UNIVERSITY OF GEORGIA
Warnell School of Forestry & Natural Resources

Publication WSFNR-22-13C

February 2022

Lightning Damage Development & Treatments In Trees

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A lightning strike and associated damage to a tree usually follows a specific eight step pattern: Figure 1.

First, the current exchange front begins to build in the phloem and xylem cambium-initials, with some tissue heating and disruption of intercellular connections.

Second, most of the current flow breaks out to the periderm surface (termed a surface flash-over).

Third, an intense explosive pressure wave is generated by the lightning core focused on a narrow portion of periderm (bark) and wood, pounding against branches and stem. Figure 2.

Fourth, the high intensity shockwave first compresses the bark and wood toward the center of the tree in addition to a surface compression wave moving around the tree circumference.

Fifth, tree tissues are subjected to tension forces as the shockwave rebounds within a tree.

Sixth, because of shockwave impacts, includes cell and tissue separations and loss of interconnections. Wood and periderm split, and tissues are shattered, leading to internal and external injuries. Figure 3.

Seventh, is compression and tension portions of the shockwave tearing through a tree leading to annual ring separations, breakage along old compartment lines, loosening of periderm and wood pieces, and propelling of loose tissue pieces away from a tree.

Eighth is mechanical stress and strain focused on existing structural faults, injury-modified wood, open spaces, gaps, cavities, drill holes, imbedded metal objects, and insect galleries. The stress and strain of the shockwave concentrates force along the edges of faults leading to additional fiber separations. Trees are torn apart along natural compartmentalization boundaries and opened to the environment. Figure 4.

The previous eight (8) step pattern of lightning damage in trees is summarized in Figure 5.

Tree Differences

Key observations of lightning damage to a variety of trees included a cited difference between thin and thick-barked trees, ring and diffuse porus trees, and associated stem architecture-based extent of tree damage. Due to internal tree structure and electric current level needed to attain flash-over, some tree attributes lead to different types of damage. (Taylor 1977) Figure 6 shows the strength of different tree structural types under compression and in tension.

The ability to sustain stress and strain of both impact and rebound from a lightning shockwave is partially based upon living wood strength. Different species of trees can handle different internal forces better than others. Most ring-porous trees can handle quite large pressures in both compression and in tension. In comparison, many diffuse porus trees are more easily damaged by lightning shockwave initiated forces. Conifers handle compressive forces well, but not tension forces.

Deformation Waves

The impact of lightning as it flashes along a tree stem is explosive. The shock wave within a tree stem takes two forms: 1) a deformation wave which travels directly across the diameter of the tree to the opposite side, and then rebounds back; and, 2) a deformation wave which travels around the circumference of the tree stem, rebounding back from the far side of the stem. Figure 7. Remember, this image represents a two dimensional image of the force paths generated, where actual lightning caused forces will be moving up and down a tree stem once or several times over a short period of time.

Thin Bark

Periderm appearance has been cited as an outward sign of potential lightning strike damage. Thin-periderm trees tend to have damage which is shallow and wide, while thick-periderm trees tend to have damage relatively deep and narrow. Thin-periderm trees, and trees with diffuse-porous xylem architecture, usually sustain little deep damage from lightning strikes. Thin-periderm trees with smooth, flat bark quickly allow surface flash-over and present little deep damage in stem tissues. Because of a strong shock wave radiating around a stem, large patches or sheets of bark can be loosened or pushed-off. Figure 8. (Rakov & Uman 2003; Uman 1971; Taylor 1977)

Thick Bark

In thick-periderm trees, and trees with ring-porous xylem architecture, damage can occur deep into sapwood with narrow portions of periderm and wood being pushed off a tree. Thick periderm species more commonly show lightning damage than thin barked species, and tend to have one or two narrow spiraling lines of damage. Along the center-line of these narrow injuries can be a thin compressed line of phloem tissues, or a radial crack moving into the wood. The radial crack can range in depth of less than one growth increment to more than four growth increments. Width of these injuries can range from 3-10 inches wide. Figure 9. (Taylor 1977)

Periderm and several layers of xylem (wood slabs) can be blown off and away from the injury. Figure 10. Thickness of the wood loss depends upon the depth of radial cracking. Pieces (slabs) pushed off a tree will be approximately one-half width of the whole injury. In other words, wood and periderm slabs loosened or blown off a tree will be of various longitudinal lengths with horizontal widths comprised of two halves. In some instances, a radial crack is present and a growth increment (ring) separation occurrs in sapwood, but wood is not blown away from a tree. (Taylor 1977)

Tissue Problems

Periderm on roots, stems, and twigs are different from one another due to weathering, compression, thickness, and age. New thin periderm on juvenile twigs can be on the same tree which has coarse, thick, corky bark on the mature stem. Historic field observations of tree lightning damage by bark type integrates many types and levels of observations into a single trait. It is clear that many tree features influence portions of the ground streamer strength (field enhancement) and charge exchange path.

Twigs and branches, where current moves internally until surface flash over (approximately the top 20% of tree height), can be disrupted and damaged severely enough to lead to decline or death. This stagheading or partial crown mortality is a common symptom of a lightning strike. Stem openings, cavities, or open insect galleries can concentrate forces which tear tissues apart.

Root damage and death from electric current being dissipated (grounded or earthed) are much more difficult to diagnosis than above ground damage. Branches may wilt and decline because of root damage. Roots killed in the grounding process can lead to later wind-throw because of lack of soil contact and loss of structural integrity.

Clean-Up

Pests are a secondary problem attacking physical injury sites and attracted by volatile tree materials released into air. A good example is pine. It is estimated that 31% of all pine beetle spots are due to a lightning strike at a center tree. A lightning strike to a pine can throw a debris shower up to 150 feet, exposing a tree to attack and scattering wood, periderm, and resin particles across a site. This lightning debris field is a large biological attractant area for many pests. Because of many internal gaps and fiber separations, pine pitching (resin exudate production) is reduced. Internal changes within a tree to prepare defensive materials reduces supplies of growth materials.

Reactions To Damage

Many trees are not visibly damaged by a lightning strike. It is difficult to ascertain if a tree has been struck if no injury is seen. Better sensing and measurement systems are required. Years after a lightning strike, a "lightning ring" may be visible as a defensive boundary among growth increments. These increment rings are similar to false rings generated by drought, pests, and floods except for the defensive chemicals deposited throughout the cell walls.

A shock wave from a lightning strike initiates a standard compartmentalization defense in and around the broken tissue connections and separated tissue layers. Cambium and ray cells set compartment lines around electric current flow pathways. Dead and damaged cells at the site of injury are sealed off.

The narrow spiral injuries seen along stem surfaces are not usually girdling. Because of crown dynamics in wind, and tree attempts to adjust for torque (twist), fiber orientation (grain) in a stem may be at some angle to the longitudinal axis of a stem. This spiral grain can be followed by the charge exchange pathway initially, leaving a spiral injury. Many vascular connections are still intact among surface injuries and function normally. If less than 25% of the stem circumference is damaged, defensive capabilities and means of resource transport should remain viable in a tree. (Taylor 1977)

Strike Symptoms

Symptoms of a lightning strike on a tree begin with a disruption and reduction in water movement capacity. In addition, resin flow is greatly reduced in species with standing resin systems. Chemical defensive compounds are rapidly generated and/or moved requiring significant reallocation of growth materials. Permanent leaf wilting on a single major branch is usually the first noticeable symptom of a lightning strike if the tree was not clearly blown apart or killed.

Another form of damage is recoverable foliage wilting which comes and goes over several months, sometimes leading to twig death. This process of sense and correction within a tree provides bark-resident pathogens avenues to effectively attack. A subtle symptom is slow branch or tree decline over 1-3 years with various pest and site constraints limiting new growth processes. (Taylor 1977)

Fire!

Approximately 12,000 fires per year are lightning initiated in the United States. Ignition is usually at the base of a tree where fine fuels are available. Constant current during a lightning strike between individual strokes can be between 100-400 amps. This constant current provides enough energy input and duration for sustained heating, leading to ignition.

Approximately 20% of all lightning strikes have this constant current. A majority of lightning strikes on trees do not cause sustainable ignition as the shock wave blows fuels and heated surfaces apart. Many charred fine particles can be found in lightning strike debris fields, but are not usually sites of ignition. (Taylor 1977)

Groups of Trees

Regardless of how we focus and concentrate our field and analytical views onto a single tree with a single strike, lightning-initiated damage and death of groups of trees demand attention. Orchards, especially in high resistance soil areas, have been decimated by single lightning strikes. In most group strikes, only one or two trees in the center may show visible above-ground injuries. Root damage from grounding impacts are the causal agent of death for the group of trees. (Taylor 1977)

Susceptible Tree Lists

Since humans have been noticing lightning struck trees, there have been lists compiled of trees most likely to be struck. Few of these lists have any statistical controls for area proportionality, crown class / tree height differences, ecological system typography and openness characteristics, species proportionality, or identification of other species and site attributes influencing ground streamer strength. Making a list is a pleasant observational study for a local area, but species differences have no influence on modifying ground field enhancements, and mean little along an average 35kA lightning charge exchange pathway.

Tree First Aid

Risk reduction and installation of a lightning conductance system in trees before a strike is the best way to minimize damage. Once a tree is injured, time until treatment is critical. The faster treatments commence, the better the biological results. Starting treatment processes within 8-24 hours, especially if little drying of tissues has occurred, can provide a window of treatment using watering and water loss prevention, and using pressure to reattach tissues. After 16-36 hours, compartmentalization processes have been initiated and reinvigoration actions to the whole tree are more appropriate.

BMPs

Due to site, tree, and injury differences, no specific treatment procedure can be defined. General best management practices (BMPs) should include a number of considerations. Figure 11.

Lightning treatment best management practices (BMPs) for trees:

-- If a tree will survive, consider if installing a tree lightning conduction system is warranted.

-- Water / watering is essential. Institute a specially targeted / zoned irrigation program for at least two growing seasons, if drainage can be assured. In exceptional cases, install crown misting and wind protection for at least one full growing season, if warranted.

-- For loosened bark and wood, consider use of a pressure belt. Use belts and surface pressure to pull / push slightly displaced tissues back into near original position for six weeks.

-- Cover the area with a temporary water conserving covering. Apply white plastic sheeting over injuries to minimize water loss for four weeks. Pruning paints can be used to slightly slow water loss and cover the injury, but do little to assist in recovery.

-- Remove clearly dead and seriously damaged branches. Do not over-prune. Delay greenwood pruning until tree allocation priorities are clear, or least one full growin season.

-- Remove and clean-up shattered tissues. Do not scribe or cut into living tissue.

-- In some areas and with some specific pests, an application of a preventative pesticide on and around wounds may be appropriate. Be sure pesticides and their carriers or stickers do not damage new parenchyma cells generated on xylem surfaces.

-- Delay nitrogen fertilization one full growing season.

-- Protect soil surface and soil health across the tree's rooting area including use of a thin layer of light mulch over small amounts of composted organic matter.

Citation:

Coder, Kim D. 2022. Lightning Damage Development & Treatments In Trees. Warnell School of Forestry & Natural Resources, University of Georgia, Outreach Publication WSFNR-22-13C. Pp.16.

LIGHTNING

1. TRICKLE
2. FLASH-OVER
3. SHOCK WAVE

TREE

4. MASH
5. STRETCH
6. SPLIT

INJURY

7. BREAKING
8. DAMAGE FOCUS

Figure 1: Typical tree lightning strike path development outline.

LIGHTNING

1. TRICKLE

Initial trickle of current rolls along phloem and xylem cambium-initials and rapidly builds in strength causing tissue heating and disruption of intercellular connections.

2. FLASH-OVER

Capacity of charge exchange pathway inside tree is limited as current flow rapidly builds. Suddenly, a majority of current flow breaks out onto periderm (bark) surfaces (a surface "flash-over")

3. SHOCK WAVE

A pressure wave formed by an almost instantaneous heating of air at the center of the charge exchange path is usually focused along a narrow portion of periderm and wood.

Figure 2: Typical first three steps of tree lightning strike path development.

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TREE

4. MASH

The large pressure wave first compresses periderm (bark) and wood toward the center of tree with a surface compression wave moving around the tree.

5. STRETCH

Tissues are subjected to an almost immediate tension force as the tree rebounds from the shock wave.

6. SPLIT

Wood and periderm, alternatively compressed then stretched, splits. Tree tissues deconstructed and interconnections shattered, leading to internal and external injuries.

Figure 3: Typical second three steps of tree lightning strike path development.

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INJURY

7. BREAKING

Compression and tension portions of shock wave within tree can lead to annual ring separations, breakage along old compartment lines, loosening of periderm and wood pieces, and propelling of loose tissue pieces away from tree.

8. DAMAGE FOCUS

Structural faults, injury modified wood, open spaces, gaps, cavities, drill holes, imbedded metal objects, and insect galleries concentrate compression and tension forces along their edges leading to fiber separations. Trees tear apart along compartment boundaries.

Figure 4: Typical last two injuring steps in tree lightning strike path development.

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LIGHTNING

1. **TRICKLE**
   An initial trickle of current rolls along the phloem and xylem cambium-initials and rapidly builds in strength causing tissue heating and disruption of intercellular connections.

2. **FLASH-OVER**
   The capacity of the charge exchange pathway inside the tree is limited as current flow rapidly builds. Suddenly, a majority of the current flow breaks out onto the periderm surface (surface "flash-over").

3. **SHOCK WAVE**
   A pressure wave formed by an almost instantaneous heating of air at the center of the charge exchange path is usually focused along a narrow portion of the periderm and wood.

TREE

4. **MASH**
   The large pressure wave first compresses the periderm and wood toward the center of the tree with a surface compression wave moving around the tree.

5. **STRETCH**
   Tissues are then subjected to an almost immediate tension force as the tree rebounds from the shock wave.

6. **SPLIT**
   The wood and periderm, alternatively compressed then stretched, splits. Tree tissues are deconstructed and interconnections are shattered, leading to internal and external injuries.

INJURY

7. **BREAKING**
   The compression and tension portions of the shock wave in a tree can lead to annual ring separations, breakage along old compartment lines, loosening of periderm and wood pieces, and the propelling of loose tissue pieces away from the tree.

8. **DAMAGE FOCUS**
   Structural faults, injury modified wood, open spaces, gaps, cavities, drill holes, imbedded metal objects, and insect galleries concentrate compression and tension forces along their edges leading to fiber separations. Trees tear apart along compartment boundaries.

Figure 5: Summarry of tree lightning strike path development.

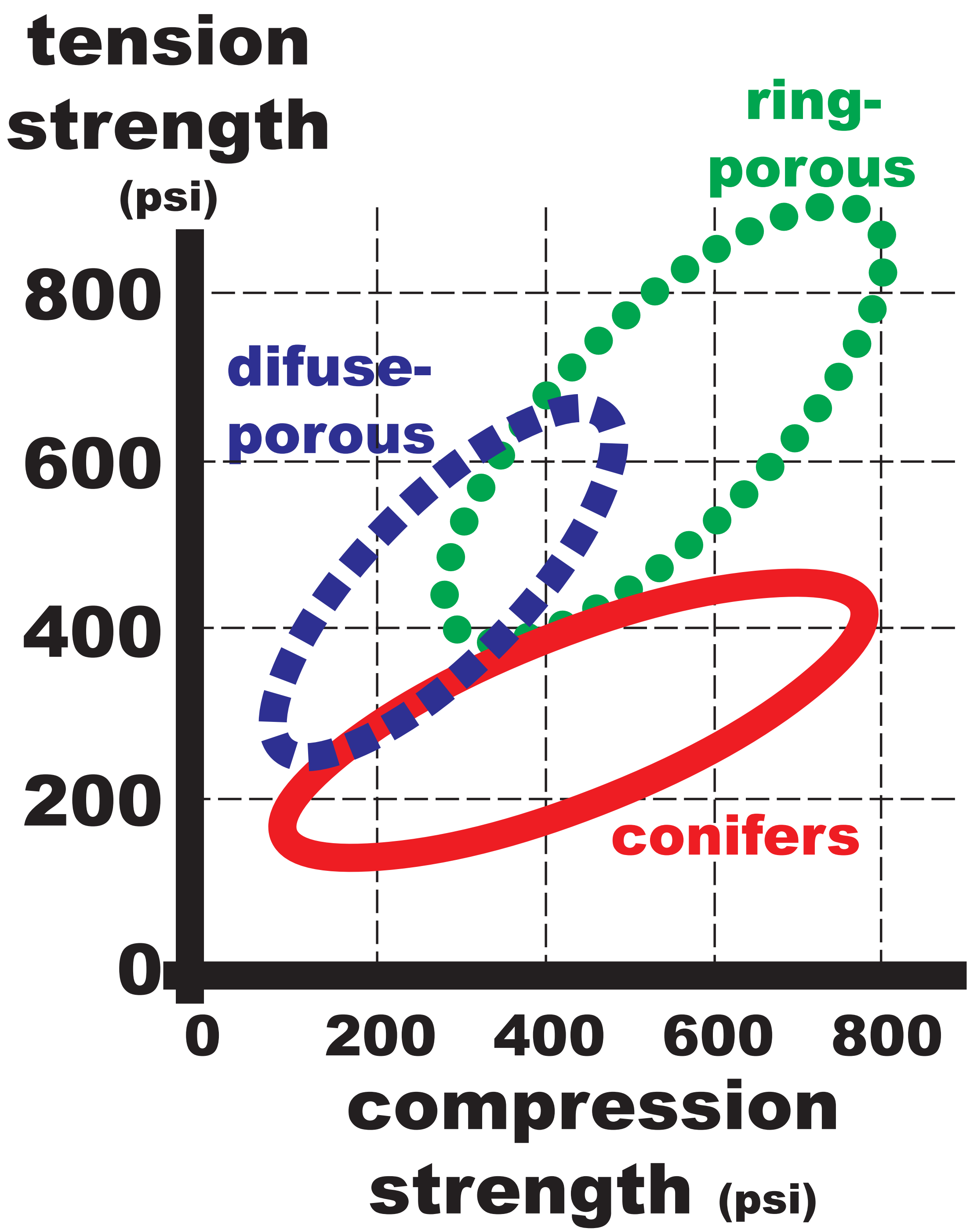

Figure 6: Estimated tension and compression strengths perpendicular to the grain of living tree wood for various North American tree species.

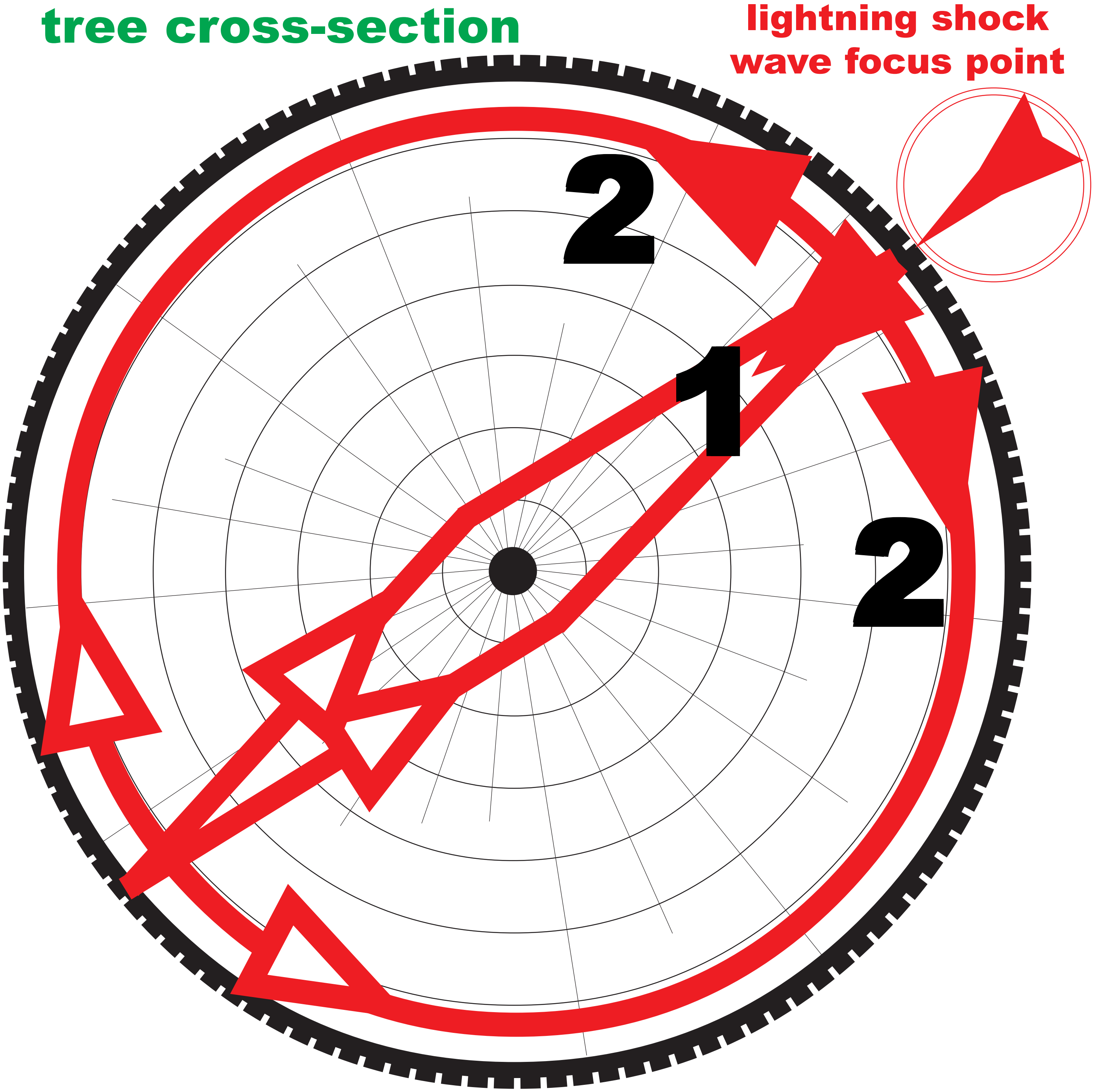

Figure 7: Lightning shock wave impact generating two types of deformation pressure waves (and their rebound) inside a tree stem: 1) through deformation wave; and, 2) circumference deformation wave.

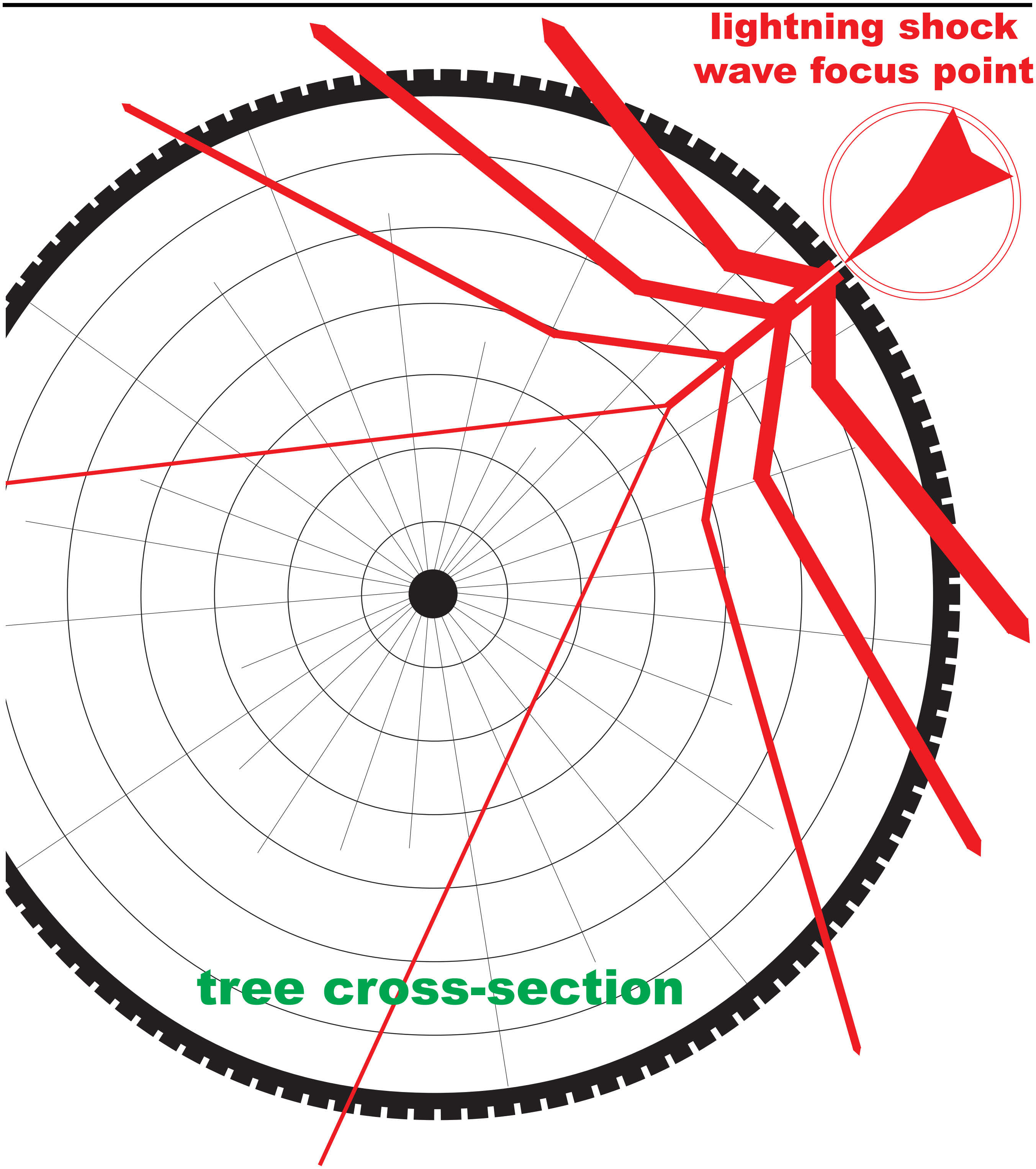

Figure 8: Lightning shock wave impact and rebound inside stem of diffuse-porous thin-barked species, or non-porous xylem species with no density differences within a single growth increment.

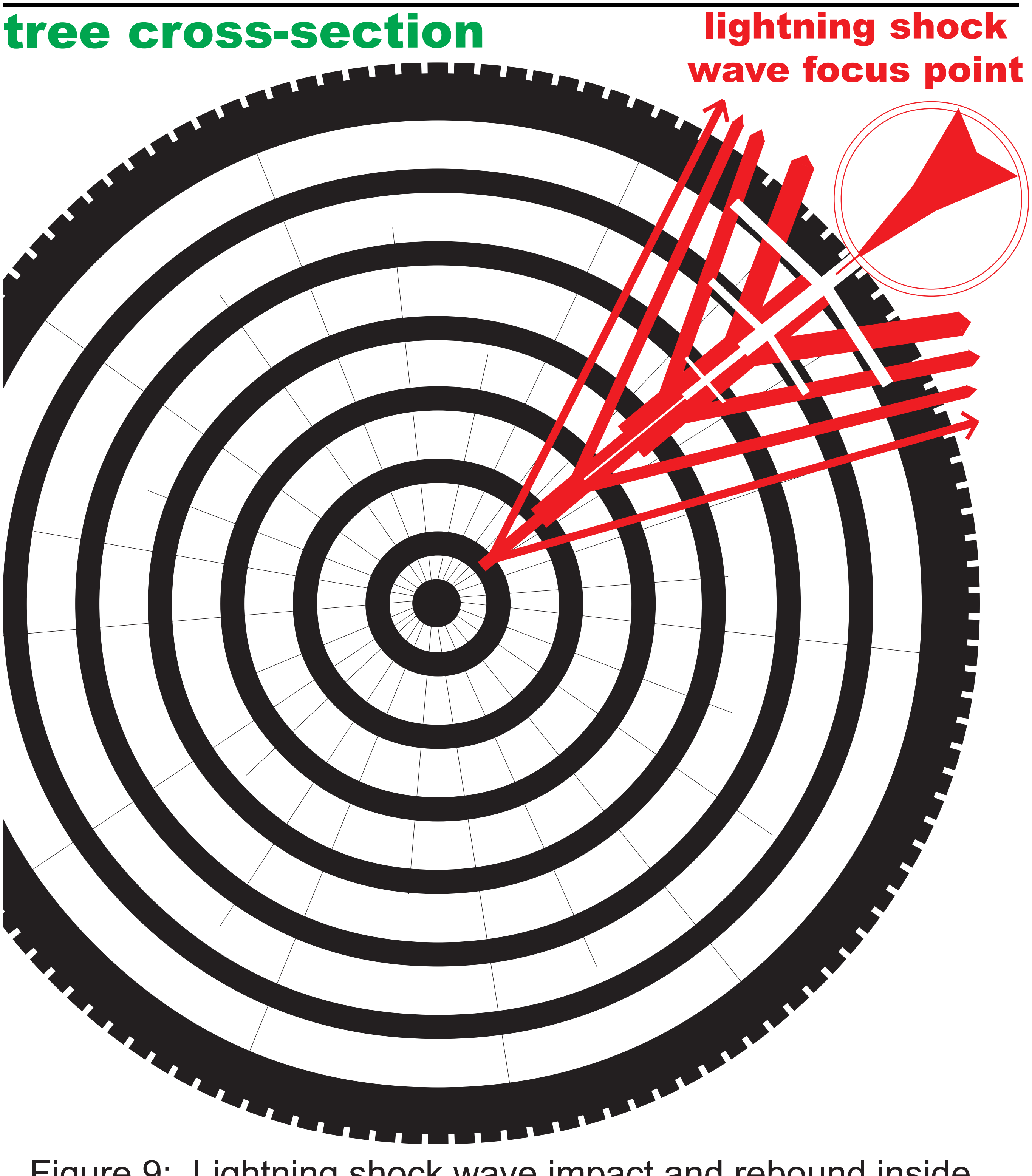

Figure 9: Lightning shock wave impact and rebound inside stem of ring-porous thick-barked species, or non-porous xylem species with large density differences within a single growth increment.

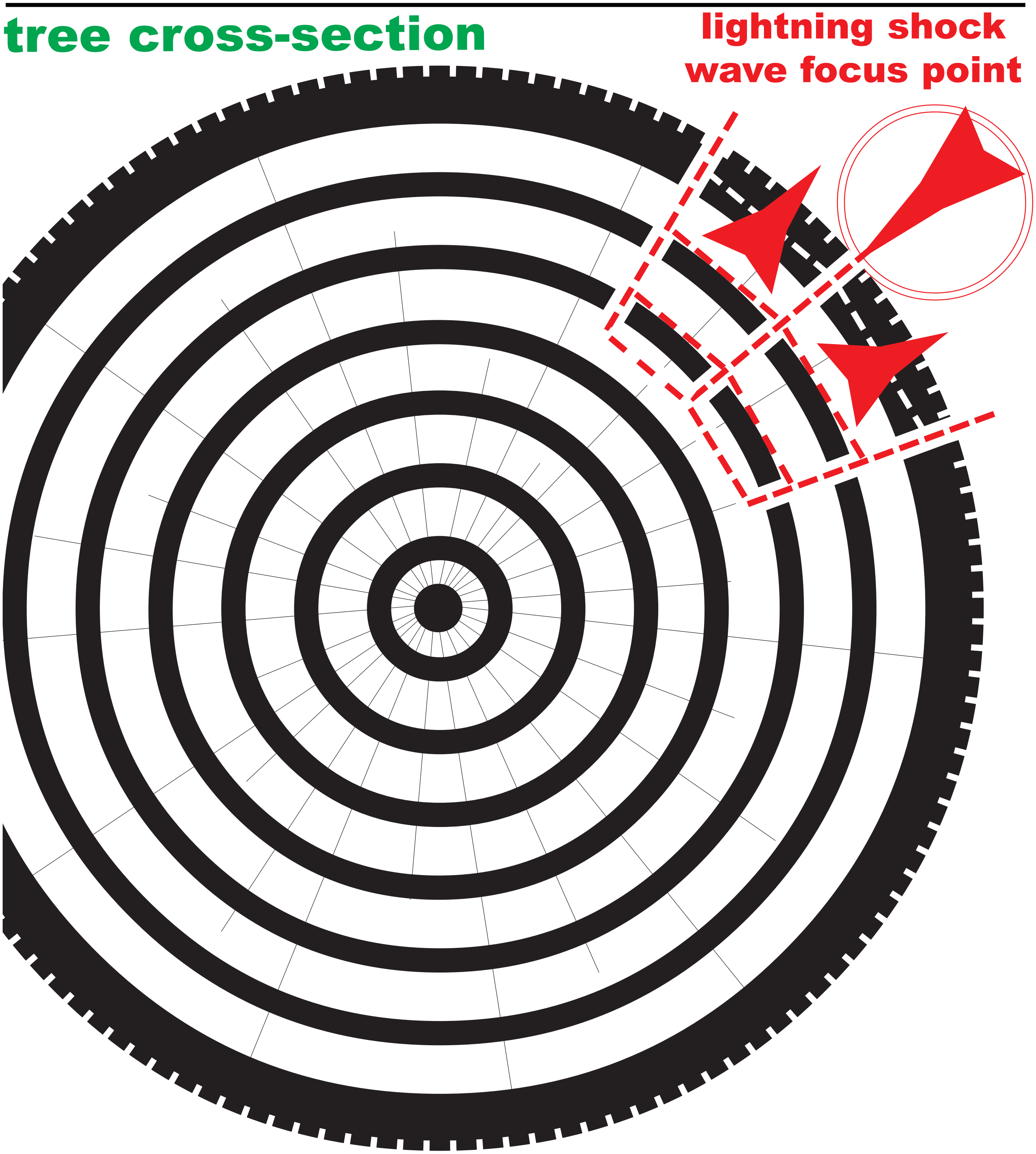

Figure 10: Lightning shock wave loosening and potentially removing bark and wood slabs in a stem of a ring-porous thick-barked species, or non-porous xylem species with large density differences within a single growth increment.

1. **lightning conduction system installed for next time**

2. **water for at least two growing seasons, if drainage can be assured**

3. **reattach loosened bark & wood with pressure belt for six weeks**

4. **cover area with temporary water-conserving covering for four weeks**

5. **remove clearly dead & seriously damaged branches, but do not over-prune**

6. **delay any greenwood pruning until tree allocation priorities are clear, or least one full growing season**

7. **remove & clean-up shattered tissues, but do not scribe or cut into living tissue**

8. **locations with specific pests present, use application of preventative pesticide on & around wounds**

9. **delay nitrogen fertilization one full growing season**

10. **protect soil surface & soil health across tree's rooting area**

Figure 11: Best management practices (BMPs) for treating lightning struck trees.