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Know Your Tree Biology

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Understanding tree biology is critical to providing appropriate tree health care. Many people know the basics of what trees need to survive and thrive—water, sunlight, air, elements—but it is important to know how these factors interact in a whole tree. This publication provides tree biology information for readers who are both new and experienced tree stewards. We start with a brief description of cell growth in trees, followed by descriptions of tree anatomy and physiology. We conclude with comments on the tree's defense system and climate change impacts on tree biology. This information is the basis for improving tree health care with suggestions for further reading at the end of the publication.

CELL GROWTH

Meristems are specific zones of new cell growth in trees. Cells reproduce in the meristem through division and differentiation. Cell division is when one cell copies its genetic material and splits into two exactly alike "daughter" cells after which the process begins again. Only one of the two daughter cells differentiate, developing a structure to fulfill a specific function for the tree (Figure 1).

Meristematic zones are either longitudinally oriented or horizontally oriented. Longitudinally oriented meristems are known as apical meristems. They are found in the shoot tips and root tips of trees and grow length-wise or elongate. Horizontally oriented meristems grow wide and split down the length, thereby increasing the diameter of the tree during each growing season. Sometimes called lateral or secondary meristems, these meristems are located along the exterior of twigs, branchlets, branches, trunks, and roots, and result in increased thickness of these organs.

Summary of Cell Division and Differentiation

1. Cells divide with half devoted to further division and half assigned specific functions needed for a tree to survive.
2. Cells with the same function create tissues.
3. Tissues combine to create organs, such as buds, twigs, leaves, and roots.
4. Organs combine to create the organism – the entire tree (Figure 1).

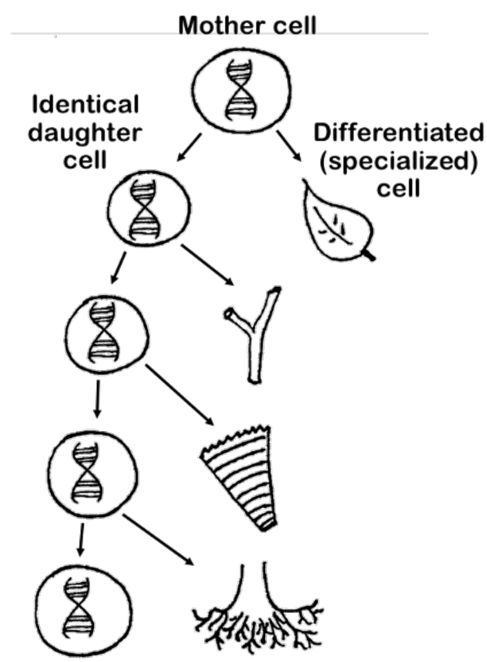

Figure 1: ***Simplified diagram of cell division and differentiation.***

ANATOMY AND MORPHOLOGY: COMPONENT PARTS OF A TREE

Wood & Bark

Lateral meristems in a tree are called cambiums and include the vascular cambium and cork cambium. Both cambiums grow laterally and develop layers of different tissues (Figure 2).

The vascular cambium is responsible for development of the inner tree and wood. This area is responsible for transport of water, elements, and sugars that allow a tree to survive and grow. The vascular cambium grows in both interior and exterior directions, creating a series of tissue networks called xylem and phloem. Inside the vascular cambium, xylem tissues are produced in layers and primarily function as the water transport for trees, delivering water from roots to shoots along the length of the trunk and branches. Xylem also assists in supporting the weight of the tree, storing sugars, and defending the tree against decay and disease. On the exterior side of vascular cambium, a vascular tissue called phloem develops in layers much like xylem does in the interior. Like xylem, phloem is responsible for transporting materials. Phloem transports sugars (i.e., carbohydrates) from the shoots to the roots—that is, from the tree crown where leaves use sunlight to create sugars, down to branches, trunk, and roots for use or storage. Xylem is created in a higher quantity than phloem, resulting in the majority of mass and structure of the tree.

The cork cambium is responsible for development of exterior bark layers of a tree, which protects a tree from injury, moderates tree temperature, and mitigates water loss. As trees cannot physically flee environmental threats, cork cambium is an essential part of their defense system. Cork cambium also grows in both an internal and external direction, much like the vascular cambium. On the inside of cork cambium, thin layers of tissue called phelloderm develop alongside aging and inactive phloem. On the outside of cork cambium, phellum tissue develops in layers, aging and dying to create bark or periderm. Periderm is a tree's first line of defense system against pests, decay, and injury (Figure 3).

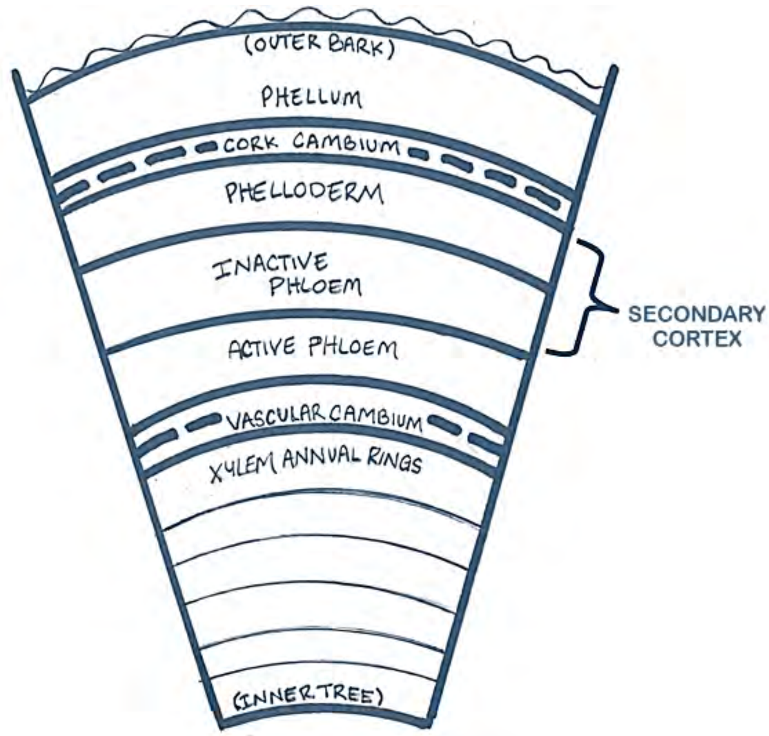

Figure 2: *A simplified diagram of the layers and secondary meristems that make up tree wood and bark. Image modified from Coder 2019.*

Figure 3: *New growth over a wound on a juvenile maple tree.*

Figure 4: *Roots systems grow laterally, with a majority of roots in the top twelve inches of soil.*

Roots

Roots are especially important to a tree as they provide necessary water and elements that provide life, and they furnish structural support against wind and gravity. Root survival and growth is guided by the availability of water, gravity, oxygen, soil volume, as well as the tree's response to temperature extremes. The space where a tree lives is critical to its long-term health because ninety percent of tree roots are found in the top twelve inches of soil. Root systems grow laterally out from a tree base, searching for water and elements (Figure 4).

Root function can be classified by the size of each root (Figure 5). The three to ten largest roots provide primary structural support for a tree and are located closest to the trunk. The area they encompass is termed "root plate." The next largest roots branching out from the root plate are transport roots. They deliver sugars to developing root tips for further growth and transport water and elements from smaller roots back to the tree trunk and up to leaves. They also provide the framework for the tree's structural stability. Lastly, smallest in size but largest in quantity, are absorbing roots, which are necessary for water and element uptake in a tree. Absorbing roots are less woody than transport and structural roots. They form fan-like horizontal layers in areas of sufficient soil resources.

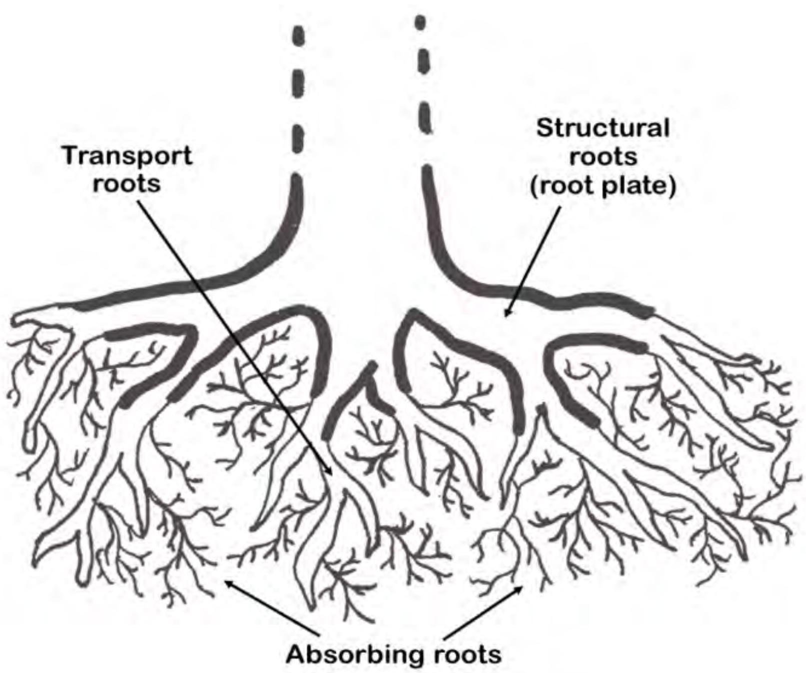

Figure 5: *Simplified diagram of root function by size.*

Shoots and Buds

Buds are found on branches and twigs and are the elongation growth points of tree crowns. Crowns capture sunlight and carbon dioxide (CO2) to make energy (derived from carbohydrates). The crown also releases water vapor, a process which powers the movement of water from roots to shoots. Buds allow for growth, expansion, and adjustment of tree crowns. Buds may also include reproductive organs like flowers.

Buds are classified according to two different locations on the tree. They occur at the tip of a twig or along the side of a twig. Buds at twig tips are called terminal or apical buds (Figure 6) and regulate the growth of other buds on the same twig using growth regulators (described below). Side buds are found independently along a twig or where a leaf is attached to the twig, an area called the node. Buds along a twig are called axillary or lateral buds (Figure 7) and are typically dormant the first year in deciduous trees until the terminal bud is removed or until it is signaled to create new shoot development (typically caused by unusual weather or a stress factor).

Lateral buds can be preventitious or adventitious. Preventitious buds are formed within a growing season and continue to grow within the tree without creating any new shoot development until signaled by a lateral bud or growth regulator. An adventitious bud forms spontaneously at the time when it is needed, usually because of a tree wound or attack, and creates shoots within the same growing season it was formed. Adventitious buds are an evolutionary adaption to improve a tree's likelihood of survival when experiencing stress.

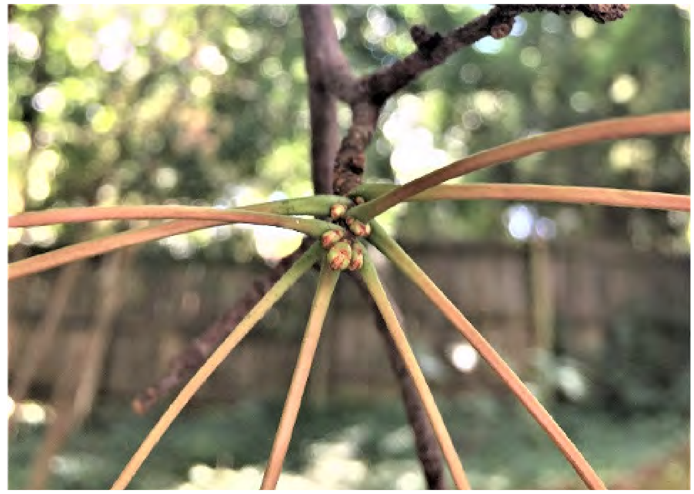

Figure 6: ***Terminal bud on a maple tree.***

Figure 7: ***Lateral buds on a maple tree.***

Twigs, Branches, and Trunk

A shoot is considered a "twig" in its first year of growth, a "branchlet" in its second and third year, and a "branch" starting in its fourth year.

Some significant parts of twigs include (Figure 8):

- lenticels - small porous areas in twig or bark for gas exchange
- nodes - areas where leaves and a corresponding bud arise on a twig
- internodes - the area between two nodes
- leaf scar – a visible area of leaf detachment on a twig
- terminal bud scale – a scar area on the twig signaling the difference between the last growth period and the current growth period, usually appearing as multiple ring-like scars that are closely compacted

Each tree branch is autonomous— a branch creates enough energy (carbohydrates) through photosynthesis to sustain itself entirely. Any extra energy produced is stored in the branch itself or sent to the trunk or roots for further use or storage.

Branches are connected to trunks with reinforced strength (Figure 9). Overlapping xylem tissues forming a zig-zag pattern create a compact connection that ensures stability and hold. The branch bark ridge, which is a line of raised bark because underlying tissues have weaved together, is where the top of a branch and trunk join (known as the area of confluence). Lack of a branch bark ridge is a sign of a weak connection. If a branch grows too upright and is therefore too close to a trunk, it may not grow the proper connection. Instead, the branch and stem grow included bark – bark that does not have tissues woven together – and is therefore susceptible to breaking.

In part, the special strength between a trunk and its branches results from the branch collar, which is where the trunk surrounds the branch base to provide extra support. The area of thickness signaling the trunk transitioning to the branch is called a trunk flange. The branch collar should be avoided when pruning to not affect the overall health of the trunk.

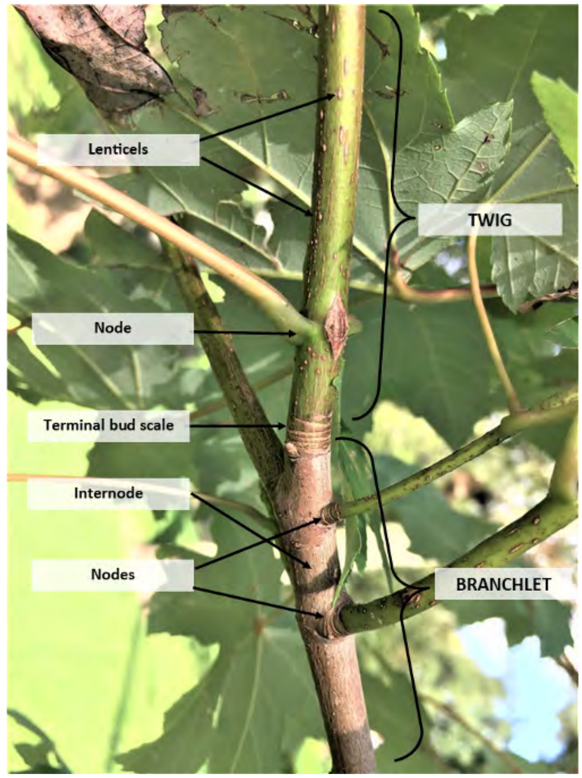

Figure 8: *Young branches on a maple tree.*

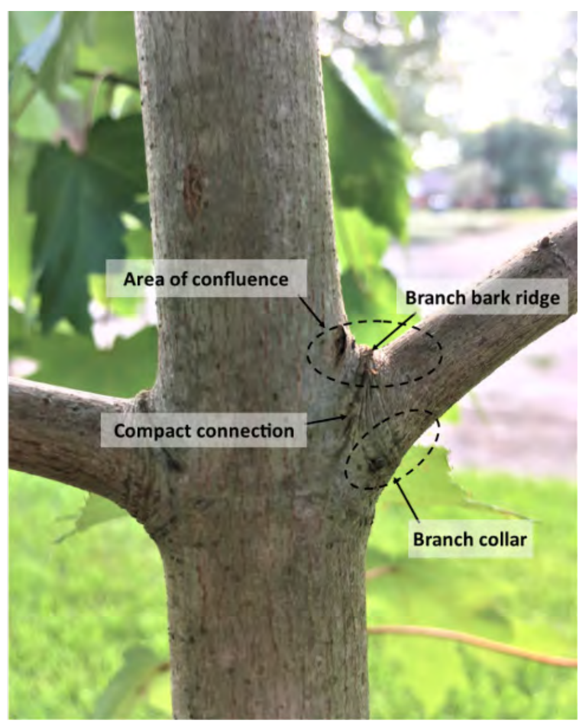

Figure 9: *Strong branch attachment with connected xylem tissues.*

Leaves

Leaves are a tree's primary source of energy production and play an important role in water uptake in the roots. Leaves require a certain amount of sunlight, water, elements, and carbon dioxide to function properly. They are highly adaptable to their surroundings, depending on tree species, and their functions vary across seasons.

Leaves are deciduous, evergreen, or in-between. Deciduous trees (for example, most oaks) lose their leaves annually and are controlled by growth regulators to signal when to function, breakdown, and drop. Evergreen tree leaves (for example, pine needles) last for multiple years. They do not drop based on seasonal changes in weather and continue to absorb light throughout the year. Some trees are semi-evergreen, meaning they keep their leaves past a single growing season, but not over multiple years.

Figure 10.: ***The underside of a maple leaf with veins for transportation of water and elements.***

Leaves use sunlight to energize water and break apart carbon dioxide cells, creating carbon chains in a process called photosynthesis (described below). These carbon chains are the primary energy source used throughout a tree for structural growth, energy storage, and more. Leaves are also involved in water uptake through a process called transpiration (described below). An initial pull of water from inside a leaf into the atmosphere creates tension throughout the tree that continues to pull a connected stream of water through xylem tissues from the branches, trunk, and ultimately the absorbing roots (Figure 10).

Leaves are specially built to interact with water and sunlight. Small pores on the underside of leaves called stomata open and close based on light and environmental conditions to control water loss. Likewise, the cuticle (outer waxy surface layer of leaves) also helps to keep water inside a leaf. Chlorophyll (a green pigment used for photosynthesis) captures sunlight energy needed to build carbon chains, while absorbing harmful levels of sunlight to protect itself.

Flowers, Fruits and Cones

The reproductive units of trees vary based upon genetics and species adaptation. All reproductive units develop within tree buds (meristematic zones), but function differently. Flowers may use seeds or pollen in reproduction processes. Fruits and cones use seeds to disseminate potential offspring (Figure 11). Many of these tree reproductive mechanisms rely on the tree's environment to distribute genetic materials, including animals, wind, water, and other environmental features (Figure 12).

Figure 11: ***The seed capsules of a mature maple tree, called samaras.***

Summary of Tree Parts and Functions

Wood and Bark
- Protect the tree from harm
- Transport carbohydrates and water
- Grow in girth to support weight of tree

Roots
- Elongate in search of best growing conditions
- Provide structural support
- Absorb water
- Uptake essential elements

Shoots and Buds
- Sense and optimize resource allocation
- Adjust for appropriate light capturing environment
- Regulate growth of new twigs and shoots

Twigs, Branches, and Trunk
- Transport water, sugars and essential elements
- Support, stabilize, and govern biomechanics and heat distribution
- Moderate internal water and temperature

Leaves
- Capture light to create energy
- Absorb carbon dioxide to make sugars
- Release water vapor to cool tree and transport

Flowers/Fruits/Cones
- Develop and protect reproductive organs
- Enhance reproductive success

Figure 12: ***A growing tree requires water, sunlight, essential elements, carbon dioxide, and oxygen.***

PHYSIOLOGY: PHOTOSYNTHESIS, RESPIRATION, TRANSPIRATION, ABSORPTION, AND TRANSLOCATION

Carbon chains formed in leaves during photosynthesis become carbohydrates, which can either be used immediately in the area they were created or stored as starch for later use. They can also be combined into transport sugars (sucrose) for delivery to other non-energy-producing parts of the tree, such as the trunk or roots. Starches will eventually be used in combination with specific elements to form some other structural or functional compound (such as amino acids, lignin, or fats that the tree needs to survive). The conditions for ideal photosynthesis rely on appropriate amounts and intensity of sunlight as well as water for the transpiration process (Figure 13).

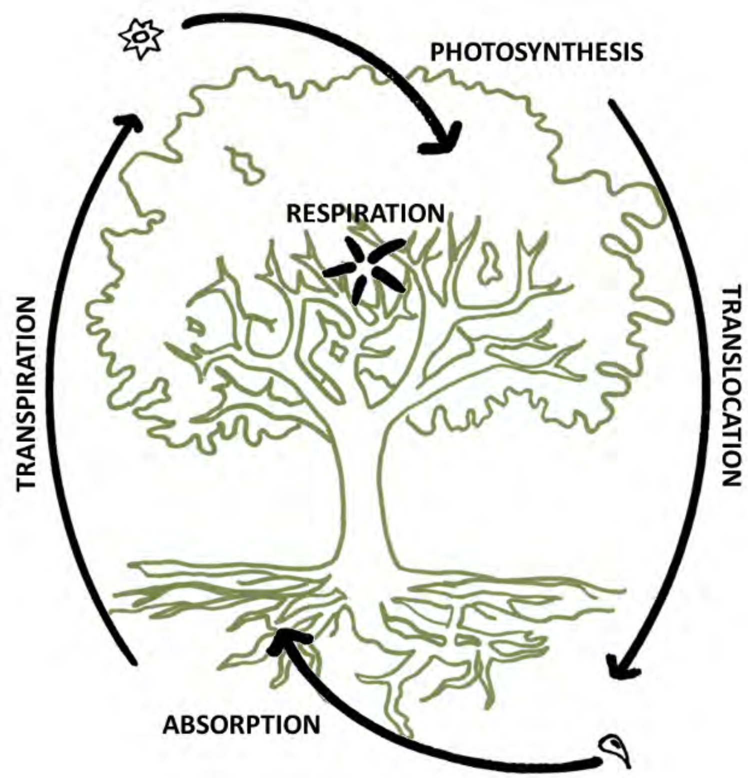

Figure 13: *A simplified diagram of the five physiological processes in a tree – photosynthesis, respiration, transpiration, translocation, and absorption.*

Another process, respiration, is the breaking up and release of energy created during photosynthesis for use in tree biological functions. Unlike photosynthesis, respiration does not happen in any particular area of a tree. The process happens everywhere in the cells. Respiration requires a carbohydrate component and oxygen, and releases water and carbon dioxide once complete. Respiration breaks the bonds of carbon chains and releases units of usable energy. Oxygen is used to pair with the broken carbon and hydrogen elements from carbon chains and release them back into the atmosphere as carbon dioxide and water. Respiration can happen without oxygen, but only for short periods.

Transpiration creates an upward pull of water within trees, from the roots to leaves. Water vapor is released from the wet interior of a leaf into the dry atmosphere via stomata. As water vapor escapes, carbon dioxide is also allowed into the leaves in small quantities, fueling photosynthesis. When stomata are closed (for example, at night) the transpiration pull remaining is strong enough to continue until the stomata open again. Water vapor released through leaves also functions to cool off the tree during the day and is part of the cooling effect of shade. Factors affecting the rate of transpiration include humidity, temperature, and water availability.

Absorption is the uptake of water in roots. Although the movement of water from roots to shoots is powered by the transpirational tension created from leaf water loss, roots have an additional system to keep water moving into a tree to feed transpirational pull. Similar to water vapor moving from the wet inner-leaf environment to a dryer atmosphere, roots rely on mass flow to bring water into the roots. Mass flow consists of water moving from high concentrations (from the soil) to lower concentrations (into the roots). A tree's mineral concentration within the roots also assists in this pull.

Translocation is the movement of transport sugars created by leaves to other areas of the tree via phloem. Following the tree's pattern of moving resources from areas of high concentration to low concentration, carbohydrate components move from source to sink; that is, from where they are created to where they are needed. Translocation itself requires energy to function and growth regulators to map out the patterns of transport.

GROWTH REGULATORS

Growth regulators coordinate and control tree processes, most notably growth and dormancy. They relay messages from roots to shoots and back, giving updates on availability of critical materials like carbohydrates and nitrogen. Primary growth regulators include auxins, cytokinins, abscisic acid (ABA), and gibberellin.

Auxin is primarily produced in shoot tips and flows downward to root tips. Auxin is responsible for developmental functions like cell growth and expansion. Cytokinins are produced at root tips and send their regulation messages to the shoot tips via the xylem water transport system. Cytokinin is responsible for cell division and shoot initiation. Auxin and cytokinins exist in a delicate balance in trees. Small changes in the ratio between the two will signal tree adjustments. Using these growth regulators, roots can communicate to the tree crown when it is lacking water or elements and signal for less growth. Likewise, tree crowns can communicate to the root system that carbohydrate production is low and signal for lower root expansion rates.

ABA is a growth regulator produced during photosynthesis. As it builds up over the active photosynthetic season, it eventually acts as a barrier to auxin growth regulators and signals leaf senescence, or leaf drop. Gibberellin is a growth regulator responsible for sending short, intermediate messages within a tree. It is involved in initiating flowering and branch development.

TREE DEFENSE (CODIT)

Trees are limited by their inability to change location or to heal injuries. Instead, trees use a compartmentalization technique, paired with chemical defenses, to recover after injury or decay (decay is caused by fungus). The model for Compartmentalization of Decay in Trees (CODIT) is described by the creation of four walls to seal off further tissue loss within a tree once wounded (Figure 14). It is important to note that trees do not heal or regenerate cells once an affected area is contained. The compartmentalized area remains empty for the remainder of a tree's life.

Wall 1 resists vertical spread of decay after injury by plugging the top and bottom xylem transport tissues. Wall 2 resists inner spread of a fungus by creating a chemical defense in the next level of annual rings towards the tree core. Wall 3 resists transverse spread through activation of chemical defenses in existing cells extending radially on either side of a wound. These three phases of compartmentalization occur within the first year of a triggered wound or decay and are collectively called the reaction zones.

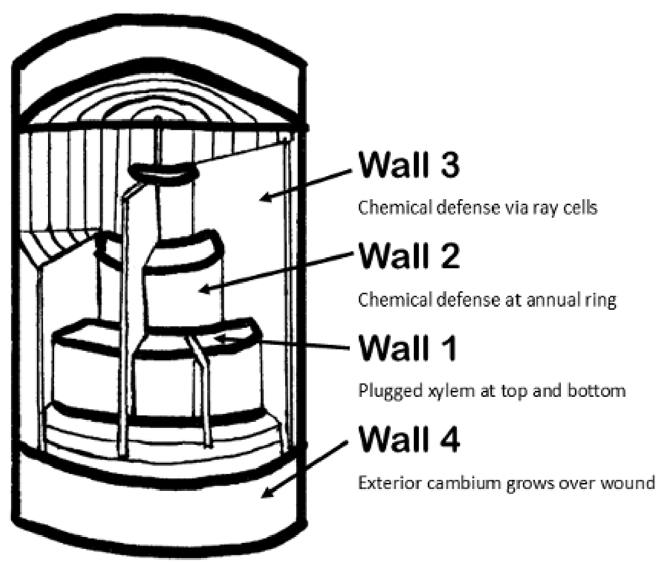

Figure 14: *A simplified depiction of CODIT*

Wall 4 is the final coverage of the wound and is formed with living cambium on the exterior of the tree. This final "growing over" of the affected area protects the tree from outward vulnerability to decay (Figure 15). Wall 4 takes more time to develop than Walls 1-3 and generally occurs a year after the wound has occurred. This wall is called the barrier zone.

Of the four walls in CODIT, Walls 1-3 are most likely to fail, allowing for the interior spread of decay. Wall 4 is chemically strong, but weak structurally and can be susceptible to breakage or cracks.

Figure 15: *CODIT in action, sealing off a pruned limb to protect from decay.*

IMPACTS OF CLIMATE CHANGE ON TREE BIOLOGY

The impacts of climate change on tree biology are complex and continue to be examined by scientists. A changing climate will affect the structure and function of trees in a variety of ways. Changes in temperature, precipitation, weather, and carbon dioxide levels will cause a number of direct and indirect reactions in just five to ten decades. Warming temperatures lengthen the growing season for many trees but will also change the geographic distribution pattern of many species. Changes in precipitation will challenge drought and flood tolerance of many species and disturb habitat suitability for those tree species that cannot handle the stresses. Too much warmth paired with a reduction in water availability will undoubtably effect tree health and development. Increases in carbon dioxide levels pose changes to species geographic distribution, dominance, and biodiversity. Increases in carbon dioxide will drive faster growth in some species, but other changes in environmental conditions, such as drought, will mitigate that potential.

Indirectly, climate change may increase occurrences of many tree disturbances, including pest outbreaks, invasive species, wildfires, severe storms, and more. The negative impacts of climate change greatly compromise a tree's ability to provide ecosystem services, as species adaptation only occurs over the course of thousands of years. Taking into consideration rapid increased in land development, air pollution, and other human impacts, proactive management of trees remains a priority to retain urban and natural forest benefits for future generations.

Figure 16.: *A juvenile stem on a growing maple tree.*

CONCLUSION

This article provided an introduction to tree biology. Understanding tree biology – including anatomy and physiology – is key to taking better care of trees. In turn, healthy trees provide critical benefits to people and other animals. Proper tree health care will only increase in importance as urbanization increases and climates change globally.

References

Coder, K. D. (2017). Whole Tree Interactions: Advanced Tree Biology (Part 3), Publication WSFNR-17-14. Warnell School of Forestry & Natural Resources. Retrieved August 2020 from https://www.warnell.uga.edu/outreach/publications/individual/whole-tree-interactions-advanced-tree-biology-manual-part-3

Coder, K. D. (2017). Tree Respiration Process: Advanced Tree Biology Manual (Part 2), Publication WSFNR-17-13. Warnell School of Forestry & Natural Resources. Retrieved August 2020 from https://www.warnell.uga.edu/outreach/publications/individual/tree-respiration-process-advanced-tree-biology-manual-part-2

Coder, K. D. (2017). Tree Photosynthesis: Advanced Tree Biology Manual (Part 1), Publication WSFNR-17-12. Warnell School of Forestry & Natural Resources. Retrieved August 2020 from https://www.warnell.uga.edu/outreach/publications/individual/tree-photosynthesis-advanced-tree-biology-manual-part-1

Coder, K. D. (2019). (Personal Communication) Urban Tree Management I Lecture. Warnell School of Forestry and Natural Resources, University of Georgia. Athens, GA.

Coder, K. D. (2019). Tree Anatomy: Leaf Shape and form, Publication WSFNR-19-31. Warnell School of Forestry & Natural Resources. Retrieved August 2020 from https://www.warnell.uga.edu/outreach/publications/individual/tree-anatomy-leaf-shape-form.

Ennos, R. (2016). Trees: A Complete Guide to their Biology and Structure. Cornell University Press.

Hirons, A. D., & Thomas, P. A. (2018). Applied Tree Biology. Hoboken, NJ: John Wiley & Sons.

Stafford, H., Larry, E., McPherson, E. G., Nowak, D. J., & Westphal, L. M. (2013, March). Urban Forests and Climate Change. U.S. Department of Agriculture, Forest Service, Climate Change Resource Center. www.fs.usda.gov/ccrc/topics/urbanforests/.

U.S. Environmental Protection Agency (2017). Climate Impacts on Forests. Retrieved November 2019 from https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-forests_.html.