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Warnell School of Forestry & Natural Resources

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# American Mistletoe: Tree Infection, Damage & Assessment

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Every Winter people notice mistletoe (American mistletoe = *Phoradendron leucarpum*). Whether in holiday greenery or in deciduous trees, mistletoe is a visible symbol of tree damage. Mistletoe negatively impacts both tree health and structure. Mistletoe is a parasite which initiates branch decline and loss, wood decay and discoloration, animal and pathogenic entry points into a tree, and oxygenation and drying of wood. Mistletoe commandeers growth resources from trees. Early intervention is critical to maintaining tree health and structural integrity.

Mistletoe has a long history of being noticed and celebrated by humans. Spiritual blessings and curses were centered around mistletoe. Some forms of mistletoe, especially when infecting a particular individual tree or species of tree, were important in naturalistic religions or rites. The term "mistletoe" has a much less exotic and revered background. Because mistletoe was thought to be propagated by bird droppings, the term mistletoe is derived from Anglo-Saxon for "a twig with bird droppings," or distantly derived from "a different kind of twig." Kissing under this parasite has many meanings.

## World Context

Of all the angiosperm plants, only about 1% are parasites. Of these angiosperm parasites, ~40% parasitize other plant shoots. Mistletoes are shoot parasites. Worldwide there are hundreds of mistletoe species. The family group is called the *Viscaceae* (*Santaleles* order) which contains ~575 species and 7 genera. Of the seven genera, three have significant tree impacts. The first of these three is *Arceuthobium*, the dwarf mistletoes, a serious conifer tree pest found around the globe with 34 species. *Viscum*, is an old world genus of mistletoe containing ~60 species. *Phoradendron* is the third major tree damaging genus found only in temperate and tropical portions of the Western hemisphere.

The genus *Phoradendron* (translated as "tree thief") contains about 235 species. Over time the genus has been given several scientific names: *Phoradendron* (1848), *Spiciviscum* (1849), *Allobium* (1851), and *Baratostachys* (1910). The center of diversity for this genera, and where most species are found, is in the Northwestern Amazonian rain forest at higher elevations. *Phoradendron* species are divided roughly into 36% found in Central and North America, 70% of the species growing South of Panama into South America as far as Northern Argentina, and 9% of the species in the Caribbean. Note this geographic division does not sum to 100% because some species have wide ranges and are found in multiple locations.

## Names

It is difficult to identify and separate different mistletoe species of the new world. Depending upon how species are botanically divided, the United States is home to five species of *Phoradendron* which are found predominately on hardwoods, and a different five species found on conifers. Currently the best designed naming structure for the dominant *Phoradendron* species found infecting many tree species across many sites in the United States is *Phoradendron leucarpum*.

In the recent past, this species was sub-divided into several sub-species under an earlier name. The old species / sub-species concept, which was distributed across the Southern United States and Mexico included: *Phoradendron serotinum* subsp. *serotinum (*American mistletoe, the typical species); *Phoradendron serotinum* subsp. *tomentosum* (Christmas mistletoe); *Phoradendron serotinum* subsp. *macrophyllum* (Western mistletoe); and, *Phoradendron serotinum* subsp. *angustifolium* (Mexican mistletoe). Recent scientific studies found no morphological or molecular support for any sub-species.

Over time there has been many attempts to name the leafy mistletoe of Eastern North America. The scientific name for this species has been changed a number of times as different taxonomists worked to categorize all *Phoradendron*. American mistletoe historically has been named: *Viscum album (1788), Viscum flavescens (1813), Viscum leucarpum (1817), Viscum serotinum (1820), Viscum leucocarpum (1830), Viscum verticillatum (1837), Viscum oblongifolium (1838), Viscum ochroleucum (1838), Viscum rugosum (1838), Viscum flavens (1848), Phoradendron flavescens (1848), Phoradendron orbiculatum (1849), Phoradendron coloradense, Phoradendron flavens* subsp. *macrophyllum, Phoradendron flavens* var. *macrophyllum, Phoradendron flavescens* var. *orbiculatum (1850), Phoradendron flavescens* var. *glabriusculum (1850), Phoradendron eatoni (1913), Phoradendron longispicum, Phoradendron macrotomum, Phoradendron tomentosum* subsp. *macrophyllum, Phoradendron tomentosum* var. *macrophyllum, Phoradendron flavens* var. *tomentosum, Phoradendron macrotomum (1913), Phoradendron flavescens* var. *macrotomum (1941), Phoradendron serotinum (1957), Phoradendron serotinum* var. *macrotomum (1957), Phoradendron serotinum* var. *tomentosum, Phoradendron serotinum* subsp. *macrophyllum, Phoradendron serotinum* var. *macrophyllum, Phoradendron leucarpum* subsp. *angustifolium, Phoradendron leucarpum* subsp. *macrophyllum, Phoradendron leucarpum* subsp. *tomentosum, Phoradendron serotinum* var. *serotinum (2003),* and currently *Phoradendron leucarpum (1989),*

Range

All mistletoe seen in the Eastern United States, except for a mahogany mistletoe in far South Florida (*Phoradendron rubrum)*, is a single species. In garden, pest, and identification books, this species of mistletoe may be called variably: *Phoradendron serotinum, Phoradendron leucarpum,* or *Phoradendron flavescens* — three scientific names all used for the same species which continues to lead to confusion. The common name for this plant is mistletoe, leafy mistletoe, ingerto, Eastern mistletoe, American mistletoe, hairy mistletoe, or oak mistletoe.

*Phoradendron leucarpum* in the Eastern United States can be found South and East of a line which runs from South Texas to Northcentral Texas on to the three corner area of Oklahoma, Kansas, and Arkansas, and then on to Long Island, NY. Figure 1. The controlling feature of the Northern range boundary of mistletoe is considered to be minimum Winter temperatures. The native Northern range of mistletoe correlates well throughout most of its range with climatic limits of:

— greater than 25°F December minimum daily temperatures
— less than an average 23 days in December or 27 days in January with temperatures below 32°F;

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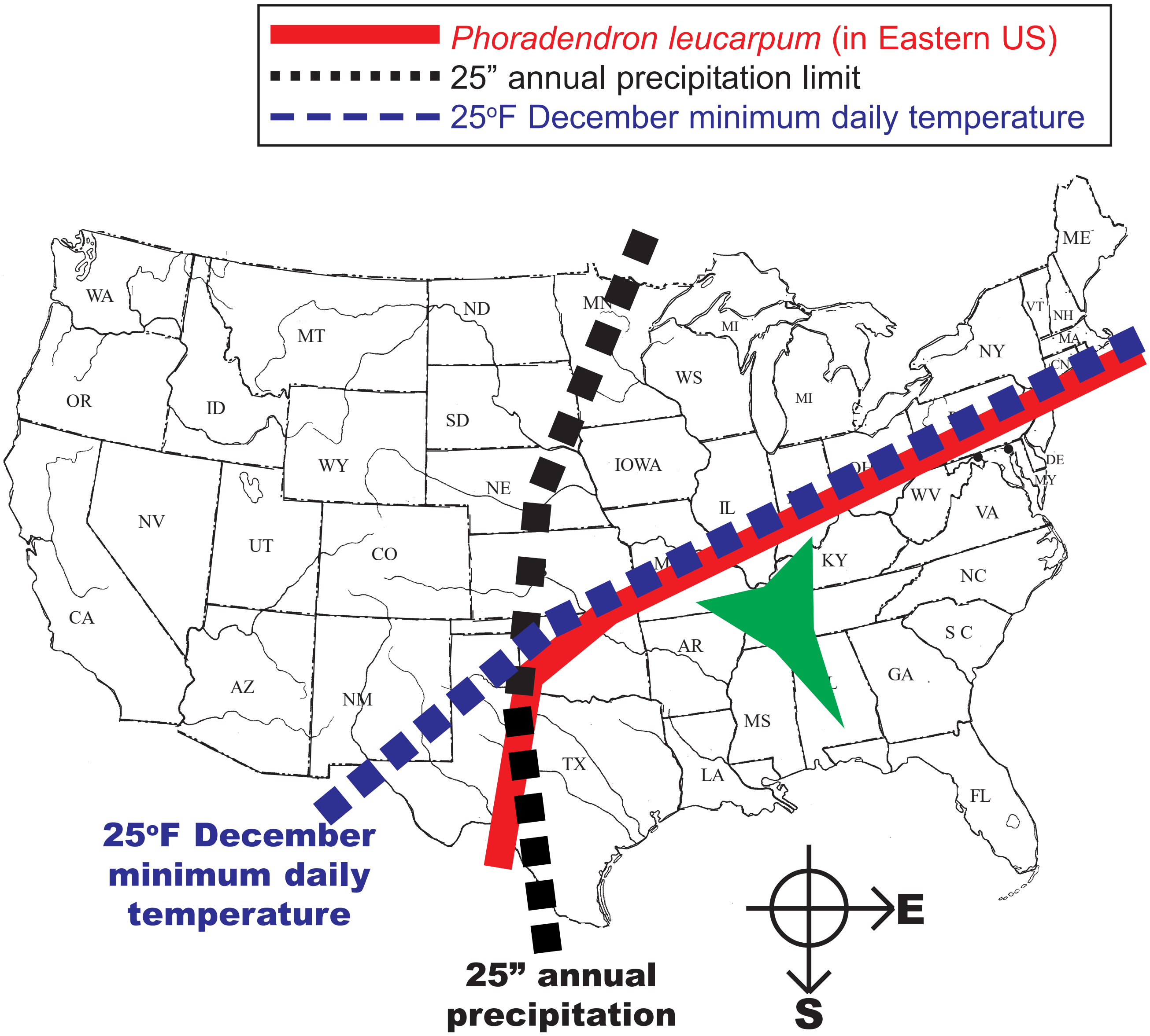


Figure 1: General range of American mistletoe (*Phoradendron leucarpum*) in the Eastern United States.
Parasite range is South and East of heavy solid line. Also shown are two climatic lines -- Western precipitation limit and minimium Winter temperature.

— greater than an average minimum Winter temperatures of 25°F;
— greater than an average most extreme minimum annual temperature of 0°F to -5°F;
— greater than an average most extreme minimum December temperature of 5°F;
— greater than an average minimum daily temperature in January of 20°F to 24°F or in February of 20°F to 25°F; and,
— greater than an annual average minimum daily temperature of 40°F to 45°F.

The range of mistletoe can be roughly estimated to be within cold hardiness zone 6b and higher. Microsites farther North can hold mistletoe for many years until a severe freeze kills it back. American mistletoe shoots do not effectively develop deep cold hardiness, while the haustoria (endophyte portion inside a branch) does not generate cold hardiness at all, and so mistletoe is susceptible to cold / freezing temperatures.

In the past, the three Southern United States sub-species were shown with overlapping ranges. Figure 2 shows the range of the three old sub-species, now all combined into *Phoradendron leucarpum*. A famous mistletoe taxonomist has stated — "The diversity of *Phoradendron* in Texas constitutes a taxonomists's nightmare." (Kuijt, 2003). These old sub-species ranges combine into the current range of *Phoradendron leucarpum*. Figure 3.

Growth Strategy

Mistletoe is an evergreen, perennial, dichotomous, parasitic flowering plant. Mistletoe derives all of its water and essential elements including nitrogen, and a small portion of its food (CHO - carbohydrates), from a host tree. Mistletoe is a water and element parasite, not simply an epiphyte. More precisely, it is classified as a hemi-parasite because it manufactures most of its own food, but steals all other essential resources from the tree. Mistletoe has an aerial portion consisting of leaves, stems, and reproductive organs like other flowering plants. Mistletoe has a resource gathering organ (forming a resource exchange interface) which establishes and grows within a tree twig or branch called a haustorium. Mistletoe is an obligate parasite, not growing or surviving on dead trees.

Leaves & Shoots

Mistletoe leaves are bright green, simple, opposite, evergreen, and thick with a smooth margin. Leaves are variable in size across the large range of the parasite. On average, leaves are about 1 inch long (range from 1/2 to 1.5 inches) and 1/2 inch wide (range from 1/3 to 1.2 inches). Older leaves and other tissues are smooth without noticeable trichomes (plant hairs). Some young tissues and large surface veins may have short thin trichomes. There is tremendous variability across the range of mistletoe in the amount of trichomes present. Host stress and environmental constraints also initiates much variability in plant size and leaf shape.

Leaves and stems are covered with a thick protective covering (cuticular epithelium) and a thick waxy cuticle which minimize water loss. Leaves and stem tissues contain many calcium oxylate crystals and tough fibers which make the plant difficult to eat and digest for herbivores. Mistletoe stems are bright green in color, and brittle, breaking apart easily at the nodes in storms and when pruned. Stems appear swollen at each node. Internodes usually range from 2 to 2.75 inches long. Stem lengths can reach 2-3 feet in length. All shoots tend to grow from one location on a tree branch (clumped), causing the whole plant to form a rounded ball-like crown of foliage. Figure 4. Figure 5.

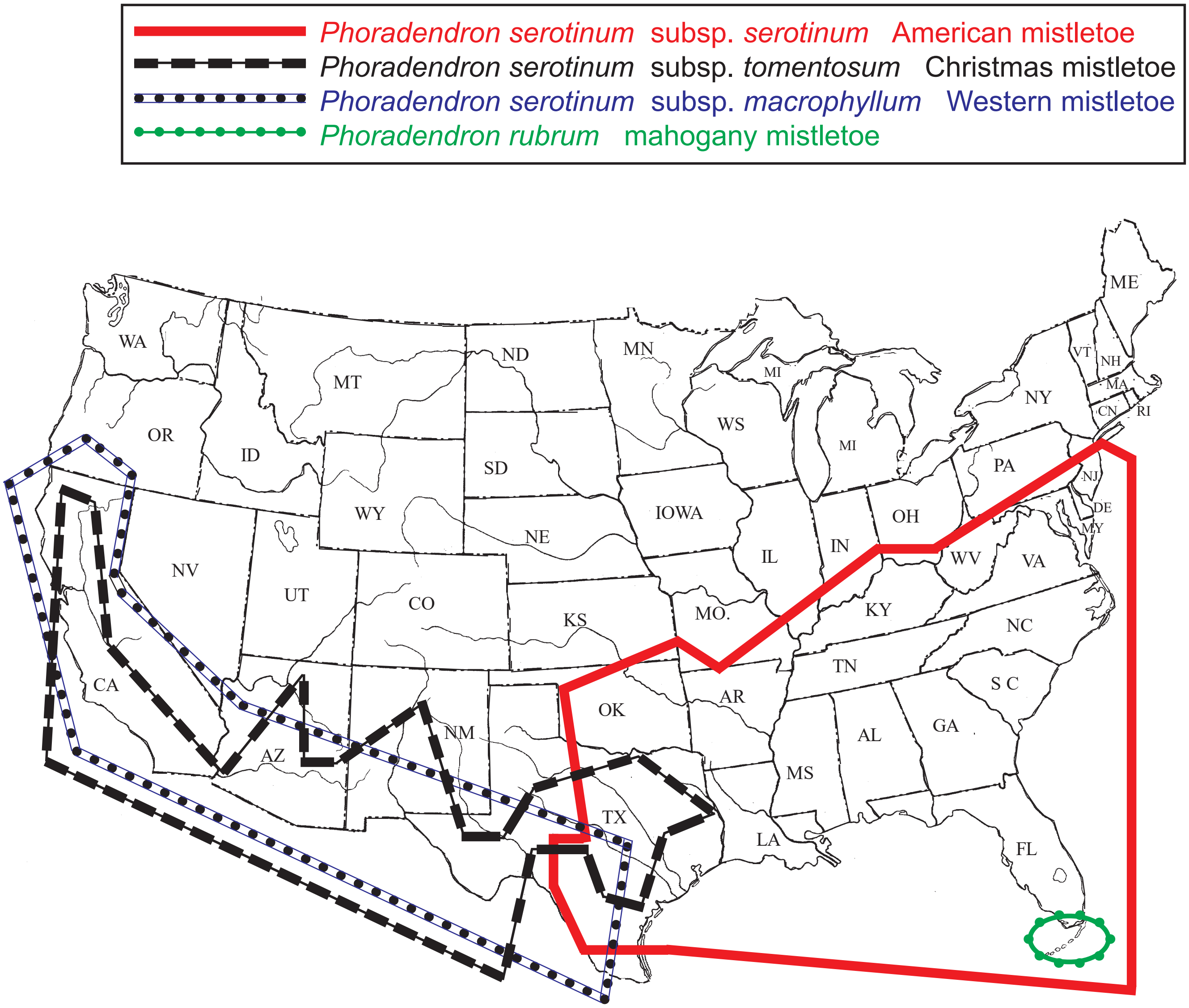


Figure 2: Defined ranges of the old sub-species concept of *Phoradendron serotinum* across the Southern United States. *Phoradendron rubrum* geographic range in South Florida is also shown. Note the taxonomic overlaps in Texas.

(after Kuijt, 2003)

# ***Phoradendron leucarpum***

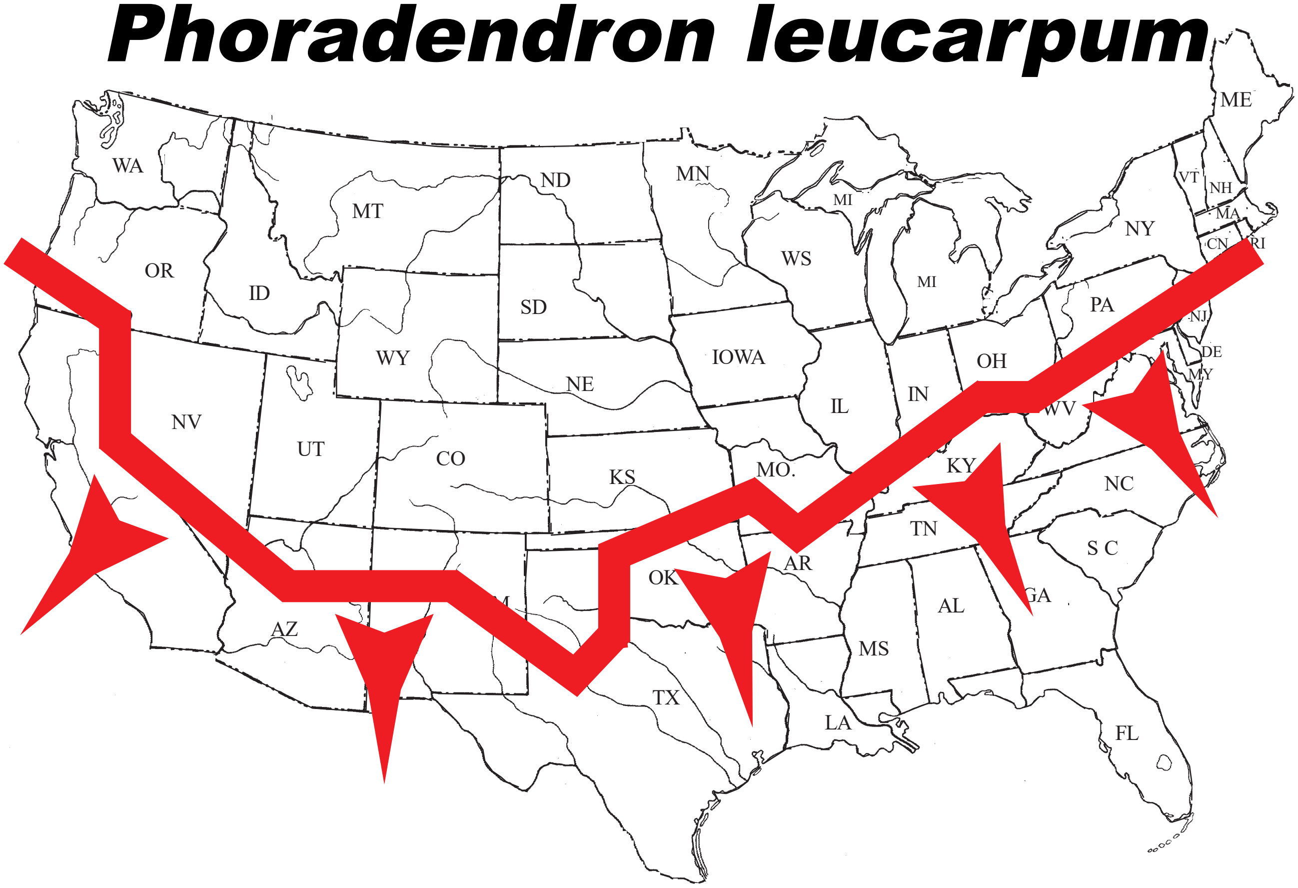


Figure 3: Range of *Phoradendron leucarpum* -- American mistletoe -- across the Southern United States from Oregon to Long Island, NY.

Figure 4: *Phoradendron leucarpum* -- leaves and shoots.
(photograph by Dr. Kim D. Coder)

Figure 5: *Phoradendron leucarpum* -- leaves and shoots -- hand seeded onto water oak branch.
(photograph by Dr. Kim D. Coder)

Flowers

Mistletoe is dioecious, with male and female flowers on different plants. Flowers grow on segmented inflorescences generated from leaf axils (leaf - stem junctions). Flowers are bright green, similar to the color of stems. When immature, the male and female flowers are difficult to tell apart. Small male flowers usually cover 4-5 flower stem segments with about 39 flowers per segment. The pollen is spherical and transported by insects to female flowers. Insect pollinators are wasps, bees, and possibly ants. In any area, there is usually a slight prevalence of male plants.

Female flowers usually cover 4 flower stem segments with about 7 flowers per segment on average. The female flowers are small with a squat, nipple-like style and stigma over an ovary. Flowers are less than 1/8 inch long. Flowering times vary across the extensive range of mistletoe but are usually from mid-September to late November. Fruit development occurs over late Fall and Winter (November to March). Fruiting begins in mistletoe around 3-5 years of age. Age is measured beginning from when a visible shoot with leaves first develops. Over time as the parasite grows, its resource gathering interface inside a tree continues to expand and shoots generate more flowers and fruit.

Fruit

Ripe mistletoe fruit is a round pseudo-berry (i.e. a berry formed with some additional expanded flower parts) with a translucent, pearlescent, bright white color. Figure 6. The fruit is 1/6 to 1/4 of an inch in diameter and smooth. The fruit skin is leathery and tough with a thick cuticle enclosing a single seed. Just below the fruit skin is a thick layer of tightly packed living cells (sub-dermal layer). The fruit surface minimizes the amount of oxygen passing inward to the seed and minimizes drying of the fruit. Figure 7. The fruit skin must be pierced or removed to allow seed germination. Fruit weathering, or passage through an animal, allow a seed to be released from its fruit covering and open to the air.

Within the fruit, and surrounding the seed, is a tangle of minute strings intermixed with many long thin-walled cells covered with a pectin jelly called viscin. The thin strings grow from the opposite end of the seed from the embryo and help seeds become entangled on tree periderm (bark) surfaces. The combination of these strings and viscin serve to strongly attach seeds to periderm. Viscin is composed of a mucilaginous mix of polysaccharides (sugars), uronic acids, and proteins. Viscin acts as a moisture sponge, an adhesive upon drying, and slows oxygen movement to the seed surface. As viscin dries it generates a translucent, thin, tough material covering the seed, fruit strings, and any surface upon which it sits.

Dispersal & Attachment

The fruit contains a single sticky seed. Figure 8. Seeds readily stick to any surface through drying viscin acting as a glue, while seed strings provide a large surface area for attachment. Mistletoe seeds are dispersed primarily by birds through seeds sticking to beaks and feet, in excrement, or by regurgitation. Birds cited with fruit consumption and seed dispersal of mistletoe include: bluebird, Carolina chickadee, crow, purple finch, thrush, yellow-rumped warbler, Acadian flycatcher, yellow-shafted flicker, Northern flicker, yellow-bellied sapsucker, brown thrasher, tufted titmouse, white-eyed vireo, pileated woodpecker, red-bellied woodpecker, Carolina wren, mockingbird, phoebe, robin, ruby-crowned kinglet, gray catbird, veery, towhee, cedar waxwings, and mockingbirds. Small mammals, like mice, and gravity play a minor role in seed dispersal.

Birds tend to deposit mistletoe seeds in crowns of trees along woodland and suburban edges. Trees which are taller, larger, and older tend to attract these types of birds. Mistletoe populations are

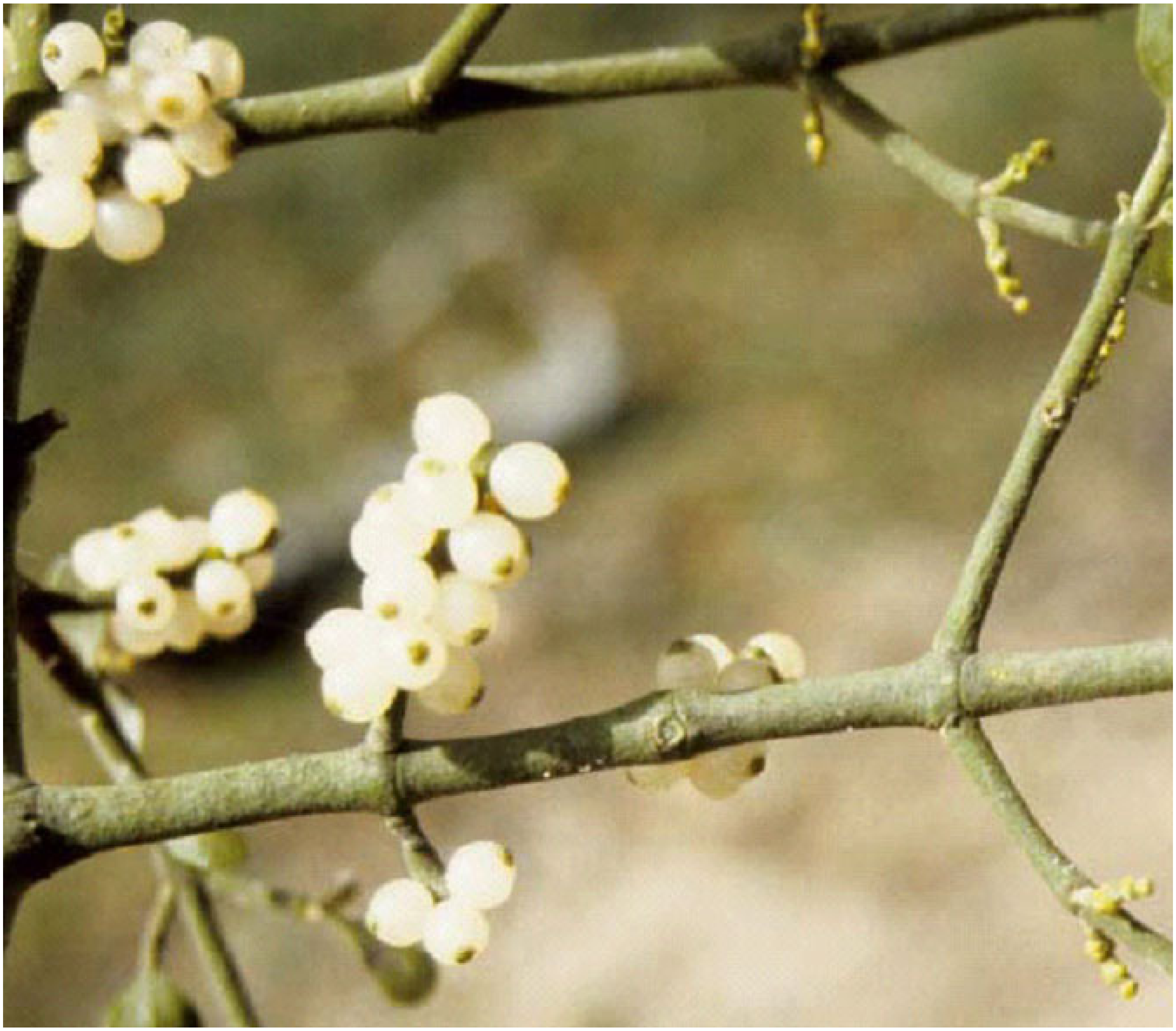

Figure 6: *Phoradendron leucarpum* -- fruit.
(photograph by Dr. Kim D. Coder)

Figure 7: *Phoradendron leucarpum* --
crushed fruit & sticky seeds.
(photograph by Dr. Kim D. Coder)

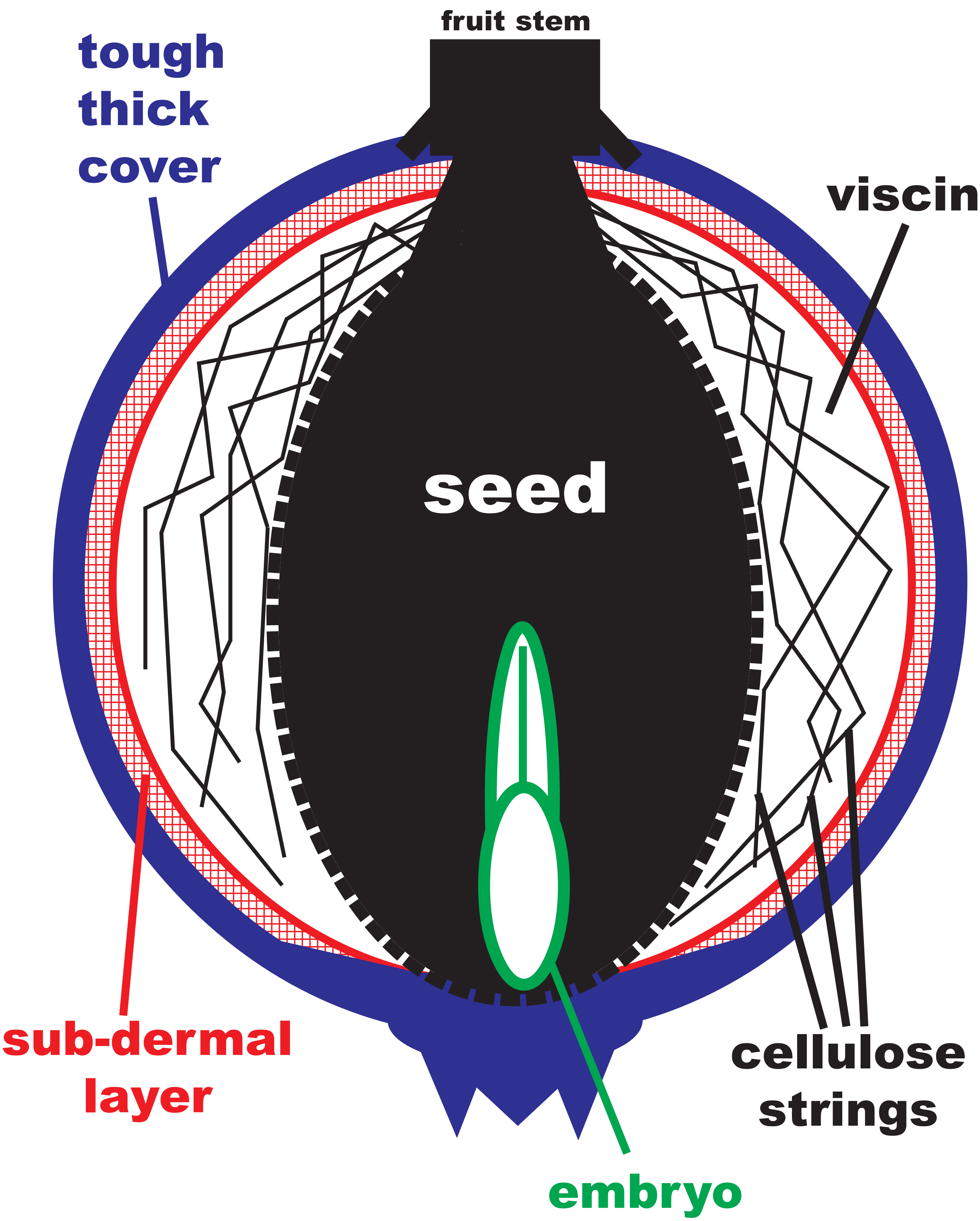


Figure 8: Simplified diagram of mistletoe fruit in cross-section.

patchy in community forests due to both tree attributes and bird behaviors. For example, mockingbirds live in territories along edges of yards, along fence rows, and around open clumps of trees. They carry mistletoe seeds into their territorial trees and begin infection centers. Trees already infected are more likely to be continually infected because of seed availability within the crown caused by birds. Infections from seeds dropping from female mistletoe clumps comprises a small number of plants. In times when food is scarce, like during drought periods, birds tend to move more mistletoe seeds and facilitate many more infections.

## Trees Infected

Across its range, *Phoradendron leucarpum* infects more than 105 tree species (>50 genera). Broadleaf, evergreen, deciduous, and conifers are all susceptible to infections. The infection process has a genetic basis as trees and mistletoe interact. There are genetic races of mistletoe which tend to only infect one species of tree. These races have not been extensively studied, but can be found throughout the mistletoe range infecting predominantly one species in one location and predominantly a different tree species in another location. Environmental aspects of successful seed germination and successful infection are also critical.

Common names of trees cited as being susceptible to mistletoe are: red maple, silver maple, sugar maple, boxelder, Ohio buckeye, river birch, hickory, water hickory, pecan, shagbark hickory, mockernut hickory, chestnut, beech, ash, white ash, elm, sugarberry, hackberry, camphor-tree, dogwood, persimmon, honeylocust, juniper, redcedar, black walnut, sweetgum, Osage-orange, chinaberry, black gum, aspen, sycamore, laurelcherry, black cherry, oak, live oak, red oak, water oak, chinkapin oak, white oak, Southern red oak, black oak, blackjack oak, black locust, basswood, sassafras, yellow poplar, alder, ginkgo, zelkova, citrus, and pear. Notably missing from this tree species list is eucalyptus and monocot plants (like palms and bamboos).

## Seed Germination

As with many plant lives, mistletoe begins life as a seed. The seed is delivered / deposited on a tree twig usually by a bird. Seeds are deposited as single units, in a row, or in a clump on a bark surface. Mistletoe seeds live for only a short time, being prone to drying out and to fungal attack. In addition, mice and ants can remove seeds from tree surfaces. A germinating mistletoe seed is extremely vulnerable on the open surface of a twig. Most seeds die within the first day outside their fruit covering.

Light and oxygen are needed to stimulate seed germination. Mistletoe seeds do not have strong dormancy. Germination is constrained by the surrounding fruit material slowing oxygen movement inward. As long as the fruit coat is intact, oxygen content at the seed surface is relatively low. Once the fruit coat is pierced, broken, or removed, oxygen content at the seed surface nears atmospheric levels and can initiate the germination process. Passage through the digestive tract of an animal is not required, but can help remove the fruit coat.

## Getting Attached

Seed germination percentage is quite high (90%). The species of tree and surface upon which a seed is deposited matters little for germination. Once germinated, seedling development is much more sensitive to the periderm substrate, with greater than 75% of all seedlings dying before initial infection of a host tree. As mistletoe begins to grow, it must successfully establish growth regulator communication with a tree, or the seedling mistletoe will quickly succumb to the harsh environment of the periderm surface. Rapid tree xylem growth and periderm expansion rates can prevent successful infection. Mistletoe strategy is to germinate quickly and make a connection with the host. Mistletoe is unique among most plants in having photosynthetic cells already positioned within the embryo, endosperm, and cotyledons of the seed for rapid development of the radicle.

The top of the embryo (more interior in the seed) has two proportionally tiny cotyledons enclosed in endosperm. As the endosperm and top portion of the embryo remain stuck down on the twig attached with dried viscin, the radicle (embryonic root) expands away from the embryo. The radicle curves away from light (negative phototropism) which pushes it into the twig. Gravity or gravitropism does not appear to have any impact on growth of the radicle. The radicle is well developed except it has no root cap like soil-living plants.

Six Step Program

Figure 9 shows a germination, establishment and growth sequence for mistletoe. The six stages begin with seed deposition onto a suitable species, location and size of twig. Fruit strings and dried viscin act to hold the seed onto a twig. The seed quickly germinates and grows out a radicle which turns into the twig. Upon contacting the twig surface, the radicle flattens out and forms a holdfast attached to the twig. Next from the holdfast area, mistletoe tissues grow into and among surface tree tissues and allow tree tissues to grow around mistletoe tissues. If cell wall to cell wall connections survive and develop, mistletoe will become established in a twig. The internal twig interface developed by the mistletoe is called a haustorium. Once established, mistletoe generates leaves and grows.

Resource Theft

The portion of mistletoe which successfully establishes an interface with a tree is called an endophytic system (generically a haustorium). This part of mistletoe should not be called a root since it has none of the features of a soil-resident plant root. The haustorium is a resource exchange interface between mistletoe and tree, and is grown over and enclosed by tree tissues.

The haustorium continues to expand and elongate in concert with twig and branch diameter growth, leading to a larger resource exchange interface over time. Living mistletoe and tree tissues remain completely separate with no cytoplasmic strands or cellular content connections. Mistletoe tissue in close proximity to both tree phloem and xylem assure an exchange of resources across a narrow boundary of cell wall space (apoplast). The rates of cell activities on both the mistletoe and tree side of the interface (infection surface area) are accelerated.

A Branch Ruse

Mistletoe operates within a tree as a "fake" branch using growth regulators to dupe tree resource allocation systems and prevent strong defensive reactions. The tree branch portion above (beyond) the infection site provides some materials for new mistletoe growth through phloem, while tree roots deliver water and nitrogen compounds. As the haustorium expands, it acts as a functional girdle on a branch, consuming progressively more resources moving from tree roots through xylem. With time, the large size of the interface, increased demands by mistletoe, and growth regulatory impacts become so great the remaining portion of a branch beyond the infection point is physically girdled and compartmentalized off.

Mistletoe generates a growth regulation field which mimics embryonic or juvenile tree tissue. The mistletoe contains high levels of cytokinins in association with almost nonexistent levels of ABA

# STAGES OF MISTLETOE INFECTION

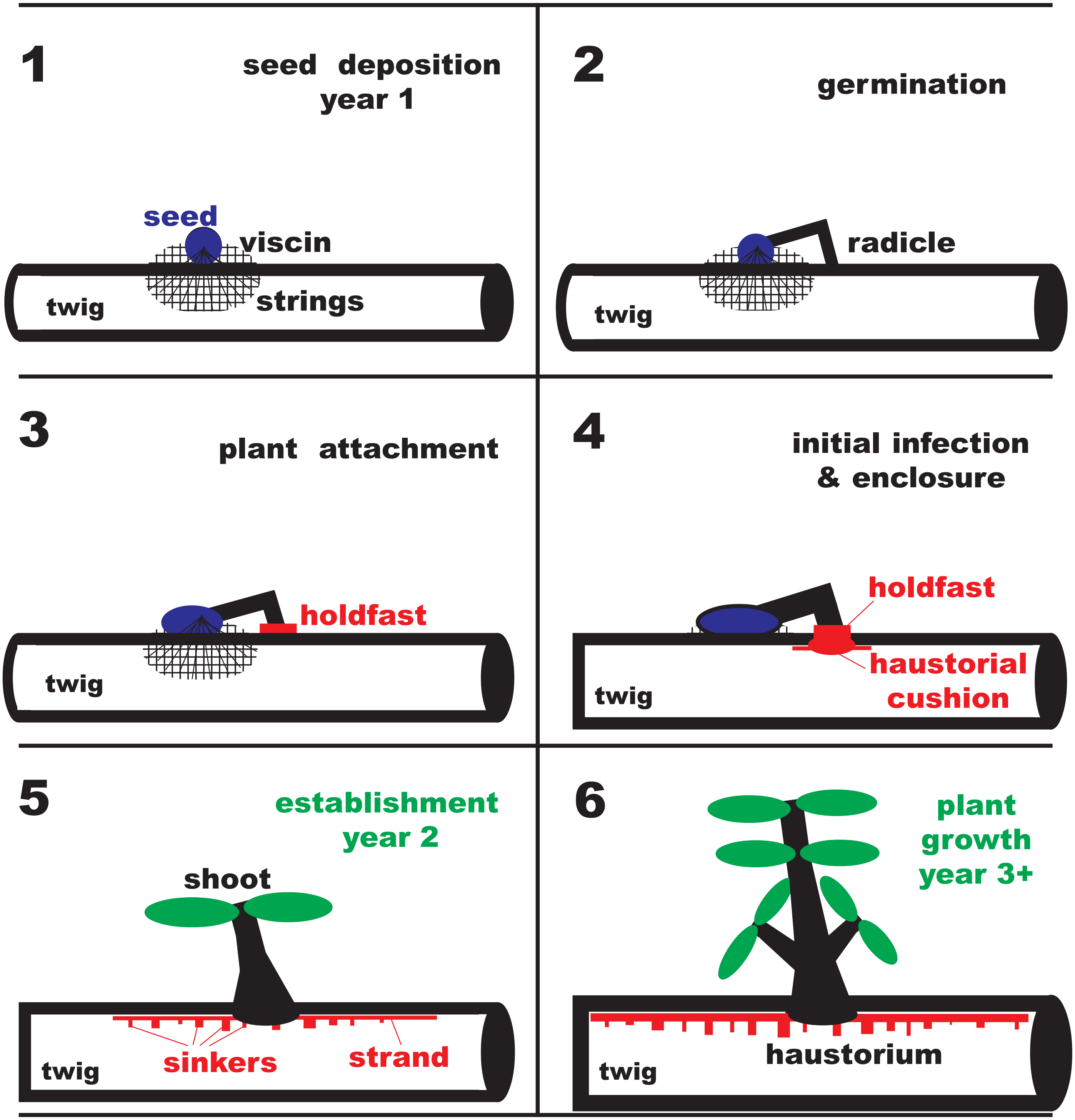


Figure 9: Diagram showing stages of twig infection and shoot development by American mistletoe.

(abscisic acid). As a result, mistletoe functions as a strong sink for resources coming from a tree. Part of the initial recognition for coupling with a tree involves how a tree responds to cytokinin signals from mistletoe. Cytokinins seeping into surrounding tree tissue from mistletoe can also initiate multiple tree bud formation and release, causing a growth reaction called "brooming," or wood layer growth called a "wood rose." Respiration levels remains high in mistletoe to actively uptake essential resources delivered to the resource exchange interface. Rapid uptake and processing of materials by mistletoe generates a strong concentration gradient which keeps materials moving into the interface area.

Twig Size & Vigor

Mistletoe establishment on a tree twig is dependent upon many climatic and biological circumstances. One critical feature is the size of the resource base from which it must draw essential elements. Mistletoe must become established on a vigorous and growing twig or branch. In marginal twigs being prepared for cladoptosis (shedding) by the tree, mistletoe infections will push a branch to seal-off these poor performing twigs. Until firmly established, mistletoe is involved in a careful growth regulation give-and-take with the infected twig and branch to which other twigs are attached. A successfully infected twig needs to be of a certain size (diameter) to sustain mistletoe growth. Mistletoe must gain access to the twig, not disrupt resource flow out of the twig to its branch, and not elicit a strong defensive reaction. Small twigs may be quickly compartmentalized if infections are not effective and accepted.

Twigs must be large enough to support the development of the parasite and not reduce the twig's regulatory contribution to the branch tissues below. Twigs and branchlets smaller than 1/4 of an inch in diameter are usually sealed-off and die before mistletoe can dominate resource delivery pathways. Branchlets and branches in the 1/2 to 3/4 inch diameter range are large enough to generate significant resources for both establishing mistletoe and for maintaining effective communications with the connecting branch. Larger branches must have thin bark and accessible lenticels available for infection. Branches larger than one inch in diameter begin to develop more corky and thicker periderm, which demands more energy from the germinating mistletoe seed to affect entrance into a tree.

Penetration & Establishment

As the elongating radicle pushes against a twig, the radicle tip spreads out and forms a small disk called a holdfast or an infection disk. This fattened and flattened end of the radicle produces secretions which dry and harden, tightly attaching the holdfast to a twig. The holdfast also generates small lines of cells (papillae) which push into lenticels and bark fissures reaching living cortical and phloem cells of a twig. These papillae enter using mechanical force pushing against the holdfast, and release enzymes which break-down and weaken cell wall materials which hold living twig cells together. The thinness of the bark is critical to infection success.

There remains a minimal defensive response to penetration and infection by a tree. Tree defensive reactions are slowed and moderated by mistletoe producing tree-active growth regulators and by minimizing cellular oxidation. Mistletoe, during establishment, is completely dependent upon the tree for water and nutrition. The cotyledons (embryonic leaves) expand and leaves develop quickly once vascular connections are functional.

Holding Fast

The holdfast or swelled end of the mistletoe seedling radicle uses several enzymes to weaken host periderm and cortical cellular connections. The haustorial cushion (sometime called the primary haustoria) develops beneath the holdfast just below the branch surface and represents the beginning of the endophyte portion of a mistletoe. Figure 10 provides a development process for the endophyte. The haustorial cushion area can generate new shoots if the top portion (ectophyte) of the mistletoe is damaged. Sprouts can also be generated from the top (just under the periderm surface) of cortical strands at some distance from the primary infection site.

Strands & Sinkers

Mistletoe haustoria have two components:

1) tissue "strands" growing among tree phloem and cortical tissues running outside and parallel with the cambium along the longitudinal fiber orientation of tree tissues; and,
2) radial "sinkers" which radially expand just past host cambium and into tree tissues to be grown around by ray cells. Sinkers are surrounded by tree tissues in Spring and early Summer, developing contacts with springwood ray cells and water conducting xylem of the tree. This term denotes the appearance of mistletoe tissues sinking into wood, but actually sinkers show the initial infection season and continue to grow outward to prevent from being overgrown and covered by wood. This suggests they are more accurately called "risers" than "sinkers".

Cortical, longitudinal strands grow up and down along the branch from the infection point. Figure 11. The cortical strands create many parenchyma contacts with host parenchyma. Although the cortical strands are among host phloem tissues, no direct intercellular contacts between mistletoe and host phloem are generated. On the underside (toward the inside of the tree) of the strands develops a mistletoe strand cambium / meristem which is maintained at the same relative radial position as the host cambium in the branch. The strand cambium generates radial areas of mistletoe tissue development among host xylem and ray mother-cell development. These mistletoe organs are called sinkers. Strands and associated sinkers use enzymes to dissolve intercellular areas and split cambial initials which reform around the sinkers.

Sinking

Sinkers appear as radial slabs of mistletoe tissue among host ray cells and functional xylem. Figure 12. Sinkers can be viewed as keel-like or flat blade-like tissues on the underside of cortical strands serving a mistletoe ray tissue function. The strands and associated sinkers do not contain mistletoe phloem tissues deeper than host phloem, and contain small sized xylem elements surrounded by host ray parenchyma and xylem cells. Sinkers are maintained over many years of branch radial growth through the mistletoe strand cambium keeping pace.

Sinkers develop vascular tissue adjacent to twig vascular tissue. The mistletoe xylem is positioned opposite cell wall pits and openings in twig xylem cells. Once twig xylem cells die and become active in transporting water, nitrogen compounds, and other essential elements from roots, mistletoe xylem cells die, leaving open connections to twig xylem. Bulk flow of materials from xylem connections amount to approximately 5% of resources entering mistletoe. Resources entering across the apoplast from living twig cells to living mistletoe cells account for about 95% of all resources used by mistletoe.

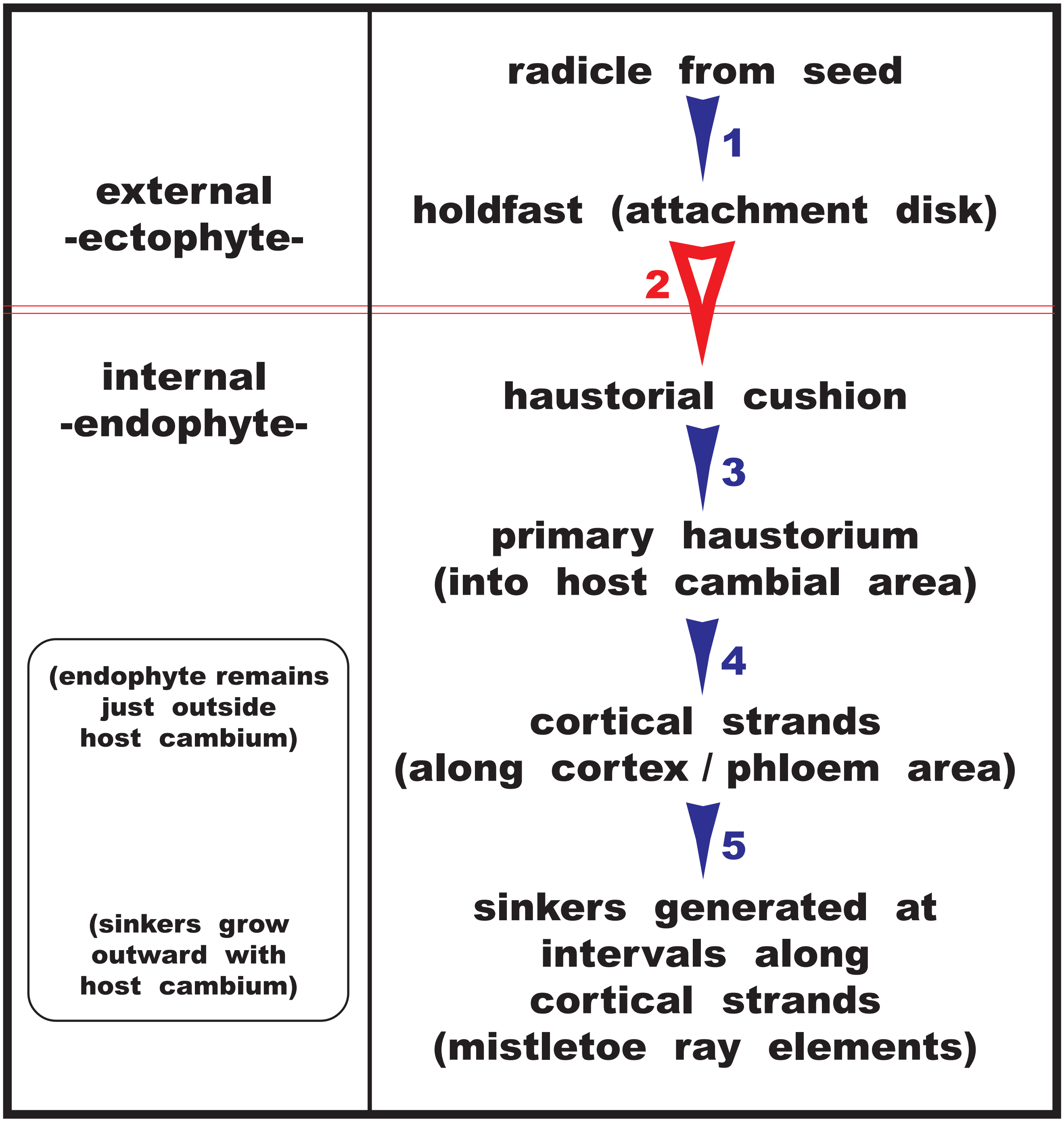


Figure 10: Mistletoe infection process. Primary haustoria establishes initial contact with host phloem, cambium area and xylem mother cells. Cortical strands establish long indirect contacts with host phloem. Sinkers establish direct (5%) and indirect (95%) contacts with host xylem.

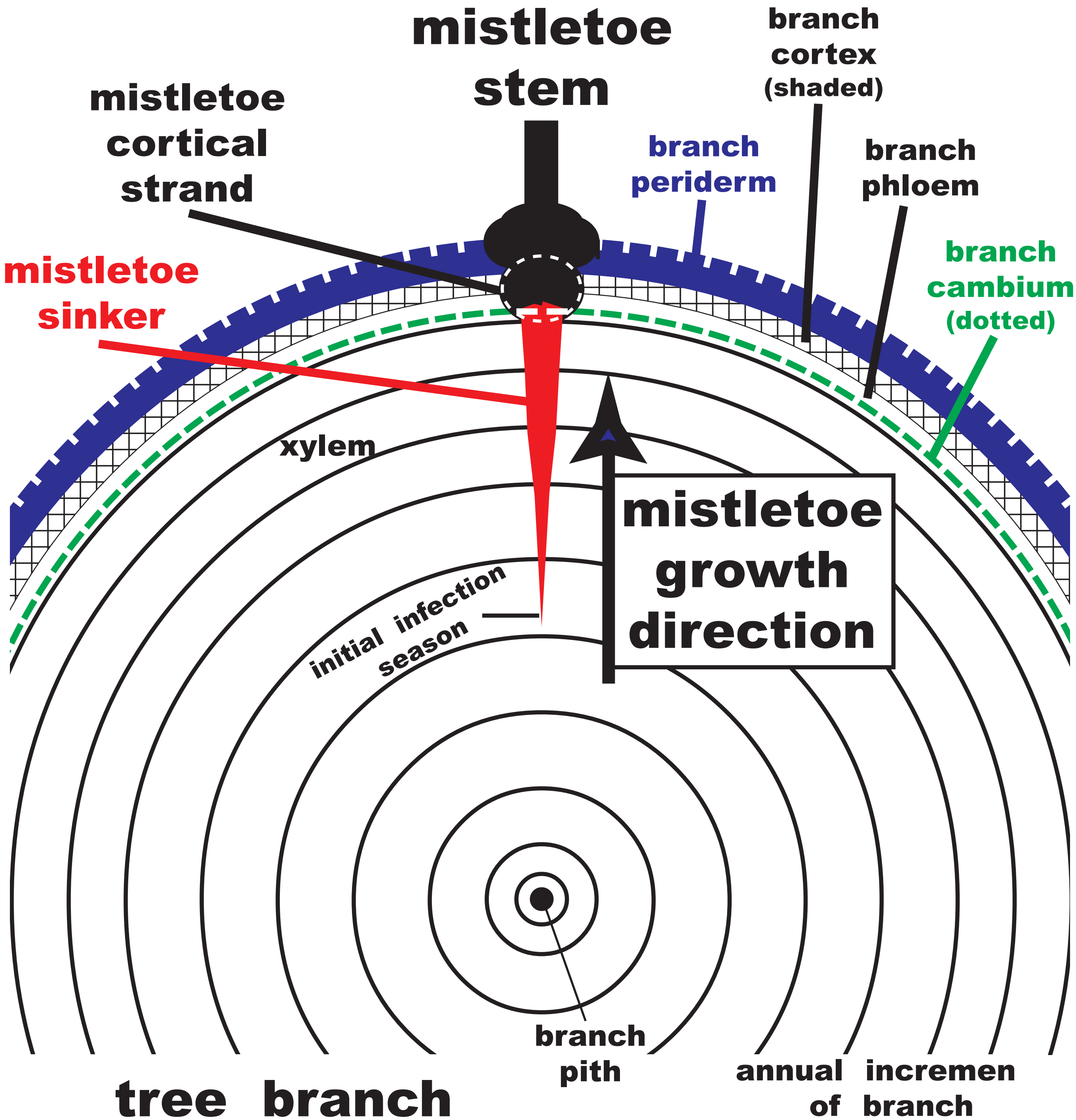


Figure 11: Simplified diagram of a tree branch cross-section with a mistletoe infection. Shown is a cortical strand and associated sinker (mistletoe ray element). The sinker is maintained with mistletoe strand meristem tissue aligned with the branch cambium.

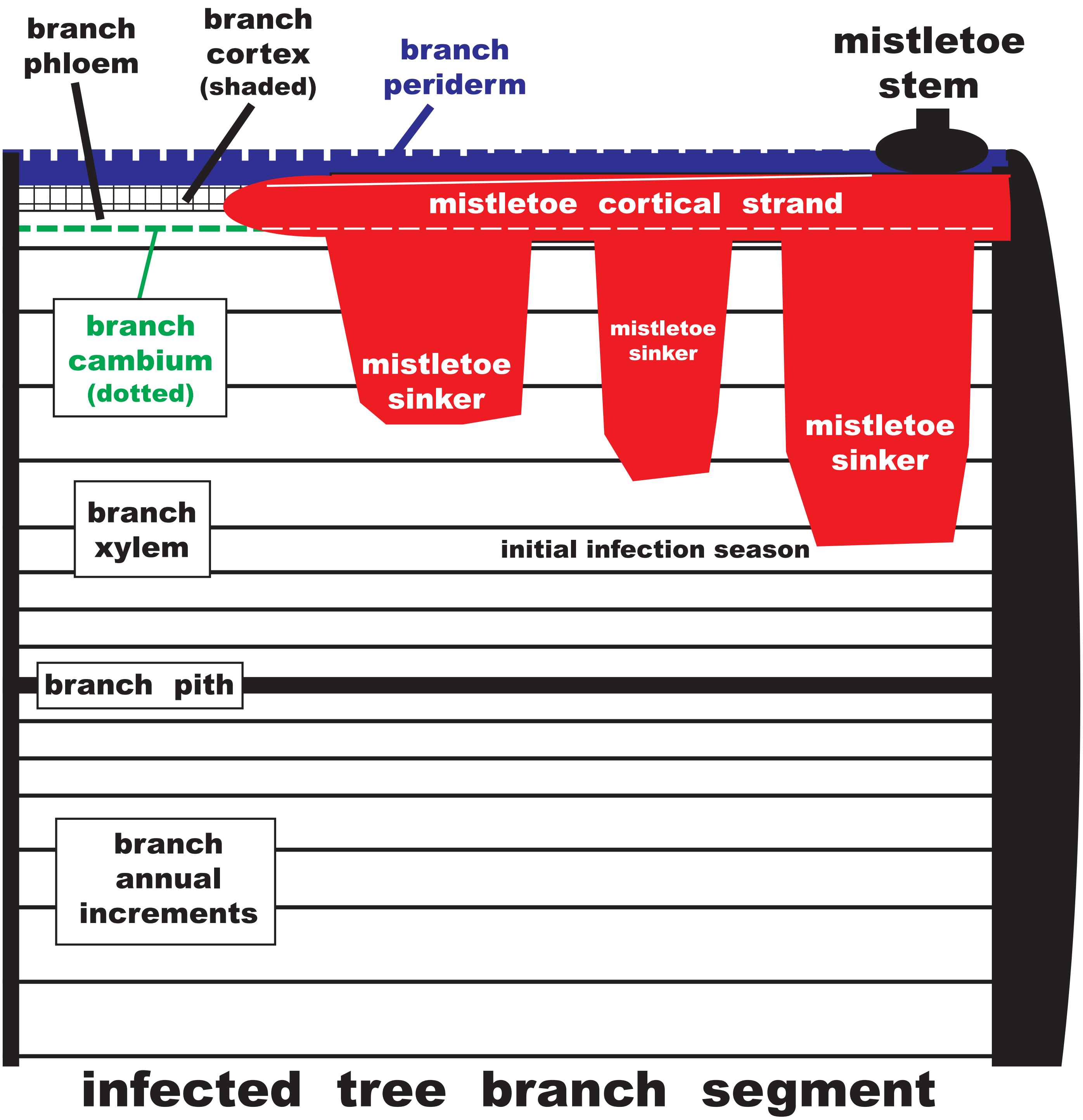


Figure 12: Simplified diagram along the longitudinal central axis of a branch with a mistletoe infection.

Shown is a cortical strand and associated sinkers (mistletoe ray elements). Sinkers grow outward with mistletoe strand cambium aligned with the branch cambium.

The remainder of living sinker cells, not associated directly with twig xylem, pair-up with living cells of the host which encase and surround the active xylem cells of mistletoe. Sinker cells are not forced deep into host xylem, but push past the cambium and into Springwood as it is forming. Sinkers are positioned to mimic twig ray cells and depend upon the cambium of an active twig to grow around, but not over, mistletoe tissue.

Contacts

Throughout mistletoe strand and sinker tissues are many living cells with unique and highly convoluted cell walls and cell membranes (i.e. flange, transfer, or labyrinth cells) which form the living interface between mistletoe and host. These cells have large surface areas abutting living twig cells and apoplast. They absorb water, organic nitrogen compounds, growth regulators, and carbohydrates. These unique cells help exchange and transport tree growth regulators which keep open and magnify resource transport pathways, and prevent defensive compartmentalization.

Mistletoe xylem is positioned to have limited direct contact with host xylem (~5% direct open conduits). Mistletoe phloem never approaches a direct contact with host phloem, always buffered and surrounded by intermediary parenchyma cells. Mistletoe pirates resources through outright theft (i.e. growth regulator deception) water, essential elements, and growth regulators from the host. Mistletoe makes almost all of its own food (CHO) except in highly stressed periods or when the shoots are removed. The parasite generates its own growth regulation field which disrupts sense and respond systems in an infected branch. Mistletoe shoots also shade host branch cortex and foliage.

Keeping Up

Haustoria are involved in active, energy dependent uptake of resources from living xylem and phloem twig cells. Haustoria must continue to expand over time to gather more resources in support of an expanding mistletoe crown of foliage. Old portions of haustorium are shed and die as they are grown over by more annual increments of twig growth. As twig cambium radially expands, growing around and interfacing with mistletoe tissue, mistletoe develops its own radially expanding meristem to maintain its relative position along the twig cambium. If mistletoe cannot maintain its haustorium growth rate to match a twig, it will be covered and the infection fails. Fast growing trees and twigs may be attacked as much as slow growing trees in a similar seed dispersal environment, but mistletoe infection success rate will be much less in fast growing trees.

Shoot Expansion

As the haustorium becomes more established and larger, more mistletoe shoots begin to expand and develop leaves. New shoot tips will grow, and after a short period, the tip will be aborted, leading to opposite lateral shoots continuing to grow. This branching pattern and brittleness of the stems, keep mistletoe in a small diameter, spherical clump. Wind and ice storms can easily break off mistletoe, providing tree owners with a rare up-close view of the plant.

Mistletoe stems and leaves have an abundance of chlorophyll which allows for strong photosynthesis. Mistletoe generates more than 98% of its own food. Mistletoe photosynthesizes anytime both the air temperature is above 55$^{o}$F and tree roots are active, which means mistletoe is photosynthesizing most of the year. In order to effectively photosynthesize, mistletoe needs a constant supply of water and organic nitrogen compounds (amino acids). These resources are exclusively supplied by tree roots.

Running Wide Open

To assure adequate water resources, and collection of organic nitrogen compounds and other essential elements carried in the water stream, mistletoe keeps its stomates open to a greater extent than its host. A high transpiration flow rate through mistletoe leaves is orchestrated by large potassium concentrations and large cytokinin concentrations, both of which act to lock stomates open in light. High transpiration rates deliver organic nitrogen compounds, processed at great expense by tree roots, to mistletoe tissues. Figure 13 lists essential elements preferentially accumulated by mistletoe.

Because mistletoe does generate most of its own food through photosynthesis, the amount of light available in a tree crown and at the infection site is important. Successful mistletoe infections are found high-up and around the outside edge of tree crowns. Here light can power mistletoe photosynthesis. Fast tree growth and large areas of tree foliage production can shade mistletoe, making it more parasitic and less successful. Mistletoe behaves like a shade plant physiologically, but requires a host in full sun. The margin of life for mistletoe comes from growing on a sun-plant host with plenty of sunlight and sunflecks entering the tree crown. Mistletoe infections help limit any shading tree foliage beyond its location. Deep shade eliminates mistletoe.

Infection Changes Everything

Mistletoe draws water and other resources to its tissues by use of growth regulators. The tree resource delivery path which brings mistletoe more resources is consolidated and strengthened over time. Drought conditions may slow tree foliage growth and food production as tree stomates partially or fully close in the day. Mistletoe leaves under the same conditions, are transpiring a large portion of any water supplied to the branch. When tree food production is constrained by stress, mistletoe increases its proportion of resources used and expands its foliage to the detriment of a branch.

Internal resource allocation changes in a tree brought about by mistletoe infection include much less host food (sugars and associated stored starch availability) transported to tree roots, and much more organic nitrogen (amino acids from tree root absorption and processing) provided to the mistletoe. Growth regulators produced by mistletoe disrupt resource transport and allocation systems of a tree. Mistletoe acts to attract water, nitrogen, soil elements, and limited carbohydrates using growth regulators pushed across the resource exchange interface.

Water Loss

The greatest resource problem for a mistletoe infected tree is loss of water from the host by mistletoe. For example in one study, moderately infected trees showed ~66% mortality after a severe drought period while trees without any infections showed a 3% mortality rate. Compared with its host tree, mistletoe always has greater stomatal conductance and associated lower leaf temperatures, and greater carbon-dioxide saturation in its leaves. Mistletoe preferentially uses large amounts of host gathered water. Figure 14 shows trees with and without infections, and their water potentials before dawn and at mid-day. Note how mistletoe infections leave the tree with 1/4 to 1/3 greater water stress.

Mistletoe develops close contacts with living tree cells immediately surrounding water conducting xylem. Mistletoe, with rapid stomatal opening and poor closing response, has a much lower water potential (more negative) than a tree. In daylight, mistletoe stomates are usually wide open regardless of water tension in tree and soil. Mistletoe is able to pull large amounts of water from a tree, amounting at times to more than two times the water volume pulled to tree foliage with the same surface

| element | symbol | amount of accumulation |
|---|---|---|
| copper | Cu | 3.0X |
| phosphorus | P | 2.5X |
| potassium | K | 2.3X |
| nitrogen | N | 1.6X |
| manganese | Mn | 1.3X |
| sodium* | Na | 1.2X |
| zinc | Zn | 1.2X |
| calcium | Ca | 1.0X |
| magnesium | Mg | 1.0X |
| iron | Fe | 0.9X |

Figure 13: Average essential element concentration accumulated in American mistletoe compared with its host tree. (* = non-essentail element)
(after Panvini & Eickmeir, 1993)

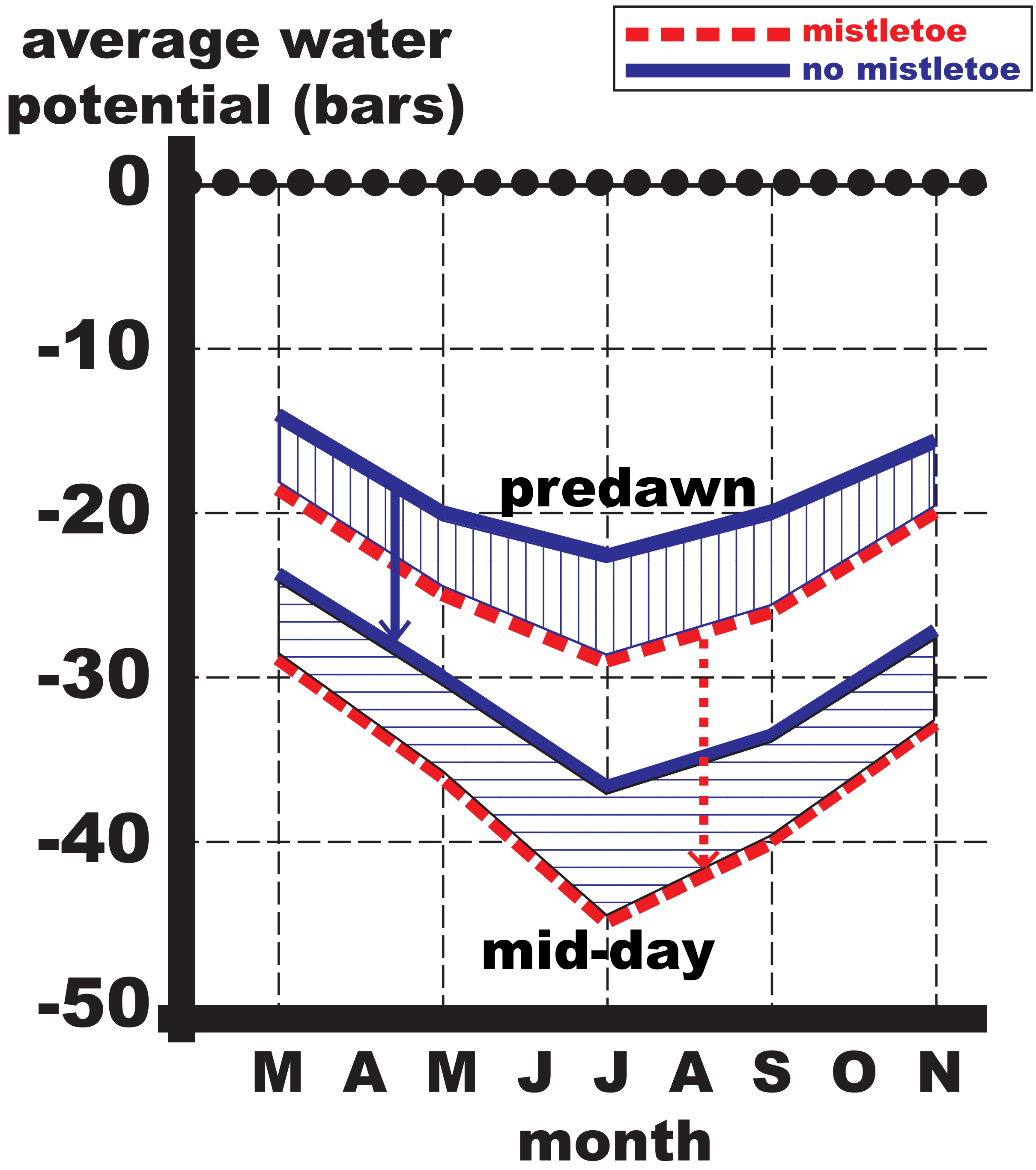


Figure 14: Growing season water potential averages for mistletoe-infected and non-infected trees at both pre-dawn and mid-day measures under semi-desert conditions. Note the -5 to -9 bars water potential decline from mistletoe. (from Lei, 1999)

area. As internal water potentials fall and a tree becomes more water stressed, heavy mistletoe infections further stress the host. In addition, heavy infections also stress mistletoes as water becomes limited for both host and parasite.

### Winning In Drought

Under water stress (drought or water inundation) conditions in a tree, mistletoe respiration and transpiration increase while tree transpiration and food production declines. Over time (if the tree does not die) mistletoe continues to gain foliage area at the expense of a tree. Mistletoe continues to pull water from a tree well out of proportion to its foliage area and generates a very poor water use efficiency. When mistletoe is flowering and fruiting, even at night, water is pulled into mistletoe in much greater proportion compared with tissues of its host tree. Liquid water droplets can also develop around the edges of mistletoe leaves over night and then evaporate with the dew (guttation).

### Tree Damage

Mistletoes infect trees in patterns related to bird behaviors and territoriality. Infections tend to be concentrated in open, upland forest stands, and in tall, open crowned trees. Figure 15 shows infection probabilities compared with tree height — the taller a tree, the greater chance of infection. Along roadways, open right-of-ways, and around old homestead sites are key locations for infections. In several studies in Tennessee and Kentucky, mistletoe infection surveys were completed by using roadways as linear sample areas. Figure 16. In one study in Kentucky, 7-10 infected trees per mile of roadway were found.

Infections begin around the upper exterior of the tree crowns with new infections spreading inward and downward over time. Some trees can be covered and consumed with infections. Figure 17. Depending upon the density and extent of mistletoe coverage in a tree crown, symptoms on a tree can vary from no significant impact to severe tissue damage and resource loss. Some advanced tree symptoms visible around successful infections include branch die-back, reduced growth (both elongation and diameter), increased stress and strain, reduced reproduction, and a brooming effect (bud formation, release, and shoot clustering). In advanced stages of infection, branch girdling, breakage, and death occurs. Tree decline and death are the end point of massive infections.

### Doorway To Disaster

Tree damage from mistletoe is most prevalent where trees are under chronic water stress, either from drought or flood. The profile of trees most susceptible to infection are: trees already stressed from other climatic or biological constraints especially drought and heat stress; trees on the edges of forests, yards, streets, fencerows, and parking lots; trees damaged by construction activities; slow growing, less vigorous trees; trees in disturbed, open forests; trees stressed by ponded water, poor soil drainage and compaction; and, wetland trees stressed by flooded soil conditions and intense competition.

A mistletoe infection site generates a structurally weak zone and a biological portal for other pests to gain entry into a tree. Fungi and bacteria can infect a tree, degrade wood, and further disrupt tree health and structure. Insects can gain access to a tree at mistletoe infection sites. From a structural standpoint, shoots of mistletoe usually break well before a tree branch fails under wind and ice storm loads. But, mistletoe co-opting tree resources can impact reaction wood development, branch taper, and branch mechanics under dynamic loads, concentrating stress and strain in a branch leading to breakage.

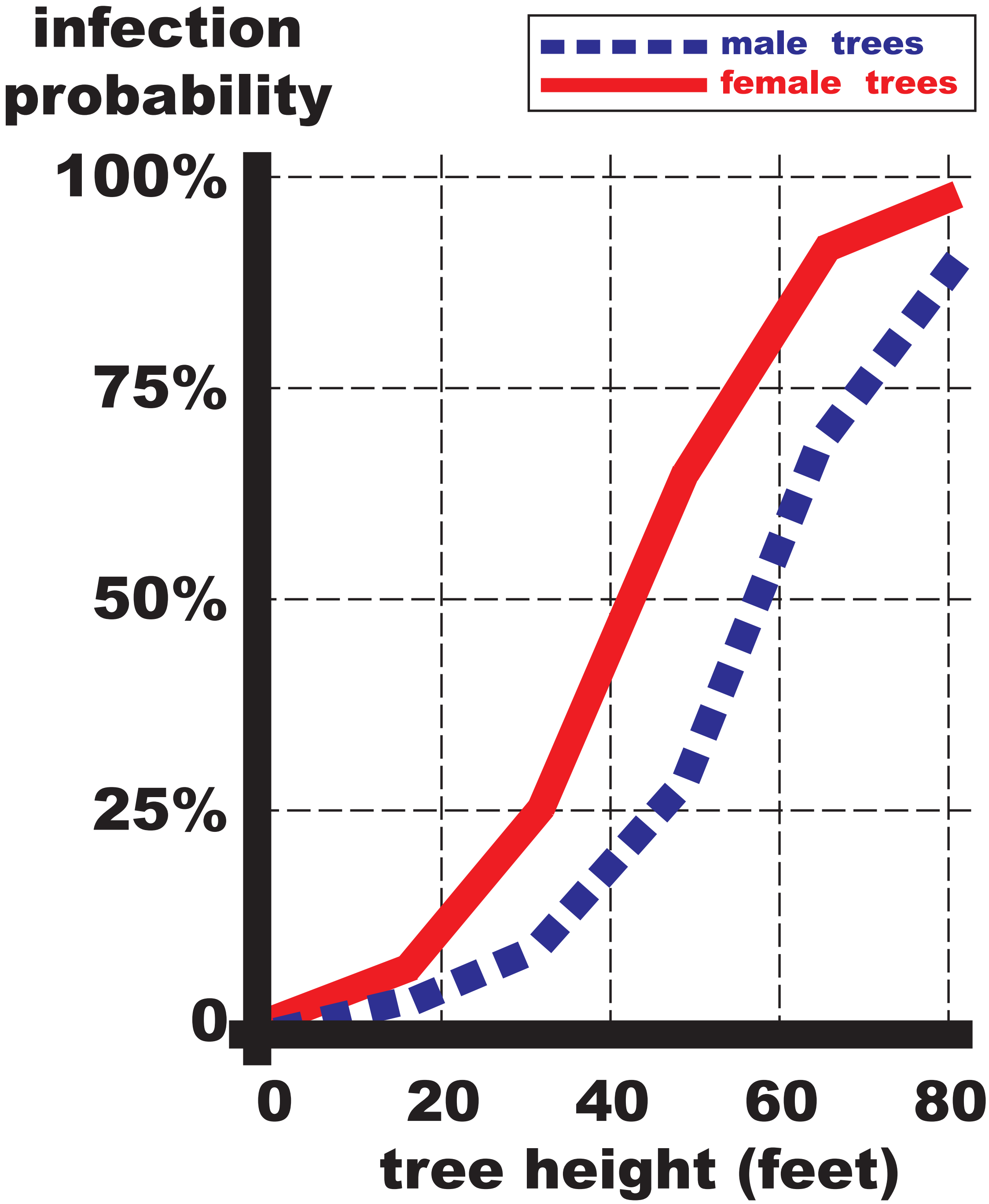


Figure 15: Representative example of mistletoe infection rates by tree height for a dioecious tree species. (from Carlo & Aukema, 2005).

| tree scientific name | average percent of all mistletoe infected trees |
|---|---|
| Juglans nigra | 35% |
| Ulmus americana | 21 |
| Ulmus rubra | 16 |
| Robinia pseudoacacia | 11 |
| Prunus serotina | 9 |
| Fraxinus americana | 7 |
| Acer saccharinum | 4 |
| Celtis laevigata | 4 |
| Gleditsia triacanthos | 4 |
| Ulmus serotina | 3 |
| Ulmus thomasi | 3 |
| Acer rubrum | 2 |
| Carya ovata | 2 |
| Celtis occidentalis | 2 |
| Maclura pomifera | 2 |
| Fraxinus pennsylvanica | 1 |
| Liriodendron tulipifera | 1 |
| Nyssa sylvatica | 1 |
| Quercus alba | 1 |
| Castanea dentata | 0.6 |
| Platanus occidentalis | 0.6 |
| Acer saccharum | 0.3 |
| Fagus grandifolia | 0.3 |
| Liquidambar styraciflua | 0.3 |
| Ostrya virginiana | 0.3 |
| Quercus prinus | 0.3 |
| Sassafrass albidum | 0.3 |
| Ulmus alata | 0.3 |
| Quercus muhlenbergii | 0.1 |

Figure 16: Composite data (average) from three surveys in Kentucky / Tennessee central hardwood forest area examining tree species infected with American mistletoe (*Phoradendron leucarpum*).

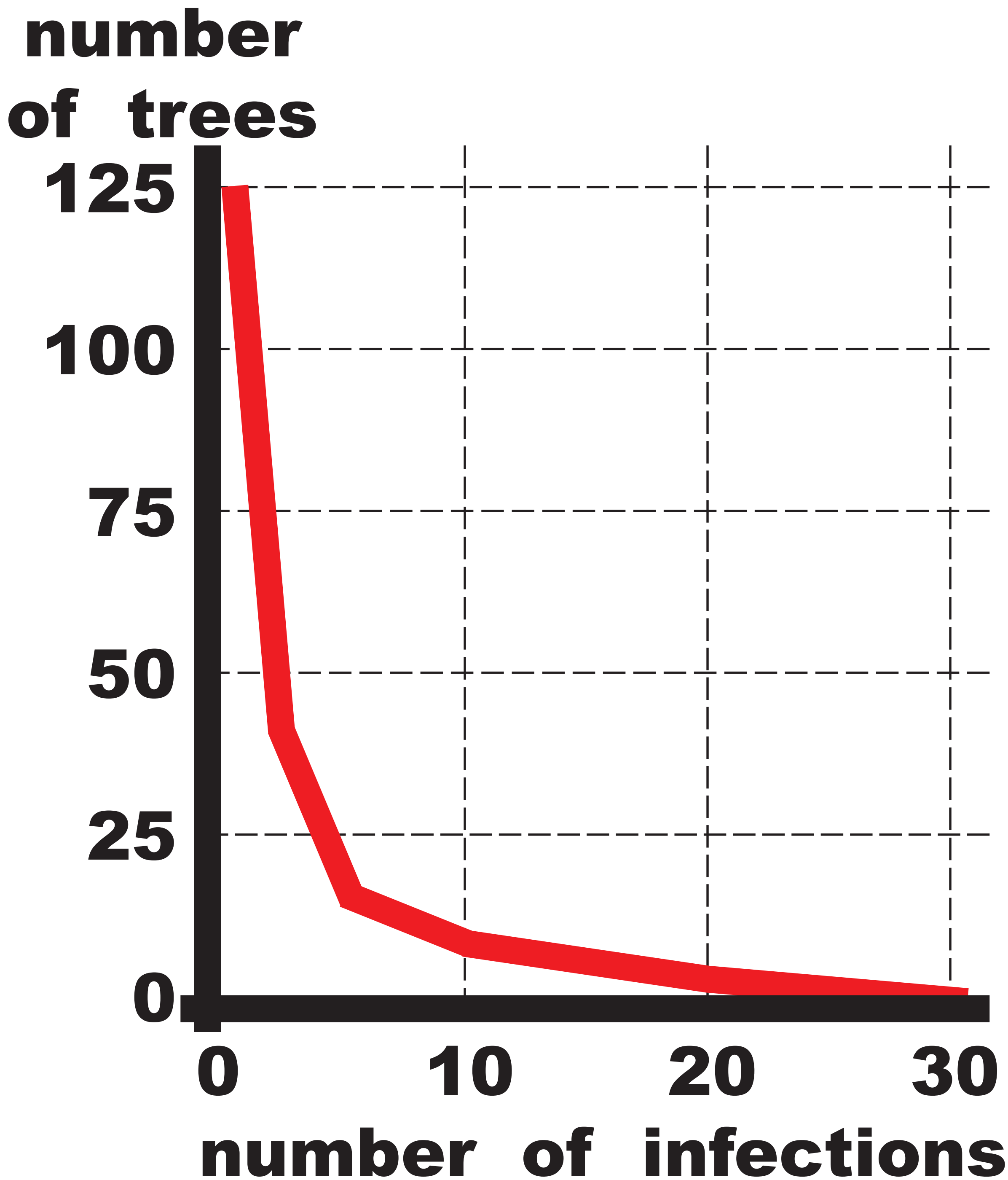


Figure 17: Representative example of the number of individual mistletoe infections (plants) per sampled tree. Percent of all trees with infections is 28%. (after Aukema & del Rio, 2002)

Vegan Surprise

American mistletoe has been popularly cited as being poisonous. Human and pet consumption of mistletoe leaves and fruit can be a problem. In relative terms, the chewing texture, smell, and taste of foliage and fruit are bad. Accidental and uninformed ingestion do occur. There are many tales regarding the toxicity of mistletoe. Most anecdotal stories of injuries and death stemming from consuming mistletoe are derived from people either having a strong allergic reaction to some component of the plant, or from concentrating water or alcohol-soluble constituents for teas or for medicinal applications. Myths regarding the spiritual and therapeutic values of consuming mistletoe are many.

Mistletoe contains a number of constituents which if released from plant cells, concentrated, consumed, or topically applied, could pose serious animal health problems. Most notable are the glycoprotein lectins which inactivate protein synthesis in animal cells. These compounds in mistletoe are at a much lower concentration and are less reactive compared with similar compounds in other plants (such as ricin in castor bean). Dropping blood pressure and slowed heart rate are a few of the symptoms. A poorly studied area in mistletoe biology is the variable toxicity of the plant as influenced by various tree species upon which it grows.

Bad Munchies

Poison center data made available in one study over four years (Spiller et.al., 1996) found 92 American mistletoe ingestion (poisoning?) cases in humans with ages ranging from 4 months to 42 years of age (average age was 6 years old). Consumption of mistletoe tissue ranged from one fruit or leaf to more than 20 berries or 5 leaves. Only 12% of cases presented any symptoms, with symptom onset occurring in less than 6 hours. Stomach and intestinal upset (55%), mild drowsiness (18%), eye irritation (1%), seizure (1% – baby), and uncontrolled muscle movements (1% – baby) were primary symptoms. No deaths were reported. Treatment recommended for about 60% of all cases was gastrointestinal decontamination, but this treatment did not appear to affect symptoms.

Tree Treatments

Mistletoe is a scourge of old and stressed trees, stealing away great volumes of water and nitrogen. Understanding American mistletoe's life cycle and its unique biological features can help tree health care professionals prepare an appropriate response and intervention program. Left alone to reproduce and prosper, mistletoe will initiate a decline and death spiral in slower growing trees which will be difficult to reverse without intervention.

Early intervention is critical when dealing with mistletoe infections. The single clump or small stem visible in January on a deciduous tree may look insignificant. Any mistletoe infection is important to note. Whenever cleaning, thinning, or reducing a tree crown, mistletoe needs to be targeted. In tree risk assessments, branch structural losses should be assessed and mistletoe removal considered. Do not leave mistletoe in trees! Use clump density assessments to prioritize trees for mistletoe removal work, remembering apathy and procrastination lead eventually to inoperative massive infections and increased structural failure risks for trees.

Assessment

The appropriate response in treating mistletoe infections revolves around assessing current number and size of infection points, sex of the clumps, expected new infection rates, and tree health status and species. Figure 18 provides the "Coder Assessment & Treatment Guide for Mistletoe

# Tree Infection Rating Value

| male infections | rating | female infections | rating |
|---|---|---|---|
| none | 0 | none | 0 |
| single stem | 0.5 | single stem | 0.5 |
| 1-3 sprigs emerging | 0.5 | 1-3 sprigs emerging | 0.5 |
| 1-3 developing clumps | 0.5 | 1-3 developing clumps | 1 |
| 1-5 developed clumps | 2 | 1-5 developed clumps | 4 |
| >5% crown volume | 4 | >5% crown volume | 9 |
| >10% crown volume | 9 | >10% crown volume | 19 |
| >25% crown volume | 20 | >25% crown volume | 35 |
| >50% crown volume | 45 | >50% crown volume | 70 |

| Rating Value Corrections: | multiplier |
|---|---|
| -high vigor, fast growing, healthy tree | X 1.0 |
| -medium vigor, susceptible species tree | X 1.3 |
| -low vigor, highly stressed tree | X 1.7 |

(take rating times the multiplier for final rating)

| Actions (mechanical / chemical): | rating |
|---|---|
| -no action | over 1 |
| -crown cleaning and clump removals | over 3 |
| -tree restoration and clump removals | over 10 |
| -potential tree removal | over 20 |
| -tree removal | over 30 |

Figure 18: Coder assessment and treatment guide for mistletoe infections in trees.
See Appendix 1 for a field worksheet.

Infections in Trees" to help determine an appropriate response. A worksheet is provided in Appendix 1. To use this assessment, examine clumps of mistletoe in a tree, differentiating between male and female clumps. If gender determination is not possible, treat all clumps as female. Count the number of clumps or crown area / volume occupied by mistletoe. Determine a basic tree rating by adding all observed scores together. Multiply basic tree rating value by a growth based Rating Value Correction multiplier to determine the Corrected Tree Rating value. Use the Corrected Tree Rating value generated to determine what action is appropriate. Remember, early intervention is critical to contain infection centers.

For example from Appendix 1, if a tree has 4 developed male clumps, 3 developed female clumps, and 1 developing female clump, the basic tree rating would be 5 points. If this level of infection occurs on a low vigor, highly stressed tree, multiply the basic tree rating of 5 by 1.7 to get the corrected tree rating of 8.5. On the action items list, a rating of 8.5 would suggest an appropriate response to be tree restoration and clump removals.

Elimination

There are currently three mistletoe elimination interventions, each delivering varying results. The three interventions are shoot pruning of mistletoe, pruning infected tree branches, and/or using a labeled chemical spray (ethephon). Note any specific commercial product mentioned here does not represent an endorsement, nor a statement of efficaciousness, but a summary of marketplace information at the time this publication was prepared.

**Mistletoe Shoot Removal** – One traditional treatment for mistletoe infection is to knock off brittle mistletoe stems from tree branches. Mistletoe stems snap off easy and nearly flush with branch periderm, leaving the haustorium behind within a branch. This treatment immediately reduces water loss from a tree, and reduces mistletoe reproduction. Unfortunately, simply knocking off mistletoe stems does not eliminate infections because the endophytic part of the mistletoe remains intact. It usually takes 2-3 years before mistletoe shoots noticeably reappear after removal. Approximately 80% of all pruned mistletoe stems regrow and while these are without green shoots, become completely parasitic on a tree. Periodic mistletoe shoot removal may be a viable treatment on main stem infections where tree branch pruning is not practical.

A few studies have used a combination of mistletoe shoot removal and blocking light to the haustorial cushion. Light has been excluded from haustoria by various wraps, sprays, and applications like heavy pruning paint applications, aluminum foil, tin disks, tarpaper, tape, caulking, or black plastic. It is critical to not injure tree tissues around an infection site with any topical coating or through affixing any covering. Mistletoe shoot pruning and light exclusion from an infection site were thought to prevent new mistletoe shoot formation and starve haustoria embedded in tree branches. Generally, these types of mistletoe shoot stub treatment have not been found to be completely effective and so, not recommended in most circumstances.

**Tree Pruning** – Infection site tree branch pruning is a common means of controlling mistletoe. A twig or branch infected with mistletoe can be pruned at the nearest healthy originating node below an infection site. Do not tip, top, or use internode cuts on a twig or branch. Figure 19. The target node for pruning should be at least 14 inches below an infection site. Mistletoe infection site elimination through branch pruning should be treated as a proper pruning (Figure 20) or reduction cut (Figure 21, Figure 22, Figure 23). These figures show proper cuts to be made at the next lowest branch node greater than 14 inches below an infection. Years will be needed for a tree to regain structural integrity after extensive mistletoe removal pruning.

**Chemical Spray** – Ethephon [(2-chloroethyl) phosphonic acid] (chemical formula = C2H6ClO3P) causes mistletoe shoot abscision and defoliation by generating ethylene, a plant growth regulator. Currently there are ethephon products labelled for mistletoe shoot control.

This product is a acidic, colorless, odorless, and clear liquid. This labeled product "... will cause the abscision of ... leafy mistletoe shoots in ornamental deciduous trees." An example of control from one research study shows, a ethephon treatment was applied to mistletoe shoots during a tree's dormant season. This treatment defoliated mistletoe shoots in 75 days with no resprouting for 225 days, and with no negative impacts on the host. This treatment did not significantly impact haustoria, and new sprouts from haustorial formed within 1-2 years.

Ethephon products should be sprayed directly on mistletoe clumps until foliage and stems are wet. Timing is crucial to prevent tree damage. Generally, spraying should be completed after complete Fall leaf drop, before tree bud burst in Spring, when daytime temperatures are above $65^{o}$F, and trees are dormant. Mix and apply product following all label directions. Spray only when no rain is forecast for a minimum of 24 hours. Use of a surfactant is recommended. Return to and respray large clumps of mistletoe in one week. Because only the mistletoe shoot is impacted, retreat every 3-4 years.

Mix and spray product immediately. Do not store mixed spray liquid for more than a few hours. Care is needed to prevent over-spray from staining or etching hardscapes or damaging painted surfaces.

Remember to carefully read and review the product label for your personal safety, safety of other living things, and the legal context of product use. Do not use this product near individuals or habitats of protected species, some of which could be around a tree site or on a tree exterior.

Other Treatments

Many types of contact and systemic herbicides have been tried, but almost all had highly variable control of mistletoe shoots, mixed results on killing haustorium, and some which killed infected host branches. Figure 24. For example in one study which examined both chemical and physical treatments, mistletoe shoot removal, shoot removal with application of latex caulking over the wound site, and infected branch pruning were the only effective treatments found after 29 months. This same study found ethephon, shoot removal followed with a synthetic auxin application, 2,4-D spray, and glyphosphate treatments to not be effective in eliminating mistletoe infections.

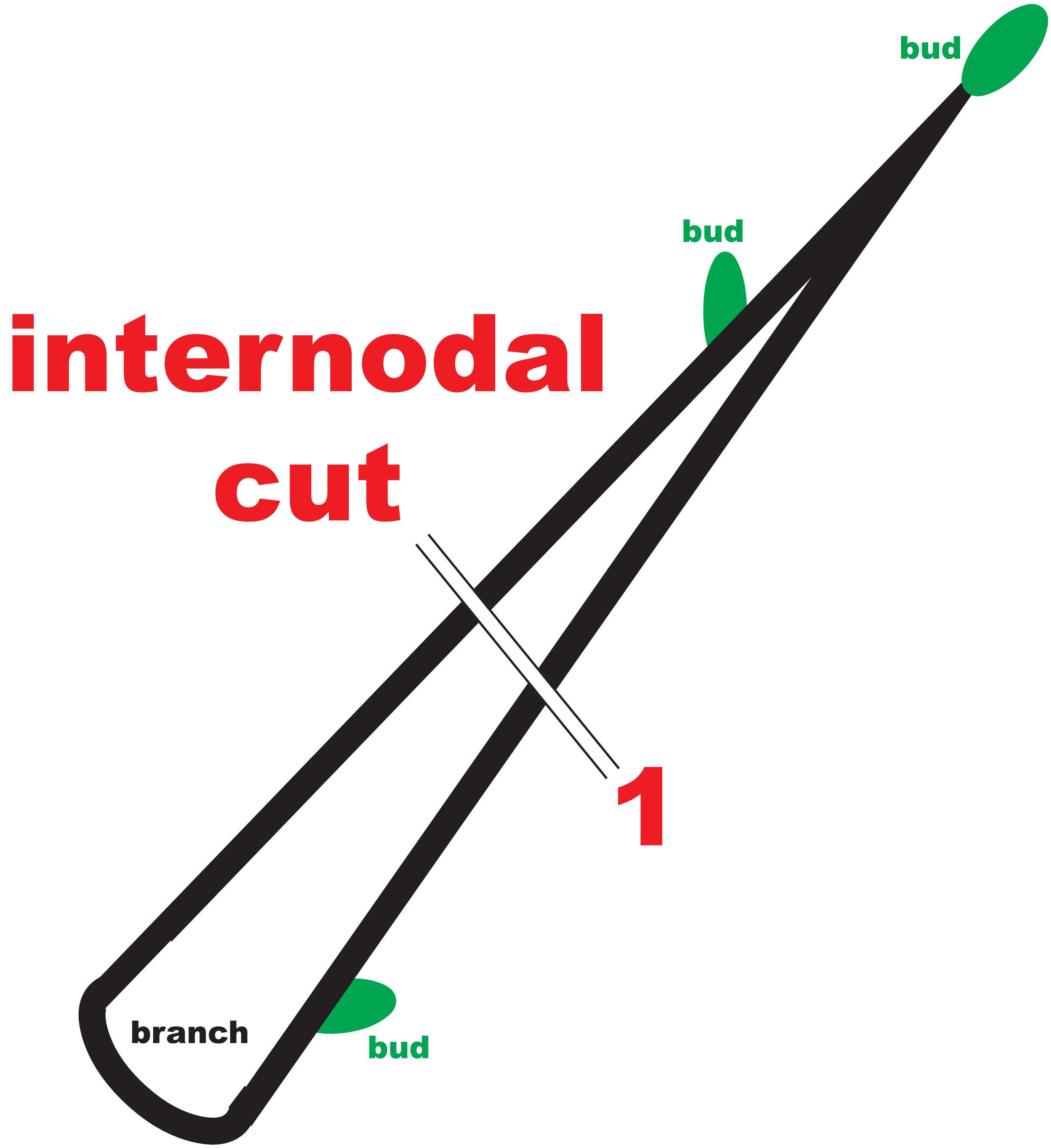


Figure 19: Diagram of an abusive, improper, and damaging internode cut. Other terms used for this abusive cut include topping, tipping, hedging, hat-racking, and trimming. It is not the size of tree part cut (stem, branch, or twig) but the internodal location which makes this cut improper and damaging.

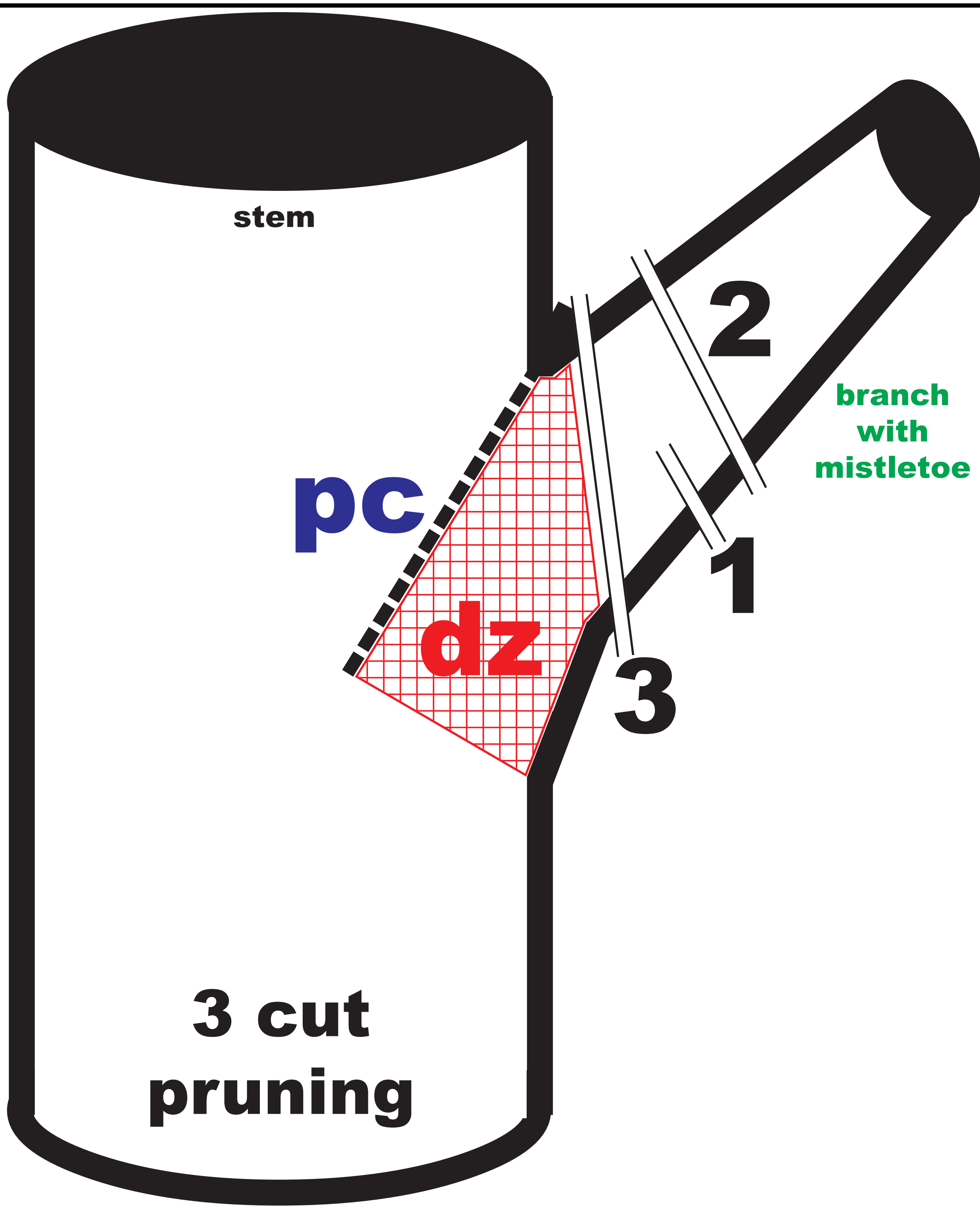


Figure 20: Diagram of stem - branch confluence area with a three-cut pruning prescription applied (in cut order) for a mistletoe infected branch where the infection is greater than 14 inches away along the branch.
Defensive zone = dz. Periderm (bark) chine = pc.

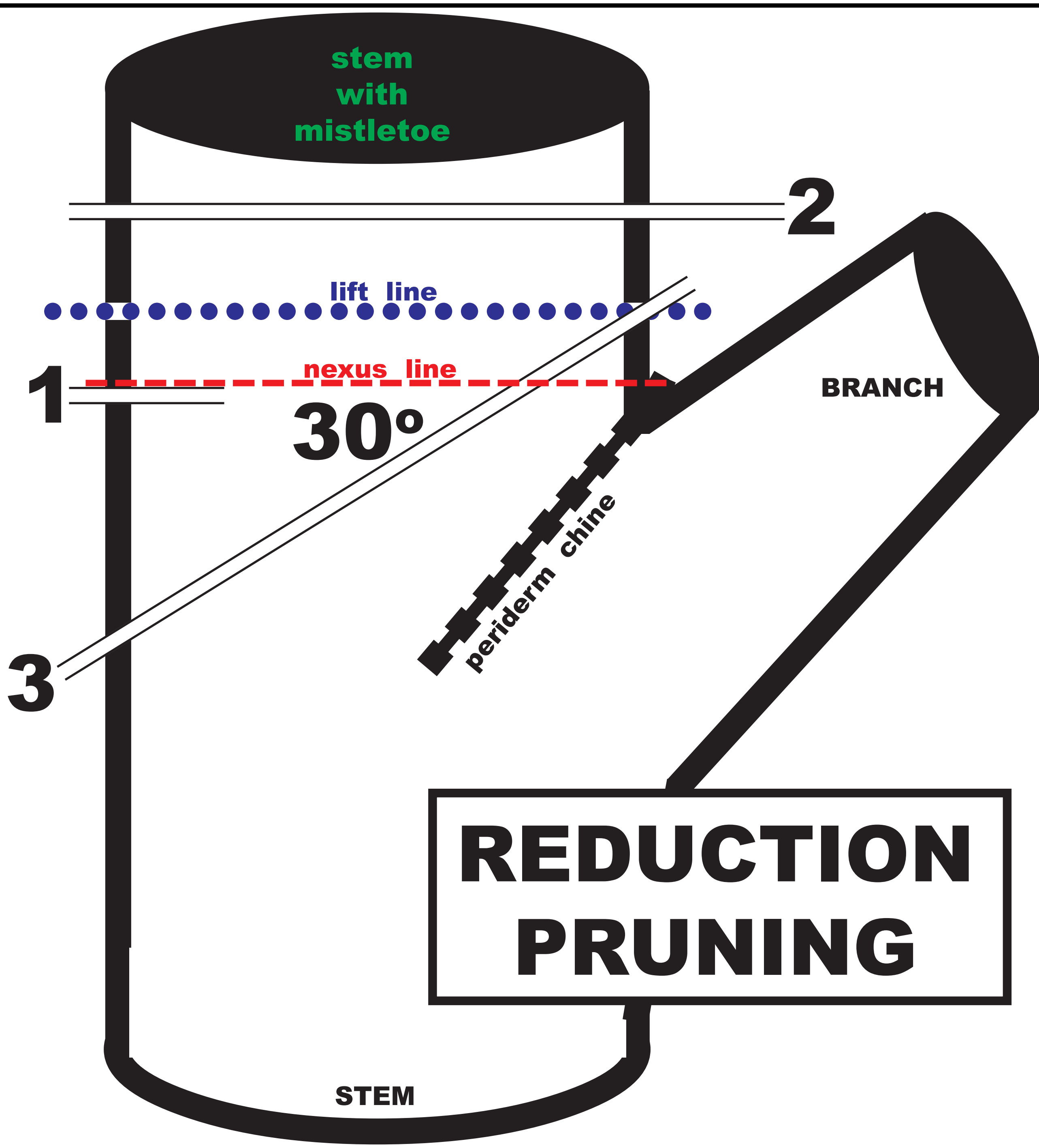


Figure 21: Diagram of stem - branch confluence with reduction cut lines, in numbered order, greater than 14 inches below / beyond a stem mistletoe infection.

Note the final (3rd) cut is at 30° down angle from the branch side of the lift line. The lift line is 1/9 of the stem diameter, or at least 3X saw kerf thickness above the nexus line.

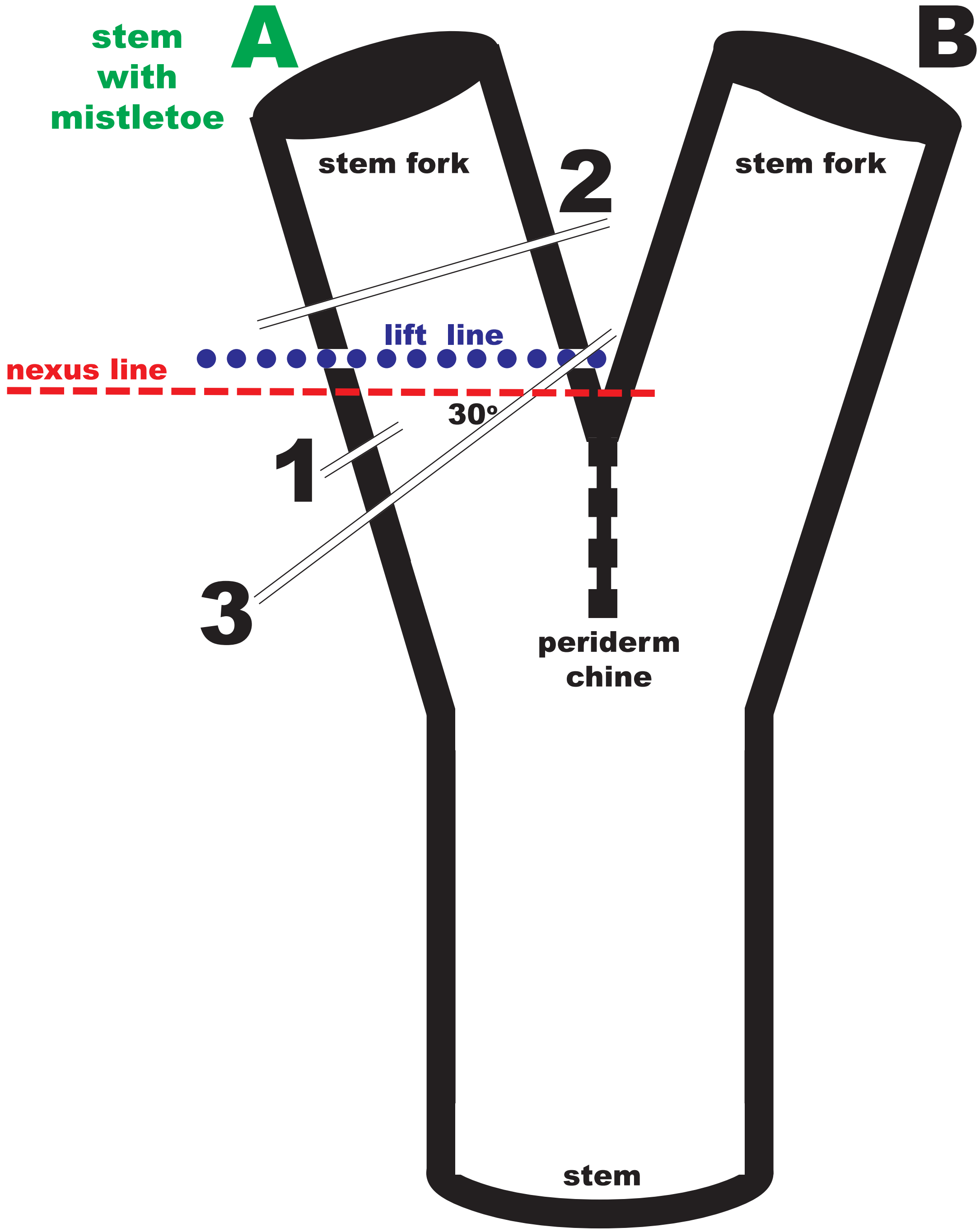


Figure 22: Diagram of forked stem with 3 cut lines in numbered order for reduction pruning stem fork A (left fork) greater than 14 inches below a stem fork mistletoe infection.
Note the final (3rd) cut is at a 30º down angle from the branch side of the lift line.
The lift line is 1/9 of the stem diameter, or at least
3X saw kerf thickness, above the nexus line.

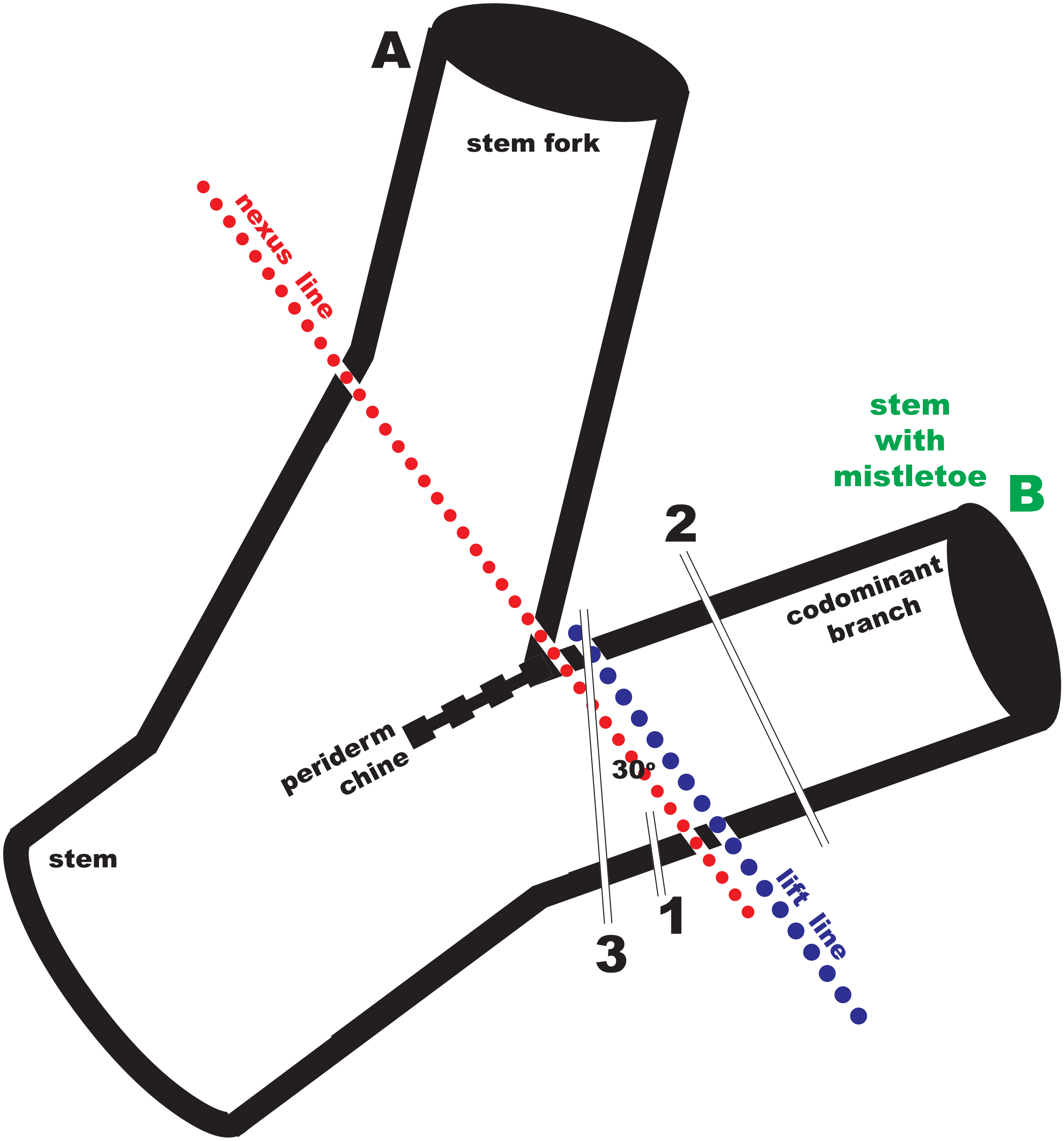


Figure 23: Diagram of a 3 cut reduction (in numbered order) of codominant branch / fork (B) greater than 14 inches below a mistletoe infection. Note the final (3rd) cut is at a 30º down angle from the branch side of the lift line. The lift line is 1/9 of the stem diameter, or at least 3X saw kerf thickness, above the nexus line.

| treatment | killed mistletoe haustoria | killed mistletoe shoot | killed host limb |
|---|---|---|---|
| none | NO | NO | NO |
| glyphosate | NO | NO | NO |
| boron | NO | NO | NO |
| ethephon | NO | YES | NO |
| paraquat | NO | YES | NO |
| amine 2,4-D | YES | YES | YES |
| dicamba | YES | YES | YES |

Figure 24: Example impacts of a single application of various control treatments on both American mistletoe and its host (pecan). Note these treatments were applied using an expiremental pesticide use lable and most are not currently labeled for use on mistletoe. (from Wood & Reilly, 2004)

Other treatments have included trunk injections, infection site injections, foliage and stem stub paints, and directed sprays. For example, copper sulphate, 2,4D (2, 4-dichlorophenoxy acetic acid), 2,4D plus dicamba, cycloheximide (citrus fruit abscission agent), glyphosphate (N-phosphonomethyl glycine), glyphosphate plus triclopyr ester, and a variety of other herbicides have all been tried with either negative or highly variable results. None of these treatments are labeled for mistletoe eradication and are only listed here to demonstrate the breadth of treatment options which have been attempted. For example in one study, 2,4-D plus dicamba sprays to mistletoe shoot stubs controlled shoots for 18 months but the haustoria remained unaffected with infection sites resprouting, leading to a recommendation of not using this treatment.

More exotic treatments have included freezing, clear plastic bagging, black plastic bagging, synthetic amino acids, and applying growth regulator cocktails. Most of the treatments attempted have had limited or no long-term effects. No effective biological control has been found. Trees resistant to mistletoe infection have been sought, but healthy, vigorous trees under little water stress out-grow the infection just as well. Reduction of the bird dispersal vector is possible, but ecologically and socially unacceptable in most cases.

## Pests On Parasite

Although there has been no successful biological control of mistletoe, there are a number of pests which attack mistletoe foliage and stems. Two of the most noticeable in the Eastern United States are the hickory horned-devil / royal walnut moth (*Citheronia regalis*), and the great blue hairstreak butterfly (*Atlides halesus*). The hickory horned-devil can consume a large volume of mistletoe foliage in a short time. Many other plants are also consumed by the hickory horned-devil.

The great blue hairstreak is wholly dependent upon mistletoe for its existence. The butterfly lays many single unclumped eggs on or near mistletoe infections. The larvae hatch in April to May and are mistletoe-green in color, turning darker green with age. After 10-20 days of gorging themselves on mistletoe tissue (starting with the youngest leaves first), larvae pupate at the tree base. Mistletoe provides good concentrated nutrition to this butterfly.

## Ecological Context

American mistletoe is a unique and common plant. Complete elimination of mistletoe is not possible, but would represent an ecological hardship for a number of animal species which depend upon mistletoe for food, especially during the barren times of Winter and early Spring. In addition to food, mistletoe generates rare habitat through dead wood and cavities in trees, structural failures of large woody materials, and woody ground debris — all of which serve as a resource for a variety of living things. Eradication of this parasite is important in established and managed landscapes, and areas which surround managed lands, because of damage to old, large, socially significant or valuable trees which cannot be easily replaced.

From an ecological standpoint, all the *Phoradendron* mistletoes represent a great living connection among plant forms. In some ways this parasite acts as a keystone species group reacting to environmental changes. Mistletoes are primarily a neo-tropical parasite dependent upon both neo-tropical forest tree species for infection and neo-tropical bird species for dispersal. Mistletoe is dependent upon good microsites on trees for seedling development. Mistletoe seeds are short-lived, must germinate upon placement, and are highly vulnerable to exposure and predation. Mistletoe flowers are dependent upon small bees and other small insects for fertilization. Tropical and temperate forest changes impact host, parasite, micro-site exposure, flower fertilization agent, and dispersal agent. Some mistletoe species are endangered by significant forest changes. American mistletoe is not one of these.

**Summary**

A) The American mistletoe (*Phoradendron leucarpum*) damages and leads to the destruction of many trees throughout the United States, especially in the Southeast. Appreciating its growth requirements and distribution are critical to control.

B) Mistletoe is an infamous tree parasite, stealing essential resources, most especially water.

C) Mistletoe is effective as a parasite because of its battery of growth regulation signals which fool a tree into providing resources while minimizing compartmentalization. It chemically "wires" itself into tree resource allocation systems and skirts tree defenses.

D) Trees are stressed, decline, and pushed to structural failure and biological dysfunction by mistletoe.

E) Continual vigilance and crown cleaning (especially of female clumps) is recommended to prevent build-up of mistletoe populations. Under intensive landscape management, a program of careful pruning or repeated chemical treatment is recommended.

F) Elimination of mistletoe, especially in socially significant and old trees, is crucial.

Citation:

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**Appendix 1:**

# Coder Assessment & Treatment Guide For Mistletoe Infections In Trees

## – *Worksheet* –

## #1. Basic Tree Infection Rating Value = _____

| male infections | rating | female infections | rating |
|---|---|---|---|
| none | 0 | none | 0 |
| single stem | 0.5 | single stem | 0.5 |
| 1-3 sprigs emerging | 0.5 | 1-3 sprigs emerging | 0.5 |
| 1-3 developing clumps | 0.5 | 1-3 developing clumps | 1 |
| 1-5 developed clumps | 2 | 1-5 developed clumps | 4 |
| >5% crown volume | 4 | >5% crown volume | 9 |
| >10% crown volume | 9 | >10% crown volume | 19 |
| >25% crown volume | 20 | >25% crown volume | 35 |
| >50% crown volume | 45 | >50% crown volume | 70 |

## #2. Rating Value Corrections:

| | multiplier |
|---|---|
| -high vigor, fast growing, healthy tree | X 1.0 _____ |
| -medium vigor, susceptible species tree | X 1.3 _____ |
| -low vigor, highly stressed tree | X 1.7 _____ |

(take rating times the multiplier for final rating)

**CORRECTED TREE RATING VALUE = __________**

## #3. Actions (mechanical / chemical):

| | rating |
|---|---|
| -no action | over 1 _____ |
| -crown cleaning and clump removals | over 3 _____ |
| -tree restoration and clump removals | over 10 _____ |
| -potential tree removal | over 20 _____ |
| -tree removal | over 30 _____ |

**INTERVENTION ACTIVITY: ____________________________**