FIRE, Ice, and Metabolism

Injury from fire and winter storms in Maine set off changes in tree metabolism. Photographs are by the author and Kenneth R. Dudzik, Northern Research Station, USDA Forest Service.

By Kevin T. Smith, Ph.D.

Loss assessments and decisions

Evaluation of tree injury often begins with a loss assessment. For winter storm injury, percent crown loss or branch breakage is often estimated. For injury from fire or some mechanical source to the lower trunk, the height and width of the killed vascular cambium and resulting scar are often measured. Both crown breakage and stem wounds provide the opportunity for infection and over time can result in wood decay.

Procedures to measure, estimate, and report those losses might be simple or complex and may fit into a flowchart or recipe book. But should these measurements or estimates be the basis for tree retention or removal?

Forestry legacy

Loss evaluation was developed to meet the needs of production forestry, such as estimates of mortality of standing trees or the volume of wood considered as cull or unusable. In the mid-1900s, estimation of the volume of discoloration and decay in living trees received much attention because the economic value of sawtimber depended on the harvested yield of clear timber free of defects such as stain, decay, and excessive changes in grain orientation. Defects were essentially any characteristic that reduced the yield of clear timber. Burls, knots, wound-wood ribs, and mineral stain were defects and sources of "degrade" with respect to log value. This focus on quantitative loss is understandable with respect to yield of clear timber for wood products.

How much of this applies to the arborist? Rather than the forest stand, an arborist is usually concerned about the benefits and liabilities provided by smaller groups or individual trees. Some of the characteristics of form that reduce the value of a tree for sawtimber can enhance value and interest for the urban, community, or residential landscape.

The need for modern arborists concerned with the living tree can move beyond evaluations based on what is lost, to value what remains and what is being added to the tree after injury. After all, tree survival and the ability to survive depend more on what is present than what was lost.

Metabolism, metabolites, and pathways

One path to go beyond loss evaluation is to recognize the context of how tree metabolism changes in response to injury. Metabolism is the set of chemical reactions that capture and release energy and build tree cells and their contents. Metabolism occurs along well-defined, stepwise pathways that modify chemical compounds (metabolites) and pass them along, often accompanied with the transfer of energy. Each step in metabolism requires one or more protein catalysts (enzymes) and may require small amounts of essential mineral elements. Distinct metabolic pathways intersect, with the intermediate or end products of one pathway being the starting materials for others. The emphasis of one pathway or another results from the underlying genetic program of the tree as influenced by the external environment.

The dominant metabolic pathway for energy capture is photosynthesis. Photosynthesis uses solar energy to split off the oxygen from water and the carbon from carbon dioxide and to precisely combine them to form glucose sugar. The chemical bonds in glucose store some of the solar energy captured by photosynthesis. In budgeting terms, photosynthesis is the only source of income for trees. Glucose is a raw material for amino acids

Coppiced cottonwood in New Mexico uses stump sprouting to full advantage in the landscape.

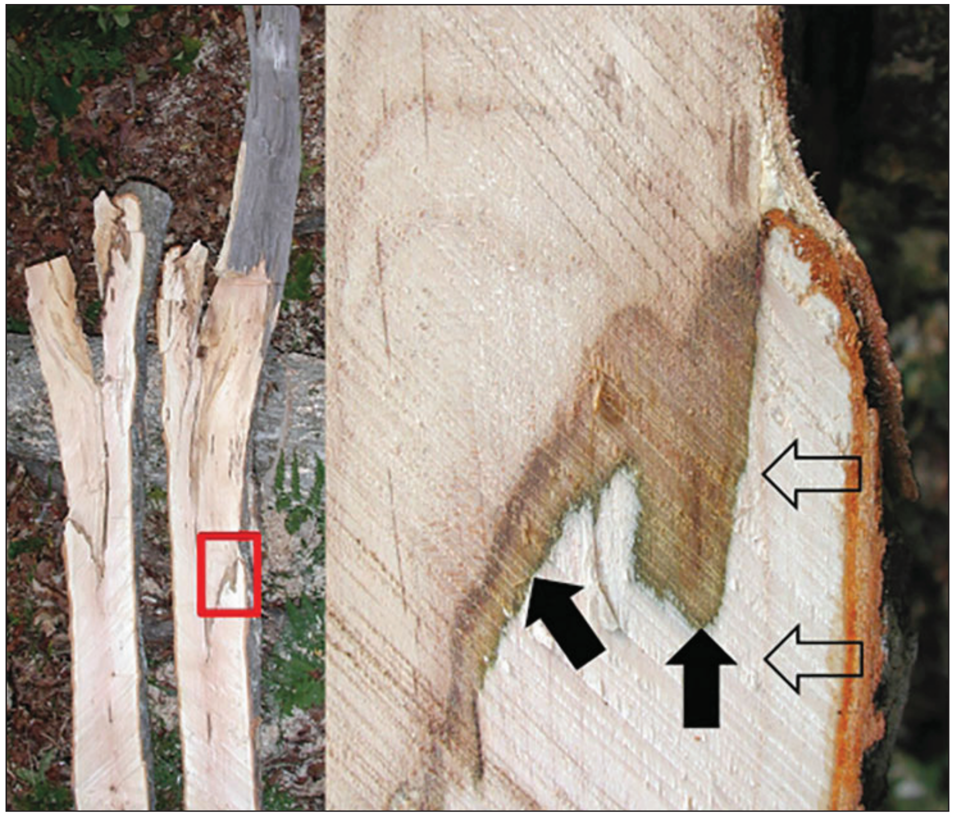
that form protein or that are diverted to form lignin for structure, nucleic acids for the genetic program, and essentially all other biomolecules. Glucose can be converted into other sugars, linked into chains or polymers such as starch for energy storage as well as for the complex structural carbohydrates for cell walls. New cells are produced by specialized tissues capable of cell division (meristems) at buds, shoot tips, and the "new cell generator" (vascular cambium) located between the outermost sapwood and the inner bark.

Several linked pathways release energy from glucose to yield carbon dioxide and water in aerobic respiration. Normal aerobic respiration spends that income to cover energy and structural expenses to feed and maintain living cells and for normal growth.

The basic processes of energy capture by photosynthesis, growth, and energy-yielding respiration were the first physiological processes in plants to be intensively studied and are collectively termed primary metabolism. The biosynthesis of other compounds such as non-photosynthetic pigments and the natural preservatives in durable heartwood were viewed as "secondary metabolism," although the materials were essential for trees as we know them. Even more objectionable is the concept that secondary metabolites in heartwood or bark are "waste" compounds. There are no waste products or metabolic dead ends with trees and other green plants. Plants shed parts, such as foliage and branches to the outside and heartwood to the inside, when their costs exceed their benefits, but there is no "waste." Animals do produce waste products that they cannot recycle, but not so for plants.

The stability of this giant sequoia in California is related more to the thick woundwood ribs that frame the scar rather than interior decay from this old fire injury.

Perhaps a more useful approach is to replace the term "secondary" with "stress" metabolism. Stress occurs in plants operating at or near the operational limits of the tree system. Mechanical injury or breakage is a common cause of metabolic stress. Injury to living sapwood initiates a cascade of metabolic changes. These changes occur in extant sapwood, in the differentiation of new wood from the vascular cambium, and the production of new apical or tip or apical meristems and associated shoots.



Three years after ice injury in New Hampshire, the spread of discolored wood and loss of healthy sapwood is resisted by reaction zones (closed/black arrows) and a barrier zone (open arrows).

Compartmentalization

To supply adequate moisture to the living network of cell contents (the symplast), water is under tension or negative pressure as it is pulled from the roots to the foliage. When living sapwood is injured, the column of liquid water in sapwood vessels and tracheids snaps as air bubbles are introduced into the wood system. Trees resist the spread of air bubbles by plugging the water-conducting xylem with stress metabolites such as resin or corky waterproofing. In many species, living parenchyma cells are sacrificed to form tyloses as their cell membranes are forced through pores in wood cells and plug water-conducting cells.

This essentially immediate process of plugging is quickly followed by shifts from primary to stress metabolism in living sapwood to produce additional waterproofing and anti-microbial boundaries. These shifts are part of compartmentalization, the system of preformed and induced boundaries that resist the spread of dysfunction and infection. These boundaries are not perfect. Compartmentalization is just one survival process. Other strategies for trees include the ability to sprout from an established root system or to produce large amounts of viable seed. Some tree species invest more metabolic energy into compartmentalization, other species less so.

Wound wood and closure

Shifts in metabolism after wounding can cause dedicated cells to lose their specialization (dedifferentiate), divide, and form a mass or pad of thin-walled undifferentiated cells (callus). Callus most frequently forms at the wounded edge of the existing vascular cambium and sometimes from living ray cells at the wound surface. Within a period of weeks, a new vascular cambium can become organized within the callus. This new vascular cambium tends to become continuous with the surviving vascular cambium at the edge of the wound.

Whether from new or surviving vascular cambium, xylem cell production is enhanced, resulting in wide annual increments of dense and strong wound wood. The width of wound wood rings may hasten wound closure, reducing the availability of the injured wound surface to infection. Perhaps more important is that the vigorous, localized ribs of wound wood strengthen the wounded stem by more uniformly distributing the mechanical stress caused by the wound. If considered at all in production forestry, wound wood was considered cull and a loss of value. The arborist can use wound-wood production as a marker of vigor and vitality as well as for structural support that can be greater than that lost from decay of the inner core.

About 10 years after ice storm injury of this sugar maple in New Hampshire, the loss of functional sapwood can be traced to the old broken top.

Stem sprouts

In addition to wound-wood formation, metabolic shifts due to stem wounding can induce formation of new buds or meristematic points that can germinate along with latent buds. These new sprouts or shoots can bear new foliage in subsequent years to replace that lost from earlier breakage of branches. In addition to the general contribution to photosynthesis, new sprouts can provide sugar to fuel localized growth and biosynthesis. Traditional forestry discouraged sprouting as the associated knots over time reduced the yield of clear lumber. Arborists are rightly concerned that stem sprouts initially have weak points of attachment to the stem, and clients may object to profuse sprouting. The metabolic tradeoff is that sprouting is the key to long-term survival of trees that had broken branches and crown loss.

In part, the practice of arboriculture came out of production forestry. Given the differences in objectives, arborists do not need to be bound by the requirements of timber production. Compartmentalization boundaries, wound wood, and sprouting can be positive indicators of value rather than a source of excessive concern. Estimates of crown and stem volume loss can be useful. But the resilience of the tree to restore lost function also needs to be considered. Indeed, each tree is both vulnerable to injury and competent to recover and thrive based on the limits of tree metabolism.

Additional resources:

Luley, C. J. 2015. Biology and assessment of callus and woundwood. Arborist News 24(2):12-21. Available from: http://www.urbanforestryllc.com/publications.asp.

Mattheck, C., Bethge, K., Weber, K. 2015. The Body Language of Trees: Encylopedia of Visual Tree Assessment. Karlsruhe Institute of Technology: Karlsruhe, Germany. 548 p.

Shortle, W.C., Dudzik, K.R. 2012. Wood decay in living and dead trees: a pictorial

Three years after severe ice storm injury in New Hampshire, ash and birch trees survive by sprouting and rebuilding new crowns.

overview. USDA For. Serv. Gen. Tech Rep. NRS-97. 26 p. Available at: http://www.nrs.fs.fed.us/pubs/40899.

Shortle, W.C., Smith, K.T., Dudzik, K.R. 2014. Tree survival 15 years after the ice storm of January 1998. USDA For. Serv. Res. Pap. NRS-25. 4 p. Available at: http://www.nrs.fs.fed.us/pubs/45483.

Smith, K.T. 2015. Compartmentalization, resource allocation, and wood quality. Current Forestry Reports 1: 8-15. Available at: http://www.nrs.fs.fed.us/pubs/47727.

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Kevin T. Smith, Ph.D., is supervisory plant physiologist with the USDA Forest Service, Northern Research Station, in Durham, New Hampshire. This article is based on his talk on the same subject at TCI EXPO 2014 in Hartford, Connecticut. An audio recording of that presentation can be accessed by going to this page in this issue of TCI Magazine online at tcia.org, under Publications, and clicking here.