# Tree Botany

## Defining a tree

As we use the word **tree** to describe a particular plant organism we have in our mind a tall woody structure with leaves or needles. For the most part we are correct in our opinion of what a tree is. To clearly separate trees from other plant organisms certain criteria have been established.

Trees share all their growth features with all other forms of plant life in one way or another. It takes a list of many features to separate trees from grasses, plants, and shrubs. A tree must have the following attributes:

- a woody structure
- roots
- a single trunk
- multiple branches
- the ability to grow tall
- the ability to increase in all dimensions

Bamboo and tree ferns are not considered trees on the basis of their inability to increase in diameter. They lack a cambium layer so their diameter remains the same as the original shoot.

Palms are eliminated as there is little to no branching and lack the "solid wood" structure.

Shrubs have almost all the same features as trees do. The fall out due to size and the fact they usually have multiple trunks.

Flowering plants and grasses fail to meet many of the criteria.

## General facts

Trees have no built in life limit. A tree's life is determined by its environment . Weather, disease, insects, animal attack, storm damage, human intervention and climate change all play a role. The longest living tree known today is a **bristlecone pine** in the Sierra Nevada mountains aged at **4800 years**. One at **5000 years** old was cut down in 1964. You must therefore think of yourself as a very temporary custodian, not as an owner of a tree. On the other hand, individual parts of trees may have very short lives. Branches that consume more energy than they produce due to damage or shading will die.

The general consensus for the **height limit of a tree** has been 350 feet. The debate is still on regarding the limit especially since a redwood in Redwoods National Park was measured at **379.1 feet** in 2007. There seems to be no consensus on the reason for the limit, be it strength or the height of the water column.

Trees, as do most plants manufacture all of their own food through photosynthesis, drawing the necessary water and elements from the immediate environment. Photosynthesis is the basis of life for almost all plant and animal life on earth (including us) and supplies nearly all of the oxygen we breathe.

There are deciduous trees and coniferous trees. Our discussion of these will be centered around temperate species with which we are most familiar.

- **Deciduous** trees are leafy and tend to lose their leaves annually. Technically they are classed as **angiosperms** and flower to produce fruit covered seeds. Here we are talking **oaks, maples, elms etc**. These are also know as **hardwoods** having a dry specific gravity (weight) above 0.41.
- **Conifers** as their name seems to imply have seed bearing cones. They are classified as **gymnosperms** meaning naked seeded. Seeds are not covered by fleshy membrane. Here we have **pines, spruces, larches, cedars etc.** These are also called **softwoods** because the specific gravity is less than 0.41. They generally keep their needles 2 to 4 years.
- There are some **crossovers**. The **larch** is a deciduous conifer and the **Balboa ginko** is a hardwood conifer.

# Tree structure

The cell walls of the trunk, bark, branches, roots and are all made of cellulous. Nature has but one formula, one universally successful chemical process. This is used by all plant species by which it easy to manufacture cellulous.

## Trunk

The function of the trunk is to support the branches and leaves. It also provides for the transport of water, nutrients and food to and from the roots and branches. It consists of bark, phloem and xylem.

The **main** stem of the **trunk** has an **apical meristem at its tip**. This is the **living growth center** which controls the size and placement of branches below it. Mature trees that maintain a **single tapering trunk** with only side branches have a **triangular shape** are called **formal upright** trees in bonsai terminology. **Oaks and beeches** follow this form. Should this apical meristem be damaged, a replacement will be formed on the trunk or a nearby branch. As some species mature, **apical control is lost** and a number of branches will begin to grow at the same rate, giving rise to a **wide crown** and a markedly different form of tree. **Maples and elms** are examples. There is a common bonsai technique to lower the height of an upright style tree by removing a section of the apex and wiring a side branch to the apical position. The tree readily accepts the new apex and naturally gives it apical control. The same is true for the apical meristem of each branch.

**Other meristems** are located at the **tips of every branch** and **root** and at every **leaf bud**. All branch leaf and root growth are the result of these meristems. There are many dormant branch and leaf meristems along the branches, trunk and roots.

- The primary function of **Bark** is to provide a **water tight barrier** eliminating water loss from the trunk. After the bark cells grow and mature, protoplasm in each cell is replaced by a waterproof, fatty substance called suberin. Bark also provides a certain amount of restrictive pressure on the trunk which is essential in the proper alignment and formation of phloem and xylem cells. **Bark** is **formed by** a one cell thick layer called the **cork cambium**, as is a small portion of the phloem. The cork cambium is responsible for maintaining the integrity of the bark and will repair damaged bark

  **Cork cambium** has a determinate life(**limited life span**) in all species of **rough barked trees**. As the cambium layer dies and is replaced by new cork cambium and new bark, the old bark is pushed out and splits forming the rough bark we see. The new **cork cambium** is **formed** by the **cambium layer** of the **xylem**, which is beneath it. Species like sycamore shed all bark annually and for a time appear to be a smooth bark species. **Most trees** are **rough bark** species.

  **Cork cambium** has an indeterminate life(**unlimited life span**) in **smooth bark species** such as beech. As the trunk grows and increases in diameter new cells are formed to maintain the integrity of the bark.

- The **phloem** is located immediately beneath the cork cambium. Its function is to **transport food from** the **leaves to branches, trunk and roots**. Principally the **transport** is **downward**. During spring in temperate climates transport may be upward for a time. The phloem grows annually but the cells remain small and growth rings cannot be seen. Most phloem cells are living cells. Two prominent cell types are sieve cells and sieve tubes. Dissolved sugars are transported through the sieve tubes. These tubular cells are controlled by the sieve cells adjacent to them.

  Together the bark and phloem are what we normally think of as bark. Phloem is continuous from the root tips to the tips of leaves.

- The **xylem** is the solid **wooden part of the trunk.** It **transports water** and **nutrients from** the **roots to the leaves**. It is continuous from the roots to the leaves. The xylem contains the growth rings and the living cambium layer. The cambium is the only growth cell structure in the xylem capable of reproducing itself and other cell types.

    - **Growth rings** are formed annually in temperate climates but may not be an accurate way to determining the age of any tree. Some tropical trees show no rings. Others may have 2 rings per year timed to dry seasons.

    - **Growth rings** are **formed** by the **cambium** layer, one cell thick which is not visible to the naked eye. This layer is the outermost layer of cells on the xylem. In temperate trees, the rings have 2 distinct layers. First we see darker inner layer of larger spring growth cells made brown from the reinforcing with lignin. Next we see a lighter ring of smaller cells considered summer growth. **Together** the **dark and light** rings are considered **one annual** growth **ring**. We are told to match up cambium layers while grafting branches and roots. An impossible task since they cannot be seen and are about 0.001" thick.

    - Growth **rings** are **thickest** at the **base of the trunk** and **thinnest** at the **top of the tree** in all open grown trees. Rings of branches are thicker on the top in response to the weight of the branch. Localized thickening is a response to gravity and wind forces and is referred to as reaction wood. Artificial wiring of growing branches will cause the rings to thicken on the outer side of the bend but prevent reaction wood due to gravity.

      Forest trees have branches only in the crown and shield each other from wind forces. The trunks remain straight as a result. There is no outside force or increase in crown size to cause ring thickening. Tapering of the rings does occur in the crown.

    - Upon visual inspection of a cross section a **trunk** it is apparent that there is a **darker center** and **lighter** colored **outer portion**.

      The **lighter outer portion** is the **sapwood** and is **active in transporting** 100% of the **water and nutrients** from the roots **to the leaves**. The **cells** are **dead** but **hollow**. The most widely accepted theory for water transport from roots to leaves is capillary, cohesion and osmosis. Water has unusual properties and tends to stick to solids and especially cellulous and itself. Water fills the cells by capillary and cohesive action and transfers from cell to cell through pores. Its movement is upward with no action taken by the xylem. Water pressurizes the tree up to and including the leaves. As the leaves loose water molecules they are replaced by osmosis through the cell walls. The osmosis causes a “pull” on the water column and the water flows up to maintain the balance. Water pressure in the protoplast of leaf cells is called turgor pressure. Turgor pressure can be lost if the roots cannot obtain sufficient water. In this instance the leaves will wilt.

The **dark inner part of wood** is the **heartwood**. It plays no active role in tree growth. It is used only for support and as a reservoir. The heartwood gets its dark color form lignin and other chemicals. It is used as a dump for all respiration products. The resulting wood is very hard, strong and resistant to insects and fungus.

- **All** the **xylem cells** are **dead except** the one cell thick **cambium** layer and some parenchyma food storage cells in the most recent growth. As each current years cells mature, the protoplast within each of them dies and evacuates leaving the xylem cells hollow. Remember that the xylem is continuous from the roots to the leaves.

- Once a tree is mature enough to begin forming heartwood, the **sapwood will remain a constant thickness** regardless of how large the diameter of root, trunk or branch gets. This can be as little as one growth ring in some oak species.

- The **xylem** of **hardwood** contains **4 basic cell types**. Tapered **wood fibers**, tapered **tracheids** with many small holes in the cell walls, **paranchima** cells and tubular shaped **vessels**. These are all oriented lengthwise along the roots trunk and branches. There are **also rays** which are perpendicular to these cells. Wood **fibers** are **for strength** only. P**aranchima** cells are used for **food storage**. **Trahceids** and **vessels** for **strength** and for **transport water and nutrients**. **Rays provide lateral channels** to move food and respiration products between the phloem, sapwood and heartwood. Individual vessels are barely visible to the naked eye, about 10/1000” in diameter. Tracheids and fibers are about 1/1000”.

  The xylem of conifers contain only tracheids and rays but has resin canals. There are no wood fibers or vessels. Cells in conifers are about ½ the size of those in deciduous trees.

## Branches

**Branches** are of the **same** structure **as** the **trunk**. Their **function** is to **create and display leaves** to optimize their exposure to sun light and to minimize shading of other branches. Branch placement is controlled by the trunk apical meristem.

- **Branches are grown** in specific **repeating patterns** along the trunk. They form at **alternate, spiral and opposite (pinnate) positions** along the trunk. As they grow, sub branches are formed in the same pattern. It is interesting to know that leaves will follow the same pattern as the branches taking positions that alternate, are spiral or oppose each other. Compound leaves will additionally be alternate or pinnate. This recurring pattern of growth gives rise to an individual branch being in many ways a representation of the form of the entire tree.

- **Branch size** is **controlled** by the apical **meristem of the trunk** and sub branch size is controlled by the apical metistem of the main branch of that sub branch. This **apical control gives** the tree its **general form**.

## Roots

**Roots** also have the **same structure as the trunk** with active cambium, phloem and xylem. The **function** of roots is to **anchor** the tree, provide for **food storage** and **supply water and nutrients** to the entire tree.

- **Roots** maintain a **balance** with the branches and **leaves** to provide all of the necessary water and nutrients through the trunk and branches. They will grow to maintain this balance.

- Trees bearing **large seeds** generally **form taproots**. Oaks are an example. Taproots are formed to break through the leaf litter of the forest floor. They reduce in size or disappear as the tree ages. **Medium size seeds** like maples **may or may not** form tap roots. **Small seeds** do not have large food stores are **incapable** of forming a taproot.

- **Roots** normally **grow** about **6” below the ground** surface following the ground contours. They grow to a length necessary to find water and nutrients.

- All water and nutrient **uptake** is done **by microscopic feeder hairs** near the ends of the roots. Hairs form near the ends of fine roots and die off as the root lengthens to maintain a relatively constant number. Visible roots are generally just conduits and cannot take up water. This changes in species that form mycorrhizae.
- Water and dissolved nutrients are taken in by the root hairs through direct contact with water in liquid form. Root hairs can form intimate contact with soil particles, sticking to them taking water directly from the particle. Water can also be absorbed in vapor form.

- The **feeder hairs** are extremely **delicate** easily **damaged** by movement or are **desiccated by** short exposure to **air and/or sunlight**. **Damaged roots** are a disruption to the balance with the branches and leaves and **will slow or stop photosynthesis** in the leaves. Repotting of bonsai may best be done on dormant trees or those just starting to grow using stored food.

- Many tree species from a **symbiotic relationship with fungi** forming **mycorrhizae**. A micorrhiza is an apical merismatic root tissue (**root growth tip**) that has been **invaded by a fungus** and is **permanently modified**. In general such roots lack root hairs are shorter and thicker and lack root caps. The **fungus receives food** in the form of sugars from the root and in return supplies nitrogen, other elements including water to the root. The **tree benefits** from the **enormous root system** of the **fungus**. This is most common in **conifers**.

## Leaves

**Leaves** are the **chemical factories** of the plant world. Their **function** is to **supply all** of the **food** and **building blocks** necessary for the growth of the entire tree. **Everything** is **dependent on the leaves**.

- Leaves are formed at specific sites along a branch that optimize their ability to catch sun light. It can be seen that **leaves and branch primordial** of the initial new growth are **formed** at the end of the **previous** growing **season**. The new branch and leaves are **fully formed** and contained **within the leaf bud** at the base of an existing leaf. This is very advantageous in that growth can initially proceed very rapidly since there is no need to create but only expand an existing structure.

  Leaf buds remain dormant as long as the existing leaf is viable. During development the bud remains indeterminate and is capable of creating only a new leaf should the existing leaf be damaged. As it matures near the end of the growing season, it will commit itself to the normal branch/leaf structure.

- **Leaf structure** is made of **cellulous** and consists of an upper and lower **skin with** the **living cells in between**. Leaves vary significantly in size and shape but their internal structure usually one of to vein structures.

- **Veins** are **bundles** of **phloem and xylem** and are usually arranged with a **center stem** and **branching side stems**(dicots) **or** a **center stem and parallel side stems**(monocots). Both types continue through the leaf stem and connect directly to the branch phloem and xylem. Again the **water and nutrients flow in through** the **xylem** and **food flows out** of the leaves **through** the **phloem**.

  Chlorophyll gives leaves their green color and is responsible for making all of the food for the tree. This happens within the protoplasm of individual leaf cells.

- **Leaf stomata** are microscopic surface pores. Their function is to let **carbon dioxide enter** and **water and oxygen and carbon dioxide exit** the leaf. The **greatest number** of stomata are always **on the bottom** surface. Some leaves have no stomata on the top surface.

  - **Small leaves** have tens of **thousands** of **stomata** where **large** leaves can have as many as **2,000,000**.

  - A **stoma is alive** can **open and close**. **Water stress** will cause **closure** of the stoma to conserve the stored water. This cuts off the supply of carbon dioxide and stops photosynthesis.

- **Leaf drop** in the fall of the year is **triggered by many factors** including temperature changes, recent and current growth rates, water availability and fading daylight hours. **No single factor** causes fall leaf drop. The process begins with the close off of the phloem and xylem and the formation of an abscission layer of cells across the base of the leaf stem. This layer disconnects the leaf from the branch except for the vascular bundle of phloem and xylem cells that pass through it. Continued motion of the leaf from wind and rain eventually fatigues the vascular bundle and the leaf drops. During this process the protoplasm in the leaves decomposes and the chlorophyll turns from green to clear. This exposes the yellow and gold colors of existing carotenoids in the leaf cells. Any sugars trapped within the leaves decompose and are responsible for the red and purple fall colors. Eventually all of the compounds decompose and we are left with the brown color of lignified cellulous.

## Chemistry of Trees - Metabolism

The chemical reactions in trees are extremely complex. Many of the process are still not entirely understood. Just what is happening and where the mass of a tree comes from has been a topic of debate for centuries.

During the 1640s a Belgian physician named **Helmont** performed a landmark experiment. He planted a **5# willow sapling** in **200#** dry weight of soil. For 5 years he watered the tree with rainwater, never adding any other nutrients. He then removed the tree and desiccated it and also dried the soil. The **willow** weighed **169# 3oz**. and the **soil 199# 4 oz.** He proved that the mass of the tree was not obtained from the soil but erroneously concluded that the mass increase was from water alone. Easy to do if atoms were not “discovered” for another 150 years.

Wood contains a multitude of organic compounds consisting by weight of:

- 20-50% Water (**$H_2O$**)
- 60-75% cellulous (**$C_6H_{10}O_5$**)
- 30-50% Lignin (**$2_{complex}2_{list}$**)
- minerals, oils, resins, gums, dyes and tannins, also (**$2_{complex}2_{list}$**)

Chemically trees are 92% C(carbon), H(hydrogen), O(oxygen). They must manufacture all the compounds necessary to support life and growth. More are needed to support respiration. Trees manufacture amino acids, proteins, protoplasm, RNA and DNA from basic raw materials. Other elements needed are:

**Constituent elements** of the living protoplasm and cellular DNA.

| | | |
|---|---|---|
| **N** nitrogen | **$NO_3^-$, $NO_4^+$** | 1-2% |
| **K** potassium | **$K^+$** | <1% |
| **C** calcium | **$Ca^{2+}$** | <1% |
| **S** sulfur | **$SO_4^{2-}$** | <1% |
| **P** phosphorus | **$H_2PO_4^-$** | <1% |
| **M** magnesium | **$Mg^{2+}$** | <1% |

| | |
|---|---|
| **Trace elements** | <<<1% used in catalysts and enzymes |
| **Fe** Iron | **$Fe^{2+}$ $Fe^{3+}$** |
| **Mn** manganese | **$Mn^{2+}$** |
| **Zn** zinc | **$Zn^{2+}$** |
| **Cu** copper | **$Cu^+$** |
| **B** Boron | **$HBO_3$** |
| **M** molybdenum | **$MoO_4^{2-}$** |
| **Cl** chlorine | **$Cl^-$** |

**Al** (Aluminum) is found in the chemical analysis of trees. It retards root growth and is currently thought to be only a detriment to growth.

## Metabolism

Metabolism is the total of all chemical changes involved in the physiology of all living organisms.

## Photosynthesis and Food

**Food** is defined as organic compounds **made by the tree** and **used by the tree** to supply energy **for** the **construction and repair of living tissues**. Foods are **carbohydrates, fats, and proteins.**

**Photosynthesis** is the process by which chlorophyll converts carbon dioxide and water into one form of food (sugar). Sugar is the fueling energy for growth of the entire tree. Although the formula is elegant and simple, the underlying chemical reactions and processes are not. Photosynthesis can only occur during day light hours.

- The protoplast within leaf cells contains chlorophyll, note constituent elements **N** and **Mg.**
  - **Chlorophyll a** is $C_{55}H_{72}O_5N_4Mg$
  - **Chlorophyll b** is $C_{55}H_{70}O_6N_4Mg$

We know now that

- **$CO_2 + H_2O$ + Energy (sun light) = $C_6H_{12}O_6$ (Sugar) + 6 $0_2$**

- The **carbon dioxide** comes **from** the **air**, **water from** the **roots** and the **energy from** the **sun**. Some sugar is stored as starch in the leaf and the rest is transported through the leaf vein phloem to the rest of the tree. Sugar is water soluble and cannot be stored. It would dissipate through cell walls and accumulate in water. When sugar is transferred to its storage site it is immediately converted to **starch** (**$C_6H_{10}O_5$)** which is **not soluble** in water. This is done with enzymes and catalysts. As starch it will remain stored.

- We also know that a tree is made up mostly of **cellulous** which is **$C_6H_{10}O_5$** and is made from sugar. Now we can correctly conclude that most of the **tree mass** is directly obtained **from** the **air** and ground **water**. Some trees like the California redwood can obtain as much as 40% or its water from moist air, but this is not the norm.

- It is interesting to note that **starch** and **cellulous appea**r to be the **same**. **They are not** and they do differ in molecular structure. It is also not coincidental that they both **differ** from sugar by 2 hydrogen atoms and one oxygen atom **($H_2O$).**

- During photosynthesis, water and nutrients enter the leaves through the leaf vein xylem. Carbon dioxide enters the leaves directly through stomata in the leaf surface.

## Digestion

Digestion is the process of releasing stored food. It uses water and enzymes to convert insoluble stored foods into water-soluble food that can be transported.

- **$C_6H_{10}O_5$ (Starch) + $H_2O$ = $C_6H_{12}O_6$ (Sugar)**

## Respiration

**Respiration oxidizes food** and uses the energy **to synthesize fats, proteins etc**., for cell growth and reproduction. Respiration of sugar is the opposite of photosynthesis. It uses oxygen to burn sugar, resulting in water, carbon dioxide and energy. All living tissues respirate 24 hours/day, releasing water and carbon dioxide.

- **$C_6H_{12}O_6$ (Sugar) + 6 $0_2$ = $CO_2$ + $H_2O$ + Energy**
- **$C_2H_5NO_2$ (Amino Acid)**
- **$C_2H_5NO_2$ + $C_2H_5NO_2$ - $H_2O$ = $NC_2H_2NO_2O(OH)$ (Protein)**
- **Combination of 100s of complex proteins = Protoplasm**

It is a misleading statement to say that trees release oxygen during the day and carbon dioxide at night. Photosynthesis occurring during the day creates oxygen and uses all of the water and carbon dioxide generated by respiration. It appears that respiration is not happening. At night photosynthesis stops and respiration continues using oxygen and releasing water and $CO_2$. It can also be said that the oxygen created in photosynthesis is used readily for respiration.

**Respiration continues with or without sufficient oxygen**. At the leaves, $O_2$ is always available and the respiration continues as aerobic respiration. At the roots in poorly aerated soils the **lack of oxygen** can cause incomplete respiration and **form acids and alcohols.** These cannot be disposed of and will eventually **damage or kill roots**. This is the major cause of root rot in bonsai. As roots must supply oxygenated water to the rest of the tree, the trunk and branches will have a similar fate.

It is interesting to consider that seeds are storehouse of starch, proteins and enzymes. They first take on water to digest, then oxygen to respirate. Growth proceed rapidly because energy and complex molecules and enzymes are already available to create protoplasm and chlorophyll. Seeds that germinate anaerobically will die.

Considerable heat can be released by the respiration process. One tropical species has been measured to increase its ambient temperature by 80$^o$F

## Cell growth

Cell **growth stops at freezing** and is **maximizes** between **68-85$^o$ F**. Cell **death** occurs at **140$^o$ F**. Localized temperature around individual leaves can be considerable higher than ambient.

**Water** is **key** to cell **growth**. Water affects nearly every physiological process.

- It provides hydrogen for food manufacture.
- It provides the internal pressure to keep leaves rigid.
- Evaporation within the leaf cool leaves.
- Low water potential stops growth.

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