Influence of *Cryphonectria parasitica* Basal Cankers on Radial Growth of Scarlet Oak in Pennsylvania

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ABSTRACT

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Basal cankers induced by *Cryphonectria parasitica* (= *Endothia parasitica*) occur throughout the natural range of scarlet oak (*Quercus coccinea*) within Pennsylvania. Because colonization of scarlet oak is thought to be a long-term host/pathogen relationship, analyses were conducted to investigate effects of basal cankers on radial growth (expressed as area increment) at 1.4 m, breast height (BH). Moderately cankered oaks grew more slowly at BH than did noncankered trees. However, severely cankered scarlet oaks generally exhibited greater radial growth at BH than did noncankered trees. This apparent anomaly likely reflects stimulated growth at BH due to the fungal infection.

Additional keywords: chestnut blight, dendrochronology, tree-ring analysis

Although the use of tree-ring analyses to study the growth of trees, especially as related to climate, is well established (2,4), few investigators have used tree-ring analyses to compare growth of diseased versus healthy trees. Han et al. (7) used tree-ring analyses to compare the radial growth of healthy white ash (*Fraxinus americana* L.) trees with those infected by ash yellows in the northeastern United States. They concluded that most diseased ash trees were growing more slowly than nondiseased trees. Van Deusen and Snow (15) reported that slash pine (*Pinus elliottii* Engelm.) infected with the needle blight fungus *Lophodermella cerina* (Darker) Darker in the southeastern United States produced less radial growth than did the nonblighted trees. McClenahan (9) advocated the use of tree-ring analysis to detect and reconstruct, and to thereby more clearly understand the nature of tree declines at both the individual and the population level. Dwyer et al. (3) used dendrochronological analyses to study black oak (*Quercus velutina* Lam.) and scarlet oak (*Q. coccinea* Münchh.) decline in the Missouri Ozarks but did not relate their findings to specific oak diseases.

We previously reported that basal cankers of scarlet oak, caused by *Cryphonectria*

parasitica (Murrill) Barr (= *Endothia parasitica* (Murrill) P.J. Anderson & H.W. Anderson), are widespread in Pennsylvania (14). However, the influence of this disease on yield, as measured by radial growth, of scarlet oak has not been reported. The objectives of this study were to compare the radial growth of cankered (basal cankers only) versus noncankered scarlet oak trees using tree-ring analyses, and to compare growth rates of infected trees differing in canker severity.

MATERIALS AND METHODS

Four oak stands located in the Buchanan, Forbes, Michaux, and Rothrock state forests of Pennsylvania, previously identified as having a significant component of infected scarlet oak trees, were selected for this study (14). In each stand, 15 cankered and 15 noncankered, codominant scarlet oaks near the stand center were selected as described (14). Diameter (D) at breast height (1.4 m, BH), D at 0.3 m height, and D at the ground line were recorded. For cankered trees, the height and width of each basal canker was measured, and depth of cankering into the tree was estimated. By definition, a basal canker had its lower edge at the groundline. Using these measurements, the approximate volume of each canker was estimated and expressed as percentage of the tree's lower stem volume. Bole or trunk cankers, usually associated with branch stubs on scarlet oak, were not considered in this study.

Two increment cores per tree were removed 180° apart at BH from all trees. Since external symptoms (e.g., swelling and/or distortion) of the cankers did not extend to BH, increment cores were always

taken from noncankered areas. Cores were placed in labeled paper straws and returned to the laboratory. Increment cores were air-dried and glued in grooved wooden mounts, with vessels of each core oriented vertically. Cores were sanded with progressively finer grits of sandpaper and buffed with lamb's wool to enhance ring boundaries. Widths of annual rings were measured to the nearest 0.01 mm using a Bannister Incremental Measuring Machine (Fred C. Henson Co., Mission Viejo, CA) interfaced with the microcomputer program TRIMS (Tree Ring Incremental Measuring System) developed by Madera Software, Tucson, AZ. A randomly selected subset of 10% of the cores was re-measured. Error between the two measurements was calculated using methods of Phipps and Field (12) as modified by Long (8). If the error was greater than the acceptable limits reported, the source of the error was located and corrected by re-measuring the core. Ultimately, all core measurements were within the prescribed limits of accuracy (12).

For each core, the radius (distance from cambium to pith) of the trunk at BH was determined for use in area calculations. For cores that contained the pith, the radius was determined using the ring width measurements themselves. For cores that did not contain the pith, the location of the pith was estimated by determining the geometric center of the arc of the earliest visible ring. The radius was then estimated by measuring the distance from the calculated pith location to the outermost complete annual ring.

Increment cores from each stand were visually cross-dated (4) to ensure that each ring width was assigned to the correct year. This procedure also aids in the detection of missing or double rings. Although missing rings do not normally occur in oak, double rings can be occasionally induced in white oaks, at least on branches, by diseases such as oak wilt (13). Following visual cross dating, data from all 240 cores (2 cores per tree, 30 trees per stand, 4 stands) were analyzed using the quality control program COFECHA (6), which matches ring patterns of individual cores with a master chronology created from all the cores in each stand. Where patterns did not match, the individual cores in question were re-measured, and the source of error was located and corrected. Only two of the 240

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cores could not be cross-dated; data from these two cores were not utilized in the analyses.

For each core, the basal area increment (BAI; area of tree growth formed at BH for the given year) was calculated from the annual ring width and radius length (12). For each stand, individual scarlet oak core BAI values were averaged to create three chronologies (sets of cross-datable cores): for noncankered trees, moderately cankered trees, and severely cankered trees.

The term “noncankered” implies that there were no readily apparent external basal cankers. The latter two severity categories were determined by approximating the cankered volume of the lower bole below BH and comparing it with the stand average. If the percentage of cankered volume for a tree was equal to or less than the mean percentage cankered volume per tree for all diseased trees in each stand, the severity was considered to be moderate. Severely cankered trees had a percent can-

kered volume greater than the stand mean for infected trees.

The influence of *Cryphonectria* basal canker on growth of scarlet oak at BH was determined using two methods. First, for each year, the mean growth value of the noncankered trees in each stand was subtracted from the mean value of the moderately or severely cankered trees, resulting in positive or negative values. Negative differences indicate that the cankered trees within each category of cankering were growing less than the noncankered trees, whereas positive differences indicate that the cankered trees were exhibiting greater growth compared with noncankered trees. Second, the *actual* annual growth (expressed as mean basal area increment) of noncankered, moderately cankered, and severely cankered trees within each stand was determined and plotted.

RESULTS

The average ages at BH for scarlet oaks in the Buchanan, Forbes, Michaux, and Rothrock stands were 67, 48, 85, and 64 years, respectively (Table 1). The percent

Table 1. Mean percentage of the lower 0.3 m of trunk volume cankered for infected scarlet oaks in each stand

State forest	Stand age (yr.)	Mean % volume cankered/stand	Mean % volume cankered/category ^a	
			Moderate	Severe
Buchanan	67	23	16 (10)	33 (5)
Forbes	48	23	13 (8)	32 (7)
Michaux	85	31	21 (7)	40 (8)
Rothrock	64	21	12 (10)	31 (5)

^a Moderately infected trees were those whose volume of cankered tissue was less than the mean. The severely cankered category contained those trees whose cankered volume was greater than the mean. Numbers in parentheses indicate the actual number of trees (out of 15) assigned to each category.

Fig. 1. Mean annual basal area growth differences (cm²) of moderately and severely cankered scarlet oaks compared with noncankered trees in the (A) Buchanan, (B) Forbes, (C) Michaux, and (D) Rothrock state forest stands. The horizontal line at zero represents a zero difference in growth between (moderately or severely) cankered trees and noncankered trees within that stand. Positive differences indicate that cankered trees were growing better than noncankered trees, and negative differences indicate that cankered were growing more poorly than noncankered trees.

volume of the lower bole that was cankered below 0.3 m, and the mean values for determining the canker severity classes for each stand also are given. Moderate cankers, which by definition had values less than the mean volume cankered for that respective stand, occupied 12 to 21% of the lower trunk volume. Severe cankers occupied 31 to 40% of the lower trunk volume within respective stands. Cankers occupied the most volume in the Michaux stand, which at 85 years was the oldest stand. Mean canker volume was the smallest in the Rothrock stand, which was 64 years old. However, except for the Michaux stand, the mean percent volume cankered per stand was fairly uniform (Table 1).

Figure 1A to D illustrates the relative differences in mean annual growth (expressed as basal area differences) between noncankered and cankered trees in each stand. In the Buchanan stand (Fig. 1A), the noncankered and severely cankered trees generally were growing similarly. That is, the difference in annual growth values between these two groups of trees was generally near zero. The moderately cankered trees were growing slightly

more slowly than the noncankered trees, as evidenced by the negative values. By 1990, the difference between the growth of the noncankered trees and the severely cankered trees was essentially zero. The difference between the growth of the noncankered and moderately cankered trees in 1990 was about $2 \text{ cm}^2 \text{ year}^{-1}$.

In the Forbes (the youngest) stand (Fig. 1B), noncankered and cankered trees began to exhibit different stand-average growth rates in the mid-1960s. After this time, the severely diseased trees grew more rapidly (note increasing positive values) at BH relative to the noncankered trees until the mid-1980s, when the relative growth decreased. By 1990, the severely cankered trees were growing 2 to $3 \text{ cm}^2 \text{ year}^{-1}$ more than the noncankered trees. In contrast, the moderately cankered trees in the Forbes stand generally grew more slowly (note negative values) than the noncankered trees after the mid-1960s. By 1990, growth of the latter two groups of trees was similar.

In the Michaux stand (Fig. 1C), the severely cankered trees grew somewhat more slowly than the noncankered trees until approximately 1970, after which they grew

more rapidly than the noncankered trees. Growth of the moderately cankered trees generally was similar to that of the noncankered trees until the late 1930s. After this point, the moderately cankered trees consistently grew less than the noncankered trees. By 1990, the difference was pronounced.

In the Rothrock stand (Fig. 1D), the severely cankered trees grew much faster than the noncankered trees throughout most of their lives, whereas the moderately cankered trees grew at rates slightly faster than the growth of the noncankered trees. By 1990, the severely cankered trees grew several square centimeters more per year than did the noncankered trees.

Figure 2A to D illustrates the annual variation in growth, as well as overall growth patterns, for noncankered and cankered trees in the four stands. In the Buchanan stand (Fig. 2A) and the Michaux stand (Fig. 2C), there appeared to be little influence of degree of cankering on the high-frequency variation (large year-to-year fluctuations). In the Forbes stand (Fig. 2B), there was a slight increase in this variation in the severely cankered trees after the mid-1970s. The severely cankered

Fig. 2. Mean annual basal area increment (cm^2) for noncankered, moderately cankered, and severely cankered scarlet oaks sampled in the (A) Buchanan, (B) Forbes, (C) Michaux, and (D) Rothrock state forest stands.

trees in the Rothrock stand exhibited a pronounced increase in high frequency variation in growth beginning in the mid-1950s (Fig. 2D).

In the Buchanan stand (Fig. 2A), as well as in the remaining three stands (Fig. 2B to D), the growth patterns of trees in various categories of cankering were synchronous. That is, the positive or negative inflections on the growth curve in a given year were generally similar among trees in the different categories of cankering.

DISCUSSION

Han et al. (7) reported that diseased ash trees suffering from ash yellows produced less radial growth than did trees without ash yellows. We anticipated similar results for the diseased scarlet oaks with basal *Cryphonectria* cankers. However, in our study, the influence of the disease on radial growth was confounded by the degree of cankering. At some point, the growth of moderately cankered trees compared with that of the noncankered group became less in three of four stands, as expected, but growth was slightly greater in the remaining stand for unknown reasons. However, overall, the relative growth of moderately cankered trees tended to be less than that of the noncankered trees, as we had assumed would happen. It is likely that the moderate basal cankers were killing cambium and impeding water uptake, decreasing radial growth at BH. Or the relatively slow growth of the moderately cankered group may reflect the tendency for cankered trees to be of lower overall growth vigor. Except perhaps for the Rothrock stand (Fig. 1D), there was some point in the chronology where growth of moderately cankered trees clearly departed from that of noncankered trees, but not necessarily in precise synchrony with relative growth changes in the severely cankered group. The reason for this departure at a given time in the life of the stand is unknown, but it may reflect the time at which the canker affects growth at BH. The timing of this departure may also be related in some manner to the stand age (e.g., young versus old stands), stand history (e.g., basal fire scars as infection courts), ecological factors such as competition or site quality, or individual tree tolerance to the event that initiated a change in the growth rate.

In contrast to our assumptions, persistent radial growth increases occurred among severely cankered trees relative to noncankered trees in three of the four stands, although the timing of the onset of the growth increase varied among stands (Fig. 1). The growth divergence between severely cankered and noncankered trees tended to be associated with periods of increasing growth (Figs. 1 and 2). In the Forbes stand in 1968 and the Rothrock stand in 1955, increasing growth and growth divergence closely coincided. In the Michaux stand, growth divergence was

apparent by 1973 following a marked growth increase (or recovery) that began around 1970. An exception, the Buchanan stand (Figs. 1A and 2A), showed a consistently similar growth regardless of degree of cankering.

We can only speculate on the reasons for the greater radial growth at BH often exhibited by severely cankered trees. These trees may have been inherently fast growing and maintained their inherent fast growth following cankering, but this is not supported by their early relative growth patterns (Fig. 1). A more likely possibility is that the fungus stimulated the severely cankered host to produce wider growth rings (at BH). That is, the observed differences in relative growth patterns may have resulted from enhanced callus formation at 1.4-m height on the stem (where the increment cores were extracted) when improved growth conditions coincided with extensive canker development. For clarification, radial growth data should be obtained at a greater standard height on the stem, well above the potential influence of cankering on ring width. Also, the use of tree-ring analysis from cores taken at BH to produce yield (radial growth) data in such situations must be used with caution, and the results must be interpreted in light of possible callus formation.

We observed occasional infected scarlet oaks in the field with the large "swollen butts" described by Ham (5) and Nash and Stambaugh (11). In these severe cases, the swelling and distortion extended almost to BH, but often only on one face of the trunk. We did not record aspect (compass direction) of the canker face in relation to where the two increment cores were removed, so we cannot comment on this relationship. This factor should be taken into account in future studies.

The growth of the severely cankered trees deviated from that of healthy trees at a relatively early age in some stands. This increase in growth may indicate early scarlet oak infection by *Cryphonectria*, and supports Ham's (5) conclusion that the basal canker is the result of a long-term interaction between the fungus and the host. This conclusion is further supported by Bissegger and Heiniger (1), who found *C. parasitica* cankers on young stems (approximately 10 years, BH $\leq$ 8 cm) of oak (*Quercus petraea* Liebl.) in Switzerland. The authors stated that *C. parasitica* disease development appeared to be slow on oak, and that some of the oaks were apparently initially infected at 3 to 4 years of age. It is possible that scarlet oaks likewise may become infected with *C. parasitica* at a very young age. Dissection of cankers to determine date of canker initiation would help answer such questions.

Examination of the nonsmoothed growth trends (Fig. 2) revealed year-to-year variations in annual growth. Variations in growth rates were generally synchronous,

even when comparing growth of trees having different amounts of cankering. That is, when factors were favorable for growth, most trees grew better, regardless of the amount of cankering. When factors were not favorable for growth, most trees grew less, irrespective of cankering severity. An interesting growth phenomenon was exhibited by scarlet oaks in the Rothrock stand (Fig. 2D). In this stand, the severely cankered scarlet oaks exhibited increased year-to-year growth variability after the mid-1950s. This variation may indicate the time at which the basal infection influenced radial growth at BH, either by diffusive growth stimulants or by callus tissue formation.

In spite of the apparent growth stimulation at BH in severely cankered trees, obvious timber loss occurred due to the canker that *Cryphonectria* induced in the butt log. In addition, the wood underlying the basal cankers was often infested with carpenter ants and infected with decay fungi, which further deteriorated the butt log, resulting in additional volume loss. We observed that the lower meter of the butt log of scarlet oaks with one or more basal cankers was often discarded in the forest during logging operations. This is often the most valuable part of the trunk. Also, scarlet oak is very drought sensitive (10), and we observed that large trees with severe basal cankering were often the first trees in an oak stand to succumb to drought-induced mortality. Therefore, although there may be an apparent increased growth rate at BH in severely infected trees, the overall timber yield of the severely cankered trees is likely reduced. This loss, in conjunction with the fact that the moderately infected trees often exhibited radial growth loss, leads to the conclusion that *Cryphonectria* basal cankers reduce the yield of scarlet oaks.

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