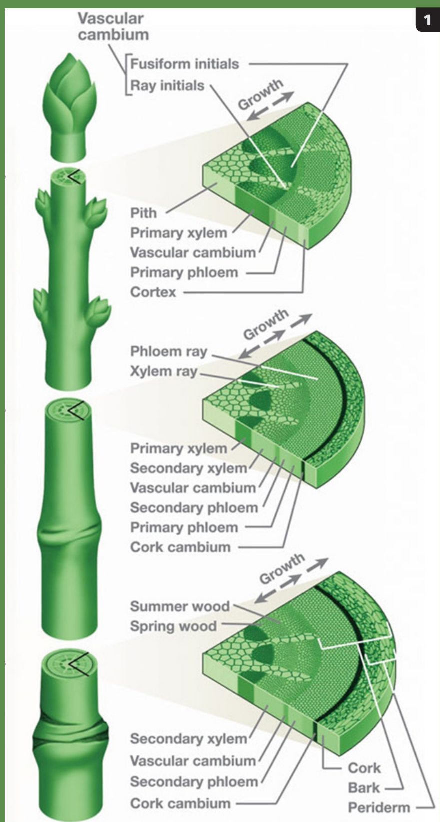
ABOUT STEM ANATOMY

A plant stem is one of the plant's organs and is comprised of several tissue systems. Its *epidermis* or skin protects the internal tissue systems of the stem limiting water loss, yet allowing the exchange of necessary gases. Inside, a stem has *cortex* and/or *pith* tissue which provides storage and support, *vascular* tissue (*xylem*, *phloem* for moving water and food) with vascular *cambium* (*meristem* or growth tissue which initiates new xylem and phloem) and cork cambium (meristem or growth tissue which initiates protective cork or bark). *Perennial*, woody *gymnosperms* and *dicots* have secondary growth in their vascular and cork cambium, allowing a stem to add girth or diameter and strength to support a plant's height. In stem cross sections of these plants (perennial, woody gymnosperms, and dicots), secondary growth in the vascular system appears as annual rings.

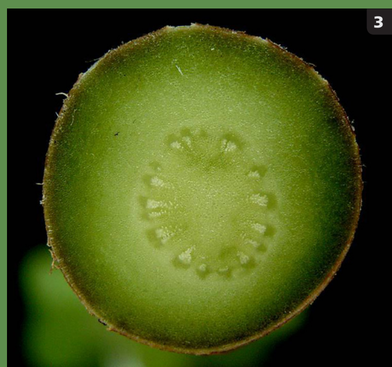
A bit more info....

Monocots, dicots (both *angiosperms*) and *gymnosperms* have different internal stem structures, with the tissue systems arranged differently. These differences can be seen primarily in the arrangement of the vascular system. Monocots have scattered vascular bundles (each bundle having xylem, phloem, and cambium) whereas dicots and gymnosperms have a ring of bundles within the stem. In a woody dicot, the vascular tissue is a continuous ring.

Cross sections of a plant's vascular system

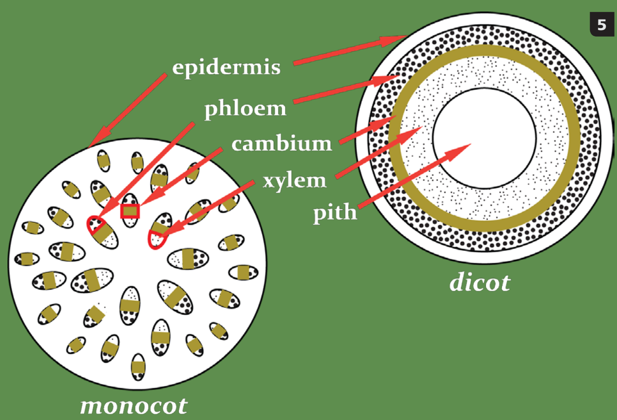


Scattered vascular bundles



Ring of vascular bundles

Woody dicot with secondary growth (rings)

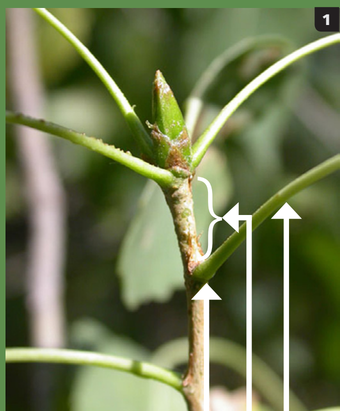


Phloem—carries a plant's food and photosynthates
Xylem—carries water and minerals
Cambium—meristem, where growth occurs, increasing girth of the stem

ABOUT STEMS AND THEIR ARRANGEMENT OF PLANT PARTS

A plant's branches, leaves, flowers, and buds can be attached to a stem in various arrangements, such as *alternate*, *opposite*, *rosulate* or *whorled*. These arrangements are typically unique to a species, so they will help with the identification of a species. Usually, the leaf arrangement for a species reflects the plant's branching arrangement. Sometimes there is variation—mixing arrangements in different parts of a plant in a given species.

Alternate arrangement of leaves and branches



Attached leaf
Stem internode
Stem node

A single leaf or branch grows at a node and appears alternate to others along the stem

Opposite arrangement of leaves and branches

Attached leaf
Stem internode
Stem node

Two leaves or branches grow at a node and appear opposite to one another along the stem

Rosulate

A rosette of leaves attached at or near one point

Whorled arrangement

Three or more leaves or branches grow at a node

ABOUT BUDS

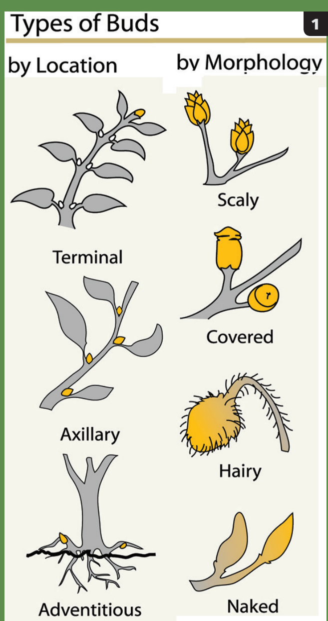
Buds are embryonic and undeveloped shoots from which leaves, stems, and flowers arise. In some plant species they can remain *dormant* for extended periods of time. Buds of most woody plants from colder climates develop tough, protective outer scales. These *bud scales* are modified leaves, and commonly fall off after the buds break open, leaving scars in the bark of the twig (*bud scale scars*). Annual plants and *herbaceous perennials* (along with a few woody perennial species) do not have bud scales that cover the new leaf bud. Some have *"naked" buds* with hairy, sticky, or no protective covering, instead having tiny green and tender leaves that more or less tightly surround the new embryonic leaves.

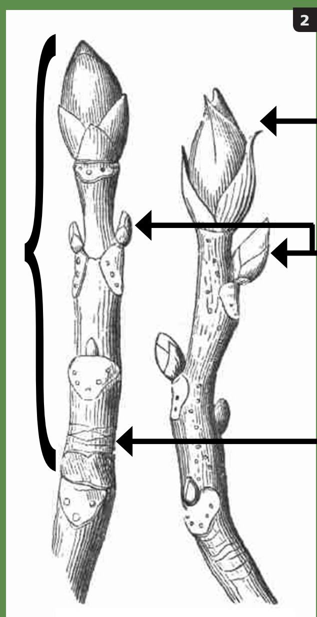
Buds are typically named based on their location on the plant stem. At the *apex* (tip) of the stem is the *terminal* or *apical* bud. A stem continues to grow in length by its terminal bud. Along the sides of the stem, in the stem *node's* leaf *axils* (directly above where the leaf stem or *petiole* is, or was, attached to the stem) are the *lateral* or *axillary* buds. Lateral stem buds if they develop, enable branching.

Occasionally buds arise on the plant in non–typical areas other than at the stem *apex* or nodes; they are called *adventitious* buds. Following a stem injury, they may arise along a lower *internode* of a stem or branch.

And of course there is variation. For example lilacs rarely have terminal buds. Two strong axillary buds taking its place, lending to a forking of branches each year as the plant grows. Being able to identify the bud type will help you report the "*breaking leaf buds*" phenophase.

Nature's Notebook Nugget—During dormancy, buds can withstand low temperatures, often requiring a duration of a specified number of days below a critical temperature before resuming growth in the spring. This is called a *chilling requirement*, and it varies for different species—and sometimes the variants of species. Once the chilling requirement is met for a plant, and the buds emerge from their dormant state in warm spring weather, they are susceptible to a late frost and can be easily damaged. Knowing more about the individual, unique plant you are observing and how it reacts to its environment can help you better understand when to expect to report each phenophase, such as "*breaking leaf buds*" in *Nature's Notebook*.





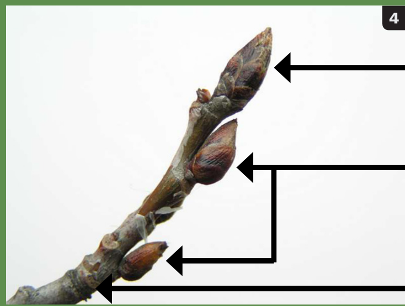
Terminal or apical bud

Axillary or lateral buds

Bud scale scars (last year's terminal bud scales)

Terminal or apical bud

The brackets in images two and three indicate one year's growth of a twig. The distance between the terminal bud and the first terminal bud scale scar reflects the growth that occurred in the current season.



Terminal or apical bud

Axillary or lateral buds

Bud scale scars

ABOUT WOODY TWIGS AND STEMS

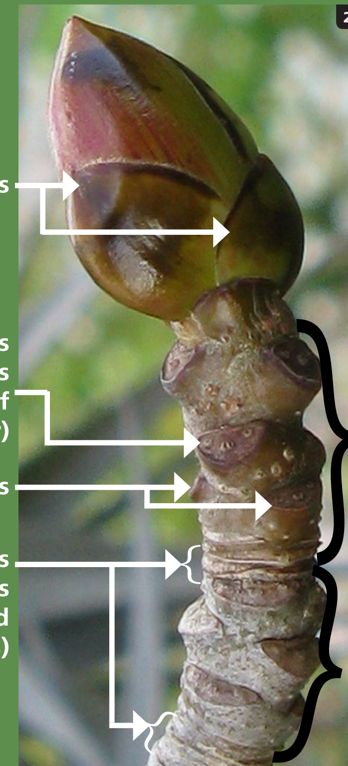
A closer look at stems reveals specific details of their anatomy that will help to distinguish one species from another, even those that otherwise look alike. The stems of woody plants can have:

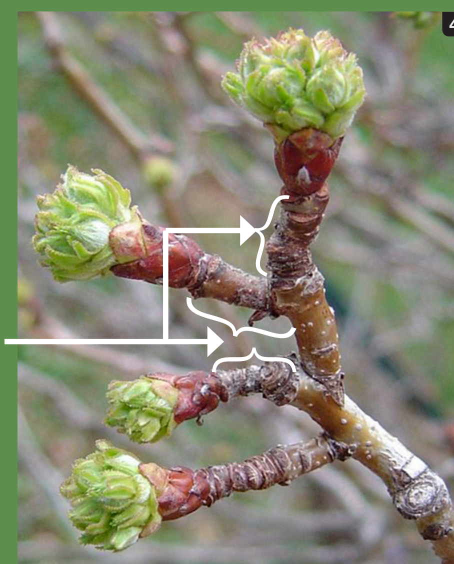
- *leaf scars* (from the seasonal shedding of leaves from the plant)
- *bundle scars* (found within the leaf scar and left from the *vascular* tissue contained in the leaf petiole)
- *terminal bud scale scars* (from the shedding of *bud scales* that protect overwintering growing points)
- *lenticels* (tiny openings that help the plant breathe or exchange gases, such as oxygen, through the bark)
- *stipule* scars (scars of various leaf–like appendages that occur on either side of the leaf *petiole* at the point of attachment to the plant stem)

The arrangement or position of the structures along a stem will help with species identification, for instance, whether the leaf scars are *opposite*, *whorled*, or *alternate* along the stem

One can even determine a plant's past annual growth rates by measuring the length of stem tissue located between bud scale scar regions.

The black brackets in images one and two indicate one-year's growth





ABOUT BREAKING LEAF BUDS

A plant's buds can be *dormant* for long or short periods, waiting until conditions are adequate to start a plant's growth cycle again. Variation in dormancy periods, and the bud type that protects the growing points during dormancy, is another way that plant species have adapted to different environments and the ability to survive and compete in their native habitat.

Nature's Notebook Nugget—In colder environments, many *perennial* species have their new buds covered with protective *bud scales* (as seen on the previous page). ***When spring arrives and the conditions for leaf emergence are adequate, it is easy to detect when the plants become active and "breaking leaf bud" occurs, as the terminal or apical bud scales begin to separate and open—and the fresh new leaf tissue can be seen at the tip of the opening bud.***

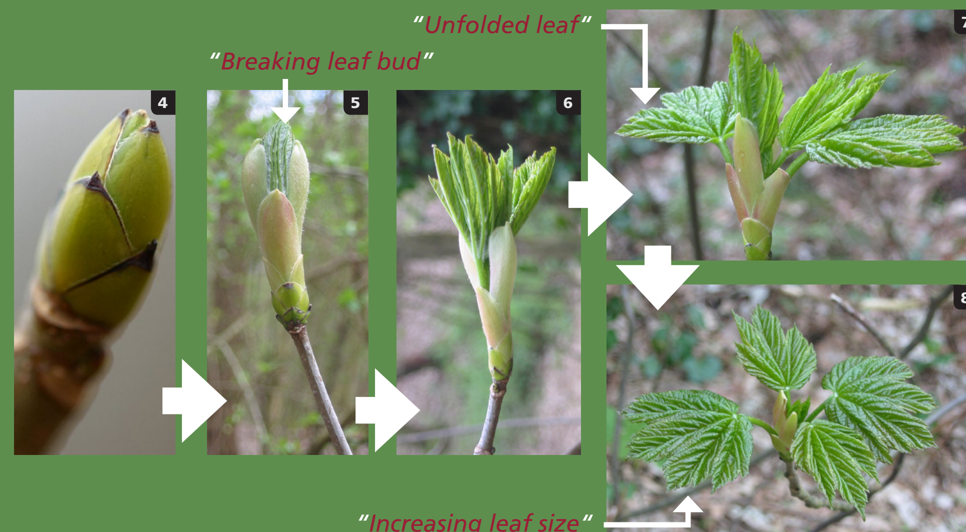
Annual plants, *herbaceous perennials* and some woody perennial species do not have bud scales that cover the new *terminal* or *apical* leaf bud. They have *"naked" buds* with hairy, sticky, or no coverings; immature and new embryonic leaves are tightly folded over each other just waiting for the right environmental conditions to begin growing again. The immature leaves surrounding the embryonic leaves and growing point (*meristem*) are the only protection. Species having naked buds occur rarely in colder climates, but when they do the buds are generally large enough to easily see (such as witchhazel, black walnut, and eastern poison ivy). Naked buds are quite common in warmer climates (such as the Texas barometer bush, saltbush, and some *Ceanothus*). They are often so small and covered by immature leaves that they are very hard to see.

Nature's Notebook Nugget—Plants species having naked, uncovered buds do not re–initiate their seasonal growth with the opening of protective bud scales. There is no "breaking" leaf bud, per se, but, generally, tiny new leaves do begin to separate from their tight cluster at the growing points or meristems on a stem. The new leaves can start out partially formed or be rather shapeless and begin to take shape and expand. In many species, there usually is a definitive start to their re–initiated growth and expansion that, if the bud is large enough to see, could be equated to "*breaking leaf buds*". *Each plant species will develop differently, and getting to know the species you wish to observe, and asking questions when having difficulty, will help you to make reliable, quality observations.*

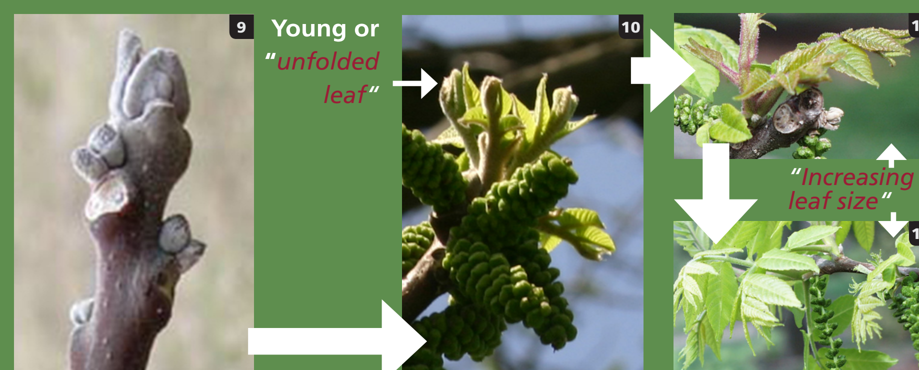
Naked buds in warmer climates—tiny buds, no scales

Buds—with bud scales

Buds—with bud scales



Naked buds in colder climates



Botany Primer

ROOTS

Roots are an important part of a plant because they provide structure and support to the above ground organs, and are key to their survival.

ABOUT ROOTS

Roots are also a plant organ. Roots function to anchor the plant, absorb soil water and nutrients sending them upwards into the above–ground plant organs, provide support for the plant stem, and sometimes store food—the products of *photosynthesis*—for the plant's future growth and survival.

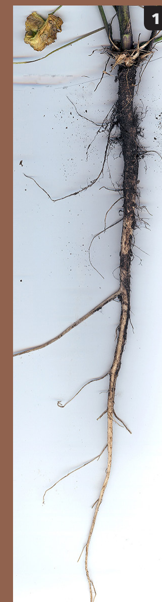
Despite being hidden, roots make up a large proportion of a plant's volume: generally 20–30 percent. Each species has an ideal balance of roots to shoots (or stems) that needs to be maintained to ensure the health of the plant. In order to obtain the necessary water and nutrients, plant species living in dry areas tend to have a higher root to shoot ratio than those native to wetter areas. A plant's roots grow continually to ensure a plant's success.

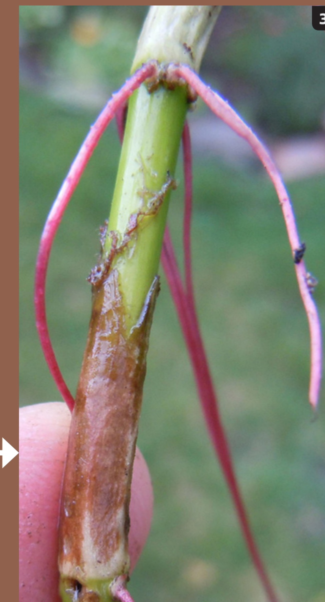
Plants obtain needed water, nutrients and minerals as a result of the root's ability to take in soil water and nutrients; once taken up, they enter the *vascular* system of the root and are transported up into the plant. The specialized cells in the roots and root hairs enable the easy passage of water from the soil into the plant. The root hairs do most of the work of water and nutrient absorption and the *root cap* (outermost cells of the *root tip*) protects the growing point or *meristem* and guides root direction in the soil.

A bit more info....

When a *seed* germinates, the first structure to appear is the new root—the *radicle* or *primary root*—which grows down into the soil. This *primary root* is the *tap root*. Branches from the primary root are called secondary or lateral roots and the branches from the secondary roots are called tertiary roots. This root system type is called a tap root system. In some plants (such as the *monocots*) the primary root ceases growth early and is replaced by numerous new *adventitious* lateral roots, all about equal in size, which then also can branch. This type of root system is called a *fibrous* (or adventitious) root system.

Two basic types of root systems

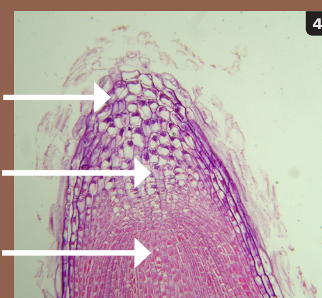


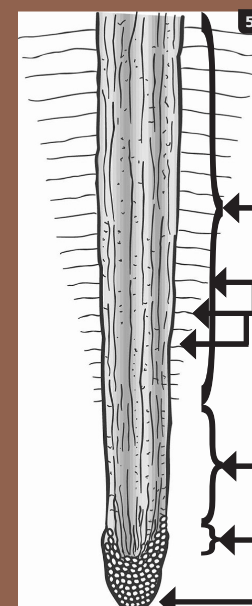


Fibrous roots

Tap roots

Adventitious roots—roots that are not part of the primary root system, sometimes found on stems or leaves





Three major zones or regions in a root:

- **the region of growth—the meristem: located at the root tip. Cell division (the generation of new cells) and growth occurs here, hidden under the root cap.**
- **the region of elongation: cells increase in size by water and nutrient absorption. As they increase in size, they push the root through the soil.**
- **the region of maturation: where cells differentiate to become specialized—epidermis, cortex, or vascular tissue—to perform specialized tasks.**

ABOUT DIFFERENT VARIETIES OF ROOTS

Plants have several additional types of roots that fulfill other necessary functions for some plant species—some of these being above-ground roots. Some of these root types are *adventitious*, that is, roots that originate from plant tissue other than root tissue, most often from stem tissue. Some of those different types are:

- *aerial, stilt* or *prop roots*—adventitious roots that initiate and develop on a trunk or branch and reach down to the soil or *substrate*, and function to prop and support or anchor a plant
- *contractile roots* (found on some *corms* and *bulbs*)—roots that shorten or shrink pulling the plant into the soil or substrate during seasonal stress
- *haustorial roots*—adventitious aerial roots of *parasitic* plants that intrude to obtain nutrients from a host plant
- *pneumatophores (knees)* and pencil roots—adventitious aerial roots that emerge above the water level of aquatic perennials to allow for the exchange of gases
- *propagative* or *nodal roots*—adventitious roots that develop from the *nodes* of *stolons* or runners (stem tissue) anchoring new growth that may initiate new plants
- *tuberous* or *storage root*—a modified portion of root that swells for nutrient or water storage; these include some taproots and tuberous roots (carrots, beets, sweet potatoes—but not yams, which are stems)

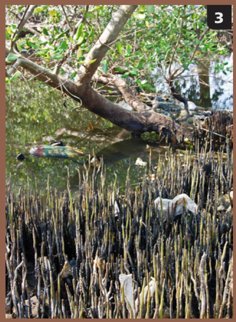
A bit more info....

Just as *monocotyledons* and *dicotyledons* differ in stem and leaf anatomy, they also differ in their root anatomy and structure. Structurally, monocots have fibrous root systems, whereas dicots tend to have a taproot (a larger, central root with smaller lateral roots branching from it). The internal anatomies of the monocot and dicot roots also differ slightly, yet they function similarly.

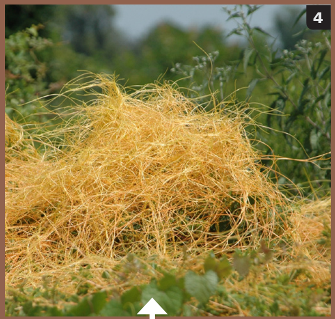
Root variation

Aerial or prop

Contractile



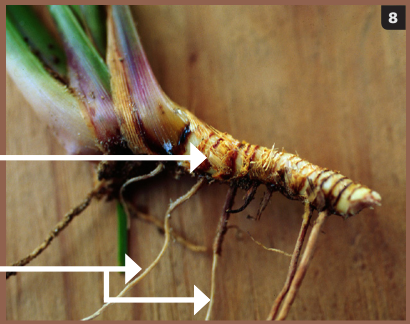
Pneumatophore or “knees”



Haustorial

Tuberous or storage

Roots have no stem nodes, so no potential for leaves as do plant stems and root-like stems (rhizomes, etc.).



Rhizome (stem tissue)

Roots

Botany Primer

LEAVES

Leaves, another plant organ, serve to make food for the plant in order to ensure survival. Knowing about leaf shape and size, arrangement, and pattern can assist in species identification.

ABOUT LEAVES

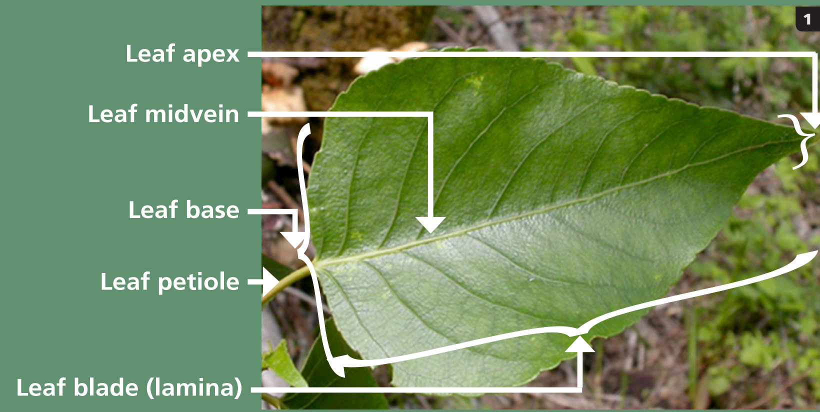
A leaf is another plant organ. Each leaf is attached to the plant stem at a stem *node*. Directly above the point of attachment of the leaf is a bud (an axillary or lateral bud)—the growing point for new leaves, flowers, and sprouts of a branch. A leaf consists of a *leaf blade* (*lamina*)—the expanded, usually flat and thin, portion that serves to support *photosynthesis*. Some plants do not have petioles—they are *sessile*—meaning the leaf blade seems directly attached to the stem or branch. The leaf *apex* is the leaf tip, and the *leaf base* is the bottom portion of the leaf where it is attached to the petiole or plant stem. In the "*axil*" of the leaf (the area on the stem or branch directly above the leaf *petiole*) is an axillary or lateral bud.

Nature's Notebook Nugget—Many leaves have a petiole—a stem that attaches the leaf blade to the stem or branch of the plant. When leaf buds begin breaking on a plant following a dormant period, the next phenophase an observer would watch for is "*leaves*". A leaf has unfolded once the leaf base or petiole can be seen.

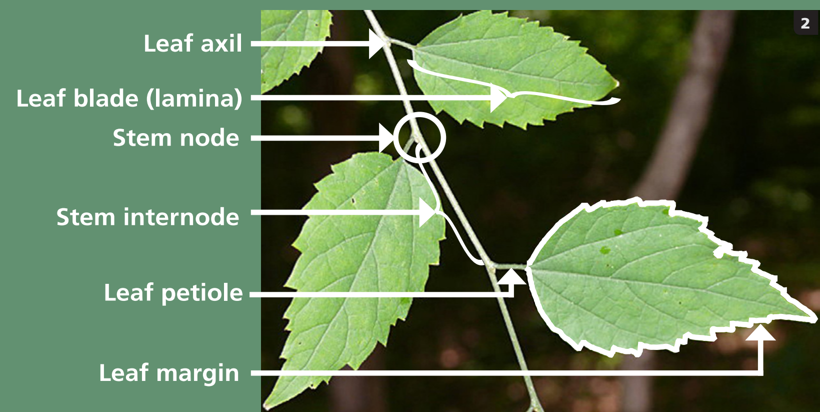
A bit more info....

You can always tell what direction is "up" for nearly all plants—including knotted up vines—because at a stem node the leaf attachment is always closer to the main stem and the base of the plant in relationship to its axillary bud; the bud is above the leaf and closer to the *terminal* growing end of the branch. Just a few plant species have hidden or sunken buds, in which case a closer look and some knowledge of the plant species will help.

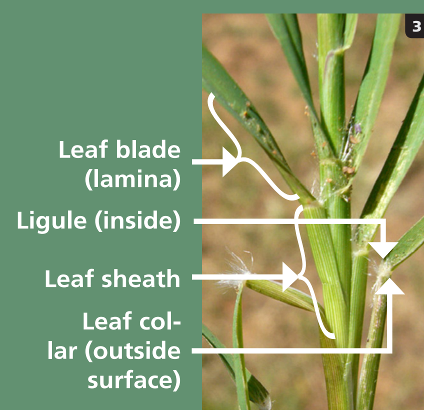
Dicot leaves



Dicot leaves



Grass leaves



Dicot leaves

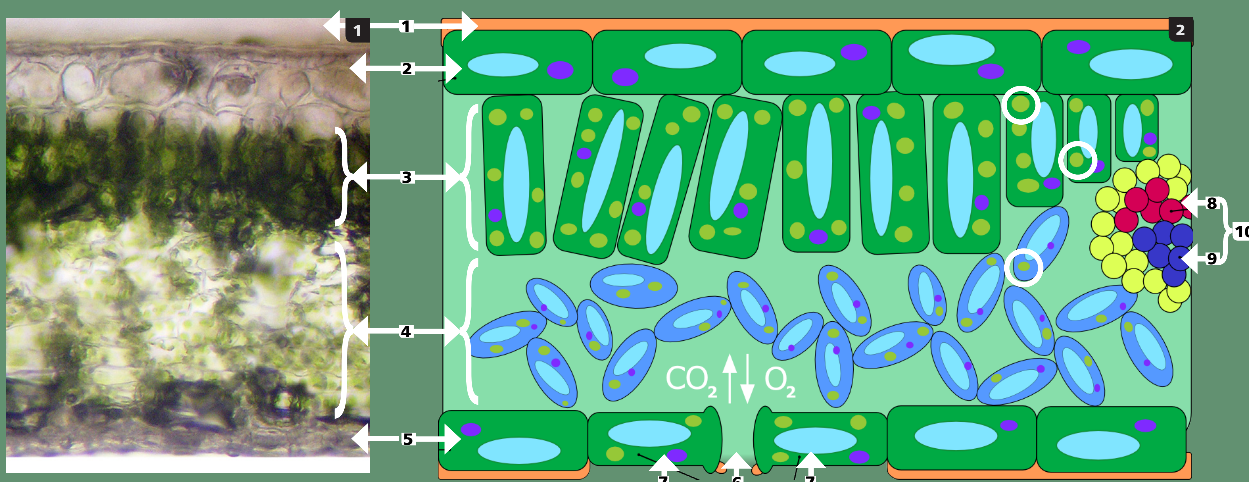
ABOUT A LEAF'S FUNCTION

A plant's leaf houses its 'food-making equipment'. These are the specialized cells and *cell organelles* that are necessary to collect light energy and to then use it to generate food (sugars) from water and carbon dioxide—a process called *photosynthesis*. This elaborate factory is constructed within the thin layers of cells under the upper *epidermis* or skin of a leaf (or needle). Although there are several different methods across the plant kingdom that accomplish this task, the general cell anatomy is similar. Photosynthesis occurs in cells having *chloroplasts*—the cell organelle that captures the light energy from the sun and then initiates the chemical processes within the cell that makes the plant's food. It is the fresh chlorophyll within the chloroplasts that colors the leaves green. New chlorophyll is constantly being manufactured to replace faded, deteriorating chlorophyll.

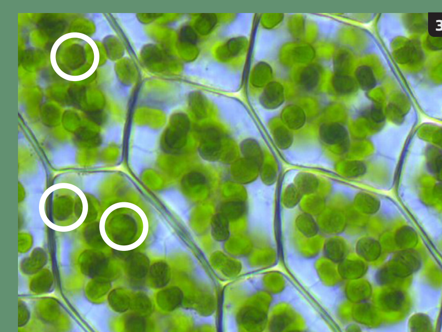
Each autumn, or when a deciduous plant experiences seasonal change or a stress response, the plant's leaves begin to separate from the plant (at a cellular *abscission* layer). The faded chlorophyll can no longer be replaced, at which point some of the leaf's other pigments are revealed—the glorious yellows and oranges and reds that we see in the fall, or the dull yellows on stressed plants.

A bit more info....

There is variation in how plants obtain food within the plant kingdom. Most plants photosynthesize to provide food for themselves (meaning they are *autotrophic*). There are some species that depend on other plants to feed them, and are *parasitic*; they don't have chlorophyll so do not have green coloration (*holoparasitic*). Examples of parasitic plant species that are wholly parasitic are some of the broomrapes (*Orobanche* spp.) and the dodders (*Cuscuta* spp.). There are other species that are green but are still parasitic, stealing water or nutrients, and yet still photosynthesizing (*hemiparasitic*). Examples of semi-parasitic plant species are the Indian paintbrushes (*Castilleja* spp.), some genera of mistletoes (*Phoradendron* spp. and *Arceuthobium* spp.), and the louseworts (*Pedicularis* spp.).



1. Cuticle (waxy layer) 2. Upper epidermis 3. Palisade parenchyma cells with lots of chloroplasts 4. Spongy parenchyma cells with some chloroplasts 5. Lower epidermis 6. Stoma for gas exchange (oxygen, carbon dioxide, etc.) 7. Guard cells for stoma (closes the opening when needed) 8. Xylem (carries water and minerals) 9. Phloem (carries photosynthates) 10. Vascular bundle or vein



The circles in these two images depict cell organelles with chlorophyll (chloroplasts). This is where sunlight is captured and processed with molecules of water and carbon dioxide to generate a plant's food (photosynthates or sugars).

USING PHYSICAL CHARACTERISTICS TO IDENTIFY PLANTS

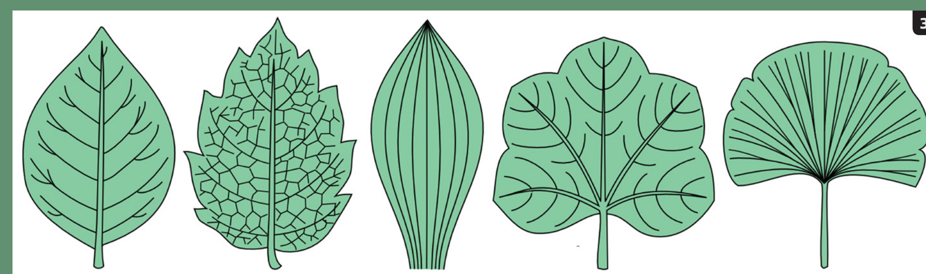
Each species has specific physical traits (*morphology*), that when carefully observed, will enable an observer to more easily identify a plant species correctly. These traits include those of its leaves, stem arrangement, type of flowers, flower arrangement, and type of fruit. An observer might start with a plant's leaves and ask:

❖ Does the leaf have a *petiole* or not (is it *sessile*)?
❖ What shape is the leaf? Round or oval or linear?
❖ What shape is the *leaf base*? Heart-shaped or square?
❖ What shape is the leaf *apex*? Sharply pointed? Does it have a sharp prickle?
❖ What kind of *leaf margin* does the leaf have? Toothed or double-toothed, wavy, or prickly?
❖ What sort of pattern do the veins have? Are they parallel or netted?
❖ And what about the leaf's "skin"—the *epidermis*. Is it hairy? Are the hairs stiff and rough or are they matted and so dense you can't see the surface of the leaf? Are the upper and lower epidermises similar? Or is one hairy and the other hairless?
❖ Does the leaf have *stipules* at the base of the leaf petiole? Are they leafy or are they thorns or spines?

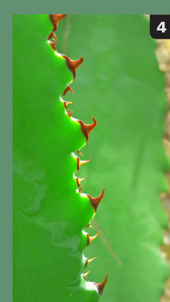
An observer would also want to check the plant to see if its leaves have more than one shape or texture. Some species have "*polymorphic*" leaves—leaves on the plant with more than one shape (characteristic for certain species, such as *Sassafrass* spp.). Other plant species have different shapes in different growing phases (*juvenile* growth vs. mature; *dormant* vs. actively growing). Still others may display size and texture differences within the individual plant canopy, based upon growth environment (*sun leaves* vs. *shade leaves*).

Leaf shape

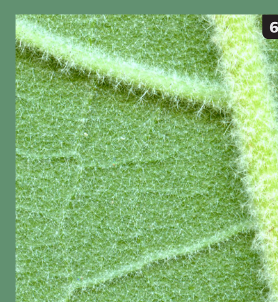
Leaf venation



Leaf margin



Leaf surface



Species polymorphism

ABOUT LEAF BLADE TYPE

There are many different basic leaf shapes, each species having a specific shape that supports its unique place in its ecosystem—although sometimes the differences may be subtle. Each species' unique leaf shape will help to narrow down the identification of its species.

A leaf can have a *simple leaf blade* or *compound blade*—meaning the *leaf blade* (*lamina*) is either one whole, undivided and continuous unit (simple) or is divided into two or more separate, arranged leaflets, each having separate blade tissue units (compound). The blade of a simple leaf can appear compound by lobed, incised or cleft margins. However, if the blade is continuous and is not divided into separate units at the midvein (see the oak leaf in image 5 below), it is still regarded as a simple leaf blade. The blade of a compound leaf has many smaller *leaflets*, *sessile* or stalked, attached and arranged in a pattern specific to a species.

You can generally determine what a "whole" leaf is for a plant—even when it is a compound and highly divided leaf—by looking for the *axillary* bud where the whole leaf is attached to the plant stem. Large compound leafs' leaflets do not have any axillary buds at the leaflet's point of attachment within the leaf blade area (refer back to the Stem and Buds section, beginning on page 20).

Simple leaves

Only the two leaves on the right side of this image are considered "compound". All others are "simple" leaf blades; there is joining leaf tissue between the lobes at the midvein.

Compound leaves

MORE ABOUT LEAF BLADES AND THEIR PATTERNS, FOR PLANT IDENTIFICATION

After determining whether the leaf has a *simple leaf blade* or a *compound leaf blade*, observe some of the other characteristics that will help with species' identification. The patterns of the leaf blade lobes or leaflet's attachment to its *petiole* or leaf stalk, and the leaf's veins, will help in identifying a plant species. There are several basic patterns that a leaf might have.

❖ Observe the arrangement of lobes or clefts within a simple leaf blade, or the arrangement of leaflets of a compound leaf blade. Does the silhouette of the lobes or leaflets mimic a feather—or do they radiate out from one central point? Simple or compound leaf blades include *pinnate* patterns (like the pinnae on a feather shaft) and *palmate* patterns (radiating from a central point like fingers on the palm of a hand).

❖ Also consider the patterns of a leaf blade's veins—its *venation*—the *vascular* system which carries food and water to other parts of the plant. The patterns can be pinnate, palmate, but also parallel or dichotomous. Some patterns are distinct for large plant groups, such as the grasses and other *monocotyledons*. They are mostly parallel veined—where veins are aligned parallel to each other along the length of the leaf. Other plant groups, generally *dicotyledons*, are net-veined in various patterns—pinnate or palmate. *Pinnately-veined* leaves have veins extending from the midrib vein to the edges of the leaf (the *leaf margin* area), whereas *palmately-veined* leaves fan out from a central point—typically where the leaf blade base meets the petiole.

❖ Consider how a leaf is attached to the plant stem; is it directly *opposite* another leaf at the stem node? Or does it *alternate* with the other leaves on the stem (look closely to make sure there isn't a leaf scar of a missing leaf at the same stem node before deciding)? Or are they *whorled* or *rosulate*? (Refer back to the Stems and Buds section, page 22 for further explanation of leaf arrangements).

Simple Leaves

Compound leaves

Simple leaves: pinnately or palmately lobed, cleft, parted or divided?

Palmately cleft

Pinnately cleft

Compound leaves: pinnately compound or palmately compound?

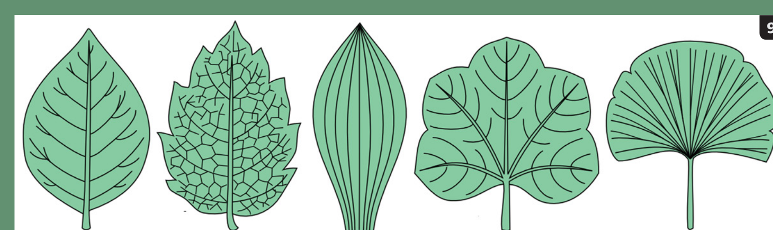
Pinnately compound

Bipinnately compound

Trifoliolate

Palmately compound

Basic leaf vein patterns



Pinnate Reticulate Parallel Palmate Dichotomous

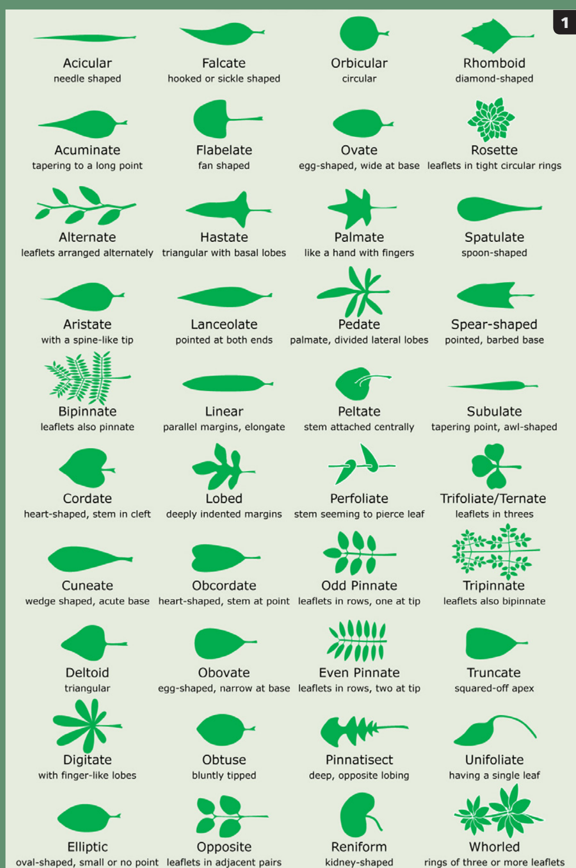
MORE (BASIC) LEAF MORPHOLOGY

There are many leaf characteristics to consider if you are trying to identify a plant species. These will include the *leaf blade*'s shape, the leaf's edges or *leaf margin* and the margin type—smooth or entire, toothed (sharp and, or double), wavy, scalloped, etc. Also observe the leaf's *apex* and *leaf base*, each having unique shapes.

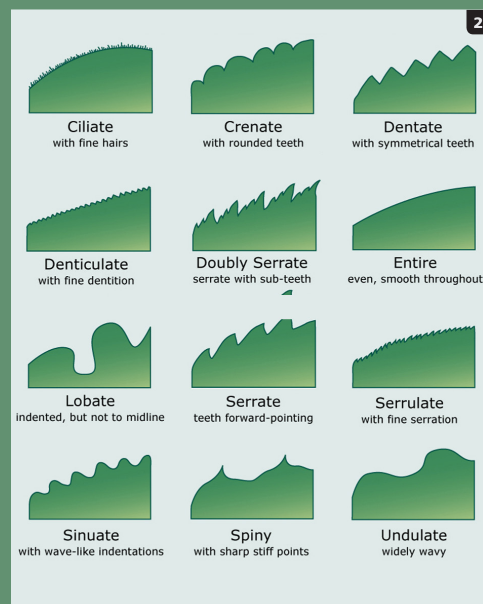
Notice the leaf surface. Does it have hairs? Not having hairs is also a distinct characteristic. If it has hairs, are they on both the upper and lower *epidermis*? And what kind of hairs are they? Soft and long? Short and sandpapery? Stiff and prickly? Tightly matted obscuring the surface? Are they star-shaped? Many branched? Sticky and glandular?

Each of these leaf characteristics combine to form a unique description, and is specific to a plant species. Many botanical books and internet sites will provide the correct botanical terminology to form a description of a leaf when identifying a plant species. It might be handy to have a botanical dictionary or internet site open when you start to describe your plant. The next page has more on dichotomous flora key, and an example for help in identifying a plant to a species level.

Leaf blade shape

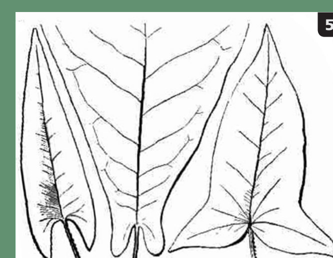


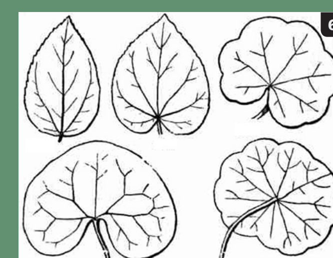
Leaf blade margin



Leaf hairs

Leaf bases





Leaf apices

DICHOTOMOUS FLORA IDENTIFICATION KEYS

Any flora key is designed to cover plants and their characteristics that are unique to a specific flora region. That region could be an area as small as a state park or a single canyon or gorge in a mountain range, or as large as a whole state, or a set of states that occur in a similar climatic region (such as the southeastern U.S.), or an entire continent or biome. Typically, at the start of the publication, it will state the region or have a map that identifies the region the flora key covers. In general, using a comprehensive key that covers the smallest region surrounding the location of the plant you are examining will help you to reach the correct answer most quickly. A key that covers an entire state, unless identified as including the entire state flora, may only include in its pages the most common or most showy plants. Erroneous identifications could be the result.

A dichotomous key asks or states either-or, true-false type questions or statements—with those questions or statements occurring in sets of two. Therefore, the key will typically number the first either-or set of questions or statements number 1—so that there will be two sentences that are numbered 1—with only one question or statement that fits the plant you are examining. (Some keys do not number the second statement or question, but the second statement will occur at the same indent level as the first question or statement of the set.) If the first question does not fit the plant you are examining, you would follow down the key to the second number 1, which should fit the plant you are examining. That is, if you are using a dichotomous key that fully covers the flora region where you observed or collected your plant. As you work your way down through the questions, by process of elimination of characteristics that don't match and by following those characteristics that do match, you should reach the name of the species of the plant you are examining.

Some flora publications start with a key that would help you identify the plant family of your plant, then once within the right family, would help you to identify the genus within the family. Finally, you use a third key that helps you to select the right species of your plant.

A very simple example of a dichotomous key:

1. Leaf blade simple
    2. Leaf margin entire
        3. Upper leaf surface tomentose
            4. Flowers have pink petals—Species one
            4. Flowers have yellow petals—Species two
        3. Upper leaf surface glaucous—Species three
    2. Leaf margin doubly serrate
        5. Flowers have pink petals—Species four
1. Leaf blade compound
    6. Leaflet margins entire
        7. Flowers have pink petals—Species five
        7. Flowers have yellow petals—Species six
    6. Leaflet margins serrate
        8. Flowers have yellow petals—Species seven

ABOUT VARIATION IN LEAVES, AND SPECIALIZED TYPES OF LEAVES

Variation not only occurs with leaf morphology, but also with function. Different leaf types often serve specific purposes for the plant. Some of the various types are *scale leaves* (as on *rhizomes*) and *cataphylls* (found on *winter buds*), seed leaves or *cotyledons*, spines (some, but not all, are generated from leaf tissue), *tendrils*, *storage leaves* (like the leaves in an onion bulb), *bracts* and *phyllaries* (leaf-like, often *involucral*, sometimes floral and showy as for poinsettia and dogwood), *stipules* and *pseudostipules* (often present at the *petiole* base of the leaf), and *trap leaves* (found on pitcher plants, sundews and flytrap plants).

Some species have different shaped leaves on the same plant at the same time, with others having them at alternate times. Those having two leaf types are called *dimorphic*. Some species have specialized seasonal leaves in two phases, such as Boston ivy (*Parthenocissus tricuspidata*) and black sage (*Salvia mellifera*) or have *juvenile* leaves while young and mature or adult leaves as the plant matures. Junipers are one kind of plant that often has awl-shaped juvenile leaves and scale-like adult leaves. There are species that have more than one adult leaf-shape—called *polymorphic*, such as sassafras (*Sassafras* sp.) and mulberry (*Morus* sp.).

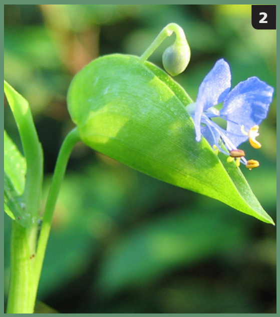
Often across a dense stand of trees or shrubs, or within the canopy of a plant, the leaves will differ in their mature sizes. This affects metabolism (sun exposure (solar irradiance) versus water loss (*transpiration*), with *sun leaves* being smaller and thicker and *shade leaves* being larger and thinner so that *photosynthetic* efficiency is achieved. The needles of *conifers* are specialized leaves, serving the same function as all leaves (photosynthesis and exchange of gases), but also having the ability to better cope with stressful environments.

Modified and specialized leaves and their functions:

- bracts, bracteoles, and phyllaries—can protect developing flowers or if showy, add to a floral display to attract pollinators
- scale leaves or cataphylls—often serve protective purposes, like protecting winter buds
- seed leaves or cotyledons—often feed the new growing seedling
- spines—often generated from leaf tissue and become protective, keeping herbivores at bay or, if dense, shade the plant in sun-rich regions
- stipules and pseudostipules—have a number of purposes especially if they become spines or glands, but also can be large and photosynthetic
- storage leaves—store resources to keep a dormant plant alive and feed or support initial growth when dormancy breaks
- tendrils—specialized thread-like leaves that hold onto other objects to support a vine
- trap or insectivorous leaves—attract and trap insects, digesting them for their nutrients

Juvenile vs. adult leaves

Bracts and phyllaries

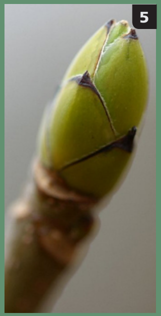


Leafy bracts surrounding flowers

Showy bracts surrounding many tiny flowers

Composite floral leafy bracts, called phyllaries

Cataphylls



Scale

Stipules

Tendril

Trap leaves

ABOUT CONIFER NEEDLES, SCALE- AND AWL-SHAPED LEAVES

Conifers (cone bearing plants) have modified leaves called "needles"—being needle-shaped, awl-shaped or scale-like. Their anatomy is generally the same as other leaves, although they are specialized and have adaptations that help protect them from desiccation and damage in stressful environments.

The leaves of pines, firs, larches, spruces, and the like are needles, with some being described as "linear" and flat. The leaves of junipers and cedars are scale-like or awl-shaped, depending on the species, although some juniper species have awl-shaped *juvenile leaves* with scale-shaped *mature leaves*. The scale-like leaves are attached two or three leaves per node (*opposite* or *whorled*) and tightly grasp the stem. The number per node is specific to a species.

Needles, depending on species, can be solitary, clustered together on *short shoots*, or bundled in *fascicles*. Fascicled needles are clustered tightly at the base with a small sheath surrounding the base—although that sheath can be *deciduous* in some species. The number of needles in each fascicle and the length of the needles are specific to the species, enabling species' identification; they can range from two to six or seven needles per fascicle, although in one species (*Pinus monophylla*) there is only one needle per fascicle.

Scale-like needles or leaves on juniper

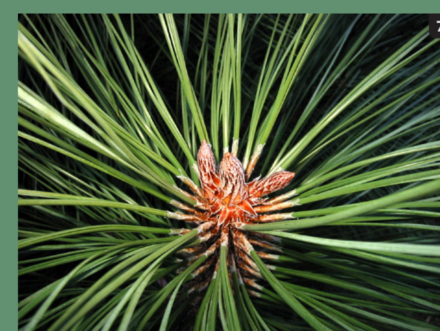
Single needles on fir

Clustered needles on larch

Awl-shaped needles on juniper

Bundled needles on pine

Needles in fascicles on pine



Botany Primer

FLOWERS AND INFLORESCENCES

Understanding what the flowers look like and the reproductive process of a plant, is helpful for identifying species, as well as knowing what to look for when making phenophase observations.

ABOUT FLOWERS

Angiosperms (the flowering plant group) have evolved to grow flowers—another plant organ. No matter how much we delight over their beauty, a flower's primary function is to enable reproduction, consequently ensuring the continuation of a species.

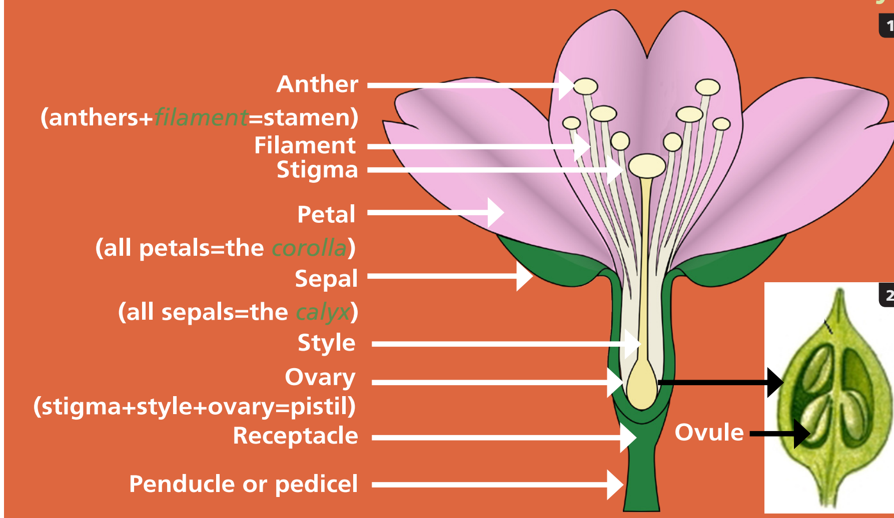
Each flower, single or in a cluster, is typically supported by a flower stem or stalk (called a *peduncle* if it is a solitary flower or supporting a cluster of flowers, and a *pedicel* for a single flower within the cluster) attached at a stem *node*. Most flowers have four *whorls* of flower parts: the *sepals*, *petals*, *stamens*, and *pistil*. These whorls are inserted into the *receptacle* atop the peduncle or pedicel. The outer whorl, the sepals, surround the petals—the showy parts of the flower. The petals help the flower "advertise" to pollinators its availability, that it is ready for visitation and *pollination*. It may offer rewards to a pollinator, such as nectar. The sepals and petals surround the stamens and pistils. The stamens are the male part of the flower; its *anthers* releasing pollen that is intended to be carried (via wind or insects) to a *stigma* and subsequently fertilize *ovules* (either in the same or other flowers) hidden inside the *ovaries*—generating new *seeds* with combined genes (sexual reproduction). The pistils are the female part of the flower containing one to many *carpels*. Each carpel contains a stigma, *style* and an ovary with ovules, and when several occur in one pistil, they are fused together. Ovules, when fertilized, are the developing seeds within the ovary. When the ovary matures, it becomes the *fruit*, surrounding and protecting the seeds. Each flower that has female reproductive capacity (functioning ovary and ovules) can produce at least one fruit having at least one seed. The number of fruits or seeds per flower is dependent on the characteristic traits of a species.

A bit more info....

In some flowers, the sepals and petals are nearly identical in color and size, as with lilies and tulips, and are referred to as *tepals*. Some species have additional floral structures called *bracts* below the four floral whorls. Bracts can be leaf-like or petal-like. For example, petal-like bracts occur in poinsettias and dogwoods. Also, ovary position within a flower can also differ between species, occurring above, below, or attached to flower parts.

Grass flowers differ quite a bit. The flowers are organized in a *spikelet*, which consists of two lower bracts called *glumes* positioned at the top of a pedicel. By their position, one is the lower glume and the other the upper glume. Above the glumes one or more tiny flowers or *florets* alternate. Each floret has a lower bract called a *lemma* and an upper bract called a *palea* enclosing three stamens and an ovary with two feathery stigmas. Depending on species, any of these parts can be reduced in size or missing, making what you are seeing confusing.

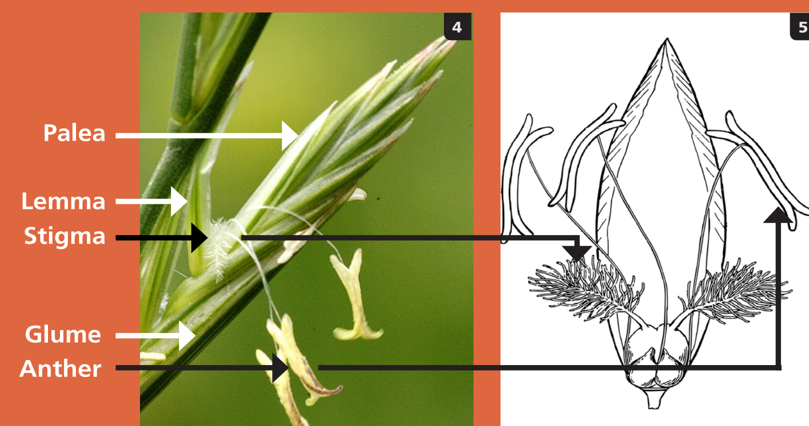
General floral anatomy



Basic grass spikelet and its flowers or florets

Grass spikelet

Grass floret



ABOUT BASIC FLOWER VARIATION

Flowers take on many forms, differing in the number of *petals* and *sepals* present or absent, and reproductive organs present or absent. In some flowers, one of the sexes may be absent—or present, but not functioning. The characteristics of a flower will help in the identification of a species—as each species has a unique floral structure. Flowers can be very tiny, others very large, some inconspicuous, others very showy. Some are grouped into showy clusters making it easier for their pollinators to find them. Some have wonderful fragrances. Some are so tightly clustered that the group appears to be just one flower (such as the sunflowers and daisies).

Depending on the plant group that a species belongs to, the flowers will follow a pattern common to their group. Remember the *dicots* and *monocots* (with leaf and stem differences)? For flowers, the dicotyledons mostly have four or five petals and four or five sepals, and multiples of four or five for their reproductive parts. The monocotyledons mostly have three petals and sepals, and multiples of three for their reproductive parts.

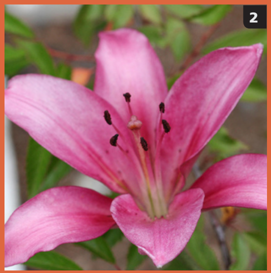
A bit more info....

A "*complete*" flower is one having all the normal floral parts (*sepals*, *petals*, *stamens*, and *pistils*). If missing any of these four parts or *whorls*, it is considered "*incomplete*". "*Perfect*" flowers are those having both male and female reproductive parts—stamens and pistils; "*imperfect*" flowers have either male or female reproductive parts—stamens or pistils. Keeping this vocabulary in mind, a flower can be both perfect and complete when it fits both definitions.

Considering only the sexual parts of the flower, if it has only female parts, or function, it is called a "*pistillate*" flower. Likewise, if it has only male parts, or function, it is called a "*staminate*" flower. Species having imperfect flowers, but having both *male flowers* and *female flowers* on one plant are called *monoecious*. Species having the male and female flowers located on separate plants are called *dioecious*. For dioecious species, a plant of the opposite sex typically will be growing nearby.

Complete, perfect, monocot flowers

Commelina cyanea



Lilium sp.

Complete, perfect, dicot flowers

Oenothera deltoides

Rosa rugosa

Single sex imperfect flowers

Inconspicuous types—very tiny with no petals

Male, has only stamens. *Salix viminalis*

Female, has only pistils. *Salix viminalis*

Showy types—with petals

Male, no ovaries—only stamens. *Cucurbita* sp.

Female, ovaries and has only pistils. *Cucurbita* sp.

ABOUT INFLORESCENCES OR CLUSTERED FLOWERS

Flowers can occur on a plant singly or grouped—in small to very large clusters. If the flowers are clustered into an arrangement it is called an *inflorescence*, each individual flower has its own reproductive parts. An inflorescence can make a fine display of flowers and advertising to attract its pollinators.

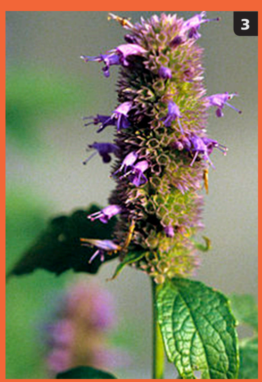
There are basic patterns for floral display and the underlying network of stems for inflorescences. Some simple arrangements are: *spike*, spadix, *raceme*, *umbel*, *panicle*, cyme, corymb, *catkin*, scorpioid, and *capitulum*. As with other plant morphology discussed so far, floral display is species-specific and can be used to help identify a species. And again, as seen with all other aspects of plants, the variation mixing the basic patterns is nearly endless. The photos below offer some common types you might find.

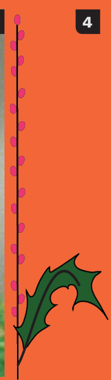
A bit more info....

A singular flower's stem is called a *peduncle*, although the vocabulary changes if the flower is clustered with numerous other flowers and organized into an inflorescence. In this case, the main stem that supports the whole inflorescence is called a peduncle and the main stem within the inflorescence is called the *rachis*. The smaller stalks that support each flower on the branches within the inflorescence are called *pedicels*. In the grasses and the like, the stem supporting the whole inflorescence is called the peduncle and the main stem within the inflorescence is called the rachis. The smaller stalks that support each spikelet are called pedicels, and further, within a grass spikelet the small stalk that supports each flower or floret is called a rachilla (refer back to the Flowers and Inflorescences section, beginning on page 42).

Some inflorescence types

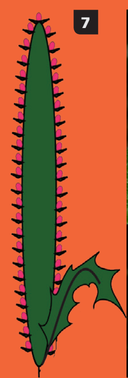
Panicle—flowers on many branches attched to one stem. *Aesculus flava*





Spike—single flowers attached directly to main stem. *Agastache foeniculum*

Spadix—a spike with a fleshy axis. *Arisaema triphyllum*



Raceme—single flowers with pedicels that alternate along a main stem. *Epilobium angustifolium*

Some grass inflorescences or flower heads

Panicle. *Sorghum halepense*

Digitate. *Eleusine indica*

Spike. *Hordeum murinum glaucum*

Spike-like panicle. *Phleum alpinum*

ABOUT INFLORESCENCES OR CLUSTERED FLOWERS (continued)

There are many variations to *inflorescence* structure. Take the umbel, for instance (see the photo on right); it is a cluster of flowers that are joined at a single point at the end of the *peduncle* or flower stalk. It can be a simple umbel or compound. A *spike* and a raceme can be combined to form a spicate raceme. Also, many *capitula* (*flower heads* having many small, tightly clustered flowers) can be grouped into a spike, a raceme, a panicle, or an umbel structure, and so on.

Another inflorescence type with small tightly-clustered flowers is the *catkin*. Tiny, inconspicuous, sometimes petal-less, flowers are tightly arranged into long spikes.

When using botanical books to identify a plant, keep these combination of structures in mind as they describe a plant's inflorescence. Grasses also have similar inflorescences, with a complex *spikelet* being the floral unit arranged upon the inflorescence's branches (refer back to the Flowers and Inflorescences section, beginning on page 42). The terminology for grasses is basically the same as for other inflorescence structures, with some exceptions, such as for the umbel-like inflorescence. For grasses, it is called "*digitate*" (having several spikes of spikelets joined, and radiating from the same point at the top of the *peduncle*).

Nature's Notebook Nugget—When an observer looks closely within a single inflorescence of a plant, they might discover that flowers are in varying phenological phases—in bud, beginning to open, fully open, with some initiating fruit. If making observations for "*flowers or flower buds*", if you see flower buds or flowers beginning to open or flowers fully open or any combination, the answer would be "yes". And following with the phenophase "*open flowers*" an observer would look for fully open flowers, where stamens or pistils are visible. If present, again, the answer would be "yes".

Additional inflorescence types

Umbel—flowers attached to the main stem at a single point

Helicoid cyme—single flowers on a coiled stem

Capitulum (or flower head)—many tiny flowers (several to hundreds) crowded onto a floral platform that is sometimes surrounded by leaf-like bracts

Corymb—flowers alternately attached to the main stem forming a flat top display

Catkin (or ament)—many tiny flowers crowded along a slim stem

ABOUT FEMALE CONIFER SEED CONES (gymnosperms)

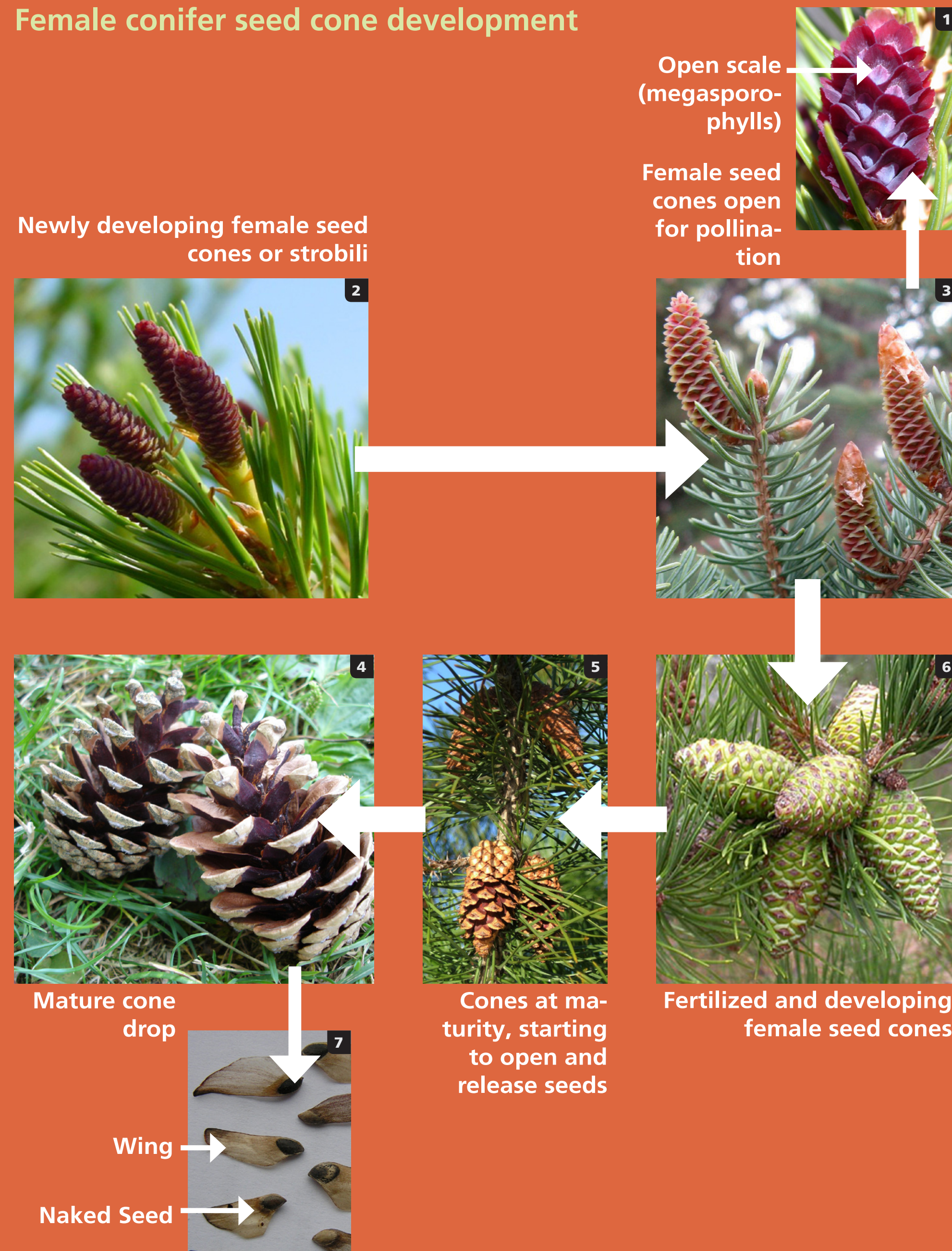
Gymnosperms (the term meaning "*naked seed*") do not have flowers and instead reproduce via uncovered *ovules* protected in a cone or other structure. *Female cones* (*seed cones*) contain ovules that, if *pollinated* and fertilized, become the *seeds*. In *conifers*, the seed cones typically initiate higher up in the tree than the male cones (*pollen cones*) and usually take several years to develop. Each cone (more correctly called a megasporangiate strobilus) is comprised of many *scales* (called *megasporophylls*) with each scale supporting two ovules (the scales sometimes woody, sometimes papery, when they mature). Each ovule has an opening (*micropyle*) that allows the entry of the male pollen which results in the transfer of the sperm that will fertilize the egg (refer to the Reproduction and Fruit section, beginning on page 50 for pollination and fertilization).

Fertilization in conifers follows a complex series of stages, and after pollination will take a year or more to occur. Once the pollen is in contact with the ovule's *nucellus*, a pollen tube grows to deliver sperm for fertilization, and then the seed can develop. A wing will also develop on the seed, to aid in its dispersal once it is mature and released from the

A bit more info....

Seed cone development can be a multi-year process for some conifer species; when it is, seed cones can be observed in several phases of development on the plant—some still to be pollinated and fertilized, while others going through the process of seed maturation.

Female conifer seed cone development



ABOUT MALE CONIFER POLLEN CONES (gymnosperms)

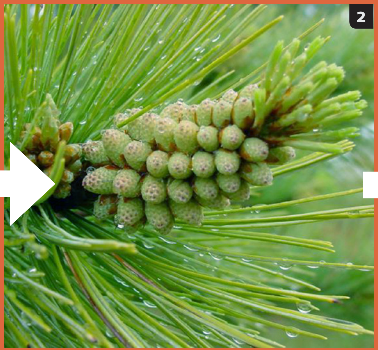
The *male cones* (*pollen cones*) are smaller than the *female cones* (*seed cones*) and contain the developing pollen. These cones are typically found clustered at the tips of lower, side branches. Each cone (more correctly called microsporangiate strobilus) is made up of many scales (called *microsporophylls*) with each *scale* supporting microsporangia in which the microspores are produced. The microspores divide and develop into a gametophyte (the pollen). During *pollination*, the pollen is transferred by wind to the female cones and their *ovules*. *Fertilization* of the ovules can now take place (refer to the Reproduction and Fruits section, beginning on page 50 for pollination and fertilization).

All gymnosperms are *wind-pollinated*, so the male pollen will be transferred to the female cone, and ovules, via the wind blowing through the plant. The architecture of the tree has evolved to enhance the dispersal of the pollen and its transfer to the female cones so that pollination can occur.

Nature's Notebook Nugget—Keep in mind that each species has its own peculiarities—cones have different shapes, sizes, colors, timing, position and orientation, and other subtleties, although for most gymnosperms there is a general progression through the different phases that this photo series highlights. The *Nature's Notebook* phenophases for conifer reproduction that observers would be tracking are: for the male cones—"*pollen cones*", "*open pollen cones*", and "*pollen release*"; for the female cones—"*unripe seed cones*", "*ripe seed cones*", and "*recent cone or seed drop*".

Male conifer pollen cone development

Pollen cones newly emerging



Developing pollen cones

Mature pollen cones

Pollen release occurs—cone opens, pollen grains become visible

Other male gymnosperm (pollen) strobili

Ginko male strobili

Taxus or yew male strobili

Juniper male strobili

Ephedra male strobili

Botany Primer

REPRODUCTION AND FRUITS

Fruits and seeds are the final stage in reproduction of a plant. The morphology of the fruit structure and the timing of fruit set are important tools for exploring the life cycle of the plant you wish to observe.

ABOUT POLLINATION AND FERTILIZATION

Pollination occurs when a flower or cone releases its mature *pollen* which is transported to the female *stigma* (of a flower) or *micropyle* of an *ovule* (in a cone)—so that sexual reproduction has the potential to occur.

Fertilization occurs when the sperm in the pollen and egg in the ovule unite to initiate a new propagule—a *seed*.

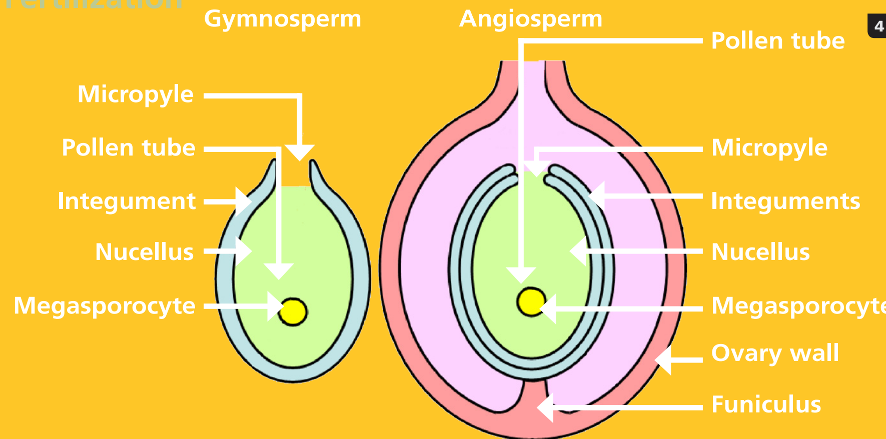
Once the pollen has been released from the male, it has to travel and hit its mark, that is, the stigma on a flower's *pistil*, or the opening of the *gymnosperm ovule*. Dispersal of released pollen can occur by wind, insect, animal, bird or water, depending on the plant species. Once a pollen grain lands on a stigma, it then needs to initiate and complete the process of fertilizing the recipient ovules. A pollen grain that has left one plant and has landed on the stigma of another plant is a process called cross-pollination. The flower's stigma (female part of the flower) contains a chemical which stimulates the growth of a *pollen tube* down through the *style* to the ovules inside the flower's *ovary*. Sperm carried within the pollen tube are released and fertilization then occurs.

Nature's Notebook Nugget—"*Pollen release*" is the phenophase in which the male *anthers* release pollen grains. When setting out to observe this stage, you might bring along a magnifier, or black paper to better see the released pollen grains, or if the plant is tall with the flowers up high, some binoculars for observation. Some plants can be barely touched to see pollen fly (as in the photo to the right), while others, need some mild disturbance with some black paper held below to see the released grains, or a closer look within the flowers and around the anthers with a magnifier. A few species release their pollen in packages—that are often designed to catch on the legs of a fly or bee to be transported. Some species self pollinate, keeping their flowers closed during the pollen release phenophase, Yet other species release their pollen, and by design, can fertilize their own open flowers.

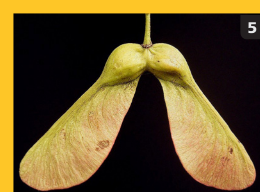
Pollen release

Pollen grains visable

Fertilization

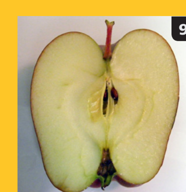


Seeds



Angiosperms—seed is surrounded by winged fruit parts

Gymnosperm—naked seed with attached wing



Angiosperms—seed(s) enclosed in fruit

FROM FLOWER BUD TO FRUIT SET

Each flower or cone which has functioning female reproductive parts (*stigma*, *style*, *ovules*) has the ability to set *seed* (*ovules*) and, in the case of an angiosperm species, develop its *fruit* (*ovary*), if *fertilized* following successful *pollination*. Pollination initiates a process that, if completed, ends with the ovules being fertilized. If fertilization occurs, the recombination of genes (sexual regeneration) occurs—so that the new *seed*(s) has a new mix of genes. *Fruit* and, or seed initiation is not always visible depending on the plant species you are observing, as the ovary (future fruit) or ovules (future seeds) might be hidden within plant or flower parts. It is important to note that not all ovaries become fertilized and thus not all flowers turn into fruits. And sometimes fruit development is aborted so not all immature fruit become ripe.

Nature's Notebook Nugget—Getting to know the details and intricacies of the plant species you wish to observe is very helpful for collecting quality observations on your species, so that you can identify the cues, sometimes very subtle, for fruit or seed set and the "*fruits*" phenophase.

A bit more info….

There are some plant species that have the ability to set seed and produce fruit without self or cross fertilization through reproductive variation. This is called *apomixis*. This type of reproduction is not sexual and the seeds will have the same genetic makeup as the mother plant (*asexual*). Nonetheless, you will still be able to observe fruit set and fruit development no matter the genetic makeup of the seeds. Fruit development looks the same no matter how seed development was initiated (refer back to the Introduction section, beginning on page 15 for a brief discussion of apomixis).

1 "*Flower bud*"

2 "*Flower bud*"

3 Fully "*open flower*"

4 "*Open flower*" and "*pollen release*"

5 "*Pollen release*" completed (anthers dried); stigma and style still "fresh" and potentially active - may still be accepting pollen

6 "*Fruit*"—a fruit set of fertilized ovary; stigma, and other flower parts dried and ready to fall off

ABOUT FRUITS AND FRUIT TYPES

Forget how you typically envision a household *fruit*. Using botanical terminology, a fruit is the container for the plant's seeds: a fruit can be what we commonly refer to as a "fruit" or a "vegetable" or a "nut". *Angiosperms* (flowering plants) always have their seeds surrounded by an *ovary*, which matures into the fruit parts: fleshy or dry or hard or shell-like (like a sunflower hull), sometimes spiky—the variation is endless and sometimes surprising. Take, for instance, a strawberry. The true fruit of the strawberry is actually what most people call its *seeds*. They are tiny, seed-like fruits having the even smaller seeds protected inside, and what we commonly call the fruit of the strawberry, or the red, fleshy part, was a part of the flower called the *receptacle*. And that red fleshy part is why that species has survived so well. It serves to ensure distribution of the mature seeds, because animals and humans love to eat it; then the fruits—and thus, its seeds—get spread into diverse places to perpetuate the species.

Nature's Notebook Nugget—Fruits can be classified as *simple fruits*, *aggregate fruits*, *accessory fruits*, or *multiple fruits*. Simple fruits develop from a single *pistil*, having one *carpel* or ovary or several fused ovaries: cherries, tomatoes, apples. Aggregate fruits develop from a single flower, but having many separate pistils: raspberry, blackberry. Accessory fruits also develop from a single flower having many separate pistils, but in addition, part of the flower structure develops into part of the fruit: strawberries (accessory and aggregate fruits are often grouped by some definitions). Multiple fruits develop from very tight clusters of many flowers each having its own pistil or ovary and borne on a single structure: pineapple, fig, Osage orange, mulberry. The many types of fruit will fit into one of these structural categories. See the photos below which cover the many types of fruits. *Nature's Notebook* includes descriptions of each species' fruit within the "*fruits*" and "*ripe fruits*" phenophase definitions to help you know what to look for.

Fleshy fruit types

Pepo

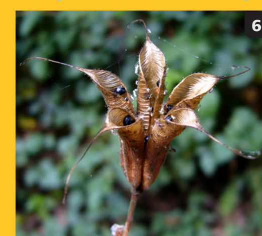
Berry

Drupe

Hesperidium

Pome

Capsule and capsule-like



Capsule

Silique

Grain

Caryopsis

Nut

Nut

Pod

Legume

Loment

Follicle

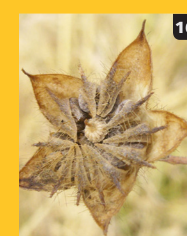
Seed-like and joined "seeds"

Samara

Achene

Utricle

Segmented



Schizocarp

ABOUT FRUITS, THEIR SEEDS AND SEED DISPERSAL

Each fruit (*angiosperm*) or cone (*gymnosperm*) is specially designed to enhance dispersal of the ripe *seeds* of a species—and without dispersal of the seeds, the perpetuation of a species could fail. Finding new places to germinate and grow allows a species to try new places that might be amenable, especially if their surrounding environment is changing and becoming inhospitable.

Again, the variation is superb and amazing. *Fruits* and cones that protect the seeds also ensure the seeds have a good chance of getting to a good spot for germination. Fruits might have fluffy, feathery attachments or papery wings to catch the breeze, or explosive walls to send them far from the mother plant (and less competition). Some have sweet juicy or fleshy coverings so they get eaten and sent through a digestive track and then planted with natural fertilizer. They might have seeds with oily or fatty sacs attached (*arils*) that appeal to ants which like to eat the energy rich, fatty sac. Or perhaps float so that they can sail away with the currents. Some have tiny hooks or barbs that act like Velcro™, and stick to the fur of a passing animal or a hiker's boot, then get carried to a new location. Or tails that react to humidity and, with help from the hairs on the fruit, drill the enclosed seed into the soil. Others have cones that only open after a fire or extreme heat, giving them open ground with little competition to have better success getting established. All are adapted to get themselves to new ground.

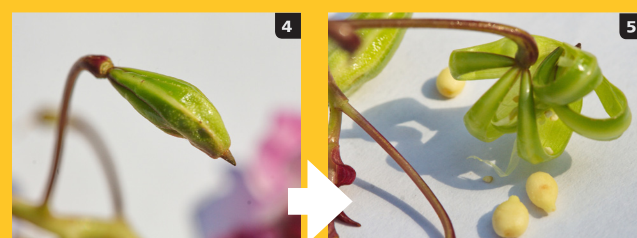
Nature's Notebook Nugget—Nearly all fruits start out green or yellow green or white and often mature through a series of colors, or phases, until they reach a state of ripeness. This might be signaled by a specific color, or level of dryness, or splitting or exploding open, or dropping from the plant. Each species displays a particular signal when the seeds are ready for dispersal. In the case of fleshy or juicy fruits, a color change often helps fruit eaters know when it is good to eat. So, getting to know a species will help observers know when they are seeing "*ripe fruits*" and report on them in *Nature's Notebook.*

Fruit dispersal types

Wind

Wind

Wind



Mechanical, explosive seed pod

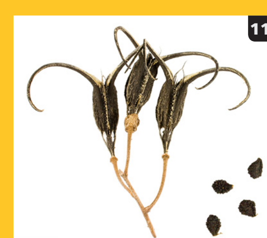
Mechanical

Multiple methods

Gravity, animals or humans

Gravity, animals or humans

Animals or humans



Animals or humans

Animals or humans

Animals or humans

Animals

QUIZ

Congratulations on completing the *Botany Primer!* In this section you will find questions for review of the information covered in the *Primer*. Use this quiz as a guide to test your knowledge and see if you need further review for understanding. This may be helpful before going out into the field.

INTRODUCTION

1. A plant species' anatomy and physiology are fine-tuned to its _____________ ___________ .

a.	habitat specifications	b.	ecological niche
c.	soil needs	d.	leaf shape

2. Plant organs play two roles in a healthy plant. ________________ functions support water and gas intake and release, and food production. _____________ functions enable plants to produce offspring.

a.	Reproductive	b.	Vegetative

3. True or false: Species survival depends on its ability to adapt to a particular biome or climatic zone.

4. A seed contains:

a.	A new embryonic plant	b.	Protection
c.	Nourishment for the plant	d.	All of the above

5. Match the name with the definition:

a.	Annual	1. Plant whose life cycle lasts three or more years
b.	Biennial	2. Plant which completes its life cycle in two years or seasons
c.	Perennial	3. Plant which germinates and dies in the same year

6. Another name for asexual reproduction is _________________ _________________.

7. The USA-NPN sponsors a _____________ Plants Project because _____________ respond to environmental predictability in the same way, regardless of where they are located. Plants that can be observed via this program include _____________ ____________ and __________ ____________ .

STEM AND BUDS

1. Stem tissue supports the plant's leaves, buds and the ________________ system.

2. A plant's branches, leaves, flowers, and buds can be attached to a stem in four types of arrangements. Which one is not one of those types?

a.	Lateral	b.	Rosulate
c.	Alternate	d.	Opposite
e.	Whorled		

3. True or false: Bud scales are found on all species of plants, no matter which climate the species is located. They always remain on the plant.

4. Another name for a leaf stem is a ____________.

a.	apex	b.	lenticel
c.	stipule	d.	petiole

5. True or false: There is a great deal of variation in plant species and individual plants, therefore you must observe your selected individuals of species for some time before you may be confident in making quality observations.

ROOTS

1. Roots make up ____________ % of a plants volume.

a.	5%	b.	65%
c.	75-80%	d.	20-30%

2. When a seed first germinates, the ____________ or primary root is the first to appear. It is also called the tap root.

3. Monocots have ______________ root systems.

a.	fibrous	b.	tap

LEAVES

1. Above the point of attachment of a leaf is a _________ , the growing point for new leaves, flowers, and sprouts of a branch.

2. A leaf is considered unfolded when the leaf base or ____________ can be seen. Some plants do not have these because they are ________ , or the leaf blade seems to be directly attached to the stem or branch.

a. apex, laminate
b. saprophytic, sessile
c. chloroplastic, parasitic
d. petiole, sessile

3. Leaf cells collect light energy and then use it to generate food from _________ and _________ __________, a process called photosynthesis.

a. water, carbon dioxide
b. sugar, strong sunlight
c. minerals, pure oxygen
d. sunlight, carbon dioxide

4. Deciduous leaves change color in the fall, or when under stress, because faded _________ can no longer be replaced, revealing the leaf's other pigments.

5. The physical traits of a species, or _______________ , enables an observer to more easily identify a plants species correctly.

a. shapes
b. characteristics
c. morphology
d. polymorphism

6. True or false: Axillary buds are present where the whole leaf is attached to the plant stem. This distinguishes between compound and simple leaves.

7. A ________________ key asks true and false questions, or provides statements, about the species to assist in identification.

a. field
b. dichotomous
c. plant
d. species

8. The modified "leaves" of conifers are called ___________ . They can appear solitary or clustered into fascicles, depending upon the species.

FLOWERS AND INFLORESCENCES

1. Angiosperms are another name for ___________ ___________. The plant's ___________ are primarily tasked with reproduction and continuation of a species.

2. Some species of plants have _________ which are additional floral structures which serve in a variety of functions, depending on the species. They are often confused with the flower itself.

a. ovules
b. fruit
c. carpels
d. bracts

3. Which plant group, dicotyledons or monocotyledons, has mostly four or five petals, four or five sepals, and for or five for their reproductive parts?

4. Match the terms with the definitions:

a. Complete flower	1. Have all floral parts (sepals, petals, stamen, and pistils)
b. Perfect flower	2. Have only male or female reproductive parts
c. Imperfect flowers	3. Have both male and female reproductive parts (stamens and pistils)

5. Species with imperfect flowers, with only male or only female flowers on one plant, are ______________ . Species that have imperfect flowers with male or female flowers occurring on the same plant are ____________.

6. Clusters of flowers can occur on a plant, each with individual flowers with their own reproductive parts. This type of display is called a(n) _________________ and serve to attract its pollinators.

a. capitulum
b. catkin
c. peduncle
d. inflorescence

7. _________________ do not have flowers, rather they reproduce via uncovered ovules in a cone or similar structure. They include the conifers, and have a complex, often multi-year, reproductive process.

8. Pollination is the process whereby a flower or cone releases its mature pollen and it is transported to the female stigma. Dispersal of the pollen can occur by ________ , ________ , _________ , _________ , or ________ depending on the plant species.

REPRODUCTION AND FRUITS

1. Pollination is the process whereby a flower or cone releases its mature _______________ and it is transported to the female ____________ (of a flower) or a ______________ of an __________ in a cone so that sexual reproduction has the potential to occur.

Place the words in the correct order in the sentence above:

micropyle, pollen, ovule, stigma

2. List three ways (out of five total) pollination can occur.

3. True or false: Fruit and, or seed initiation is always visible on the plant species you are observing.

ANSWER KEY

Introduction: 1.) Ecological niche; 2.) Vegetative, Reproductive; 3.) True; 4.) d. All of the above; 5.) a-3, b-2, c-1; 6.) Vegetative propagation; 7.) Cloned, cloned, cloned lilac, cloned dogwood.

Stems and Buds: 1.) Vascular; 2.) Lateral; 3.) False. They are generally only found on species in cooler climate and serve to protect the tender bud. The scales fall off after the buds break open; 4.) d. Petiole; 5.) True.

Roots: 1.) d. 20-30%; 2.) radicle; 3.) a. Fibrous.

Leaves: 1.) bud; 2.) d. petiole, sessile; 3.) a. water, carbon dioxide; 4.) chlorophyll; 5.) c. morphology; 6.) True; 7.) b. dichotomous; 8.) needles

Flowers and Inflorescences: 1.) flowering plants, flowers; 2.) d. bracts; 3.) dicotyledons; 4.) a-1, b-3, c-2; 5.) dioecious, monoecious; 6.) d. inflorescence; 7.) Gymnosperms; 8.) wind, insect, bird, animal, or water.

Reproduction and Fruits: 1.) Pollen, stigma, micropyle, ovule; 2.) wind, insect, animal, bird, water; 3.) False. Fruit and, or seed initiation is not always visible. It depends on where the ovaries are located within the plant structure.

IN CLOSING...

The natural world is diverse, beautiful, and full of wonder. Keen observers of nature often have a deeper understanding of cyclic changes unfolding around them, and view everyday nature in a different light. Being able to accurately track and record observed changes in plants and the activity of animals contributes to a rich information resource for anyone interested studying changes in seasonal activity over time. We hope this introductory guide to Botany for *Nature's Notebook* helps observers feel more confident as they begin to participate in the world of phenology monitoring for research and decision-making.

REFERENCES AND FURTHER READING

Bell, Adrian D. *Plant Form: An Illustrated Guide to Flowering Plant Morphology.* Portland: Timber Press, Inc., 2008. Print.

Bold, Harold C., Constantine J. Alexopaulos, and Theodore Delevoryas. *Morphology of Plants and Fungi.* Harper & Row, Publishers, New York. 1987. Print.

Elpel, Thomas J. *Botany in a Day APG; The Patterns Method of Plant Identification.* Pony: HOPS Press, LLC, 2013. Print.

Harris, James G., and Melinda Woolf Harris. *Plant Identification Terminology: An Illustrated Glossary.* Spring Lake: Spring Lake Publishing, 2001. Print.

Ingrouille, Martin. *Diversity and Evolution of Land Plants.* Chapman & Hall, 2-6 Boundary Row, London. 1992. Print.

Raven, Peter H., Evert, Ray F., and Susan E. Eichhorn. *Biology of Plants.* New York: Worth Publishers, 2009. Print.

CONTRIBUTIONS AND ACKNOWLEDGEMENTS

Patty Guertin and LoriAnne Barnett defined the structure and content of the *Botany Primer.* Patty Guertin, Botanist for the USA National Phenology Network, developed the written and photographic content. Careful review and editorial suggestions were provided by Ellen Denny throughout development. Graphic design was conceptualized by Terry Moody and implemented by Sara Schaffer. Theresa Crimmins, Kathy Gerst, Erin Posthumus, Alyssa Rosemartin and Sara Schaffer provided additional editorial suggestions.

Dorothy Tompkins, (Virginia Master Gardener and Master Naturalist) and Tanya Quist, (Assistant Professor of Practice, School of Plant Sciences at the University of Arizona—Director of the University of Arizona Campus Arboretum) served as external reviewers for the *Primer*.

We gratefully acknowledge our citizen and professional scientists and volunteer leaders who participate in the *Nature's Notebook* phenology monitoring program. Their active contributions and support create a framework for the broader understanding of how our planet's species are responding to environmental change.

GLOSSARY OF TERMS

Throughout this document, you have read over terms in *italicized green text*. These terms will be defined in more detail in this section. Some terms included in this glossary were not directly mentioned in the text, but will give you greater understanding and insight into the field of botany. Additional terms are defined and can be found online at www.usanpn.org/glossary.

A

abscission	The process by which a plant sheds one of its parts,, such as leaves, flowers, and, or fruits, following the development of separation tissue
accessory fruit	A fruit that has developed from a single flower having many separate pistils, but in addition, part of the flower structure develops into part of the fruit. Such is the case with a strawberry, in which several pistils developed into tiny achenes (see achene) imbedded on the surface of the flower's expanded and succulent receptacle (what we think of as "seeds" of the strawberry are, in reality, individual fruits)
achene (fruit type)	A dry, indeshiscent, one-seeded fruit that has developed from one flower having a single ovary, and the ovary wall becomes rigid at maturity (such as a sunflower "seed"—which is a fruit)
active transport	Active transport uses the plant's energy to accomplish the transport of molecules, unlike passive transport (such as osmosis) which does not use energy
adventitious (buds, roots)	Refers to structures or organs developing in a place or position where it is not normally expected, such as a root or bud that arises along a stem internode
aerial root	A root that exists and functions only above the soil or substrate or water surface (wholly above ground)
aggregate fruit	A fruit that has developed from a single flower having many separate pistils. Such is the case when the pistils develop into a tight cluster of fleshy drupelets (see drupe) on the surface of the flower's receptacle (such as a raspberry or blackberry)
alternate arrangement	Leaves and branches that are not opposite to each other on the stem or axis, but occur singly at each node
angiosperm	A seed plant species that produces flowers—in which the ovules are contained within an ovary; the ovary maturing to a fruit containing the seeds (fertilized and matured ovules)
annual plant	A plant species that completes its life cycle (germination of a seed, flowering, reproduction, and senescence) within a duration of one year
anthers	The expanded part of the stamen (the male flower parts) that contains the pollen. The mature anthers will open to release the pollen
apex (see apical or terminal)	Refers to the top or tip of a structure, organ, such as a leaf or stem (and the point farthest from the point of attachment)
apical (see apex or terminal)	Refers to the top or tip of a structure, organ, such as a leaf or stem (and the point farthest from the point of attachment)
apomixis	As it pertains to agamospermy; reproduction (seed production) without fertilization
aquatic	Refers to plant species that grow in water: whose seeds germinate in water or in the bottom soil of bodies of water, usually with submersed or floating leaves
aril	An appendage growing attached to a seed, either growing at or near the hilum of a seed, or a fleshy thickening of the seed coat
asexual reproduction	Propagation of plants by means other than fertilization (sexual); natural methods (apomixis, bulbils or cormels or offsets and other clones, layering) or human-induced (cuttings, layering, division of clumps,

and tissue cultures)

autotrophic — Refers to organisms that are capable of producing their own nutritive substances—processing inorganic materials into organic ones (feed themselves) by using energy from outside the organism such as with photosynthesis (sunshine on chlorophyll)

axil (at a stem node) — The point of the angle formed between a leaf or branch where it is joined to a stem (axis)

axillary (see lateral) — As pertains to stems: situated in or arising in an axil. A side shoot or bud; typically situated in the axil at a stem node—lateral buds are typically axillary

B

berry (fruit type) — A fleshy or pulpy, several-seeded fruit that has developed from one flower having a single ovary divided into several carpels, and is fleshy or pulply throughout without a tough rind (such as a tomato)

biennial plant — A plant species that completes its life cycle (germination of a seed, flowering, reproduction, and senescence) within a duration of two years or seasons, with the second season typically devoted to reproduction (flowering and fruiting)

biomass — The total mass of all living organisms in a given area, but in this instance pertaining to the total plant mass produced, vegetative and reproductive

biome — A very large regional community, or major ecosystem, of the earth which is distinguished by its climate, fauna and flora—such as grass savanna, desert, temperate forest, or the Arctic tundra

bipinnately compound leaf — Twice pinnate; a leaf blade divided into leaflets and having twice-diverged branching

bract — A modified leaf that can appear leaf-like or petal-like: such as a reduced leaf, that subtends a flower or inflorescence, or sometimes occurs along a stem. Or, on occasion, bracts are highly colored and surrounding tiny flowers, such as with poinsetta, bougainvillea, and dogwood

bracteole — A small bract or secondary bract, such as one occurring upon the pedicel of a flower

broadleaf (or broad-leafed) — Refers to a plant or plant species which does not have needles or grass-like leaves, but generally leaves with expanded leaf blades

bud scale (see cataphyll) — A small, modified leaf or bract that covers and surrrounds, and protects, buds

bud scale scar — The scar left by a bud's protective bud scale

bulb — A short underground stem having fleshy scales or leaves (storage leaves) that surround a bud or meristematic region, such as an onion

bulbel — A small bulb that arises from the base of a larger bulb, generated by asexual reproduction

bulblet (or bulbil, bulbet) — A small bulb or bulb-shaped body, borne above ground typically upon the stem in a leaf axil, generated by asexual reproduction

bundle scar — Tiny, somewhat circular dots within a leaf scar, caused by separation or breaking of the fibrovascular bundles passing through a leaf petiole into the leaf blade. Left once a leaf drops off from the stem of a plant

C

calyx — The outer whorl of the flower's perianth and the collective terminology for all of the sepals of a flower; typically green and which often protects the flower bud

cambium (vascular, cork) — A layer of meristematic plant tissue (lateral meristems) of many woody seed-bearing plants, producing new xylem towards the inside of a plant (stem, root) and new phloem to the outside of a plant (stem, root). The vascular cambium forms tissues, xylem and phloem,

	that carry water and nutrients throughout the plant. Addition of the new tissue causes the diameter to increase. The cork cambium creates cells that eventually become bark on the outside and cells that add to the cortex on the inside.
canopy composition	The tree species that comprise a forest canopy
capitulum (or capitula)(flower head)	A tightly clustered inflorescence of unstalked flowers, sometimes flat (like daisies or dandelions) or globular (like buttonbush)
capsule (fruit type)	A dry, dehiscent fruit that has developed from one flower having a single ovary divided into several carpels—often fused, and splitting open along a seam of the carpel or opening at pores at maturity
carpel	The simplest unit within a pistil (ovary, style, stigma). A simple pistil has one carpel (ovary, style, stigma) or a compound pistil has multiple carpels (each having an ovary, stigma, style—joined in various ways)
caryopsis (fruit type)	A grain, such as for grasses; a dry, indeshiscent fruit that has developed from one flower having a single ovary, where the seed coat is fused to the ovary wall
cataphyll (see scale leaf)	A small, modified leaf or bract that can surround vegetative or floral meristems (buds and growing points), or occur on a rhizome; commonly providing protection
catkin	An inflorescence of very densely clustered flowers in a spike-like form, often hanging down, and often having flowers of just one sex.
cell organelle	A membrane-bound body found within a cell's cytoplasm that performs specific cellular functions
chilling requirement	The minimum period of cold weather needed, after which a fruit-bearing tree will blossom. It is often expressed in hours
chloroplast	The organelle within the cell which contains chlorophyll, and is necessary for photosynthesis to occur.
chromosome	An organized structure of DNA, protein, and RNA found in cells. It is a single piece of coiled DNA containing many genes
cladode (or cladophyll)	A flattened, leaf-like stem or branch which functions like a leaf
clone (or clonal)	A group of individual plants all originating by vegetative propagation (asexual) from a single plant, and therefore genetically identical to it and to one another
cloned plant	A plant that has originated by vegetative propagation (asexual) from another plant, and therefore is genetically identical to it
coleoptile	In monocotyledons, the first leaf following the cotyledon, which forms a protective sheath around the plumule or stem tip
complete flower	A flower having all the whorls of principal parts: sepals, petals, stamens and pistils
compound blade (compare: simple leaf)	A leaf blade that is divided into separate leaflets
conifer (or coniferous)	A plant species that does not flower and instead bears cones (or strobili)
contractile root	A root that can shorten itself, pulling the plant deeper into the soil. They typically have a wrinkled surface that serves for expanding and contracting
corm	A short, solid, underground stem having thin, papery leaves that surround a bud or meristematic region
cormel	A small corm that arises from the base of a larger corm, generated by asexual reproduction
corolla	The inner whorl of the flower's perianth and the collective terminology for all of the petals of a flower; typically colored, petals separated or joined (connate), and commonly advertising a flower's sexual readiness
cortex	In roots and stems, the tissue between the stele (primary vascular structure and tissues) and the epidermis
cotyledon	Seed leaf; embryonic leaf; the first leaf or one of the first pair of leaves to develop in a seed plant. Cotyledons, when they emerge with the seedling shoot, do

not look the same as the plant's "true leaves," which develop after germination

culm — The hollow or pithy stem which bears inflorescences or flower heads, found in grasses, sedges, and rushes

cuticle — The waxy, waterproof layer on the surface (and covering the epidermal cell layer) of plant leaves and stems

D

deciduous — Plant parts falling off, and not persistent (such as plant leaves from a non-evergreen plant)

dehiscent — Opening at maturity or ripeness, to discharge contents (such as pollen, seeds or spores)

dermal — Refers to the epidermis

dicotyledon (or dicot) — A flowering plant species whose seedling have two cotyledons, or seed leaves. Typically the seed leaves have a different shape than the "true" leaves, which are the typical shape for the plant species

diffusion — The intermingling of molecules of a fluid due to random motion

digitate — Finger-like; lobed or veined and radiating from a common point, or divided with the units arising from a common point

dimorphic — Having two forms or distinct morphological variants, such as when a plant species has two forms of leaves or two forms of fruit

dioecious — Refers to a plant or plant species with imperfect flowers (unisexual), having male and female flowers occurring on separate plants

dormant (or dormancy) — A temporary, inactive phase when growth and development stop, but potentially will become active following a seasonal or environmental stimulus

drupe (or drupelet) (fruit type) — A fleshy or pulpy, one-seeded fruit that has developed from one flower having a single ovary, and the seed has a hard or stony endocarp (the pit) (such as cherries, peaches, plums). A drupelet is a very small drupe

E

epicotyl — The embryonic stem of a seedling above the cotyledons and below the first true leaves

epidermis — The "skin" or outermost layer of cells of a non-woody plant organ (stem, leaves, roots)

epigynous (see inferior) — A flower's ovary position when located below the attachment of the sepal, petal, and stamen whorls

epiphyte (or epiphytic) — A plant or plant species which grows upon another plant, but does not draw water or nutrients from that plant

evergreen — A plant or plant species that retains green leaves or needles throughout the year; is not deciduous

F

fascicle — A tight bundle or cluster

female cone (see seed cone) — A female cone (megasporangiate strobili) of a conifer supports and protects the ovules (future seeds) of the plant

female flower (see pistillate) — A pistillate flower, with or without a perianth, that has only functioning female reproductive parts, or if male reproductive parts (stamens) are present, they are non-functioning

fertilization — The union of male and female gametes, following pollination in seed plants

fibrous root system (compare: tap root) — A root system with no prominent central axis, branches spread in all directions and all branches of similar thickness (such as in grasses and other monocot plants) *filament* — The stalk of the stamen (the male flower parts) that supports the anthers.

floret — A small, individual flower, usually one in a dense cluster—such as in a grass spikelet or in a flower head of the Asteraceae family (daisies, dandelions, thistles, sunflowers)

flower head — An inflorescence of tightly clustered florets or flowers, such as a capitulum (daisies, dandelions, thistles, sunflowers), or or a grass inflorescence (containing many grass spikelets)

follicle (fruit type) — A dry, dehiscent, many seeded fruit that has developed from one flower having a single-celled ovary, and splits open along one seam at maturity (such as milkweed)

forest stature — The stage of growth of a forest or woodland; e.g., old growth (primary) and second or third growth (regrowth after disturbance or cutting)

fruit — The mature, ripened ovary of a seed plant, and the structures that are attached, accompany and ripen with the ovary

functioning anther (male) — An anther within the stamen that produce, mature, and release pollen (versus a non-functioning organ; in some plant species the flowers might typically house non-functioning, sterile male parts)

functioning ovary (female) — An ovary within the pistil that produces seeds (versus a non-functioning organ; in some plant species the flowers might typically house non-functioning, sterile female parts)

fundamental tissue (see ground tissue) — The ground tissue of plants contains three main cell types called parenchyma, collenchyma, and sclerenchyma. These cells types primarily support storage, mechanical support, but can also serve for food production in the photosynthetic cells, or serve in wound healing and regeneration, depending on which class of cells they belong to

G

gland (or glandular) — A protuberance, appendage, or other structure that secrets substances, sticky or oily

grafting — Where the tissues of one plant are aligned with the tissues of another to create a joined plant; they will grow together if properly processed

grass-like — Plants or plant species that have similarities to the grasses (long, thin leaves; inconspicuous, non-showy flowers grouped into inflorescences and seed heads that are also non-showy; small grain-like fruits) although their anatomy may differ

ground tissue (see fundamental tissue) — The ground tissue of plants contains three main cell types called parenchyma, collenchyma, and sclerenchyma. These cells types primarily support storage, mechanical support, but can also serve for food production in the photosynthetic cells, or serve in wound healing and regeneration, depending on which class of cells they belong to

gymnosperm — A seed plant that does not flower—in which the ovules are not contained within an ovary, and are "naked"; the ovary maturing to a seed protected by a surrounding cone or fleshy appendages

H

haustorial root (haustorium (singular); haustoria (plural)) — A specialized, modified root of parasitic plants that penetrates into a host plant and functions to acquire necessary nutrients from the host plant they attached themselves to

hemiparasitic — A plant species that is parasitic but also partially photosynthetic, thus acquiring nutrients from the host plant but also making and supplying some of their own nutrients *herbaceous* — Refers to a plant or plant species having little or no woody tissue; but also refers to a perennial plant which dies back to its roots each year during winter, and resprouts and grows when the environmental conditions are acceptable

hesperidium (fruit type) — A berry-like fruit, with pulpy sections inside, having a tough or leathery rind outside (such as citrus fruits)

hilum — A scar on a seed indicating its point of attachment to the ovary

hip (fruit type) — A berry-like fruit that has developed from one flower having many ovaries—consisting of an enlarged and globose hypanthium that surrounds and encloses many achenes (such as with roses)

holoparasitic — A plant that is completely parasitic on other plants with virtually no chlorophyll

hypogynous (see superior) — A flower's ovary position when located above the attachment of the sepal, petal, and stamen whorls

I

imperfect flower — A flower having only one set of sexual organs (unisexual), either stamens or pistils (male or female)

incomplete flower — A flower lacking one or more whorls of principal parts: sepals, petals, stamens or pistils

indehiscent — Remaining closed upon maturity and ripening

inferior (see epigynous) — A flower's ovary position when located below the attachment of the sepal, petal, and stamen whorls

inflorescence — The flowering part of a plant; a group or cluster of flowers arranged on an axis or stem that is composed of a main stalk, and often having a complex arrangement of branches

infructescence — A group or cluster of fruits arranged on an axis or stem that is composed of a main stalk, and often having a complex arrangement of branches. An infructescence is a result of an inflorescence of flowers successfully maturing to fruit

insectivorous — insect-eating—by way of trapping and digesting them for nutrients

internode — The portion of a stem between two nodes

involucral — (involucre) referring to tissue or a structure that surrounds and, or supports a cluster of flowers, such as the layers of phyllaries that surround a flower head in the daisy family (*Asteraceae*)

involucre — A whorl of bracts subtending a flower or flower cluster, such as for sunflowers

J

juvenile — Refers to an immature phase

L

lamina (see leaf blade) — The expanded, leafy portion of a leaf or frond, which can be one entire unbroken leaf (simple) or a highly dissected and divided leaf (compound)

larva — The newly hatched, earliest stage of any of various animals that undergo metamorphosis, differing markedly in form and appearance from the adult. Caterpillars are the larval form or larvae of butterflies and moths

lateral (see also axillary) — As pertains to stems: borne along a side. A side shoot or bud; typically situated in the axil at a stem node—lateral buds are typically axillary

layering — A method of propagating a plant in which its stem is induced to send out roots by surrounding a section of it with soil while still attached to a parent plant; natural layering can occur when the stem makes contact with the soil and spontaneous rooting occurs (such as when young trees are pushed over by snow, rock, or soil slides)

leaf base The basal portion of the leaf blade. Each plant species has specific characteristics for the leaf base that can help with identification

leaf blade (see lamina) The expanded, leafy portion of a leaf or frond, which can be one entire unbroken leaf (simple) or a highly dissected and divided leaf (compound). Each plant species has specific characteristics for the leaf blade that can help with identification

leaf collar The area on the outside of a grass leaf where the leaf blade meets the leaf sheath. Each grass species has specific characteristics for the leaf collar that can help with identification

leaf margin The edge of the leaf blade or lamina. Each plant species has specific characteristics for the leaf margin that can help with identification

leaf scar An imprint or scar left on stem tissue at the separation or breaking off of the leaf petiole from the plant stem or branch. Left once a leaf drops off from the stem of a plant

leaf sheath (as pertains to grasses) The leaf base that surrounds the grass stem or culm and is attached to the upper leaf blade or lamina. Each grass species has specific characteristics for the leaf sheath that can help with identification

legume (fruit type) A dry, several-seeded fruit that has developed from one flower having a single-celled ovary, and splits open along two seams at maturity (such as peas, beans); often a long pod. Mostly dehiscent, but some species being slowly-dehiscent, with a few species' fruits being indehiscent

lemma In grasses, the lower bract which, with the palea (upper bract), encloses a flower's or floret's reproductive organs. Each grass species has specific characteristics for the lemma that can help with identification

lenticel A slightly raised, often lens-shaped area on a stem surface that allows exchange of gases

ligule A tongue or strap-shaped organ; in grasses and some sedges, an appendage that arises from the inner surface of a grass leaf where the blade or lamina meets the leaf sheath, thus it is inside of where the collar region is located on the leaf. Each grass species has specific characteristics for the ligule that can help with identification

loment (fruit type) A dehiscent legume, several-seeded fruit that has developed from one flower, which narrows or constricts and is jointed between its seeds, drying and splitting apart at maturity into one-seeded segments, each having two seams

M

male cone (see pollen cone) A male cone (microsporangiate strobili) of a conifer that supports and protects the pollen of the plant

male flower (see staminate) A staminate flower, with or without a perianth, that has only functioning male reproductive parts, or if female reproductive parts (pistils) are present, they are non-functioning

mature (as pertains to leaves for some plant species) An phase in some plant species where leaves or needles take on a different shape (morphology) as the perennial plant ages. These species have "dimorphic" leaves. Some junipers fit into this category, as do some broadleaf species (*Hedera helix* (English ivy), *Ficus pumila* (creeping fig))

megasporophyll (as pertaining to gymnosperms) A bract or modified leaf tissue that supports the megasporangium or developing ovule (in the case of gymnosperms—such as the bract of a pinecone or seedcone)

meristem (or meristematic tissue) Undifferentiated cells in actively dividing plant tissue, found in the zones where growth takes place—such as at the tips of shoots and roots (apical), in buds and nodes of stems (apical), along grass leaves and stems

	(intercalary), in cambium (vascular and cork), and in a layer of cells in roots (pericycle)
micropyle	A minute opening on the ovule through which the pollen tube usually enters
microsporophyll (as pertaining to gymnosperms)	A bract or modified leaf tissue that supports the microsporangium or developing pollen (in the case of gymnosperms—the tiny bract in pollen cone)
midrib	The central or principal rib of a leaf
midvein	The central or principal vein of a leaf
monocarpic	A plant species that flowers and produces fruit just once and then dies (its typical life cycle); can be applied to annuals, biennials, and perennials
monocotyledon (or monocot)	A plant species that has a single seed leaf (cotyledon)
monoecious	Refers to a plant or species that has separate male or staminate and female or pistillate flowers (imperfect flowers (unisexual)) that occur on the same plant
morphology	The study of an organism's form and structure
multiple fruit (or syncarp, see synconium)	A fruit that has developed from more than one flower, in which the flowers are tightly clustered, and mature into a tight cluster of individual fruits (such as mulberry, pineapple, fig, osage orange). This differs from an aggregate fruit which derives from a single flower. (Fig is a rather unusual inflorescence and fruit.)

N

naked bud	A bud which lacks bud scales, with hairy, sticky, or no protective covering. Naked buds occur in two types of plants, those with naked winter buds and those with naked or uncovered resting buds of warmer climates
negative data	The record of not seeing an animal of study or observing that a phenophase is not occurring. Negative data is just as important as sightings of animals observing phenophase occurrence
niche (habitat)	The specific part or segment of a habitat, or relational position in an ecosystem, occupied by an organism
nodal root (or propagative root)	An adventitious root that arises from a node, such as the node of a stolon or runner that will anchor new growth and initiate new plants
node (or stem node, or leaf node)	The location on a plant stem where buds (leaves, flowers, stem branches) initiate
non-vascular	Refers to plants or plant species having no vascular tissues or vessels to carry water or nutrients, etc., such as mosses, fungi, algae
nucellus	Tissue within an ovule in which the embryo sac develops
nut and nutlet (fruit type)	A dry, indeshiscent, one-seeded fruit that has developed from one flower having a single ovary, and the ovary wall becomes tough and hard at maturity. A nutlet is the same but very small

O

offset	A short, prostrate shoot arising from the base of a plant
opportunistic (pertaining to plants in climatically variable landscapes)	Plants or plant species that display an opportunistic response to environmental variations in resource availability, such as species that leaf out when water is available and drop their leaves when stressed—repeatedly, or flowering unpredictably a second time later in the season when water is available during the warm months
opposite arrangement (pertaining to leaf arrangement)	Leaves and branches arranged along a twig or shoot in pairs, opposite each other at a single point (stem node) along a stem or axis
osmosis	The spotaneous diffusion of liquid through a semipermeable membrane (such as a cell wall) in a direction that will equalize solute concentrations on both sides of the membrane. Describes the physical process in

which any solvent moves, without input of energy. This is the process by which water is drawn from the soil up into the tissues of a plant and transported, and moved in and out of cells (compare with active transport)

ovary — The part of the flower that develops into a fruit

ovary position — Describes the position of the ovary in a flower relative to the whorls of the perianth (calyx or sepals and corolla or petals). A superior ovary describes an ovary that sits above where the perianth is attached to the floral structure; an inferior ovary describes an ovary that sits below the point of attachment of the perianth and stamens—and are attached at the top of the ovary, with the exposed style and stigma; a perigynous ovary describes an ovary that is surrounded by floral parts (a calyx tube) that is attached to the perianth and stamens around the ovary, but not attached—making the ovary appear more or less half exposed

ovule — The haploid body which, after fertilization, becomes a seed or propagule

P

palea — In grasses, the upper bract which, with the lemma (lower bract), encloses a flower's or floret's reproductive organs. Each grass species has specific characteristics for the palea that can help with identification

palmate — Leaflets, lobes, or veins that arise from a common point

palmately compound leaf — A leaf which is divided into smaller leaflets, those leaflets originating from a single point of attachment, similar to the fingers on a hand

palmately-veined (or palmate venation) — A leaf blade having the principal veins radiate out from a single point, most commonly where the leafstalk or petiole ends, and diverge out toward the edge of the leaf

parasite (or parasitic) — A non-mutual relationship in which one organism depends on another for its nutrients, or other services, and benefits at the expense of the other (its host)

pedicel — A flower stalk of a single flower, or grass spikelet, within an inflorescence; the stem supporting the entire inflorescence is called a peduncle

peduncle — A primary flower stalk, supporting a solitary flower or an entire cluster of flowers (inflorescence)

pepo (fruit type) — A fleshy, several-seeded fruit that has developed from one flower having a single ovary divided into several carpels, which develops a firm or tough rind as it matures (such as a melon, squash, cucumber)

perennial plant — A plant or plant species whose life cycle lasts for three or more years

perfect flower — Describes a flower having both pistil and stamens—female and male reproductive organs; bisexual

perianth — Collectively, the calyx (all sepals) and corolla (all petals), or if similar in appearance the tepals, of a flower

pericarp — The fruit wall which has developed from the mature ovary wall

perigynous — A flower's ovary position with the sepal, petal, and stamen whorls attached to a surrounding cup

petal — A modified leaf in the whorl of flower parts that surround the whorls of the reproductive parts (stamens and the pistil). Typically they are colored and showy so as to attract and guide their pollinators. Collectively, all of the petals are called the corolla

petiole — The stalk of a leaf, that attaches a leaf blade to the plant stem

phenological phase (pertaining to plant species) — A vegetative or reproductive phase in a plant's life cycle, such as the opening of leaf buds or the release of pollen from flowers

phenology — Phenology refers to key seasonal changes in plants and animals from year to year—especially their timing and relationship with weather and climate

phloem The food or sugar conducting tissue in vascular plants, distributing the photosynthetic products within the plant

photosynthesis The manufacturing of food or sugar in plants, some algae and cyanobacteria—by converting light energy to chemical energy and storing it in the bonds of sugar. Carbohydrates are synthesized from carbon dioxide and water, with oxygen released as a by-product

phyllary An individual bract under a flower head of a plant, within the involucre, such as occurs especially in, but not exclusively, the Asteraceae plant family—in daisies, dandelions, sunflowers, thistles, asters, etc.

pinnate Having two rows of branches, lobes, leaflets, or veins arranged on either side of a common axis. The word "pinnate" means "like a feather", which might help you to visualize its structure or architecture

pinnately compound leaf A leaf which is divided into smaller leaflets, those leaflets arranged on each side of the leaf's central stalk or rachis (axis). A pinnate leaf can either be even-pinnate or odd-pinnate, indicating whether or not a terminal leaflet exists: even-pinnate leaves have pairs of leaflets attached along the leaf's central stalk or rachis (axis) with no terminal leaflet, although may occasionally have a tendril (therefore an even number of leaflets in total); odd-pinnate leaves have a terminal leaflet at the end of the leaf's central stalk or rachis (axis) along with pair(s) of leaflets attached along the leaf's rachis (therefore and odd number of leaflets in total). A bipinnately compound leaf is twice pinnate; a leaf blade divided into leaflets and having twice-diverged branching

pinnately-veined (or pinnate venation) A leaf blade having conspicuous lateral veins which diverge from the midvein towards the leaf margin and are approximately parallel to one another

pistil The female reproductive part of a flower made up of the ovary, style (stalk) and stigma (sticky tip that receives pollen)

pistillate Refers to a female flower, with or without a perianth, that has only functioning female reproductive parts, or if male reproductive parts (stamens) are present, they are non-functioning

pith The spongy, central tissue in some twigs, stems, and roots

plantlet A small plant, usually one produced vegetatively (asexually), from a parent plant

pneumatophore A specialized, erect root (aerial) in certain aquatic plants that protrudes above the soil or water surface and has many lenticels, which supports gas (oxygen, etc.) exchange

pollen A mass of microspores in a seed plant, usually appearing as a fine dust. Pollen grains are transported (typically by wind, water, insects or animals) from a stamen to a pistil, where fertilization occurs

pollen cone (or male cone) The conical, pollen-bearing unit of a conifer (male strobilus)

pollen tube The slender tube that grows from pollen grain and holds the sperm, penetrates and delivers the sperm to the ovule

pollination The release and transfer of pollen from the anther of the flower to a stigma of a flower, sometimes within one plant (self-pollination) or from one plant's anthers to the stigma of a different plant (cross-pollination)

polymorphic Having more than two forms or distinct morphological variants, such as when a plant species has three forms of leaves—as with *Sassafras*

pome (fruit type) A fleshy or pulpy, several-seeded fruit that has developed from one flower having a single ovary divided into several carpels surrounded by a hypanthium or receptacle from flower parts which then becomes fleshy or pulpy as it matures (such as an apple). (see ovary position—perigynous—for further information) *primary root (see radicle)* — The portion of the plant embryo in a seed below the cotyledons that will develop into the primary root

prop root (also stilt root) — An adventitious root that arises from a stem that provides support for a plant (aerial)

propagative root (also nodal root) — An adventitious root that arises from a node, such as the node of a stolon or runner that will anchor new growth and initiate new plants

propagule — Any unit or structure having the capacity to generate a new plant, whether through sexual (such as with seeds) or asexual (vegetative) reproduction. This includes seeds, spores, and any part of the vegetative body capable of independent growth if detached from the parent plant

pseudostipule (see stipule) — An often-modified, basal pair of leaflets of a compound leaf appearing very close to the plant stem, close to where stipules might occur

R

rachilla — The axis (stalk) within a grass or sedge spikelet. Further, the stalk of a grass spikelet is called a pedicel; the primary axis of the entire grass inflorescence is called a rachis

rachis — The main stalk or axis of a flower cluster (inflorescence) or seed head (grass inflorescence), or the main leaf stalk within a compound leaf

radicle (see primary root) — In a seed, the portion of the embryo below the cotyledons that will form the roots

rank, ranking (leaf ranking) — A vertical row along an axis such as a plant stem, as with leaves. When you sight along the length of a branch stem, from the tip end, if it appears there are two rows of leaves, either opposite or alternate, the branch is two-ranked; if three rows, it is three-ranked, etc.

receptacle — The more or less thickened portion at the top of a flower stalk (peduncle or pedicel) to which the floral organs or clustered florets (in the case of daisies, etc. (Asteraceae family)) are attached. For those familiar with artichokes, the artichoke heart is the flower's receptacle

reticulate (as it pertains to venation) — Veins are branched repeatedly, forming a net-like pattern

rhizome — A horizontal, modified, underground root-like stem of a plant, often having adventitious roots and shoots from its (stem) nodes and having scales subtending the buds or shoots at its nodes or scale scars, and is typically thick, fleshy or woody

root cap — A thimble-like covering which protects the growing root tip (meristematic region) on plant roots

root tip — The end region of a root, including the root cap, where many phases of cell development are taking place, from the meristematic regions where cell division is occurring to the zone of elongation and zone of maturation, where cells are differentiating into different tissues and the root is developing root hairs

rosette (see rosulate) — A dense, radiating cluster of overlapping leaves (or plant organs) at or near ground level

rosulate (see rosette) — Refers to leaves arranged into a basal rosette, with a very short or lacking stem

S

samara (fruit type) — A dry, indeshiscent fruit that has developed from one flower having a single ovary divided into one-seeded carpels, each having a wing at maturity

saprophyte (or saprophitic) — A plant, lacking chlorophyll, that lives on dead, organic debris. Certain fungi or bacteria also fit in this classification

scale — In conifers—within a cone, the structures arising from the cone axis that support the ovules are often called scales (strictly, they are sporophylls)

scale leaf	A modified or rudimentary leaf, such as those protecting buds; in the case of conifer cones, a sporophyll (a modified leaf) is often referred to as a scale—onto which the reproductive parts are positioned
schizocarp (fruit type)	A dry, several-seeded fruit that has developed from one flower having a single ovary divided into several fused carpels, and splits into one-seeded, indehiscent segments (between carpels) when mature
secondary growth	As occurs in dicot plants and gymnosperms. The thickening or expansion of a woody plant axis (added girth) through the activity of lateral meristems (the vascular cambium in stems); the end result is increased amounts of vascular tissue, such as added tree rings
seed	The ripened ovule—a small embryonic plant enclosed in a protective covering called the seed coat, usually with some stored food
seed cone (see female cone)	The conical, seed-bearing unit of a conifer (female strobilus)
seed head	An inflorescence of clustered florets or flowers, as in grass spikelets arranged in various larger displays
semi-evergreen	A plant that loses all of the leaves in winter only if it is cold enough
seminal root	A primary root
senescence	The process of biological aging in a plant or plant part (such as a leaf) from full maturity to deterioration and death
sepal	A modified leaf in the outermost whorl of flower parts that surround the whorl of petals. When the flower is in bud, they cover the flower and then open first. Typically they are colored green, but occasionally are similar to the petals (and then called tepals). Collectively, all of the sepals are called the calyx
sessile	Attached directly, without a stalk, such as a leaf without a petiole or leaf stalk
short shoot or spur	A stubby branchlet (short, slow-growing) with densely crowded leaves, nodes, and leaf scars, and potentially, flowers and fruit. (Fruiting spur: a short twisted branch which flowers and produces fruit)
silique and silicle (fruit type)	A dry, dehiscent, elongated fruit, typically more than twice as long as wide, formed from one flower having a single ovary divided into two carpels, separated by a partition (septum) that bears the ovule or seeds; generally, the carpels separate when ripe, although a few separate between seeds along joints (plants of the mustard family). (A silicle is a short silique, no more than twice as long as broad)
simple fruit	A fruit that has developed from one flower with a single pistil having one carpel or ovary or several fused carpels or ovaries
simple leaf (compare: compound leaf)	A leaf with an undivided lamina or blade
spikelet (pertaining to grasses)	The basic form of grass and sedge flower clusters; where one or many small flowers or florets attached to an axis are subtended by two bracts (glumes)
spore	The reproductive cell in cryptogams (plants and plant-like organisms that lack flowers and do not reproduce by seeds) which in function corresponds to a seed but is haploid (has half a set of chromosomes)—unlike a seed that is a product of sexual reproduction and has a full set of chromosomes
spur or short shoot	A short shoot (short, slow-growing) having densely crowded leaves, nodes, leaf scars, and potentially flowers and fruit
stamen	The male reproductive part of a flower made up of a filament (stalk) and anthers (contain pollen)
staminate	Refers to a male flower, with or without a perianth, that has only functioning male reproductive parts, or if female reproductive parts (pistils) are present, they are non-functioning

stigma	The portion of a pistil (often at the top)—that receives pollen—and once received can promote (or restrict) the growth of the pollen tube to initiate the process of fertilization
stilt root (also prop root)	An adventitious root that arises from a stem that provides support for a plant (aerial)
stipule (or stipular)	An appendage, often leafy, at the base of a leaf petiole, mostly appearing in pairs, one on each side of the petiole
stolon (or stoloniferous stem)	A specialized, slender, horizontal, elongate, creeping stem initiating from the base of a plant, and having minute leaves at its nodes, also rooting at the nodes, and developing new plantlets or plants that will eventually root and separate from the mother plant (a colonizing organ that enables a plant to reproduce, producing new clone plants that may surround it)
storage leaves	Leaves of a plant specifically modified for storage of energy (generally in the form of carbohydrates) or storage of water, such as the storage leaves found in bulbs
storage roots	Roots that function to store plant nutrients or food
strobilus (or strobili)	A cone-like cluster of sporophylls on an axis, such as a male pollen cones or female seed cones of a conifer
style	The portion of the pistil (female flower reproductive organ) connecting the stigma to the ovary, usually narrow
substrate (pertaining to biology)	The surface on or material in which a plant or animal lives
succulent	Juicy or fleshy, such as a plant having fleshy stems or leaves
sucker	A shoot originating from below ground, as from a root or lower part of a stem
sun leaves or shade leaves	Sun leaves and shade leaves are common in plant canopies, with sun leaves located on the top and outer, unshaded perimeter of the plant and shade leaves located on the shaded sides of the plant, under the sun leaves within the canopy. Shade leaves receive less sunlight (photosynthetically active radiation) than sun leaves. As a result of their position within a canopy, individual leaves respond by developing slightly differently (called plasticity) but suited to their position within the canopy: morphologically, anatomically and metabolically. All this leaf variation, within one plant, results in maximizing a plant's net rate of energy capture. Shade leaves differ morphologically by being larger, less deeply lobed (if the species has lobed leaves), and thinner, and can have a deeper green coloring and a different texture than sun leaves on the same plant. Anatomically, sun leaves are thicker by having more or thicker palisade mesophyll cell layers with longer cells, a less developed spongy mesophyll, and a thicker cuticle than shade leaves. Shade leaves contain more chlorophyll (chloroplasts) within their thinner layer of mesophyll cells, resulting in an increased ability to harvest sunlight at low radiation levels.
superior (see hypogynous)	A flower's ovary position when located above the attachment of the sepal, petal, and stamen whorls
synconium	A fruit that has developed from more than one flower, in which the flowers were tightly clustered, and matured into a tight cluster of individual fruits—yet these flowers—ovaries or fruit are borne inside of the hollow, inverted receptacle (such as fig). The fleshy fruit consists mostly of receptacle tissue

T

tap root system (or taproot) (compare fibrous root)	A root system with a prominent central axis, having the main root axis larger with smaller branches radiating from it
taxonomist (plant taxonomist)	Someone who studies the science or technique of classifying, in this case, plants

tendril	A slender, clasping, twining, outgrowth of the stem that aids in support of climbing plants
tepal	Whorls of the perianth of a flower in which the sepals or calyx and petals or corolla are undifferentiated—and identical or almost identical in appearance—such as with tulips and lilies and magnolias
terminal (see apical or apex)	Refers to the top or tip of a structure, organ, such as a leaf or stem (and the point farthest from the point of attachment)
transect	A fixed path in a given area along which one observes and records occurrences of plants or animals of study
transpiration	The release or emission of water vapor from plant leaves (primarily through stomata) and stems into the atmosphere
trap leaf (or insectivorous leaf)	A modified and specialized leaf designed to function as a trap, such as a Venus Fly-trap leaf that closes in half upon a receiving a trigger or stimulus and trapping an insect that it will digest for nutrients
trifoliate (or trifoliolate)	Having three leaves, or leaflets, or similar structures
true leaves	The leaves typical of a plant species that emerge subsequent to the cotyledons (which are often shaped differently)
tuber (compare: tuberous root)	A thickened and short subterranean stem having numerous nodes and buds (in white potatoes—the "eyes") and functioning for food storage
tuberous root (compare: tuber)	A swollen, modified root that has thickened for nutrient storage, such as a sweet potato and cassava (which has no "eyes" (nodes or buds))

U

utricle (fruit type)	A dry, indeshiscent, one-seeded fruit that has developed from one flower having a single ovary, and the ovary wall becomes more or less bladdery or inflated at maturity

V

vascular	Refers to conducting tissues, as in xylem and phloem, and plants that have these tissues (vs. non-vascular plants)
vascular bundle	A conducting strand or cluster of tissues (xylem and phloem for conducting water, nutrients, photosynthates or food) in a plant
vegetative reproduction	Asexual reproduction in which the propogated plant(s) has the same genetic makeup (identical chromosomes) as the mother plant, and in which no genetic material or DNA was exchanged
venation	The arrangement and pattern in which the veins occur in a leaf (specific to species)

W

whorled arrangement	An arrangement of three or more leaves that attaches at a node, circling the stem
wind-pollinated	Refers to the transport, by wind, of pollen from a flower's anther to another flower's stigma
winter buds	Leaf or flower buds that are in a dormant phase during the coldest season and are protected by bud scales or dense hairiness

X

xylem	The specialized vascular plant tissue that functions in the transport or conduction of water and minerals upward through the plant

IMAGE CREDITS AND DETAILS

We have altered and edited images as allowed by the licenses, and required to report. All photos have been edited or altered, except one on page 45 (*Phacelia minor*) which license is ND—no derivatives

COVER: BOTANY PRIMER

1 Ellen G. Denny—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (*Magnolia spp.*)

PAGE 4: BOTANY PRIMER—HOW TO USE THIS MANUAL

1 Brian Powell—Creative Commons Attribution-Noncommercial-NoDerivatives 4.0 International

PAGE 6: ABOUT A PLANT'S LIFE

1 International Society of Arboriculture, International Society of Arboriculture, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License

2 International Society of Arboriculture, International Society of Arboriculture, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License

3 Kelvinsong via Wikimedia Commons—Creative Commons Attribution 3.0 Unported License

4 Kelvinsong via Wikimedia Commons—Creative Commons Attribution 3.0 Unported License

PAGE 7: ABOUT A PLANT'S LIFE (CONTINUED)

1 Norman Criddle *in* Farm Weeds of Canada by George H. Clark, B.S.A. and James Fletcher, LL.D., F.R.S.C., F.L.S. with illustrations by the Canadian naturalist Norman Criddle. Published by direction of the Hon. Sydney A. Fisher, Minister of Agriculture, Ottaw—Public domain in the USA, out of copyright in Canada, hence royalty-free stock image for all purposes and no usage credit required (*Hierochloa borealis*)

2 Albert Meyer *in* Fuchs, Leonhart, 1543. New Kreüterbuch. Basel, Michael Isingrin—This work is in the Public domain in the United States because it was published (or registered with the U.S. Copyright Office) before January 1, 1923. (*Phaseolus vulgaris*)

PAGE 8: ABOUT PLANT SPECIES VARIATION

1 Franz Xaver via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Cornus canadensis*)

2 James Henderson, Golden Delight Honey, Bugwood.org—Creative Commons Attribution 3.0 License (*Stenocereus thurberi*)

3 *Brian Stansberry via Wikimedia Commons—Creative Commons Attribution 3.0 Unported License*

4 Tsnena via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Mahovina na steni*)

5 BerndH via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Riccia glauca*)

6 ©2011 Wynn Anderson—Creative Commons Attribution-Non-Commercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Pinus contorta ssp. murrayana*)

7 H. Zell via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Solanum lycopersicum*)

8 H. Zell via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Solanum lycopersicum*)

9 Forest & Kim Starr, Starr Environmental, Bugwood.org—Creative Commons Attribution 3.0 License (*Pritchardia* sp.)

10 Dennis Brown via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Zinnia* sp.)

PAGE 9: VASCULAR VS. NON-VASCULAR

1 Laurenprue216 via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

2 Micropix via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Tradescantia* sp.)

PAGE 10: FLOWERING VS. NON–FLOWERING PLANTS

1 Amada44 via Wikimedia Commons—Public domain

2 Ulf Mehlig, Andreas Plank images separated, via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.5 Generic License

PAGE 11: MONOCOTS VS. DICOTS—THE SEED'S COTYLEDONS

1 Rasbak at nl.wikipedia via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

2 Ton Rulkens via Flicker—Creative Commons Attribution-ShareAlike 2.0 Generic

3 Dennis Brown via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

4 Pipi69e via Wikimedia Commons—Public domain (*Allium ursinum*)

5 Amada44 via Wikimedia Commons—Public domain (*Rheum rhabarbarum*)

6 Vinayaraj via Wikimedia Commons—Creative Commons Attribution-*Share Alike 3.0 Unported License*

7 Tazztone via Wikimedia Commons—Public domain (*Malus* sp.)

8 ©2012 Barry Rice—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Abies concolor*)

PAGE 12: ABOUT PLANT LIFE CYCLES

1 Amada44 via Wikimedia Commons—Public domain (*Rheum rhabarbarum*)

2 Tazztone via Wikimedia Commons—Public domain (*Malus* sp.)

3 Laitche via Wikimedia Commons—Public domain (*Helianthus annuus*)

4 Emõke Dénes via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.5 Generic License (*Helianthus annuus*)

5 Kaldari via Wikimedia Commons—Public domain (*Helianthus annuus*)

6 Mary Ellen (Mel) Harte, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Helianthus annuus*)

PAGE 13: ABOUT PLANT LIFE CYCLES (CONTINUED)

1 Amada44 via Wikimedia Commons—Public domain (*Rheum rhabarbarum*)

2 Tazztone via Wikimedia Commons—Public domain (*Malus* sp.)

3 John Ruter, University of Georgia, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Acer rubrum*)

4 4028mdk09 via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Ilex aquifolium*)

5 Jan Samanek, State Phytosanitary Administration, Bugwood.org—Creative Commons Attribution 3.0 License (*Acer platanoides*)

6 Forest & Kim Starr via Wikimedia Commons—Creative Commons Attribution 3.0 Unported License (*Sambucus mexicana*)

7 John Ruter, University of Georgia, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Acer buergerianum*)

8 Jason Sharman, Vitalitree, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Acer saccharum*)

9 Paul Wray, Iowa State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Quercus rubra*)

PAGE 14: ABOUT PLANT VARIATIONS

1 Jason Sharman, Vitalitree, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Quercus macrocarpa*)

2 ©2011 Wynn Anderson—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Ceanothus cordulatus*)

3 Walter Siegmund via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Claytonia megarhiza*)

4 Michael Wolf via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Ipomoea coccinea*)

5 John D. Byrd, Mississippi State University, Bugwood.org—Creative Commons Attribution 3.0 License (*Imperata cylindrica*)

6 Rebekah D. Wallace, University of Georgia, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Osmunda cinnamomea*)

7 Oven Fresh via Wikimedia Commons—Public domain

8 Robert Vidéki, Doronicum Kft., Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Picea abies*)

9 BS -Thurner Hof via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Agave parryi*)

10 Jean-noël Lafargue via Wikimedia Commons—Copyleft: This work of art is free; you can redistribute it and/or modify it according to terms of the Free Art License.

11 Kohlnf via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Tillandsia recurvata*)

12 ©2009 Barry Breckling—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Nuphar polysepala*)

13 Forest & Kim Starr, Starr Environmental, Bugwood.org—Creative Commons Attribution 3.0 License

14 ©2009 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Phoradendron villosum*)

15 ©2010 Barry Breckling—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Sarcodes sanguinea*)

PAGE 15: ABOUT PLANT REPRODUCTION

1 Alpsdake via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Fragaria × ananassa*)

PAGE 16: ABOUT PLANT REPRODUCTION (CONTINUED)

1 Anneli Salo via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Kalanchoe daigremontiana*)

2 ©2008 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Fragaria chiloensis*)

3 Hardyplants at English Wikipedia via Wikimedia Commons—Public domain

4 John Fielding via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.0 Generic License (*Taraxacum* sp.)

5 Raul654 via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Agave parryi*)

6 ©2009 Gary A. Monroe—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License (*Populus tremuloides*)

7 Chi1112000 via Wikimedia Commons—Public domain

PAGE 17: ABOUT PLANT CLONING

1 Dorian Bianco via Wikimedia Commons—Public domain (*Syringa vulgaris*)

2 Leslie J. Mehrhoff, University of Connecticut, Bugwood.org—Creative Commons Attribution 3.0 License (*Lonicera tatarica*)

3 Wendy VanDyk Evans, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Cornus florida*)

PAGE 20: ABOUT STEMS AND VARIATION

1 ©2009 Will Cook—Will Cook has given Ellen Denny (NPN) permission to use his photos on NPN pages. (*Ulmus americana*)

2 Amada44 via Wikimedia Commons—Public domain (*Allium* sp.)

3 Stephen Ausmus, USDA ARS via Wikimedia Commons—Public domain (*Allium sp.*)

4 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (*Opuntia santa-rita*)

5 Frank Vincentz via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Euphorbia neostolonifera)*

6 ©2008 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Fragaria chiloensis*)

7 Stan Shebs via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Opuntia phaeacantha*)

PAGE 21: ABOUT STEM ANATOMY

1 Photohound via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

2 Rasbak via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Zea mays*)

3 Frank Vincentz via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Crassula ovata*)

4 Minnecologies via Wikimedia Commons—Creative Commons CC0 1.0 Universal Public Domain Dedication (*Fraxinus pennsylvanica*)

5 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

PAGE 22: ABOUT STEMS AND THEIR ARRANGEMENT OF PLANT PARTS

1 ©2009 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (*Populus fremontii*)

2 Mary Ellen (Mel) Harte, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Populus balsamifera*)

3 Ohio State Weed Lab Archive, The Ohio State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Acer negundo*)

4 Jan Samanek, State Phytosanitary Administration, Bugwood.org—Creative Commons Attribution 3.0 License (*Acer negundo*)

5 Stan Shebs via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Agave palmeri*)

6 Orchi via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Goodyera repens*)

7 Javier martin via Wikimedia Commons—Public domain, worldwide (*Taraxacum obovatum*)

8 Gmayfield via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported (*Lilium michiganense*)

PAGE 23: ABOUT BUDS

1 Mariana Ruiz Villarreal 'LadyofHats' via Wikimedia Commons—Public domain

2 The Project Gutenberg EBook of The Elements of Botany, by Asa Gray—Copyright expired in the U.S.

3 © 2004, Clayton J. Antieau—see http://biology.burke.washington.edu/herbarium/imagecollection/wtu3500-3999/md/wtu003627_md.jpg (*Fraxinus latifolia*)

4 © 2004, Clayton J. Antieau—see http://biology.burke.washington.edu/herbarium/imagecollection/wtu3500-3999/md/wtu003644_md.jpg (*Populus tremuloides*)

PAGE 24: ABOUT WOODY TWIGS AND STEMS

1 JonRichfield via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Liquidambar styraciflua*)

2 JonRichfield via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Liquidambar styraciflua*)

3 Opuntia via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Aesculus hippocastanum*)

4 Nadiatalent via Wikimedia Commons—Public domain (*Crataegus mollis)*

PAGE 25: ABOUT BREAKING LEAF BUDS—PLANTS WITH BUD SCALES AND THOSE WITHOUT

1 Frank Vincentz via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Leucophyllum frutescens*)

2 ©2012 Aviva Rossi—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License (*Baccharis pilularis*)

3 André Karwath aka Aka via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.5 Generic License (*Acer pseudoplatanus*)

4 Sten Porse via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Acer pseudoplatanus*)

5 Donar Reiskoffer via Wikimedia Commons—Creative Commons Attribution 3.0 Unported (*Acer pseudoplatanus*)

6 Donar Reiskoffer via Wikimedia Commons—Creative Commons Attribution 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Acer pseudoplatanus*)

7 Donar Reiskoffer via Wikimedia Commons—Creative Commons Attribution 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Acer pseudoplatanus*)

8 Donar Reiskoffer via Wikimedia Commons—Creative Commons Attribution 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Acer pseudoplatanus*)

9 © 2004 Susan Sweeney via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Juglans nigra*)

10 SB Johnny via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Juglans nigra*)

11 Paul Wray, Iowa State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Juglans nigra*)

12 Paul Wray, Iowa State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Juglans nigra*)

PAGE 28: ABOUT ROOTS

1 Hardyplants at English Wikipedia via Wikimedia Commons—Public domain

2 Steve Dewey, Utah State University, Bugwood.org—Creative Commons Attribution 3.0 License (*Eragrostis cilianensis*)

3 Matt Lavin via Flicker—Creative Commons Attribution-ShareAlike 2.0 Generic

4 Clematis via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.5 Generic License

5 International Society of Arboriculture, International Society of Arboriculture, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License

PAGE 29: ABOUT DIFFERENT VARIETIES OF ROOTS

1 Randy Cyr, Greentree, Bugwood.org—Creative Commons Attribution 3.0 License (*Ficus* sp.)

2 Dvortygirl via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

3 Wie146 via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Avicennia marina*)

4 Chris Evans, Illinois Wildlife Action Plan, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Cuscuta* sp.)

5 Barry Rice, sarracenia.com, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Cuscuta japonica*)

6 Gerald Holmes, Valent USA Corporation, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Ipomoea batatas*)

7 Ohio State Weed Lab Archive, The Ohio State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Helianthus tuberosus*)

8 John D. Byrd, Mississippi State University, Bugwood.org—Creative Commons Attribution 3.0 License (*Paspalum notatum*)

PAGE 32: ABOUT LEAVES

1 ©2008 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Populus trichocarpa*)

2 ©2009 Will Cook—Will Cook has given Ellen Denny (NPN) permission to use his photos on NPN pages. (*Celtis occidentalis*)

3 ©2008 Zoya Akulova—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License

4 Vinayaraj via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Lagerstroemia microcarpa*)

PAGE 33: ABOUT A LEAF'S FUNCTION

1 Mnolf via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

2 Nova via Wikimedia Commons—Public domain

3 Kristian Peters-Fabelfroh via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Plagiomnium affine*)

PAGE 34: USING PHYSICAL CHARACTERISTICS TO IDENTIFY PLANTS

1 debivort via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

2 MFP via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Juniperus chinensis*)

3 Agnieszka Kwiecień (Nova) via Wikimedia Commons—Creative Commons Attribution 3.0 Unported License

4 Stan Shebs via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Agave bovicornuta*)

5 Petr Dlouhý via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Drosera adelae*)

6 Channer via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Solanum mauritianum)*

7 Rlevse via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Sassafras albidum*)

PAGE 35: ABOUT LEAF BLADE TYPE

1 Robert Vidéki, Doronicum Kft., Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Liquidambar styraciflua*)

2 Paul Wray, Iowa State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Ulmus rubra*)

3 ©2006 Will Cook—Will Cook has given Ellen Denny (NPN) permission to use his photos on NPN pages. (*Aralia spinosa*)

4 The Project Gutenberg EBook of The Elements of Botany, by Asa Gray—Copyright expired in the U.S.

5 ©2008 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Quercus garryana*)

6 Ohio State Weed Lab Archive, The Ohio State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Acer negundo*)

7 Chris Evans, Illinois Wildlife Action Plan, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Carya aquatica*)

PAGE 36: MORE ABOUT LEAF BLADES AND THEIR PATTERNS, FOR PLANT IDENTIFICATION

1 Pearson Scott Foresman via Wikimedia Commons—Public domain

2 Pearson Scott Foresman via Wikimedia Commons—Public domain

3 Reggaeman via Wikimedia Common—Creative Commons Attribution-Share Alike 3.0 Unported License (*Fatsia japonica*)

4 Paul Wray, Iowa State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Quercus rubra*)

5 MPF via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Fraxinus excelsior*)

6 James H. Miller & Ted Bodner, Southern Weed Science Society, Bugwood.org—Creative Commons Attribution 3.0 License (*Aralia spinosa*)

7 Frank Vincentz via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Trifolium repens*)

8 Paul Wray, Iowa State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Aesculus hippocastanum*)

9 Agnieszka Kwiecień (Nova) via Wikimedia Commons—Creative Commons Attribution 3.0 Unported License

PAGE 37: MORE (BASIC) LEAF MORPHOLOGY

1 User Debivort via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

2 User Debivort via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

3 Rebekah D. Wallace, University of Georgia, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Cnidoscolus stimulosus*)

4 Forest and Kim Starr, Starr Environmental, Bugwood.org—Creative Commons Attribution 3.0 License (*Pritchardia* spp.)

5 The Project Gutenberg EBook of The Elements of Botany, by Asa Gray—Copyright expired in the U.S.

6 The Project Gutenberg EBook of The Elements of Botany, by Asa Gray—Copyright expired in the U.S.

7 The Project Gutenberg EBook of The Elements of Botany, by Asa Gray—Copyright expired in the U.S.

PAGE 39: ABOUT VARIATION IN LEAVES, AND SPECIALIZED TYPES OF LEAVES

1 MFP via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Juniperus chinensis*)

2 Vinayaraj via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

3 ©2008 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Cornus nuttallii*)

4 Mary Ellen (Mel) Harte, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Helianthus annuus*)

5 Sten Porse via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Acer pseudoplatanus*)

6 Stan Shebs via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Agave ferox*)

7 Joseph M. DiTomaso, University of California - Davis, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Salix lasiolepis*)

8 ©2013 Zoya Akulova—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License (*Vitis californica*)

9 Noah Elhardt via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.5 Generic License (*Sarracenia oreophila*)

PAGE 40: ABOUT CONIFER NEEDLES, SCALE- AND AWL-SHAPED LEAVES

1 The Project Gutenberg EBook of The Elements of Botany, by Asa Gray—Copyright expired in the U.S.

2 Stan Shebs via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Juniperus scopulorum*)

3 Joseph O'Brien, USDA Forest Service, Bugwood.org—Creative Commons Attribution 3.0 License (*Abies balsamea*)

4 Paul Wray, Iowa State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Larix decidua*)

5 Stan Shebs via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Juniperus communis*)

6 ©2009 Gary A. Monroe—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License (*Pinus flexilis)*

7 Walter Siegmund via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Pinus benthamiana)*

PAGE 42: ABOUT FLOWERS

1 Fred the Oyster via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

2 Chrizz via Wikimedia Commons - from Prof. Dr. Otto Wilhelm Thomé (1885)—Creative Commons Attribution-Share Alike 3.0 Unported License

3 D. Walters and C. Southwick, CPHST, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Eragrostis pilosa*)

4 James Lindsey at Ecology of Commanster via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Elymus repens*)

5 Andreas Plank via Wikimedia Commons in Armstrong, Sydney Frederick (1917): British grasses and their employment in agriculture, page 13 and File:Lolium spp Sturm52.jpg—Creative Commons Attribution 3.0 Unported License (*Lolium perenne*)

PAGE 43: ABOUT BASIC FLOWER VARIATION

1 Mike Young via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Commelina cyanea)*

2 Lesley Ingram, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Lilium* sp.)

3 Willow via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.5 Generic License (*Salix viminalis*)

4 Willow via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.5 Generic License (*Salix viminalis*)

5 Abrahami via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Cucurbita* sp.)

6 ©2009 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Oenothera deltoides*)

7 Leslie J. Mehrhoff, University of Connecticut, Bugwood.org—Creative Commons Attribution 3.0 License (*Rosa rugosa*)

8 Abrahami via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Cucurbita* sp.)

PAGE 44: ABOUT INFLORENCENCES OR CLUSTERED FLOWERS

1 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

2 A. Barra via Wikimedia Commons—Creative Commons Attribution 3.0 Unported License (*Aesculus flava*)

3 Wayne Ray via Wikimedia Commons—Public domain (*Agastache foeniculum*)

4 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

5 James H. Miller, USDA Forest Service, Bugwood.org—Creative Commons Attribution 3.0 License (*Sorghum halepense)*

6 ©2005 Luigi Rignanese—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License (*Eleusine indica*)

7 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

8 William M. Ciesla, Forest Health Management International, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Arisaema triphyllum)*

9 ©2006 Steven Thorsted—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License (*Epilobium angustifolium*)

10 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

11 Joseph M. DiTomaso, University of California - Davis, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Hordeum glaucum*)

12 ©2010 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Phleum alpinum)*

PAGE 45: ABOUT INFLORENCENCES OR CLUSTERED FLOWERS (CONTINUED)

1 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

2 Liné1 via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Heracleum mantegazzianum*)

3 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

4 ©2007 Debra Hansen—Creative Commons Attribution-NonCommercial-NoDerivs 3.0 (CC BY-NC-ND 3.0) License (*Phacelia minor*)

5 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

6 Davefoc via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Ericameria nauseosa)*

7 Nize via Wikimedia Commons—Public domain (*Taraxacum officinale)*

8 Montana Statewide Noxious Weed Awareness and Education Program Archive, Montana State University, Bugwood.org—Creative Commons Attribution 3.0 License (*Leucanthemum vulgare*)

9 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

10 Matt Lavin via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.0 Generic License (*Spirea splendens*)

11 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License

12 Ellen G. Denny—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (*Corylus* sp.)

13 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (*Prosopis velutina)*

PAGE 46: ABOUT FEMALE CONIFER SEED CONES (GYMNOSPERMS)

1 Mary Ellen (Mel) Harte, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Abies lasiocarpa var. arizonica)*

2 Richard Sniezko, US Forest Service Dorena Genetic Resource Center via Wikimedia Commons—Public domain (*Pinus monticola)*

3 Nadiatalent via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Picea glauca*)

4 BeAr via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Pinus nigra*)

5 MPF via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Pinus contorta)*

6 ©2009 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Pinus muricata)*

7 Beentree via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Pinus sylvestris*)

PAGE 47: ABOUT MALE CONIFER POLLEN CONES (GYMNOSPERMS)

1 ©2008 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Pinus sabiniana)*

2 Richard Sniezko, US Forest Service Dorena Genetic Resource Center via Wikimedia Commons—Public domain (*Pinus monticola*)

3 Joe Decruyenaere via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.0 Generic License (*Pinus longaeva*)

4 B.gliwa via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.5 Generic License (*Picea abies*)

5 USFS Region 5 via Wikimedia Commons—Creative Commons Attribution 2.0 Generic License (*Pinus contorta)*

6 H. Zell via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Ginkgo biloba*)

7 ©2008 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Taxus brevifolia)*

8 Walter Siegmund via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Juniperus maritima)*

9 Stan Shebs via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Ephedra viridis)*

PAGE 50: ABOUT POLLINATION AND FERTILIZATION

1 Lukas Riebling, Username Luke1ace via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License

2 Beatriz Moisset via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Pinus* sp.)

3 Leonardo Ré-Jorge via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Luffa cylindrica)*

4 Tameeria via Wikimedia Commons—Public domain

5 Frank Vincentz via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Acer pseudoplatanus*)

6 Frank Vincentz via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Acer pseudoplatanus*)

7 Beentree via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Pinus sylvestris*)

8 Leonardo Ré-Jorge via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Bixa orellana)*

9 Justin Smith via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Malus* sp.)

10 Forest & Kim Starr via Wikimedia Commons—Creative Commons Attribution 3.0 Unported License (*Erythrina sandwicensis*)

11 H. Zell via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Cardiospermum halicacabum*)

PAGE 51: FROM FLOWER BUD TO FRUIT SET

1 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (*Citrus* sp.)

2 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (*Citrus* sp.)

3 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (*Citrus* sp.)

4 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (*Citrus* sp.)

5 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (*Citrus* sp.)

6 Patty Guertin—Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License (*Citrus* sp.)

PAGE 52: ABOUT FRUITS AND FRUIT TYPES

1 Californiacondor via Wikipedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Cucurbita* sp.)

2 Fastily via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Lycopersicum* sp.)

3 Alina Zienowicz (Ala z) via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Prunus cerasus*)

4 André Karwath aka Aka via Wikimedia Commons—Creative Commons Attribution-Share Alike 2.5 Generic License (*Citrus* x *limon)*

5 Glysiak via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported (*Malus* sp.)

6 ©2008 Zoya Akulova—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License (*Aquilegia formosa*)

7 ©2011 Barry Breckling—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Cardamine oligosperma)*

8 Howard F. Schwartz, Colorado State University, Bugwood.org—Creative Commons Attribution 3.0 License (*Hordeum vulgare)*

9 Paul Wray, Iowa State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Quercus rubra*)

10 ©2011 Zoya Akulova—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License (*Lupinus sericatus*)

11 Mary Ellen (Mel) Harte, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Hedysarum alpinum*)

12 Mdf via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Asclepias syriaca*)

13 Paul Wray, Iowa State University, Bugwood.org—Creative Commons Attribution-Noncommercial 3.0 United States License (*Acer platanoides)*

14 Joseph Berger, Bugwood.org—Creative Commons Attribution 3.0 License (*Helianthus annuus*)

15 Kirkbride, J.H., Jr., C.R. Gunn, and M.J. Dallwitz. 2006. Family Guide for Fruits and Seeds, vers. 1.0—Public domain (*Atriplex canescens*)

16 ©2012 Zoya Akulova—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License (*Anoda cristata*)

PAGE 53: ABOUT FRUITS, THEIR SEEDS AND SEED DISPERSAL

1 Mdf via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Asclepias syriaca*)

2 ©2009 Keir Morse—Creative Commons Attribution-NonCommercial-ShareAlike 3.0 (CC BY-NC-SA 3.0) License (*Cercocarpus betuloides*)

3 Joseph Berger, Bugwood.org—Creative Commons Attribution 3.0 License (*Taraxacum officinale*)

4 Losch via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Impatiens glandulifera*)

5 Losch via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Impatiens glandulifera*)

6 ©2007 Luigi Rignanese—Creative Commons Attribution-NonCommercial 3.0 (CC BY-NC 3.0) License (*Erodium moschatum*)

7 Jamain via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported, 2.5 Generic, 2.0 Generic and 1.0 Generic License (*Phaseolus* sp.)

8 H. Zell via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Zea mays*)

9 Eva-Maria Kintzel via Wikimedia Commons—GNU Free Documentation License, Version 1.2 or any later version (*Rubus* sp.)

10 Joe Mabel via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Cucurbita pepo*)

11 Roger Culos via Wikimedia Commons—Creative Commons Attribution-Share Alike 3.0 Unported License (*Proboscidea parviflora*)