Pruning Trees:

Anatomical, Biological & Structural Foundations

-- a training manual --

Dr. Kim D. Coder
Professor of Tree Biology & Health Care
& University Hill Fellow
Warnell School, University of Georgia

UNIVERSITY OF GEORGIA
Warnell School of Forestry & Natural Resources

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INTRODUCTION

Most values people desire and appreciate from trees come from an elevated, full, and well distributed canopy of leaves. A tree crown is the volume occupied by living branches, twigs, and leaves. Tree crowns are manipulated by pruning. Young tree crowns are managed through a process of training where a short pruning cycle is used to maximize biological efficiency. Pruning is designed to minimize current and future liability issues, both biological and structural.

Pruning is a tool which can generate both good and bad results. It is the tree-literate arborist's or tree health care specialist's responsibility for correctly applying pruning treatments. Pruning is used to maintain tree values, help trees appreciate in value over time, and minimize liabilities. Proper pruning increases tree owner and user value perceptions of management while minimizing structural problems, and accentuating health. Given the positive values which can be generated by a correctly pruned tree, it is critical to carefully consider every cut.

Training Trees & People

There are many pruning criteria and guidelines. Most organizations which deal with trees adhere to, or have developed, detailed tree pruning specifications. Some specifications are primarily based upon biology and structure, while others are based upon aesthetics or utility. Some specifications deal with only one management class of tree like newly planted, historic, large, or storm damaged trees. Among all pruning specifications, there are a number of common foundation principles based upon tree biology, structure, and human design aesthetics.

A key issue in correctly applying any pruning treatment is how to quickly allow new people to understand branch and stem manipulations used in reaching given tree and site management objectives. Workers with more experience may also need to be reminded about how changing scientific findings continue to impact tree pruning treatments. Educationally, the basic scientific and design foundations of tree pruning must be presented in simple multiple steps which build on each other, not a simplistic set of hard rules. Trees are pruned by the educated mind not a saw.

Foundations

The prescription process presented here is designed to help both novice, and more accomplished tree health care provider to be on-target when applying pruning treatments. Presented here is a pruning algorithm (a progressive step-by-step process) for understanding how and why young trees can be pruned into a biologically efficient, structurally sound, and aesthetically acceptable form. This process concentrates on design pruning for young shade and street tree branches following classic architectural design (i.e. arboritecture). This classic design and biologically anchored pruning process is applied to the above ground portion of a tree and does not concern root pruning.

Pruning foundations built here provide for intellectual expansion to meet and exceed changing management objectives while defending tree health and structure. The complexities of individual business pruning standards and unique organizational pruning practices are left for more specific and proprietary trainings. The process outlined here is an educational tool designed to help people competently and confidently understand pruning of trees under community forest, amenity, utility, or health maintenance circumstances while meeting aesthetic targets.

BRANCH CONNECTIONS

Branches are connected to trees through a growth process where both stem and branch generate new tissues which are intermeshed with each other. Growth regulators and carbohydrate flow from photosynthesizing leaves provide stimulus, energy, and storage materials at the juncture of stem and branch tissues. One way to consider this stem branch connection is by viewing the process as a water flow problem in pipes (Figure 1), or in a stream and its tributaries. A stream contains water flowing downward in a channel. A tributary has water flow which joins the stream, generating a turbulent area where both water flows interact with each other, and the tributary waters change direction and turn to flow down the stream channel. The place where the two water flows meet is a confluence.

Confluence

In trees, all the crown above (toward tip or more apical) a branch connection is generating and transporting carbohydrates and growth regulators down the stem (toward base or more basipetal). This is a stem flow of growth / energy resources. (Figure 2). A branch also represents a downward flow of resources from its leaves. The place where branch and stem meet is a confluence of resource flows. It is staggering to think of all the production from hundreds of twigs flowing into, and being consolidated within, the thin layer of active phloem of branches, and all the branch productivity flowing downward and being consolidated within the active phloem of a stem.

Each confluence of resource or material flow represents a resistance or constraint to flow, and a change in relative direction. A confluence can be thought of as an area of transport turbulence and friction. Figure 3 demonstrates the stem and branch phloem continuity beneath the periderm across all exterior living surfaces of a tree. The branch xylem (wood connections) descent from a branch into the stem generates both a branch tissue tail and a stem xylem branch gap below the branch base. Branch xylem tissue does not connect with stem xylem above the branch base, but grows into the stems and downward.

Stem-Branch Union

A confluence of a stem and branch generates a number of growth features which are used to apply proper pruning, and assess branch health and structure. Figure 4 shows a branch attached to a stem. Each year both the stem and branch grow in diameter producing an area of interlaced tissues called the stem flange and generates, and adds to, a defensive zone in the confluence zone. This interlaced tissue area helps define the limits of branch and stem interactions. The functional result is generation of the most efficient and quickest way to transport materials past the confluence by phloem while effectively sustaining biological and structural branch effectiveness.

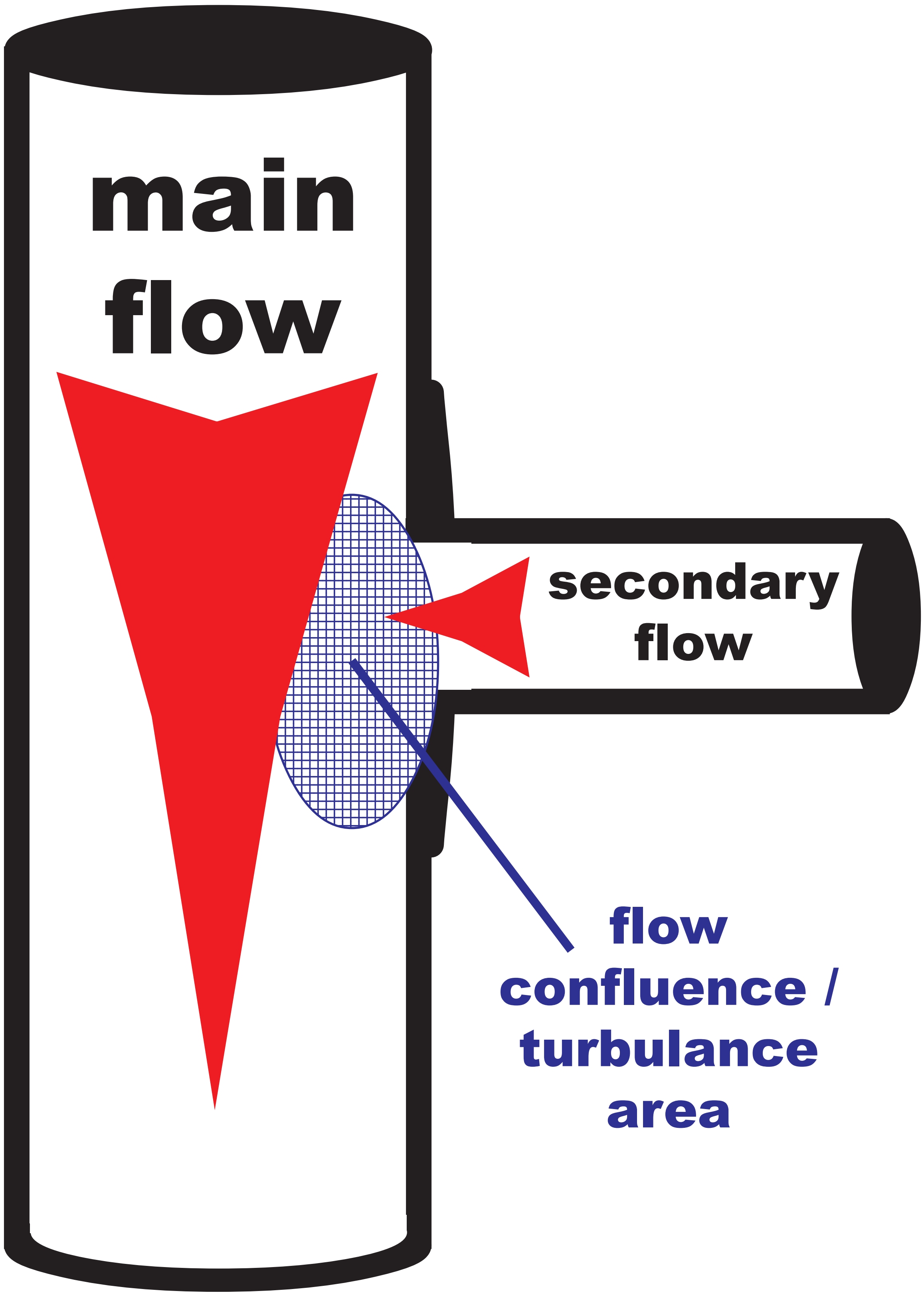

Figure 1: A pipe model of material flow and a confluence of two converging flow pathways.

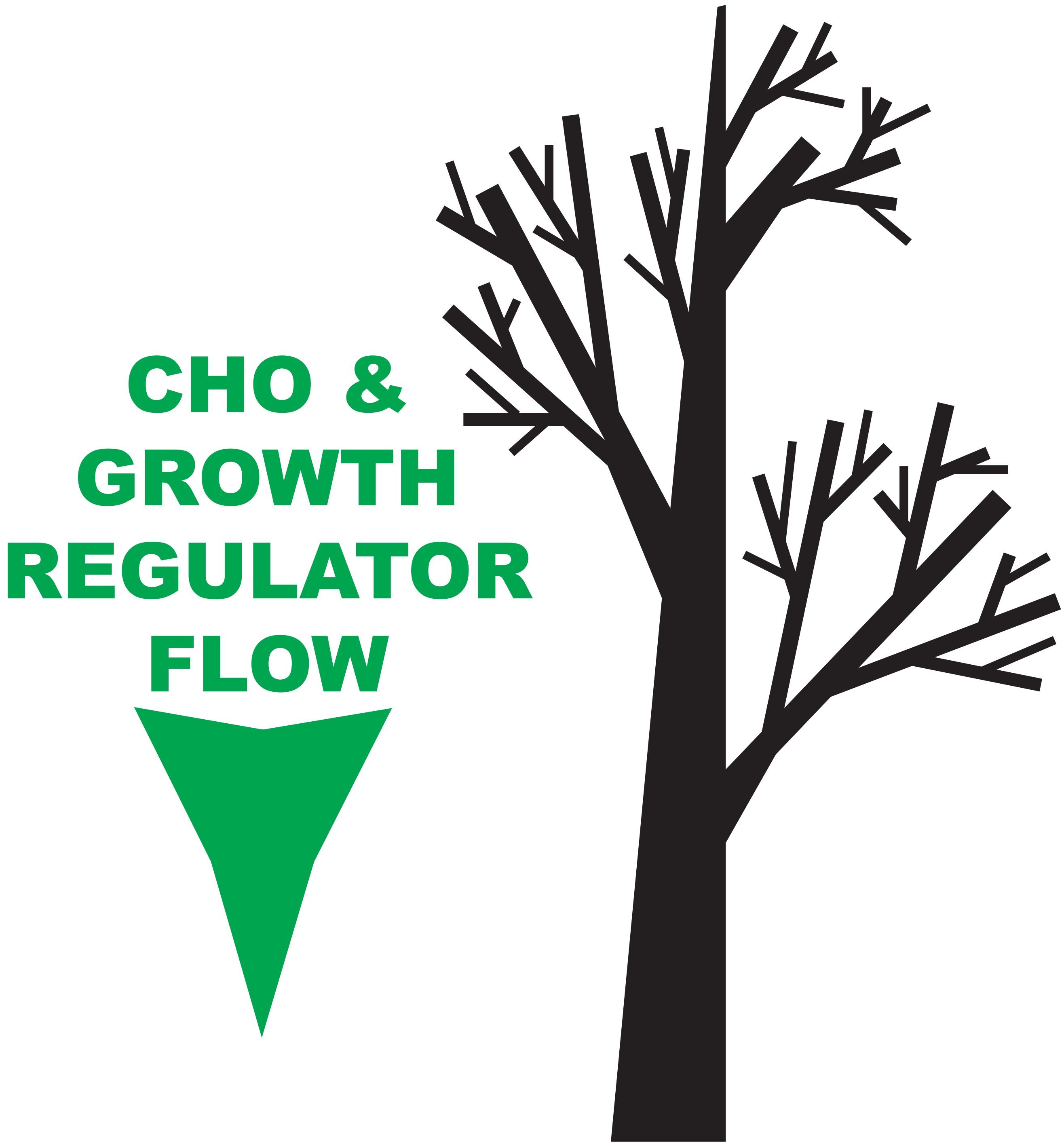

Figure 2: Leaf production of carbohydrates (CHO) and growth regulators flow through a series of progressively larger twig and branch confluences until reaching the main stem. Each confluence represents a restriction to resource movement and a defensive zone.

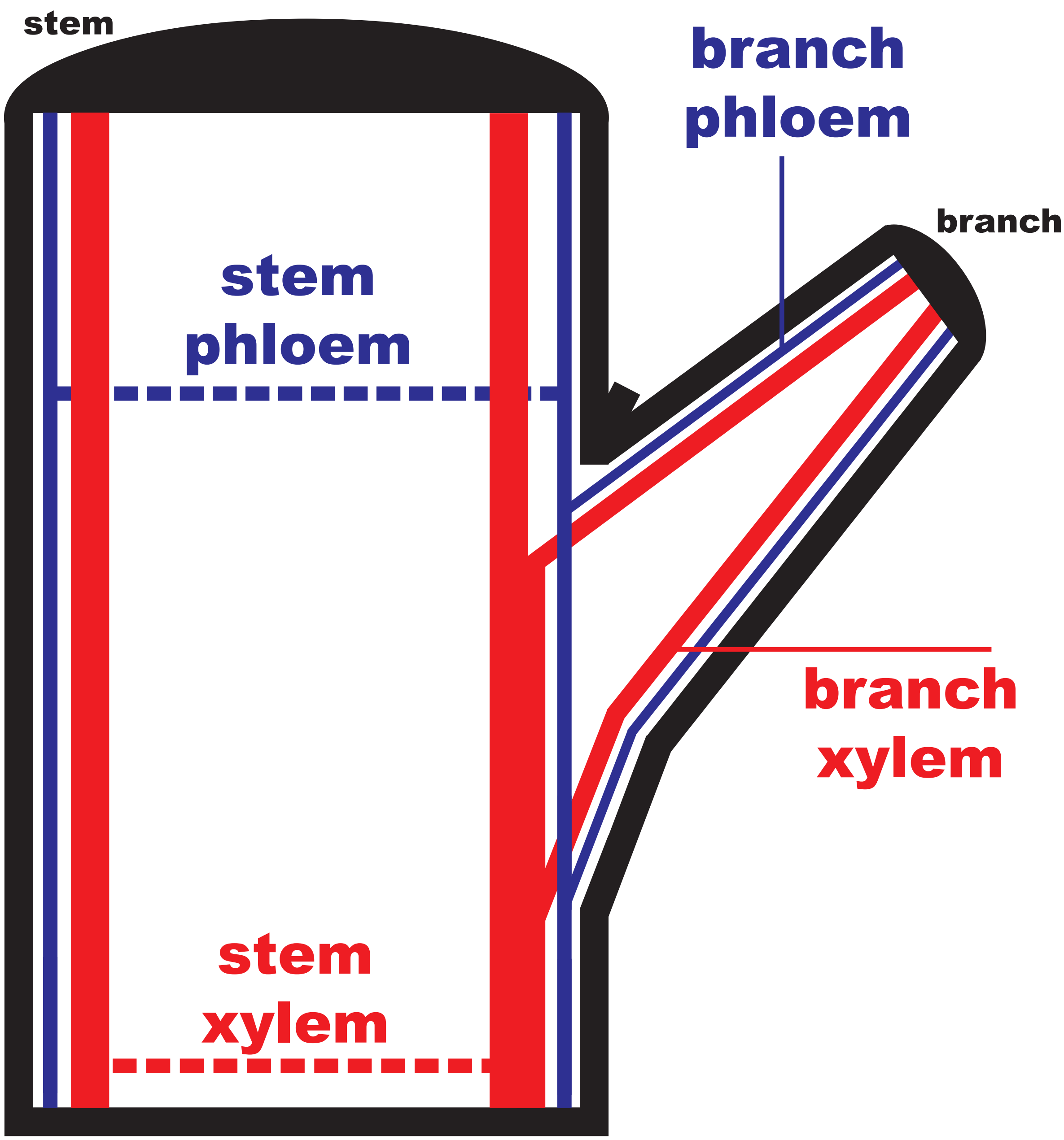

Figure 3: Stem and branch phloem continuity beneath periderm across all exterior living surfaces of a tree. Branch xylem descent from a branch generating a branch tissue tail and stem xylem branch gap below the branch base. Branch xylem tissue does not connect with stem xylem above the branch base.

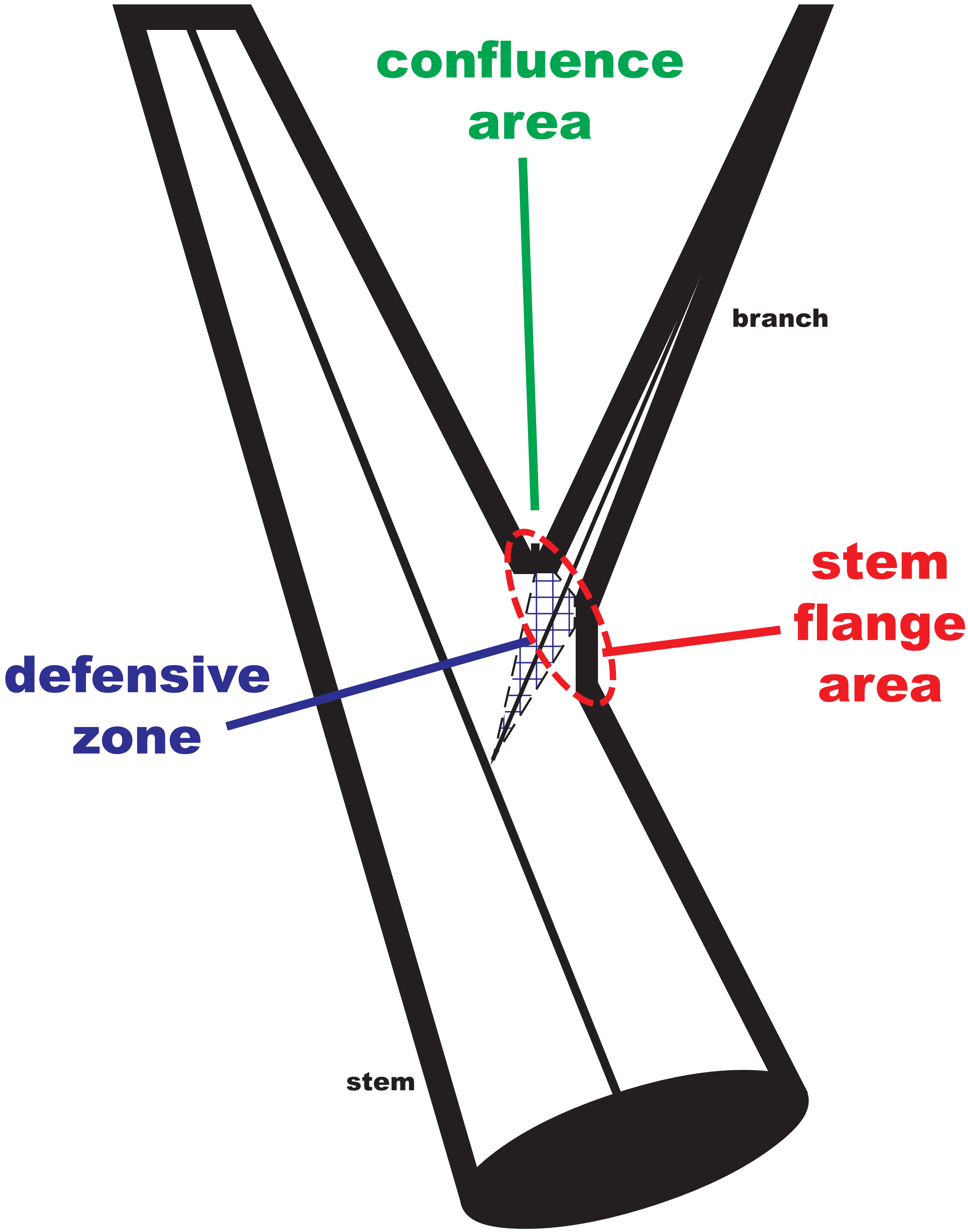

Figure 4: A confluence between a stem and branch. The branch shows developed pruning targets. The stem has a consolidated stem flange and defensive zone surrounding the base of the branch.

A simple way of thinking about stem-branch connections is by appreciating growth material flow through and around the confluence area. Branch materials are being transported toward the stem and then flow downward within the stem-branch phloem at the confluence. (Figure 5). Stem materials from further up in the crown are flowing downward past the confluence area. The stem tissues approach and change orientation swirling around the topside of the branch base, flowing down the branch base sides until the stem tissue pathways eventually reunite a short distance below the confluence. In some trees this area below a confluence shows a quickly closing longitidinal crevice or indentation representing stem tissue closing after parting to grow around branch base tissues.

Interconnections

Branches are unique features in trees. They are designed to be flexible, able to undergo lifting forces, downward loads, and a twisting figure-eight shaped sway motion in lateral wind. Branches hold leaf arrays within resource containing volumes to allow capture and control of any growth resources present. If branches do not maintain net food production and growth regulator flow out of the branch, compartmentalization processes are initiated which limit, then seal-off resource supply lines. As branches become shaded, lose water and nitrogen supplies, or are damaged by pests or injury, branches are closed down (senescence) and die. Only a few twigs and branches are ever successful. The rest are sealed-off when young and the environment (or humans) eventually remove the branch from a tree.

A branch is connected to a stem with highly interlaced and overlapping stem and branch tissues. Each year at the base of a branch, branch tissues are held onto a stem and change orientation to transport materials downward. Stem tissues flow around the branch base. Stem tissues provide support for the branch base, and branch base tissues are surrounded by stem tissues. Each year a new growth increment invests the branch and stem union area with overlapping and interlaced tissues. The branch becomes greater in diameter every year as the stem becomes bigger every year. The confluence area becomes larger in tissue volume. A stem-branch confluence allows branches to be productive while allowing the whole tree to control growth, defend itself, and remain structurally sound.

Flanges

As branch and stem tissues flow around and down from the branch base, an enlarged area of reactive tissue is maintained. This enlarged area of stem and branch tissue both surrounds the branch base and is part of the growing stem tissues of the stem-branch confluence. The tissues involved in this cooperative venture of maintaining a branch on a tree stem is called the stem flange (i.e. branch collar, stem-branch collar, stem-branch nexus, union, convergence area). (Figure 6). On the underside of a branch, as branch tissues enter the stem and turn downward, the branch base noticeably increases in diameter beyond branch diameter. The tissue growth on the branch underside as it approaches the stem is part of combined supporting stem and branch tissues. This part of the stem flange may be visible for some distance along the branch underside.

Because branches get larger in diameter every year, and the stem gets bigger in diameter every year, there is an area on top of a confluence where living tissues are close to the surface and periderm is being generated quickly to cover the site. Growth pressures in this area caused by the branch and stem tissue confluence and associated localized periderm growth, causes a visible disruption of confluence growth / expansion patterns visible as a periderm (i.e. bark) union. (Figure 7).

Periderm Unions

A periderm union is initially formed on the top (adaxial) confluence of stem and branch, and represents a sensitive and damage-prone point in a tree. Figure 8 demonstrates over time how localized periderm growth,

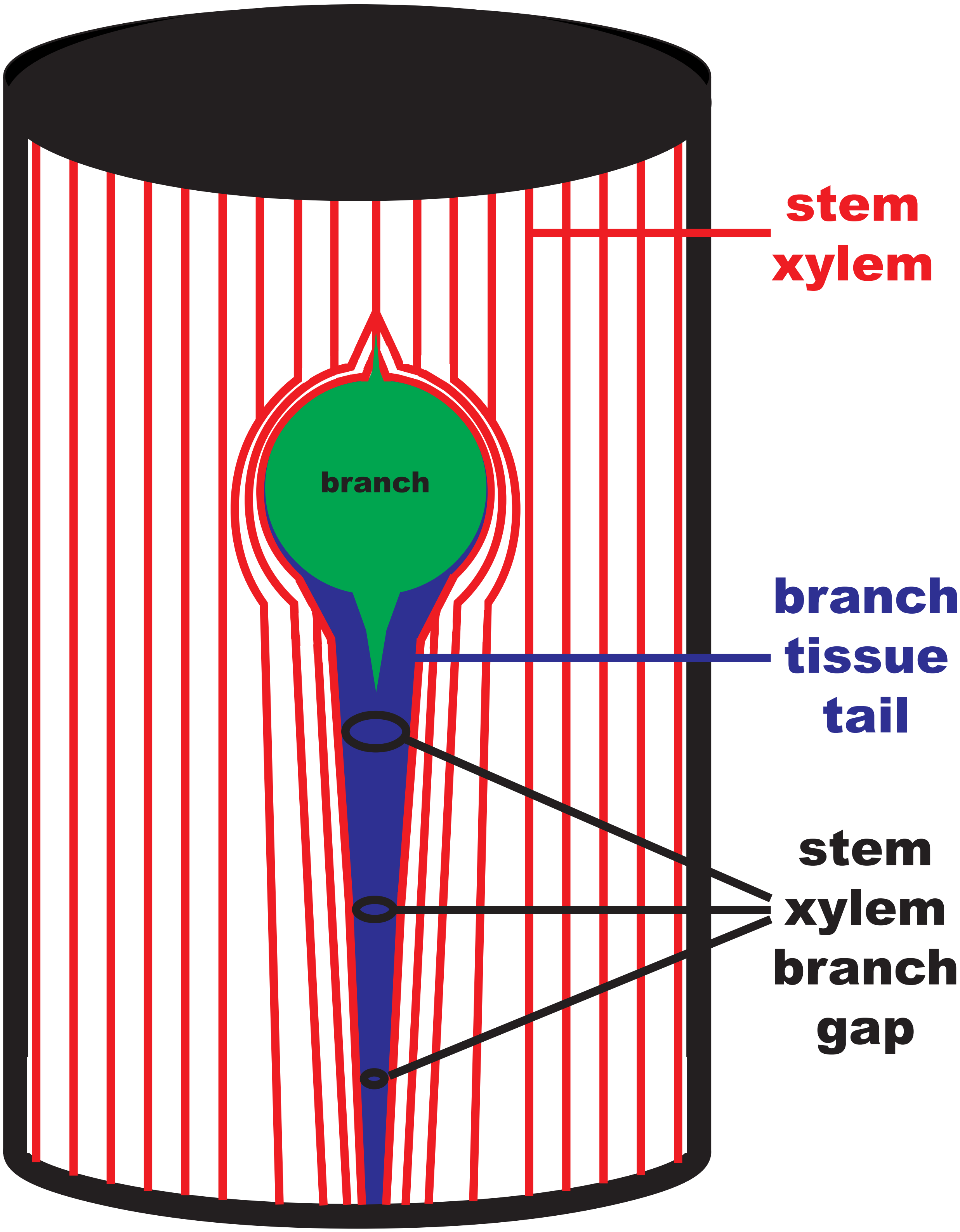

Figure 5: Tail of branch xylem below branch and gap in stem xylem flowing past branch. Stem tissue path disrupted by branch.

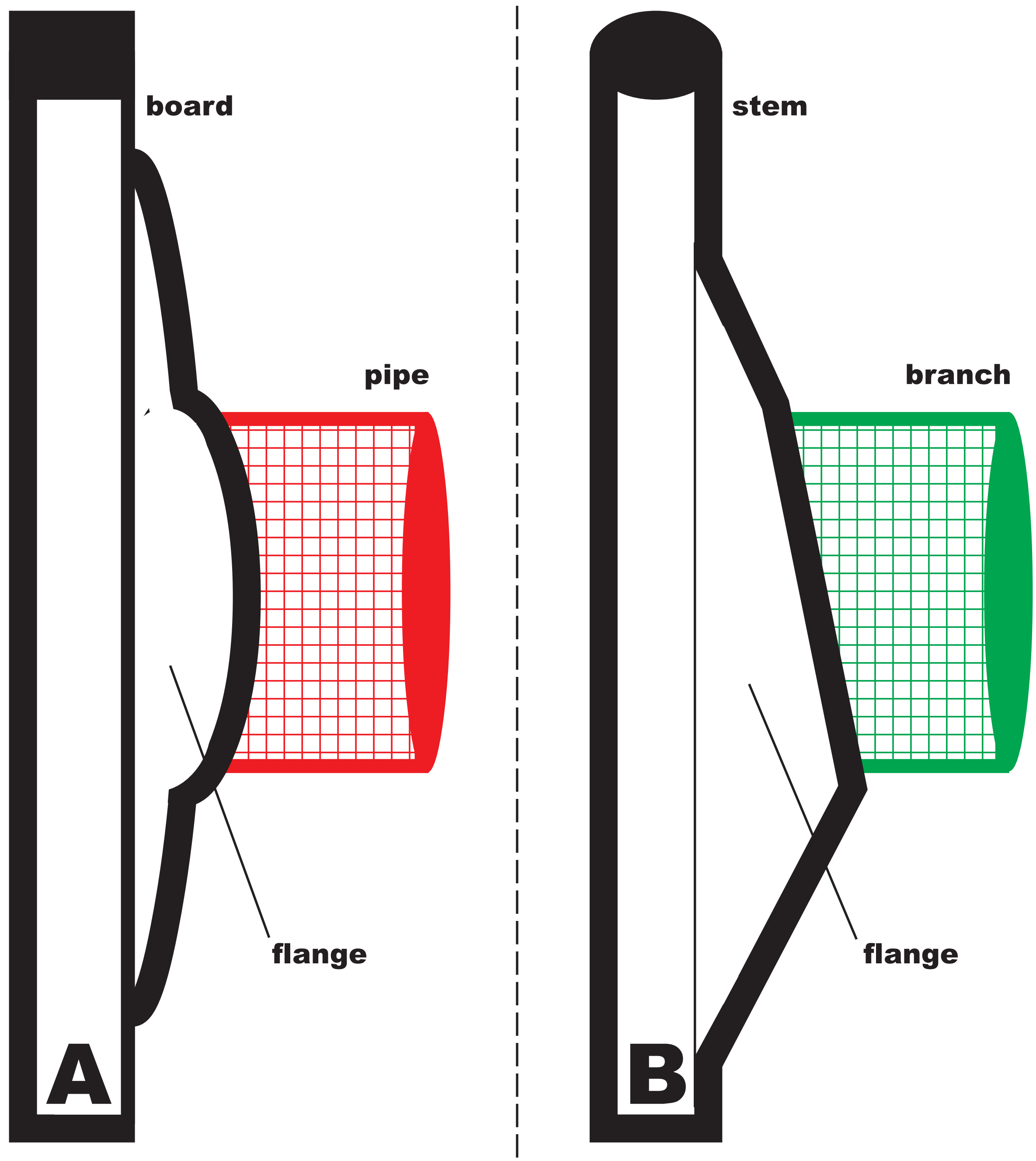

Figure 6: Descriptive model of a pipe held onto a board with a flange (A), and a branch held onto a stem with a combined tissue area acting as a flange (B).

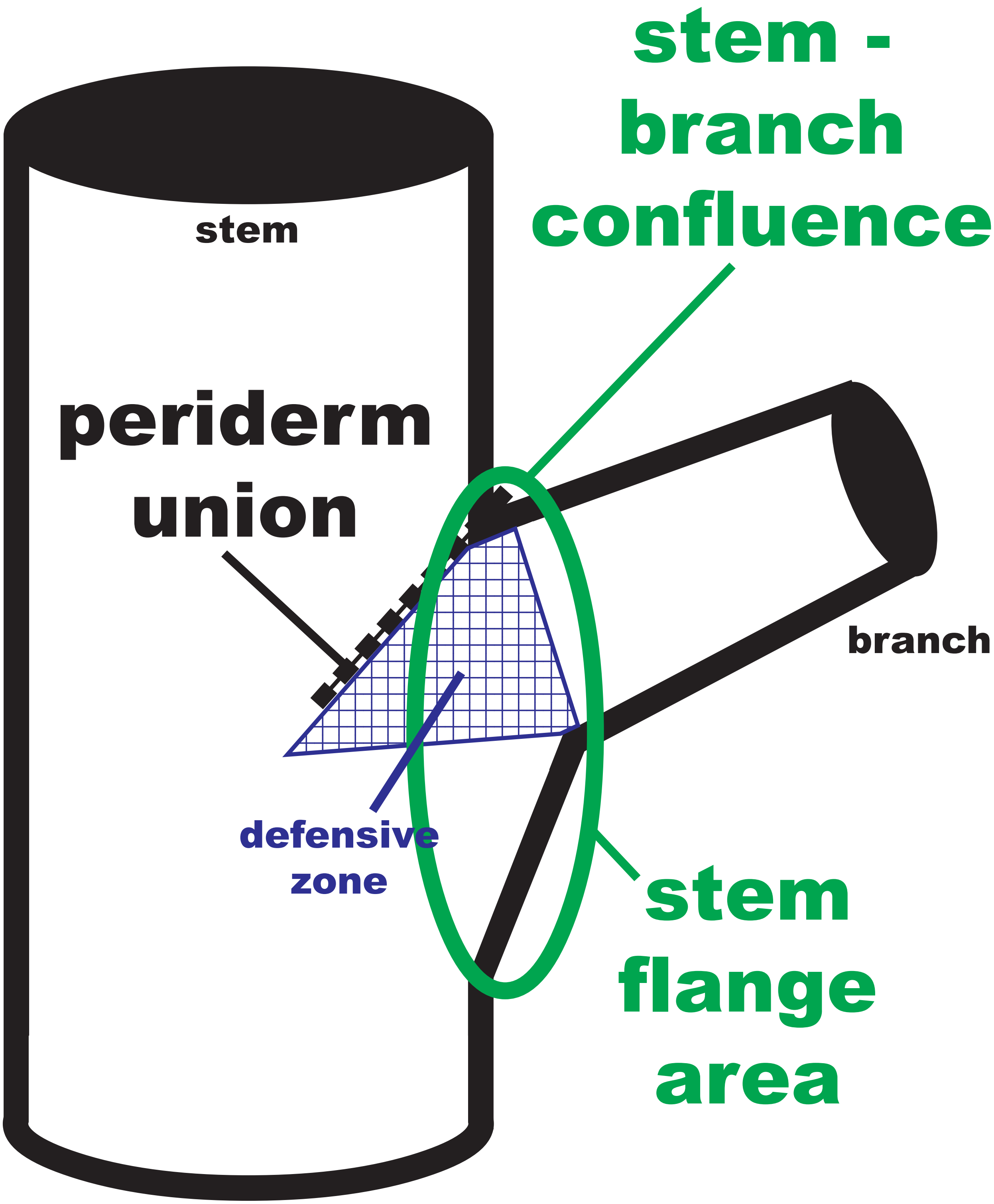

Figure 7: Diagram showing stem - branch confluence and stem flange area (within oval), with periderm union and defensive zone.

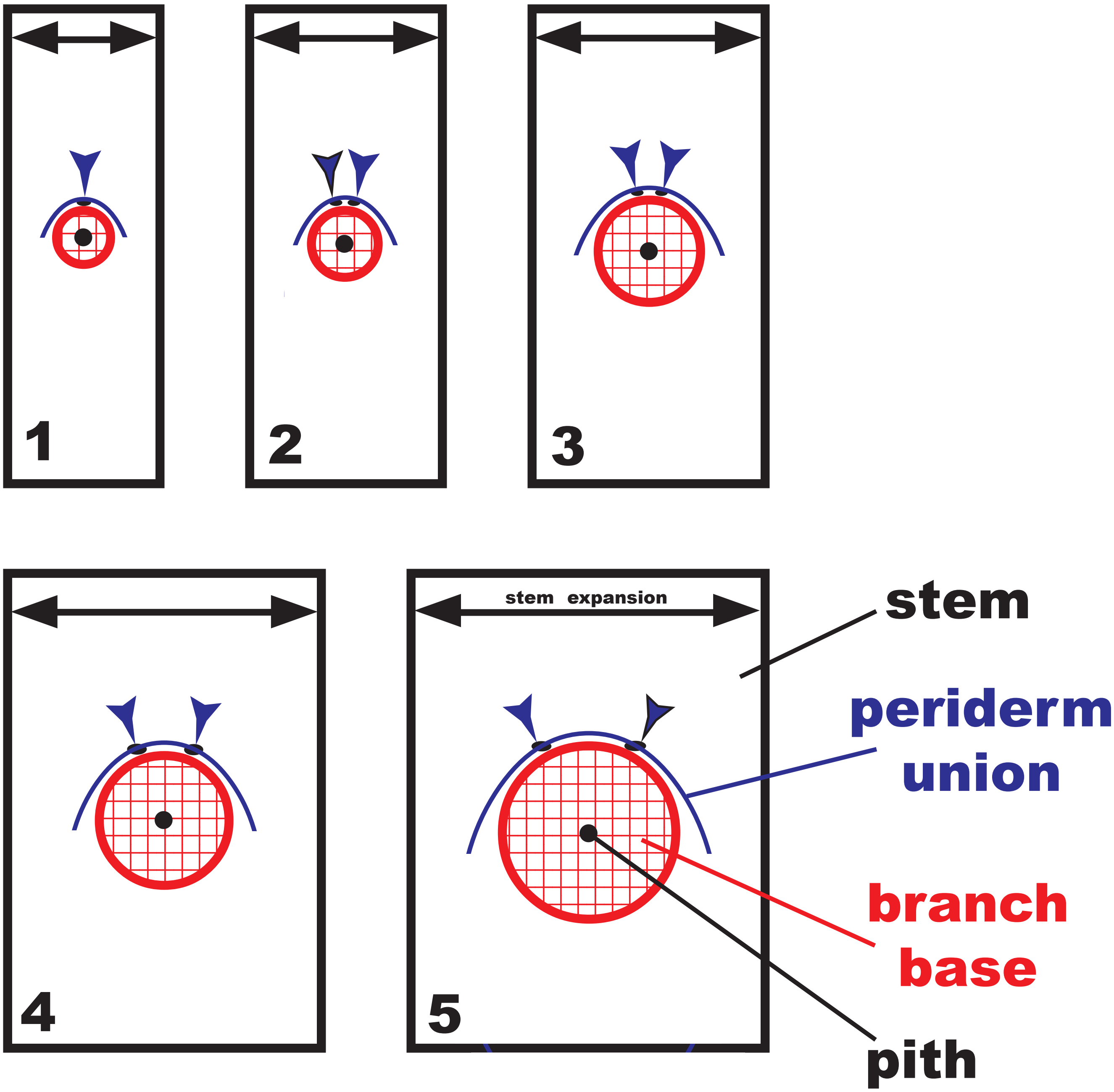

Figure 8: Diagram representing circular cross-sectional areas (shaded) of a branch base at the confluence with a stem over time (#1 is youngest / smallest size). A periderm chine is initiated at the topmost position over the branch (#1 -- note arrow point) where tissues of stem and branch grow against each other. As both stem and branch grow in diameter (#2 - #5), points of the same age diverge along the

underlain by interleaved multiple tissues, expands and extends over time. This topmost area of the stem - branch confluence is the periderm union or periderm ridge (i.e. branch bark ridge (BBR), stem bark ridge, branch union bark ridge). As both stem and branch grow, as in an expanding balloon, adjacent points on the circumference grow apart. A periderm union can be seen arcing over the top side of every branch base and represents limited and incomplete branch history by its length and angle.

The periderm union, or localized periderm growth area, is usually rapidly growing, covering new stem and branch tissues. The growing / expanding areas of stem and branch push against each other at the top of the confluence generating a periderm chine, which is an outward growing, pushed-up ridge. Figure 9. The phellogen (i.e. periderm cambium or cork cambium) is regenerated rapidly to prevent exposure of secondary cortex and phloem. Sometimes, due to growth regulator transport problems and physical constraints of a narrow and confining confluence area, phellogen can become folded in upon itself, generating periderm to peridem contact (included "bark") inside the confluence area.

This aberrant periderm growth form fails to produce a normal outward growing periderm ridge or chine, and instead leaves a visible indentation, fold, or rimple. (Figure 10). This process of forming a folded rimple yields periderm inside the confluence area called "included bark" or "included periderm." Included periderm weakens the stem flange area. These types of periderm rimples are telltale signs of structural problems at the base of a branch, and are usually pruned away in young trees.

Nodes

Trees are modular and segmented organisms. They grow discrete parts and pruning removes these parts. One means to think about trees is to liken their crown structure to an antique childrens' toy generically called "tinker toys". These construction toys were made of round pieces with many insertion holes, and various lengths of straight sticks. With just these two components a child could construct many three-dimensional shapes. The rules were simple for construction, a stick could not be held by a stick and a round block could not hold another round block, but alternating these components allowed for construction. For trees, the round blocks represent multidirectional nodes and the straight sticks separate these nodes by some distance (i.e. internodes).

In trees, everywhere a leaf, bud, or twig emerges is a node -- a place where tissues have been redirected to connect and support tissue growth. In between nodes are straight twig, branch and stem segments -- called internodes. (Figure 11). On any small branch there will be lateral branches, lateral buds, new sprouts, and leaves. Each of these organs arise from a node and are separated by internodes. Nodes are areas in trees where many ray cells and transport tissues are concentrated to support, supply, and defend tissues growing in new directions. Nodes are centers for strong defensive reactions, closing off more distant tissues if they are not productive. Internodes have limited defensive capabilities, especially along their longitudinal axis. Damaged internodes usually are sealed off at the nearest stem-side node.

Defense

One component of pruning which must always be kept in mind is the capacity of living tissues which remain after a pruning cut to defend themselves A strong compartmentalization response is essential to prevent compounding and collateral injuries at the pruning wound site. Key to understanding a tree's defensive response is the conical shaped defensive zone behind the pruning wound face comprised of interlaced older stem and branch tissues.

This defensive zone acts to minimize loss of valuable electrons from within living tissues, minimizes water loss, and resists attack from other organisms seeking entry into a tree. Figure 12 shows where a defensive zone exists and can be more fully developed behind a pruning wound for a small diameter branch.

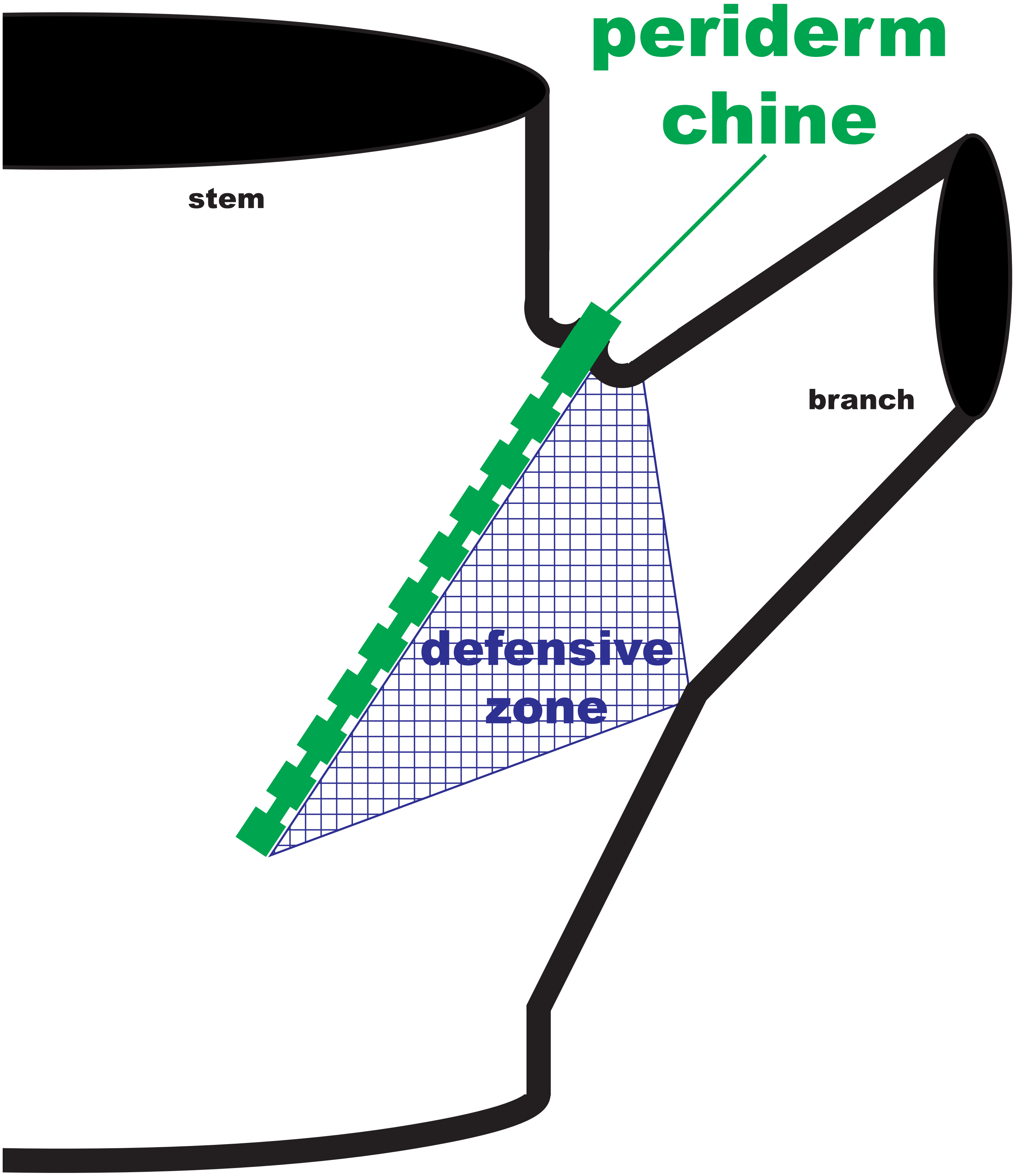

Figure 9: Upper side of a stem-branch confluence (flange area) with a periderm chine (i.e. ridge or crest).

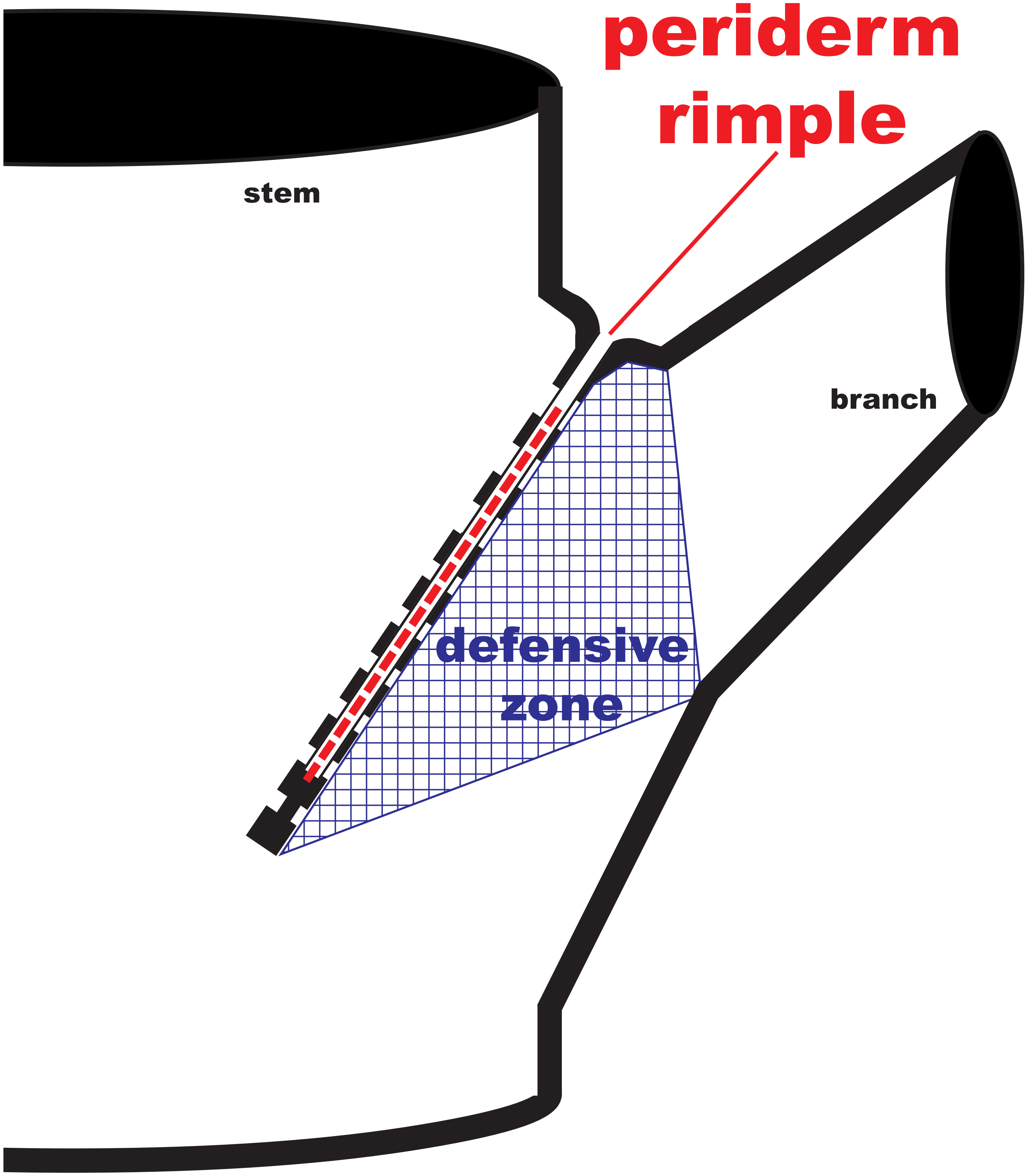

Figure 10: Upperside of a stem-branch confluence with a periderm rimple (i.e. fold or wrinkle). The rimple periderm union can contain periderm tissues folded inside and grown over.

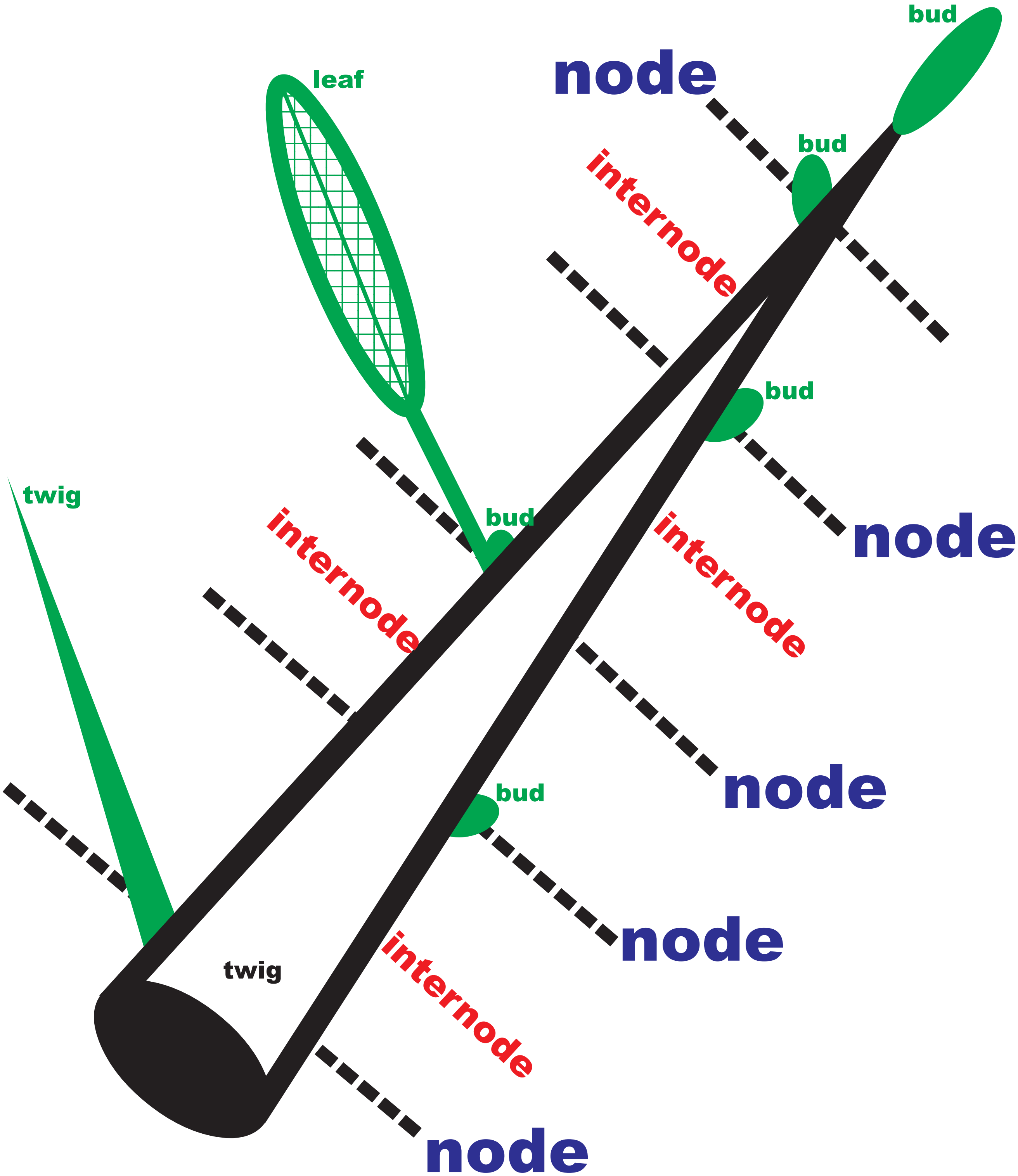

Figure 11: Diagram of twig with five nodes and four internode areas identified along a short length. Internodes are spaces or twig lengths between nodes. Nodes are where buds, leaves, sprouts, twigs, or branches develop.

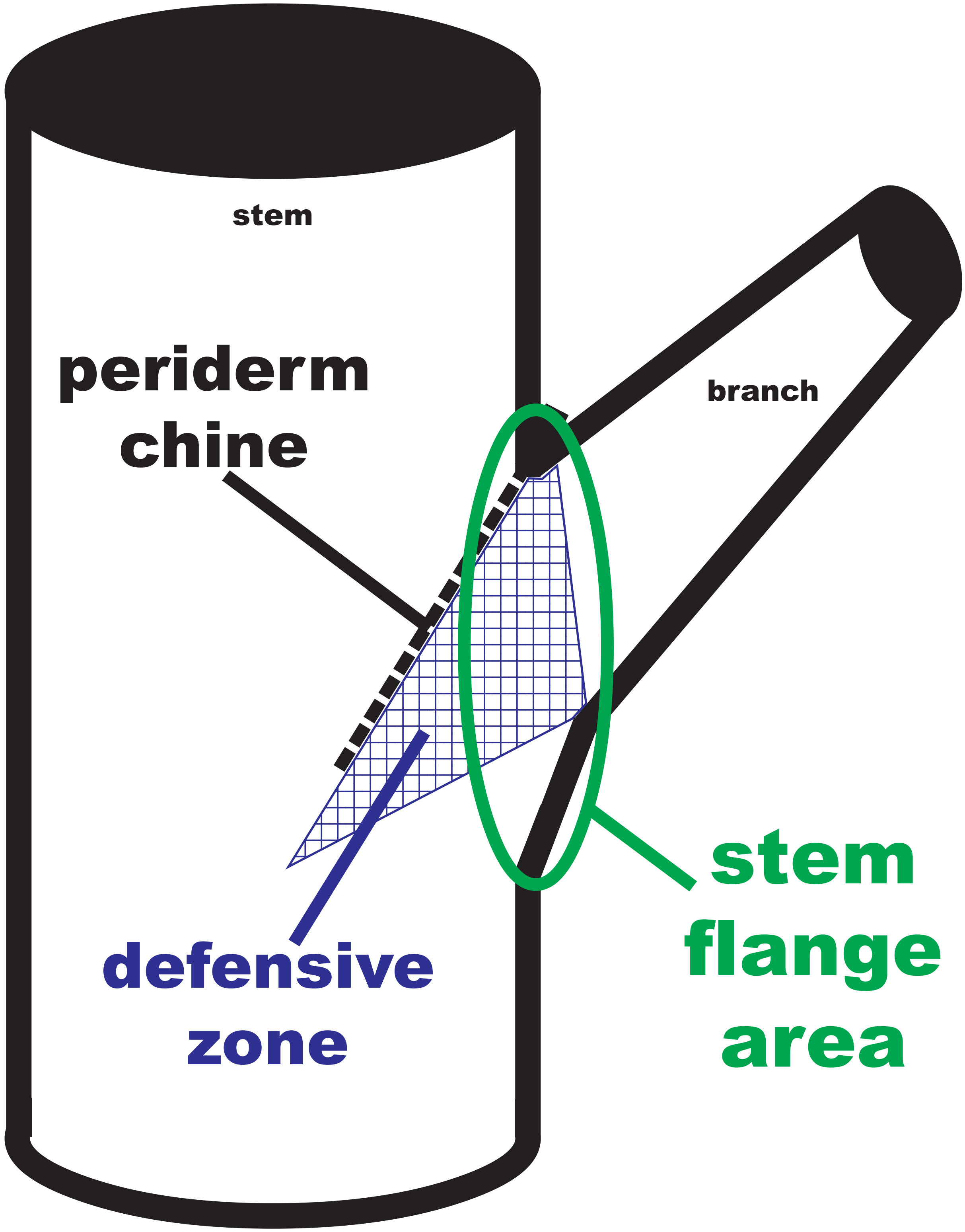

Figure 12: Stem flange or confluence area showing the periderm chine (bark ridge) and defensive zone (shaded) on a normally proportioned branch.

Remember these two-dimensional diagrams are representing three dimensional, conically shaped volumes from multiple years of growth.

Forked stems (multiple upright stems) and codominant branches (branches growing from other branches or stems which have nearly the same diameter at the confluence) have defensive architecture compromised by rapid relative growth rates and physical diameters of their connections, and by slowed / more ineffecient reactivity. Forks should be removed early in a tree's life. (Figure 13). Forked stems and codominant branches do not effectively develop defensive zones at their bases. Pruning of a codominant branch leaves a tree in a poor defensive position to deal with wounding. It is clear branches should not be allowed to reach basal diameters approaching the diameter of a stem where they are attached (i.e. codominance).

PRUNING CUT FOCUS

Figure 14 provides a graphical definition of branch diameter limits for pruning. Figure 15 is a diagram showing the largest branch size to be pruned should be less than one-third to one-half stem diameter at the confluence. Remove branches as they approach or exceed this diameter ratio. (Figure 16). Delaying pruning of large diameter branches (codominant branches) can lead to many problems for a tree both in the short and long run. Early prevention of codominant branches is essential.

For branches which have well established stem flanges, and are 1/3 to 1/2 the diameter of the stem where they are attached, a proper pruning cut is essential. Depending upon size and weight of a branch, either a one-cut or three-cut pruning process can be used. A three cut method, sometimes called the Davey, Shigo, or target pruning cut, identifies specific structural targets in the stem flange area.

Collared

Note, any final pruning cut is always applied immediately outside a stem flange. The stem flange is blended tissues of stem and branch growing together at the confluence. (Figure 17). A stem flange helps stitch the branch onto a stem or larger branch. The outside edge of a stem flange can be identified both on top and bottom of a branch just as branch tissues enter a stem. Figure 18 shows the primary defensive zone in the sapwood, and secondary defensive zone in the heartwood at the base of a branch. Heartwood-bounded defensive zones (secondary defensive zones) are not as effective as active primary defensive zones in defending the tree because the tissue is dead.

The bottom branch-side edge of the stem flange can be seen as a slight swelling of tissues on the branch underside just before branch tissues enter the stem. Never nick or cut into this area. The upper branch-side edge of the stem flange can be seen outside the periderm union just before branch tissues enter the stem. The stem flange begins at a point where the upper side of a branch base starts to swell or curve up forming a periderm chine. Figure 19 shows a diagram identifying pruning targets on a confluence. Never cut on the stem side of the periderm chine, on the periderm chine, or the branch side swelling which pushes up into the periderm chine.

The stem flange area is composed of both branch and stem tissues. Never nick the top or bottom of the stem flange. Pruning should only remove branch tissue, not expose and damage stem tissues any more than possible. In addition, do not injure stem tissues in the confluence area with the back of a saw. The goal is to find the stem flange targets (or outward limits) the tree provides in any confluence, and then cut just to the outside / beyond the target marks or line. Prune outside the stem flange on branch tissues a minimum width of one to two full saw kerfs, missing the identified targets. These tree defined targets are meant to be missed in pruning -- not hit.

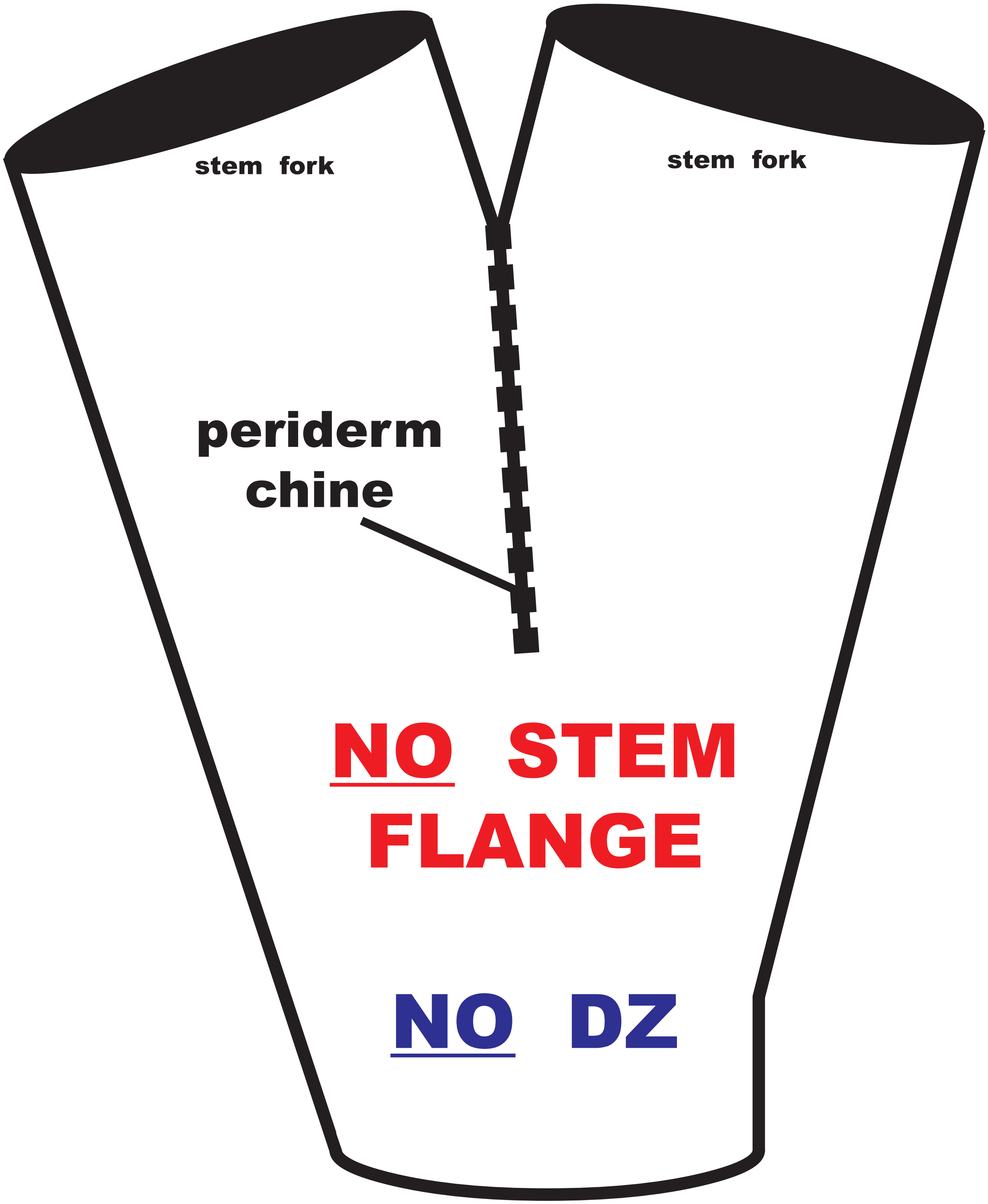

Figure 13: Diagram of a fork (codominant stems) with periderm chine shown. This stem - branch architecture would not provide a defendable stem flange area or defensive zone (DZ) if either side was removed.

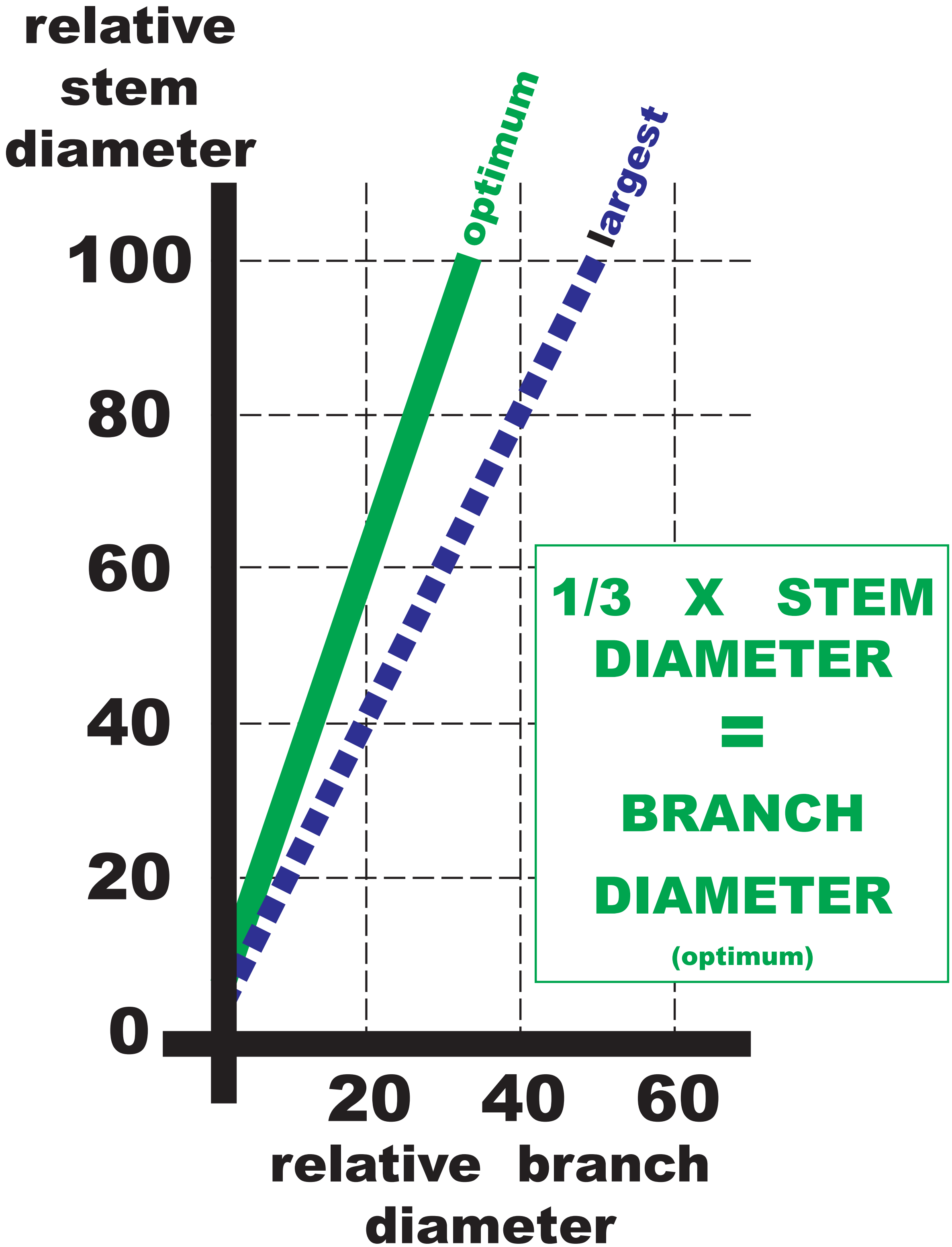

Figure 14: Relative stem diameter versus largest branch diameter at confluence for optimum form [branch diameter = 1/3 stem diameter].

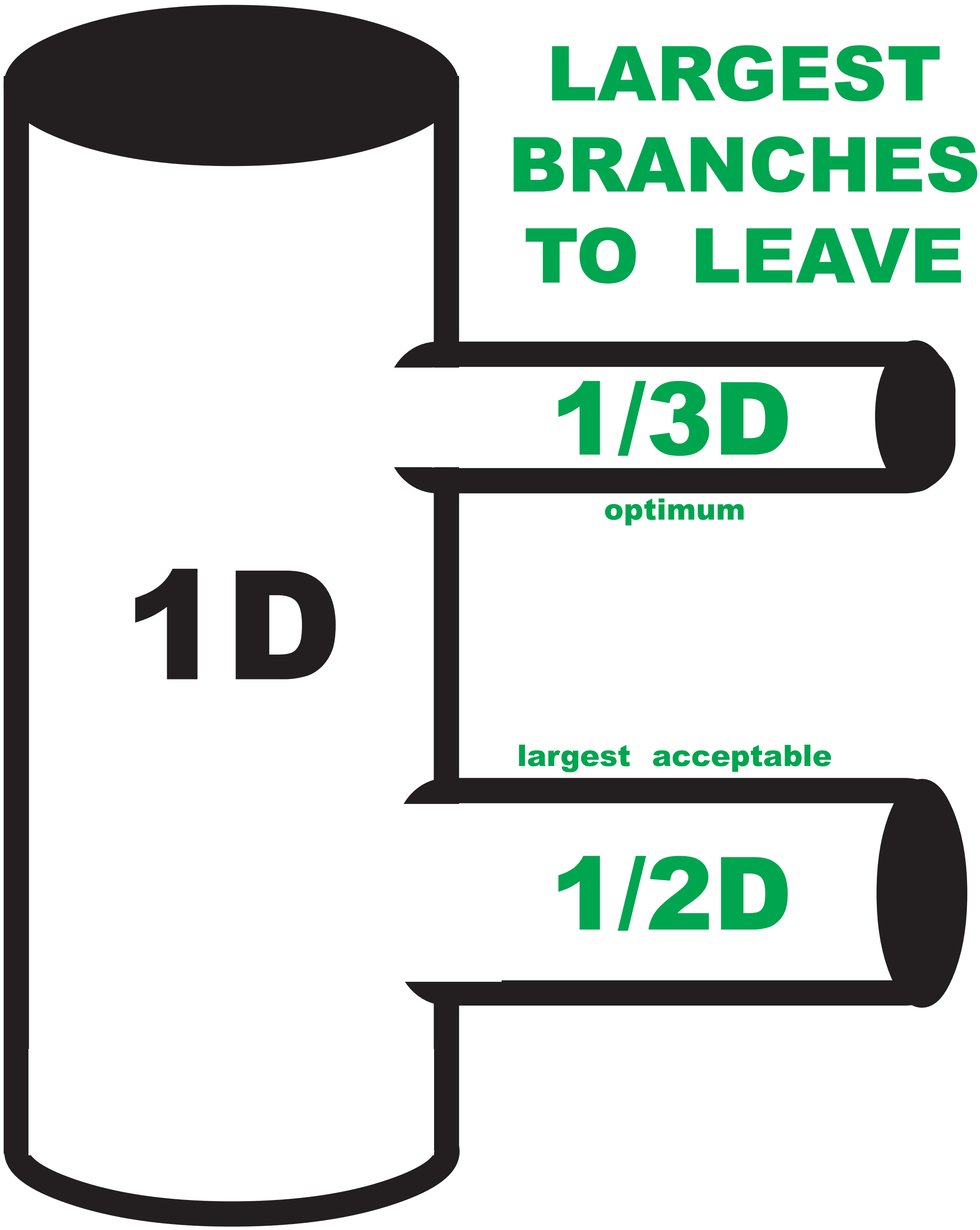

Figure 15: Largest branches to leave on a stem with branch diameter to stem diameter ratios of 1/3 to 1/2. D = diameter.

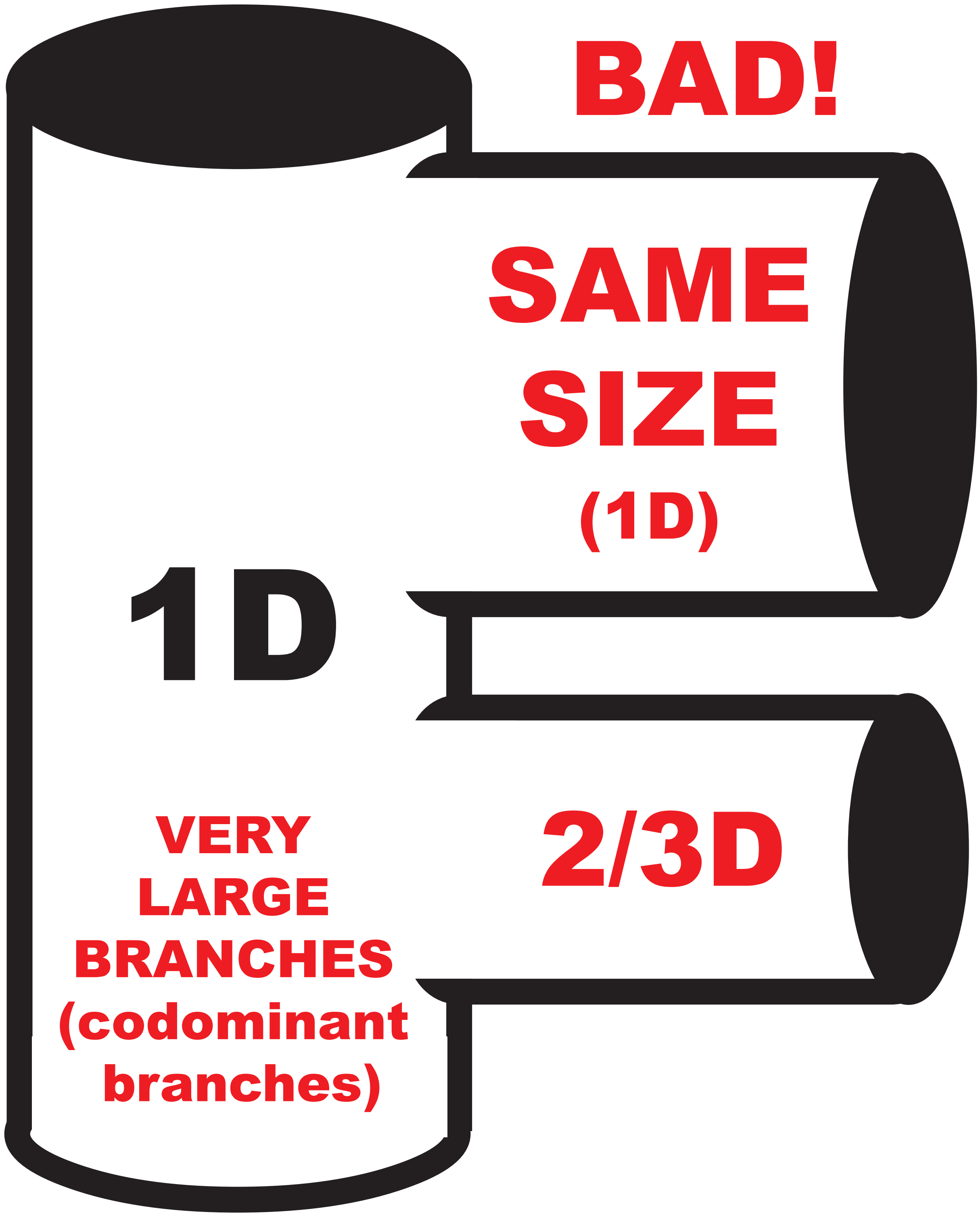

Figure 16: Branches too large to leave (i.e. to be removed) on a stem with branch diameter to stem diameter ratios of 2/3 to 1/1 (near same size as the stem). D = diameter.

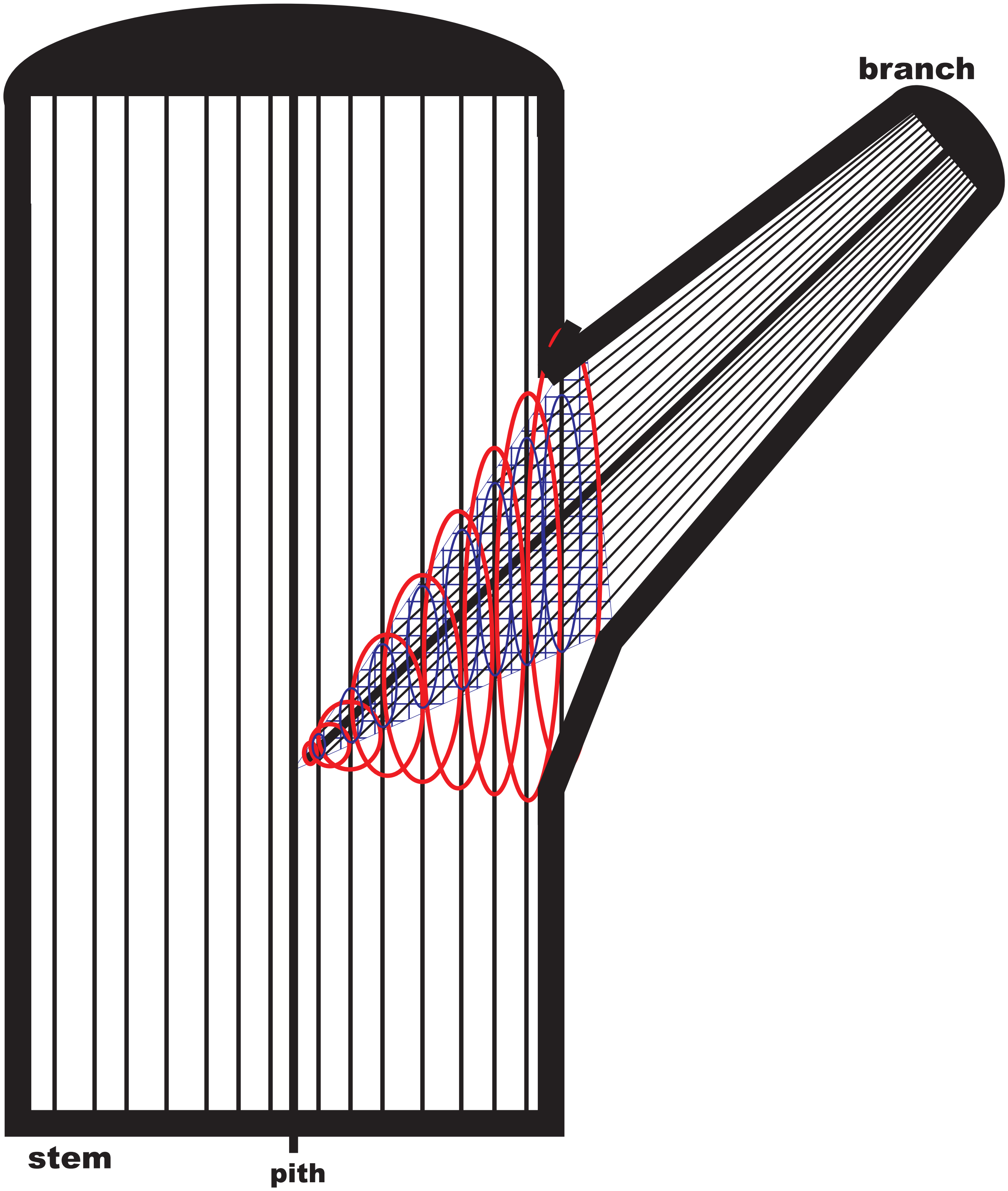

Figure 17: Diagram of stem - branch confluence area (stem flange) showing defensive zone (shaded), annual increments of tissues, and enveloping of branch tissues by stem tissues (ovals).

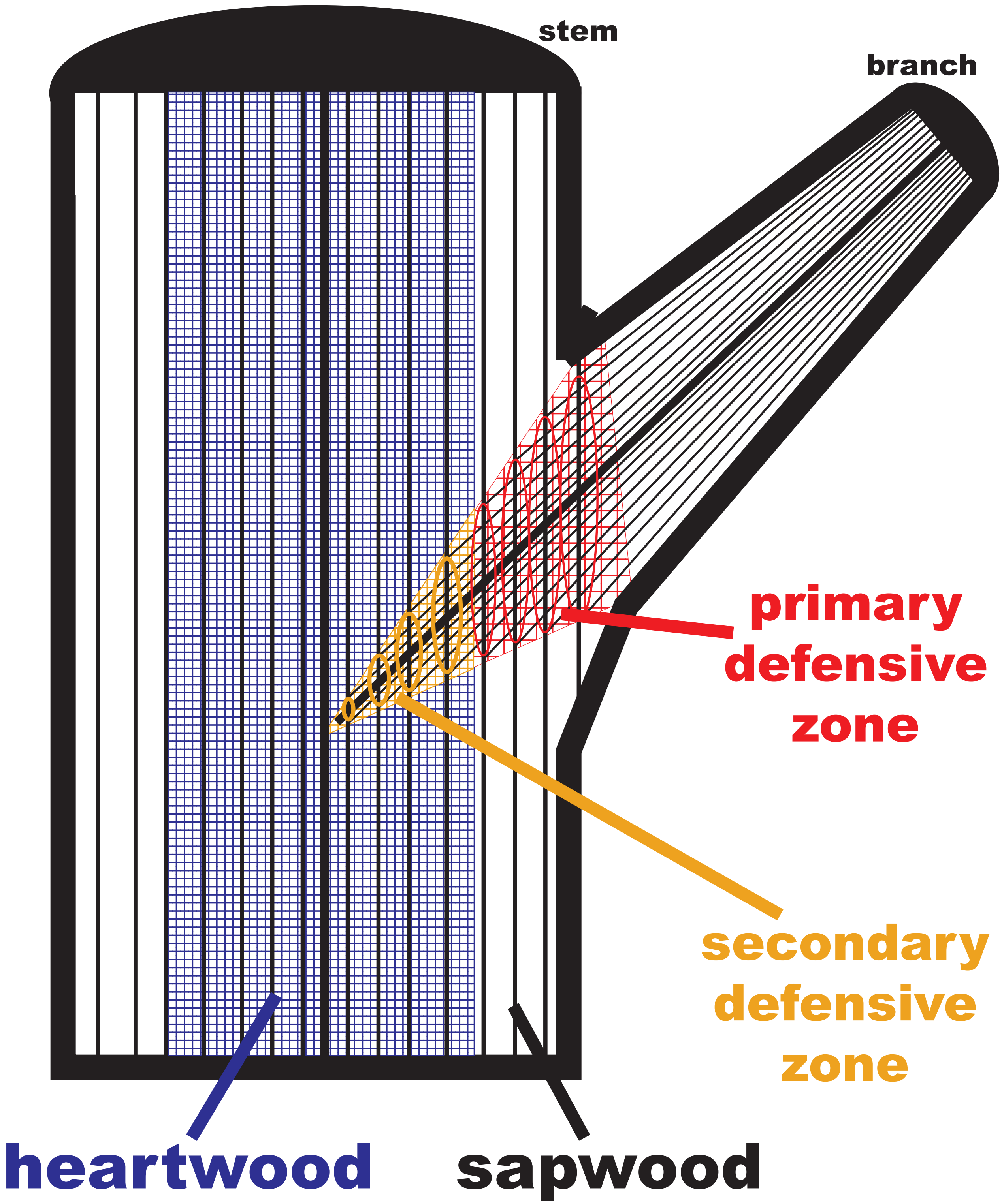

Figure 18: Primary (sapwood) and secondary (heartwood) defensive zones within branch base.

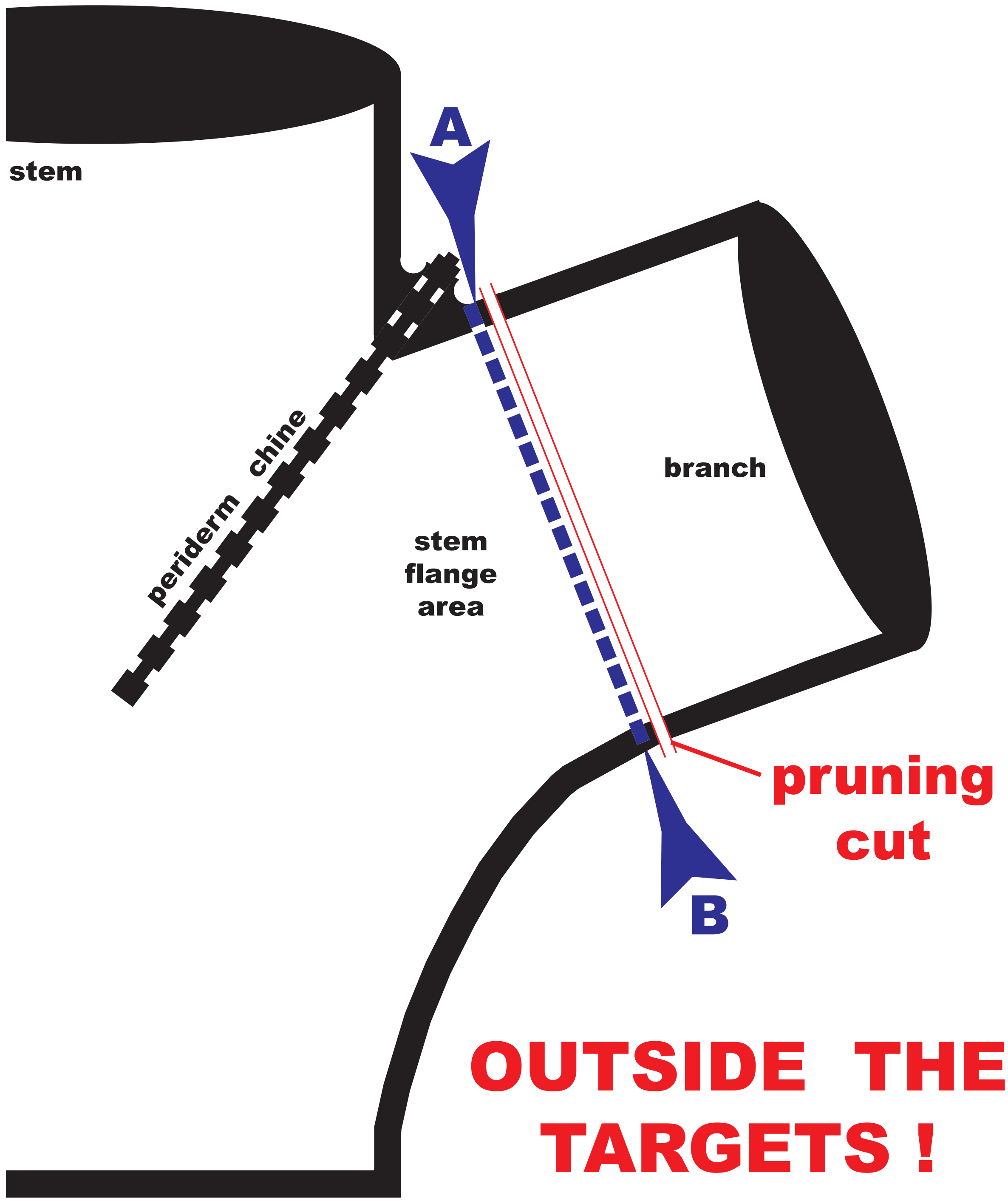

Figure 19: View of stem flange area at a stem-branch confluence. Visible flange edge targets: Target A is on the branch side (outside) of bark chine just before tissues begin to curve up into chine; Target B is on the branch side (outside) of tissue swelling or gathering point on branch underside. Dotted line represents edge of stem flange. Cut outside the targets.

Cut'em

Once branch pruning targets are identified, they are used to set the boundary and saw kerf line of the final pruning cut. Figure 20 demonstrates target pruning for generic angiosperms and Figure 21 demonstrates target pruning for generic gymnosperms. The one-cut method of pruning a branch identifies the same targets in the branch union area as the three-cut method, but is used on small, hand-holdable branches. (Figure 22).

The defensive zone and stem flange must be left intact and undamaged after a branch is removed. Some pruning tools tend to damage defensive zones and should not be used. A clean, relatively smooth wood and periderm surface should remain after pruning. Periderm surrounding the wound site should still be firmly attached and not jagged. Bypass-pruners and saws should be used for pruning cuts, never anvil-type pruners. Dull, damaged, pinching, or crushing pruning tools should not be used on trees.

Flush-n-Stub

Two abusive cutting techniques made by tree-illiterate people are flush cutting and stub cutting. Flush cutting removes branch tissue and the stem flange area even (flush) with the stem or primary branch surface. Flush cutting damages, at the very least, stem and primary branch tissues above and below the wound. Flush cut wounds are significantly larger than needed for branch removal and are difficult for a stem or primary branch to defend because defensive zone boundaries have been breached. (Figure 23).

Stub cutting is topping (an internodal cut), where a significant amount of branch tissue remains attached at the confluence. As this branch stub dies, a large volume of dying tissue is exposed to the environment while physically interfering with stem tissue effectively growing over and sealing-off the stub. (Figure 24). Stub cutting is not a "better," more tree conserving method than flush cutting.

To summarize, a critical feature of proper pruning is to leave a defendable wound area. Flush cutting and leaving stubs of various lengths prevent effective defensive responses and leaves a tree open for other problems. (Figure 25).

Wounds

Pruning wounds expose living and dead tree tissues to the atmosphere which accelerates oxygenation, water loss, and oxidation. Figure 26 provides a summary of tree anatomy visible across a cut wound face of a large stem or branch. Open wounds are prone to invasion by a succession of micro and macro-organisms attempting to use undefended growth materials and to find habitat for their life-cycle. Oxidation at the wound surface immediately initiates a compartmentalization response in a tree, sealing off from the environment the inside of a tree. If defensive zones are not breached, living rays cells in the defensive zone will begin a growth and closure process, eventually sealing off and sealing over wound sites.

If pruning targets presented at the confluence site are recognized and conserved, a wound closure from all sides will develop. If the defensive zone is breached on any side, particularly top and bottom of the wound as occurs in flush cutting, wound closure will occur primarily from each side pushing into the center. This wound closure pattern of tree-illiterate pruning will form a longitudinal line or crack. Figure 27. The compartment lines set around this abusive pruning wound can lead to a number of other aesthetic, structural and biological problems later on in the life of a tree, some potentially life threatening. Proper wound closure is not a long crack, sometimes perpetually open, but a single point soon grown over.

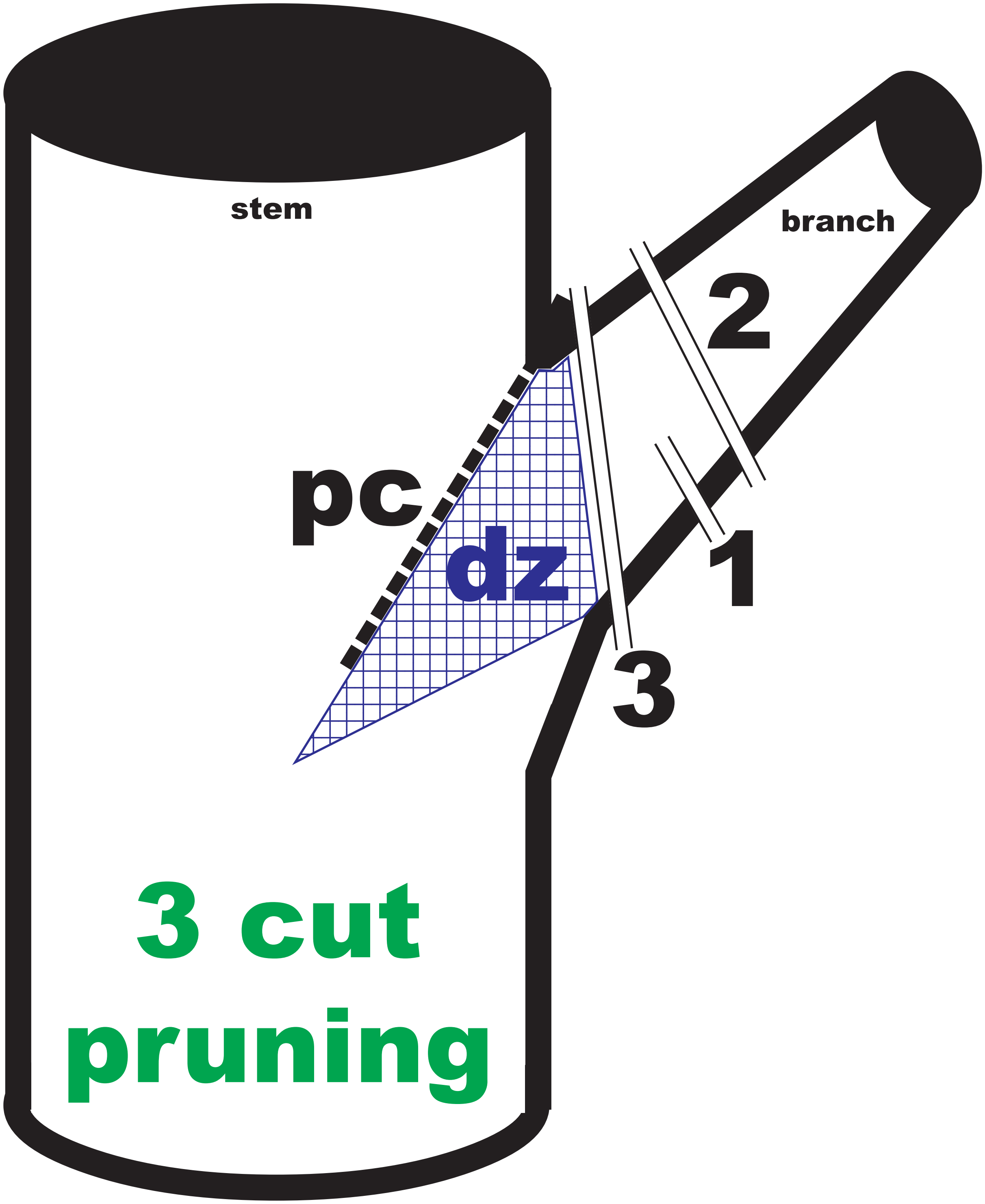

Figure 20: Diagram of stem - branch confluence area with a three-cut or target pruning prescription applied (in cut order) for a normally proportioned branch.
Defensive zone = dz. Periderm chine = pc.

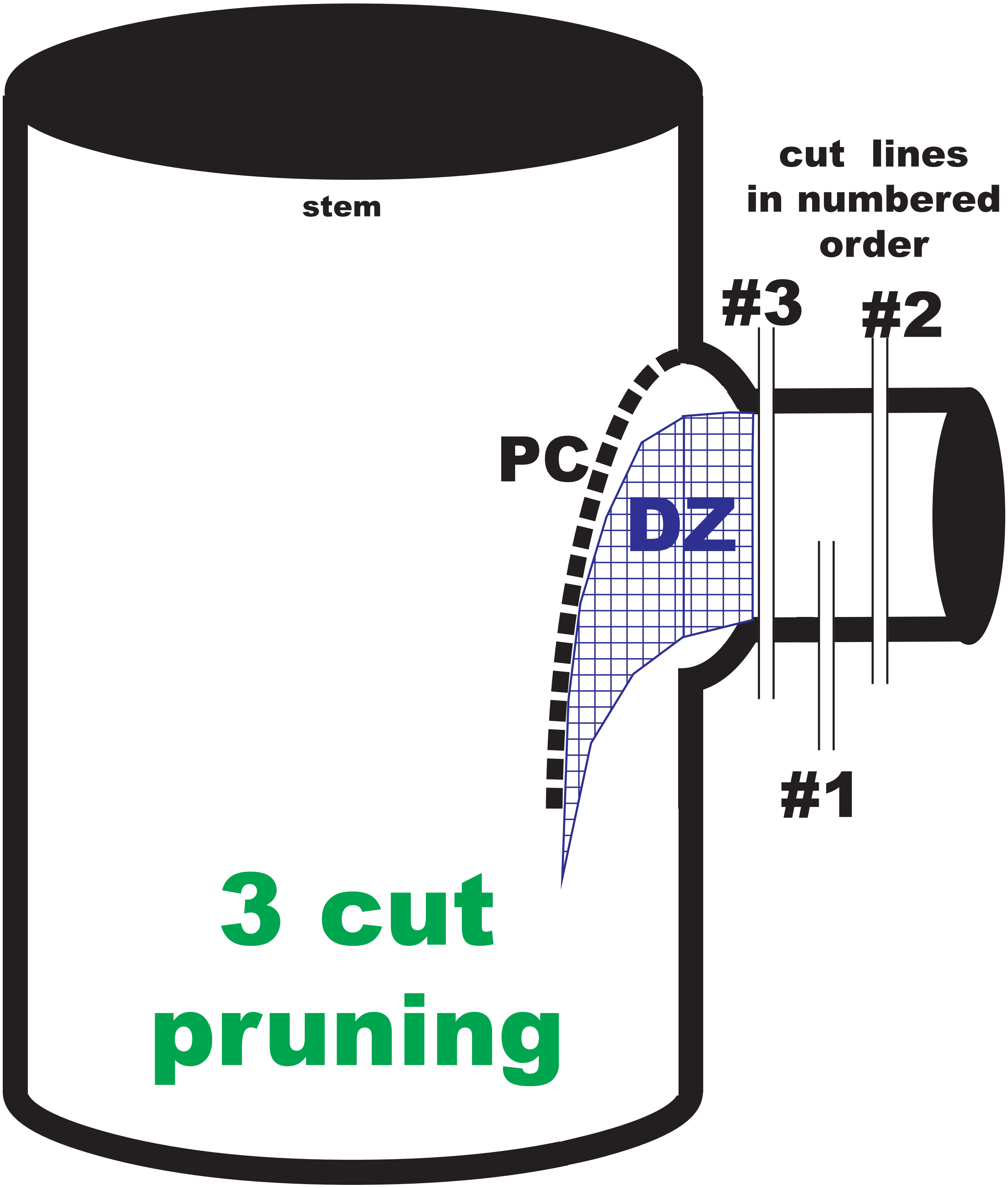

Figure 21: Diagram of a three-cut target pruning technique on a round stem-flanged tree such as a gymnosperm.
DZ = defensive zone. PC = periderm chine.

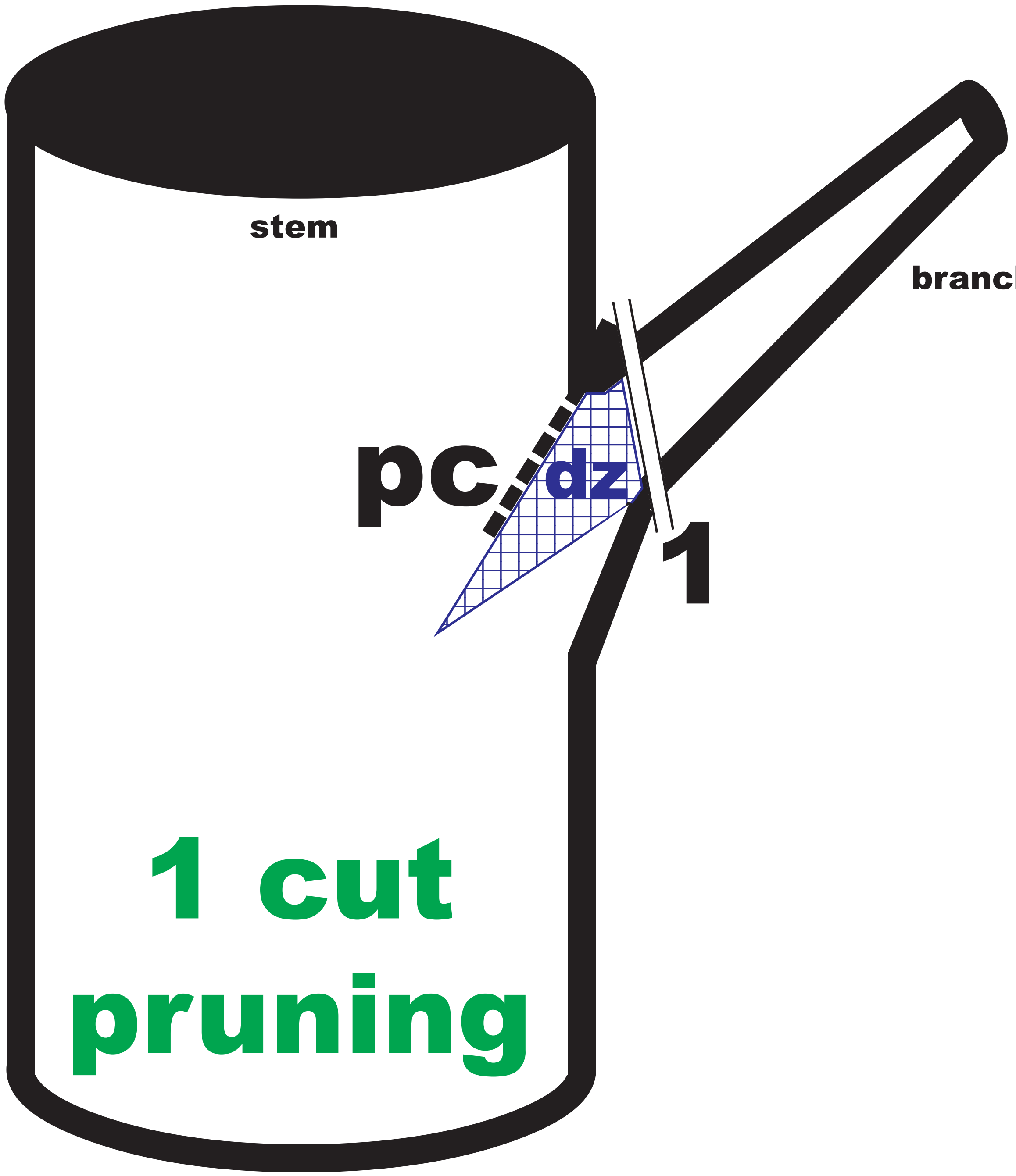

Figure 22: Diagram of confluence area with a one-cut pruning prescription applied for a small proportioned branch.
Defensive zone = dz. Perdierm chine = pc.

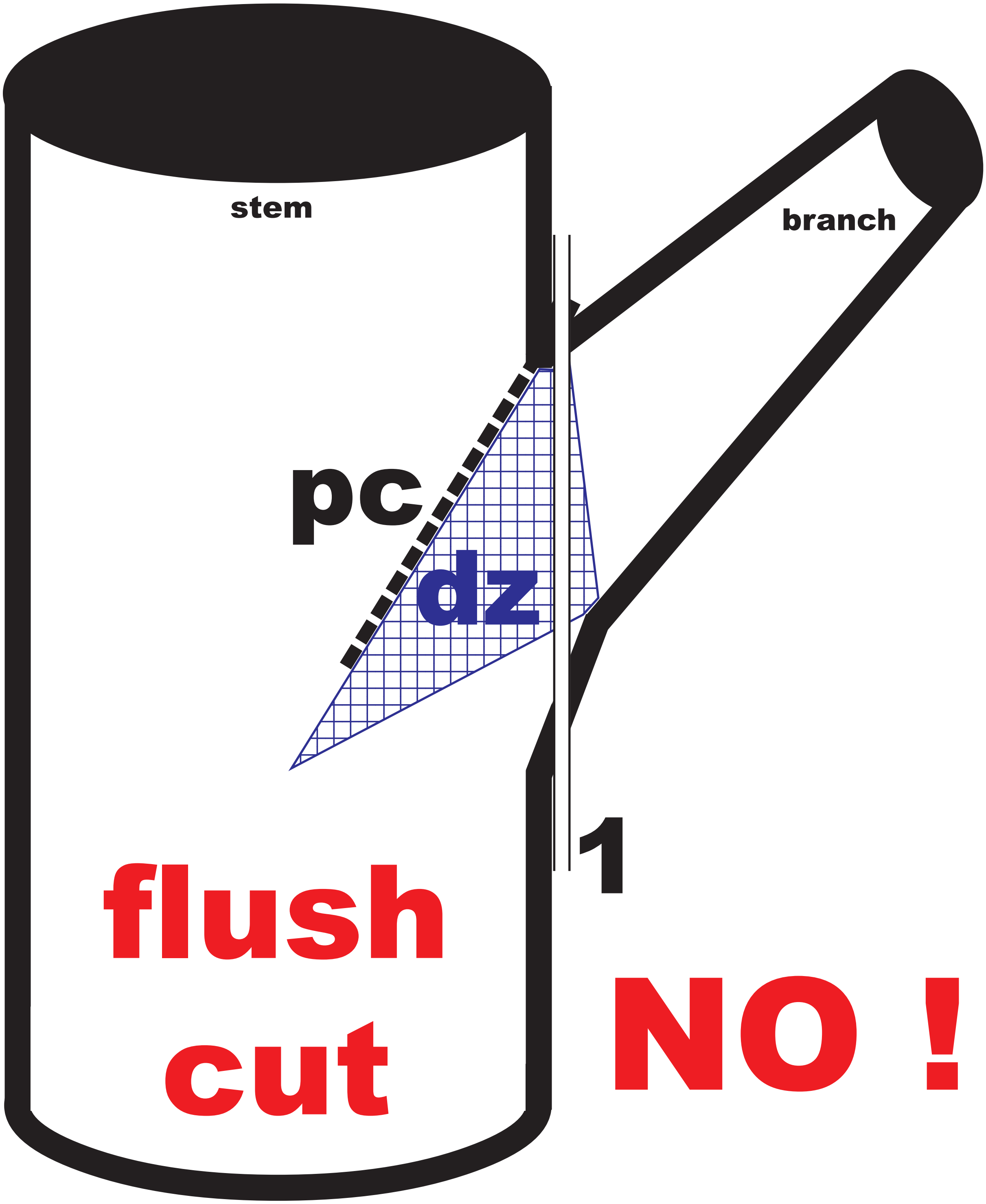

Figure 23: Diagram of confluence area with an abusive, improper flush cut applied.
Defensive zone = dz. Periderm chine = pc.

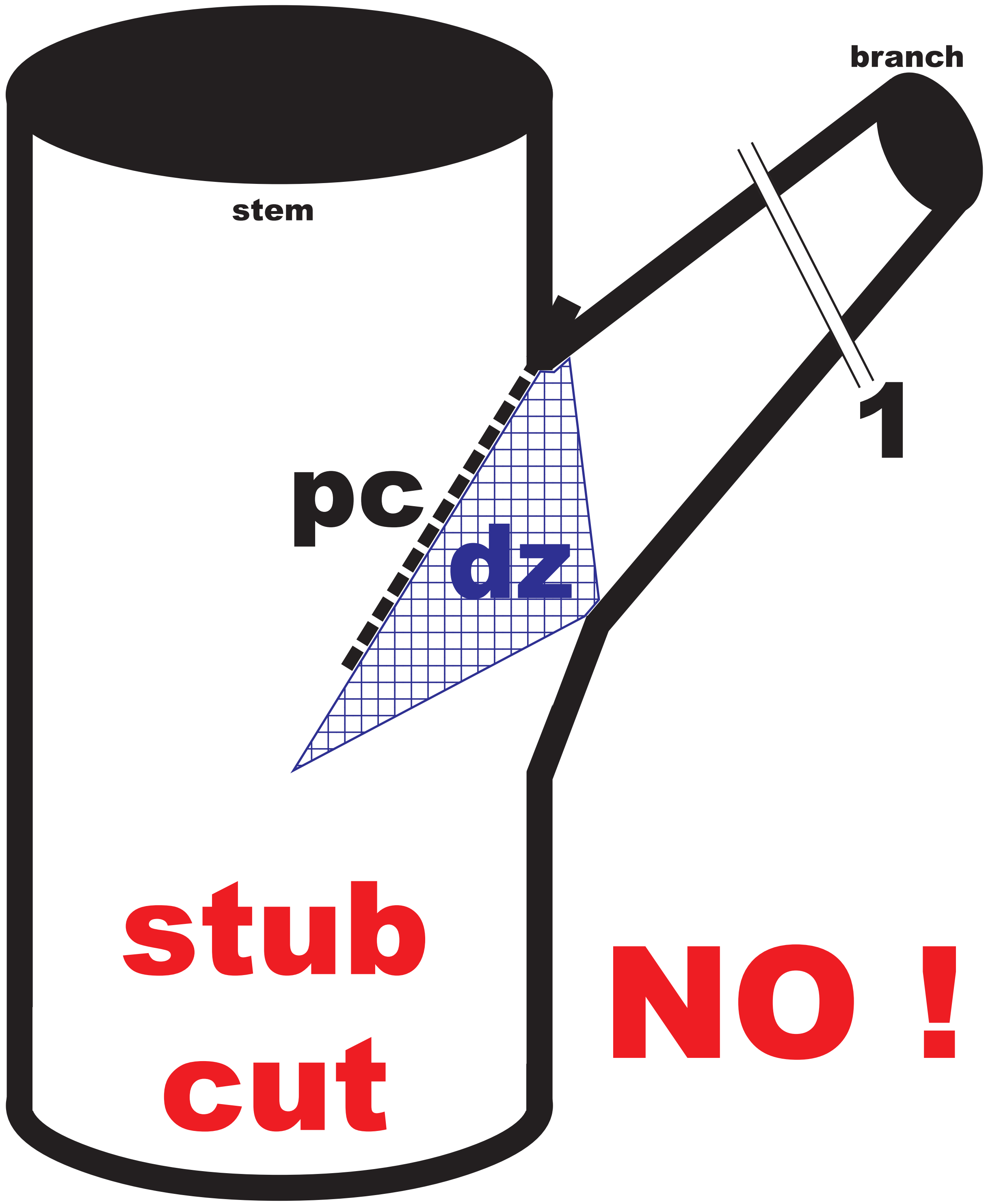

Figure 24: Diagram of stem - branch confluence area with an abusive, improper stub cut applied.
Defensive zone = dz. Periderm chine = pc.

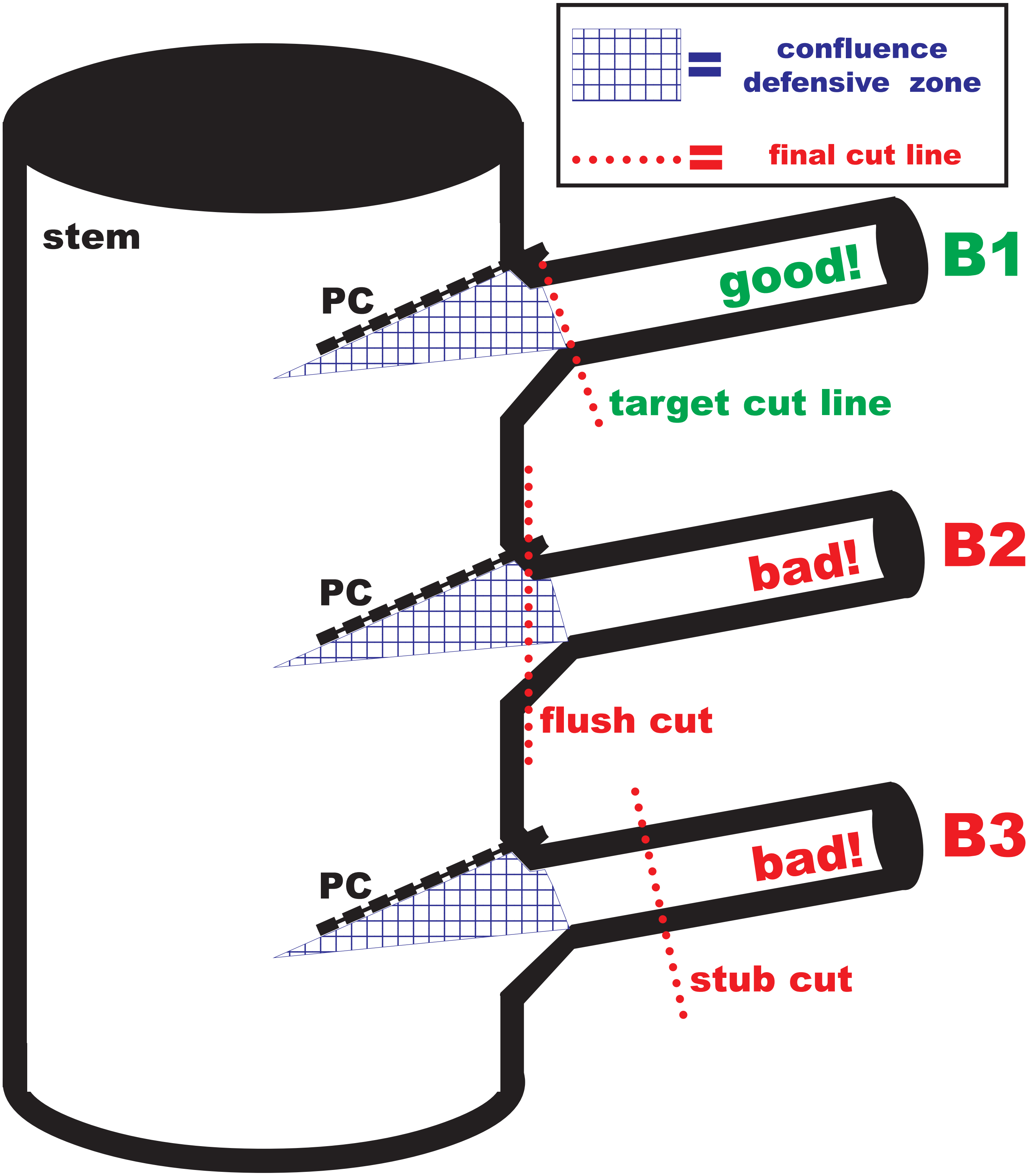

Figure 25: Example diagram of three tree branch cuts: target pruning B1; flush cut B2; and, stub cut B3. Note target pruning cut (B1) is the only acceptable technique.
PC = periderm chine

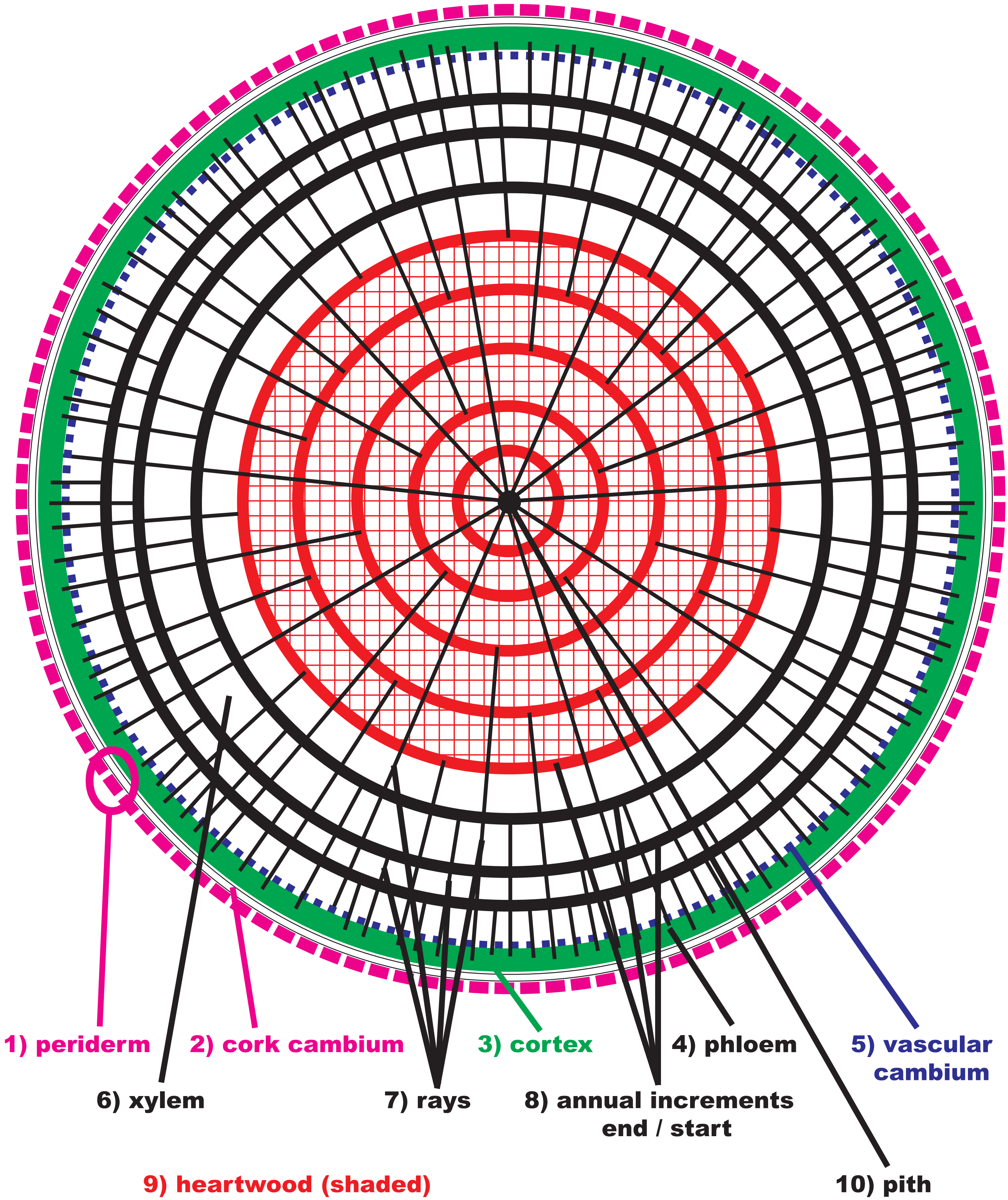

Figure 26: Diagram of generic stem or branch cross-section with different tissues / layers crossed when pruning, in numbered order from outside / surface.

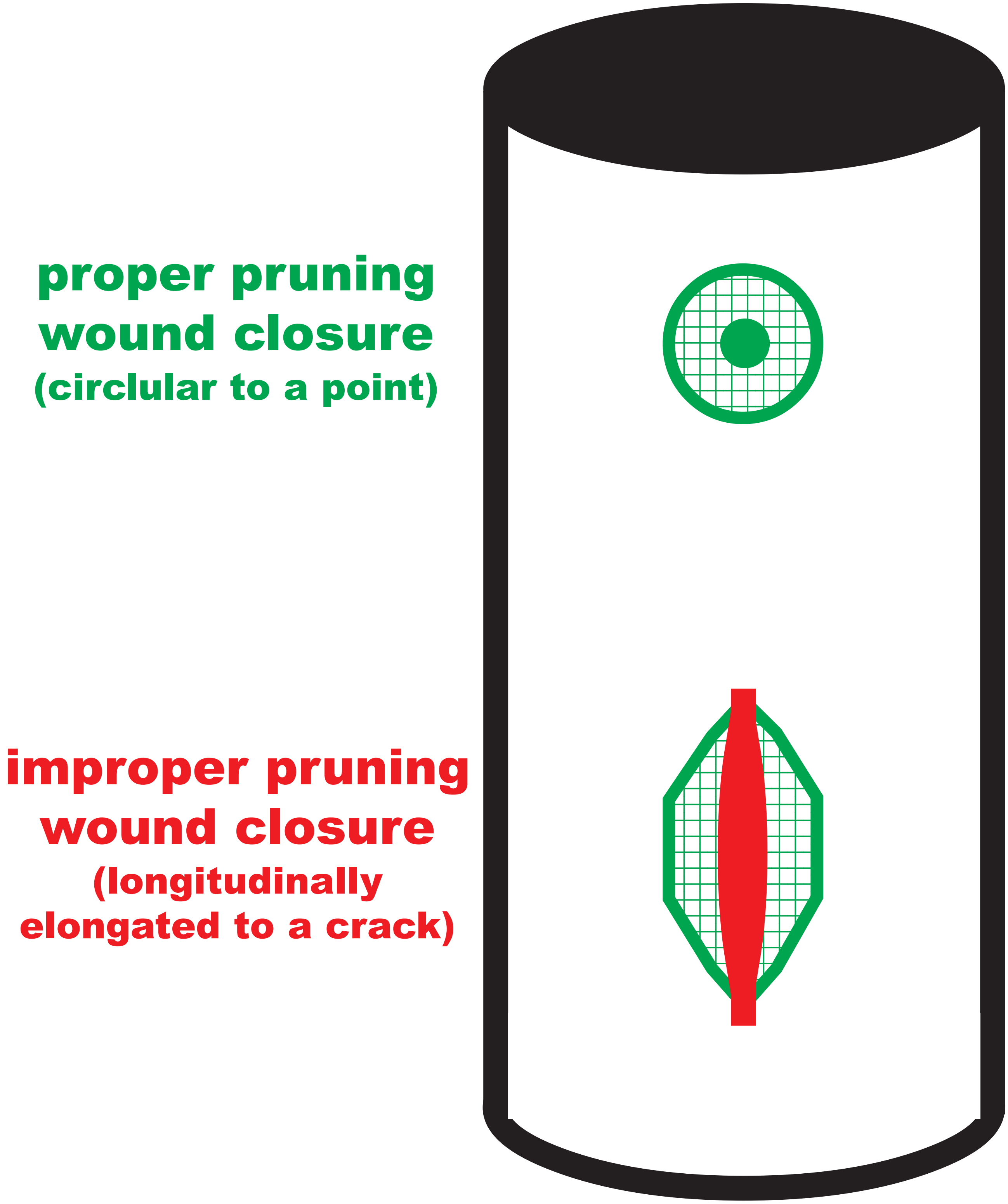

Figure 27: Diagram of a pruning wound closure or seal from a properly executed branch pruning (top), and an abusive, improper flush cut (below) on the same diameter branch.

Waiting Too Long

For a branch approaching 2/3s the same diameter as a stem at its confluence, defensive reactivity and effectiveness are greatly reduced. Proportionally large diameter branches (codominant branches) do not have strong defensive zone and are difficult to prune. The structural targets easily identified on proportionally small branches are veiled or do not exist in codominant branches.

Pruning wounds of codominant branches have a great risk of tissue drying, oxygenation and decay, as well as providing a greater opportunity for pest entry. Pruning cuts on codominant branches should attempt to preserve any residual collar that may exist. In this case, erring on leaving slightly too much of a stub (3-5 saw kerfs) is preferable to flush cutting with codominant branches. If your prescription includes pruning many codominant branches, then you waited too long to begin a pruning program.

REDUCING REACH & EXTENT

Pruning cuts in a tree are not always simple branch removals, or pruning cuts of proportionally smaller branches on larger branches and stems. Another pruning cut is used to reduce the reach and extent of a branch or stem, not to be fully removed. This pruning cut (reduction or abridging) removes proportionally large stems and branches, leaving at the terminus a proportionally smaller branch. Unfortunately, there is no established defensive zone to conserve with this cut. Figure 28 demonstrates targets for reduction pruning.

Shortening

For a reduction cut, first a line perpendicular to the main axis of the stem or branch to be removed must be established. The "nexus" line is anchored at the top-side of the confluence. Next a lift line is established parallel to and above the perpendicular line (nexus line) by a distance "L". This distance is roughly 1/9 stem diameter at this location, or at least three times saw kerf thickness. Figure 29 demonstrates the proper 3-cut pruning process for reducing a larger stem or branch back to a smaller, but active lateral branch growing upward or in a desired direction. The confluence selected as the reduction point should always have a lateral branch at least 1/3 the diameter of the stem or primary branch to be removed. The final cut line is a 30^{o} down angle from the lift line intersection with the stem over top/above the confluence.

The target for reduction pruning is centered around periderm chine location. Targeting the reduction cut is to assure the greatest tree defensive response possible for such a large wound. Because of tissue drying and potential heartwood exposure, these wounds can be difficult for trees to seal off and grow over. The distance left above the confluence and periderm chine location are key. A slanted final cut, not perpendicular to the stem or branch being removed, does leave a larger wound area but should be positioned to not collect water. The angle is not nearly as critical as a clean smooth cut, and not damaging tissues near the periderm chine of the remaining branch.

Forked

Removal of one side of a forked stem follows a similar procedure as above. Figure 30 provides target lines for setting up a proper pruning cut. First, a line roughly perpendicular to the main stem axis is established resting on the top of the confluence. This line is the nexus line. A lift line is then established parallel to and above the nexus line by a distance "L". As before, the distance L is 1/9 the stem fork diameter in the cut area, or at least three saw kerf thicknesses. A 30^{o} down angle cut line is then established anchored to where the lift line and the fork to be severed meet over the confluence. Figure 31 shows the three-cut method for removing one of the stem forks.

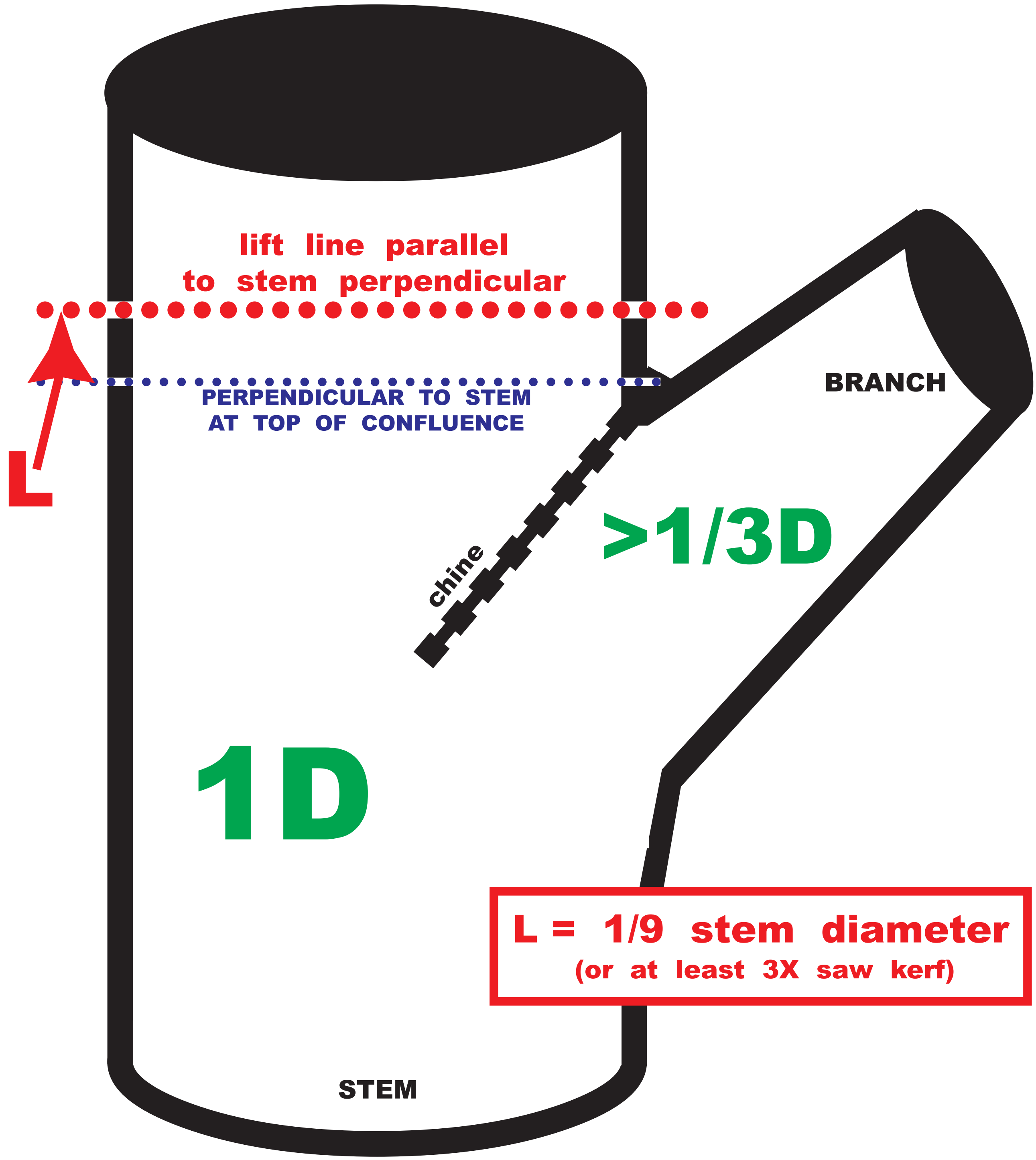

Figure 28: Diagram of stem - branch confluence with target lines for initiating a reduction pruning cut. Note stem of given diameter will be reduced to a branch never less than 1/3 stem diameter. "L" is lift line distance above the perpendicular (nexus line) across the stem at the top of confluence.

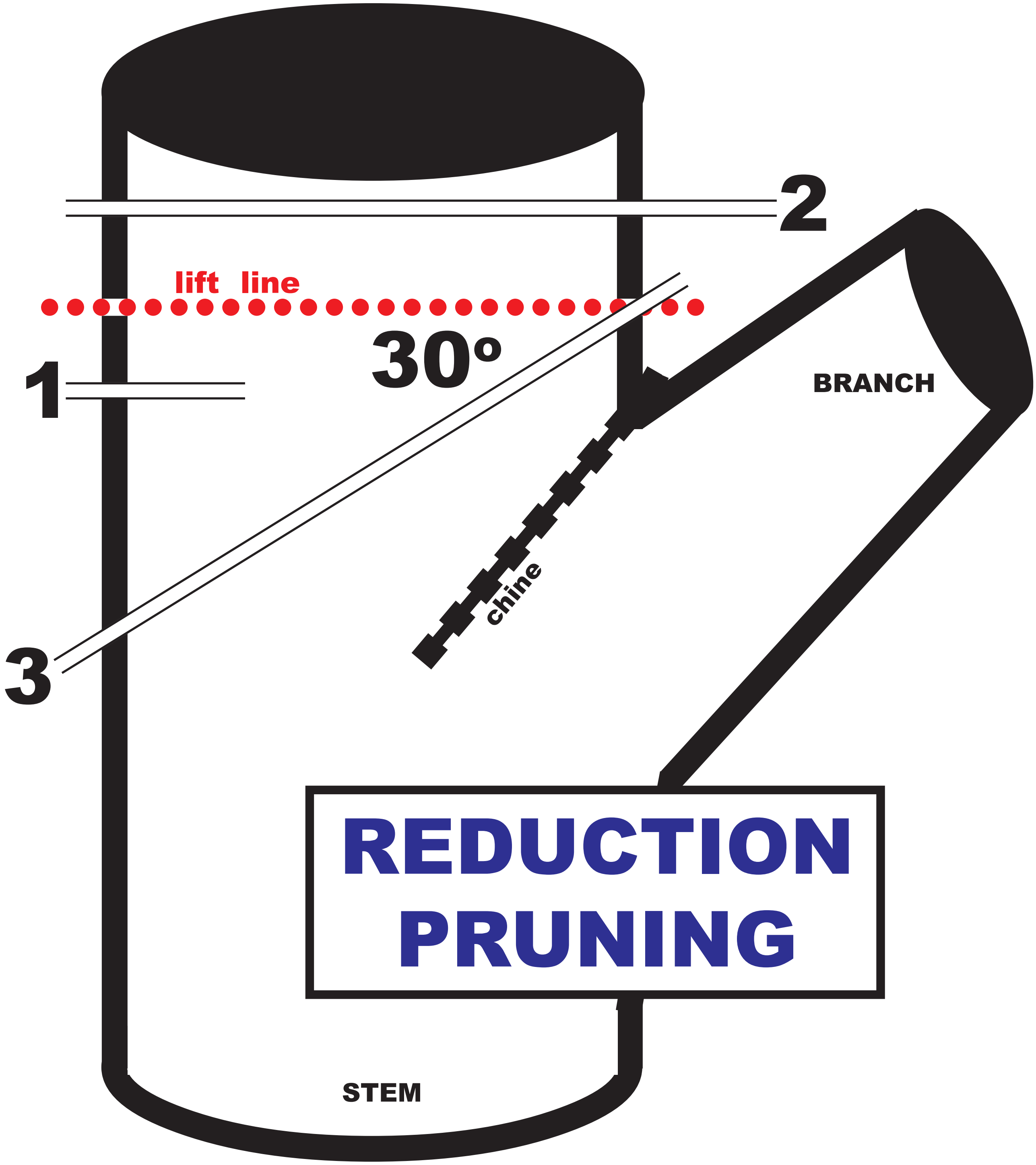

Figure 29: Diagram of confluence with three cut lines, numbered in order, for a reduction pruning prescription. Note the final (3rd) cut is at 30° down angle from the branch side of the lift line. The down angle is not dependent upon the chine or branch angle.

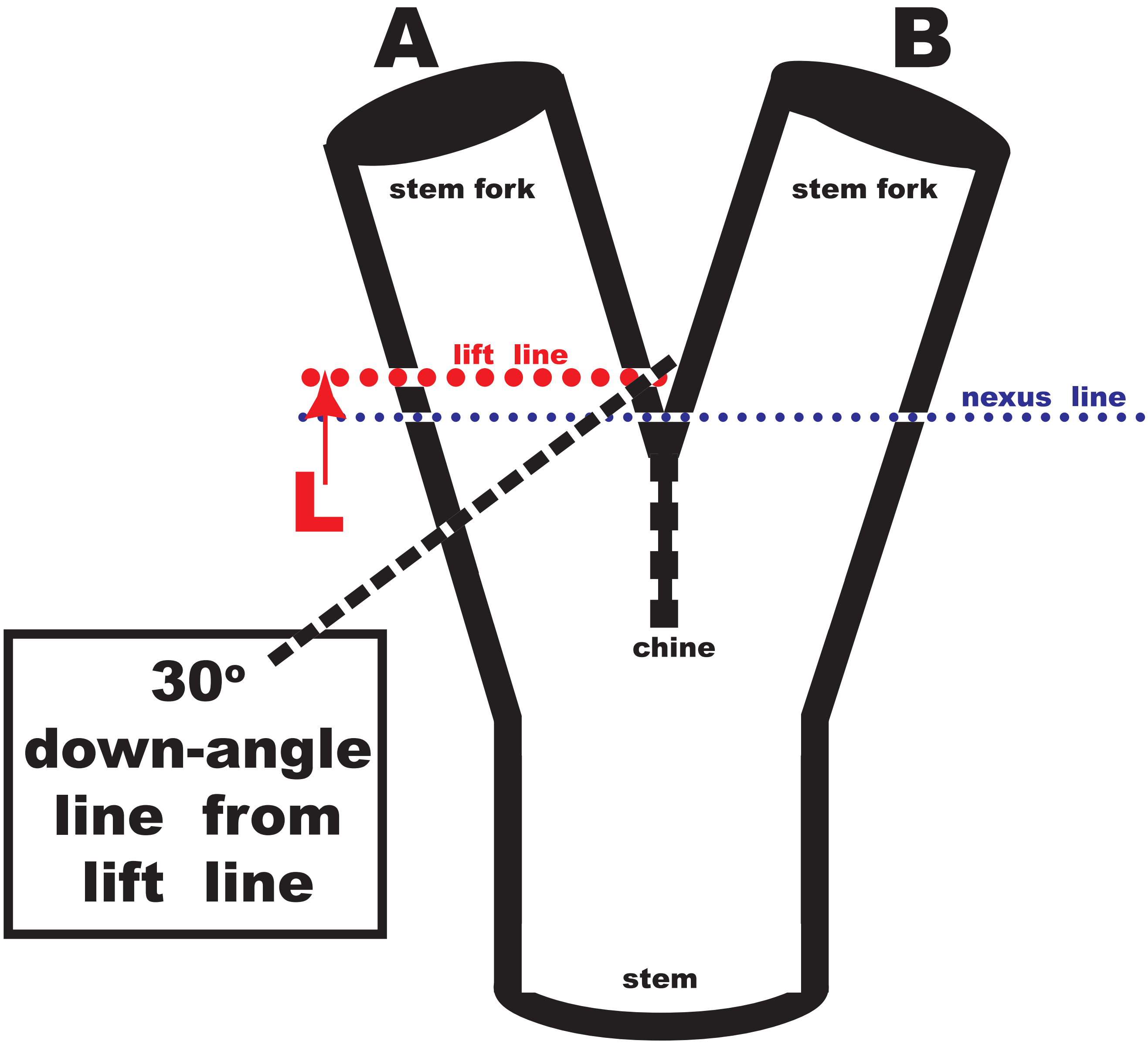

Figure 30: Forked stem with target lines established to initiate a reduction pruning prescription on stem fork A (left fork).
Note lift line is made parallel to and above nexus line which is perpendicular to the longitudinal axis of the main stem before the fork and anchored at top of confluence. L distance upward is 1/9X stem fork A diameter, or at least 3X saw kerf.

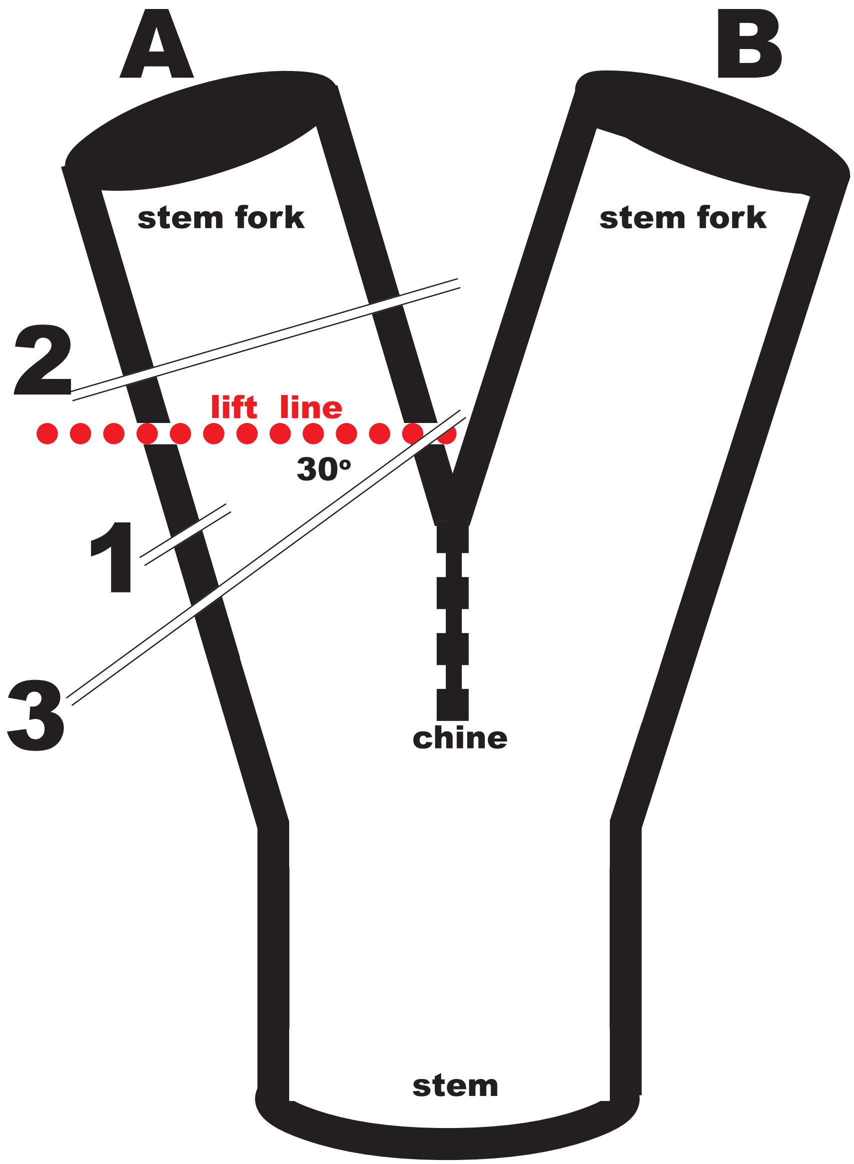

Figure 31: Diagram of forked stem with 3 cut lines placed in numbered order for a reduction pruning prescription on stem fork A (left fork).

Note the final (3rd) cut is at a 30° down-angle from the lift line beginning above the top of stem fork nexus. The down angle is not dependent upon the chine or stem fork angles.

A choice must be made when removing one side of a fork. Ideally, the side of the fork to remain has the largest crown volume, is in the most direct line to the tree base and soil surface, and is the largest in diameter. If the fork confluence has noticeable included periderm, continue to make a proper reduction cut and not dig/cut into the included periderm area.

Figure 32 shows the set-up and three-cut removal of a codominant branch / forked branch. A nexus line is established at the top of the confluence. The nexus line is perpendicular to the main longitudinal axis of the stem or branch below the fork. The lift line is placed a distance "L" above, and parallel to, the nexus line. The distance L is 1/9 diameter of the codominant branch for removal, or at least three time the saw kerf thickness, beyond the nexus line. The final cut line is a 30^{o} angle to the lift line anchored above the top of the confluence.

Topping

Topping, or internode cutting, is one of the most abusive biologically, damaging structurally, and disfiguring treatment applied to trees. Topping in all its many guises and fanciful names is an abomination on trees and the people who care for trees. An internode cut is an untargeted and uneducated slice with a cutting tool. (Figure 33). An internode cut is not made at a node where some defensive capabilities exist, but is made somewhere along an internode where damage can be severe and the wound poorly defended. Figure 34 provides an example of a topping cut on a stem and a branch. Topping cuts are made with no care for survivability of the remaining tree tissues, or for future health, structural integrity, or aesthetic values.

CROWN DESIGN CONSIDERATIONS

It is important each branch has good structural integrity, is biologically efficient, and positioned to add to whole tree aesthetics. In order to accomplish these goals, branches must be well distributed along and around the stem. Light capture is the principle task of a branch, twig, and leaf system on a tree. Assuring branches are positioned where each can make sufficient food for itself and to share with the rest of the tree below, is the task of prescribed pruning. Branch spacing must be sufficiently widespread for adequate light capture, while minimizing direct tissue shading and wind driven movements which injure leaf tissues and surrounding branches.

Branch Positions

Branches should be ideally positioned to minimize direct shade effect distances and utilize full sun, sun flecking, and diffuse shade resources. Branch occupied resource space must be filled with both a good quality and quantity of light. Selecting which branches to conserve and to prune must be based upon the number of leaves, number of twig orders present, branch length, and total volume occupied per leaf area. No branches should be maintained which shade each other, parallel another in its primary growth direction, share significant resource space volumes, or touch under wet, normal growing season conditions and wind loads.

Under ideal conditions, approximately twelve to eighteen individual branch resource spaces can be delineated, each containing a single, healthy, structurally sound branch which adds positive values to whole tree aesthetics. The number of individual branch resource spaces can be modified as leaf effective shade diameters and associated direct shade distances change. The geometry of how leaves are arrayed for light capture is critical to understand in delineating branch resource spaces along a stem.

Space Management

Taking space which contains essential light and CO_2 resources, and allowing for capture of these resources with a finite number of leaves which must be held effectively by structural tissues connecting leaf

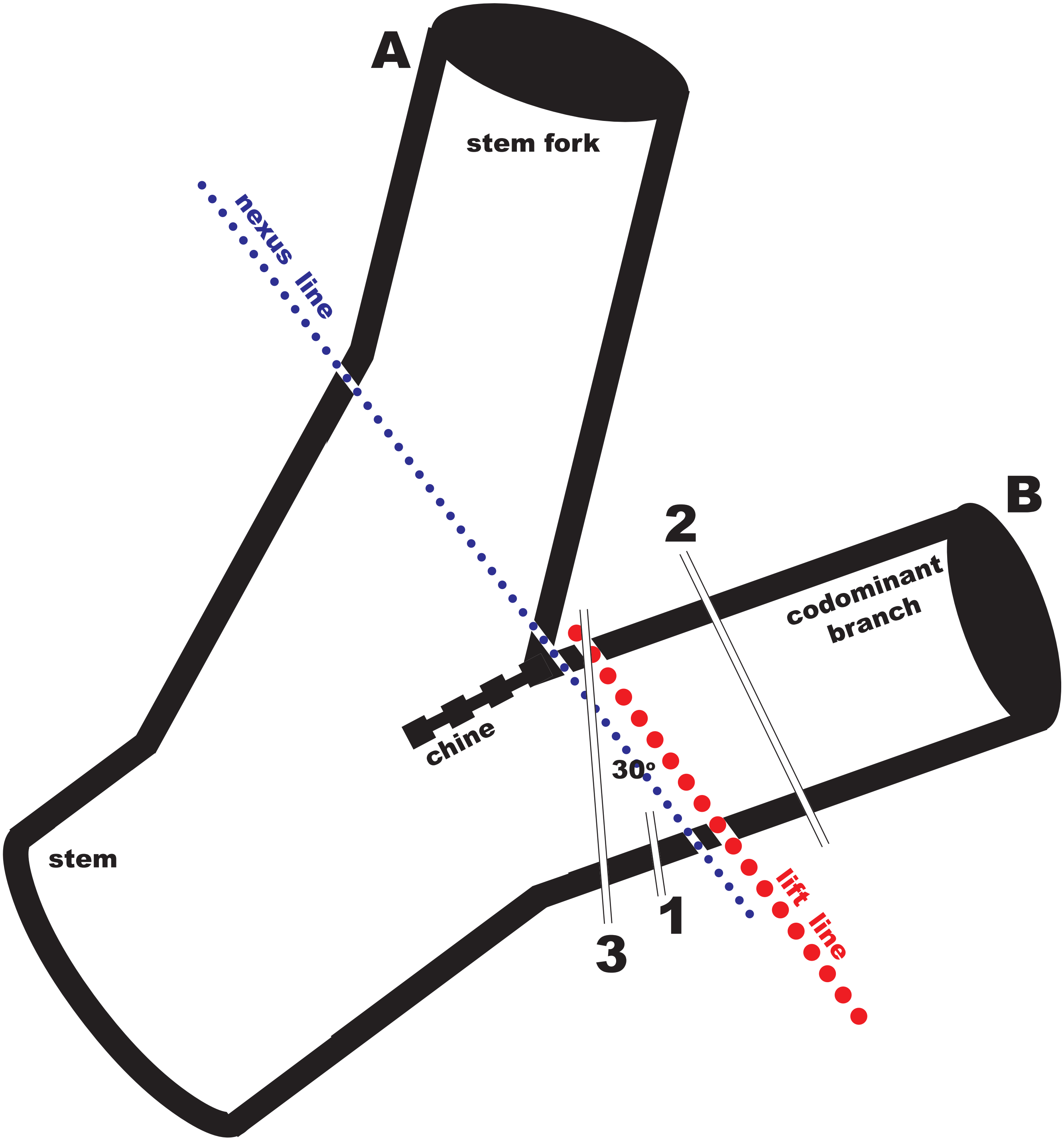

Figure 32: Diagram of a 3 cut (in numbered order) reduction pruning prescription on a codominant branch / fork (B). The final cut (3rd cut) is at a 30° angle from the lift line anchored above the nexus of the codominant branch and stem fork.

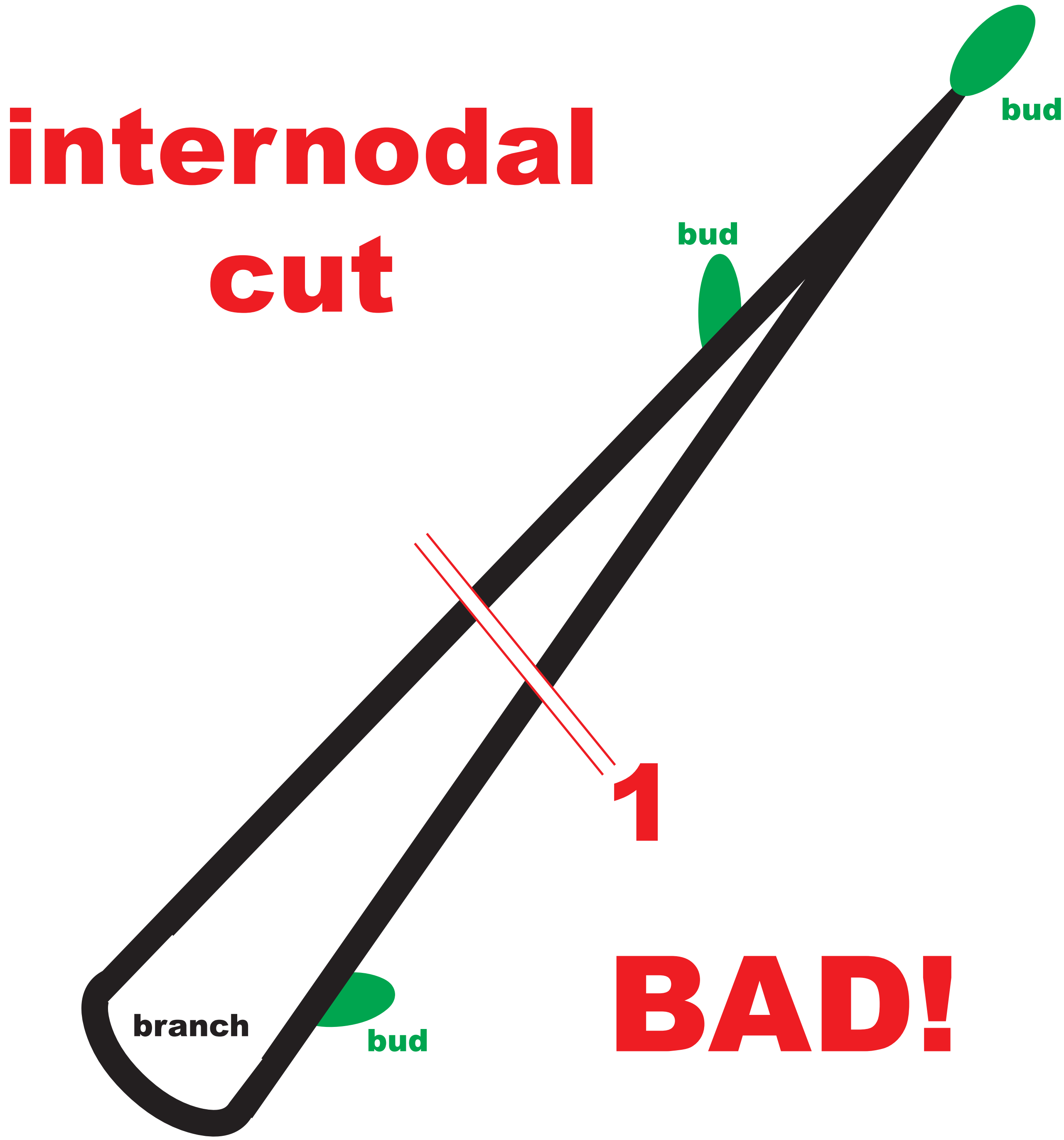

Figure 33: Diagram of an abusive, improper, and damaging internode cut. Other terms used for this abusive cut include topping, tipping, hedging, hat-racking, & trimming. It is not the size of tree part cut (stem, branch, or twig) but the internodal location which makes this cut improper and damaging.

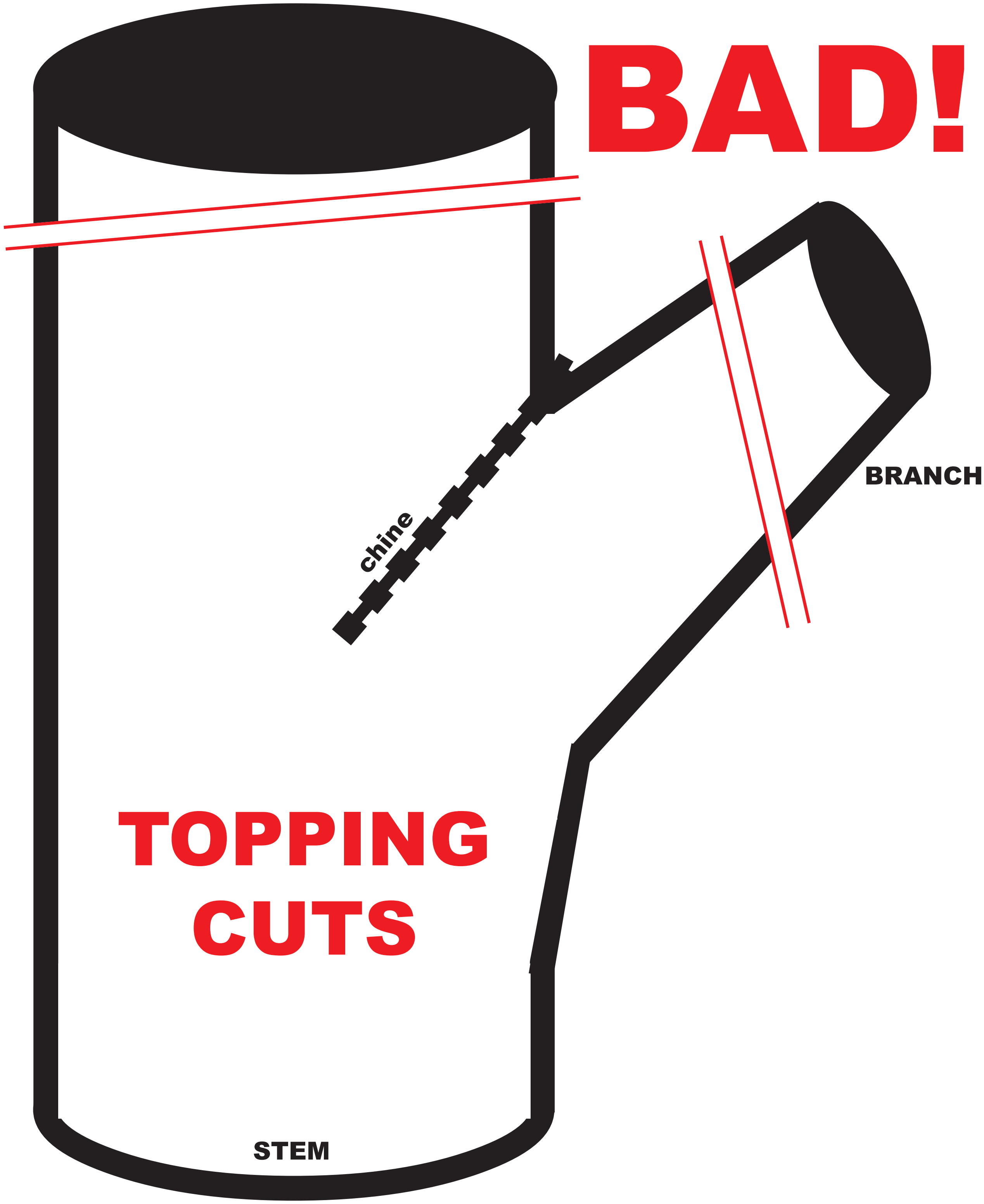

Figure 34: Diagram showing abusive and damaging topping (internodal) cuts on a stem and branch.

factories to soil based growth resources, is difficult. Trees maintain leaves on supporting twigs and branches at various levels of productivity as part of a redundancy in case of disaster or severe stress.

Tree health care specialists, like all landscape managers, attempt to assemble tree components to meet multiple goals and objectives, including meeting expectations of surrounding humans. Pruning prescriptions are designed to have the best looking, best performing, biologically healthy and structurally sound tree as possible. Depending simply upon natural tree genetic / environmental interactions, plus chance, to reach landscape goals can provide undesirable and unreliable results.

Arboritecture Thirds

Ideally, trees should be proportioned in height as 1/3 clear stem and 2/3 live crown. This proportion meets the architectural perception of a well balanced and shaped tree. In pruning prescriptions, the top two-thirds of a tree should ideally contain twelve to eighteen equal volume resource spaces. One primary branch should ideally be positioned to utilize each resource space. Branches are distributed in this way to minimize two or more branches from occupying the same resource space and occurring along the same light interception path for a significant portion of the day. Effective distribution of these branches represents an optimum packing density. Packing of leaves along a twig, twigs along a branch, and branches along a stem have genetic, environmental, and chaotic components. In this arboritecture prescription process, only the branch on stem distribution will be emphasized.

Green Proportion

The distance between confluences can be highly variable in effectiveness at gathering resources and holding resource space. Much of this variability is derived from competitive interactions with neighboring trees, topography / aspect, and human objects impacting branch success starting from its first year. One successful branch can inhibit other branch success nearby. Due to direct shading effects and light impact angles during growing season days on a tree crown, small short branches at the crown top can be somewhat closer together than large, long branches near the live crown base. Upper branches can partially overlap lower branches without much added stress because lower branches are longer, holding leaves farther into valuable resource space.

For ease of understanding, the twelve to eighteen resource spaces around each primary branch of an ideal crown can be distributed around and along the stem in a helix. Branch confluence positions are determined by optimum packing density. In many natural systems, the packing density of leaves, twigs or resource gathering tissues are offset to prevent one from being directly above or beside the other. The offset seen often approaches the golden angle or golden proportion of a circle (360^o X 0.382 = 137.5^o). (Figure 35). Here the golden angle of 137.5^o is approximated with a simple green angle of 135^o ($90^o + 45^o$). From crown top to bottom, each vertically adjacent confluence area is separated around the stem circumference from each other by the green angle of 135^o. (Figure 36).

Space Between

The vertical distance between confluences is determined by dividing live crown height (in feet) by the number of resource space volumes or branch positions, plus one for the terminal position. For example, for twelve branch positions, divide live crown height by 13 (12 +1), or for eighteen branch positions, divide live crown height by 19 (18 + 1), to determine vertical distance between confluences.

The resulting value is a vertical distance (in feet) between consecutive confluences, although they would be off-set along the branching helix by 135^o, the green angle. Figure 37 provides the idealized vertical distance

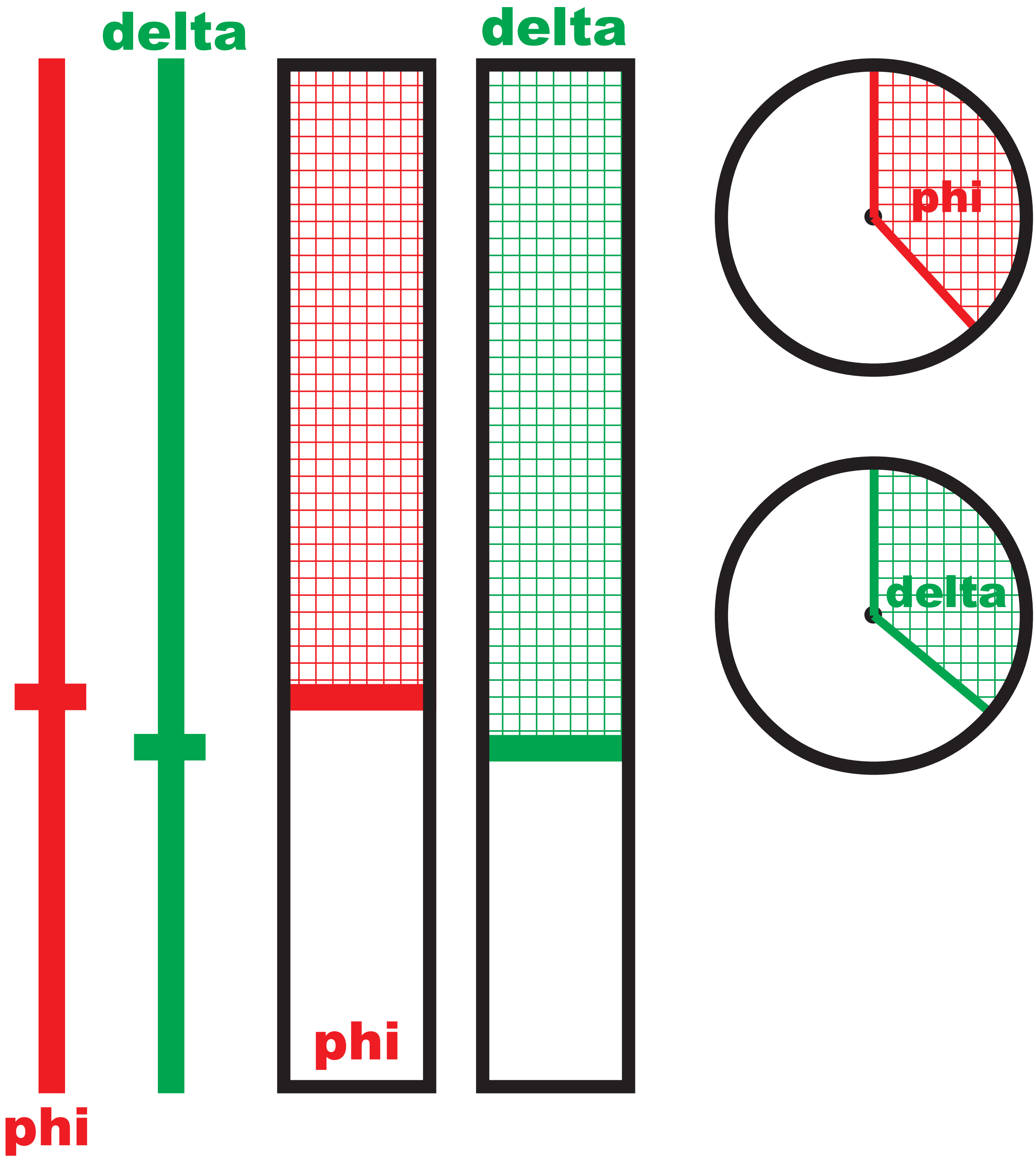

Figure 35: Graphical views of the golden proportion (*phi* = 1:1.618) in line, block, and circular forms. The circular form is usually termed the golden angle (*phi* = 137.5^{o}). In classic design pruning the golden proportion is replaced by a close approximation called the green proportion (*delta* = 1:1.667) or green angle (*delta* = 135^{o}).

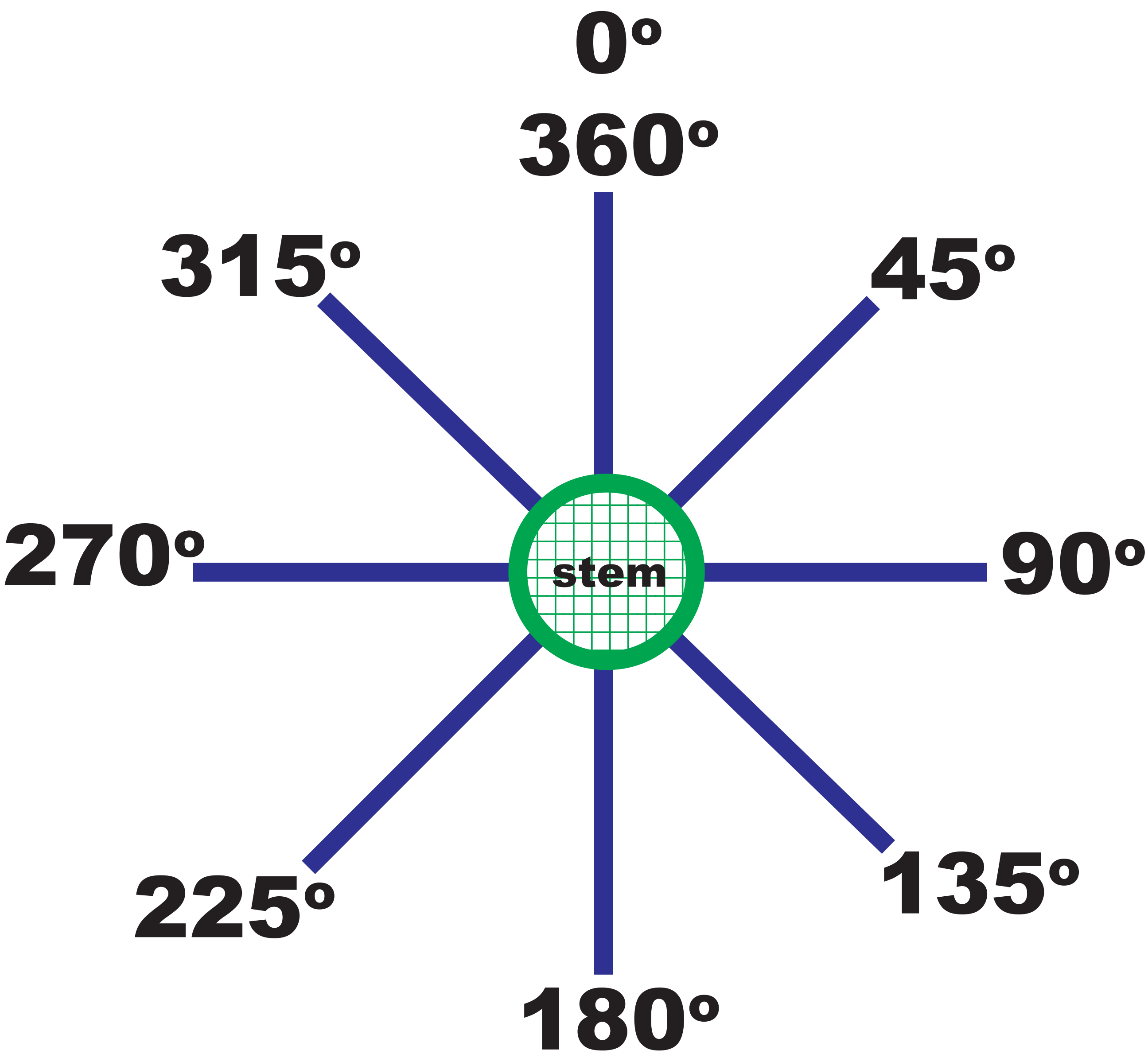

Figure 36: Possible idealized confluence positions on a tree stem based upon the green angle of 135°.

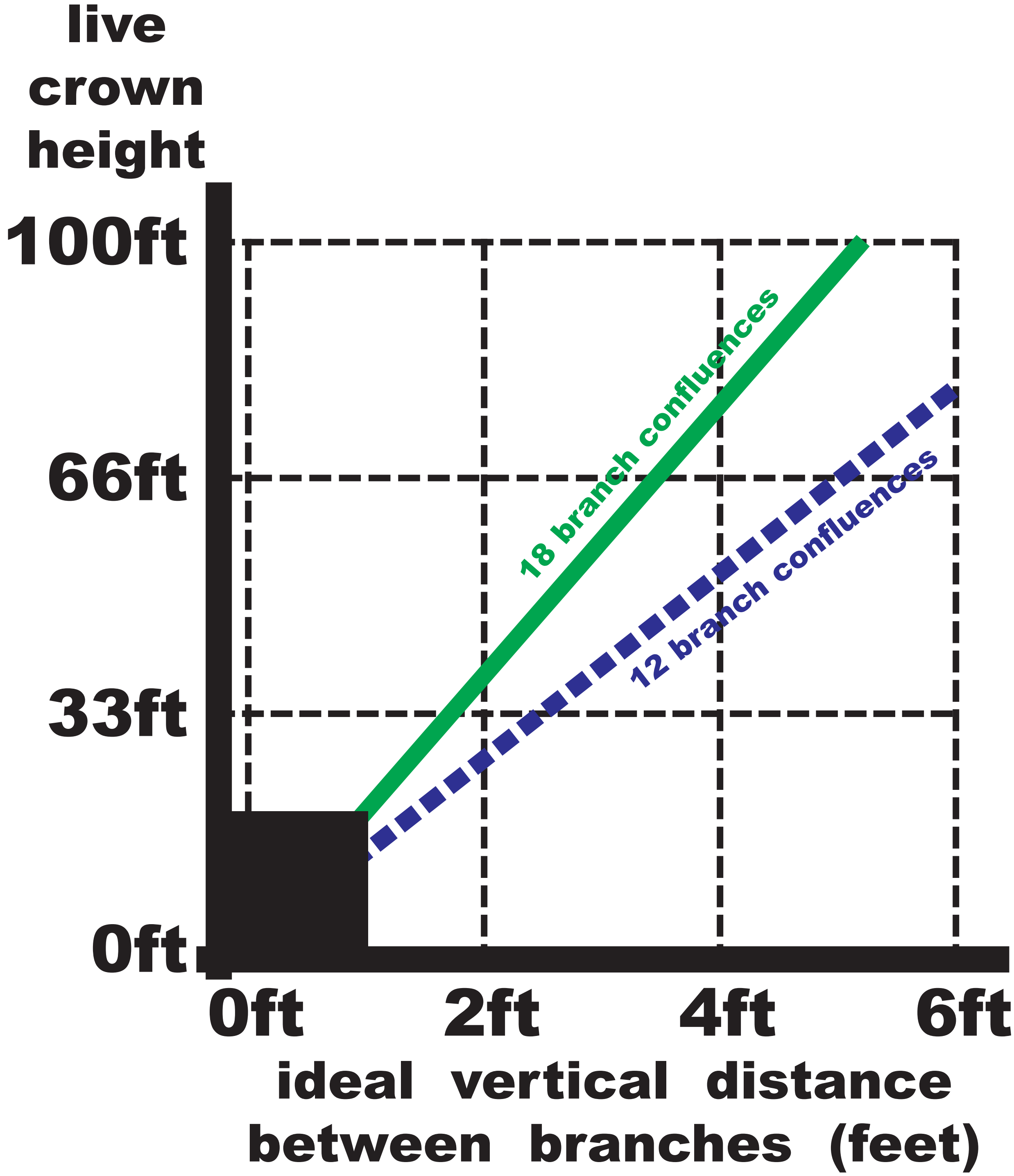

Figure 37: Idealized vertical distance in feet between 12 or 18 confluences on a tree stem based upon live crown height.

in feet between stem - branch confluences for given live crown heights (not total tree height). In actual practice, confluences which are smaller and near the top of the stem can be spaced closer together.

Within the top third of total tree height, or top half of live tree crown, a total of six to nine resource space volumes (i.e. half of all resource space volumes), containing a single branch should be maintained. Each branch would never be directly above another except in the 1st and 9th branch position (eight branch positions apart vertically). (Figure 38). A total of six to nine resource space volumes (branches) should also be ideally maintained within the middle third of total tree height or bottom half of live crown.

Distribution

For a whole tree, a total of 12-18 primary confluences, divided into 6-9 confluences for both top and bottom halves of the living crown, would be maintained. Figure 39. All branches should be well distributed around and along the stem. No two neighboring branches (physically close branches) should share the same position horizontally or vertically on the stem (i.e. a branching helix form). Every branch would always be separated from its nearest neighbor around the stem by 135^{o} and by a vertical distance of:

[(1 / (branch confluence number + 1)) X height of live crown].

Any confluence would only have another confluence directly above or below it vertically every eight branch positions (in an 18 branch configuration). Figure 40 shows confluence distribution along one vertical plane demonstrating ideal branch separation or packing density.

Strength

For long term structural stability, only one confluence should be allowed to disrupt longitudinal fibers of the stem along the same vertical or horizontal line. Branches should always be maintained in a roughly alternating or helically separated pattern. Branches which arise from the same horizontal place (circumference) around a stem (like opposite or whorled branching pattern species) concentrate significant stress and strain on the stem at the site of multiple confluences, as compared with alternate branches. Separating a confluence horizontally and vertically allows a well-defended and structurally sound stem and branch to grow.

In trees with distinctly whorled patterns of branch generation, like many gymnosperms, several aspects of pruning must be modified. Branch distribution in these species should be visualized as:

1) will the tree be skirted (in live branches) almost to the ground;
2) how close together are the whorls; and,
3) how many branches per whorl currently exist.

Always raise the live crown at least so foliage does not touch soil (consider placing foliage above the rain splash height), in order for branches to not recline on the ground when wet during the growing season. If whorls are closer to each other than one mid-whorl stem diameter to each other, consider all branch removal on some whorls. Ideally prune to no more than two or three even spaced branches around the circumference at each whorl. Alternate vertical branch placements for each adjacent whorl. (Figure 41).

Stuff Happens

Because trees, arborists, and past treatments are not perfect, confluences may exist in non-ideal positions and represent significant tree resources. If confronted with confluences out of idealized positions, a

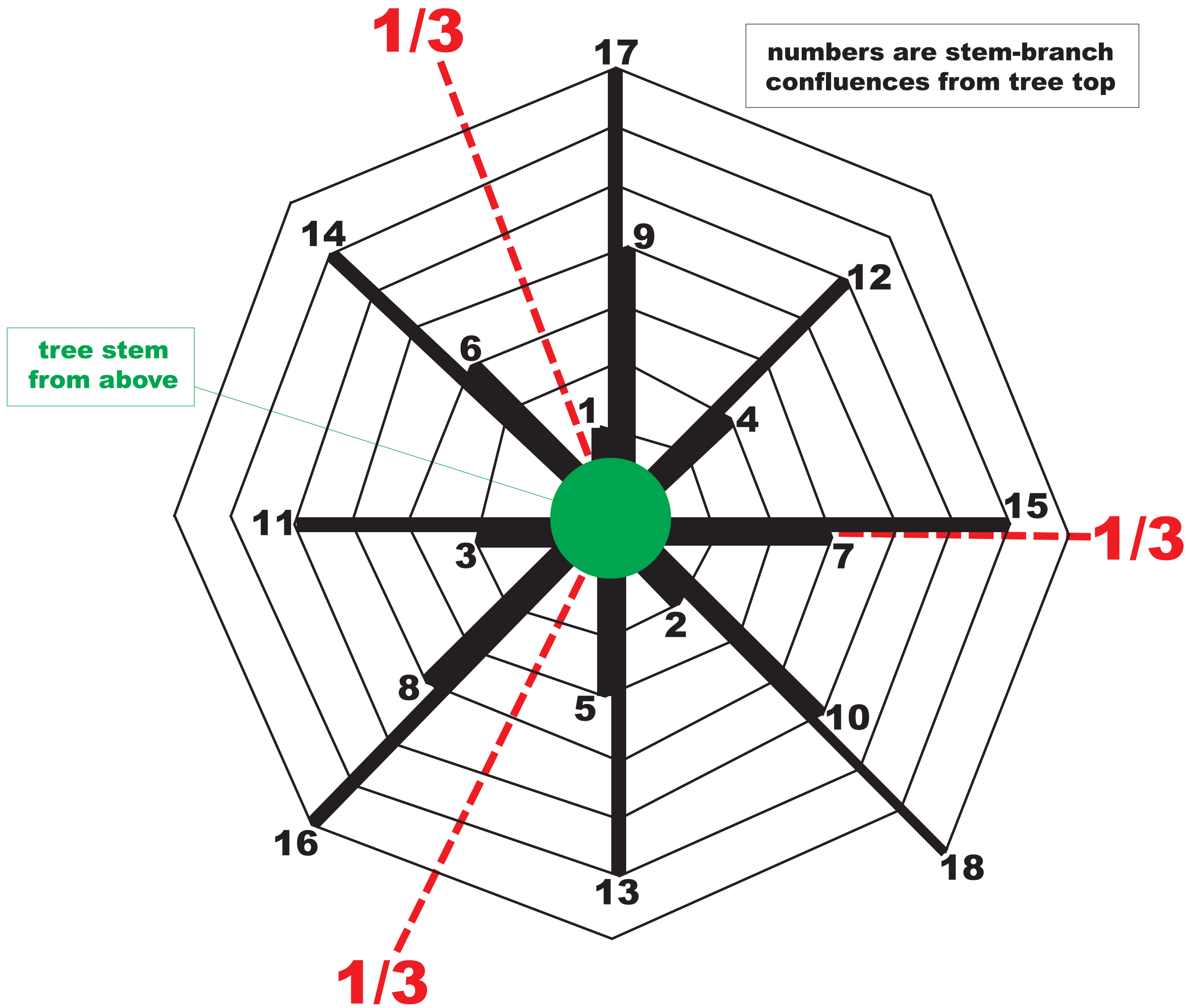

Figure 38: Ideal distribution or packing density of 18 branches within the live crown of a tree as seen from above.

Branch confluences are numbered starting at crown top with number 1, proceeding down and around the stem. Each branch is separated from the next branch above and below by 1/19 live crown height and by 135^{o} stem circumference. The live crown is divided into vertical thirds with six branches in each third. Note, distribution is along a branching helix (i.e. conical helix), not a spiral form as shown.

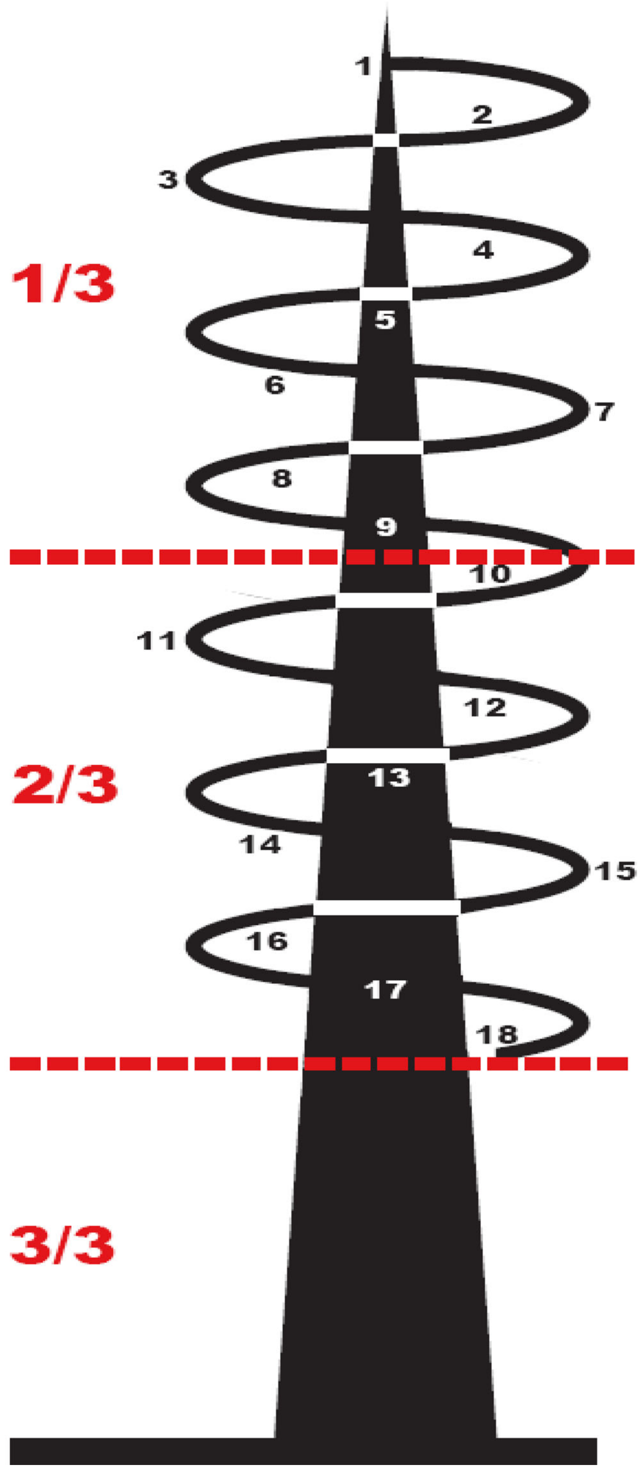

Figure 39: Two dimensional diagram showing a branch helix draped over a tree stem. Numbers represent 18 stem-branch confluences in numbered order along the helix beginning from tree top. Each confluence is vertically separated from each other, in this case, by 1/19 live crown height and 135° horizontally around the stem. Each full loop of the branch helix is 2.67 confluences apart (~1/7 live crown height apart).

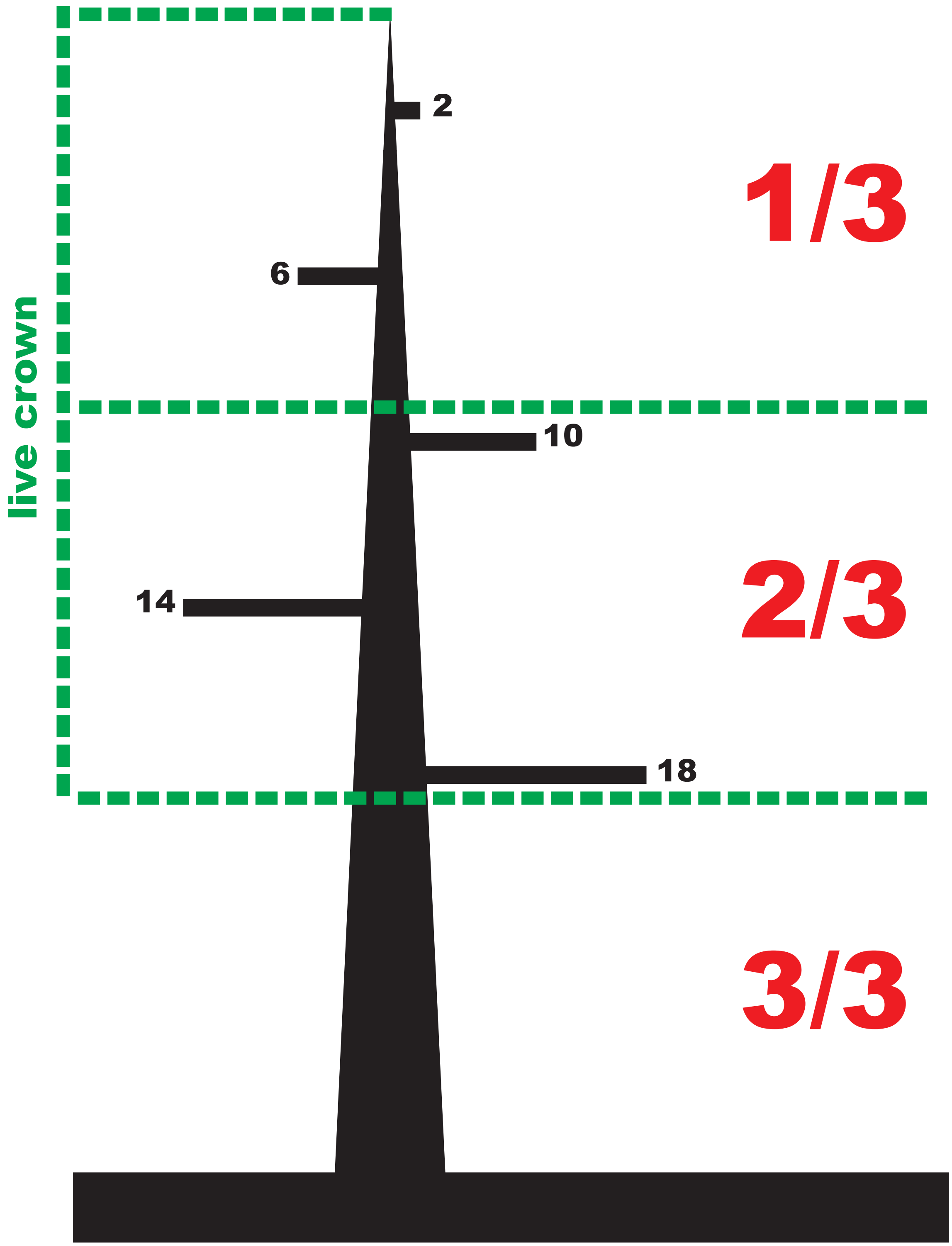

Figure 40: Ideal distribution of five branches distributed along one vertical plane within 18 resource space volumes around and along a tree stem listed by stem-branch confluence order number.

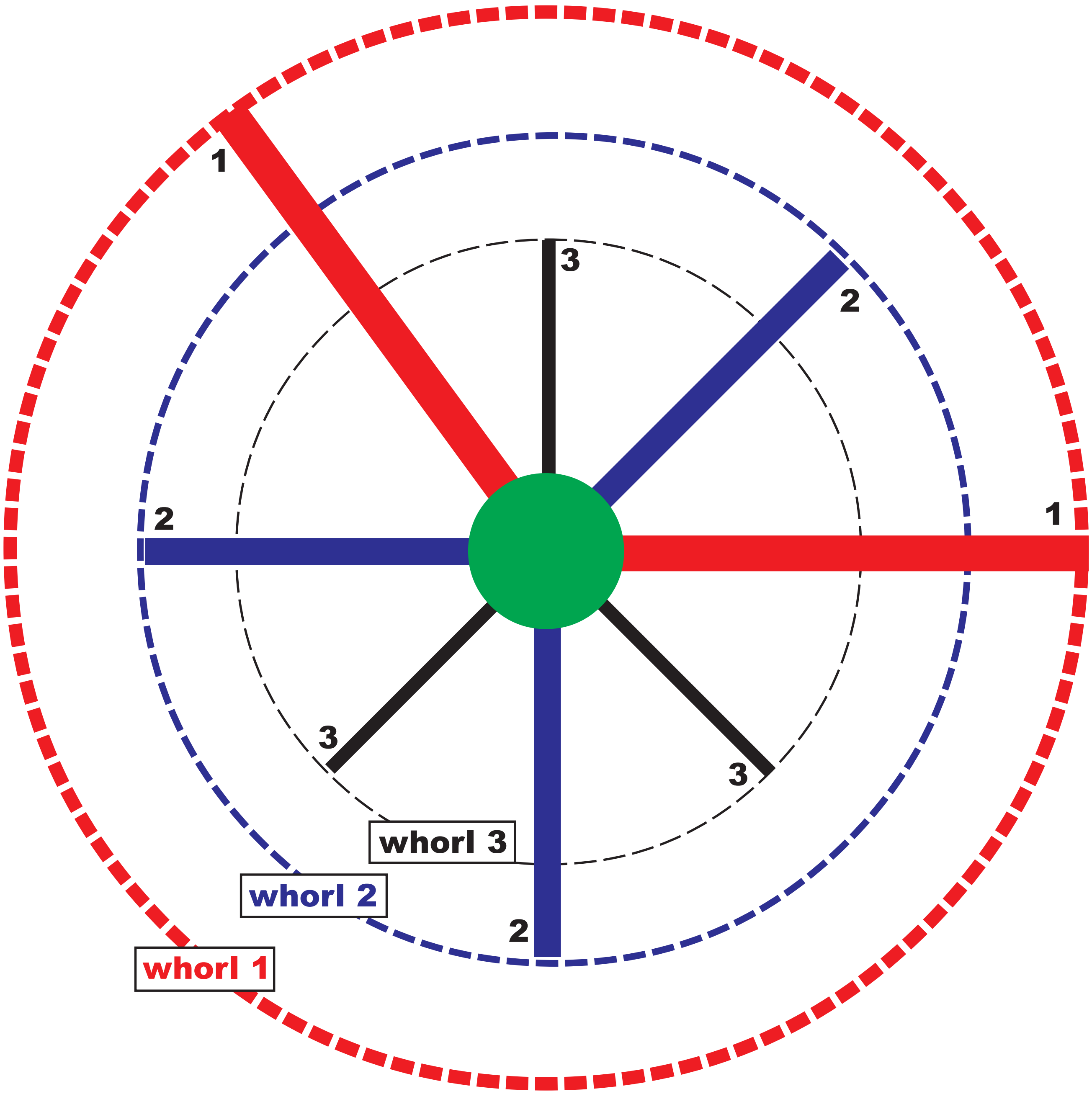

Figure 41: Diagram from above of a stem containing three branch whorls with vertical branch patterns per whorl alternating to minimize shading of branches below. Whorl 1 is on the bottom and whorl 3 is at the top.

minimum set of pruning criteria should be followed. The most extreme minimum vertical distance between branches should be at least four times the branch base diameter above and below each confluence.

In a small tree with many tightly packed branches, there can be many permutations of which branches to keep in optimizing crown aesthetic value, structural integrity and biological efficiency. No two neighboring branches should share the same vertical position (above or below the other) on the stem, or share the same longitudinal grain pathway (resource transport pathway). Estimating transport pathways are difficult especially with trees having slightly lopsided crowns generating crown twist (torque) held by significant spiral grain. No two neighboring branches should share the same circumferential area horizontally around the stem. Every branch must have its own resource control and delivery path, and its own stem position for structural stability.

Grow Low

The role of upper and crown edge branches are different from lower and interior branches. Because of chlorophyll and axillary pigment differences, coupled with different leaf architecture, trees gather all the resources possible throughout the above ground resource spaces they dominate. Upper and outer branches are designed to fill in and colonize new spaces rich in light.

Lower and interior branches react to changing light resources by filling in old resource spaces within the crown. Lower branches are designed to capture light not fully utilized by top branches. Leaf area and respiring sapwood volume are proportionally different on lower and internal branches when compared with upper, full sun branches. (Figure 42).

Lower stem branches can function physiologically near the margin of net food production for long periods. As such, people argue removal of these branches make little difference to overall food and resource allocation processes in a tree. Changing internal allocation economics is but one potential impact of lower branch removal. Marginal, low, and interior branches play a significant role in tree health and structure. Conservation of these branches is important, but these branches need to be controlled and prevented from dominating resource supply pathways. A healthy tree usually generates a growth control field to keep lower branches in check. Abridging these branches accomplishes the same thing.

Transient Values

Original branches, or later generated sprout-origin branches, along a stem in the lowest third of the tree are usually considered temporary or transient branches. Unfortunately, the drive to push for a clear trunk by raising the live crown quickly can disrupt food allocation, growth regulator distribution, root development and tree structural stability. These lowest branches are not the best food producers, but they still generate net production of food and growth regulators. Transient branches should be conserved and controlled.

Transient branches have great value in development of stem taper and root health. They are the driving force (literally the driven force) in sensing bend and torque stress, helping a tree effectively add new tissues to resist these stresses, while acting as shock absorbers for mitigating storm wind loads. Low branches on a young tree will not exist in the mature tree. For example, branches which are 5 feet off the ground now in a 20 feet tall young tree, usually will be removed eventually to yield a 75 feet tall mature tree with 25 feet of clear stem. (Figure 43).

Skirting

Cultivating a natural aesthetic sometimes requires maintaining many low branches. A number of trees have a natural form which includes many lower branches, poor self-pruning (marginally productive

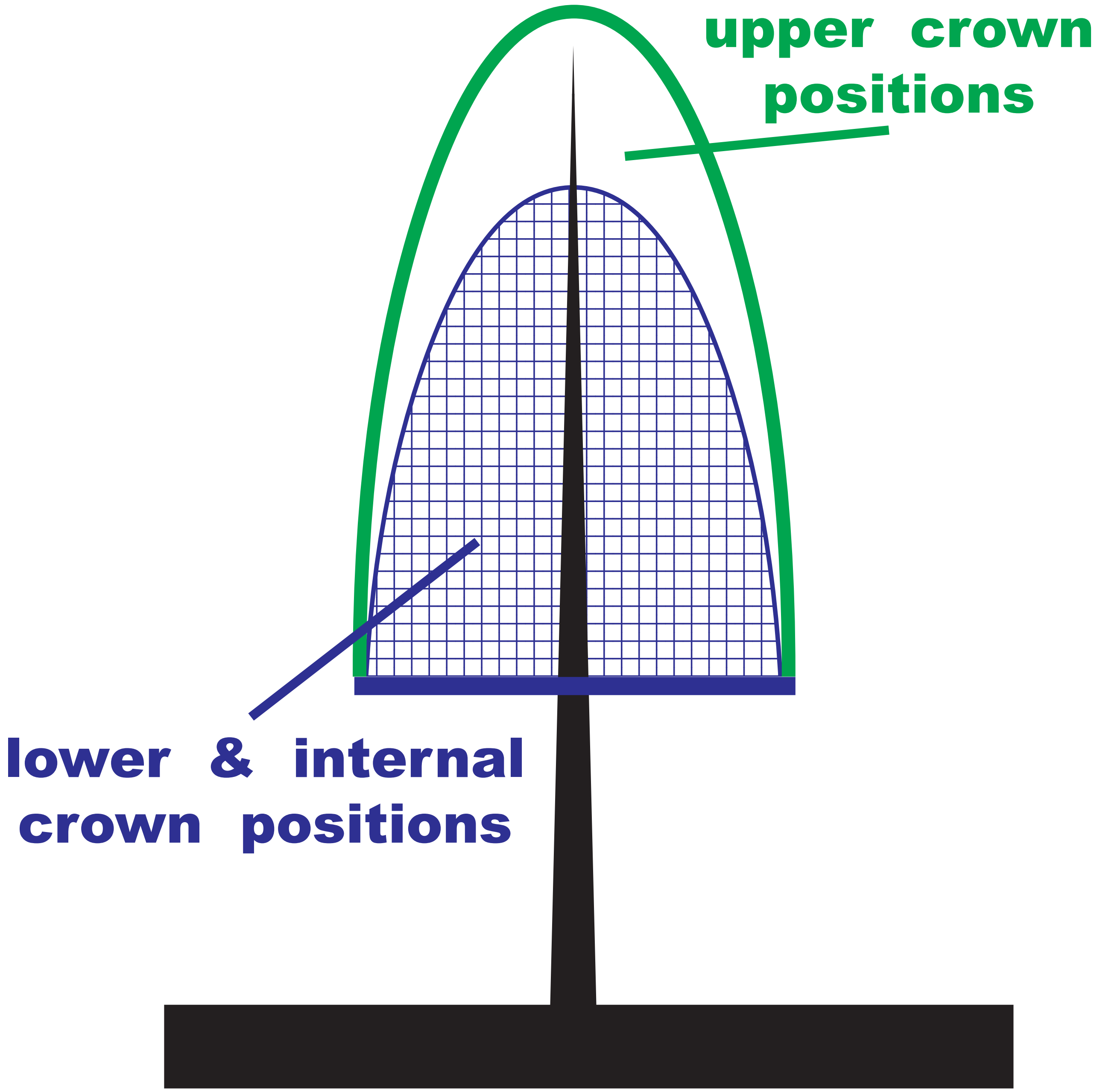

Figure 42: Diagram of crown positions in a tree where different leaf area, leaf productivity, and sapwood volume proportions exist.

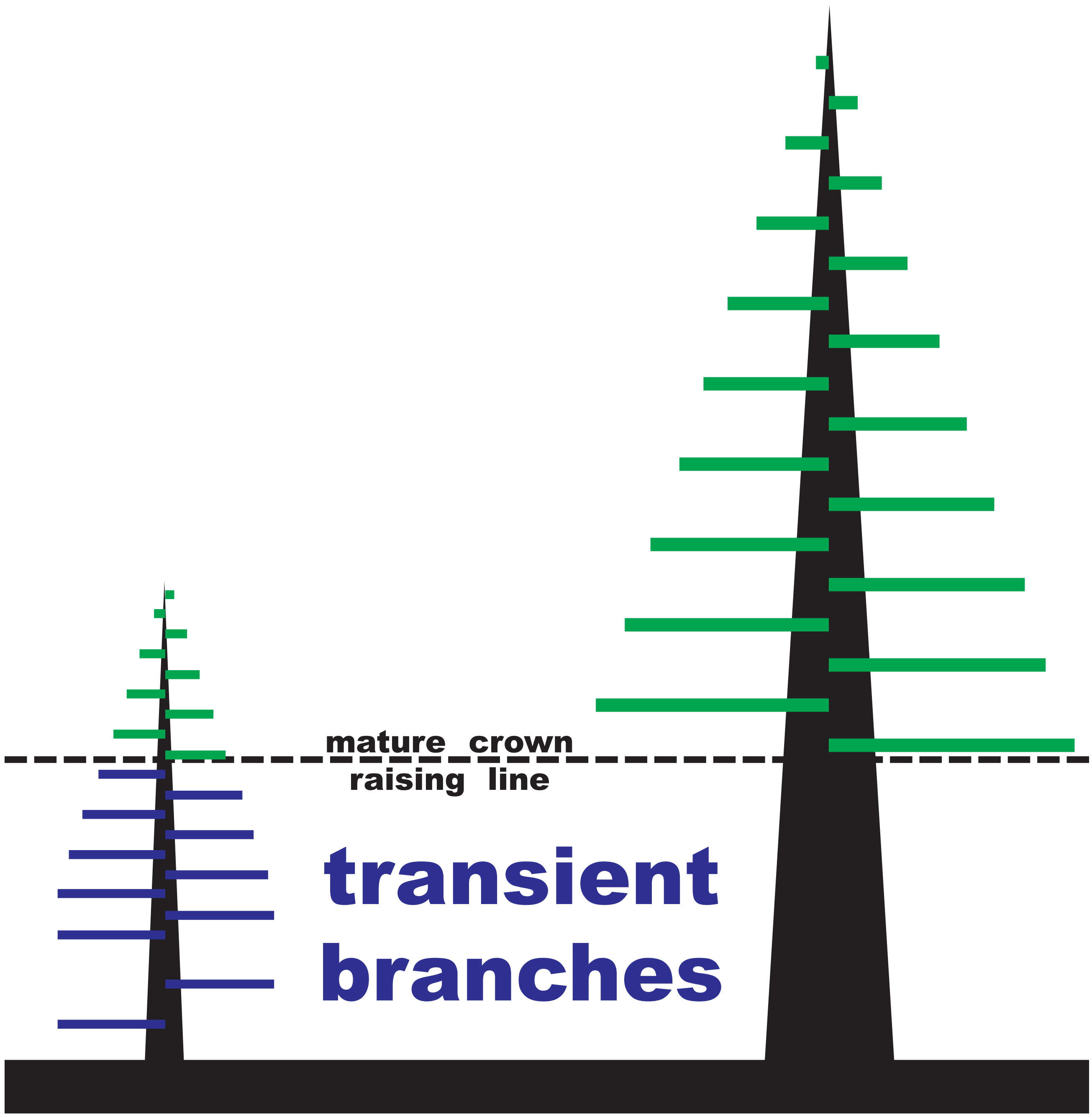

Figure 43: Diagrammatic example of transient branches on a young tree growing from a height above the ground which will require their removal as the tree grows taller.

branches held longer), and evergreen leaf forms. In trees intended to be skirted (low branches maintained) and not clear-stemmed, there are two interacting concerns: 1) branches should not have ground contact; and, 2) prevention of branch damage from landscape maintenance equipment. Slight crown raising on these trees can improve health and reduce damage impacts.

Do NOT use a pruning prescription as an excuse for raising the live crown on species such as holly (*Ilex* spp), evergreen magnolias (*Magnolia* spp.), spruce (*Picea* spp.), fir (*Abies* spp.), and other naturally skirted tree forms. Raise low skirted trees to only the first or second whorl, or first few branches, and then stop raising. Mulch, fence, and/or defend low branches from mowers, trimmers and pedestrians.

PRUNING DOSE

Branch autonomy processes in a tree dictate each branch must produce enough food for itself and extra to transport to the stem and roots below. When branches do not produce this net amount of food, they are compartmentalized off (self-pruning or cladoptosis). If every branch is producing extra food to transport out to the stem and roots along with associated growth regulators, the transport stream of growth materials moving downward in the phloem is consolidated, reaching its greatest net concentration at the base of the live crown.

The base of the live crown has a large concentration of food and growth regulators passing through, and is a center for stem reactions to structural load changes. The cambium / ray junctures act as mechanical sensors which help determine the mix of wood components developed to support the tree crown. The base of the living crown is where most rapid diameter growth in a tree occurs.

Upward Bound

As branches are pruned (or self-prune), the base of the live crown moves upward on a stem. As the position of the live crown base moves upward, stem tissues generate rapid growth and development following the live crown base as it retreats up the stem. The longer the live crown base is in one location, the greater growth that stem area undergoes. If crown raising pushes the live crown base upwards too quickly, the stem fails to structurally develop as effectively in response to yearly wind conditions and gravity loads. The faster live crown base passes through a stem area, the less stem taper develops. Once the live crown base has passed upward, it is difficult to effectively retrofit the lower stem for sensing and resisting new stresses and strains.

For strong stems and branches, it is critical the living crown base is moved gradually up the stem over time. In some skirted species, the live crown base never moves significantly. For trees with crowns raised to present a clear stem, a slow assent is needed to develop taper and resistance to bending and twist (torque). Never raise live crowns in direct response to top height growth. The position and movement of the live crown base is a key arboritecture management marker in design of a strong and efficient tree. Changing or maintaining the live crown base is how a tree health care specialist manipulates aesthetic values, structural integrity and biological efficiency in a tree.

Crown Raising

There are some circumstances which may not meet, or are ever intended to meet, idealized proportions. In these cases, patience must be used in how gradual crown raising progresses. Figure 44 provides the maximum crown raising for any given live crown ratio (Coder Crown Raising Dose Assessment). Note, for trees with small live crown ratios, the maximum per year raising which can be effectively adjusted to is quite small on a height basis.

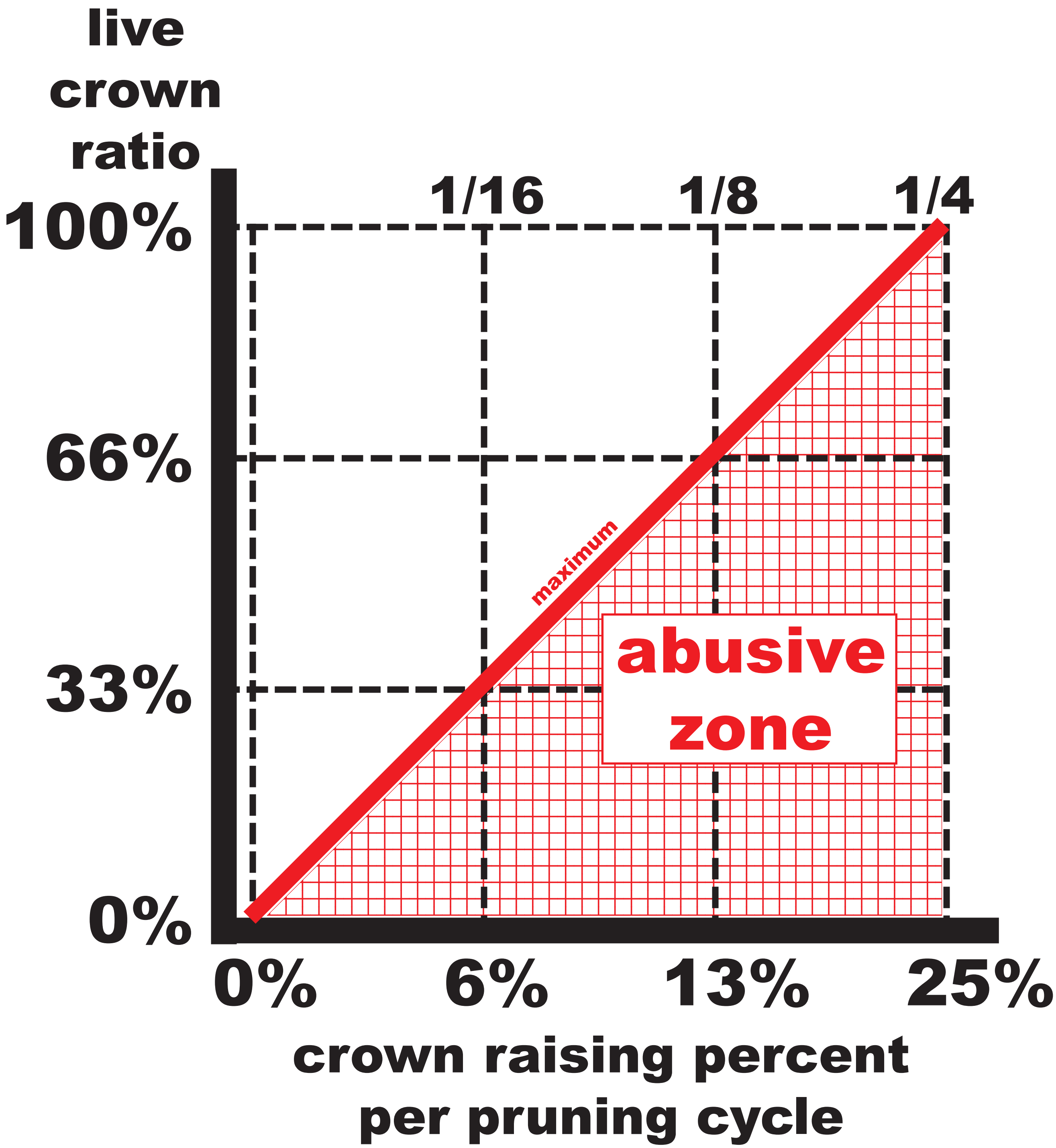

Figure 44: Coder Crown Raising Dose Assessment per pruning cycle for demonstrating potential crown raising abuse. Graph is percent of live crown (height basis) that can be removed, if warranted, every pruning cycle (not less than every two - three years) in a crown raising process.

For example, a tree with 33% live crown should not be raised more than 1/16th (6%) of live crown per pruning cycle. The less crown, the less food and growth regulators generated, reducing the ability of a tree to react to change. Ideally, a healthy tree with a live crown ratio of 66% should be able to sustain up to 1/8 (~13%) of the live crown removal in any pruning cycle. The larger the crown (and everything else being equal), the more accepting a tree is physiologically to productive crown loss. Healthy trees with 100% live crown ratios should be able to effectively react to crown raising up to 1/4 (25%) of living crown height in any pruning cycle.

The base of the living crown and its rapid growth create wood in positions to resist mechanical loads. Stem taper is essential for allowing trees to withstand lateral wind loads and control sway. In addition, the diameter of a tree must continue to grow at a much greater rate in proportion to height growth to maintain the same stem strength in resisting bending and twist. Figure 45 demonstrates the need for greater proportional diameter increases with increases in height. The key point is the live crown base must be allowed to develop a strong tree by building diameter and a well-tapered shape. Do not push crown raising too fast.

Heartwood Exposure

Many examinations of pruning and mechanical injuries in trees have shown small, shallow wounds are much easier for trees to effectively react to than deep wounds that are small in area. Many tree health care specialists have at times misinterpreted this research.

Depth of injury is not about the number of inches into the tree which damage extends. A deep wound is one that reaches into heartwood, whether the stem is three inches in diameter or thirty inches. Depth of injury in a tree concerns the number of annual growth increments breached and the ability of the surrounding cells to react to injury. Shallow wounds remain entirely surrounded by sapwood.

One of the most important issues in pruning is to always make cuts which cross 100% sapwood. (Note: Do not confuse a large pith with heartwood.) (Figure 46). Do not make cuts into or across heartwood, as this would be a deep injury and difficult for a tree to react to effectively. Accumulation of heartwood exposure on many pruning wounds can be devastating over time. It is not just the large diameter branches, but all heartwood containing branches regardless of size which can present defensive problems for a tree. Even small, slow growing branches may have heartwood at their core, and exposing heartwood can signify long-term structural and biological problems. Figure 47 provides a graphical definition of deep versus shallow – sapwood versus heartwood exposure -- pruning cuts.

How Bad?

Figure 48 provides a risk assessment measure using the amount of heartwood exposed by pruning. The Coder Heartwood Exposure Assessment is shown in Figure 49. Heartwood exposures should be minimized in a tree. Minimize heartwood exposure for each pruning event, allowing time for a tree to properly react and adjust to deep injuries. A major concern is there are few ways of judging if a pruning cut will show 100% sapwood exposure until the cut is completed. Once the wound is made, heartwood exposure can be assessed. Figure 50 lists the number of pruning wounds a tree should sustain, by heartwood and sapwood exposure type, for each pruning cycle.

Deep pruning wounds exposing significant amounts of heartwood area demonstrate how these branches should have been cut much earlier when the branch was small and more effective in dealing with wounding. In this case, pruning was delayed too long. Once a pruning prescription is applied, a continual assessment of the amount of heartwood exposed should be tallied. Once too much heartwood is exposed, pruning should be terminated for this pruning cycle.

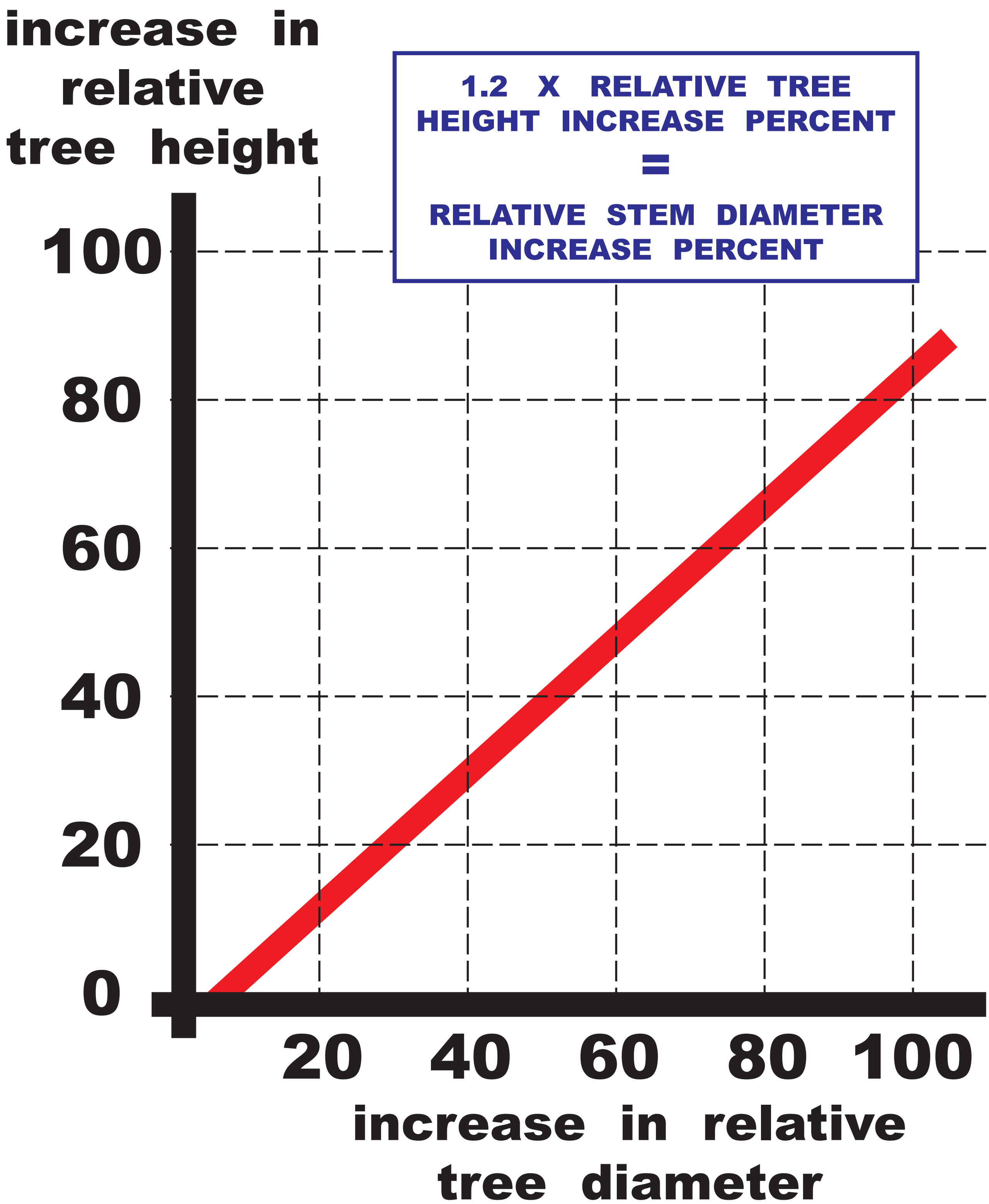

Figure 45: The increase in height and diameter of a tree to maintain a similar proportional strength level (resistance to bending and torque (twist)).

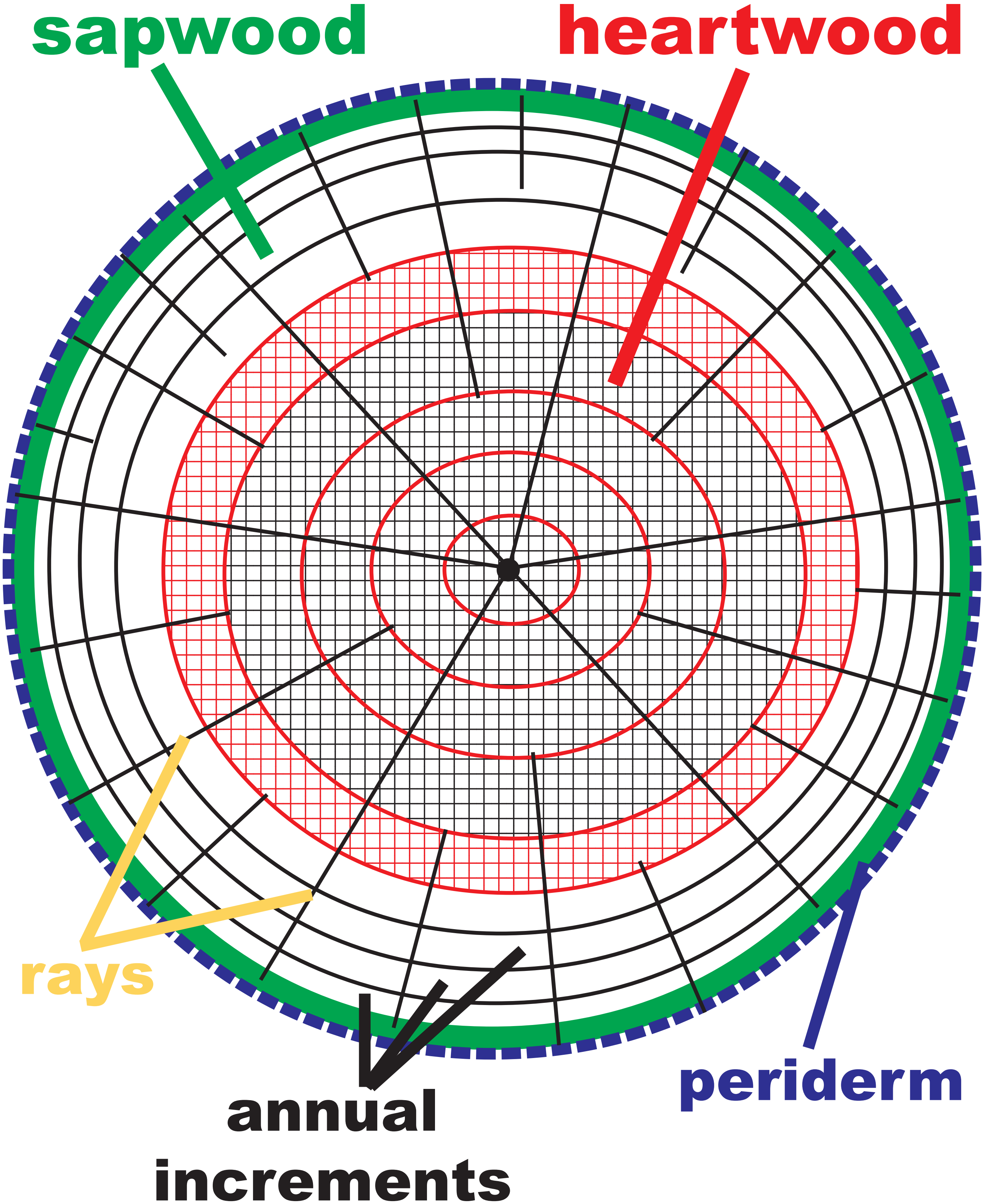

Figure 46: Diagram of a stem cross-section showing sapwood and heartwood (shaded).

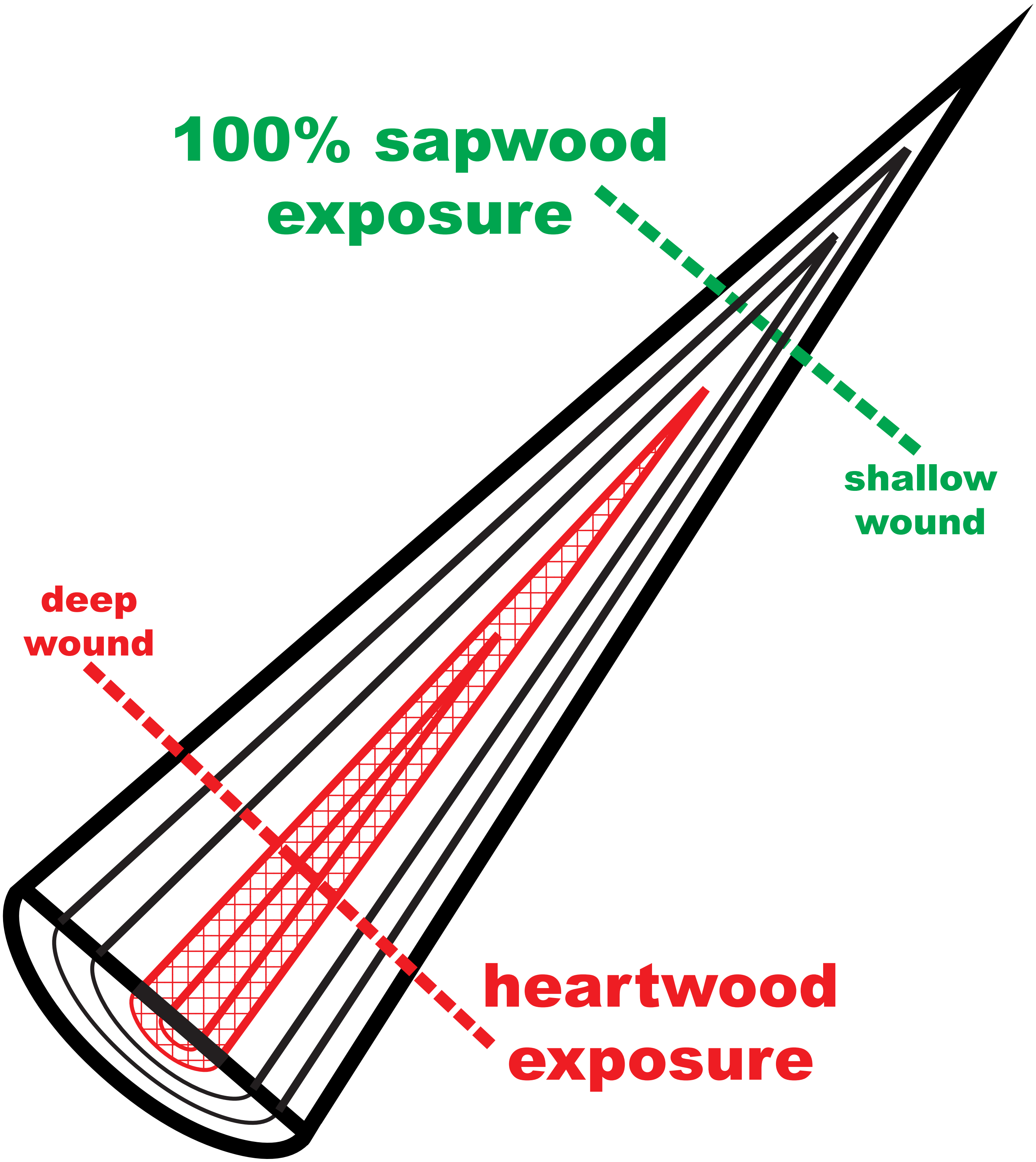

Figure 47: Diagram of a deep cut and a shallow cut using heartwood exposure to gauge relative wound depth. Note this diagram is an example of a deep and shallow pruning wound -- it is assumed a proper nodal pruning cut will be made.

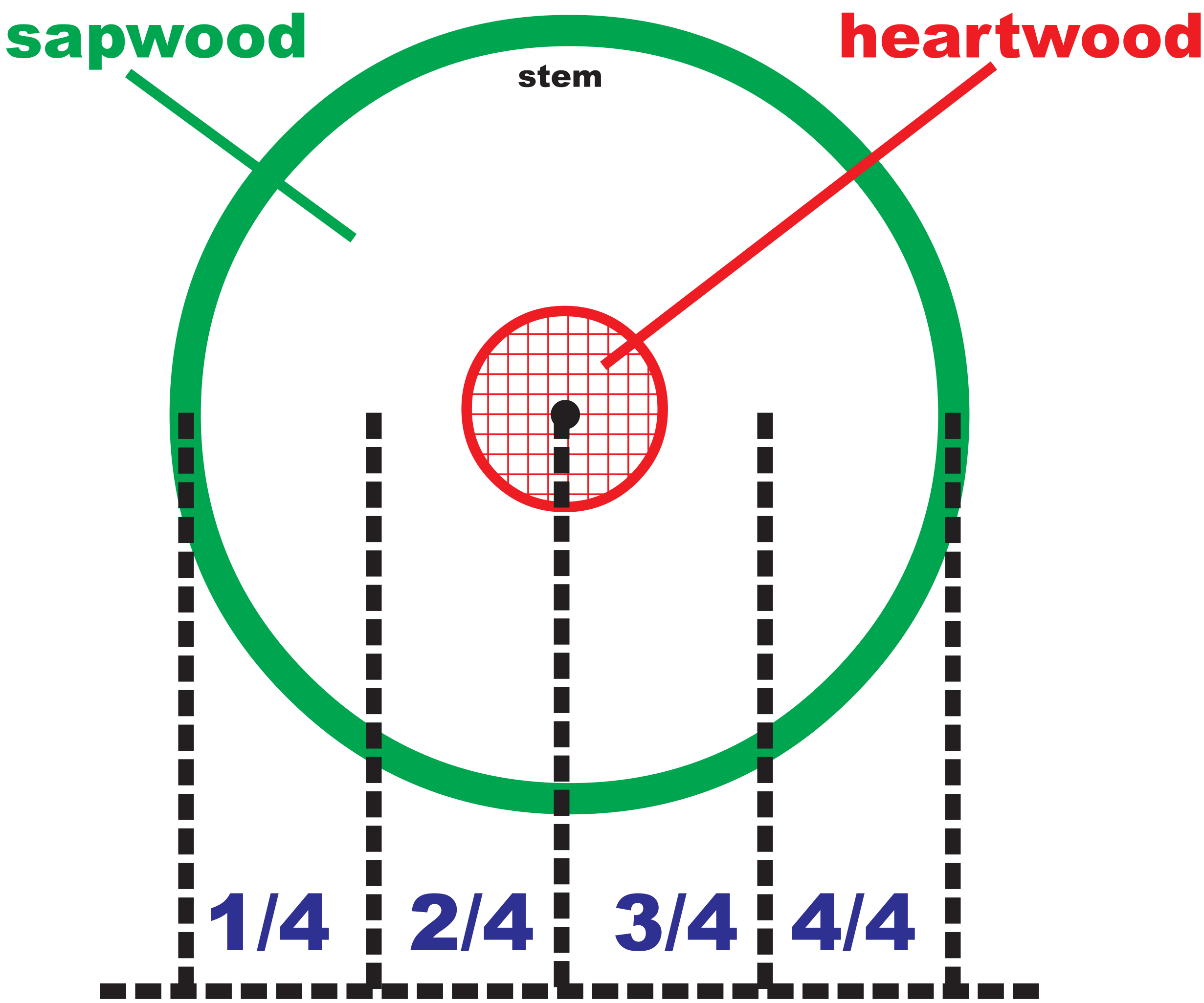

Figure 48: Diagram showing how heartwood size in a branch or stem can be measured. Heartwood exposure is described as a percent or fraction of total branch or stem diameter. In this case heartwood comprises 1/4 of stem diameter.

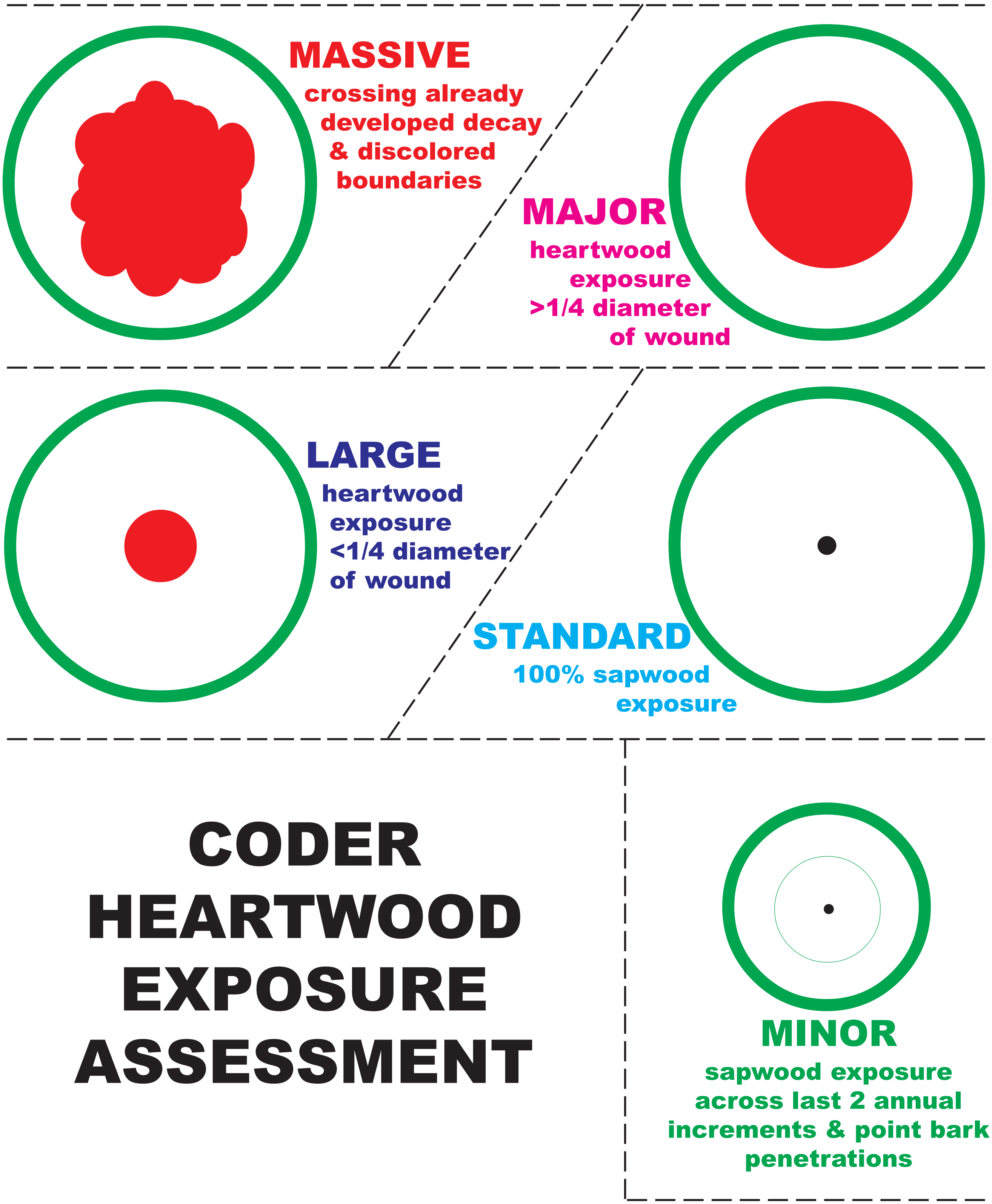

Figure 49: Diagrams describing the five types of branch pruning wounds using sapwood and heartwood exposures from wound faces.

CODER HEARTWOOD EXPOSURE ASSESSMENT

pruning wound type	maximum number of pruning wounds to a single tree
massive	1
major	3
large	7
standard	15
minor	31

Figure 50: Maximum number of pruning wounds to be applied to a tree by wound type in one pruning cycle.

The minimal pruning cycle should be two (2) years for diffuse-porus wood architecture trees and three (3) years for ring-porus and gymnosperm wood architecture trees. Usually, pruning cycles are much longer and include age and size specifications. Shorter pruning cycles are used to train trees when young into manageable forms. Brutalizing a tree with massive heartwood exposures from a few large cuts, or many small cuts, is not acceptable.

Transport Stress

Research on tree aging shows a major component in age on-set tree stress is the increasing number of nodes between leaf arrays and stem base, and complexity of the route water and essential elements must pass to reach a leaf. The more nodes between the source of gathered resources and sink (point of use), the greater chronic transport stress within a tree. A tree minimizes this type of stress through branch and twig abscission or self-pruning. Trees maintain only a limited number of branch orders over time.

If every growing season produced a successful new lateral twig off of last year's lateral twig, by year fifty there would be fifty branch orders – and fifty twig and branch nodes between the stem and farthest twig tip. Figure 51 presents a diagram showing nine branch orders from the stem. If branch orders are counted, most trees maintain no more than 5-9 branch orders on lower branches, and only 3-4 near tree tops. The more stressful the site, especially for soil resource space and water resources, the trend is for fewer branch orders to be maintained. Transport stress can slow or disrupt photosynthesis, water supply, nitrogen compound delivery, and use of stored food.

Count & Reduce

To minimize chronic transport stress at an early age, prune to abridge or eliminate higher order branches and twigs, leaving the remaining twigs biologically effective in generating photosynthate and growth regulators. A pruning prescription would simplify total transport path length to 4-6 branch orders. This minimal transport path acts as an accelerated natural process (cladoptosis) minimizing transport stress. The stress aging of young and middle aged trees can be significantly reduced by this process.

Branch Dominance

The feedback loop in a branch for success involves continued large pulses of bud-produced growth regulators (principally auxin). These pulses define root regulator pathways essential for water and essential element delivery. Water and elements are used to generate more food, which in turn is shipped out to the roots along established growth regulation defined highways. The roots reciprocally, supply more raw materials to those successful food producing areas of the stem. Around the outside of a crown, dominant and active buds on major branch tips control both lateral bud growth and twig resource delivery pathways behind and below branch tips.

Lateral buds, branches and twigs are partially controlled by lack of resources associated with limited growth regulator signaling. The terminal and active buds manage and control branch resources, and so, control the buds and twigs farther down the branch toward the stem. There are several times a year (most notably in the early senescence period of fall) when crown control and dormancy processes leave lateral buds, twigs and branches free from most controls by terminal buds for a short period of time. Dormant buds, lower twigs on a branch, and lower branches on a stem can pilfer additional resources from transport and storage systems, and grow.

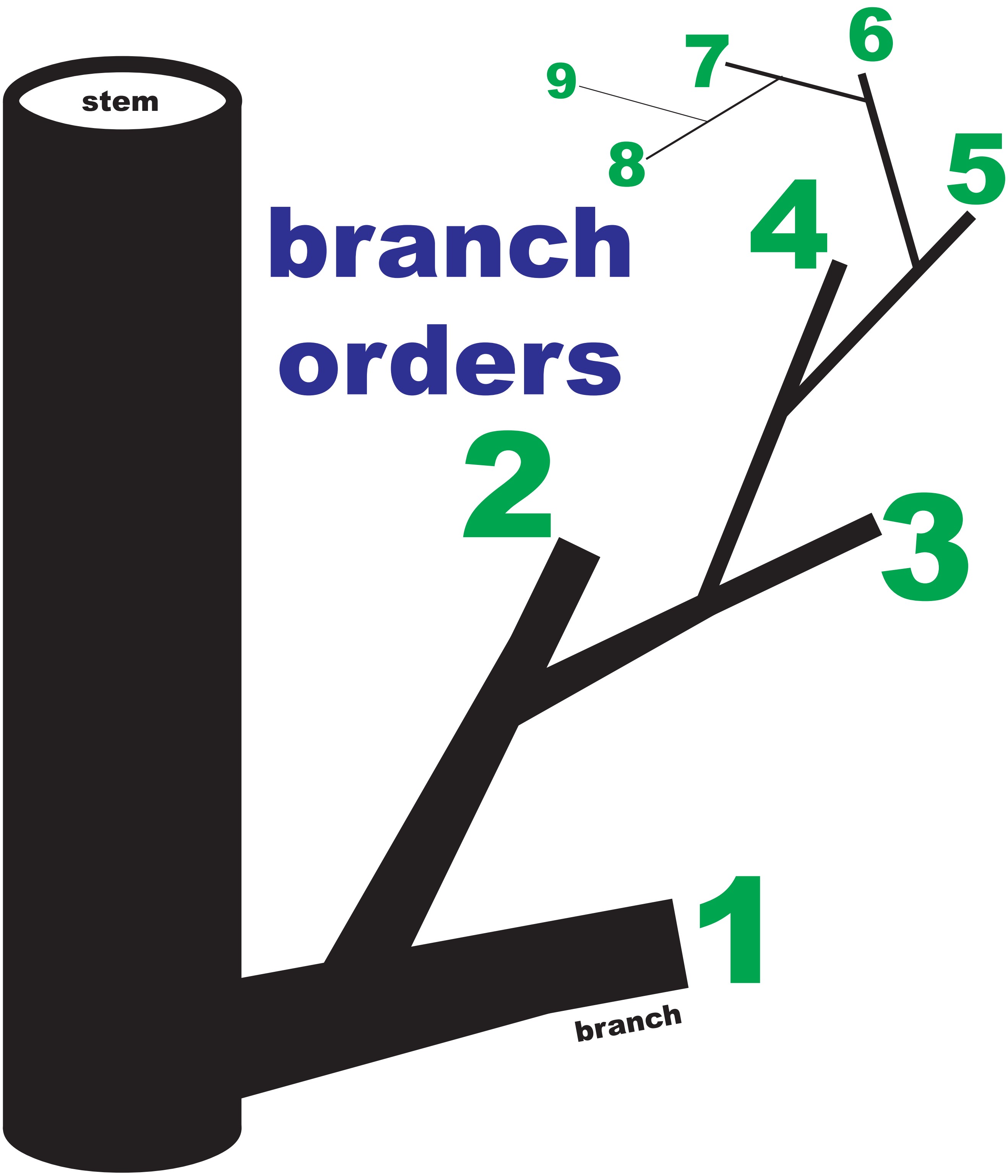

Figure 51: Diagram demonstrating how branch orders are counted. This set of branches and twigs have 9 (nine) branch orders. More branch orders can signify more transport resistance and resource availability stress.

Coup d'etat!

As the tree top slows down in growth material production and prepares for winter, and the roots are still active, lateral tissues can become more active for a period of time (released from control / dominance). Dormant buds can be released in positions where light resources are available. If lower branches attain better light resources by elongation and better connections to raw material transport paths, a lower branch can start to grow, control resource space, and expand its dominance. Stressful environmental conditions and damage can also act to constrain crown terminals which can lead to lateral branch and twig growth, and dormant bud release.

The long term problems of lower sprouts, twigs, and branches attaining dominance in a tree can lead to top or upper branch stress and loss, as well as disrupting transport and defensive capabilities. Newly released sprouts from dormant (latent) buds should be removed within one growing season. To manage tree domination and transport control by lower branches, aggressive branches should be abridged back into shade. (Note: this is branch reduction NOT removal.)

"Abridging to shade" for terminal portions of aggressive twigs and branches, (terminal plus the next three lateral buds/nodes or twig terminals in angiosperms, or the single twig terminal area in gymnosperms), will help upper branches retain/regain firm control. Because transport pathway success accelerates growth success, several small abridgments over several pruning cycles will usually be needed. Abridge lower aggressive twigs or branches enough so they are shaded. Shading calms all growth feedback processes.

Dominating

As discussed earlier, lower and side branches should not be completely removed unless it is absolutely essential, or the branch base diameter is becoming too large for the stem. Abridging the branch to shade allows food and growth regulation production to continue at a limited level while maintaining single trunk dominance. Abridging, not removing, aggressive branches allows internal consolidation of transport paths and branch resources. This abridgment to shade is of value to the whole tree under many management objectives. "Shorten not remove" is a key learning point about pruning lower branches.

Pruning Time

If a tree is healthy with plenty of stored food, timing of pruning is not as critical as when trees are stressed and constrained by site resources. Unfortunately, most shade and street trees have resource gathering, control, and transport problems which make timing of pruning more important. There are three physiologically related time targets within an annual growth cycle of a tree when pruning should NOT be completed. Especially avoid the growth period from first noticeable bud change in Spring until leaves have fully expanded. Do not prune in the heat of summer (high temperatures above 85^{o}F).

Later in the growth period, avoid the leaf senescence season from first yellowing (start of foliage color change) in Fall until all shades of green (or green islands or patches in leaves) have been completely lost. Obviously, this last temporal target is for deciduous hardwoods. These hardwood trees, if in full sun, can be used as ecological sensors for knowing when to treat surrounding evergreen gymnosperms and angiosperms. (Figure 52).

Chilled

Prescribe pruning treatments for after full leaf expansion in late Spring and early Summer, and in the dormant season. Care must be taken with various species initiating bud changes in early Spring to assure no pruning in this bud change period. Avoid late dormant season pruning in species that generate large root water pressures to minimize wound weeping or oozing.

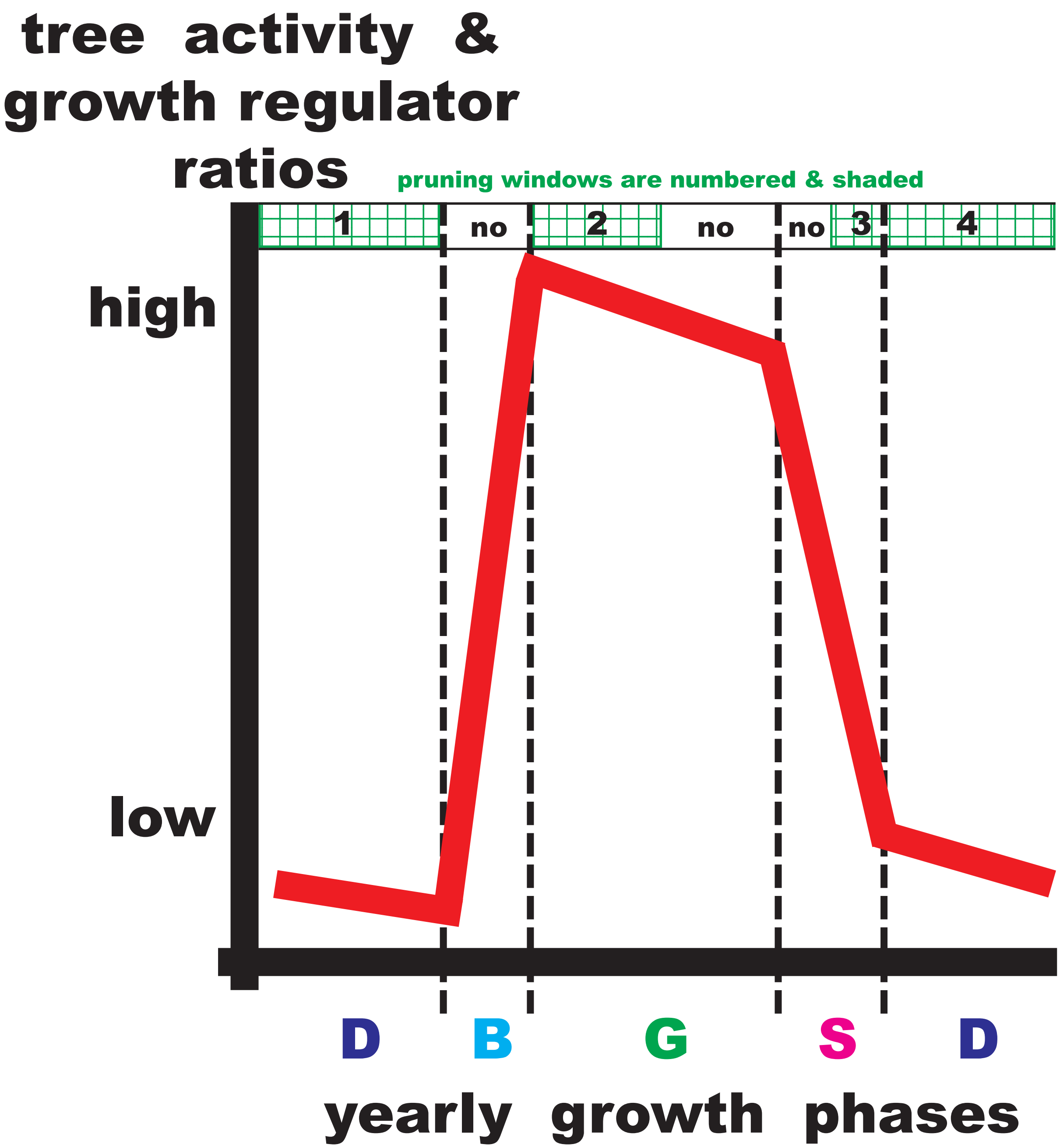

Figure 52: Graphical description for timing of pruning prescription applications. D = dormant; B = bud & leaf expansion; G = growth phase; S = senescence. There are four pruning windows (shaded & numbered), and three times when pruning is not acceptable ("no").

It is critical late Spring / early Summer pruning does not facilitate pest success. In some parts of the continent and in some tree species, the chilled temperatures of late dormant season pruning is the only choice because of pest problems. For example, the Southern yellow pines (*Pinus* spp.) should only be pruned in the late dormant season when daily high temperatures are below 65°F due to bark beetle concerns. Growing season pruning under low to moderate temperatures, remains a best management practice in most places for most species.

How Often?

Due to resource collection and growth rates of young, active trees on good sites, a short pruning cycle should be installed after establishment for training young trees into ideal forms. Expect to prune trees every two to three years, depending upon shoot growth patterns, for the first three cycles. These pruning events should concentrate on removing problems and helping a tree become aesthetically pleasing, biologically efficient and mechanically sound. After the initial phase of pruning cycles, lengthen pruning cycles for maintenance, not training.

It is important to gauge pruning cycle timing by the size of branches, relative to stem sizes at the each confluence. Branches should be conserved if they are less than 1/2 (ideally 1/3) the diameter of the stem from where they grow. The absence of heartwood revealed in pruning cuts is also important in gauging pruning cycle. Strive to have 100% sapwood pruning wounds. Lengthen or shorten the pruning cycle to assure no heartwood exposure and no codominant branch formation.

Getting To Dose

The amount of pruning a tree can sustain at any one time or event can be estimated by experienced tree health care professionals. Crown raising limits and heartwood exposure assessments can suggest how much to prune a young healthy tree. Most means of determining pruning dose try and estimate volume, density, or surface area of leaves. The more leaves a tree can sustain over time, the greater chance it will be productive. Health and productivity of individual leaves and branches are difficult to estimate, allowing pruning dose estimates to be filled with errors.

One way of estimating leaf number and activity is by examining the non-photosynthetic living tissue supported by leaves. These tissues are found within sapwood (living tissues comprise 5-10% of sapwood) and depend upon leaves for food and, in turn, support leaves by defending and maintaining the growth material transport systems. Sapwood must be fueled by leaf productivity. Low leaf productivity increases heartwood volume and decreases sapwood volume. Greater leaf productivity sustains more sapwood. Depending upon species and site, there is a relationship between leaf productivity and sapwood area.

Sapwood

The sapwood area in a branch or stem supported by, and supporting, a set of leaves can be measured by increment core, by recording diameters of pruning wounds, and by estimating growth rates. As trees grow larger, more sapwood is generated and less leaves per unit of sapwood are sustained. The longer the branch and the larger branch diameter, the less leaves per sapwood are sustained. Sapwood volume, as estimated by its cross-sectional area, can be used as a simple assessment of the leaves present.

For example, the proportion of tree leaf area to sapwood area (m^2/cm^2) is cited as 0.4 for redwood (*Sequoia*), 0.67 for cherrybark oak (*Quercus*), 0.24 for green ash (*Fraxinus*), 0.5 and 0.41 for eucalyptus (*Eucalyptus*). [change units of measure: m^2/cm^2 X 69.4 = ft^2/in^2]. The proportion of leaf weight to sapwood area (kg/cm^2) was found in one study to be 0.12. The proportion of leaf area to sapwood area divided by tree diameter ((m^2/m^2)/mm) was found in another study to be 2.6. All of these proportions represent a highly limited set of species, individual trees, and sites, but demonstrate how leaves and their productivity can be estimated by other tree measures, like sapwood. Also note sapwood area pruning dose estimations do not function where tree skin / core relationships have not developed yet .(i.e. when young tree stems are 100% sapwood).

Living Area

Clearly one usable ratio in trees is leaf area to sapwood area, which acts as an approximation of tree (i.e. leaf) productivity. The more leaves, and the more productive each remains, the greater cross-sectional area of sapwood sustained. As trees grow, especially under harsh conditions, the amount of sapwood area can decline while the amount of heartwood area can increase. Measuring sapwood area estimates the productivity of the branch or stem above the measure.

Figure 53 provides sapwood area in square inches for various branch and stem diameters, and with varying amounts of sapwood visible outside the heartwood core. Note this figure is only effective for species with clearly visible heartwood, and for circumstances where discolored wood from injury and decay can be differentiated from true heartwood.

For example, a 10 inch diameter stem has about 79 square inches of sapwood area if the entire cross-section is sapwood (100% sapwood). If this tree is cored and found to have only one (1) inch of sapwood around the outside of a heartwood core, there is only about 29 square inches of sapwood area. Additionally, if a branch four (4) inches in diameter (branch diameter not branch collar diameter) is pruned and is 100% sapwood, it would have ~13 square inches of sapwood area.

Pruning Dose

The amount of pruning allowed in a tree for any pruning cycle can be estimated by using the Coder Sapwood Area Pruning Dose Assessment formula. The formula calculates the cumulative amount of sapwood area pruned off a tree from branches compared with the amount of sapwood area present in the stem. The Coder Sapwood Area Assessment formula uses:

1) tree sapwood area in square inches multiplied by 0.334;
2) divide result by a sum of all branch sapwood areas in square inches which have been pruned, with each multiplied by their crown position value within a tree;
3) crown position value is a multiplier for branch sapwood area based upon whether the branch was in the highest crown position, lowest or internal crown position, or was a new sprout.

Figure 54 is the formula for the assessment. The final result is the pruning cycle dose (PCD). If the PCD is greater than 1 (one), then the pruning was within biologically sustainable limits. If the PCD is less than 1, then pruning exceeded biological limits, stressed the tree, and is a treatment overdose. Figure 55 presents an example using the assessment and pruning dose formula.

FINISHING TOUCHES

Few transformations in tree health care have been as comprehensive in the last 40 years as pruning wound treatments. From the past, when heavy, opaque, petroleum based salves were slathered onto new

diameter (inches)	sapwood depth to heartwood (inches)								100% sapwood
	0.5”	1”	1.5”	2”	2.5”	3”	3.5”	4”	
0.2 in									0.03
0.4									0.13
0.6									0.28
0.8	--								0.5
1	--	--							0.8
2	2 in^2	--	--						3
3	4	6	--	--					7
4	6	10	3	--	--				13
5	7	13	17	19	--	--			20
6	8	15	21	25	27	--	--		28
7	11	19	26	32	36	38	--	--	39
8	11	22	30	37	43	47	49	--	50
9	14	25	36	44	51	57	61	63	64
10	15	29	40	51	59	66	72	76	79
11	16	31	45	56	67	75	82	88	95
12	18	34	49	63	74	85	93	100	113
13	20	38	54	69	83	94	105	113	133
14	21	41	59	75	90	104	115	126	154
15	23	44	64	82	98	113	127	138	177
16	24	47	68	88	106	122	137	151	201
17	26	50	73	94	114	132	148	163	227
18	27	53	77	100	121	141	159	175	254
19	29	56	82	106	129	150	170	188	283
20	31	60	87	113	137	160	181	201	314
21	32	63	92	119	145	169	192	213	346
22	34	66	97	126	153	179	203	226	380
23	35	69	101	132	161	188	214	238	415
24	37	72	106	138	169	198	225	251	452
25	39	76	111	145	177	208	237	264	491
26	40	79	116	151	185	217	248	277	531
27	41	81	120	157	192	226	258	289	572
28	43	84	124	163	200	235	269	301	615
29	45	88	129	169	208	245	280	314	660
30 in	47	92	135	176	216	255	292	327in^2	707in^2

Figure 53: Sapwood area in square inches for tree or branch

Coder Sapwood Area Pruning Dose Assessment

tree sapwood area in square inches X 0.334

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sum of all
[branch sapwood area pruned X
branch crown position value]

1	=	<1 year old sprouts
2	=	lowest & internal crown positions
3	=	highest crown positions

=

PRUNING CYCLE DOSE (PCD)

> 1.0 = within biological limits
< 1.0 = exceeded biological limits -- stress

Figure 54: Assessing the amount of pruning allowed in one pruning cycle based upon sapwood area measures.

Example: 10" diameter tree (DBH)

diameter branch pruned	crown sapwood area	crown position	position value	calculated values
3"	7	low	2	14
2"	3	low	2	6
1"	.8	low	2	1.6
1"	.8	high	3	2.4
0.6"	.28	high	3	0.84
0.4"	.13	sprout	1	0.13
		[sum of all =		$23.37\ in^2$]

If tree is:

100% sapwood tree:
PCD - pruning cycle dose = 1.13

3" sapwood in tree:
PCD - pruning cycle dose = 0.94
(6% overdose)

1" sapwood in tree:
PCD - pruning cycle dose = 0.41
(59% overdose)

Figure 55: Example of the amount of pruning allowed in one pruning cycle based upon sapwood area measures to determine the PCD.

pruning wounds -- to newer research supporting open oxidation and drying concepts, wound treatments have been viewed from many angles.

Pruning Wounds

Research shows pruning paints of whatever variety, application method, ingredients, or formulation do not prevent decay or aid in natural defensive zone effectiveness. Heavy coats of different pruning paints have been shown to accelerate decay behind the pruning wound surface by aiding decay organisms. No pruning paint has been consistently cited as helping in the quick and effective closure of pruning wounds, as non-damaging (not phyto-toxic) to living tree tissues, and as not interferring with compartmentalization processes.

Concealer

In most circumstances, wound paints are cosmetic at best, and a facilitator of tree damage at worst. Best management practices for pruning wounds is to leave them open to the environment which will oxidize the wound surface, dry and illuminate the surface, and initiate a strong compartmentalization response. Aesthetic concerns about visible wounds on trees can be solved by use of tree wound paint without a petroleum or ammonia-based carrier to lightly color and hide the wound. Do not use house paint (either oil based or latex based) as these products will damage living tree cells around the wound, essentially expanding the wound and causing more damage.

Pruning wound treatments do have value in some situations. Some specially designed, non-phytotoxic wound paints or covers have been found to be effective in preventing select vascular diseases spread by wound attacking insects in the growing season. Special use wound treatments are prescribed solutions to some tree health care issues.

Stay Clean

Pruning provides several opportunities for further tree health problems. The two most noticeable problems are removed remains of living tree tissues, and newly opened wound sites. Dying and newly dead tissues recently pruned from trees are filled with essentials of life. These materials, if still in an "as-pruned" form, contain many essential elements, nutrients, and enclosed spaces needed by micro- and macro-organisms. All materials removed should be:

1. physically taken away from the pruned tree vicinity;
2. chipped into much smaller pieces and left to quickly dry or compost;
3. chipped into a transportable form for bagging; or,
4. quickly cut-up and removed from the site.

Pruning wounds must be left free of dangling, crushed, cracked, abraded, or torn tissues. Periderm must be firmly and completely attached all the way around a wound. A sharp saw (and a sharp user) leaves the best defendable wound for a tree. Do not rub soil on wound sites. Ideally, pruning wounds should not be positioned to accumulate water and debris, scarred or scored, or covered.

Cold (hand) pruning saws and shears should be cleaned free of cutting debris and disinfected often, especially if treating a tree with known disease problems. Hot saws / powered saws which generate friction heat should be cleaned of cutting debris often and occasionally disinfected. Disinfect cutting surfaces and anything which touches wound surfaces with ethyl alcohol (not rubbing alcohol) and allow the surface to completely dry before use.

CONCLUSIONS

The basics of tree pruning are easy to learn but can be difficult to apply across many species, forms, and field situations. A few summary statements can be emphasized. Key among these are:

– Prescribe pruning techniques based upon a whole tree concept for attaining an aesthetically pleasing, biologically efficient, and structurally sound tree.

– Have a pruning plan which returns to classical design proportions in most situations (arboritecture process).

– Manipulate tree crowns by managing branch sizes and allocating resource space.

– Generate only small sized, shallow wounds with minimal heartwood exposure.

– Generate only nodal, targeted cuts which help a tree defend confluence areas.

– Avoid use of growth disrupting or pest facilitating treatments on wounds.

– No internode, tipping, topping, or hedging cuts!

– Always cut back to shaded branch unions (confluences) within crowns.

– Patience! Gain tree values through thoughtful and prescribed pruning applied over years – do not rush or over-apply pruning prescriptions.

A young tree training program, a mature tree pruning program, and a careful maintenance / damage management program should be parts of an educational process used for developing pruning specifications and field experience. Once pruning fundamentals are appreciated, effective and informed pruning using sharp pruning tools -- well-applied -- can conserve and add value to trees.

Citation:
Coder, Kim D. 2021. Pruning trees: Anatomical, biological & structural foundations. University of Georgia, Warnell School of Forestry & Natural Resources Outreach Manual WSFNR21-33B. Pp.75.