Botany for arborists: Stems

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Introduction
The primary supporting structure for a tree’s architecture is referred to as the trunk, bole, or stem. The latter, though, commonly refers to the main axis of a seedling or young tree. Branches are sometimes called stems because they share many of the same features, but in this article, the term stem refers to the main stem or central axial portion of trees, not the individual branches. Stems may form branches (scaffolds) in the lower crown which in turn produce additional branches, forming a rounded (decurrent) crown. Other trees form a central, dominant leader with lateral branches that increase in length from the top down, forming a pyramidal (excurrent) crown. (Figs. 1, 2).

A single, dominant, well-tapered stem, lacking serious defects, such as extensive decay, competing stems, crowded branches, and weak branch unions, particularly those with included bark, ensures structural stability and greater longevity. Failure due to stem breakage or root instability, typically results in a tree’s death. Having a better understanding of tree stems, their function, structure, and management practices, e.g., wound avoidance, standard pruning practices, and periodic structural pruning, will help to extend the useful lifespan of trees in urban landscapes, which provide significant environmental and economic benefits.

Primary and secondary growth: juvenile vs mature
When a tree seed germinates, its cotyledon leaves, attached to the developing hypocotyl (early stem), are the first to emerge and begin collecting sunlight to sustain growth of the developing tap root. Most trees are tap-rooted in the first year of their lives. The portion of the stem between the first root (radicle) and the cotyledon leaves is called the hypocotyl, the portion of stem between the cotyledon leaves and the first true leaves is the epicotyl. (Fig. 3) Once the cotyle-

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Figure 1. (Left) An example of an excurrent hardwood tree with a central, dominant leader. Photo: B. Hagen
Figure 2. (Center) This valley oak (Quercus lobata) is a good example of round-headed (decurrent) tree. Except for the lower stem, there is no dominant leader. Photo: B. Hagen
Figure 3. (Right) A germinating rain tree (Koelreuteria spp.) seed. Note the hypocotyl, epicotyl and first leaves emerging just above the cotyledons. Photo: Vinayaraj
don leaves fall away, the hypocotyl and epicotyl regions of the stem become less distinct. Young stems at that point are just beginning to connect their vascular bundles with their fascicular cambia, ultimately forming the vascular cambium that gives rise to wood and bark (xylem and phloem). (Fig. 4) The anatomy of this young stem is somewhat complicated because the vascular tissue is contained within fascicles or bundles, and are arranged in a ring within the stem. They are surrounded by parenchyma cells, sometimes called ground parenchyma. The phloem within each bundle is arranged to the outside, while the xylem is arranged to the inside. Since the vascular cambium is not yet formed, and growth is mostly upward (stem elongation), these vascular bundles are called primary tissues because they are responsible for primary growth or stem elongation. The young stem comes with an intact shoot apical meristem, which gives rise to the three pro-meristems: the procambium, protoderm, and ground meristem. Meristems are undifferentiated tissues that give rise to new cells and growth. The cells within the apical meristem develop into the epidermis, vascular bundles, and ground tissues, respectively. Once cells in the vascular bundles connect to form the vascular cambium, secondary or radial growth begins.

**Stem tissues**

Stems contain a variety of tissues. Pith, at the center of a stem, is a remnant tissue that can sometimes be seen in a stem cross-section. Pith is the remains of the cortex that was formed by the ground meristem located inward from the fascicles during primary growth. Since these cells lack thick secondary wall formations and are not lignified, they are usually crushed when the vascular cambium starts to produce heavy-walled secondary xylem. (Figs. 5, 6) Pith survives in some trees as a remnant hollow tube in the center of some stems and not in others. The phloem or bark is composed of living and non-living portions and includes the cork cambium and outer rhytidome layers found in some trees. (Fig. 7) Stems on some trees (especially those with thin bark) have visible lenticels in the outer bark. (Fig. 8) Lenticels...
are eruptions in the epidermis of the stem that allow for gas exchange. They’re perennial, grow for years, and are most noticeable on small woody stems. Although hard to see, lenticels continue to form in cracks in newly formed periderm.

**Morphology: branch vs stem**

Why is a stem a stem and a branch a branch? Shigo was perhaps the first to point out that branches are not directly connected to their stems in the strictest sense. According to Shigo (1986), when new branch wood forms, it grows downward until it contacts the stem. There, it flows, if you will, around the branch base, laterally and downward to a point where it coalesces with stem wood below. (Fig. 9) Later, wood produced by the stem grows downward and around the branch base, enveloping the leading margin of previously formed branch wood. (Fig. 10) So, essentially there is little or no structural or conductive connection between the branch and the stem at the top and along the sides of a branch/stem union, only at the bottom side of the branch. Wood produced annually by a branch overlaps, to some extent the wood produced by the stem the previous season. And wood produced by the branch overlaps the leading edge of the previous season’s branch wood. (Fig. 11). Thus, the branch base or ‘collar’ contains both branch and stem wood. (Fig. 12) In this manner, the overlapping of the two tissues, year-after-year, greatly strengthens the branch/stem union, providing resistance to the increasing load. The branch collar contains a branch protection zone (BPZ) that serves to prevent invasion by decay pathogens after branch injury or removal. They can be seen as cone-shaped areas of discolored wood at the base of dead branches. This is not the case for branches that are large relative to the stem. Furthermore, the strength of the branch collar is largely dependent on the comparative size of the branch to the stem. This has implication in managing risk potential in trees. The comparative size of the branch also influences the for-
Current pruning standards discourage making large pruning wounds greater than about 5 inches in diameter, and specify that branch collars be left intact when branches are removed to avoid damaging the BPZ. Branches with diameters less than that about half that of the stem they arise from are firmly attached and seldom fail. When overloaded, they typically fail beyond the branch union. Codominant stems and branches that are greater than half the stem’s diameter often split out or break within the branch collar. The reason is that codominant stems lack strengthening branch collars and the branch collars on those that are comparatively large relative to the stem, are poorly formed. (Fig. 13) So there is a compelling reason to do structural pruning early in a tree’s development and periodically as a tree grows larger. (Figs. 14, 15) Another important consideration is that codominant branches often develop bark inclusions that greatly weaken attachment strength. (Fig. 16)

Buds (embryonic leaves, flowers or leafy shoots) are formed at nodes along stems, and at the stem tip. (Fig. 17) Other meristematic points can form at other locations. Initially the shoot apical meristem forms the various procambium, then leaves and axillary buds form along young developing stem from the primary meristems. (Fig. 17) Axillary, or lateral buds, usually form between the leaf petioles and the stem they’re attached to. These dormant buds develop the following season and produce new branches. Some, however, may develop if the apical bud is removed or damaged. (Fig. 18)
Stems are also responsible for formation of latent buds that may later give rise to *epicormic* branches—those that grow from the surface of larger branches or stems, and that originate from latent or epicormic buds, just under the bark of larger stems. These *latent* buds remain dormant until previously shaded stems are exposed to direct sunlight due to loss of canopy cover, for example: excessive pruning, topping, stem failure, tree decline, branch dieback, etc. *(Figs. 19, 20, 21)* Severe stress may also be involved in stimulating latent buds. *(Fig. 22)* On larger branches and main stem there are no recently formed axillary buds to generate new stems and leaves. Thus, latent buds allow trees to recover from disastrous storm damage, topping, or excessive pruning when all or most axillary buds are removed.

When epicormic buds are stimulated or ‘released’ to grow, new shoots develop to replace lost parts of the crown. Everything that forms from these latent buds is termed the *epicormic complex*. The combination...
of all epicormic complexes on a tree are termed the epicormic composition. There are two types of epicormic buds: preventitious and adventitious. The difference between these terms is developmental: preventitious buds, which originate from apical meristems, develop exogenously (from the outside) and adventitious buds originating from non-meristematic tissues, develop endogenously (from within). (Fig. 23)

Preventitious buds are initially formed by the apical meristem and survive as a trace of parenchyma cells that develop outward perpendicular to the pith of the young stem. They survive by extending outward as the tree enters secondary growth and can be seen as traces in the wood when branches or stems are cut in transverse sections. Radial extension of the trace occurs at the same rate as the diameter growth of the main trunk, enabling the meristem to stay positioned under the bark, ready to grow when needed.

Adventitious epicormic buds develop independently of annual shoot growth or cambial growth increments, they have no connection to the pith and often are associated with callus or woundwood. Continued development of these buds can result in an epicormic trace once vascular tissues form. They can be confused with preventitious epicormic buds as their ontogeny is not obvious once they have formed and new wood is laid down.

The ability of a tree to form epicormic shoots is under genetic control. The number of buds that will form in a tree, however, is strongly influenced by environmental conditions and plant vitality. The sum of all buds in a tree, referred to as the bud bank, and part of the epicormic potential which is mostly dependent upon age and tree species. Epicormic potentials can range from 50 to 300 meristems per meter of stem. These buds can be arranged in stems according to different strategies, some forming as multiple axillary bud clusters that later become epicormic complexes. Others form in the bark along meristematic traces, and still others form as isolated buds, randomly arranged along the stem. The release of epicormic buds for growth is stimulated by different factors such as plant stress, loss of vitality, increased light levels, and changes in tree architecture.

**Variations in shape due to loading**

Stems generally are cylindrical in cross section. However, all trees tend to taper at the base. (Fig. 24) The degree of taper varies again with genetics, as well as exposure to wind. Consider the wide buttressing stem root complexes of the banyan tree compared to some conifers or Eucalypts that taper very slightly as they enter the ground. Taper is widely considered response growth to stress imposed by gravity and stem weight, but mostly stem movement acting on the vascular cambium near the tree base. Uniform response growth to bending stresses (lateral force, such as wind, acting along the stem) results in a flared trunk base or buttress, imparting greater resistance to stem bending and breakage. Trees exposed to strong prevailing winds from one direction develop elliptically-shaped lower stems to prevent breaking. As Claus Mattheck has shown in his *Body Language of Trees*, the main stem responds to movement, exposure to strong wind, structural weaknesses, lean and partial failures, and defects like decay, cracks, bark inclusions, etc., by developing response growth—deviations from the normal cylindrical growth pattern. (Fig. 25) Thus, abnormal

**Figure 22.** A profusion of epicormic shoots typically develops following a heading cut. Such sprouts are weakly attached, but their attachment strength increases over time. *Photo: B. Hagen*
shapes and growth responses can be used to visually access potential risk in trees, particularly in conjunction with newer technology such as sonic tomography to quantify instability. Unusual bulges or distortions of the main stem should be carefully evaluated for underlying defects. (Fig. 26)

**Function**

Stems have a number of functions: the most obvious being the main support for a tree’s crown structure. They provide the framework for holding the leaves that collect sunlight to make energy. Another extremely important function is to absorb and dissipate wind energy. Recent work by James and others, shows that stems of trees act to dampen or dissipate, thereby protecting trees from breakage. Branches within the crown move independently of each other helping to reduce movement of the branches and main stem caused by wind. They detune the tree from harmonics (oscillations) that could potentially result in stem and branch breakage during high wind events. This brings into question the practice of excessive thinning, and ‘lion’s tailing’ which alter wind-movement dynamics, reducing the damping effect of branches on the movement of larger branches and ultimately the main stem. (Fig. 27) This can result in greater wind-loading on the remaining branches, potentially increasing the likelihood of branch or stem breakage.

Stems conduct water and nutrients upward in the xylem to the leaves and photosynthesize downward to living cells in the stems and branches, fruit, and other growing areas, including the roots of a tree. The physiological active transport tissues (xylem) may only be a few centimeters thick. This is why even shallow girdling can kill some trees. The remaining biomass is non-living and non-conductive. Stems also function to store carbohydrate made by the leaves. Carbohydrates (sugars) are transported by the phloem then inward through the rays of the phloem and xylem to living cells in active sapwood where it is converted to starch for storage and later use. In times of need, the starch can be converted back to sugar and transported to where it is needed—usually meristems.

There is growing concern regarding elevated and increasing levels of...
Pruning branches only as needed, keeping cuts few in number and small in size (generally less than about 3 inches in diameter) and avoiding damage to the branch collar (swollen branch base) are some precautions that will help maintain tree health and promote longevity. Stems are naturally protected by their outer bark which prevents desiccation and invasion by most pathogens. Therefore, it’s important to avoid wounds that expose the inner bark or wood to drying and colonization by wood decay fungi. Trees, however, are well-adapted to defend themselves against most pathogens that enter through small wounds. Large wounds, though, are more problematic. The bark and wood of stressed trees, however, can be penetrated by wood boring insects and canker causing fungi. Keeping trees well hydrated will help them maintain natural pest resistance to such pests and pathogens. (Figs. 28, 29)

Figure 28. (Left) Large pruning cuts, and those that damage the branch bark ridge often lead to serious stem decay. This tree will be too unstable to retain in the near future. Photo: B. Hagen

Figure 29. (Center) The watery exudate on the bark of this white alder (Alnus rhombifolia) is a sign that the larvae of alder borer (Agrilus burkei) have begun to tunnel through the bark. Photo: B. Hagen

Figure 30. (Right) The larval galleries of the Pacific headed borer (Chrysobothris mali) have destroyed the phloem of this oak that had declined due to severe drought. The oval tunnels in the wood are where the larvae pupate and then exit through smaller round holes in the bark. Photo: B. Hagen

Figure 31. An example of a properly made pruning cut. Note that the collar is still intact and the cut is comparatively small. Photo: B. Hagen
of the best management practices to emphasize when pruning. (Fig. 30) Branch removal cuts should be made outside the branch collar. The branch bark ridge between the branch and stem generally marks the location for starting the pruning cut. From there, the cut should be angled downward to just outside the often swollen branch base. (Fig. 31) You may have to approximate the branch bark ridge because it may not be obvious.

Cutting outside the branch collar helps to preserve the natural branch protection zone within the branch collar that effectively prevents the entry of wood pathogens. (Fig. 32) If you’re in doubt about how to make proper pruning cuts get a copy of the ISA Tree Pruning —Best Management Practices, 2nd edition, or a copy of Ed Gilman’s An Illustrated Guide to Tree Pruning, 3rd edition. Prune early during structural development and frequently so that cut size is small. The best approach is to emphasize the structural development which focuses on:

- improving tree structure to minimize risk of failure
- developing and maintaining a single dominant stem by removing or subordinating (shortening) competing branches, and those with included bark. (Fig. 33) Subordinating branches that are greater than 50% percent of the diameter of the main stem. This slows their growth and ultimately increases branch attachment strength.
- ensuring that retained branches are distributed horizontally and vertically around the stem
- eliminating weak structure to reduce the likelihood of tree failure.

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