



Tree Anatomy: Branch Attachment

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Twigs are one year old or less age tissue. Branchlets are 2-3 year old tissue. Branches are shoot tissue separated from a stem or primary axis which is 4 years old and older. Scaffold branches are considered first order (1^o) structural units attached to a main stem or large codominant stems. These branches are usually old and large, upon which the rest of the crown is arrayed.

Normal branches are generated from a twig, branchlet, branch sequence of an apical shoot. Both branch and apical shoots continue to grow. Sprout branches are derived from preventitious and adventitious growing points released / generated sometime after an apical shoot tip has elongated past, or have elongated from old injury / wound area.

Branch Definition

Across many definitions of a branch, 15 general descriptors tend to be used. The word branch is derived from language concepts dealing with a foot or paw where toes or claws radiate away from a central point. Figure 1 presents the common descriptors used for a branch. Roughly 46% of descriptors define a branch as a sub-division of the main axis or stem of a tree which diverges from the main stem to expand and extend the tree's reach. Some terms are used in a size sequence: stem > bough > limb > branch > branchlet > twig.

Branch Attachment

Branches are connected to another branch or stem with a number of clearly defined (and usually visible) forms of tissue connections. In general terms, branches are attached through a cooperative growth pattern at its base where each growing season diameter increases for both branch and stem. Figure 2. As each increases in diameter, all living tissue around the circumference of each branch and stem continue to generate secondary tissues through the phellogen and vascular cambium. Visible components of the branch attachment area include periderm unions, xylem confluence / stem flange area (Figure 3), and phloem continuity flowing downward toward roots, Figure 4.

Unions

The point where periderm of a branch and stem meet generates two visible attributes: A) a periderm union; and, B) a stem flange. The first is a periderm union on the top side of a branch base. A periderm union (sometimes referred to as a bark union or bark ridge) is an external periderm disruption at top of a stem-branch confluence.

Periderm unions come in two types – a periderm chine or rimple. A periderm chine is a ridge of combined stem and branch periderm tissue pushed up and out in the confluence area. Figure 5. A periderm rimple is formed when combined stem and branch periderm tissue is trapped internally within the confluence area. Figure 6. A rimple is a crack or wrinkle showing where periderm has been grown around and trapped within the confluence area.

Lengthening Union Line

As both stem and branch continue to expand in diameter, the periderm union's length around a stem continues to grow. At the moment when secondary growth in the stem and branch confluence area began, the periderm union in the confluence was initiated. With continued diameter growth of stem and branch, periderm of stem and branch grew against each other at the top of the confluence, and was continually pushed off to each side of the confluence by diameter growth. Figure 7. Depending upon the branch-stem confluence angle and growth pattern, the periderm union demarcation can be seen on a stem as a straight, drooping, or curving surface disruption line stretching downward (basipetally) and around the stem from the upper side of the branch base..

Phloem Continuity

The branch attachment area contains interlaced structural and protective tissues. The phloem transport system and vascular cambium which generated phloem, functions as a two dimensional surface. Active phloem and cambium exist as a thin continuous living film over the surface of the xylem, protected by periderm.

The closest to the tree surface exterior phloem reaches occurs at the top of the stem branch confluence. In this location, the secondary cortex is thin and the phellogen is constantly disrupted and regenerating a full periderm, while diameter expansion of the branch and stem continually stretch and thin out the tissues. This confluence zone is susceptible to attack from many environmental agents.

Xylem Confluence

The area where stem and branch meet is a unique zone of overlapping and interlaced tissues from both stem and branch (a tissue confluence zone). Figure 8. An old term for this area was crotch. Branch tissues in this area form the base of a branch and are overlain by stem tissues. Branch tissues are orientated downward (basipetally) and do not turn upward along the stem. Under some circumstances there is a noticeable branch gap (Figure 9) in stem tissues under a branch for some distance along a stem until stem tissues reform the stem cylinder.

Branch Role

In summary, a branch is stuck into the side of a stem and stem tissues separate and enclose the branch base to hold it onto a tree. A branch with this structural form can be compartmentalized off if it is damaged or does not generate enough food and growth regulators for the rest of the tree growing below the branch. A branch remains reasonably flexible and disposable (through self pruning / compartmentalization), while the tree remains in control of resource allocation and defense at the branch base / stem flange area.

Flange

The stem-branch confluence area is both a defensive zone and mechanical support zone at the base of a branch where branch tissue is diverted downward (basipetally) toward roots, and lower stem tissues. Stem tissues intermingle with branch tissues and sweep around the branch base. There is no connection between stem xylem and branch xylem above (apically) a branch. The stem flange area (old term = branch collar) for each year is dominantly stem tissue and should not be injured. Pruning or branch removal should eliminate a branch without damaging the stem flange area or other portions of the stem.

Over years of growth, as both branch and stem grow in diameter, a conical shaped branch base / stem tissue area develops. These shallow nested growth cones surrounded by stem xylem, from each year's confluence tissues, comprise the stem flange area over time. The sapwood component of this area is termed a primary defensive zone. The heartwood component of this area, which is usually impregnated with additional extractives and secondary compounds, can be considered a secondary defensive zone. Figure 10.

Supporting Tissue

Mechanical support of a branch by the branch base surrounded and overtopped by stem tissue represents the stem flange. Figure 11. A stem flange is an area at the confluence of stem and branch providing vascular connection and mechanical support to a branch, and defensive potential to the stem. A stem flange is much larger / thicker on the branch base bottom than on top in order to resist gravity downward, and the wind laterally and upward.

The outward extent or farthest along the branch a stem flange reaches can be visualized using two visible targets. Along the branch top as the confluence zone is approached, just before the periderm union of a branch begins to curve up (or down) in meeting the stem part of the periderm union, is one target. This target represents the edge of a stem flange on top of the branch and in the confluence area.

Seconds

The second target is on the branch bottom as it approaches the stem. The point just before the branch diameter taper rate noticeably changes and thickens, is the bottom edge of the stem flange. If any modification of branch diameter size or form occurs on the bottom side (swelling or change in surface angle to stem surface), this would be the beginning of the stem flange. Note, these stem flange targets are not in-line with the stem's vertical surface and may represent a significant nub or stub of tissues reaching beyond the stem surface. This tissue area sticking beyond the stem is the stem flange. Figure 12.

Inner Space

The inward extent of the stem flange is delineated by all past annual cones of intermixed stem and branch tissues in the confluence area (i.e. seen as a knot in a wood plank). The conical shaped volume dwindles down until it nears the pith, or until the annual increment year when the branch initial first developed. This area functions as a complex compartment for decay control. As a branch is shed, these branch associated tissues are sealed off. The stem can quickly grow over the site from all sides generating a circular compartment closure. This area can also, through decay over time, present a small conically shaped cavity in a stem. This cavity is usually limited in volume depending upon branch base size.

Twinned

In some trees where nodes support opposite growing points and organs, where a main axis has been damaged, or where a branch has grown as large as the stem to which it is attached, two types of poor branch growth forms occur. The first poor branch growth form is a fork. Figure 13. A fork is conjoined stems or branches of roughly the same size where both sides of the confluence is stem-like (equal on both sides). A fork's defensive zone is compromised or nonexistent, and no stem flange is present although a periderm union can be visible within the fork confluence.

The second poor branch growth form type is a codominant branch. Figure 14. A codominant branch forms when a secondary branch generated by a primary branch or main stem grows in diameter $>2/3$ the diameter of originating branch or stem. A codominant branch has a diminished defensive zone and associated wound reaction. A fork union and codominant branch union share many negative characteristics, but are derived from different starting points.

Branch Removal

Pruning branches involves recognizing features of a stem — branch confluence area which differentiates between different connective and defensive tissues. Pruning for most branches larger than a finger in diameter requires establishment of three (3) cut lines – two preparatory and one final cut.

A pruning cut on a small branch, less than a finger in diameter and which can be held while safely making a pruning cut with a sharp saw, can be completed in one cut. Most people over-estimate their ability to hold a small branch effectively while making a proper pruning cut especially in wind and under wet conditions. Figure 15. The result of a single, less than ideal cut is damage to the stem flange area and disconnection of periderm around the wound edge on the stem side of the cut with significant chance of longitudinal tearing of tissue down the stem.

Trinity Cuts

Tree sustaining pruning involves making three (3) cuts to remove a branch, made in order to minimize residual damage, defend defensive zones, facilitate wound closure, and conserve remaining live branch / stem tissue. The first two cuts are made to assure a final cut can be positioned just outside visual confluence targets.

The alignment of the first two cuts attempt to assure: A) a final cut can be accurately made; B) periderm tears on remaining tissues are minimized; and, C) sawyer safety and effective control of the branch. The first cut is an undercut through periderm and inward at least $1/4$ the diameter of a branch to minimize any tissue tearing. This cut is made a multiple number of saw kerfs (up to several inches) outside / beyond the stem flange edge on a branch. Figure 16.

The second cut is made to remove the weight of, and sever, the branch. The second cut is made just beyond the first cut on a branch from the top side (cutting toward the gravity fall point). The second cut can intersect the first cut if the first cut was deep enough to avoid tearing tissues around the edges when the second cut is completed. The branch may hinge on central wood tissue, but must not pull strips of tissue when it falls.

Best Cut

The final cut (3rd cut) is made with a sharp green-wood saw aligned clearly just outside the stem flange area at the base of a branch. The saw kerf of the final cut should be to the outside of the branch union area at the top of the confluence (both stem and branch periderm union areas). The saw kerf of the final cut should be

outside (branch side) of the stem flange swelling on the branch underside. A straight line cut to sever tissues is normal. Specialized tools which leave a slight conical indentation on the wound surface into the center of the stem flange is allowed if the circumference edge of the wound remains outside the stem flange area.

It is critical the anatomical edges of the stem flange be identified (points referred to as targets). These targets or stem flange edges should remain undamaged after the 3rd pruning (final pruning cut) is completed. In other words, be sure to miss these targets! The tree-identified targets help establish pruning cut lines. The stem flange targets must be missed along the outside edge (branch side) of the stem flange. Hitting / nicking the targets, or cutting inside the target points, represents significant damage to the stem flange and is called a flush cut. In some whorled branch trees the stem flange is round and can stick out from the stem equally on all sides. Do not nick the stem flange. Figure 17.

Reduction

If the stem portion or primary branch of a confluence is to be removed and the second order or higher branch is to remain, then a reduction cut should be used. Reduction is cutting the stem side back to just above a viable branch node to reduce the extent and reach of a branch or stem, while allowing a relatively large branch to remain at the remaining node. The branch to remain should be no more than $\frac{1}{2}$ the diameter of the stem at its attachment node. Ideally the remaining branch should be near $\frac{1}{3}$ the diameter of the stem at its attachment node. Figure 18. Smaller branches less than $\frac{1}{4}$ diameter of the removed stem at its attachment node should not be left in reduction.

Reduction requires establishing two imaginary target lines from the confluence. The first is a nexus line. A nexus line is an imaginary line placed at the top of a branch / branch or branch / stem confluence perpendicular to the long axis of the stem to be removed. In the case of a fork, the nexus line should be imagined perpendicular to the periderm union line (chine or rimple). The purpose of the nexus line is to help establish a lift line. A lift line is an imaginary line established which is at least three (3) saw kerfs (or ideally $\frac{1}{9}$ the diameter of the stem or branch to be removed), above (more distal to) and parallel to the nexus line. Figure 19.

Making the Cut

Locate the position of the lift line within and above the confluence of the branch to be retained. The highest point of the lift line on the confluence side is one cut target. Three reduction cut lines are established to sever the branch or stem, and leave undamaged and sustainable a side branch. Three cuts are made to minimize residual damage. Preventing excessive tissue drying, defending defensive zones, facilitating wound closure, generating a strong oxidative wound surface, and conserving a relatively large diameter remaining live branch are key results of proper reduction.

The first cut is made above the lift line on the opposite side of the confluence. Periderm and woody tissues are severed for at least $\frac{1}{4}$ stem diameter to minimize potential tearing of tissues downward. The second cut is made slightly above the first, either including the top of the first cut or a wholly separate cut completely severing the stem above the node to be conserved. The second cut is to remove the weight and sail of a stem to facilitate a proper reduction cut (3rd cut). Rigging should be used on removed parts to minimize human safety concerns as well as minimize damage to remaining tree tissues and site. Figure 20.

Finally

The final cut is a straight cut either beginning or ending at the lift line intersection above the confluence. The final cut is a 30° down angle from the lift line point in the confluence. This 30° down angle cut line from the lift line on inside of a fork, or on inside of a stem or branch for removal, is not based upon tree structure or biology, nor on periderm or confluence appearance. This angle leaves a sloped wound surface and attempts to leave in-place and undamaged a buffer area where compartmentalization walls and defense from microorganism succession and/or drying can occur without compromising the defensive zone and vascular connection of the remaining branch.

Fork Cut

Correcting a fork by removing one side of the forked confluence is also a type of reduction cut. Figure 21. Use a nexus line perpendicular to the confluence. Decide which fork is to remain. The side with the most direct line to the tree base, the side with the largest crown volume, and the side which is most upright would be key decision points. The goal is to select the side of a fork to remain which will have the best chance of longterm success. Establish the lift line above the nexus line on the side to be removed and then make the proper reduction cuts. Figure 22. The final pruning cut should leave a smooth slanted cut face.

Sudden Fall

Under some conditions branches will catastrophically fail. Recent past damage to reaction wood from heavy wind gusts (branch lifts), hot conditions, and micro-cracks causing quick drying are key components. This type of failure is called a brash separation because there is a sudden break across the wood grain which generates a smooth (non-fibrous) failure surface. This type of failure is a compounding of wood creep with changing moisture contents and hot conditions after a recent shock / abrupt heavy loading from wind pushing branches upward (lift) in storm turbulence.

In a brash failure, micro-compression faults occur on the upward side of the branch among tension wood in *Angiosperms*, or across the long fibers / tracheids in *Gymnosperms*. The *Angiosperm* failure is more prominent. The micro-compression faults lead to micro fractures, invasion by cell killing and decay organisms, and loss of water with more oxidation. Impact or rupture strength declines (compromised fiber walls), while compartmentalization and new tissue generation lead to less structural cell wall materials (more parenchyma and extractives). Heat exacerbates wood creep which places more strain on damaged tissue. Sudden summer limb drop is the result.

descriptors	number used (%)	cummulative value (%)
stem / main axis sub-division	22%	22%
divergence from main stem	15	37
expansion or extension of tree's reach	11	48
ramification of main stem (ramify)	6	54
off-shoot of main stem	6	60
bough of tree	6	66
(large branch only from stem)		
separate part of tree	6	72
>3 years old tissue off of main stem	4	76
secondary woody stem from	4	80
trunk or bough		
limb of tree	4	84
(large branch only from		
trunk or bough)		
extended part of complex tree crown	4	88
fork of stem	4	92
appendage of stem	4	96
furcate from main stem	4	100

Figure 1: Branch descriptors from common definitions.

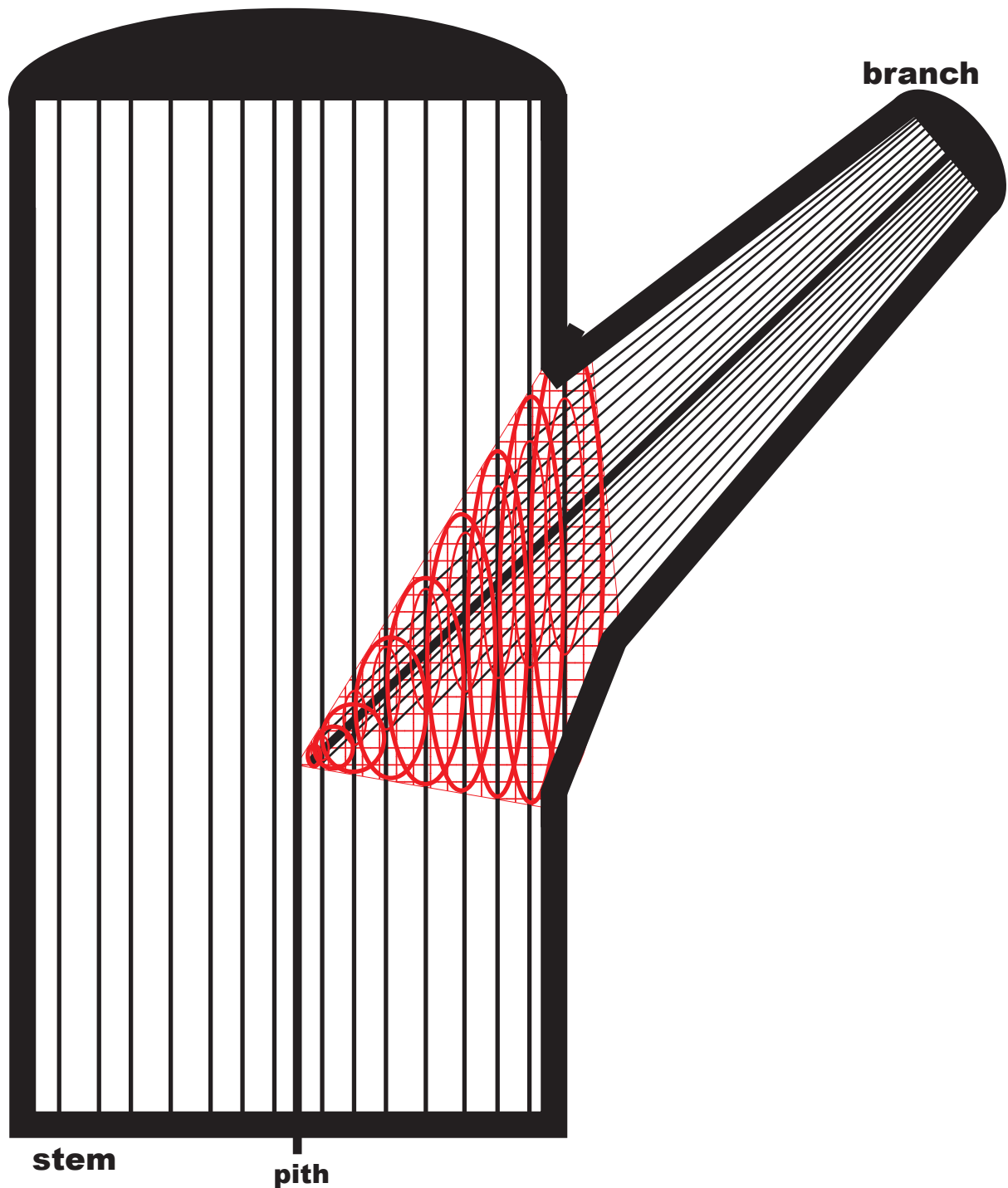


Figure 2: Diagram of stem - branch confluence area with a stem flange, showing defensive zone (shaded), annual increments of tissues, and enveloping of branch tissues by stem tissues (ovals).

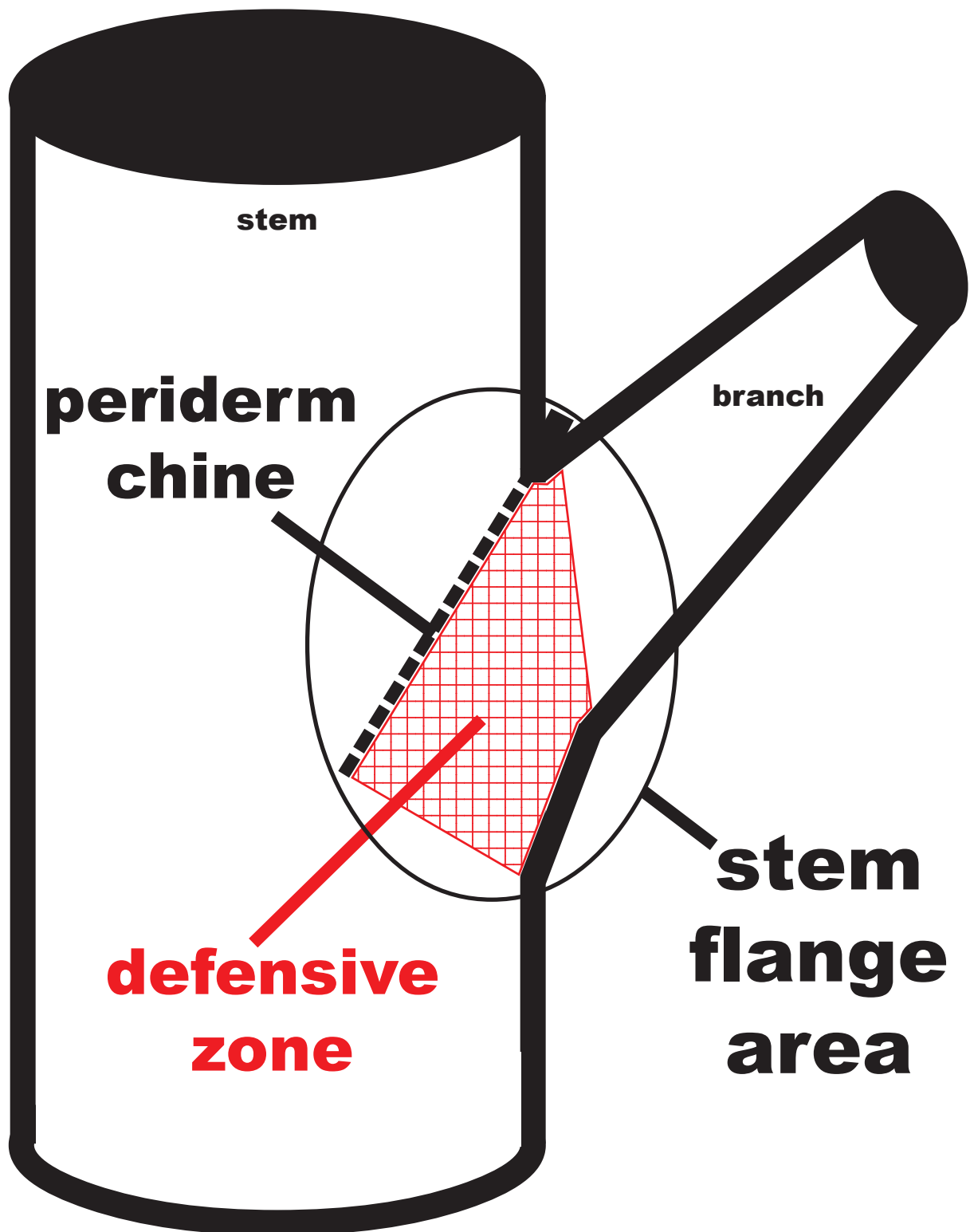


Figure 3: Stem-branch confluence area showing periderm chine (periderm ridge), stem flange area, and defensive zone (shaded).

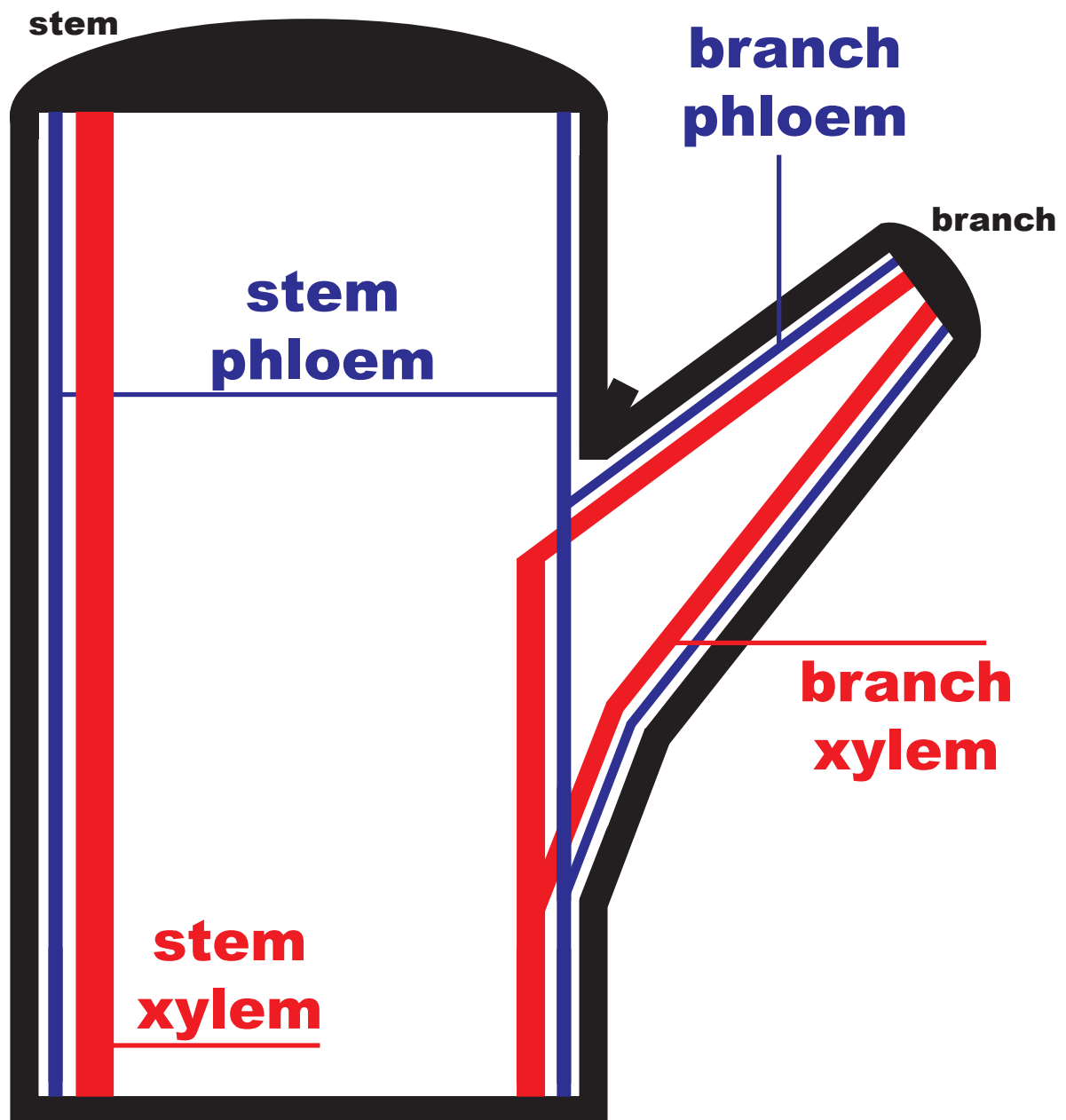


Figure 4: Stem and branch phloem continuity beneath periderm across all exterior living surfaces of tree, and branch xylem descent from branch generating a branch tissue tail and stem xylem branch gap below the branch base. Branch xylem tissue does not connect with stem xylem above branch base.

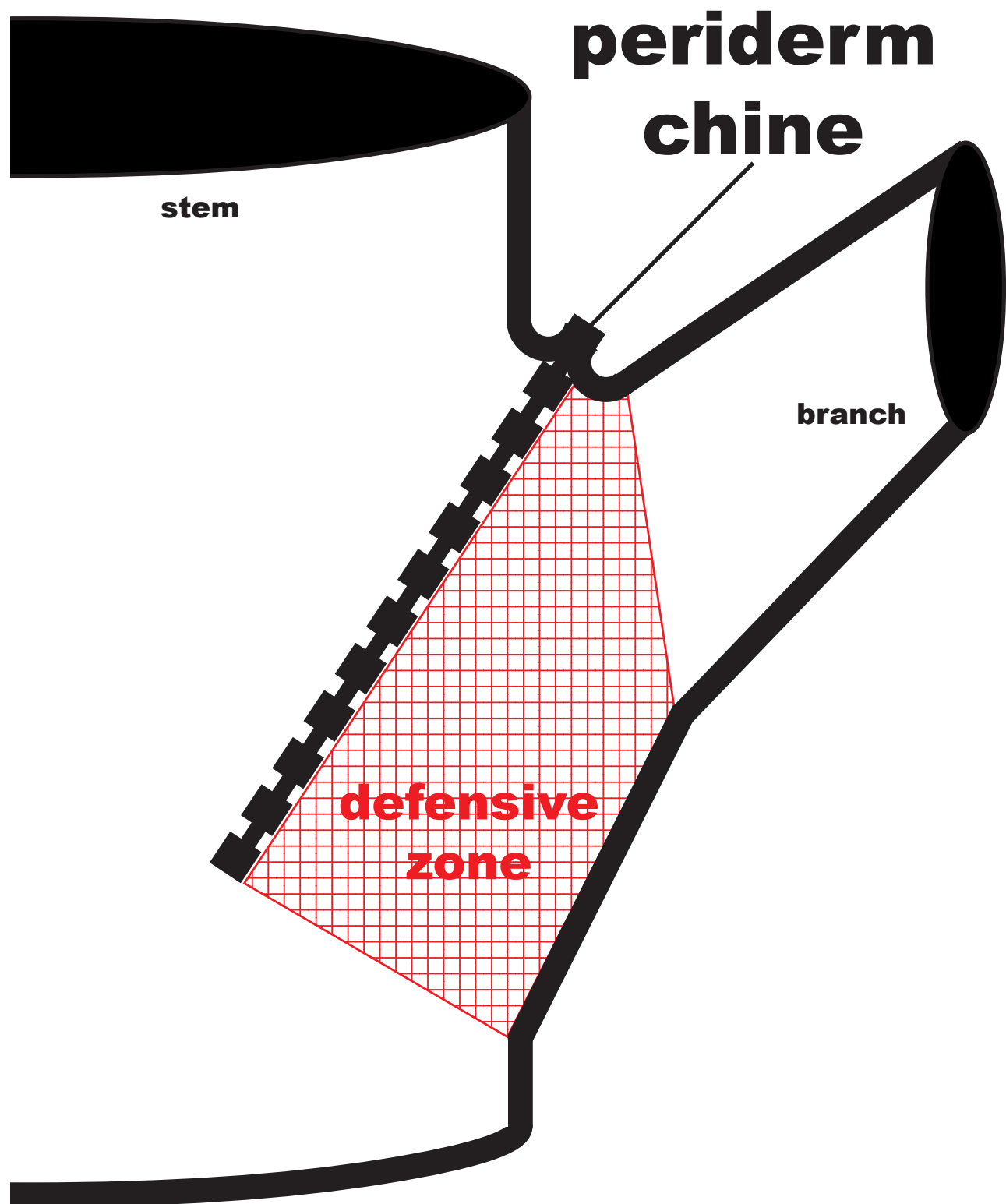


Figure 5: Upper side of a stem-branch confluence (flange area) with a periderm chine (i.e. ridge or crest).

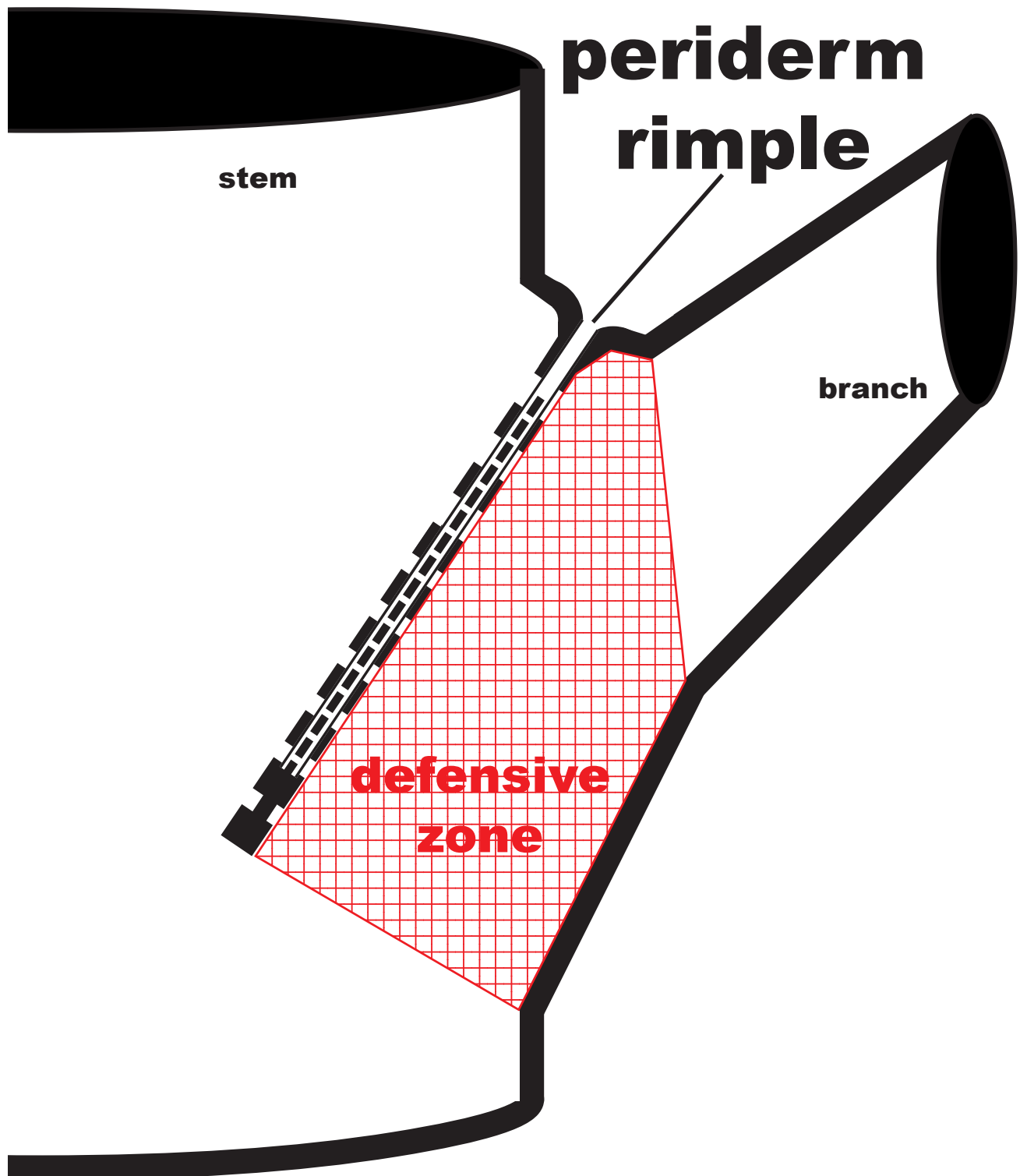


Figure 6: Upper side of stem-branch confluence with periderm rimple (i.e. fold or wrinkle). The rimple periderm union can contain periderm tissues folded inside and grown over.

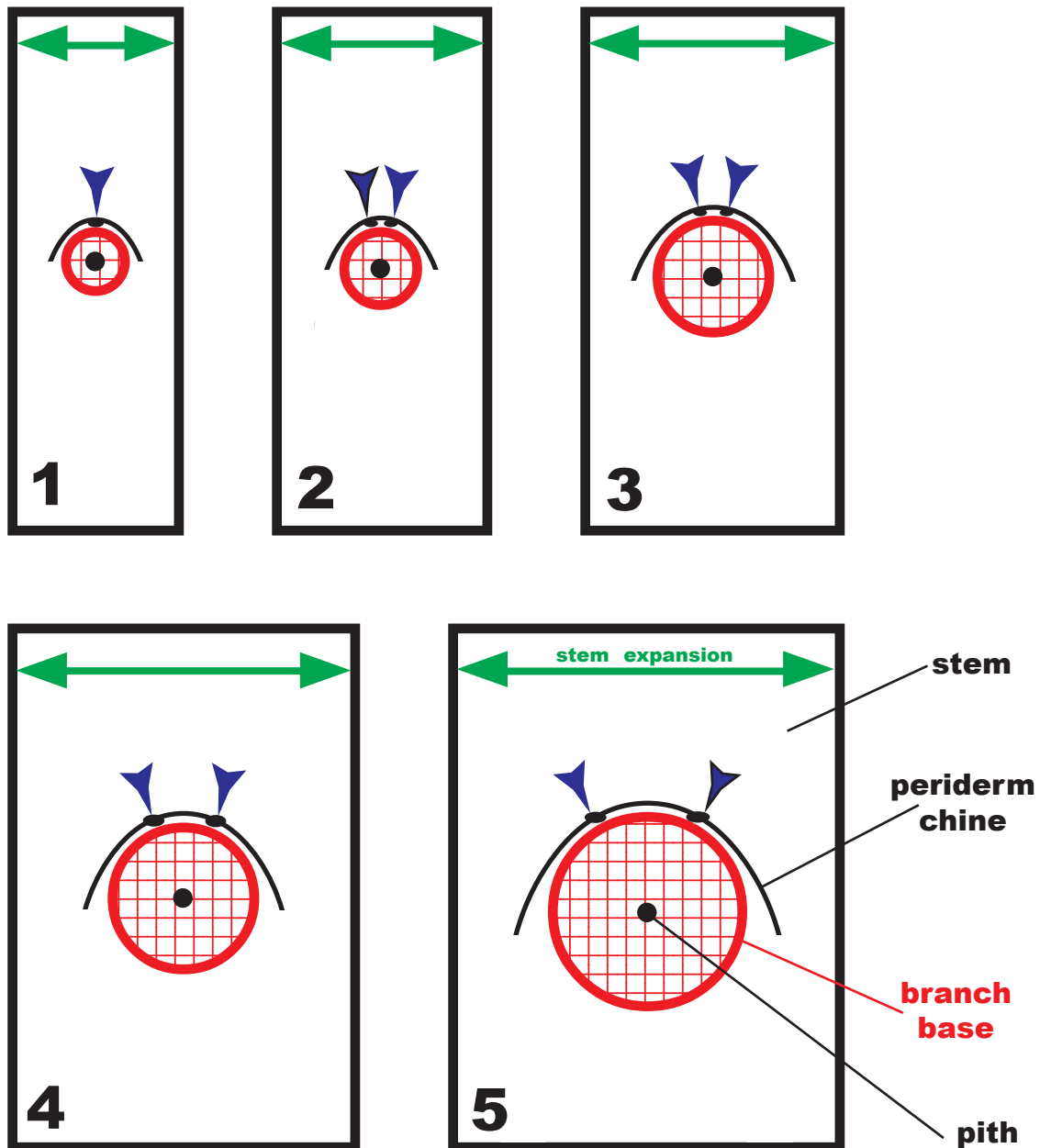


Figure 7: Diagram representing circular cross-sectional areas (shaded) of a branch base at the confluence with a stem over time (#1 is youngest / smallest size). A periderm chine is initiated at the topmost position over the branch (#1 -- note arrow point ▼) where tissues of stem and branch grow against each other. As both stem and branch grow in diameter (#2 - #5), points of the same age diverge along the periderm chine (arrows) continuing to show greater separation.

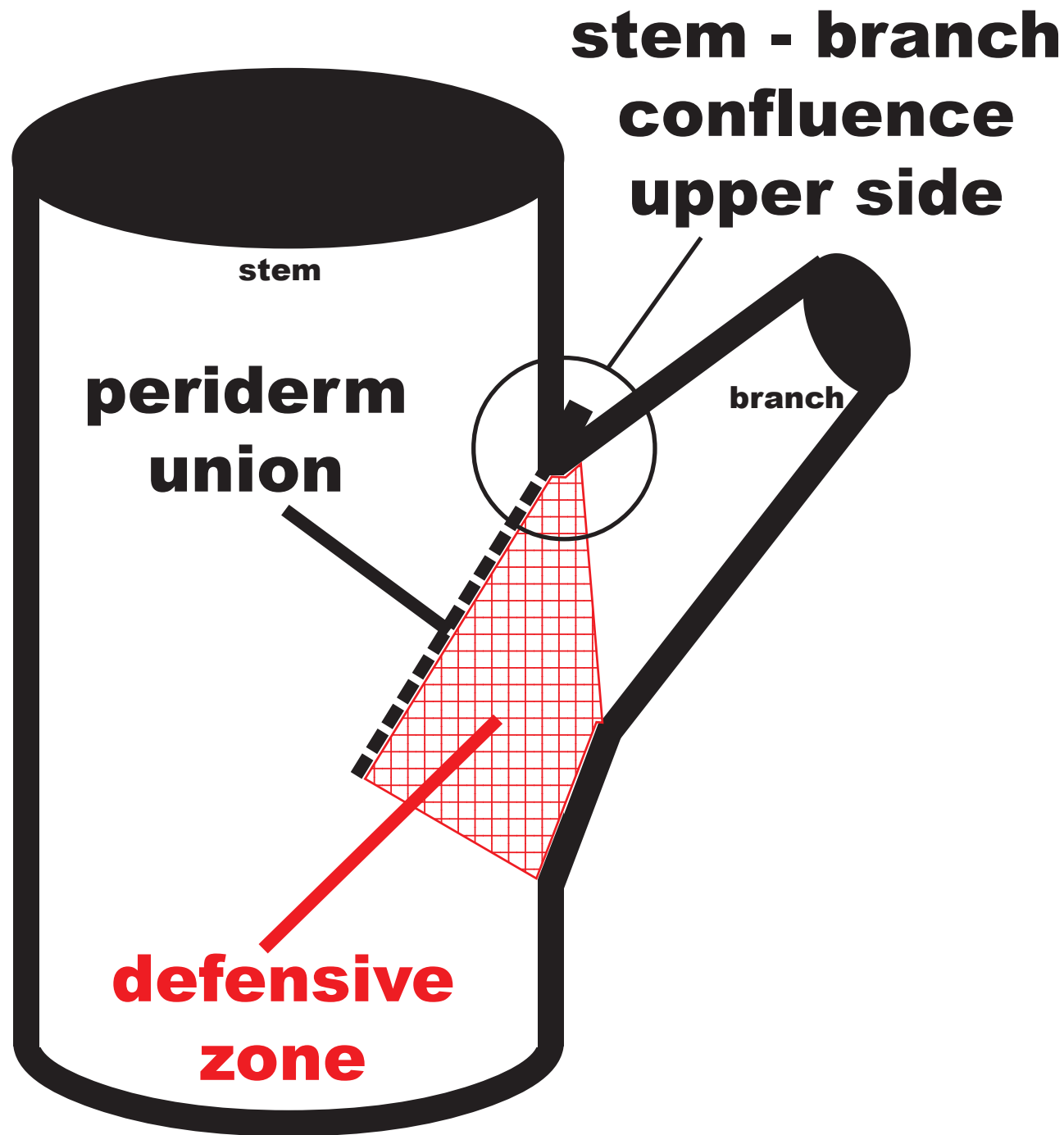


Figure 8: Upper side of a stem-branch confluence showing periderm union area and defensive zone.

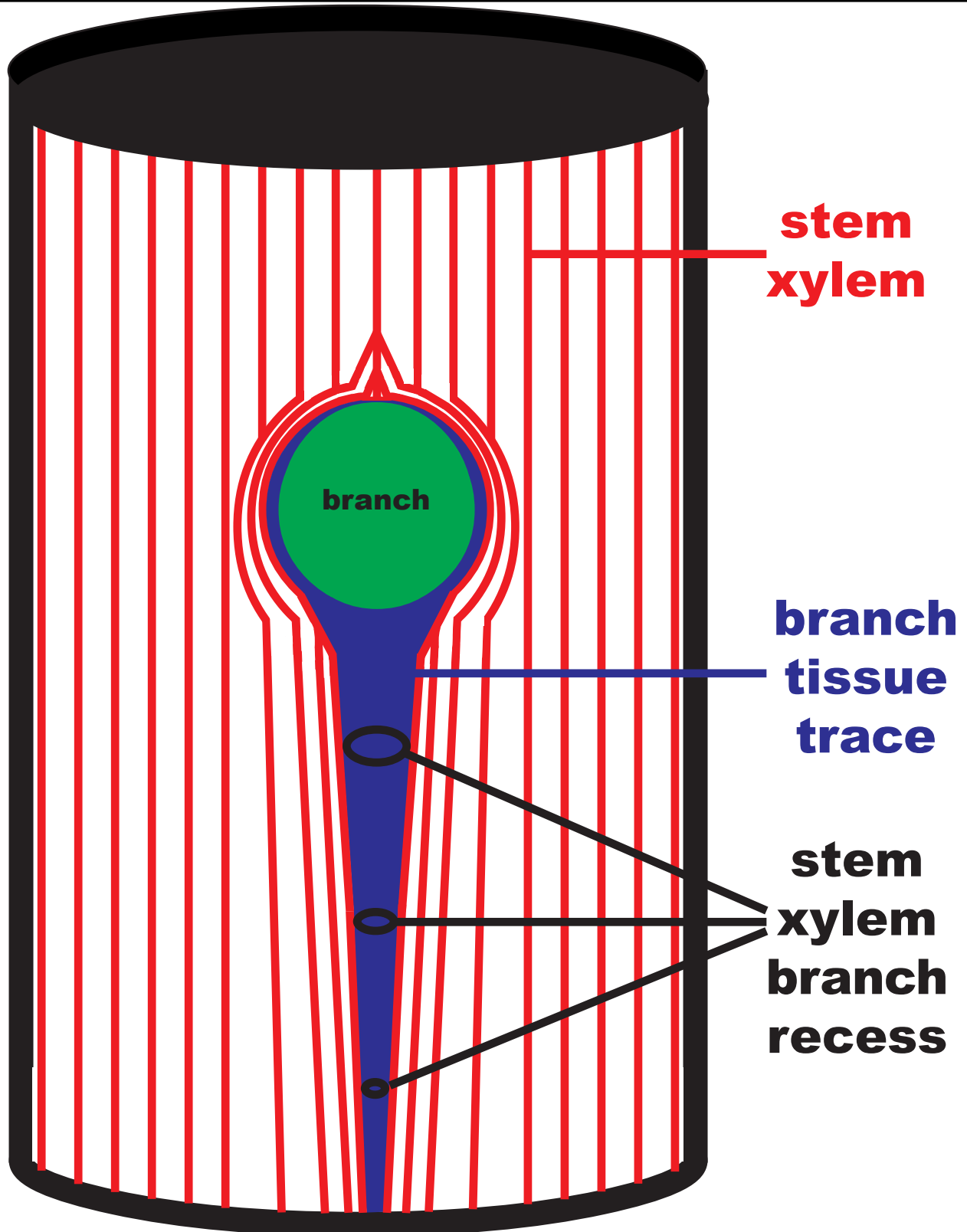


Figure 9: Trace of branch xylem below branch, and recess in stem xylem flowing past branch.

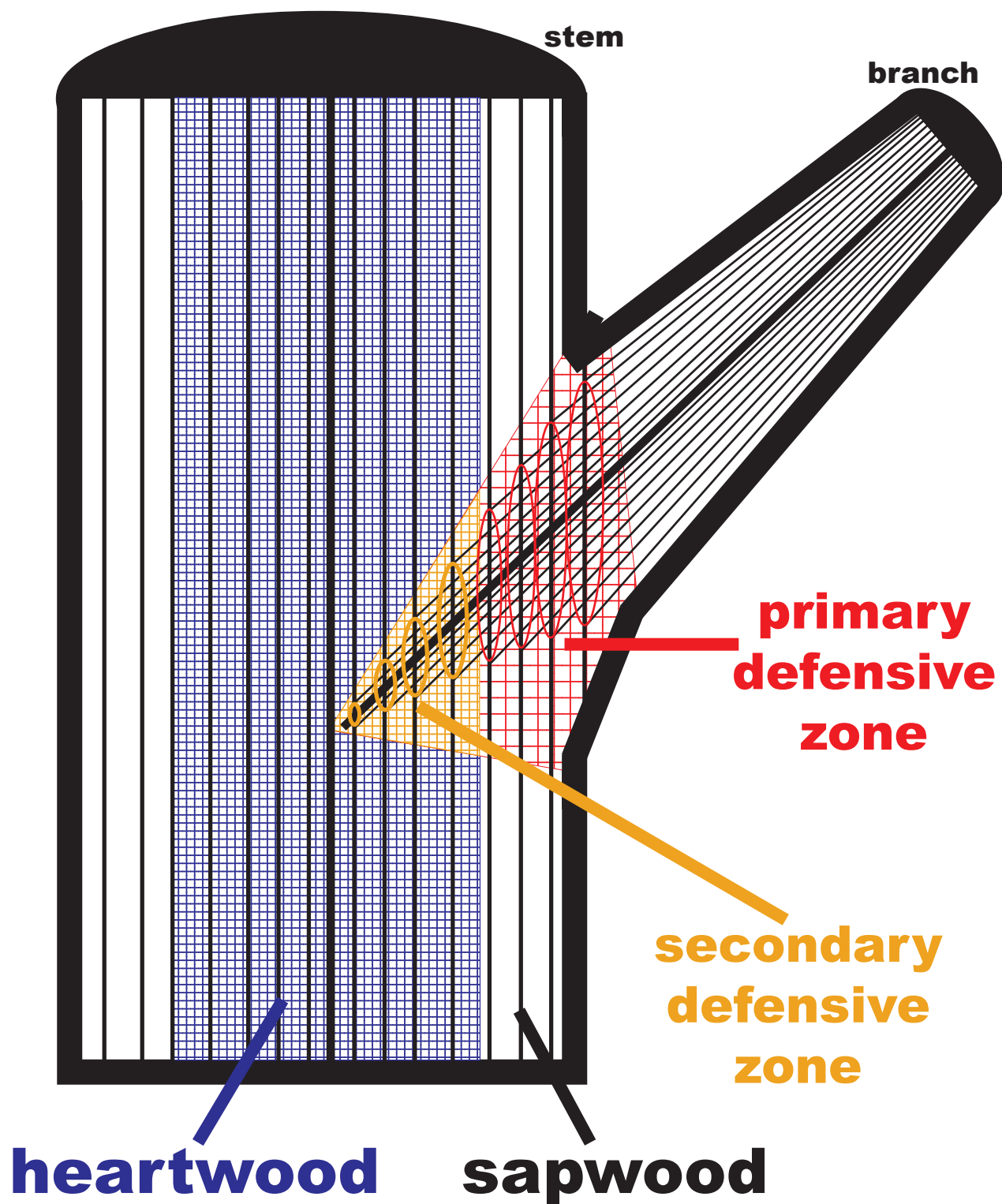


Figure 10: Primary (sapwood) and secondary (heartwood) defensive zones within branch base.

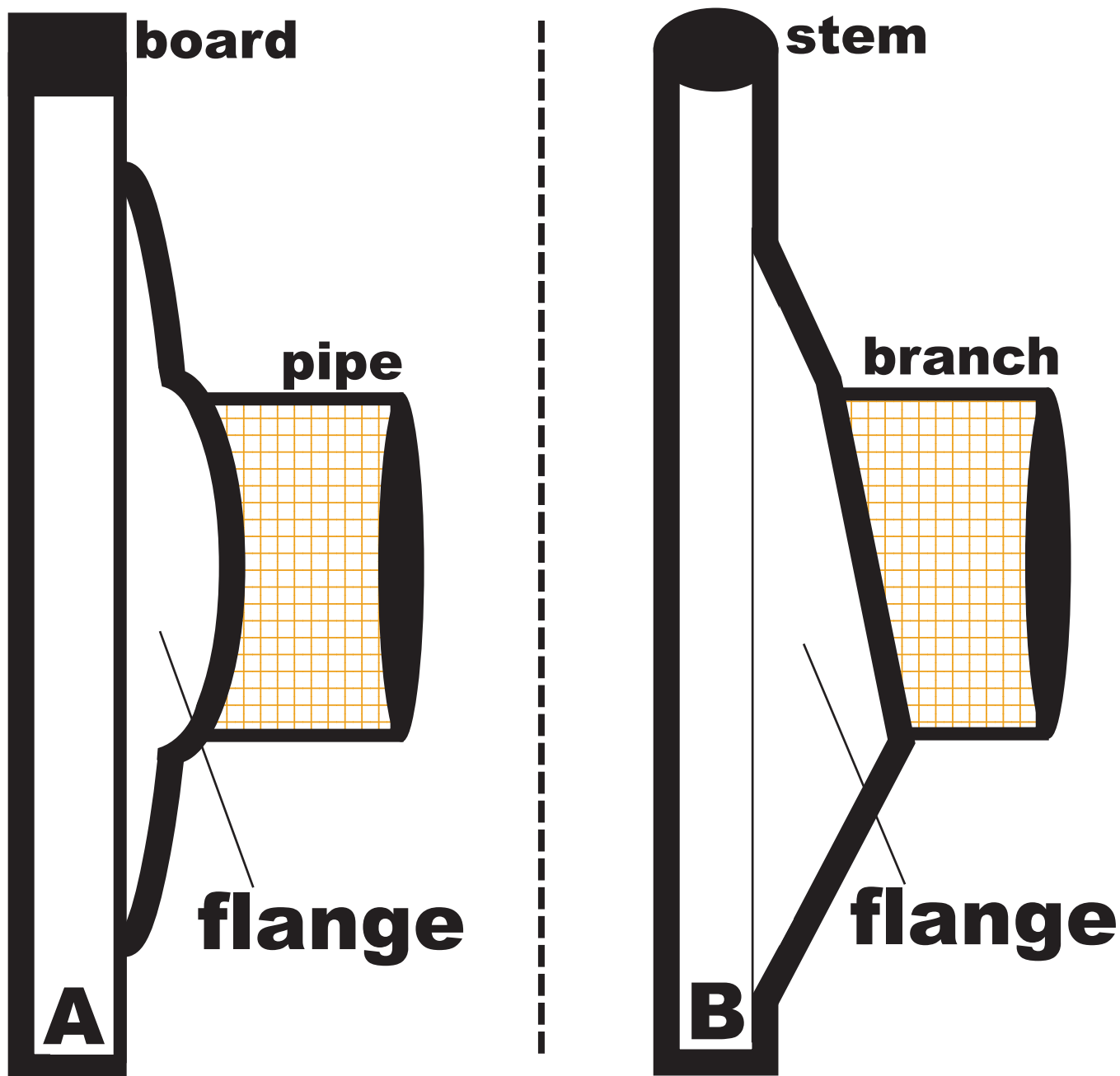


Figure 11: Descriptive model of a pipe held onto a board with a flange (A), and a branch held onto a stem with a combined tissue area acting as a flange (B).

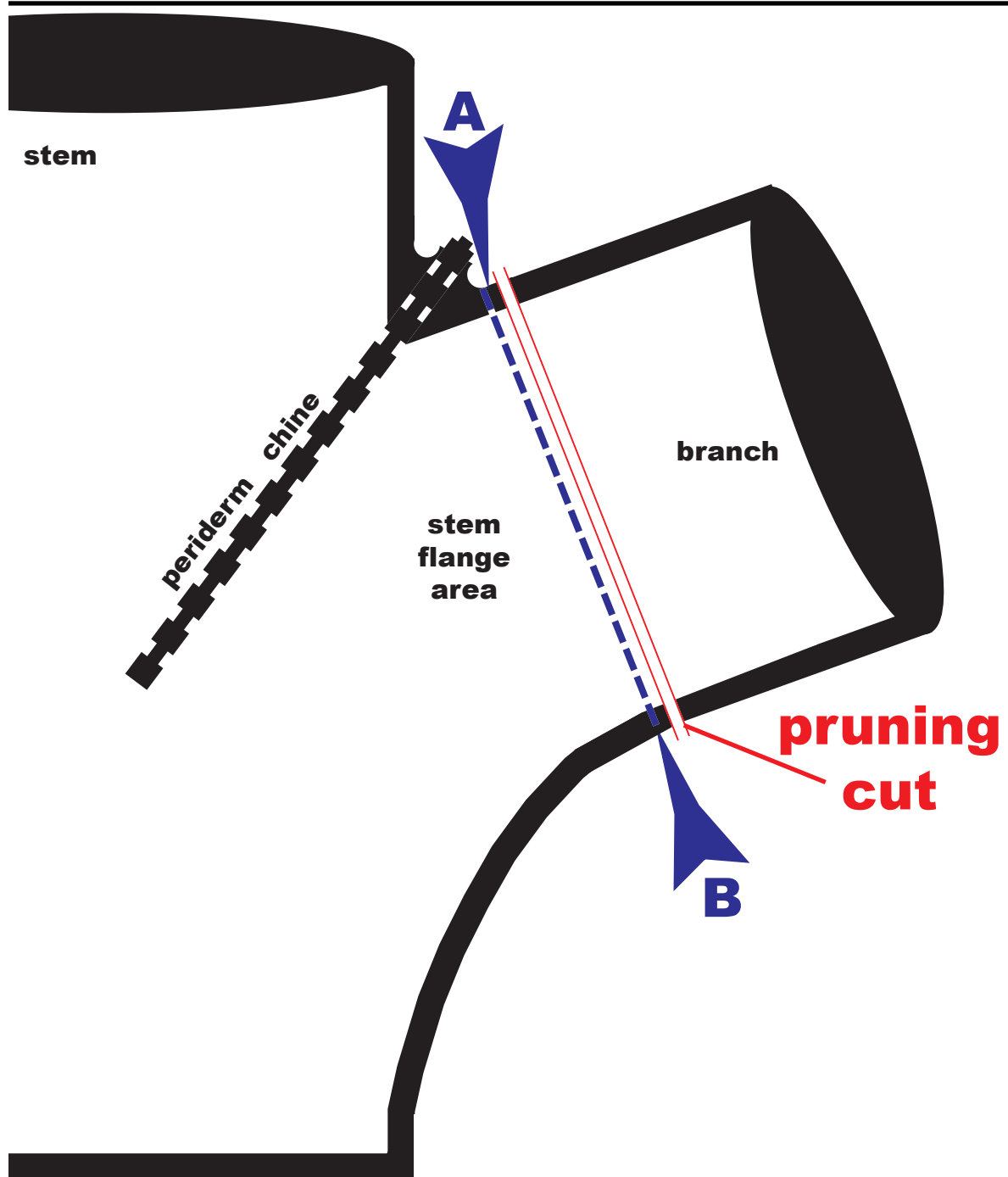


Figure 12: View of stem flange area at stem - branch confluence. Visible flange edge targets: Target A is on branch side (outside) bark chine just before tissues begin to curve up into chine; Target B is on branch side (outside) of tissue swelling or gathering point on branch underside. Dotted line represents edge of stem flange. Double line is pruning cut.

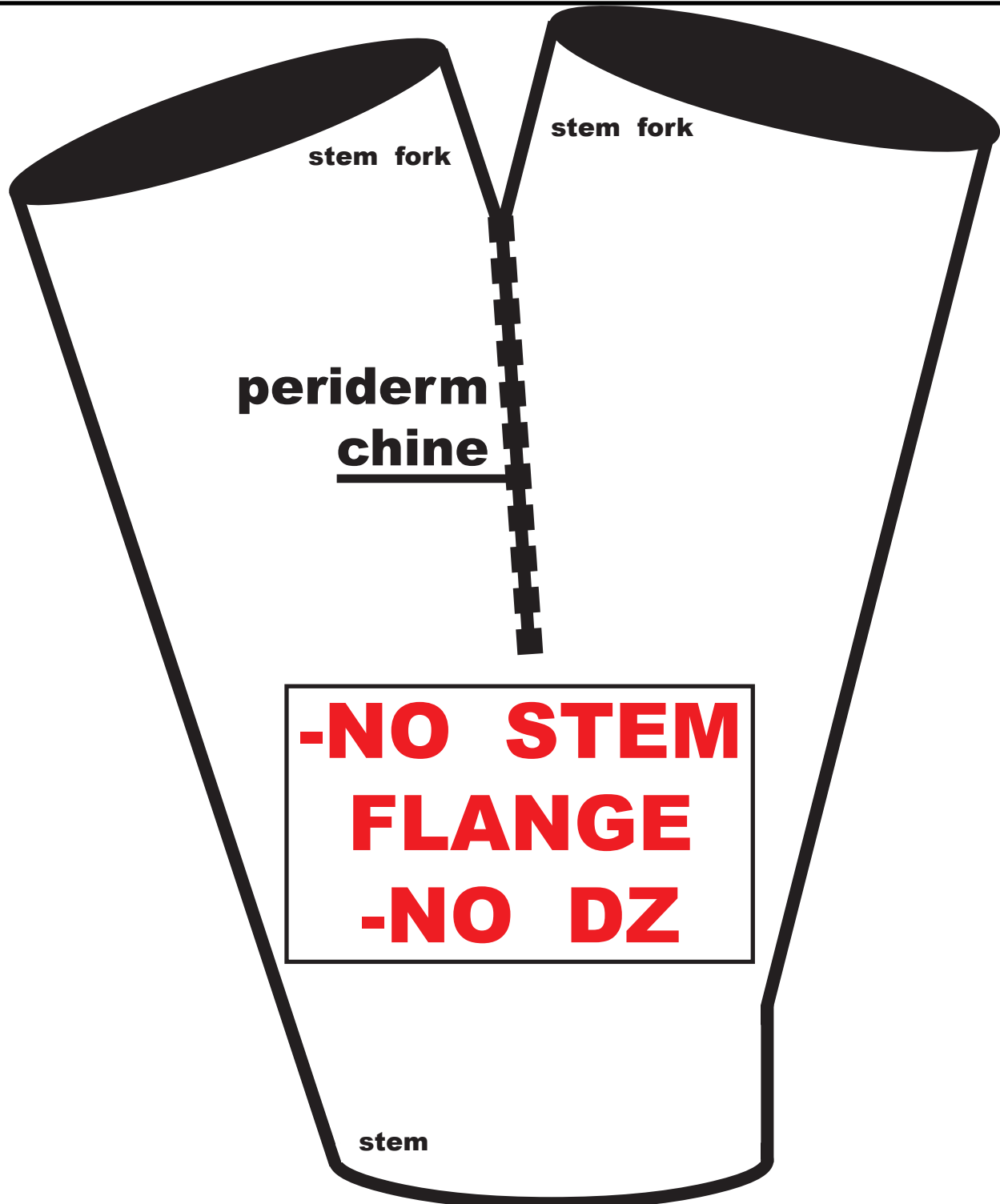


Figure 13: Diagram of a fork (codominant stems or branches) with bark chine shown. This stem - branch architecture would not provide a defendable stem flange area or defensive zone (DZ) if either side was removed.

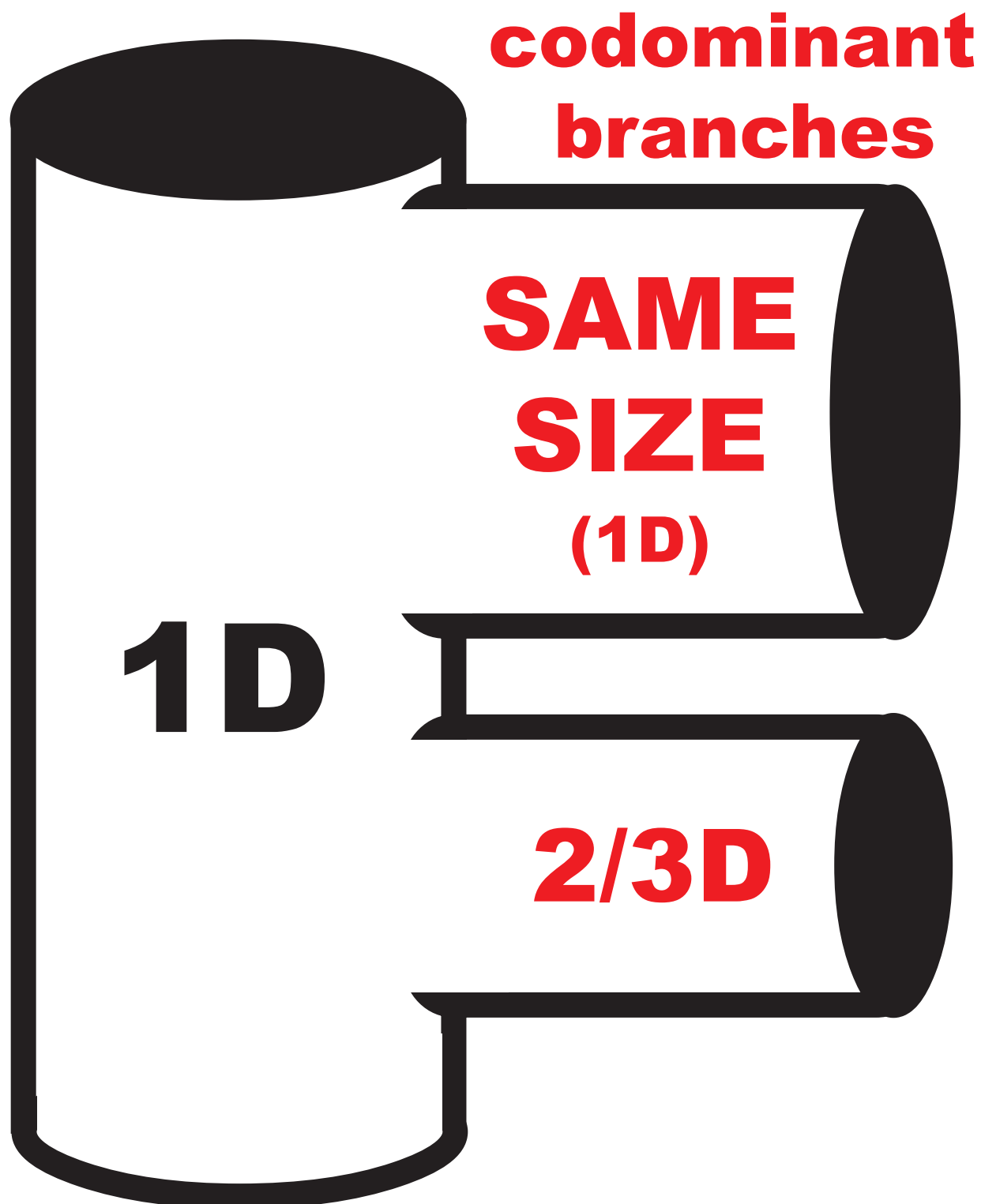


Figure 14: Branches too large to leave (i.e. to be removed) on a stem, with branch diameter to stem diameter ratios of 2/3 to 1/1 (near same size as the stem). D = diameter.

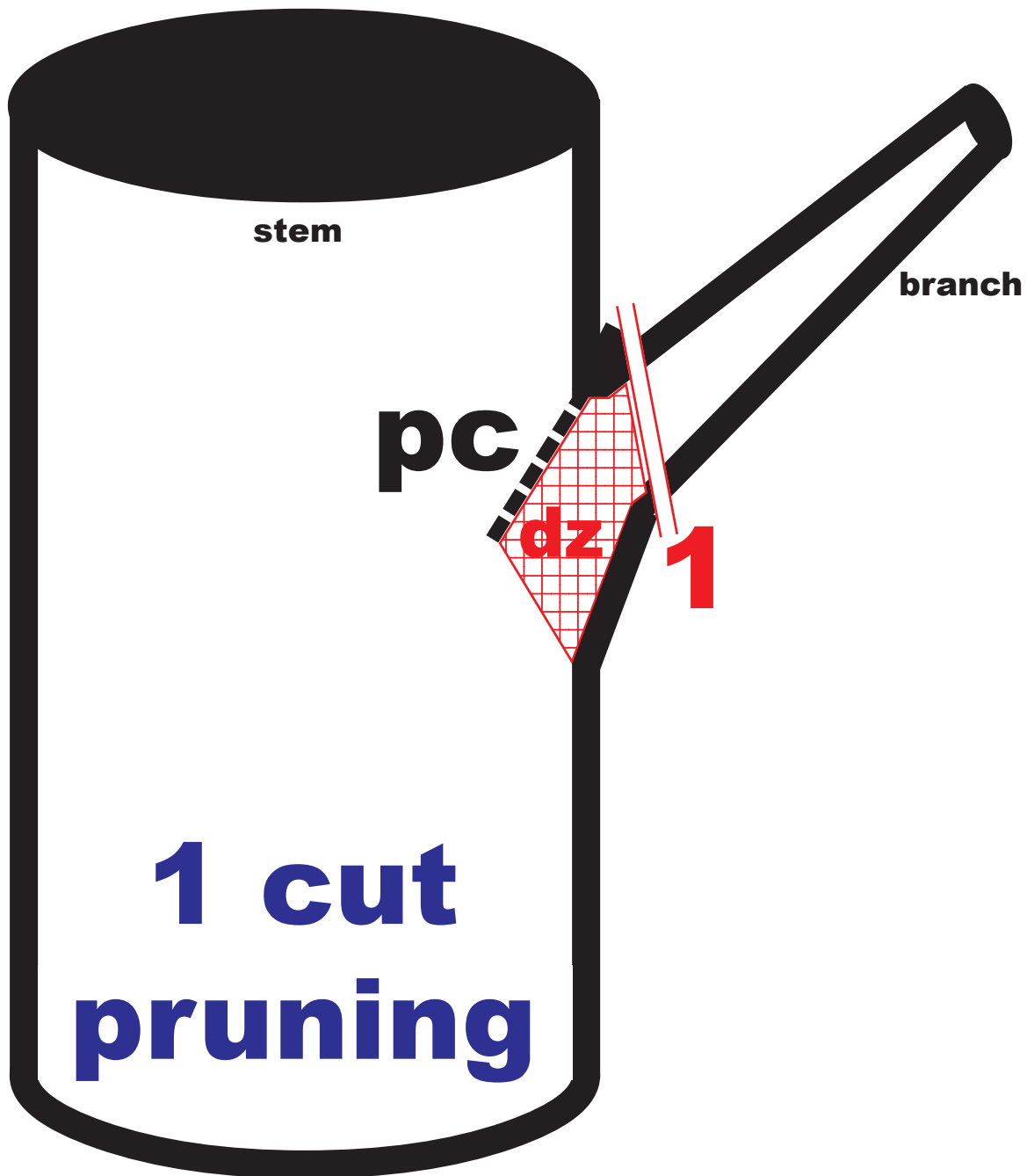


Figure 15: Diagram of stem - branch confluence area with a one-cut pruning prescription applied for a small proportioned branch. Defensive zone = dz. Periderm chine = pc.

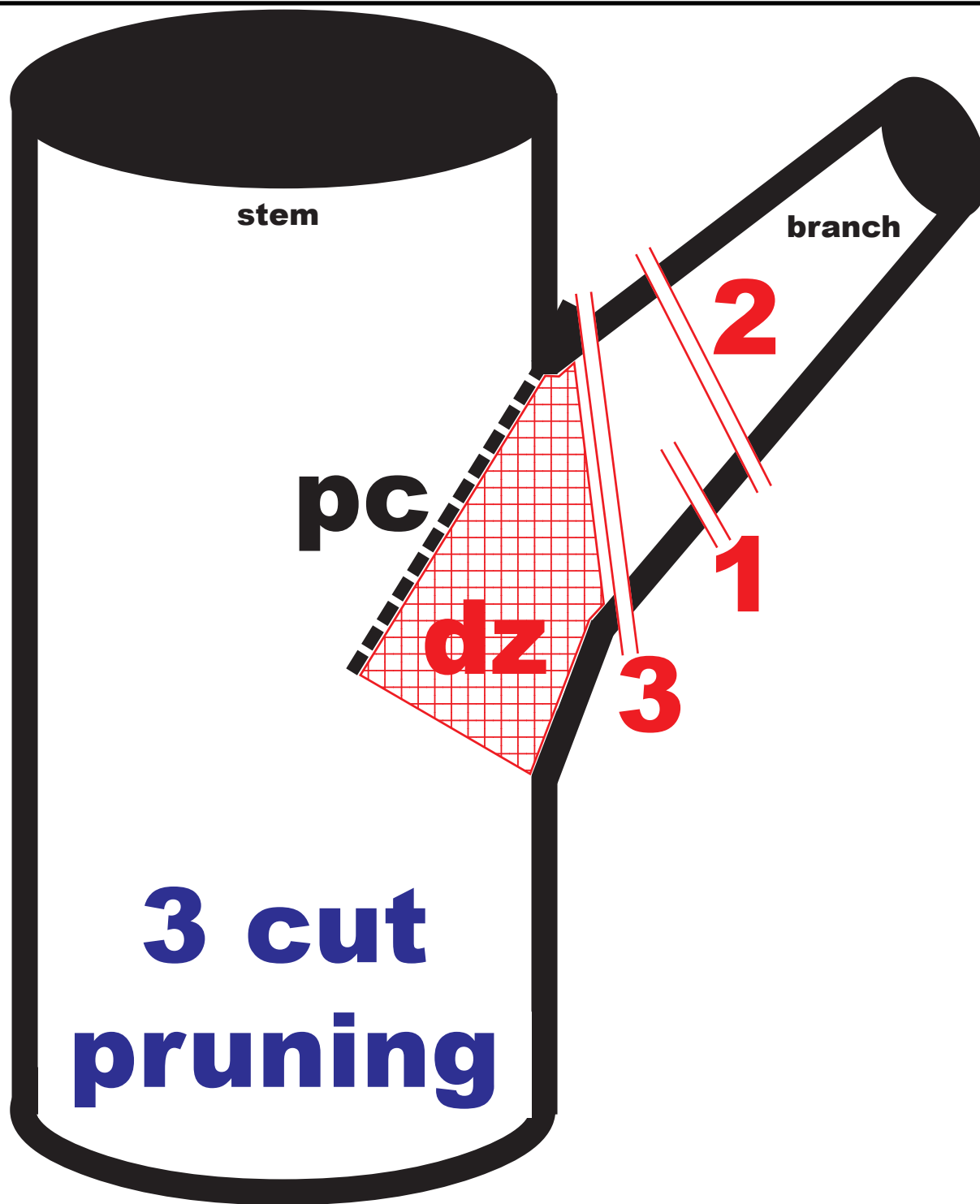


Figure 16: Diagram of stem - branch confluence area with a three-cut or target pruning prescription applied (in cut order) for a normally proportioned branch. Defensive zone = dz. Periderm chine = pc.

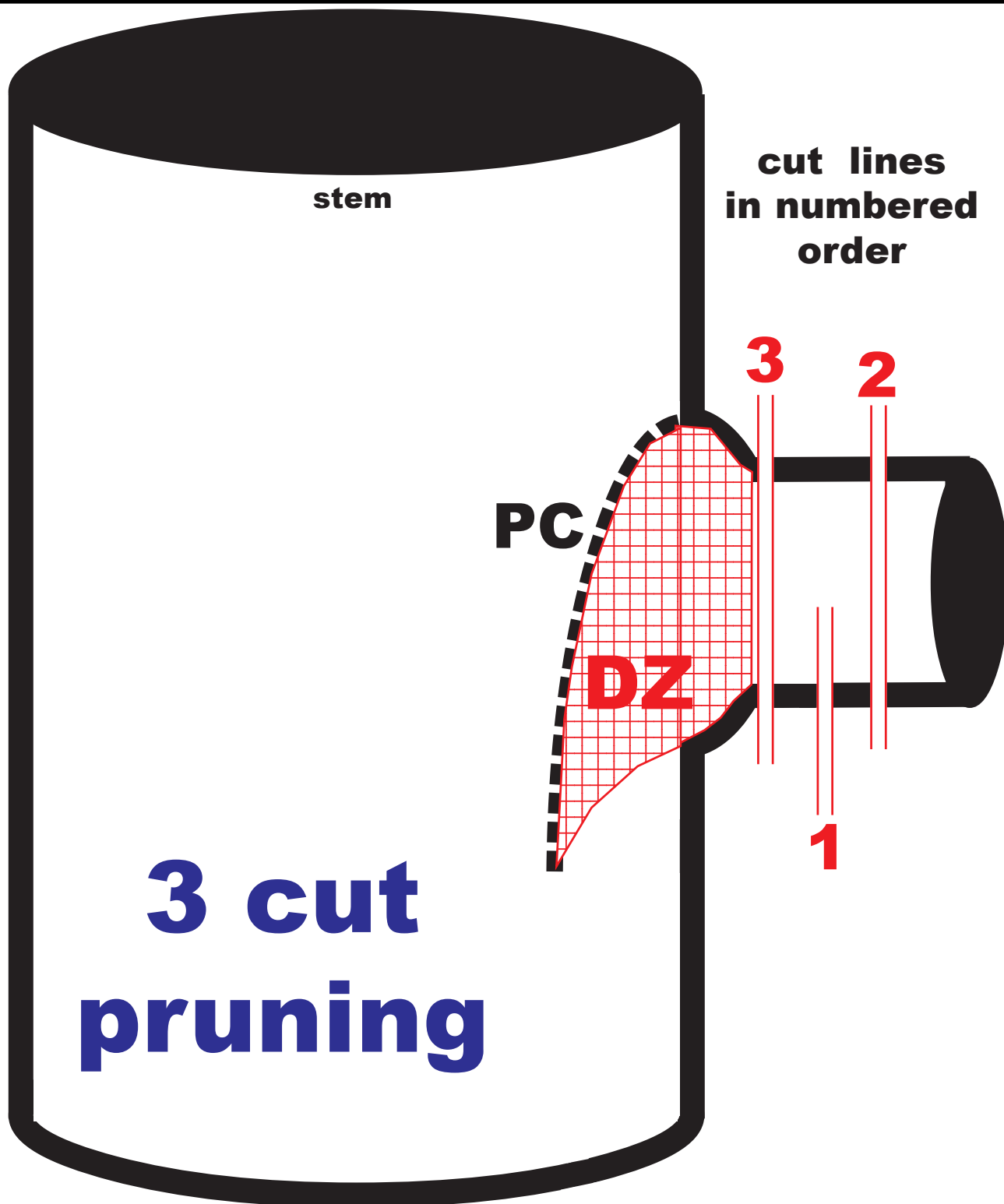


Figure 17: Diagram of a three-cut target pruning technique on a round stem flange tree such as some gymnosperms. DZ = defensive zone. PC = periderm chine.

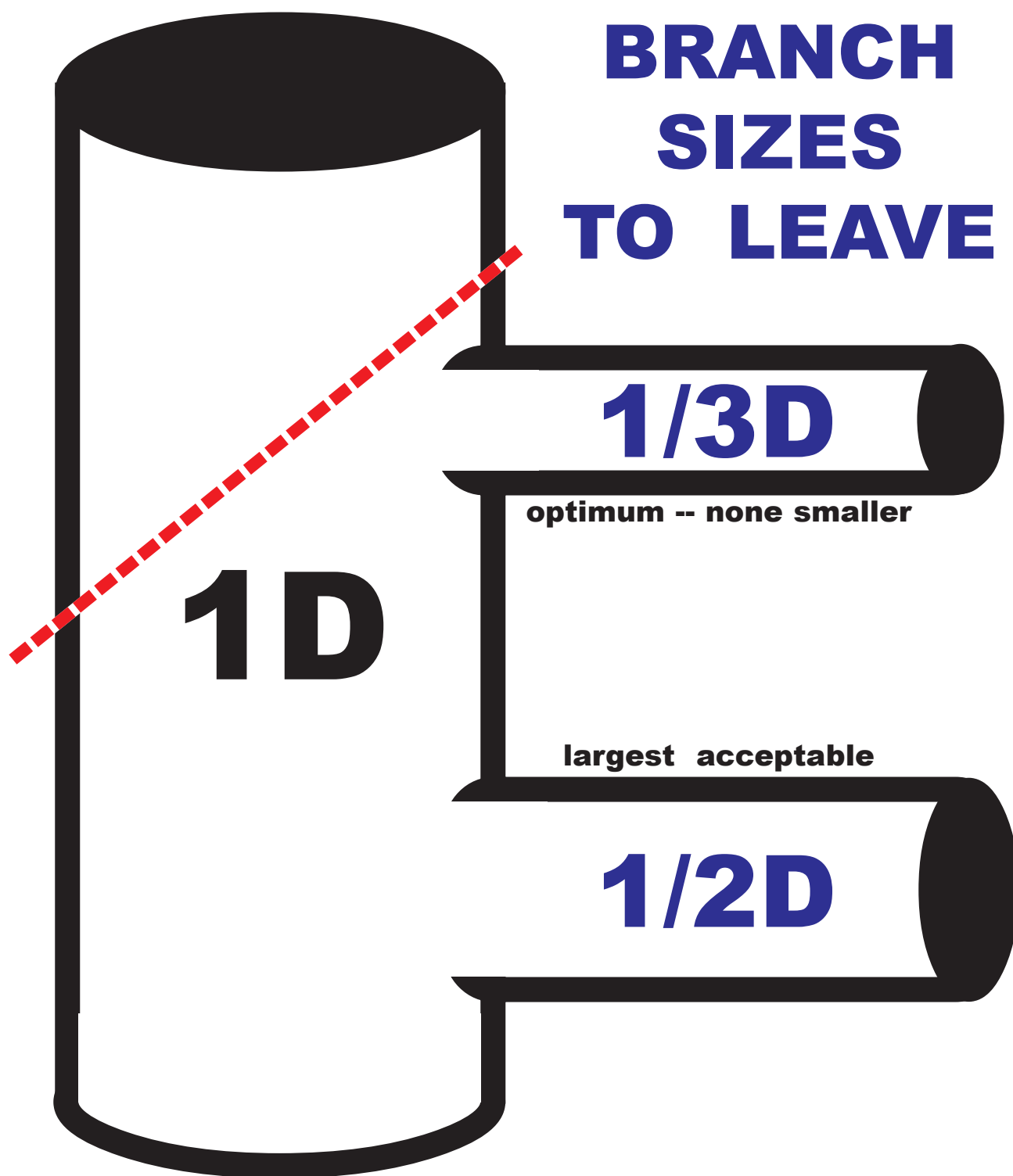


Figure 18: Size of branches to leave on a stem with branch diameter to stem diameter ratios of 1/3 to 1/2. D = diameter.

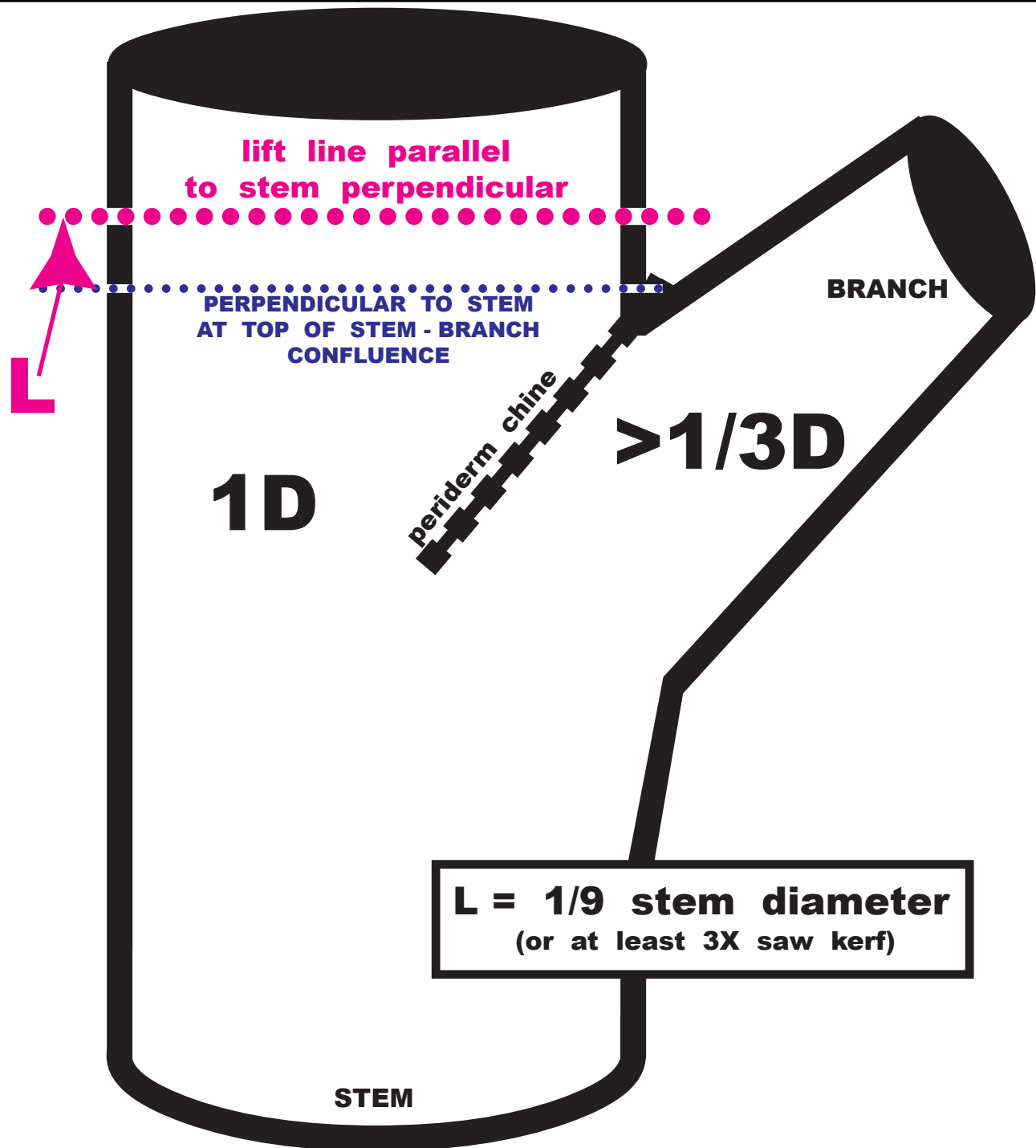


Figure 19: Diagram of stem - branch confluence with target lines for initiating a reduction pruning cut. Note stem will be reduced to a branch never less than 1/3 its diameter. "L" is lift line distance above the perpendicular (nexus line) across stem at top of stem - branch confluence.

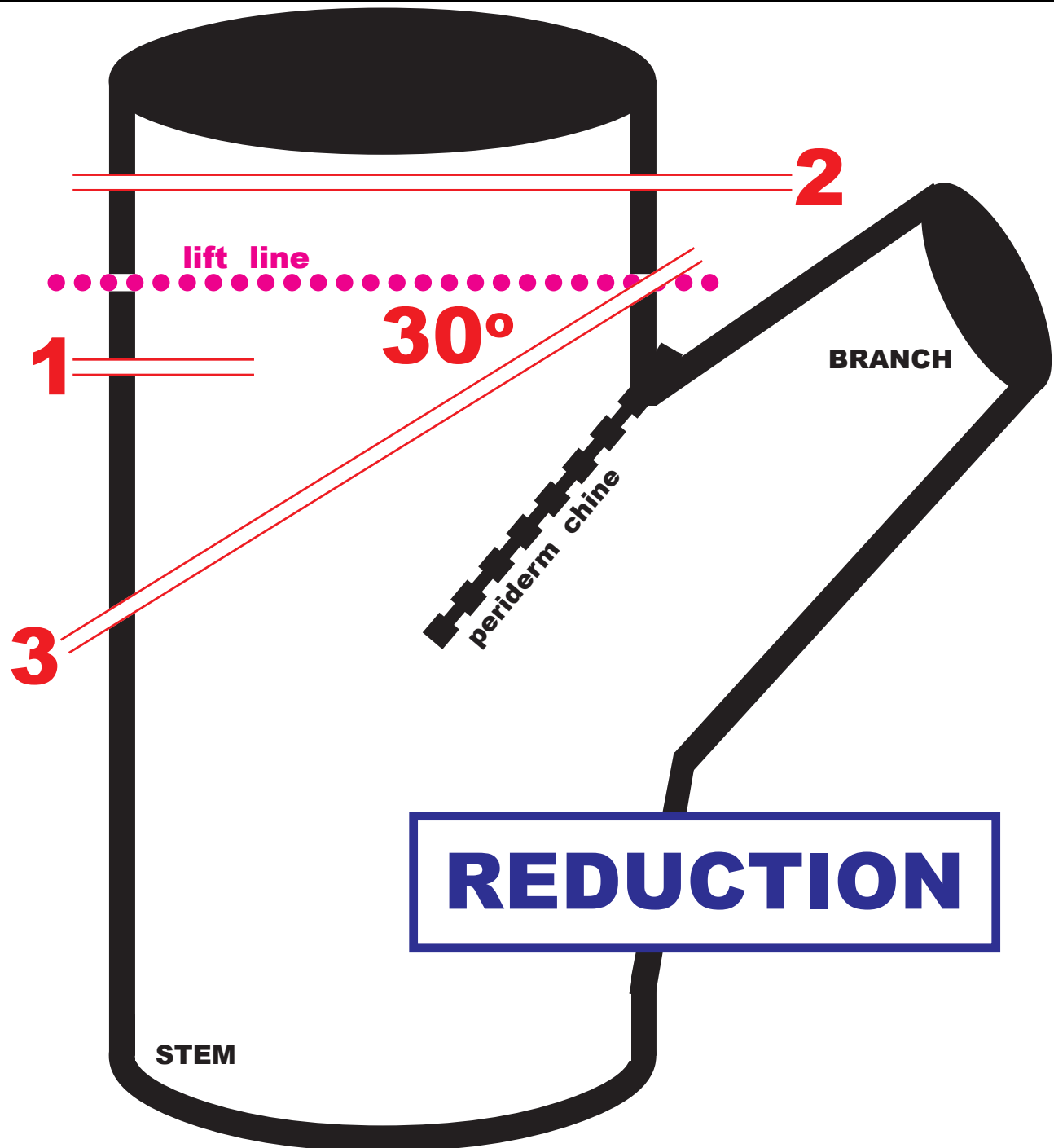


Figure 20: Diagram of stem - branch confluence with three cut lines, numbered in order, for a reduction prescription. Note the final (3rd) cut is at 30° down angle from the branch side of the lift line. The down angle is not dependent upon the periderm chine or branch angle.

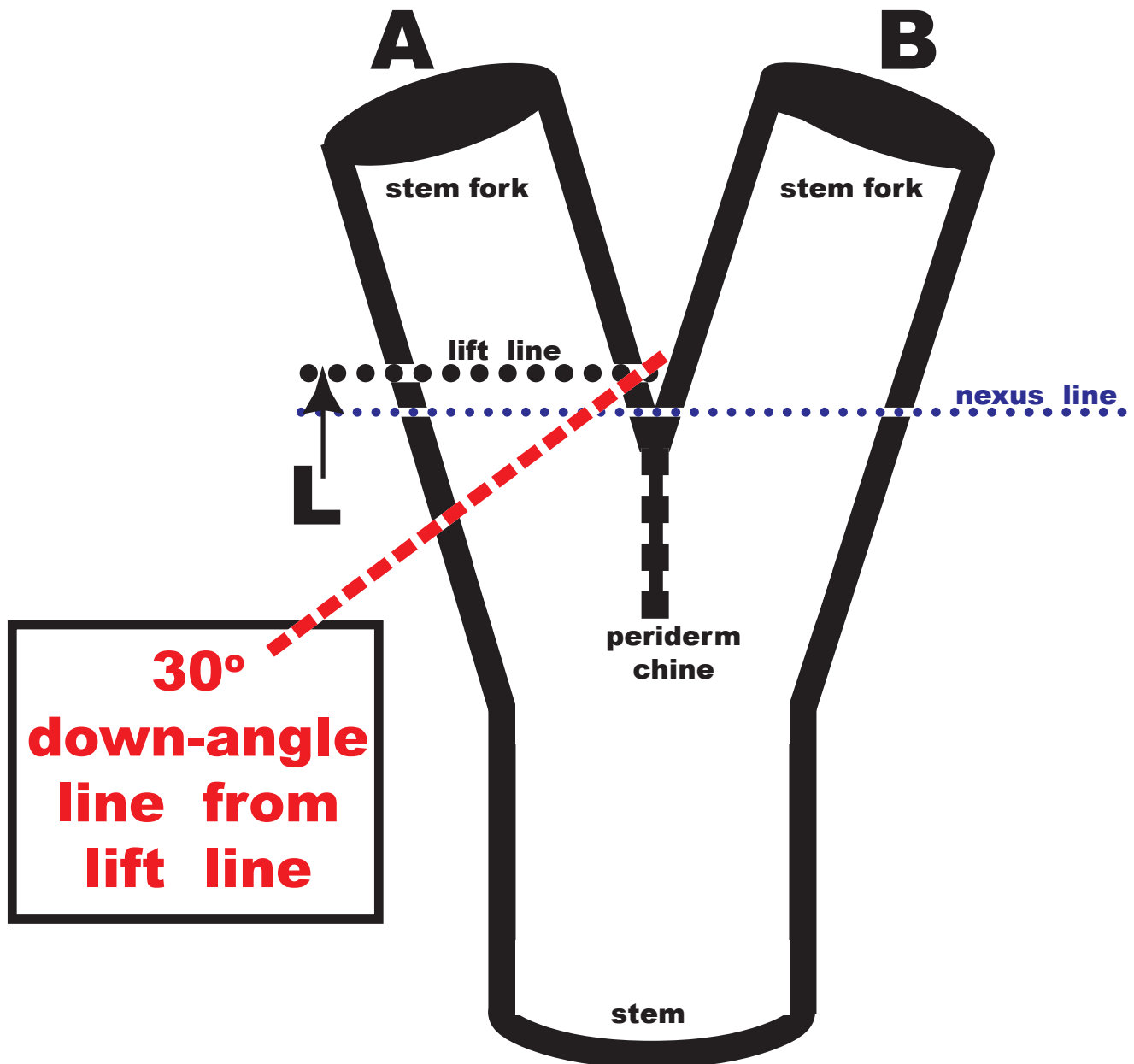


Figure 21: Diagram of forked stem with target lines established to initiate a reduction pruning prescription on stem fork A (left fork). Note the lift line is made parallel to and above the nexus line which is perpendicular to the longitudinal axis of the main stem before the fork and anchored at the top of the stem - branch confluence. L is $1/9X$ stem fork A diameter, or at least 3X saw kerf.

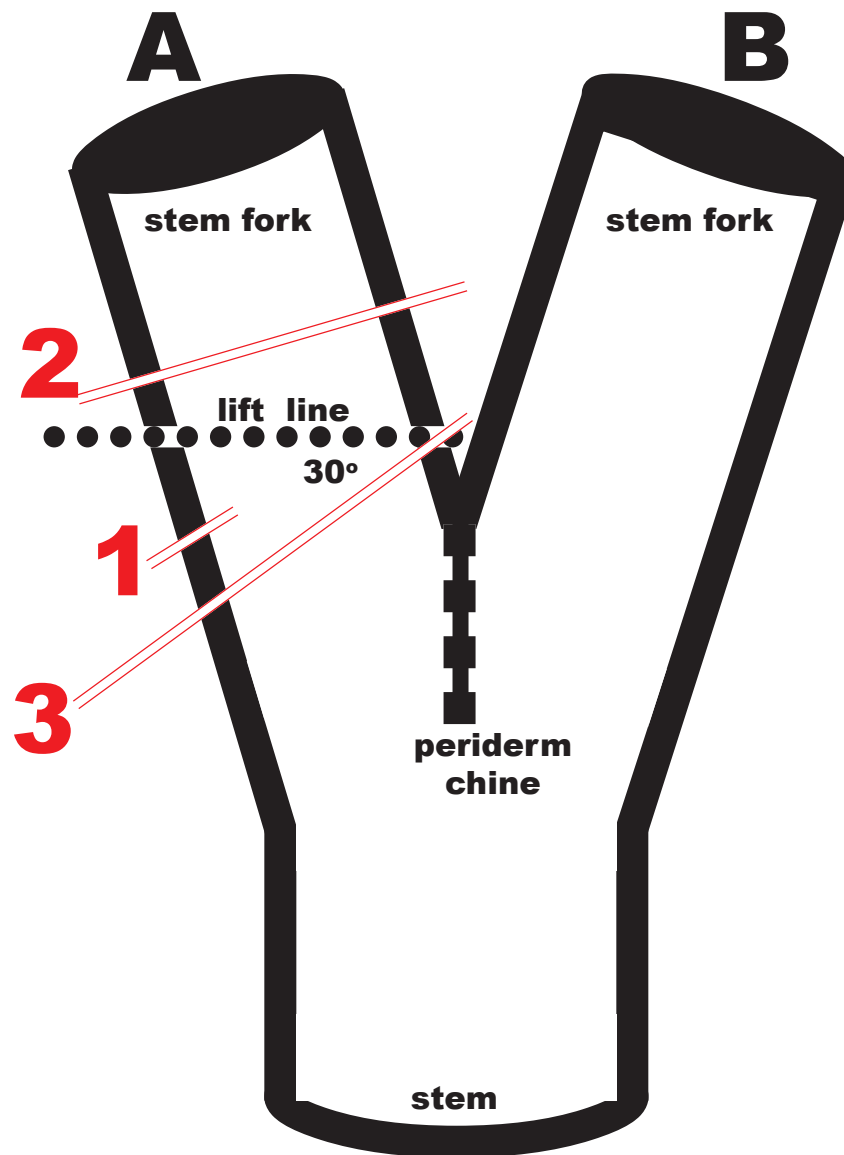


Figure 22: Diagram of forked stem with 3 cut lines placed in numbered order for a reduction pruning prescription on stem fork A (left fork). Note the final (3rd) cut is at a 30° down-angle from the lift line beginning above the top of the stem fork nexus.

The down angle is not dependent upon the periderm chine or stem fork angles.

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