

A PHOTO GUIDE **to the patterns of** **DISCOLORATION AND DECAY** **in living northern hardwood trees**

by Alex L. Shigo
& Edwin vH. Larson



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A PHOTO GUIDE

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DISCOLORATION AND DECAY

in living northern hardwood trees

The Authors

ALEX L. SHIGO, plant pathologist, is in charge of a special U.S. Forest Service project for research in discoloration and decay of living trees, headquartered at the Northeastern Forest Experiment Station's research unit at Durham, N. H. A graduate of Waynesburg College, Waynesburg, Pa., in 1956, he received his Master's degree in 1958 and his Ph.D. degree in plant pathology in 1959 at West Virginia University. He joined the U.S. Forest Service in 1959.

EDWIN vH. LARSON, editor, is chief of publications at the Northeastern Forest Experiment Station, Upper Darby, Pa. A graduate of Rutgers University in 1936 with a Bachelor of Letters degree, he worked for 6 years as a feature writer and copy editor on a daily newspaper, and 4 years in the U.S. Army as a training film scenario writer at The Infantry School and overseas as a prisoner of war interrogator and intelligence staff officer. He joined the U.S. Forest Service in 1947.

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HOW CAN YOU TELL?

HOW CAN YOU TELL, by looking at a living tree, what quality it has? One tree may be rotten at the core yet still may contain a large volume of high-quality wood. Another may be thoroughly sound from pith to bark yet may be so damaged by minute discolorations that it is worthless for high-quality products. How can you tell?

This guide has been prepared to help you estimate the extent and severity of discoloration and decay in northern hardwood trees. Though this certainly is not the last word on the subject, our research in this has progressed to the point where our findings, combined with the findings of others, can be put to practical use.

By dissecting living trees and studying the organisms that infect them, we now know that discoloration and decay develop in certain definite patterns. And the patterns of discoloration and decay within the tree can be predicted from external signs.

Discoloration and decay are the most serious defects of northern hardwood trees. In speaking of defect, we must distinguish between injury and damage. Injury harms the tree: damage lowers the quality of the wood. For example, a disease like vascular wilt may kill the tree but do no damage to the wood. But an insect like the cambium miner may do very little harm to the tree yet do great damage to the wood.

The unseen damage done to a tree is important in the economics of forestry. Every operation in growing a tree, harvesting it, and converting it into products costs time and money. And after all the time and money have been spent on a tree, the product made from it may prove to be not worth the effort; and the tree might have been used more profitably for some other product that does not require high-quality wood.

The increased use of veneer offers an illustration. A veneer log brings top prices. But its actual value may not become apparent till it is put on a lathe and peeled. A log that looks very good, and sound to the core, may have minute streaks of discoloration scattered all through it, so that all the veneer it produces is badly streaked with defects. On the other hand, a log that has a rotten core surrounded by clear wood may produce the highest quality of veneer.

So it is not so important how much discoloration and decay a tree has, but where these defects are in a tree. The pattern of the discoloration and decay—that's the important thing.

STUDY METHODS & MATERIALS

This guide is based primarily on the findings from a series of studies made by the senior author in northern New England. Begun in 1959, these studies are being continued in efforts to clarify further our understanding of the discoloration and decay processes.

The Species

The northern hardwoods make up one of the major forest types of northern New England. They are American beech (*Fagus grandifolia* Ehrh.), paper birch (*Betula papyrifera* Marsh.), yellow birch (*B. alleghaniensis* Britt.), sugar maple (*Acer saccharum* Marsh.), red maple (*A. rubum* L.), and white ash (*Fraxinus americana* L.).

Most of the sample trees grew in the White Mountain National Forest in New Hampshire.

The resource of northern hardwoods is plentiful today, but it contains an overabundance of poor-quality trees. Foresters repeatedly ask two questions about the northern hardwoods: What can we do to assure future crops of high-quality trees? And how can we make the most of what we have now?

The Methods

A new large-scale method of dissecting living trees was used in these studies, to get at the defects inside the tree. This might have seemed an obvious thing to try. Yet large-scale dissection had not been tried on trees—at least not in quite this way.

True, pathologists had studied decay in wood and had isolated and identified fungi. Studies had been made of the cut ends of logs. And wood defects had been studied on freshly cut boards at the sawmill. But logs taper, and many of them are not straight; and though the surfaces of lumber cut at a sawmill reveal discoloration and decay, they do not reveal the complete patterns.

The development of the gasoline-powered chain saw since World War II made possible this method of dissection. By using a portable chain saw, it was possible to go into the forest and work on living trees. One could fell a tree and cut it into bolts and disks at once and rather quickly—a tedious and discouraging job with hand saws. Moreover, it was now possible to begin at one end of a tree stem and slice it down through the middle, following the natural curve of the stem. And it was possible to cut at any spot and any angle, and to lay open any particular area of a tree for study.

After a tree had been cut open, the defects were systematically

mapped. Then, from specimens of wood taken into the laboratory, chips 1 x 0.3 cm. were cut with a gouge from clear wood, discolored wood, and decayed wood, and from the zones between—six chips in each series, at intervals up and down the tree stem. These chips were cultured on agar plates. Every organism found was recorded, and most were identified.

Scope of the Studies

During these studies more than 3,000 trees were dissected, and some 100,000 isolations were made to identify organisms. More than 10,000 photographs—both black-and-white and color—were taken to record the patterns of discoloration and decay in the freshly dissected trees. From these, 100 color photographs have been selected to illustrate this guide.

GENERAL RESULTS

As dissection of the living trees disclosed general patterns of discoloration and decay, a clear understanding about three aspects of the discoloration and decay processes emerged.

A Succession of Organisms

Decay in a tree had been thought to center about three simple events—a tree is injured: a fungus enters: decay begins. But our studies showed that a complex succession of events must take place before decay can begin. It works roughly like this—a tree is injured: the tree reacts: chemical changes take place in the wood: the wood discolors: bacteria and non-decay fungi become active: the wood discolors further: decay fungi infect: decay begins.

The process is irreversible. And it cannot be shortcut. Decay does not begin until all the other events in the succession have taken place. Decay does not begin until the wood has been discolored. And the succession may stop at any stage: the wood may become discolored but may not decay.

A Consistent Pattern

The discoloration and decay in a northern hardwood tree take a definite pattern. They form a column in the tree, related

to the location of the injury. This column can spread up and down inside the tree, but it seldom spreads outward. The diameter of the column of defect is no larger than the tree was at the time of injury. In effect, growth of the tree after the injury forms a pipe of healthy new wood, and the discoloration and decay are held within this pipe.

Discoloration not Heartwood

In some tree species, like black cherry and walnut, true heartwood forms as a result of chemical change that follows normal aging processes in the wood cells. But in northern hardwoods the darker wood is not true heartwood in this sense: it is a result of discoloration processes initiated by injury.

THE PROCESSES OF DISCOLORATION AND DECAY

The development of discoloration and decay in the wood of a living northern hardwood tree is a complex continuum of events that merge and overlap in time and place. Several columns of discoloration and decay may be present in various stages of development at the same time and place. It is difficult to say where one stage ends and another begins. But for the sake of convenience in describing the processes, we divide them into three broad stages.

Stage 1

The process begins with an injury to the tree. A branch may die or break off; insects or birds or animals may attack the tree; a fire may burn the base; or a logging machine may scrape it in passing.

Some cells are killed by the injury, and others may be injured to some degree. The injured cells are exposed to the air. At this time gases and moisture can pass out of the tree, and air and moisture can pass into the tree. These changes start chemical processes in the wood cells about the wound.

Discoloration results. It may be due to the materials formed by the chemical processes, or to the darkening of cellular material

as a result of exposure to the air. Sometimes the discoloration may be a bleaching rather than a darkening. Microorganisms are not involved.

These early discolorations do not alter the strength of the wood. And the process may stop right here. It depends on the severity of the wound and the vigor of the tree. But the discoloration may advance inward toward the pith, and around the tree.

Then in time a new growth ring forms. The first cells in this ring are different from the cells that are usually produced. They act as a barrier to the discoloration process. The discoloration seldom moves into the new cells. Instead, it moves up and down the stem within the pipe of barrier cells—but not outward into the new tissues.

The extent of discoloration depends on the vigor of the tree, the severity of the wound, and on time. Discoloration advances only as long as the wound is open. Thus the entire cylinder of wood present when the tree was wounded may not become discolored. Meanwhile the tree continues to form new growth rings that are free of discoloration.

Stage 2

Stage 2 begins when microorganisms infect. As soon as the tree is wounded, many different organisms begin to grow on the wound surface. They compete; and many do not survive. Of those that survive, only a few types are able to begin growing into the wood through the wound—only those that can thrive in the discolored wood.

These first microorganisms to invade the tree—the pioneers—are bacteria and fungi. The fungi are non-Hymenomycetes: they do not cause decay. These pioneers infect only the cells that have been altered by the chemical processes, so the new tissues formed after the injury remain free of infection.

The infected cells are further altered by the pioneer microorganisms. The discoloration may increase; the cells become more moist; pH (acidity) and mineral content of the cells rises; and certain parts of the cell walls may be eroded. The wood

affected at this stage is called wetwood, redheart, or blackheart. The process may stop at this stage.

Stage 3

Stage 3 begins when decay fungi (Hymenomycetes) become active and begin to digest the cell walls. These fungi affect only those tissues that first have been altered by chemical processes and then by the pioneer organisms. The new growth of wood that continues to form remains free of infection.

The decay process continues as long as the wound remains open. Many species of microorganisms may interact until the wood is completely decomposed. The succession of organisms does not stop when the first decay fungus enters. It stops when the tissues are completely digested.

The advancing decay column is often separated from the new white wood by a band of discolored wood. In some species the margin of this band may be bleached. The pioneer organisms remain in this band. Later, as decay continues, the decay fungi slowly digest this discolored band; and only a hard black rim then separates the by-then hollow core from the healthy white wood. This rim forms first near the wound.

To this point the process may take 40 to 50 years. Healthy white blemish-free new wood will surround the hollow core, unless other wounds have been inflicted meanwhile.

We want to emphasize this point: the processes need not go through to completion. Healing of a wound, antagonisms among organisms, unfavorable environment, and other forces may cause the processes to abate in any stage.

Importance of Time

What we have described above is a continuum of events that follows a single wound at one period in the life of the tree. But a forest tree is apt to be injured a number of times. The same processes take place each time. And the discoloration and decay processes that follow a new wound are not affected by the effects of older wounds.

THE PATTERNS OF DISCOLORATION AND DECAY

A cross-section of an ideally healthy northern hardwood tree shows a pencil-thin cylinder of pith in the center of the stem, surrounded by unblemished white wood. But what you see in most trees is a core of darker wood, of varying diameter, surrounded by white wood. The pattern of the discolored wood will depend upon what has happened to the tree: when the branches died, how fast it healed its wounds; what logging wounds it had; and how much injury was done to it by insects, fire, birds, animals, or other agents.

Central Column

The most typical pattern of discoloration is a column of discolored wood extending up and down in the center of the tree. This discolored wood is always associated with some injury to the tree, like a broken branch or stem. Where decay occurs, it occurs within this column of discoloration.

In northern hardwoods, this central column of darker wood is not true heartwood—though it is often called heartwood. It does not increase in diameter as the tree grows. The discoloration is due to changes in the wood brought about by processes that are begun by wounds or other injuries.

True heartwood does occur in some hardwood species such as black walnut, cherry, and the oaks. This darker wood is due to processes associated with normal aging of the tree. As the tree grows, the column of darker wood increases in diameter. The cylinder of true heartwood extends rather uniformly throughout the entire tree, from the base up into the branches.

Columns of discolored and decayed wood, caused by injury to the tree, can form within the column of true heartwood. These columns of discolored and decayed wood do not increase in size as the heartwood does. Of course in a tree like black walnut the difference between true heartwood and discolored wood is hard to distinguish.

The differences between true heartwood and discolored wood can be tabulated roughly this way:

Heartwood

Process initiated by aging.
Internal stimuli.
Proceeds centrifugally.
New tissues affected each year.

Oldest tissues affected first.
No hard rim at margin of white wood.
Intermediate zone between heartwood and white wood.

In ring-porous species summerwood colored mostly.
Color mostly in cell walls.
Continuous.
Throughout tree.
Disrupted about wounds.
Stabilized.

Mostly in ring-porous species.
Checks radially.

pH not high.
Moisture not high.

Mineral content not high.

Cylinders of heartwood not pointed at ends.
Usually circular in cross-section.

Discolors when wounded.

No microorganisms.

Discolored wood

Process initiated by wounds.
External stimuli.
Proceeds centripetally.
Tissues that form after wounding are seldom affected.
Youngest tissues affected first.
Hard rim between discolored wood and white wood.
No intermediate zone between discolored wood and white wood.
Springwood and summerwood colored.
Color in walls and cell contents.
In columns.
Depends on wounds.
Forms first about wounds.
First stage of a process that can develop further.
In all species.
Honeycomb checks, and around rings.
pH high in advanced stages.
Moisture high in advanced stages.
Mineral content high in advanced stages.
Column of discoloration pointed at ends.
Circular or any other configuration.
Does not discolor further when wounded.
Microorganisms present as the processes continue.

Multiple Columns

When a tree is injured at different times, multiple columns of discolored wood develop. The multiple columns can be seen most easily on the ends of logs, where they take on a concentric pattern or a cloud-like pattern. Very careful dissections are necessary to trace each column to its source.

If two injuries to branch stubs occur at about the same time, the two columns of defect may join to appear like one column.

But if wounds occur at different times, the processes that result in discoloration and decay begin and develop independently for each wound.

If a cylinder of discoloration is already present in the stem, a later wound does not affect it. The discoloration from the new wound forms around or beside the old column of discoloration. It may completely envelop the old column, like a pipe sliding down over a smaller pipe. Or it may develop alongside the old column in the shape of a crescent or half moon. It may be wedge-shaped in cross-section.

Major injuries to the tree—such as broken stems and branches—tend to discolor the entire core of the tree that was present at the time the injury occurred. Minor injuries such as small insect wounds may cause only localized streaks of discoloration— islands of defect within sound white wood.

Because each column of defect is separate in both time and cause, the discoloration and decay processes may be more advanced in one column than in another. Decay may form in one crescent-shaped column while other adjacent columns may be discolored but still sound. Sometimes columns of defect enclose areas of clear wood. For example, a tree may have a sound center surrounded by a ring of decayed wood.

When the wood begins to dry after the tree has been cut, checks often form between the boundaries of the defect columns. The checks often follow the growth rings—ring shake. When the defect column is a complete cylinder in cross-section, the shake may develop in a complete circle along the growth ring. Because the defect columns may be in different stages of the discoloration and decay process, the stresses that develop in drying are not uniform; so checking may occur in many different patterns.

For example, this is common in sugar maple when branch stub wounds and borer wounds occur in the same place on the stem. Honeycombing or tissue collapse may result in the moist discolored tissues. And because the beetles wound the wood in a diagonal pattern, crossing many growth rings, a jagged column of defect sometimes forms that checks in all directions when the wood dries.

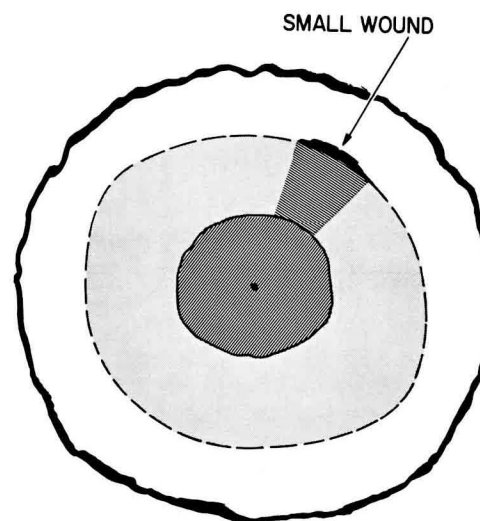
Defects under Cankers

The defects that form under cankers are somewhat different. A canker tends to produce a localized defect rather than a column of discoloration and decay.

When a canker develops about a wound, the tree usually already has a central column of discoloration and decay. The defect from a canker usually forms beneath the canker, in the wood between the central column of discoloration and the bark surface area where the canker forms. The defect from a canker usually does not spread around the entire stem: it lies immediately beneath the canker.

Mineral Streak and Stain

Wounds also begin the processes that result in the discolorations that are commonly called mineral streaks. The accumulations of salts in such discolorations may be due to the evaporation of liquids that are drawn to the exposed wound, as in a wick action. Because fungi are the agents most consistently associated with wounds does not mean that other organisms, especially bacteria, do not also alter the wood. And viruses can also cause discolorations; so they cannot be ruled out as agents inciting stain.



Even though an entire central column may not be discolored by a small wound, the whole central column may take on a slightly darker hue.

Other Patterns

The wounds caused by sapsuckers, fire, and other agents have some typical patterns, but the course of discoloration and decay follows the same patterns described above.

Sometimes, when a wound is small and not severe, the discoloration affects a small area rather than a complete new column; yet the new central column takes on a slightly darker hue—usually light pink.

EFFECTS ON DIFFERENT SPECIES

All the northern hardwood species do not react exactly the same way to injuries. Some notes about each of these species follow.

Sugar Maple

Of all the northern hardwoods, the most resistant to discoloration and decay is sugar maple. Yet many sugar maple trees are very defective. This is because some agents of injury seem to prefer sugar maple to the other species: for example, sapsuckers, cambium miners, squirrels, and—most important—the sugar maple borer. Discolorations associated with wounds of sugar maple are often called mineral streaks. Of the fungi that cause decay in sugar maple, the most important are *Fomes connatus*, *F. igniarius*, and *Polyporus glomeratus*.

Red Maple

In general, red maple is considered to be very susceptible to defect. Discoloration and decay advance much faster in red maple than they do in sugar maple. The central columns of discoloration are usually due to branch stubs, most of them between 4 and 10 feet up on the stem.

Sprout clumps are common in red maple, and they present some serious problems. Branch stubs on sprout stems of red maple cause more defect than the old parent stumps cause.

Many fungi cause decay in red maple, but the principal one is *Polyporus glomeratus*.

Yellow Birch

Discolorations and decays advance in this species fastest of all. Large low branch stubs—usually not well healed—are most common in yellow birch. In older trees, top breakage accounts for wide columns of discoloration. Yellow birch is one of the favorite feeding trees for sapsuckers. The most common fungi that cause decay in yellow birch are *Poria obliqua*, *Pholiota* species, and *Fomes igniarius*. *F. igniarius* var. *laevigatus* causes cankers on overmature trees.

Paper Birch

Paper birch reacts like yellow birch in most ways, except that discoloration and decay do not advance so rapidly, and large low branch stubs are not so common. Advanced decay is like that in yellow birch. The cambium miner is more common on paper birch, and so is the ambrosia beetle. Paper birch is not a favorite feeding tree for sapsuckers; but they do attack it, and heavy attacks cause black bands on the stem. The same decay fungi that attack yellow birch also attack paper birch.

Beech

The beech bark disease is the most important disease of beech. It has decimated beech in many areas.

One special feature of beech is that its base is vigorous, and wounds near the base rarely cause much damage to the roots. The notable exceptions are the defects caused by *Fomes applanatus* and *Armillaria mellea*. Because of its vigorous base, a beech tree with a defective bole may stay alive for a long time.

Ants sometimes infest wounds on beech trees, and their activities increase the defect by keeping the wound open. These insects are rarely found on other northern hardwoods.

Branches from dormant buds on the stem may cause small defects when they die.

Ash

In ash trees, most of the defect comes from the top downward. Poorly healed stubs in the crown, and broken tops, should be considered important in this species. The principal decay

fungus of ash is *Fomes fraxinophilus*, which affects the upper stem. Frost cracks are common on ash in some areas.

STUBS WITHIN THE STEM

How to Estimate Size, Angle, and Depth

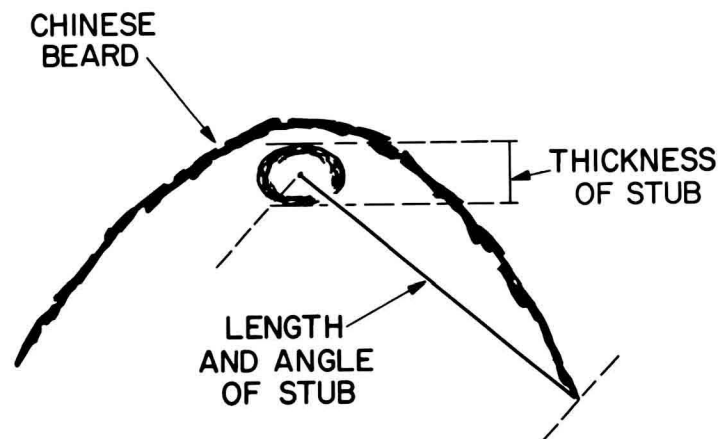
The size and position of a branch stub buried in the wood inside a tree can be estimated roughly from the scars on the bark. And from this in turn you can estimate the size of the defect column and the amount of clear wood outside it. Much of the information on this subject comes from research done in Europe.

Two types of bark scars provide the clues. One, called a chinese beard, is like two drooping moustaches. The other, like a mouth under the moustaches, is the more or less round scar that marks where the stub was.

The chinese beard forms this way: as a branch grows on the tree stem, a layer of thick-walled cells forms in the axil above the branch. The bark becomes roughened over this ridge of thick-walled cells. In some species, like paper birch, the bark also turns dark here.



Stub scar and chinese beard on a beech tree.



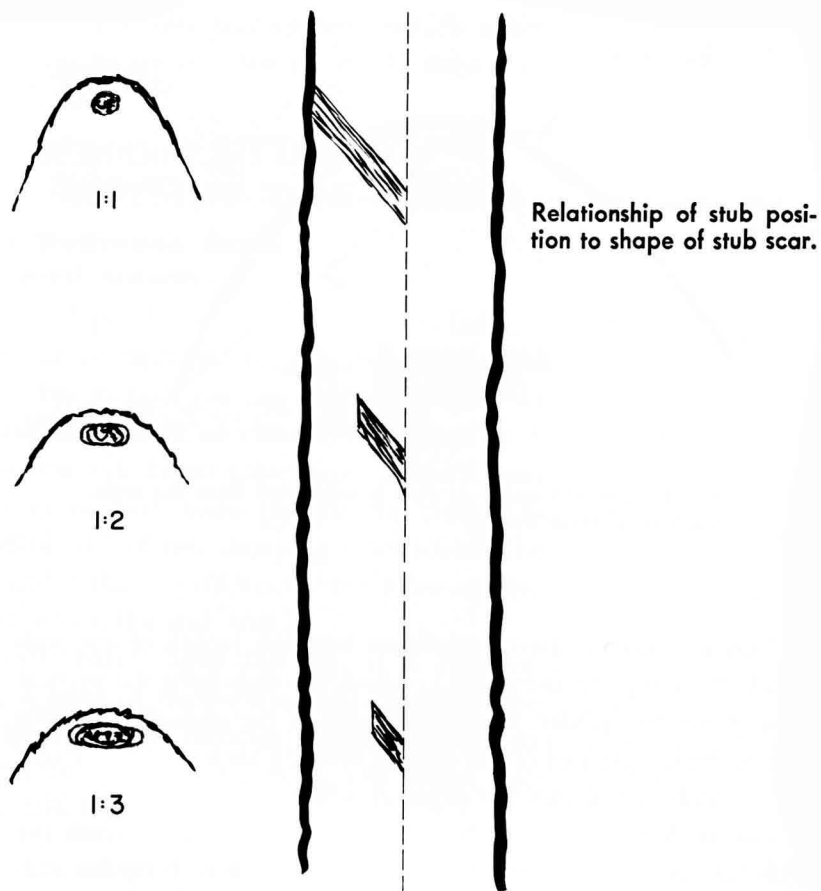
How length and angle of stub is estimated from the stub scar and chinese beard.

This scar can be used to estimate both the length of the stub inside the tree, and the angle at which the stub joins the vertical axis of the tree center. From the center of the stub scar, draw a line to the bottom end of the chinese beard. This equals the length of the stub and shows the angle at which it lies.

The thickness of the stub can be estimated directly from the stub scar. Assume that the branch that broke off to form the stub was practically round. The *height* of the stub scar shows the size. If the stub scar is about 2 inches high, the stub is about 2 inches in diameter.

How far inside the tree the stub is buried can be estimated from the *shape* of the stub scar. As a tree adds new growth rings, the growth at any one spot on the stem is outward, not upward. The height of the stub scar remains the same. But as the new growth is added, the bark is pushed outward, and the scar spreads at the sides, gradually changing in shape from a circle to an ellipse.

The scar's ratio of height to width indicates how far the stub extends from the pith center of the tree toward the bark; and this tells conversely how much new wood has formed over the stub.



For example, if the stub scar is round, it has a ratio of 1 : 1. This means that the end of the stub lies just at the bark surface—an unhealed stub—and no new growth covers it. If the scar is twice as wide as it is high, the ratio is 1 : 2. This means that the stub extends $\frac{1}{2}$ the distance between the pith center and the bark, and that the other $\frac{1}{2}$ is white wood. And if the ratio is 1 : 3, the stub extends $\frac{1}{3}$ the distance between pith center and bark. And so on.

This rough formula can be applied to all the northern hardwood trees. As time passes, use of this formula becomes more difficult, especially on the maples.

PHOTO GUIDE

These photographs illustrate all the major defects of northern hardwoods, as we now recognize them, and the fruit bodies of the most important decay fungi.



FIGURE 1.—LOW BRANCH STUB.



This sugar maple (left) has a low stub, but the base is free of wounds. The long stub of hard wood shows that the stub has not been dead long, and that the discoloration processes have not had time to progress to an advanced stage.

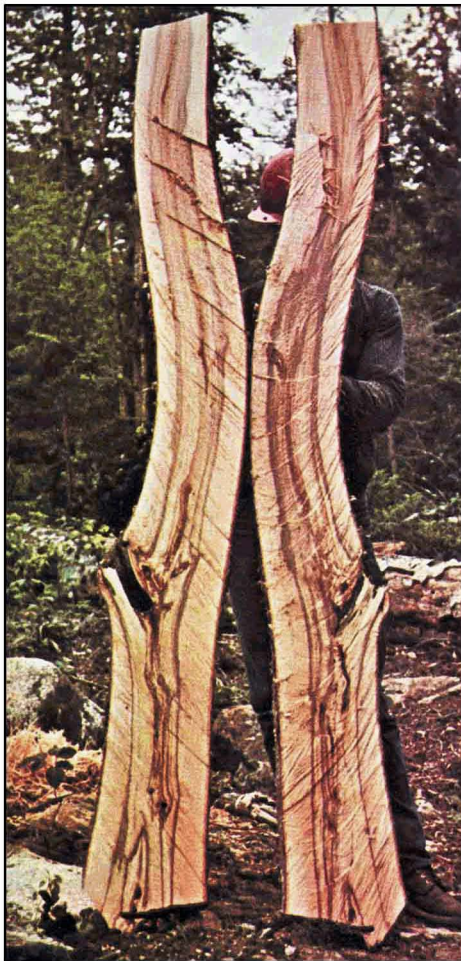


Dissection (right) reveals the pattern of the discoloration. The wood at the base is clear. The column of discoloration from the large stub dwindles toward the base, but joins above with a wider column of discoloration from an older stub above, where the processes are more advanced. The wood formed after the stubs died remains free of discoloration. These discolored tissues are *not* heartwood.



FIGURE 2.—LOW BRANCH STUB, DECAYED.

This yellow birch has a low stub, and the callus ridge and advanced decay show that the stub has been dead a long time. Roughened bark at the base indicates basal wounds and root wounds typical of injury caused by logging equipment.



Dissection reveals discoloration and decay originating from both the basal wounds and the stubs above. The base is both discolored and decayed. The dark lines within the decay at the base indicate the limits of earlier columns of discoloration. The diameter of the widest column indicates the diameter of the tree when the large branch died.

FIGURE 3.—HIGH BRANCH STUB, UNHEALED.

This paper birch bolt contains a large unhealed stub from high on the tree. The decayed stub indicates advanced discoloration and some decay. The dark drooping lines of the bark scar — chinese beard — indicate the angle and length of the stub inside the stem.



The discolored wood associated with the stub is redheart — very wet and dark, and — beginning to decay. The column of defect from the stub does not enter the older central columns of defect, but extends up and down alongside them. Multiple columns of defect like this are common.

FIGURE 4.—HIGH BRANCH STUB, HEALED.

This healed stub wound on a paper birch illustrates how the position of the stub inside the tree can be estimated. The dark line of the Chinese beard shows the length and angle of the stub. The height of the stub scar tells the diameter of the stub.



Dissection shows the relationship. The length, angle, size, and depth of the stub are approximately as indicated by the external signs. Note that the stub healed before the last bit broke off, leaving a pinched-off piece; this affects the accuracy of the formula. In this bolt the discolored wood is as sound as the white wood; it is not moist (thus not redheart), and no organisms have invaded to alter the wood.



FIGURE 5.—HIGH SMALL BRANCH STUB, HEALED.

Full view of a small well-healed stub from high on a paper birch tree. The ellipse form of the stub scar (a 1 : 2 ratio) shows that the stub is buried about halfway between the tree center and the bark. Small, high, well-healed stubs like this indicate discoloration, but not decay.



Dissection reveals that the discolored wood in the stem is sound. The small stub was associated with a column of discoloration that formed after the branch died, when the tree was about 8 inches in diameter at this point. A central column of discoloration had formed earlier after branches died when the tree was about 4 inches in diameter. This is shown by the light-colored boundary streak in the discolored core. As other larger stubs died above, other columns of discoloration formed, enveloping the older and smaller columns.

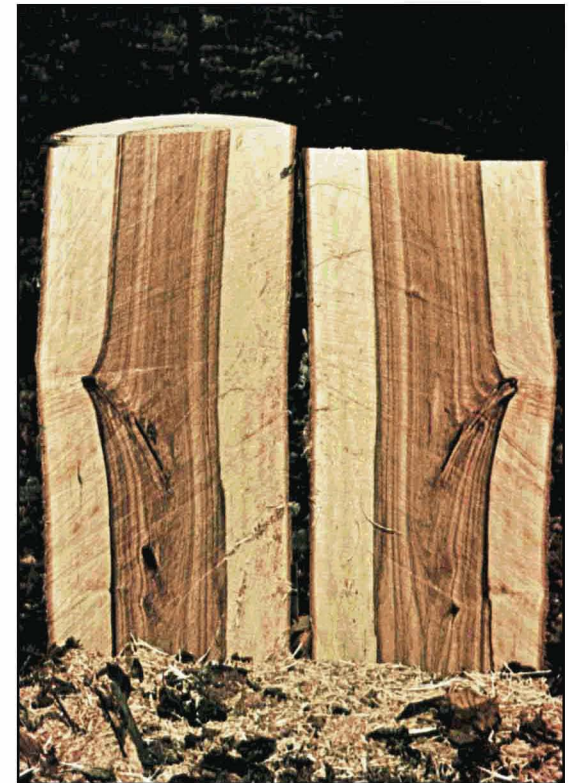


FIGURE 6.—BRANCH STUBS IN SMALL STEMS.



Dissection of these small red maple stems shows that discolorations begin early in the life of the tree. At this age, poorly healed stubs give invading organisms the advantage. A young tree that tends to heal branch wounds slowly is a poor risk for a crop tree.

FIGURE 7.—*HYPOXYLON RUBIGINOSUM* ON STUB.



The red-brown patches on this large low red maple stub are fungus material that contains fruit bodies of *Hypoxylon rubiginosum*, a pioneer invader of wood. Its presence indicates that discoloration is advanced and decay is beginning. Trees that have several large low stubs like this usually have large central cores of defect. Large cracks may form under such stubs; and then the discoloration and decay processes go faster.

H. rubiginosum is one of the few non-Hymenomycetes that cause decay as well as discoloration. It is one of the most aggressive fungi in the forest. It infects both living trees and slash.

FIGURE 8.—BASAL STUB ABOVE ROOT COLLAR.



On this red maple tree a low basal stub joins the stem *above* the root collar. The color and feel of the stub indicate that discoloration and decay are associated with it. The diameter of the stub indicates the diameter of the defect column. Note also a small healed wound above the stub.

Dissection reveals the decay and discoloration in the base. The pattern illustrates the sequence of events in the discoloration and decay processes. The column of discoloration at the top is sound and dry, and no organisms are present. Below, the discoloration is darker and moist (blackheart), and contains organisms that do not cause decay. At the bottom is the dark moist core of decay, which contains decay fungi. The small island of discoloration above is due to the small wound.



FIGURE 9.—BASAL STUB BELOW ROOT COLLAR.

The large decayed stub on this yellow birch is joined to the stem *below* the root collar. This position, plus the angle of the stub, indicates that the decay does not go into the main stem.



Dissection shows that the decayed stub is separate from the main stem and does not affect it. The central column of discoloration marks the diameter of the tree when most of the branch stubs above died.

FIGURE 10.—SPINDLE-SHAPED CANKER ON STUB.

The spindle-shaped canker on this red maple formed after the branch stub was infected with *Polyporus glomeratus*, one of the principal fungi that infect red maple and sugar maple and cause cankers and decay. Sometimes a swollen area forms about the stub. The decay column usually becomes more extensive as it moves up the stem and meets other columns from higher branch stubs, then dwindles in size as it reaches the crown. The fertile stage of this fungus forms on dead and down trees, and the entire stem of a dead tree may be covered with fruit bodies in the fall.



Dissection reveals advanced discoloration and decay. Discoloration occurs first; then *P. glomeratus* infects the discolored wood. After the fungus becomes established, it kills the bark about the stub, thus forming a canker.

FIGURE 11.—SPROUT CLUMP.

A typical red maple sprout clump, formed low on the old parent stump. The parent stump decayed rapidly, so there is little connection between the old stump and the sprouts. If a sprout stem has many poorly healed branch stubs, it has little future value. But if the stubs are small, few, and well-healed, the sprouts can have good future value even if the base looks poor. The poorer sprouts can be cut without causing damage to the remaining sprouts.



stubs. The section at extreme left has a decayed stem stub. The next has a *Polyporus glomeratus* canker; the decay is light-colored, and the rim of the column is dark. All three sections on the right are infected with *P. glomeratus*.

Dissection shows that the base is sound, but all the stems have discoloration and decay due to branch



FIGURE 12.—STEM STUB.



This sugar maple has a stem stub, where once the main stem broke and a branch became the new leader. Such stubs catch and hold water, and this is why they result in more damage than branch stubs of the same size and age. Sound stem stubs indicate discoloration; decayed stem stubs indicate advanced discoloration and decay. Stem stubs are usually found between 4 and 16 feet up the stem.

Dissection shows the pattern of defect from this stem stub. The wood is damaged more near the stub because this area has been affected longer. The discoloration is the diameter of the stub, and it spreads downward. The upper part of the discoloration is blackheart; the tissues are moist and infected with organisms. The lower part of the column is lighter in color, drier, and contains no organisms. The small core of defect in the new leader is due to branch stubs in the new leader.



FIGURE 13.—DECAYED STEM STUB.



The stem stub on this yellow birch decayed; and all that remains is an unhealed stub hole, indicating that the stub has been present a long time. Stem stubs like this are common on birches that have been broken by heavy loads of ice or snow. The discoloration and decay processes have had a long time to work on this tree.

Dissection shows that the older leader has completely decayed. Yet the decay fungi did not advance out into the new tissues. The columns of discoloration that formed later enveloped the old defect column.



FIGURE 14.—STEM STUB IN BEECH.

In this beech tree the original leader died at the 5-foot level. Even though the stem stub completely decayed and the tissues below were decomposed, the base of the tree contains very little defect. In beech, columns of defect narrow abruptly as they approach the base. The boundary of the discoloration column is white in beech.

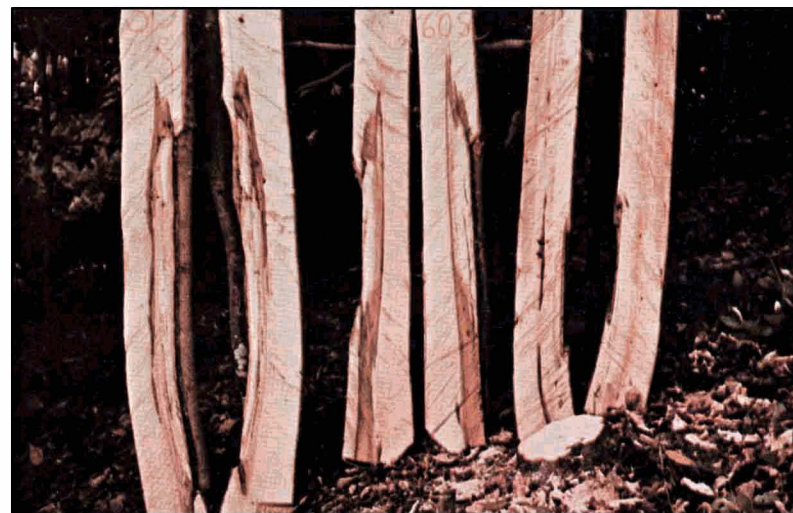


Close-up of a dissected stem stub in beech. Even though the stem stub is decayed, the boundary of the decay is a hard rim, a barrier zone between the defect and the white wood.

FIGURE 15.—LOGGING WOUNDS ON SUGAR MAPLES.



These three sugar maples were wounded by logging equipment, 8 years earlier. The tree on the right is dead; it had severe root wounds. The other two have good callus growth, which indicates vigorous growth; and the well-healed stubs indicate that the wounds, though severe, did not produce extensive decay.



Dissection shows that the dead tree did not develop discoloration. In the other two trees, decay was present, but the defect ended abruptly above the wounds. The defect was wedge-shaped in cross-section. Because the trees had small, well-healed stubs, no central column of discoloration developed; and the wood was white from bark to pith.

FIGURE 16.—LOGGING WOUND ON YELLOW BIRCH.



A severe old logging wound on a yellow birch. The face of the wound is decayed, indicating decay in the tree.

The cross-section shows the effect on growth of the tree. The 2-inch central hard core of discoloration was already in the tree when it was wounded at 6 inches. The discoloration and decay due to the logging wound did not penetrate the smaller defect column. This is another example of multiple columns of defect in living trees. Just as they do not advance out into new tissues, the discoloration and decay also do not penetrate tissues affected earlier.



FIGURE 17.—LOGGING WOUND ON PAPER BIRCH.

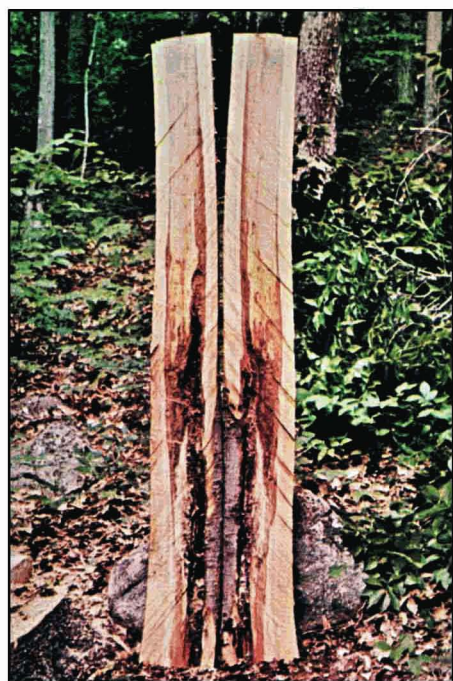
This 100-year old paper birch has a 50-year-old wound, which extends to the base of the tree. There is a wound of similar size and age on the opposite side of the tree.



Dissection of the tree to 16 feet. The lower 8-foot section (right) has a 5-inch hollow center. Yet the decay did not go into the new wood formed after the tree was wounded. In the upper 8-foot section (left) the advance of the decay fungus can be seen as dark streaks in the wood.

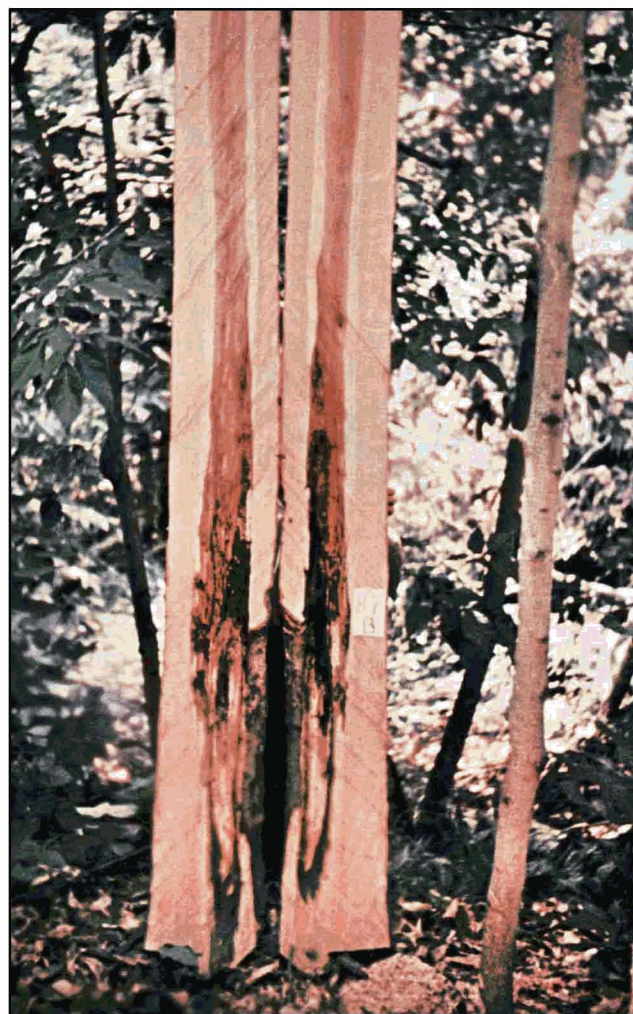
FIGURE 18.—LOGGING WOUND ON BEECH.

A 100-year-old beech tree with a 50-year-old wound, which does not extend to the base of the tree. The hollow behind the wound indicates advanced decay.



Dissection shows that, although the decay is advanced, the base is free of decay. The decay column narrows abruptly above the wound. The boundary of the column is white. The decay advances farthest as a streak above the wound site.

FIGURE 19.—LOGGING WOUND ON BEECH.



This beech tree had a single wound above the base. Dissection shows that the base is clear, but discoloration and decay spread upwards. The decay fungi advanced through tissues first infected by other organisms; and decay was limited to these tissues. A white band surrounds the column of discoloration but not the decay column near the wound. The tissues in the white band contain plugged vessels.

FIGURE 20.—LOGGING WOUNDS ON RED MAPLE.



This red maple has two 8-year-old wounds, the smaller on the left facing the sun, the larger on the right mostly in the shade. The face of the small wound is white; the face of the larger wound is dark. Dark wound faces indicate more defect than light wound faces.



Dissection shows the difference on the lower 8-foot section at left. Very little defect is associated with the small white wound. But the defect caused by the larger dark wound meets the central column of discoloration from the branch stubs. In the upper sections of the tree, the larger branch stubs give rise to dark, moist discoloration and decay. Many stages of discoloration and decay processes can be present in the same stem.

FIGURE 21.—WHITE-FACED WOUND.



This white-faced wound, on a sugar maple with well-healed branch stubs, indicates very limited defect. The face of such a wound is hard, and often has tan streaks.

Cross-sections through the wound and directly above it show that the defect

was limited to the wound area and did not advance above it. The discoloration did not go into the tree center. The small central defect column indicates that the tree lost most of its branches when it was about 3 inches in diameter. The white zone around the central dark columns contains wood with plugged vessels. These tissues are drier than the other tissues.



FIGURE 22.—WELL-HEALED SMALL WOUND.

This yellow birch has a well-healed wound at 5 feet. On vigorous trees shallow narrow wounds like this heal fast. Areas of smooth bark should be checked to determine whether a wound is present.



Dissection shows that hard dark tissue and wavy grain are associated with the wound. The large central defect column indicates that many branch stubs did not heal till late in the life of the tree.

FIGURE 23.—OPEN WOUND.

An open 9-year-old wound on a yellow birch with well-healed stubs. The callos and healed stubs indicate a vigorous tree.



Dissection reveals red-heart associated with the wound. The infected tissues are dark red, moist, and contain decay organisms. The defect column narrows abruptly as it approaches the base of the tree. A well-healed stub is present several feet above the wound.

FIGURE 24.—ROUGH DARK WOUND.



This sugar maple has an 8-year-old wound. The callus tissue is healthy. But the face of the wound is rough, dark, and splintered; and this indicates that the defect may be serious.



Dissection shows decay typical of *Hypoxylon rubiginosum*. The dark, moist column of discoloration is wetwood or black-heart; it extends up to a branch stub at 8 feet. Note that the decay is advancing through the discolored column. In cross-section the defect area is wedge-shaped.

FIGURE 25.—*FOMES APPLANATUS* ON WOUND.

This beech tree has a large basal wound on which can be seen fruit bodies of *Fomes applanatus*, which indicates advanced decay, extending to base and roots. In beech, this is the principal fungus that infects the base. The face of the wound is dark and rough.



Dissection shows that decay extends from the base to 4 feet above the wound, where it ends abruptly. The central column of defect is very wide; this is due to the large wound and the infection of the tree base by *F. applanatus*.

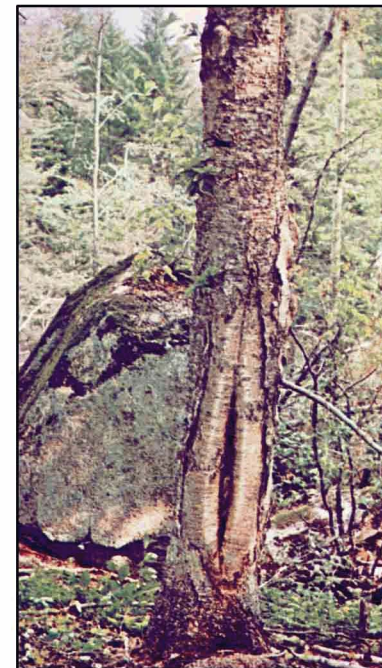
FIGURE 26.—*FOMES IGNIARIUS* ON WOUND.



This beech tree had a fruit body of *Fomes igniarius* at 4 feet. Dissection reveals that decay is extensive above, where it meets defect columns from branch stubs, and narrows toward the base. The decay column is surrounded by a dark band, which is moist and contains other organisms. In the lower section is a smaller defect column that formed when the tree was young. The later defect column enveloped this small column, but *F. igniarius* did not penetrate this small column.

FIGURE 27.—*FOMES IGNIARIUS* VAR. *LAEVIGATUS*.

A 160-year-old yellow birch with a 60-year-old logging wound. The wound surface bears flat brown fruiting bodies of *Fomes igniarius* var. *laevigatus*.



Dissection shows that the decay caused by *F. igniarius* var. *laevigatus*, even after 60 years, has hardly penetrated the central column of discoloration that was formed before the wound occurred. Note that the discolored margin of the decay column is only on the wound side.

FIGURE 28.—*POLYPORUS VERSICOLOR* ON WOUND.



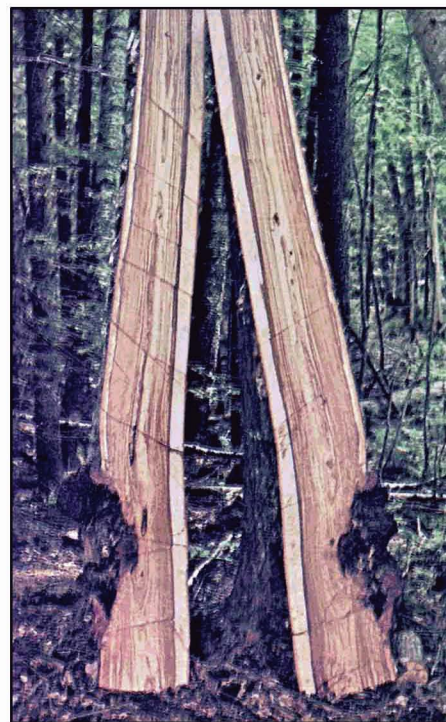
This yellow birch has a severe 8-year-old basal wound bearing fruit bodies of *Polyporus versicolor*. This is one of the first decay fungi to invade the dead wood on the face of a logging wound. The fruit bodies, the dark wound surface, the splintered wound face, and the poorly healed stubs indicate much defect.



Dissection to 16 feet shows the decay caused by *P. versicolor* on the lower margin of the wound, the decay caused by another fungus in the interior of the tree, and the central column of discoloration and decay associated with the branch stubs. The darker discolorations on the sections at left indicate wetwood or redheart.

FIGURE 29.—*PORIA OBLIQUA* ON OLD WOUND.

This is a sterile conk of *Poria obliqua* on an old basal wound on a paper birch. The orange-tan ooze below the conk indicates moist decay. *P. obliqua* infection causes the tree stem to swell so it resembles a bowling pin. A tree with this type of swelling can be identified at a glance as being infected with *P. obliqua*.



Dissection shows advanced decay caused by *P. obliqua*. The decay is darker and moister above the wound. This fungus can kill trees. It kills the bark slowly, and enlarges the wound. The fertile fruit body forms in the wood beneath the bark of dead standing trees. Trees infected with *P. obliqua* should be felled and left on the forest floor.

FIGURE 30.—BOWLING PIN EFFECT FROM
PORIA OBLIQUA.



Dissection of this paper birch to 24 feet reveals the typical bowling pin swelling (butt sections, at left) caused by *Poria obliqua*. Note the range in color. The butt section at left is bright orange-tan, the middle section is tan, and the upper section (right) is light orange to pink. The discoloration and decay are most advanced at the base. The dark rims of earlier defect columns are obvious. As *P. obliqua* kills tissues about the wound, enlarging it, and as new branch stubs form, new columns form and envelop those formed earlier.

FIGURE 31.—OPEN WOUND BY SUGAR
MAPLE BORER.



When injury by the sugar maple borer is severe, large open wounds result. Then the galleries made by the borers can be seen on the wound face. The sugar maple borer (*Glycobius speciosus*) has a 2-year life cycle; and in that time it normally bores in a spiral path to the center of the tree and then bores its way out again. A number of events can halt a borer; and the severity of the wound depends upon how much of its gallery the borer completes.

FIGURE 32.—SELECTIVE ATTACK BY BORER.



The sugar maple on the right was injured by the sugar maple borer at many points on the bole, but the tree on the left was not touched by them. This is common, but we do not know why. The injury done by the borer may be minor, causing no more than a small bump on the bark; or it may be a major wound, exposing the wood and the borer galleries. In an area where borer injury is common, small bumps on the bark may be signs of small aborted borer galleries. Discoloration, decay, and twisted grain are associated with these wounds.

FIGURE 33.—*FOMES CONNATUS* FRUIT BODY AND BORER WOUND.

The large fruit body on the face of the old basal wound on this sugar maple is *Fomes connatus*. It is typically white and moist, and has green moss on top. Above it is a large open wound caused by a sugar maple borer. Borer wounds can be found on all parts of the stem. These beetles apparently are attracted to the trees left after logging. We do not know whether it is the open condition of the stand or the stress after

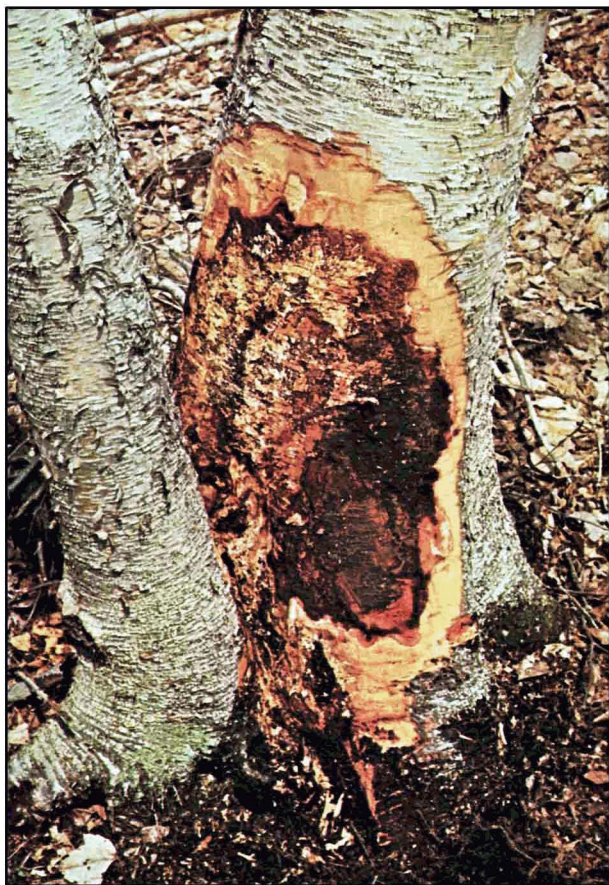


logging that favors borer infestation.



Dissection shows that the sugar maple borer attacked the tree soon after it was wounded at the base. The decay due to *F. connatus* is dark brown to black, and moist. The decay is advanced, but ends a short distance above the fruit body. Another decay fungus is advancing downward from the borer wound. The diameter of the defect column indicates the diameter of the tree when it was wounded.

FIGURE 34.—*ARMILLARIA MELLEA* INFECTING
BASE OF PAPER BIRCH.



The wet orange-brown ooze at the base of this paper birch is a good indicator of *Armillaria mellea* infection. Here the bark was chipped away to show the dead area at the base of the birch and the plates of white fungus tissue. This fungus usually advances upward from the roots. Infected trees should be harvested as soon as possible.

This fungus may act either as a cambium killer, as shown here, or as a root and butt rotter, as shown in the three photographs that follow.

FIGURE 35.—COLLAR CRACK OF PAPER BIRCH.



In yellow birch and paper birch, *Armillaria mellea* infects the roots, and cracks form at the base of the trees. Once the cracks form, other decay fungi have easy access to the bases of the trees. Usually fungi that are more aggressive than *A. mellea* above the base enter at these openings. Once this occurs, the base decays fast. Such trees should be cut as soon as possible.

FIGURE 36.—HOLLOW BUTT CAUSED BY *ARMILLARIA MELLEA*.



Dissection of this beech tree shows a hollow butt (left) caused by *Armillaria mellea* advancing upward from the roots. The hollow in the upper section (right) was caused by other fungi advancing downward from branch stubs. If you see only the ends of logs, and both ends have hollow centers, you might guess that what you see is all one defect from one cause. Often this is not so. Butt decays often end abruptly in northern hardwoods.

FIGURE 37.—*ARMILLARIA MELLEA* ROOT DECAY.

The fruit body of *Armillaria mellea* at the base of this beech tree indicates root and butt decay. Fruit bodies like this can be found only in the fall. Cracks on roots and wet spots usually indicate root decay.



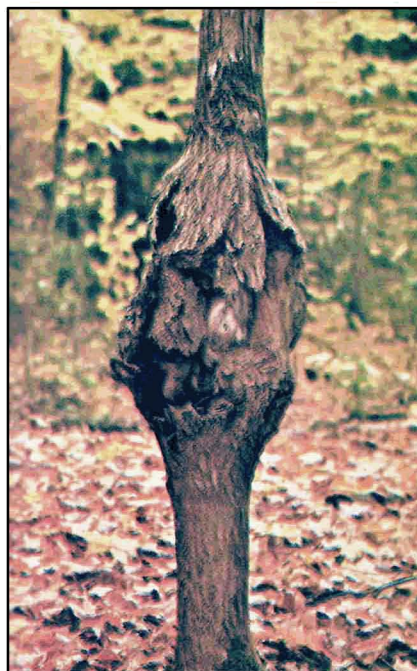
Dissection shows that both the butt and root are decayed. In early stages the infected wood is dark brown and very moist. Dark zone lines are common in the dark discoloration and decay. In later stages *A. mellea* decay is moist, bleached, and stringy. The fungus produces black ropy strands of mycelium that resemble shoestrings — hence the name shoestring fungus. Other organisms, especially bacteria, are associated intimately with *A. mellea*.

FIGURE 38.—NECTRIA CANKER ON PAPER BIRCH.



This target canker on a paper birch tree is caused by *Nectria galligena*. Such cankers usually begin at branch stubs. The face of the canker is hard and light in color. Very little discoloration is associated with these cankers; it may go only a few inches above and below the canker. The cankers themselves are highly decay resistant—except in trees also infected with *Poria obliqua*. Sapsuckers often tap the stem above the canker. These cankers are common on trees on poor sites, especially dry mountain tops.

FIGURE 39.—NECTRIA CANKER ON SUGAR MAPLE.

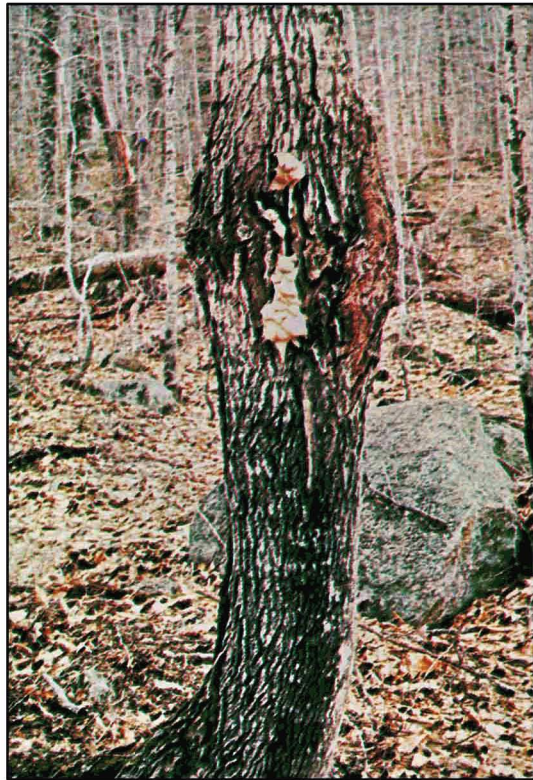


A *Nectria* canker on a small sugar maple. The bark is broken and the hard white surface of the wood is exposed. The minute red fruit bodies of the fungus can be found in these cankers. In some stands such cankers are common.



Dissection shows that discoloration is limited: it does not extend far above or below the canker. The wood in the canker is very dense and heavy. This canker formed below a stem stub.

FIGURE 40.—DECAY FUNGI IN CANKERS.

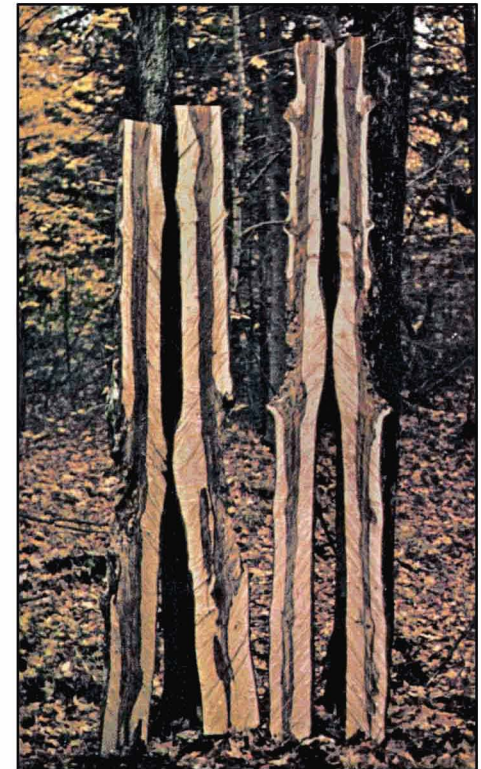


The canker on this sugar maple has been infected by decay fungi. Though decay fungi will infect some cankers, the advance of decay is very slow. *Fomes connatus* is one of the fungi that infect such cankers on sugar maple.

FIGURE 41.—*EUTYPELLA* CANKERS ON SUGAR MAPLE.



Eutypella parasitica caused the cankers on these two sugar maples. Decay by other fungi followed. The fruit body of *E. parasitica* is minute and black, and has a neck about $\frac{1}{4}$ inch long.



Dissection shows that the cankers and the unhealed stubs have made these two trees worthless. However, the defect associated with the cankers alone is very slight. Stems often break at canker sites.

FIGURE 42.—OTHER CANKERS ON SUGAR MAPLE



A canker of unknown origin on a sugar maple. Such cankers are very hard. They are usually found at branch stubs. They are similar to those caused by *Polyporus glomeratus*, except that no sterile conk is present.



Dissection shows that very little defect is associated with this canker. When in doubt about a canker like this, cut it open with an ax: if you find no sterile conk, the defect will be limited to the canker area.

FIGURE 43.—STEM SWELLINGS.



This sugar maple tree had two healed swollen areas near the base. Dissection shows very little defect. When such areas are healed tightly, very little defect is associated with them. Note that the central column of discoloration narrows abruptly toward the base. This kind of stem swelling is common in some areas.

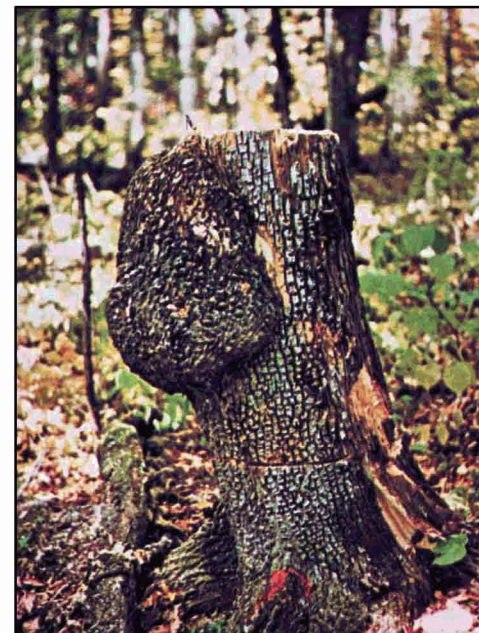
FIGURE 44.—SUNKEN STEM CANKER.



This sunken stem canker on a paper birch is caused by *Fomes igniarius* var. *laevigatus*. These sunken cankers are most common on mature and overmature paper birch and yellow birch trees. They indicate advanced decay—especially on trees with large poorly healed stubs. The fruit body resembles a flattened fruit body of *F. igniarius*.

FIGURE 45.—STEM BURL

A stem burl on an ash tree. Burls and large swollen areas—often called tumors—can be found on all northern hardwood species. The bark is usually intact.



Dissection shows very little defect is associated with burls like this—unless the bark is broken; then decay is often present. Wavy grain is usually found a short distance above and below these abnormal growths. The cause of these burls is not known.

FIGURE 46.—FUSIFORM SWELLING.

Fusiform (spindle-shaped) swelling on the stem of a yellow birch. The bark is rough, thick, corky, and dark on these swollen areas. Swellings like this are also found on other species of northern hardwoods.



Dissection shows very little defect, except hard dark spots in the wood and some wavy grain a short distance above and below the swelling. However, if an ooze is found on the swollen area, you can expect extensive discoloration. The cause of such swelling is not known, but a disease of the outer bark after it has been wounded is suspected.

FIGURE 47.—CORKY BARK.

This sugar maple has a swollen area, with rough corky bark. The wood is not exposed as in *Nectria* cankers. Bark insects are common in the corky bark. Such trees are often found in clusters.



Dissection shows that only slight discoloration is associated with the swollen area under the corky bark. The wood is dense and hard, and often separations occur between some of the growth rings.

FIGURE 48.—LARGE BURLS.



Large burls can be found on all northern hardwood species. This one is on a yellow birch. Very little defect is associated with these large burls as long as the bark is tight. Trees with burls like this are often found in clusters.

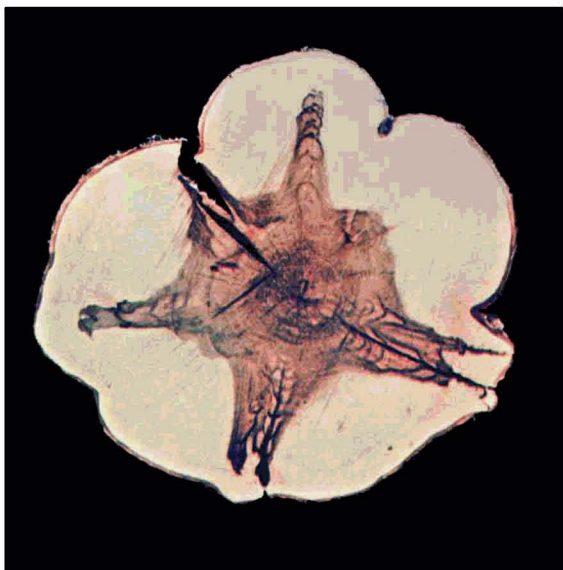
FIGURE 49.—SEAM OR FROST CRACK ON PAPER BIRCH.



The black band on this paper birch marks where cracks formed above and below a wound. The white bark usually falls away from such areas. (This should not be confused with the black bands that form after bark has been stripped off.) The cracks have lips that open in winter and close in summer. Seams or frost cracks often begin at wounds and branch stubs. Discoloration is associated with all cracks, and sometimes decay is too.

**FIGURE 50.—SEAM OR FROST CRACK
ON RED MAPLE.**

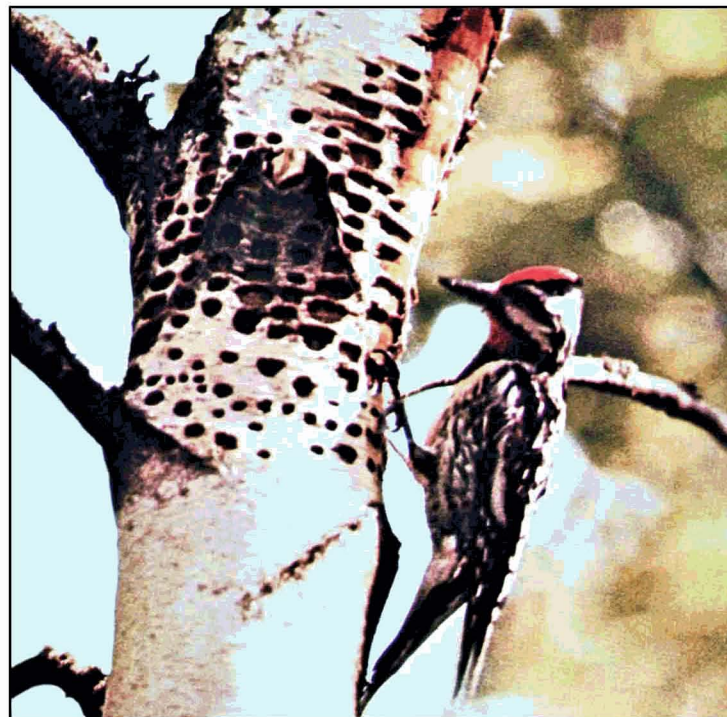
This red maple has a large seam or frost crack, bearing a fungus fruit body. Discoloration and decay is usually associated with stem cracks like this. The open lips on this crack indicate extensive defect.



Cross-section of a red maple stem with five frost cracks shows the pattern of defect. Though the defect often is only a slight discoloration, the pattern makes it difficult to saw out a board free of discoloration.

FIGURE 51.—SAPSUCKER INJURY.

The yellow-bellied sapsucker, which drills holes in living trees, causes considerable damage in the forest.



This section of a yellow birch stem shows typical discolorations from 1-year-old sapsucker wounds. The streaks may be a few inches to more than a foot long. In cross-section they create islands of discoloration.

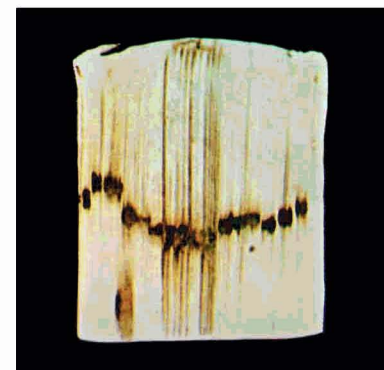


Figure 51, Continued

This shelled-out section of paper birch stem illustrates the ring shake that may form in living trees where sapsuckers have caused severe damage.



Some wood shakes apart later after the boards have been sawed and dried. Drill holes made by the sapsucker can be recognized in the bark after more than 50 years.



This black band on a paper birch bolt is typical of severe injury caused by sapsuckers. Usually seen high on the tree, these bands can be found on all northern hardwood species.

FIGURE 52.—SQUIRREL INJURY.

This wound on a small sugar maple was caused by a red squirrel. Red squirrels bite young trees in the spring to start sap flows, which they drink. The teeth marks can still be seen on the wound surface.



Dissection of a small red maple shows the discoloration caused by injuries inflicted by a red squirrel.

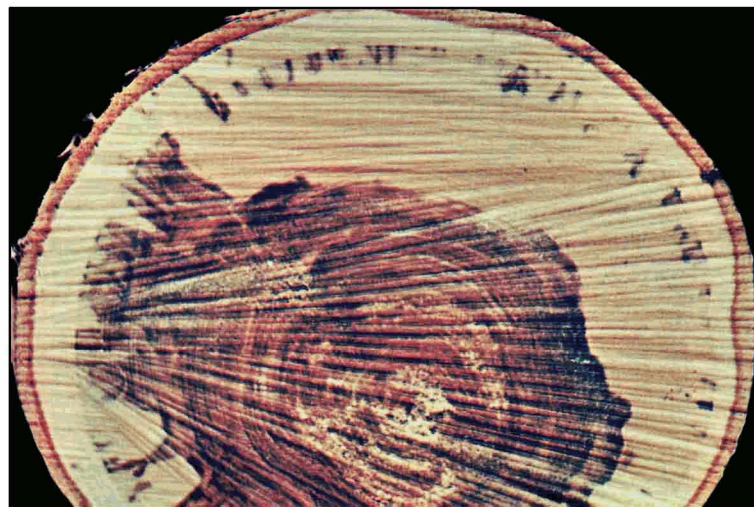
FIGURE 53.—AMBROSIA BEETLES.

The bleeding from this paper birch is from holes made in the bark lenticels by ambrosia beetles. Small bleeding spots like these can be found on all northern hardwood species; and dead spots in the bark are usually associated with them. Bleeding spots may indicate early canker formation.



A hole made in a paper birch by an ambrosia beetle. The discoloration extends several inches above and below the hole. Small holes in bark lenticels signal this kind of defect. Such trees should not be used for veneer.

This cross-section of a paper birch bolt shows the islands of discoloration due to holes made by ambrosia beetles. The islands in some areas merge with the central column of discoloration.



These bolt ends show effects of a light infestation by ambrosia beetles.

FIGURE 54.—CAMBIUM MINER (PHYTOBIA SP.).



This piece of paper birch veneer shows damage due to the cambium miner. Defects like these are sometimes called worm tracks. The injury to the tree is slight, but the damage to the wood is great. The injury can be seen as soon as the tree is cut. In cross-section the insect galleries appear as brown to orange-brown pencil marks about $1/16$ to $1/8$ inch long within the growth rings. If the marks are concentrated in the center of the tree, little damage is done. But if they are scattered throughout the stem, it is ruined for veneer. Cambium miner marks occur in all the northern hardwood species. In the maples they are brown.

FIGURE 55.—PORCUPINE INJURY.



The wound at the base of this beech tree was caused by porcupines. They attack all the northern hardwood species. The teeth marks can be seen even after the wounds are very old. These wounds should be regarded like any other kind of mechanical wounds. Discoloration is commonly associated with them; and decay is associated with old wounds that have dark splintery surfaces. Beavers cause similar injury.

FIGURE 56.—*FOMES CONNATUS*.



The fruit bodies of *Fomes connatus* on this beech tree indicate decay. This fungus causes advanced decay in maples and beech. The decay is dark, wet, and spongy. The decay column ends abruptly a few inches to a few feet above the wound.

FIGURE 57.—*FOMES FOMENTARIUS*.



Fomes fomentarius is common on beech trees injured by the beech bark disease. This fungus usually infects recently killed tissues. Decay is usually limited to the area killed by other agents.

FIGURE 58.—*FOMES IGNIARIUS*.



Seen here on beech, *Fomes igniarius* fruit bodies are common on all northern hardwood species. The fruit body has white flecks inside; these can be seen easily by splitting the fruit body open. Decay caused by this fungus narrows abruptly near the base. How far it extends above the infection depends on other wounds in the tree.

FIGURE 59.—*PHOLIOTA* SP.



Pholiota sp. is a major decay fungus that often goes unnoticed. It is common on the birches, but can be found also on other species. The decay this fungus causes is usually extensive, especially in trees with poorly healed stubs.

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WHAT TO LOOK FOR

Here are the things to look for in estimating the type and extent of discoloration and decay in living northern hardwood trees. Please bear in mind that this is the best information we have now. Research is being continued; and as new knowledge about discoloration and decay is acquired, we hope to be able to refine and modify this guide.

This list of external signs to consider is ranked from the most important to the least.

Branch Stubs

First consider branch stubs—the stubs left where branches have broken and died. In general, large branch stubs 4 to 16 feet up the stem on trees nearing maturity cause the most defect. Stubs in the crown have little effect on the central column of discoloration. Here are the main signs:

- Small branch scars, all well healed: a tree of high vigor, with a small central column of discoloration.
- Many branch scars 4 to 16 feet up the stem, not all well healed: a tree of medium vigor, with a medium-size central column of discoloration. The column tapers toward the base and toward the crown.
- Most stubs well healed, except a few large open stubs at 4 to 16 feet: the discoloration column will be irregular in form.
- Many poorly healed branch stubs: a large central column of discoloration, moist wood, and probably decay.
- Stubs that join the stem below the root collar usually do not affect the main stem. Stubs that join above the root collar cause the most defect. And the farther up into the crown, the less the damage.

Stem Stubs

A stem stub marks where at some time the main stem of the tree has broken, and a secondary stem or branch has taken over dominance to develop into a new main stem. Stem stubs can oc-

cur at any point on the stem, from base to crown; but they are most common between 4 and 16 feet up the stem.

If the remains of the stub can be seen, the size of the defect can be estimated easily: the defect column is the diameter of the stub; and it goes toward the base, narrowing as it nears the base.

Sprout Clumps and Branch Stubs

For sprout clumps, consider first the branch stubs, then the condition of the clump base. A sprout with well-healed branch stubs and a doubtful base is a better risk than a sprout with poorly healed branch stubs and a sound base. A stub with a swollen knot or a spindle-shaped canker (*Polyporus glomeratus*) signals a serious defect. Sprouts with well-healed branch stubs can be cut out of a clump without causing serious damage to the other sprouts of the clump.

Decay-Causing Fungi

Branch stubs are the main entry point for decay-causing fungi. Other types of wounds come second. Branch stubs give entry to the deep interior of the tree; mechanical wounds expose only the exterior layers of wood. Different decay-causing fungi enter these different types of wounds. The principal decay-causing fungi found in an undisturbed area will be different from those found in a logged area where there are many mechanical wounds.

An ooze flowing from an open stub or wound indicates wet-wood or decay, or both. The ooze kills algae growing on the bark, and a bleached area becomes evident. Many fungi produce fruit bodies or sterile masses of fungus tissue on branch stubs or other wounds. Some of the more important fungi to look for are:

Poria obliqua.—The black sterile conk, common on birches, indicates advanced decay. The amount of decay can be judged by the number of poorly healed stubs and other wounds. It may range from 2 to 4 feet above and below the sterile conk, on trees with well-healed stubs, to the entire stem of trees with poorly healed stubs.

On trees with advanced decay, the fungus causes swelling about the entry point. This is easy to see, because the swollen part takes the shape of a bowling pin.

This fungus kills the cambium, and a canker forms. An ooze below the canker indicates a very moist column of decay. The conk also forms on other types of wounds. In advanced stages, the sterile black conks begin to break out at other places on the bark. At this stage the tree is a total loss. Because the fertile stage of the fungus forms beneath the bark of standing trees, infected trees should be felled rather than girdled.

Polyporus glomeratus.—Small masses of sterile black fungus tissue—in swollen knots and spindle-shaped cankers on maple and beech trees—indicate advanced decay. As with *Poria obliqua*, the extent of decay can be judged from the condition of other entry courts: from a few feet to the entire stem.

To determine whether this fungus is present, cut into the swollen knot or spindle-shaped canker: a black cinder-like material flecked with dark brown areas indicates *P. glomeratus*. Also, the decayed wood has a strong medicinal odor.

The length of the spindle-shaped canker equals the length of the defect in the outer portion of the tree. The total defect extends from the central column to the bark, directly below the canker.

Because *P. glomeratus* seldom infects wounds other than branch stubs, the infection points are usually at least 6 feet high on the stem. The bases of infected trees are seldom decayed by *P. glomeratus*. Because the fungus infects stubs, and stubs form up on the bole as branches die, the decay is usually more severe above the lowest point of infection.

It is because of this fungus that branch stubs are more important than parent stumps as infection centers for decay in sprout clumps of red maple.

Fomes igniarius.—This fungus forms a black fruit body on all northern hardwood species. Split it with an ax; and you will see white flecks inside. The fruit body is found on both branch stubs and other wounds. A light-colored dry rot, usually with dark zone lines, is caused by this fungus.

A variety of this fungus, *F. igniarius* var. *laevigatus*, is common on birches. It has a flattened surface; and it is associated with sunken cankers, usually on overmature trees. These fruit

bodies indicate advanced decay, from a few feet to the entire stem, depending on the presence of other infection courts. The decay column usually narrows near the base. This is one of the most common fruit bodies on northern hardwoods.

Fomes applanatus.—The light-colored shelf-like fruit body of this fungus (often called “the artist’s konk” because it has a smooth white undersurface that people have found they can draw on) occurs on all northern hardwood species, usually on wounds and stubs low on the stem. This fungus rots the roots and base of a tree, and causes a wide column of discoloration. The decay caused by *F. applanatus* narrows abruptly as it advances above the wound, unless the tree has other wounds and poorly healed branch stubs on the lower 16-foot section of stem. This fungus continues to grow and produce spores for many years on dead and down logs.

Fomes connatus.—The spongy white fruit body, often covered on top with green moss, is found commonly on maple and beech trees. The presence of the fruit body indicates advanced decay, but the decay ends abruptly above and below the wound unless other wounds are present. This fungus usually infects low wounds; it is most common below 8 feet on the stem. It infects the base of the tree but seldom causes much decay, even when large fruit bodies are present. Decay generally is limited to the lower part of the stem.

Fomes fomentarius.—The fruit body is light gray, and the bottom surface is light in color. It is found on all northern hardwood species. This fungus usually infects dead wood. For example, it is common on beech trees injured by the beech bark disease. Where you find *F. fomentarius*, look for other injuries. The decay is limited to the outer layers of wood under the bark. This fungus seldom infects discolored wood.

Fomes fraxinophilus.—The light gray fruit body usually occurs high on the stems of white ash trees; so it is hard to see when the tree is in leaf. It indicates advanced top decay. On trees with many open branch stubs, the decay may spread down to the 16-foot level.

Armillaria mellea.—This is the honey mushroom, also known as the shoestring mushroom; and it is common in clumps at the

base of northern hardwood species. The cap is light honey-brown, and there is a ring on the upper stem. The fruit body is found in September and late fall. This fungus rots roots, and causes cracks to form at the base of some trees. In birches the condition is called collar crack.

In some areas this fungus builds up heavily, especially where soils are thin and cutting has been heavy over many years, leaving an abundance of root wood in the soil as a food base. Such areas are common where balsam fir is cut; and basal cracks on balsam fir trees are good clues to root-rot areas. Birch trees growing in such areas often have root decay. Many trees with up-turned knobby roots are good evidence of this.

Birches with collar crack should be cut as soon as possible. Once the cracks form, other decay fungi get in and begin to rot the stem. This root-rot fungus causes more damage to forest trees than is commonly realized.

Pholiota species.—Although one of the major species has been identified as *Pholiota squarrosa-adiposa*, other species may be involved, so for this we use the general term *Pholiota* species. These fungi produce yellow to light tan fruit bodies, with scales on their caps, on all species of northern hardwoods—but most commonly on the birches. The fruit bodies can be seen only in the fall. These are among the principal decay fungi, but they often go unnoticed because the fruit body is not perennial.

Pholiota species are associated with advanced decay. They are most common on branch stubs on the lower stem. The firm light-colored to yellow decay narrows above the wound unless there are other branch stubs above; and when the stubs above are well healed, the decay ends within 3 or 4 feet. The decay narrows toward the base of the tree, and the base itself is usually sound.

Stereum murraii.—This fungus causes a canker and white rot of maples and birches, especially red maple and yellow birch. The cankers are common about branch stubs. The cankered part of the stem is flattened, and dull white crust-like patches of the fruit body form on the face of the canker. Decay is limited to about a foot above and below the canker on pole-size trees. On

overmature trees the decay is extensive, especially on yellow birch. The fungus fruits abundantly on dead and down trees. The infected wood has a distinctive odor.

Stereum complicatum.—This is one of the first decay fungi to infect the dead faces of logging wounds. A white decay results. The fruit bodies of *Stereum* species are thin, tough, and have a very smooth light undersurface.

Polyporus versicolor.—Like *Stereum complicatum*, *Polyporus versicolor* also is found on the dead faces of logging wounds. The fruit body is thin and varies in color; the undersurface is white with many small pores.

Hericium species.—These include the coral fungi and the bear's head fungi. They cause a moist dark decay. The fruit bodies are found in the fall.

Hypoxylon species.—The major species that infect northern hardwoods are *H. rubiginosum*, *H. cohaerens*, and *H. coccineum*. Their presence indicates early decay. They produce brown to brick-red patches 1 to 12 inches long, or circular mounds $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter, on wound faces or branch stubs.

Daldinia concentrica.—This fungus also produces brown to brick-red circular mounds, $\frac{1}{2}$ to 3 inches in diameter, on wound faces and branch stubs. It indicates early decay. Species of *Hypoxylon* and *Daldinia* are not closely related to the common decay fungi, yet they do cause decay.

Logging Wounds

Logging causes many wounds of northern hardwood trees. Tractors and skidding machines scrape against trees and injure the base and roots; trees along skid trails are skinned by logs being skidded past; and falling trees fall against standing trees and scrape them. Though some breaking of branches may be due to logging, we consider logging injury mainly as wounds near the base of the tree. Here are some of the features of logging wounds to look for:

- A dark surface on a wound indicates more defect than a hard white surface. A rough surface indicates more defect than a smooth surface.

- Wounds below the root collar injure the base of the tree; wounds above the root collar seldom injure the base.
- Root wounds, which may be hidden by leaves and litter, may result in basal decay.
- Defects are limited to the wood present when the tree was wounded. How far the defect extends into the tree depends on the severity of the wound.
- Multiple wounds on the same tree result in severe defect.
- Logging wounds on trees with well-healed stubs indicate less defect than similar wounds on trees with many open stubs.
- Fruit bodies of fungi indicate decay.
- Vigorous callus indicates limited decay.
- Healed wounds indicate limited defect; but some wavy grain can be expected around healed wounds.
- Where insects bore into the tree through logging wounds, considerably more defect can be expected.
- The fungus fruit bodies common on logging wounds—and that can be seen easily—are, in order of appearance: *Hypoxylon* species, *Stereum complicatum*, *Daldinia concentrica*, *Polyporus versicolor*, *Polyporus* species, *Pholiota* species, *Fomes applanatus*, *Fomes igniarius*, and *Poria obliqua*.

Sugar Maple Borer

The sugar maple borer (*Glycobius speciosus*) bores through the bark into the wood of sugar maple trees. This beetle has a 2-year life cycle: 2 years from the time it enters the tree till it emerges. During this time any number of events may occur to kill the beetle; so the wound and the defect may vary from minor to severe, depending on how long the beetle is in the tree. In high winds, trees often break at the site of borer wounds.

In the beginning the gallery the beetle makes is small. Minor wounds heal, leaving small raised areas on the stem. Small galleries can be found by cutting into the small closed wounds. As the wounds become more severe, the bark falls away, and the

gallery of the beetle is exposed. Some of the borer holes may be 1/2 inch in diameter and several feet long. The beetle spirals around and into the stem.

Discoloration is common both above and below the wounds; and decay may be associated with big old wounds. *Fomes con-natus* may infect these wounds. The defect is continuous near the wound; but as the discoloration spreads, it forms streaks of discoloration. The pattern is like a hand with outstretched fingers. A cross-section of the stem at the palm of the defect reveals a solid continuous defect; but a cross-section through the fingers shows island of defect. These are often called mineral streaks.

Sapsucker Wounds

The yellow-bellied sapsucker (*Sphyrapicus varius*), a species of woodpecker, feeds on all northern hardwood species, drilling into the tree to drink the sap. Sapsucker feeding trees are often found near the margins of areas recently logged, or near roadsides in full sunlight. There is some indication that sapsuckers prefer trees already weakened. The wounds they make have three patterns:

1. Rows of wounds scattered over the stem. These wounds cause streaks of discoloration, some extending a foot or more above and below the wound—especially in yellow birch. In cross-section of the wood, the discoloration looks like small islands. On sugar maple, the sap that flows from such wounds is often covered by black fungi; so black bark on sugar maple is a good sign of sapsucker injury.

2. Wounds concentrated in one spot, in one season. This kind of wound often causes a dark band on the tree. Discolored streaks form above and below such wounds. Also, ring shake is associated with such wounds; the extent of the shake depends upon the severity of the wounds and the time since wounding.

3. Wounds concentrated in one spot, over several seasons. These are found on feeding trees that the sapsuckers revisit year after year. The sapsuckers drill all around the top of the tree. Decay often forms behind the large open wounds. Squirrels and other small animals enlarge the wounds and aggravate the injury. These wounds can kill the section of stem attacked and the

branches above. When the wounds encircle the stem below the crown, the entire tree may die.

Cambium Miner

The cambium miner (*Phytobia* species: more than one species may be involved) attacks all species of northern hardwoods. This fly lays eggs on the upper branches of the tree. The young larvae mine down the stem through the cambium and often into the adjacent wood. The minute wounds they make in the wood cause small discolorations called pith flecks.

These marks can easily be seen on the freshly cut stump or log end, like pencil marks 1/16 to 1/8 inch long along the growth rings. In birches the flecks are red-brown, in maples dark brown.

The amount of this defect that can be accepted depends on the product. For example, if the marks are many, and in the outer layers of wood, the stem usually cannot be used for veneer, for the flecks will appear on the veneer as long streaks. If the marks are confined to the central core, the stem can be used for veneer. As the logs age, the marks become harder to detect.

Squirrel Wounds

Early in the spring red squirrels (*Tamiasciurus hudsonicus*) inflict feeding wounds on smooth-barked young sugar maples and red maples. The squirrels bite the trees, usually on the south side, to start the sap flowing; then they drink the sap after it has begun to evaporate. Black-green streaks of discoloration form above and below the wounds; and various organisms infect some wounds and cause cankers. The tooth marks of the squirrels persist for at least 10 years on the wound faces.

Ambrosia Beetles

The ambrosia beetle (*Xyloterinus politus*) attacks birch trees that have already been wounded and weakened by other agents. The adult beetles bore into the tree at the lenticels to lay their eggs; and the young develop in the tree, which may continue to lose vigor and finally may die.

When a tree recovers, the beetles leave; but their small galleries in the wood remain. Discolorations form above and below the wounds. The number of holes in the lenticels indicates the

number of discoloration streaks. As the tree grows older, the bark thickens about the holes, and nodular mounds form. Trees with many holes cannot be used for veneer. The beetle holes remain visible for as long as 40 years.

Sometimes the beetle holes are infested by a scale insect, *Xylococcus betulae*. A sure sign of this is the white wax tube from the insect's anus, which protrudes as much as an inch out of the hole in the bark. Woodpeckers feed on these scale insects and thus keep the wounds open. Small bark flaps indicate woodpecker activity.

Seams and Frost Cracks

Seams and frost cracks may form on all northern hardwood species. Often they begin where the stem has already been weakened by mechanical wounds or branch stubs. Cracks that have evaginated lips indicate defects that penetrate the stem. Cracks without lips are often superficial. When trees have several cracks with lips, the defect pattern inside the tree may be star-shaped in cross-section; so it is impossible to saw high-quality boards from such trees. Fungus fruit bodies in cracks indicate decay.

Nectria Canker

Nectria canker, caused by the fungus *Nectria galligena*, may form on all the northern hardwood species.

The cankers commonly form about branch stubs. Discoloration is associated with the cankers; but the defect rarely goes more than a few inches above and below the canker. The bark falls from the stem, and hard white wood is exposed. Trees often break at the canker.

The canker itself is very hard and decay-resistant. *Fomes conatus* and *Poria obliqua* are sometimes found in the cankers. When *N. galligena* infects logging wounds, the defect is usually limited to a few inches above and below the wound. The fruit bodies are minute red lemon-shaped structures. You can find them (with a hand lens) in the bark cracks between dead and living bark.

Eutypella Canker

This kind of canker, caused by the fungus *Eutypella parasitica*, is found on maples. These cankers are sometimes called "cobra cankers" because the tree stem becomes flattened and bends back somewhat like a cobra about to strike. Though the canker occurs on young trees, it takes the cobra form only on older trees. The fungus commonly infects branch stubs. The defect is limited to several inches above and below the canker. The fruit bodies of the fungus are minute black forms with necks up to 1/4 inch long.

Burls and Swollen Stems

Burls and swollen stems occur on all the northern hardwoods. The fusiform (spindle-shaped) swollen areas on maples and birches are probably different from the common burl. No wood is exposed on the swollen areas. But here the bark is very corky, and you often may find frass from bark-mining insects on this corky bark. Some fusiform swellings may be due to fungi infecting the outer bark.

Defect from burls is usually limited to the area of the burl or swelling. The discolorations are brown-red to green in maples, and bright orange-red in birches. Wavy grain may form in the stem. When an ooze flows from the swollen part, the discoloration is advanced, and may extend 4 to 6 feet above and below the swelling. This advanced defect is most common on yellow birch.

Fire Wounds

Fire wounds are not common in northern hardwood forests, but you may find some on mature trees along old railroad lines. The wounds are bell-shaped, and always at the base of the tree. Such wounds are usually associated with serious decay. On mature trees with well-healed stubs, the decay may extend 4 to 6 feet above the wound. On old trees with large open stubs the decay may extend as much as 12 feet above the wound.

Beech Bark Disease

Beech bark disease is caused by Nectria fungi—especially *Nectria coccinea* var. *faginata*—that infect bark wounds made by the scale insect *Cryptococcus fagi*. The disease may kill small areas

on the stem, though the bark remains smooth. Sometimes a callus ridge forms to wall off the dead spots; and little defect results. But trees heavily infested by the insect and then infected by the fungus are killed. Such trees should be salvaged as soon as possible.

Secondary decay organisms are quick to attack trees that have beech bark disease. *Hypoxylon* species, *Fomes fomentarius*, and others invade the wood beneath the bark. Fruit bodies on the dead bark indicate decay. Check for *Hypoxylon* species first.

Cankers caused by another scale insect, *Xylococcus betulae*, may follow the onset of beech bark disease. These cankers have a slit through the center. A white wax tube 1/2 to 1 inch long, which protrudes from the insect, is a sure sign of the presence of this scale insect. An individual canker causes little defect, but many of them together cause serious damage.

Bleeding Cankers

Bleeding cankers can be found on all northern hardwood species. On birches and beech, the oozing liquid is red to red-tan; on maples it is black. The wet spots in the bark are associated with dead areas on the stem. These may be small spots less than 1 inch in diameter; or they may be long strips extending several feet from dead roots far up the stem. Bleeding spots are most common directly below branches.

Isolated bleeding spots may indicate insect injury, or they may indicate an early stage of canker formation. On birches, check bleeding spots for ambrosia beetle injury.

Stem Borers

The stem borer *Xylotrechus aceris* attacks young red maple trees, usually near a branch stub. The wound looks like a small sugar maple borer wound. Dark moist discoloration and decay are associated with the wounds, and several infestations can cause serious injury to young trees. Infested trees should be cut in early weedings.

Many other stem-boring insects attack northern hardwood trees, mostly those trees already weakened by other agents. One example is the bronze birch borer (*Agrilus anxius*), which attacks the trees

injured in logging; and the pigeon tremex (*Tremex columba*), which attacks beech trees weakened by beech bark disease. Wounds by these insects initiate the discoloration and decay processes; and trees injured by these insects should be harvested as soon as possible.

In general, if you see signs of attack by stem-boring insects, look for some other primary cause of injury to the tree.

Sunscald

Sunscald may occur when tree bark that has been shaded all its life is suddenly exposed to long periods of full sunlight. This happens when trees are exposed by windthrow or logging operations. The bark is often killed and falls away, leaving a wound face that is usually bright white and dry. Discoloration processes begin as soon as the bark dies, but little defect results. However, insects may infest the wounds, and sometimes woodpeckers drill for these insects and wound the surface enough to begin discoloration and decay processes. Sunscald does not injure large trees much, but may severely injure young trees with thin bark.

Hypoxylon Species

Hypoxylon species are among the most aggressive fungi that infect wounds recently inflicted. They may cause cankers and injure all northern hardwood species in various ways. However, the *Hypoxylon* cankers are not common. On maples, a target-shaped canker forms about branch stubs. The red-brown mounds of fungus tissue that contain the fruit bodies can be found on the canker face. The mounds, 1/8 to 1/4 inch in diameter and jet black inside, may occur in clusters. The common result is a dull red and white mottled discoloration and decay 1 to 2 feet above and below the canker.

The coal fungus, *Hypoxylon deustum* (*Ustulina vulgaris*), causes a white rot in the lower parts of maples and beech. The fungus tissues that contain the fruit bodies are black and crusty, resembling coal. In wounds on overmature trees, this fungus may cause decay 1 to 3 feet above the wound. The coal fungus is common on old stumps, which look like black burned wood. The

decayed wood due to the coal fungus has many black zone lines.

Hypoxylon species also injure the tops of suppressed young beech trees. Once established in a dead leader, the fungus grows slowly down the main stem. This kind of injury is common in thick stands of young beech under heavy shade. The result is a dull red and white discoloration and decay.

RECOMMENDATIONS

From what we know now about the patterns of discoloration and decay in the wood of living northern hardwood trees and about the external signals of this decay and discoloration, we can offer some recommendations. Our recommendations are aimed to answer two questions: What can we do to assure future crops of high-quality trees? And how can we make the most of what we now have?

We do not mean to say that this is the last word on the subject. We do not have all the answers now. But we are continuing our research on this subject, and we hope to use whatever new knowledge we acquire to further clarify and refine our present concepts. Meanwhile, the knowledge we have now can be put to some practical use.

General

First, learn to recognize the external signs of defect in the wood of the living tree, and to understand the processes of discoloration and decay. This is suggested as an aid to making decisions about treatment of the individual tree and the forest stand.

Do not overestimate the amount of defect in northern hardwood trees. This is easy to do. As you have seen, northern hardwood trees have a way of sealing off their defects and limiting them to certain areas so that clear new wood can grow, unaffected by earlier defects. Some wounds that look very bad do little damage to the wood.

Bear in mind that time is important: the most serious wounds cause little damage in a short time; decay takes time. If you can

tell the age of the wound—dates of past logging jobs might be helpful—this might help you estimate the severity of the damage.

Mature Trees

Carefully evaluate all the external signs of discoloration and decay to make the most reliable possible estimate of the wood quality in the tree, and the pattern of the decay and discoloration. Watch especially for poorly healed stubs, on all species.

Again, do not overestimate the amount of decay. In the northern hardwoods, decay columns end abruptly. Columns of discoloration and decay advance up and down the stem, as time passes, but they do not spread outward into the new wood formed after the tree was injured.

Put each tree to the best use that its pattern of discoloration and decay allows. Be cautious in selecting trees for high-quality uses such as veneer if there are signs of many small damaging defects such as injuries by ambrosia beetles, sugar maple borers, cambium miner galleries, and sapsucker holes.

Sprout Clumps

From sprout clumps, select for crop trees the one or two dominant stems that have well-healed small stubs. Do not consider using clumps whose stems all have many poorly healed stubs.

Young Trees

In selecting young trees to favor for future growth as crop trees, select those that have lost their lower branches and have healed branch-stub wounds.

Use silvicultural practices to grow trees that are tall and slender with well-developed crowns, and whose branches below the 16-foot height are few and small.

Do not select for crop trees those that have any cankers, sugar maple borer injury, or large cracks at the base. Above all, do not select those that have many large unhealed branch-stub wounds.

Differentiate carefully between those signs of discoloration and decay that may look serious but do not indicate poor vigor—such as mechanical wounds—and those that do indicate poor vigor—such as unhealed stubs. Favor trees of good vigor.

Pruning

The purpose of pruning should not be to prevent all defect, but rather *to limit* defect to a small central core. Much past emphasis has been put on how to prune without causing discoloration and decay. This may be impossible: some discoloration and decay cannot be avoided. The question is rather: how much central defect can a log have and still contain a large volume of high-quality wood?

So if you want to limit the defects in trees to a central core less than 4 inches in diameter, then treat the trees when they are 4 inches in diameter. How treat them? Prune those you want to keep, and cut the rest.

Which trees should be pruned? Certainly not all trees, for pruning takes time and costs money. Select for pruning those trees that have few low heavy branches, and have healed their branch stubs well. Do not waste time and money on trees that show signs of poor stub healing.

Prune to make good trees into better ones. But economically it is not yet good practice to try to make poor trees into good ones.

The Stand

High-quality trees tend to occur in groups; and so do low-quality trees. So consider not only the individual tree, but also the stand.

Consider the species in the stand. One area seldom supports good growth of all the species. And on some areas, trees simply do not grow well. For example, mountain tops are no place for birch: tops break, and *Nectria* cankers abound.

In looking at a particular species in a stand, look at the whole group of trees of that species for a sign of defect that can be recognized easily. Determine how common that defect is among that species in that stand. For example, sugar maple borer wounds often occur in groups of trees. If you find them on one tree, you may easily find them on 50 more. The same applies for swollen knots on red maple, galls on yellow birch, and collar cracks on paper birch. This is often called the "cluster effect."

Where you find a cluster of individuals that have signs of the same defect, evaluate those trees for the pattern of discoloration and decay in their wood. Then you can decide what to do with those trees.

Also, in areas where diseases have killed or deformed many of the trees, do not cut the few trees that have remained healthy and vigorous and have healed their wounds well. These may be the genetically resistant trees that are needed for seed to regenerate better stands for the future.



For Additional Information —

see Shigo, Alex L., *SUCCESSION OF ORGANISMS IN DISCOLORATION AND DECAY OF WOOD: International Review of Forestry Research II*: 237-299. Academic Press, New York, 1967. This publication lists 300 literature references on this subject.

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