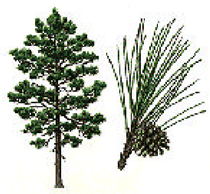
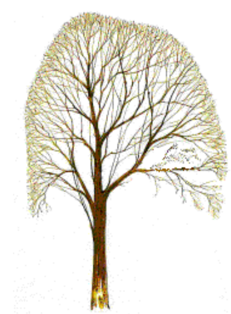


Incredible Trees
How They Grow and Survive

By Jana Albers & Bob Heyd

OUTLINE



INTRODUCTION

How do trees react to pests - from the tree's perspective?

There have been new concepts in the past 10 years or so, describing how trees survive stressing events. With these concepts, you will better understand how trees react in a given circumstance, and you may need only a few details about a specific pest or problem to determine the probable fate of trees.

NECESSITIES FOR LIFE

Let's begin by reviewing how things happen in healthy, fully functioning trees.

What are the necessities of life for the functioning of a healthy tree?

About six things:

1. A supply of sugars produced by photosynthesis
2. Enough water to maintain metabolism
3. Enough nitrogen and mineral elements
4. Plant hormones to integrate the metabolic processes
5. Association with mycorrhizal fungi
6. An environment favorable for life and growth.

1. **Photosynthesis** is called the most important chemical process in the world because it supplies the energy used by virtually all living organisms. It is only the first step in the complex series of biochemical processes that produce and maintain a tree.

Photosynthesis creates glucose, a sugar. Glucose is used as energy in respiration and is altered in many ways to create other chemicals necessary for metabolism and building cell walls. Essentially, it captures solar energy and converts it to chemical energy, which can be used later.

$$6CO_2 + 6H_20 \rightarrow C_6H_{12}O_6 + 6O_2$$

or

Carbon Dioxide (6)+ Water (6) + Solar Energy → Glucose (1) + Oxygen (6)

It's interesting to note that trees also create anti-pest chemicals, like terpenes, tannins,and alkaloids, to prevent invasion by pests - diseases, insects, and larger game.

2. **Water!** Large amounts of water move through a tree on a summer day . . .

. . . something like 50-100 gallons.

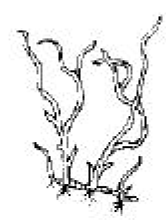
Water is passively absorbed into the cell walls of root hairs, then it moves into the sapwood (xlyem) of the root, and up into the sapwood of the stem, branch, twig and into the leaf.

The leaf needs water for all of its metabolic functions.

Water from the leaf carries food (glucose) and other chemicals to carry out other processes and to build wood.

Girdling interrupts the food supply to the roots. Root growth stops and roots die. Dead roots can't supply the stem and leaves with water, minerals, stored food or hormones -so the whole tree dies.

3. **Trees require nitrogen** and about 20-30 mineral elements for their growth and development.

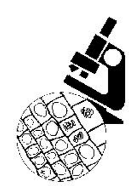


Although the atmosphere is mostly nitrogen - green plants only obtain nitrogen from the soil after it is altered by bacteria to ammonia or nitrate.

Mineral elements - weathering bedrock & recycled nutrients from fallen leaves, branches and roots carried by water to soil micro-organisms and plant roots.

4. **Hormones** are created in minute concentrations and are moved to different locations to affect physiological processes. Some are produced in leaves, some in roots and some in response to injury.

5. **Mycorrhizae** (=myco-fungus, rhiza-root) extract nutrients from mineral sources and from decomposing organic matter. They do this much more efficiently than plants. Most plants and all trees have mycorrhizae. Mycorrhizae also increase water absorption.



Mycorrhizal relationships are very specific; only a few species of fungi are able to form mycorrhiza with each tree species.

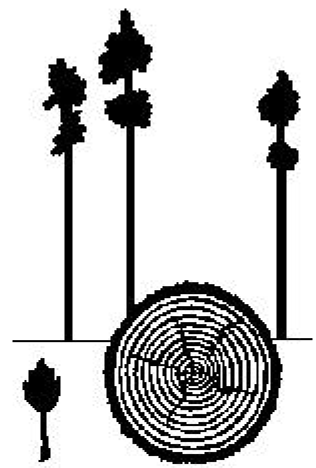
In conifers, a sheath of fungal cells forms on the surface of non-woody roots. In hardwoods, the fungal cells are integrated right into the body of the non-woody roots.

Mycorrhizae protects roots from root pathogens.

Changes in the soil environment (acidification, compaction, pollution, etc.) have profound effects on mycorrhizae and can ultimately lead to the decline and death of the trees.

6. Finally, trees need a **favorable environment** for the biochemical and biophysical processes of growth and survival. Rainfall, temperature, sunlight and soils are some of the necessary environmental factors. Each factor must be available to the tree in the appropriate quantity, form, location and at the appropriate time.

STRUCTURES AND THEIR FUNCTION



Leaves	make glucose, gas exchange with the air short-lived and shed
Branches	height support leaves transport fluids store energy
Stem	height support leaves transport fluids store energy
Roots	anchor & support water and nutrient uptake transportation storage and defense
Non-woody Roots	short-lived and quickly shed root hairs and mycorrhizae increase absorption

In cross-section:

Bark	protects the tree, keeps water and gases in
Phloem	transports sugars, mostly downwards
Cambium	generates new phloem and xylem
Xylem	transports water and nutrients, mostly upwards
Sapwood	mostly live cells

Heartwood mostly dead cells

Root systems are shallow and extensive.

Roots need at least 8% oxygen to survive, so most roots occur in top 3 feet of soil. In fact, 75% of the roots occur in the top twelve inches.

Tree roots grow far beyond the dripline when unimpeded.
Root systems commonly extend two to four times the height of the tree.
So, a 60-foot maple can have a root system radius of 120 to 240 feet.

Roots anchor the stem in the soil. A 2" diameter root pulling force equal to the weight of two elephants; a 4"root, the weight of 10 elephants. Surprisingly, it's the numerous small diameter (like 2") roots that are critical in anchoring the tree.

What happens when roots are severed or killed?

Trees can survive loss of roots but after one main branch root is lost, you're starting to affect structural stability and tree vigor.

So, how much of the root system can be lost?

The **Critical Root Radius** is an estimation of how much of the root system is necessary for the stability and function of a tree. Use the “CRR” as a rule of thumb; do not disturb the roots or soil inside the CRR.

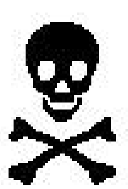
The CRR is DBH " x 1.5 radius in feet.

DBH	CRR
5”	7.5'
10	15.0
20	30.0

This has applications when determining how much of the root system can be lost when paving, grading, utility line trenching, road building or building a home.

Stresses the importance of not operating in the woods when soils are wet and susceptible to compaction, erosion, or the need for working when soils are frozen - if they freeze!

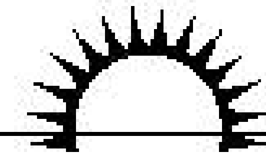
HOW DO TREES DIE?



1. Dysfunction — Cells/ tissues are unable to function properly due to poor genetics, poisons or toxin.
2. Energy depletion — Starvation due to loss of energy (not being produced, transported or stored).
3. Mechanical disruption — Woody structure fails due to sudden overloading or slowly due to decay, canker, etc.

ENERGY BUDGET

A tree needs and uses a tremendous amount of energy. These are priorities for how and when trees use energy:



1. Maintain respiration of all parts.
2. Produce fine roots and leaves.
3. Produce flowers and seed.
4. Extend branches and roots.
5. Store energy rich chemicals.
6. Add wood to stem, roots and branches.
7. Create anti-pest chemicals for defense.

Trees are very efficient in using energy.

All living cells require energy and for many months of the year, and rely on stored energy!

Tree activity periods and stored energy.

> During leaf formation, energy reserves are low. If injuries or infections occur, tree could be in trouble because it can't mount a strong defense. Responses vary by species and individual tree health.
>
> Early, mid- & late-season defoliation. Early defoliation causes energy reserves to tapped twice, which is a major stressor on the tree. Late season defoliation is less stressing because the tree has nearly completed annual growth and re-stocking of energy reserves.

Trees can die due to energy depletion or starvation. Pests that can affect energy are:

Production	insect defoliators leaf diseases
Transportation	bark beetles diffuse cankers wilt diseases porcupines
Storage	root rots flood/ drought root system removal

Some forest pests only cause problems for stressed trees. A condition of low energy that is called "predisposed".

> *For example, a pine growing with too little water will be predisposed to infection by a number of pests, especially bark beetles, because it can't fight them off. Under droughty conditions, pines do not have the energy to make terpenes and don't have the fluids to drown attacking beetles with sap. The would be true for oaks and Armellaria root rot.*

Predisposed trees easily succumb to additional pest infections or adverse environmental conditions.

Defensive dieback

Defensive dieback is a model that describes how trees react to limit the impact of pests that affect the tree's energy budget.

If a tree's metabolism is disrupted by an external event or agent (stressor), its energy is decreased. As a tree becomes stressed or is damaged, it has less energy to defend itself, less energy to grow and less energy to maintain itself. When a tree runs out of energy, it dies.

If a tree is under stress and is short of energy, it will die back. This is defensive dieback. Dieback is when branches in the crown die back from the branch tips toward the trunk.

Defensive dieback - the crown and root systems of a tree become smaller. A smaller tree requires less energy. Defensive dieback reduces the number of parts a stressed tree has to feed and defend, often allowing the tree to survive the stress.

The model of defensive dieback is based on the depletion of reserved water, food stores and dormant buds.

If there's not enough food or water reserves to supply the whole tree, then twigs and rootlets die back.

However, if conditions return to normal (prior to reaching about 40-60% dieback), trees can rebuild reserves, return to a normal metabolism and rebuild their crowns over a period of years.

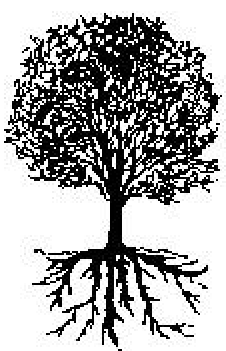
But, if conditions continually worsen, the tree uses more reserves causing more dieback in branches and roots. The stored buds are also used - once the crown dies back - to replace the leaves lost in the upper crown. These buds create epicormic branches on the main stem and large branches.

Finally, the tree dies due to starvation. There is just not enough energy left.

Defensive dieback extends the amount of time a tree can survive on dwindling energy reserves because a smaller tree has fewer parts to feed and defend.

So in the energy allocation scheme, you can see that as trees have less and less energy, fewer and fewer metabolic processes get done, particularly, creating defensive chemicals and storing energy. No wonder stressed trees grow slower and are more susceptible to additional pests.

TREES ARE GENERATING SYSTEMS



The location and pattern of wood formation follows sophisticated design rules termed "adaptive growth".

Trees have receptors which react to loads and bending. Wood is then created thicker in overloaded places, the weakest spots are repaired most rapidly, and, annual rings form so as to minimize cracking.

Adaptive growth tries to provide an even load distribution:

1. By adjusting stem and branch taper.

Trees taper off towards the top to adapt themselves to decreased wind loads higher up.

In areas of mechanical stress, the annual ring is made thicker. Once the stress is corrected, ring widths are equal again.

2. By shape optimization of branch unions and root unions.

   Bending stresses are strongest nearest the root collar and decrease as you go further out the root.

3. Weakest spots are repaired quickest.

Trees can die due to mechanical disruption. What are some of the pests and problems that affect tree or wood structure?

> Decay, cankers, root rots, cracks, fire, human-causes (wounds from logging, vandalism, improper pruning), root system destruction or restriction.

Compartmentalization

Compartmentalization is another survival mechanism. Compartmentalization is a model that explains how trees resist or delay mechanical failure.

> *Mechanical failure of trees is caused either by suddenly overloading the strength of the wood (wind and ice-storms) or by slowly destroying the structural integrity of the wood (cankers, decays or root rots).*
>
> *To stop or delay mechanical failure due to decay, trees have evolved both chemical and physical barrier zones to slow the spread of these invading organisms.*

Trees are highly compartmented plants. When a tree is wounded or invaded by a decay-causing fungus, the compartmented nature of the tree helps limit or slow the spread of the invading fungus.

> *A wounded tree sets up a "barrier zone," both chemical and physical, in the year that it was wounded. The wounded wood and the fungus are sealed inside the tree by the barrier zone.*
>
> *Note that the barrier zone encompasses the entire cylinder of wood inside the annual ring (up and down the stem and around the circumference of the tree). Barrier zones are formed during the year of wounding.*

New wood laid down in subsequent years is free from decay. The fungus is sealed inside and behind the barrier zone. That is the essence of compartmentalization. Inside, the wood is "decay altered."

This pattern of barrier zone formation holds true for wood anywhere; also for branches and roots.

Fires, especially surface fires, can kill bark and cambium creating a wound that decay-causing fungi can enter.

Branches have additional protective zones and patterns of decay. Learning about them is **critical** to the success of pruning. Never cut into the branch collar! Remember that the outer layer of a branch collar is stem wood.

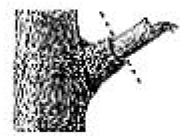
> *The asynchronous growth of wood forms a ball and socket in the spring. Wood formation starts at twig tips and works down from the tip of the branch toward the stem. This forms the ball. Then wood forms down the stem. This is the socket.*

Ball then socket. The topmost layer is stem wood. It's part of the annual layer that the tree creates.

Cutting into the stem wood (the socket) creates a barrier zone the size of the whole tree, so eventually the whole tree will be decayed. Leaving the branch collar (= stem wood) intact allows the branch protective zones to work, too.

> Pattern A. In live branches, invading fungi are stopped inside the branch collar-Branch collars are protective and defensive. When branch collars are left on, fungi are stopped inside the branch collar. If branch collars are removed, it's easy for fungi to invade the stem and difficult to get good wound closure.
>
> Pattern B. In dead branches, invading fungi are stopped inside the branch corewood. Stem tissues are still sound.
>
> Pattern C. In codominant stems and branches, invading fungi are stopped only by the barrier zone. Codominant stems and branches do not have a branch collar protection zone.

In codominant stems/branches, if the branch is dead, wounded or pruned off, decay spreads up and down the remaining branch and stem until it's limited by the barrier zone. This has serious implications for the future decay of the remaining codominant stem/branch.



> ***The moral of the story is, prune outside the branch collar.***

Up to this point, we've been talking about compartmentalization of decay. Not all fungi cause decay; some cause **cankers**. A canker is a dead area of bark and cambium, which often disfigures bark and/or wood beneath it.

Target canker formation starts with a wound. In spring, fungus gains a toehold killing the edge of the woundwood, but by fall, the tree has compartmentalized it. The next year, the fungus enters bark and cambium as it is growing, but by fall, the tree has again compartmentalized it. The process repeats until the canker so deforms the stem that it fails due to overloading. However, the tree's life was prolonged some 20 to 50 years.

Some “clever” fungi have developed other ways to get past compartmentalization. They are the canker-rot fungi. What is different? Decay is not limited by the barrier zone in the annual ring where it was originally wounded. By forming a wedge of fungal tissue in the initial wound opening, the fungus prevents the wound from closing, thus preventing the sealing process.

> *The important point is that the trees never get a chance to form a solid shell of wood. The canker-rot fungus rewounds the tree each year and decay spreads to all new layers of wood as they form. The tree does not have a solid shell of wood and is especially weak at the point of infection.*

Compartmentalization extends the amount of time trees can survive with decay, cankers and cracks.

Discoloration & Decay

Stage 1 - Tree Injury

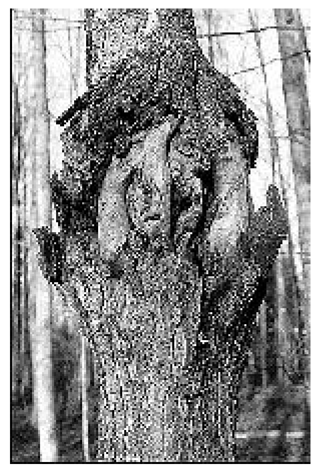
> Injured cells are exposed to air. Gases & moisture pass in and out of tree beginning chemical changes. Discoloration is caused by formation of new materials and the

darkening or lightening of cellular material. **Microorganisms are not involved. Wood strength is not altered.** Discolorations may advance inward toward pith and around the tree. The process may stop here.

- New growth rings act as a barrier to discoloration. Discoloration is confined within the pipe of barrier cells.
- The extent of discoloration depends upon tree vigor, wound severity and time. Discoloration advances only as long as the wound is open.

Stage 2 - Microorganisms Infect

Many organisms try colonizing the new wound surfaces. Of the few that survive, a few can invade discolored wood - bacteria & fungi. These pioneer invaders do not cause decay (non-Hymenomycetes). They can not invade newly formed tissues. **These pioneers further alter discolored wood** - color may change; pH & mineral content may increase; and cell walls may be eroded. This produces wetwood, redheart or blackheart. The process may stop here.



Stage 3 - Decay Fungi

Decay fungi (Hymenomycetes) affect only those tissues that have gone through stages 1 & 2. Thus, **new wood is not infected**. Decay continues as long as the wound remains open. The succession of organisms continues until tissues are completely digested. The rate of decay is affected by wound healing, tree species & vigor, and decay environment - both biotic & abiotic factors.

Growth Patterns

Grow Fast - Ignore Defense

Fast growing trees allocate relatively small portions of their resources to defense. They rely upon the ability to outgrow invaders. Yet, as these trees grow large, growth rate declines. They can no longer add more tissue than decay organisms remove. At this point, structural failure becomes likely. (Salix, Populus, Alnus, Abies (balsam fir), Pinus banksiana)

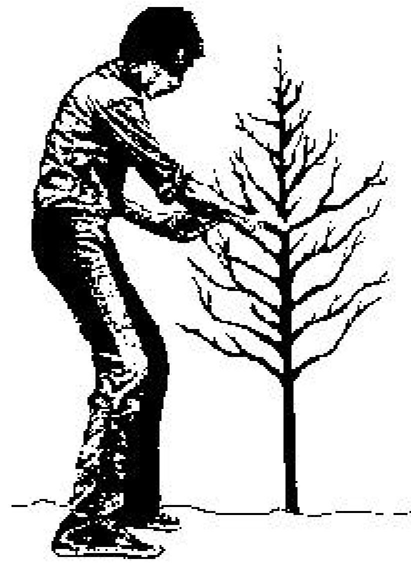
Grow Slowly - Build Defense

These trees allocate a high proportion of resources to defense. They are more capable of compartmentalizing wounds and accumulating compounds in leaves that are unpalatable to pests. These trees tend to be long-lived. (selected species of Quercus, Acer, Pinus)

Old Trees

Old is species and site specific. In urban areas trees have a shorter life. Over-mature trees are more likely decayed, and more likely to shed branches. Cohort Senescence is when an entire stand or resource reaches over-maturity, predisposing it to catastrophic regeneration or replacement. (northern pin oak, white birch, balsam fir, aspen).

HOW CAN PEOPLE PROMOTE TREE HEALTH?



How can we help trees avoid death due to energy depletion?

1. By matching the species and cultivars to the site conditions.

   Think about the extremes that the particular site undergoes and choose the species that can tolerate or even thrive under those conditions

2. By maintaining tree vigor.

   Trees need room to grow. Thin stands to maintain vigor. This is especially true of the root system. Use the Critical Root Radius as a guide for adequate root system space. Watering, fertilizing, protecting from insect and disease problems.

3. By encouraging species and age class diversity.

   The landscape is more resilient to disturbances; be it from pests (esp. exotics such as Dutch elm disease) or ice storms (conifers catch more ice) or humans.

How can we aid trees in limiting crack, canker, and decay formation?

The answer is easy! Eliminate (or avoid) wounding.

- Especially during timber stand improvement (TSI) and intermediate cuts.
- Eliminate topping, tipping, and flush and stub cuts when pruning.
- Avoid encroaching on the root system inside the CRR when paving, trenching or grading. Never park vehicles on roots inside the CRR.
- Avoid wounding when plowing snow or mowing grass.

If you must wound a tree by pruning, use the proper methods and time it correctly. Prune from October through February.

MICHIGAN STATE UNIVERSITY EXTENSION

MSU Upper Peninsula Forestry Extension Office 8/2000.