Reconstructing the development of two Ozark chinquapin (*Castanea ozarkensis*) stands in the pre-blight forests of northwest Arkansas[1]

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PAILLET, F. L. AND K. C. CERNY (University of Arkansas, Fayetteville, AR 72701). Reconstructing the development of two Ozark chinquapin (*Castanea ozarkensis*) stands in the pre-blight forests of northwest Arkansas, J. Torrey Bot. Soc. 139: 211–225. 2012.—A survey of Ozark chinquapin in northwest Arkansas showed the tree to be widespread but uncommon, locally concentrated on sandstone benches and upper slopes in karst terrain. The remains of pre-blight chinquapin trees were mapped and measured on two 200 ha sites in Benton and Washington counties. Tree density was estimated at about 1 tree per ha, consistent with published upland witness tree surveys. 108 relatively intact logs were documented, representing about half of the total large chinquapins estimated to have grown on the two sites. Most of these grew as single-stemmed trees up to 20 m in height and 40 cm in diameter. The predominance of single-stemmed trees may indicate the relative absence of fire in pre-blight forests. The lack of subsequent sprouts from the base of large trees and the abundance of living sprout clones not associated with old trees indicates most sprouts are old seedlings. Tree rings were used to reconstruct stand history on six 20 × 60 m plots. Release of adjacent trees showed that blight arrived in 1957. Stand recruitment was concentrated in an extended period from 1920 to 1940, with a few older trees dating to the mid 1800's. Estimated ages for chinquapin logs seemed to pre-date oak and hickory recruitment, suggesting release of suppressed understory stems. Tree rings were used to determine the diameter of trees on the plots in 1955. Height-diameter projections were used to compare the stature of the stand with reconstructed remains of chinquapin logs, demonstrating that Ozark chinquapin was growing as a canopy-dominant tree at the time when blight arrived.

Key words: Chestnut blight, chinquapin growth form, disturbance ecology, forest reconstruction, Ozark chinquapin, stand history.

The native chinquapin of the Ozark region was previously characterized as a separate species (*Castanea arkansana*, Ashe 1923); and more recently reduced to a variety of the species *C. pumila* (Allegheny chinquapin) (Tucker 1975, Johnson 1985). We follow most modern usage in referring to Ozark chinquapin of northwest Arkansas as *C. ozarkensis* Ashe (Moore 1992). Older botanical literature reported that Ozark chinquapin grew as a substantial tree reaching up to 1 m in diameter, and heights of 18–20 meters (Ashe 1923, Moore 1992). Large Ozark chinquapins were subsequently killed by the introduced chestnut blight, which reached the Ozarks after 1950 (Hepting 1974, Anagnostakis 1987). Root sprouts from chinquapin continue to live in the understory of upland oak-hickory forests and occasionally manage to produce small nut crops before being killed back by the blight (Graves 1950). Almost all chinquapin clones seen today in the Ozarks grow as small bushes or heavily suppressed subcanopy trees that rarely exceed about 3 m in height or 10 cm in diameter.

In an earlier study of Ozark chinquapin, Paillet (1993) noted remains of large blight-killed chinquapin trees that were more than 40 cm in diameter and generally had a definite treelike growth form at locations in the Ozark National Forest of north-central Arkansas. He also noted that the numerous living chinquapin sprout clones on the forest floor showed a striking similarity to repeatedly blighted American chestnut sprouts within the range of that species. Chinquapin sprout clones showed the same ability to withstand heavy suppression for extended periods, and then attain growth rates significantly greater than those of competing species in the wake of canopy opening. In fact, local foresters noted that chinquapin often dominated wildlife clear-cuts in the first four or five years after overstory removal (Ralph Odegard, personal communication 1991) in the same way that chestnut sprouts are known to dominate woody vegetation in similar clear-cuts in the Appalachians (Boring et al. 1981). By analogy to chestnut at other locations, and based on the lack of

recognizable remains of canopy-sized trees adjacent to the living sprouts, Paillet (1993) indicated that most of the surviving Ozark chinquapin sprout clones represent "old seedlings" that never attained large tree size. A few chinquapin sprouts surviving today have attained substantial size since the original appearance of blight, while others have retained a small, shrubby stature through repeated cycles of blight girdling and resprouting. Otherwise, observations show that very few of the large original canopy-sized chinquapin managed to survive after initial blight girdling. The one major difference noted for Ozark chinquapin was the mode of sprout generation. Chestnut is observed to sprout almost exclusively from pre-formed buds on the root collar (Matoon 1909, Paillet 1984) whereas Ozark and Allegheny chinquapin generate sprouts from an extended region of callous tissue developed around the root collar (designated as woody lignotuber by Del Tredici, 2001).

This study was undertaken to document the stature (growth form, competitive status, and ecology) of Ozark chinquapin at two representative locations in the pre-blight forests of the Ozarks. There is some urgency behind this effort because it has been more than 50 years since blight killed these trees, so that downed wood is deteriorating. We are fortunate in that *Castanea* wood is especially decay resistant (Panshin et al. 1964). The popularity of controlled burns as a forest management technique now threatens to erase much of the remaining evidence presently available about pre-blight chinquapin by destroying these residual stems along with the information they provide about their size, shape and ring-width history. Immediate action is now required if the size and growth form of the original chinquapin blight killed by the chestnut blight in the Ozarks is to be documented.

Study Sites and Methods. Study sites were selected after surveying the presence of pre-blight chinquapin wood and surviving chinquapin sprouts in northwest Arkansas. Most abundant sprouts and the remains of large chinquapin trees judged to have been killed by the original pandemic of chestnut blight (hereafter referred to as original blight kill) were consistently found on locations underlain by the Boone Limestone formation. Although chestnut and chinquapin are known for
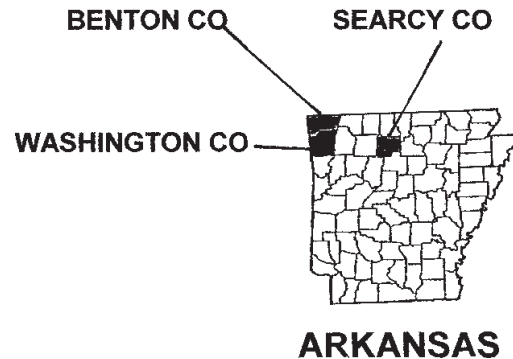

FIG. 1. Location of the study sites at Hobbs Conservation Area (Benton County), Wedington Block of Ozark National Forest (Washington County), and Tyler Bed at Buffalo National River (Searcy County).

avoiding alkaline soils developed on limestone (Braun 1950), the Boone Formation weathers to a deeply dissected landscape characterized by precipitous ravines and sinkholes. The abundant chert in the formation is left as a gravel-like residuum with an acidic pH in the 4.5–6.0 range (Schalm 1973). Chinquapin oak (*Quercus muehlenbergii* Engelm.), known to be associated with calcium-rich soils is consistently present in the area, but the acidic nature of the cherty residuum is indicated by an almost continuous shrub layer of *Vaccinium* spp. Chinquapin was found to be widely distributed but relatively uncommon on sandstone ledges and benches wherever soils are not derived from the Boone Limestone.

We selected three potential study sites: the Wedington block of the Ozark National Forest near Fayetteville, The Hobbs Conservation Area east of Rogers, and the Tyler Bend section of the Buffalo National River southeast of Harrison (Fig. 1). All three locations are characterized by deeply dissected terrain developed on the Boone Limestone. Tyler Bend was found to be a useful location for the study of chinquapin sprouts, but the remains of original blight kill were largely consumed by surface fires over more than half the area. Both Wedington and Hobbs were found to have many well-preserved chinquapin logs, and numerous living chinquapin sprout clones. The Wedington site was originally a mosaic of woodlots and subsistence farms taken over by the Soil Conservation Service in 1938 and eventually transferred to the Forest Service in 1964 (Schalm 1973). At

the time of take-over, plowed fields and open pastures were planted to pines, and in other areas with an assortment of hardwoods where tree cover was deemed unacceptably sparse. This appears to have been mostly bottomland along major drainages, and can be traced by the presence of tree species either not native to the area (*Liriodendron tulipifera* L. and *Quercus michauxii* Nutt.) or not otherwise common in the area *(Liquidambar styraciflua* L.). Our study focused on the part of the area that was mapped as woodland in 1938 and was largely free of any alien species. The upland forest habitat containing chinquapin is dominated by oaks (*Q. alba* L., *Q. stellata* Wangenh., *Q. velutina* Lamb., with some *Q. muehlenbergii* Engelm., *Q. falcate* Michx., *Q. rubra* L., and *Q. marilandica* Muenchh.), hickory (*Carya cordiformis* Wangenh. (K.koch) and *C. texana*), and black gum (*Nyssa sylvatica* Marsh.). The subcanopy contains red maple (*Acer rubrum* L.), dogwood (*Cornus florida* L.) and serviceberry (*Amelancheir Canadensis* (L.) Medik.). The forest at Wedington contains no native pine and almost no red cedar (*Juniperus virginiana* L.). The shrub layer is largely composed of hazel (*Corylus americana* Marshall) and one to several *Vaccinium* spp.

The Hobbs Conservation Area has always been wooded but was heavily logged for pine in the late 1800s by the Van Winkle Mill (Valentino 2006), and then selectively logged for hardwoods up until at least 1940 by the Hobbs Tie and Timber Company (http://www. friendsofhobbs.com/history). Local residents (Bill Sharp, personal communication, 2010) report that the logged-over woodland was heavily used by livestock as late as 1920, with such use gradually waning until about 1940. Our study focused on a sub-area of Hobbs that has been protected against fire since the land was acquired by the Arkansas State Park system in 1979. The upland forest is similar to that at Wedington, with the addition of a major native pine component (*Pinus echinata* Mill.) and the lack of hazel.

We selected two representative areas of 2 square kilometers each for detailed mapping at Wedington (Washington County) and Hobbs (Benton County) (Fig. 1), hereafter referred to as study sites. We mapped the location of old original blight kill and the distribution of living and dead sprout clones. Original blight kill was identified by the distinctive characteristics of *Castanea* wood (Panshin et al. 1964).

Only trees that would have been larger than 15 cm in diameter with bark on (13 cm without bark) and appearing so deeply weathered as to be 50 years old were selected. We measured the diameter and length of all well-preserved chinquapin logs, diagramming the horizontal planform of each such tree. Diameter was sometimes difficult to measure exactly because the lower sections of trunks had a tendency to be hollow and partially collapsed. The intent was to provide diameter estimates at the height of 1.5 m above ground level, but some measurements were made higher on the trunk and extrapolated down to 1.5 m by estimating the taper of the trunk cylinder. Tree height with intact crown was estimated by assuming an additional 1.5 m of height for every 1 cm of diameter on the uppermost branch of the tree remains. This was based on observations of a limited sample of living chinquapin trees with diameters from 15–20 cm that had temporarily escaped blight and displayed single-stemmed, upright growth form. We then selected three locations (hereafter referred to as study areas) at each site where we mapped the positions of all canopy trees, live chinquapin sprouts and dead chinquapin wood on a 20 × 60 m transect centered on one or more well-preserved remains of large chinquapin trees assumed to have been killed in the original blight pandemic. All dead wood identified as *Castanea* was assumed to be chinquapin since the range of American chestnut does not extend west of the Mississippi and there are no records of chestnut having been planted at either Wedington or Hobbs. We cored all living trees greater than 15 cm in diameter on each transect, and took sections from any reasonably intact standing dead or downed wood (including the chinquapin logs). Tree cores were used to: 1) determine release dates indicating when blight removed large chinquapin trees from the forest; 2) determine the disturbance history of the local study area and how that might relate to the origin of dead and living trees on each specific site; and 3) reconstruct the stature of the forest at the time when chinquapin blight arrived in the area. The detailed results from the six study areas are necessarily a limited sample of conditions on the study sites, but are assumed to be representative of the conditions in the vicinity of typical groves of chinquapin that characterized the pre-blight forest in northwest Arkansas.

The final step in the data analysis was a reconstruction of the forest and the chinquapin trees within that forest immediately before blight first arrived in the area. We estimated that time should be about 1955, and release dates subsequently confirmed that 1955 just preceded the date of the blight pandemic. We measured the diameter and height of each tree using baseline and clinometer on a 10 m wide strip passing through the center of the transect. We then used the cores from trees on the transect to determine their diameter in 1955, with 2.5 cm added to allow for bark thickness, and projections of growth rates made for the few hollow trees where rings did not extend back to 1955. Fallen trees were added by cross-dating cross-sections for logs and snags that were intact enough to yield useful data. For all of these trees we have two data points: present day height and diameter and another point where both diameter and height are zero. If tree growth is treated as a first-order resource allocation process, the solution to the relevant differential equation is an exponential function characterized by amplitude and curvature. Amplitude is given by the present height and diameter. We then have to decide what curvature (given as the exponential "decay constant" associated with one cm of diameter increase) best represents the tree growth trend. We did this by recognizing that the six study areas had been continuously forested at least since the late 1800s, so that the height-diameter distribution on the areas today can be used as an approximation for the height-diameter distribution when trees competed under similar forested conditions in the past. A single exponential decay constant was found to bracket the distribution of points on the height-diameter distribution at the six areas, with a few outliers on the low side representing trees with major crown loss in a recent ice storm (Fig. 2a). This analysis allowed us to compare the reconstructed stature of the long dead chinquapin trees to the surrounding trees in the forest as it existed in 1955 (Fig. 2b).

Results. The chinquapin distributions in the two study sites selected for detailed investigation (Hobbs and Wedington) show an irregular distribution of both sprouts and original blight-killed trees. The old trees were almost entirely restricted to the edges of ridges located just above steep slopes and were found in
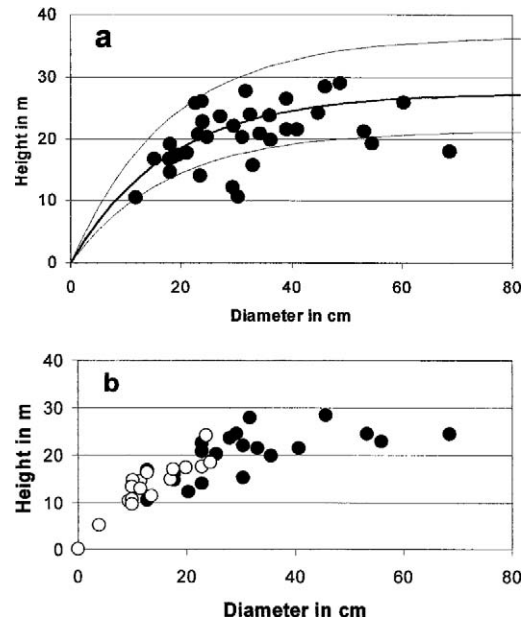

FIG. 2. Diameter-height distributions for area A at Hobbs: a) all modern trees on the 20 × 60 m area bracketed by exponential growth curves using a growth decay scale of 17 cm; and b) modern trees along the center of the area (solid circles) compared to the population of trees inferred to have been located on this area in 1955 after correcting ice-storm damaged crowns (open circles).

small clusters of a few to a dozen or so separated by areas with no recognizable evidence for original blight kill. One-hundred eight individual trees were intact enough to provide meaningful reconstructions of the former trees. Some large pieces of broken chinquapin wood were found such that other trees were clearly present, but their size and shape could not be documented. A few other such remains probably escaped detection in debris piles or under the jumbled remains of trees that collapsed in the 2009 ice storm. We estimate that about 60% of the 2 km² area at each of the two sites was suitable upland (upper slope and ridgetop) habitat for chinquapin. If we further assume that the 108 individual trees represent about half of the total that were originally present, then large canopy or subcanopy chinquapins had an average density of about 1 per ha. This appears to contradict recollections of some older residents, but their impressions may be biased by the concentration of chinquapin along the upper edges of ravines where they were indeed locally abundant, although large
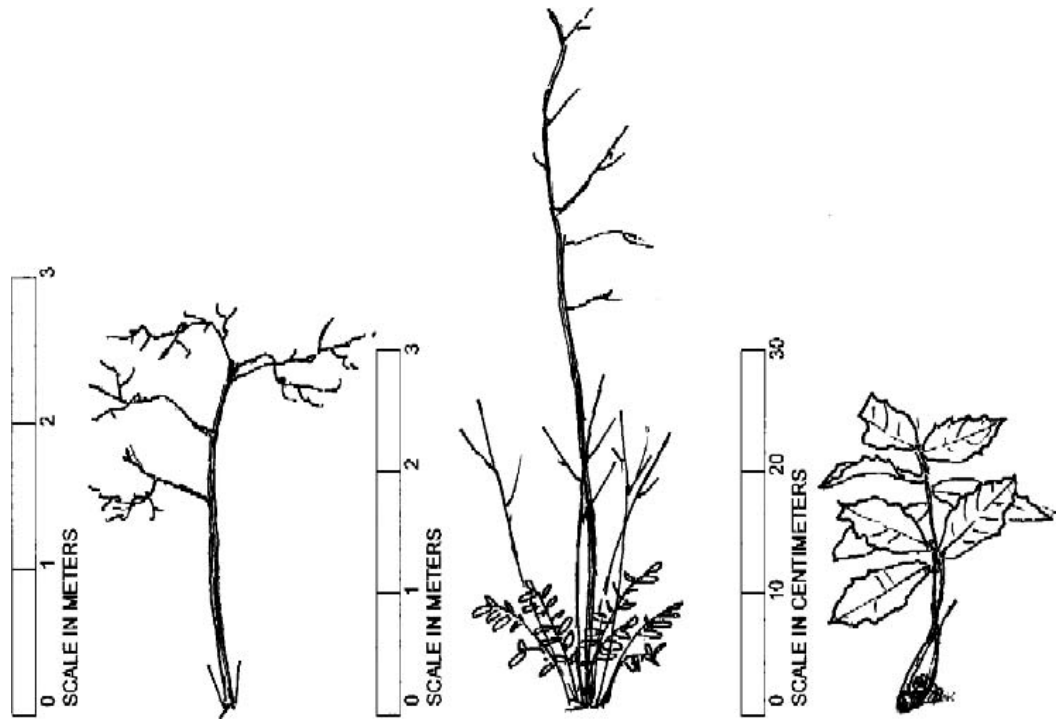
FIG. 3.   Typical sizes and shapes of surviving chinquapin sprout clones at Wedington, Hobbs, and Tyler Bend: a) sprout clone growing in a closed forest not subjected to disturbance for many years; b) sprout clone subjected to fire in the previous winter and four years earlier; c) heavily suppressed clone subjected to several cycles of die-back and resprouting in dense shade.

intervening areas had no such large chinquapin trees at all. The relatively low average density of large chinquapin trees in Ozark uplands is supported by a survey of witness tree records (Foti 2004) where chinquapin compromised 7 out of 792 entries or just under 1% of the witness tree population described by early surveyors. On that basis, large chinquapins were about as abundant as white ash (1.3% of witness trees), which, like chinquapin, can be described as widespread but not abundant in Ozark upland forests.

Live and recently dead chinquapin sprouts had a similarly irregular distribution, and seem to be loosely clustered around the former seed source provided by the large, blight-killed trees. Live chinquapin sprouts were relatively sparse at Wedington, being absent or very rare in some areas with the remains of large trees, and sporadically present in other locations with otherwise similar remains. In contrast, Hobbs had a rather dense distribution of sprouts, many of which appear to have died in the past two decades. Local sampling of live and dead clones at Hobbs consistently indicated about 150 clones per hectare, with more than half now completely dead. No dead clones were found at Wedington, and highest concentrations of sprouts never exceeded more than 10 or 20 per hectare. Since almost none of the large blight killed logs showed any indication that they regenerated viable sprouts after they were killed, and because the density of sprouts at Hobbs greatly exceeds the pre-blight population of large trees, we conclude that most surviving chinquapin sprouts found today had never attained a canopy or sub-canopy position. These seem similar in both growth form and density to the chestnut "seedling sprouts" described by Paillet (1984, 2002) in Massachusetts. We found that the growth form of chinquapin sprouts could be separated into three classes (Fig. 3): small subcanopy stems with a single-stemmed tree form; clusters of vigorous stems released by damage from ice storm, fire, or blight; and small and heavily suppressed clusters of very small and crooked stems. Although this observation seems to have little relevance to the documentation of the size and shape of the
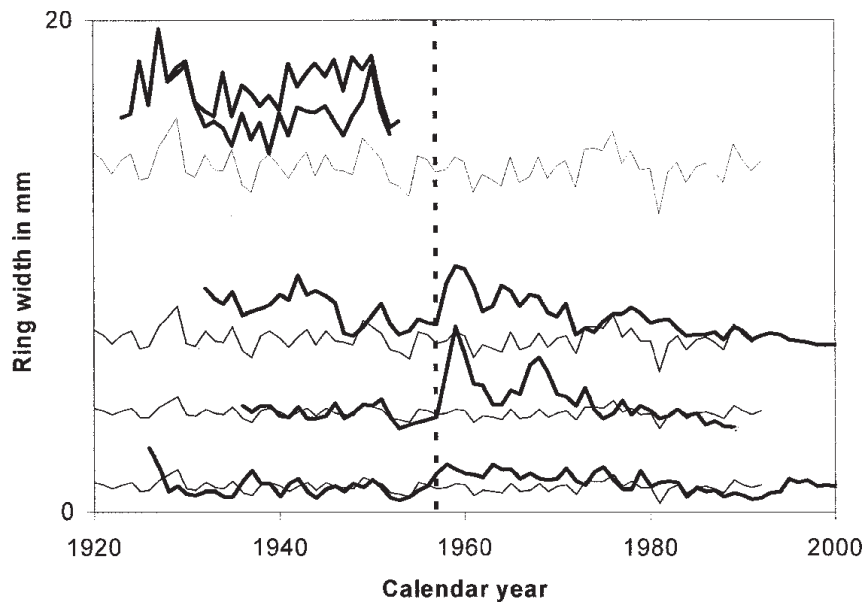
Fig. 4.   Tree ring series (bold) compared to amplitude adjusted Wedington post oak chronology from Stahle (1992) for: (top) two sections from an old chinquapin log on Hobbs study area C, and (bottom) three oak cores (two living white oaks and a ring-dated black oak snag) taken from trees growing next to former large chinquapins from Hobbs, Wedington and Tyler Bend study sites. Dashed vertical line denotes blight arrival date.

original blight kill, sprout growth form is relevant to the growth form of trees that might develop when they are released as advanced regeneration.

We determined the time of original blight appearance by selecting mature oaks within 3 m of the base of former large chinquapin trees. In every case, the released oaks showed that the first year of enhanced growth was the 1958 growing season, so that competition from the chinquapin was effective until the end of 1957 (Fig. 4). The release date identification is complicated by the occurrence of a severe drought that suppressed growth on all trees over the 1952–1954 time period. Some oak releases seem to start in 1954 as the trees were coming out of the drought conditions. We addressed this by using a standardized Wedington post-oak ring chronology (Stahle 1992) to represent the climate potential for each tree. We adjusted the amplitude of the Wedington chronology such that the individual oak and chronology trends coincided for the period before 1952, providing an effective

Table 1.   Summary of measurements made on original blight-kill chinquapin on the Hobbs and Wedington study sites.

Parameter	Hobbs site	Wedington site
Number of samples	52	56
Diameter range	13–48 cm	13–51 cm
Average diameter	26.2 cm	24.5 cm
Log length range	3.7–20.7 m	4.9–14.3 m
Average log length	10.9 m	10.4 m
Estimated height range	9.4–25.3 m	8.2–17.3 m
Average estimated height	15.7 m	13.7 m
Height low main branch range	1.2–7.9 m	1.2–7.0 m
Average ht low main branch	3.5 m	3.5 m
Percent single stemmed	74	59
Percent double stemmed	23	18
Percent 3 or more stems	3	23
Percent with basal sprouts	23	18

FIG. 5.   Representative examples of the planforms of original chinquapin blight kill showing tree forms that closely represent the shape of the average log. Note the prevalence of large lower branches on all and the remains of basal sprouts on two of the four.

indication of growth potential predicted by the standard chronology for each individual oak that would apply in the absence of other conditions such as release from competition with an adjacent tree. In each case, the post oak chronology growth prediction and the individual oak ring-width series tracked each other coming out of the drought and up to the 1957 growing season. The 1958 ring width clearly corresponds to the first year in which each released oak showed a growth rate far in excess of that "predicted" by climate as represented by the standard chronology of Stahle (1992).

The measurement of old chinquapin logs showed that many of the trees on the two study sites had a consistent growth form (Table 1). Figure 5 shows examples of four such trees selected to represent the average of the sampled trees. Most of the measured logs (nearly 74% at Hobbs and 59% at Wedington) had a single upright stem. Many of the rest had two approximately equal-sized stems, and very few consisted of 3 to as many as 8 large trunks at Hobbs, with more than 20% of the trees having several stems at Wedington (Fig. 6). Diameters ranged from 13 to more

FIG. 6. Examples of unusual or extreme forms of chinquapin logs, showing trees with double or many trunks, and an original blight-killed chinquapin with evidence of prolonged basal sprouting after the arrival of blight.

than 40 cm, averaging just under 30 cm without bark (26.2 cm at Hobbs and 24.5 cm at Wedington), and with some outer wood possibly eroded (Fig. 7). The logs had lengths ranging from about 4 to more than 20 m, and reconstructed heights of 8 to 25 m. Average reconstructed height was about 15 m, compared to an average present canopy height of 20–24 m (Fig. 8). Trunks showed evidence of the lowest major branch at heights from 1–8 m, averaging 3.5 m. A significant number of logs (about 20% in all) showed the presence of small basal stems attached to the root collar, and their small size indicates that such remains could have decayed beyond detection in other cases. These basal stems seem similar to the basal stems attached to live, canopy dominant chestnut trees showing no sign of injury or distress as described by Paillet and Rutter (1989) in the West Salem chestnut outlier before blight arrived at that stand, and by Pridnya et al (1996) for a virgin European chestnut (*C. sativa*) forest in Russia. Most trees showed large lower branches within a few meters of the ground, and numerous bayonet-shaped stem joints where upward growth

could have been deflected by disease or injury. Only two of the reconstructed logs showed definite evidence that they had produced sprouts that reached more than several cm in diameter and persisted over a substantial period after the original stem was killed by blight in 1957 (Fig. 6).

We attempted to obtain datable ring width series from sections taken from original blight-killed logs. However, almost all of these trees had major hollows in the base of the trunk, and the ring-width series from the remaining wood failed to show a meaningful correlation with the standard chronology when processed using COFECHA (Grissino-Mayer 2001). In one case we were able to take a sound section from a 40 cm log but only at a point about 6 m above the base where trunk diameter had decreased to 33 cm, with a second partial section collected about 3 m from the base. The ring series from the upper intact section yielded a significant cross-correlation with the post oak chronology to indicate an inner pith date of 1923 and an outermost partial ring dated at 1954. Two ring series measured on this cross-section are shown at the top of
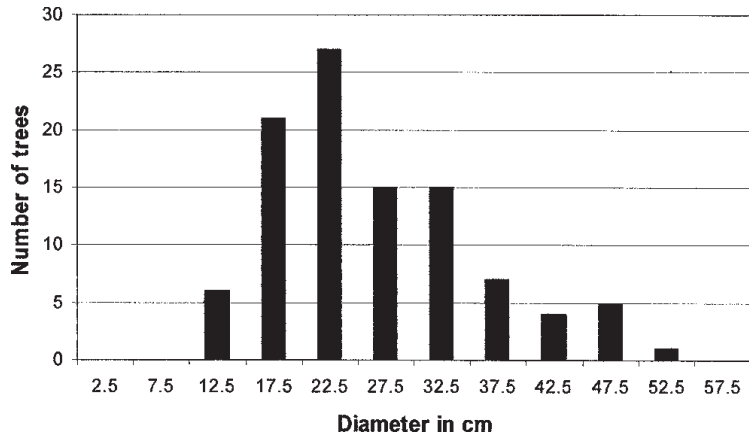
FIG. 7. Diameter distribution of original blight-killed chinquapin logs on the Wedington and Hobbs sites.

figure 4. Since we have a firm 1958 release date from an oak near this log, we assume that the outer three rings were eroded from the wood, which is consistent with the weathered appearance of the log. Only one other long ring series could be obtained from a 40 cm log that appeared unusual because the shattered base was still standing and intact, and growth rings were some of the narrowest of all large chinquapin logs. The ring width series from this tree was so complacent that it could not be correlated with the rings on living trees, but an adjacent oak showed the expected dramatic release in 1958. The outermost ring can thus be dated at 1957. This tree had 88 rings, with no indications of outer wood erosion and an

FIG. 8. Distribution of present log length (open bars) and reconstructed height (solid bars) of those trees for original blight kill chinquapin trees on the Wedington and Hobbs sites.

estimated 4 rings missing from the very center, making 1865 the probable date of origin. This is the oldest of all the chinquapin logs we described in detail. Using partial ring counts from the outer wood cylinder, we estimate that many large chinquapins were at most 40 years old, although a small inner and now missing cylinder of heavily suppressed growth cannot be discounted.

One of the study areas (B at Wedington) had the largest population of large chinquapin blight killed logs on the 6 tree-ring transects. We examined the history of this area by estimating the recruitment and disturbance history of the local forest on the basis of tree rings (Fig. 9). Most of the oaks on the area originated in the 1920s and 1930s in the years before the study site was taken over by the SCS after 1938. A few post oaks, although not noticeably larger than other canopy trees on the site, had ring series going back into the 1800s. These trees show evidence of major release events that must represent disturbance, most likely related to selective cutting for firewood and building materials. This wood use was probably accelerated as subsistence farmers prepared to sell off their woodlots. The recruitment trend for oaks and hickories is confined to a period from 1920 to 1940. The recruitment is based on the innermost ring of cores, many of which came close to but did not intersect the pith, and so slightly underestimate the age of the trees. The chinquapin series come from logs with somewhat more missing rings because most were hollow. Based on this evidence, it appears that the present
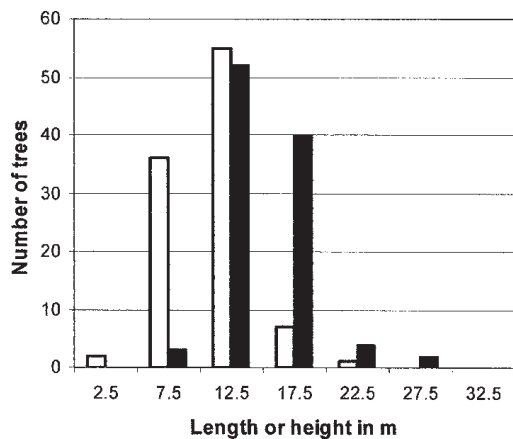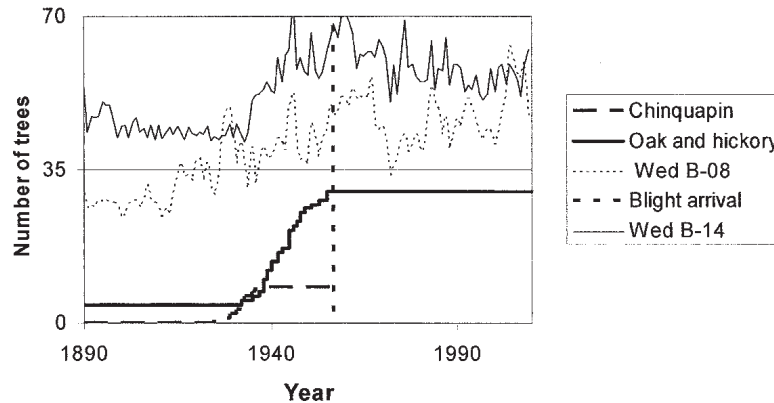
Fig. 9. Local disturbance history inferred from tree ring series from the oldest oaks and canopy recruitment for younger oaks, hickories, and chinquapin on Wedington area B.

oak and hickory forest largely originated after disturbances in the 1920s and 1930s, with chinquapin originating somewhat earlier. This is consistent with chinquapin originating as suppressed subcanopy trees in the forest that had a head start when disturbances occurred. The growth form of suppressed chinquapin sprouts we see today shows a single dominant stem on clones that have not been affected by blight or fire in recent decades (Fig. 3), which is consistent with the predominantly single-stemmed form of the older logs. It is unfortunate that the inner cylinders that would demonstrate such a release response are either missing from logs, or the intact section is taken so far up the stem that the location would be above the height of the ordinal stem before release.

The stature of chinquapin in the pre-blight forest of 1955 is illustrated by comparing the profiles of the forest on Hobbs study areas A (the most mesic of all the study areas) and C (typical of well drained upland) as they exist today (2010), and as they were just before blight arrived by projecting growth back to 1955 (Figs. 10 and 11). The upper panel in each figure shows a cross-section of the 2010 forest with the fallen chinquapin logs raised into an upright position. The lower panels show the same cross-section as it would have looked in 1955 with the crown of the chinquapin restored and the surrounding trees projected backwards in growth. The reconstructions indicate that chinquapin was growing as a canopy dominant tree at all six study areas. The chinquapin trees had crowns embedded in the upper canopy, and most

chinquapin stems were as large as or larger than those of adjacent oaks, hickories, and pines.

Discussion. Our measurements of the original blight killed chinquapin at Hobbs and Wedington confirm estimates of the size of Ozark chinquapin reported in the early literature (Ashe 1923, Moore 1992). Although multiple-stemmed chinquapin trees were not uncommon, the data show that a majority of chinquapin trees had single, upright trunks. These chinquapins were growing as canopy-height trees and not shrubs such as Allegheny chinquapin or subcanopy trees such as dogwood. In the case of multiple-trunk trees, the chinquapins had a growth form similar to that of oaks growing in clumps as a result of past injury. The data set indicates that very few large blight-killed chinquapins managed to survive for long by resprouting from their bases. Although known as prolific sprouters, both chestnut and Ozark chinquapin apparently could not consistently generate viable basal sprouts from the root systems of large trunks. Some of the early literature reported that chestnut had reduced ability to produce basal sprouts with age (Zon 1904, Mattoon 1909). Paillet (1984, 2002) suggested that this may be in part a mechanical stability issue such that the toppling of dead trees as their roots weaken pulls the sprouts out with the trunk and root collar. This conjecture was supported by the observation that saw-cut stumps of chestnut had a higher incidence of basal sprout survival (Paillet 1984). A similar effect may operate with chinquapin, but we

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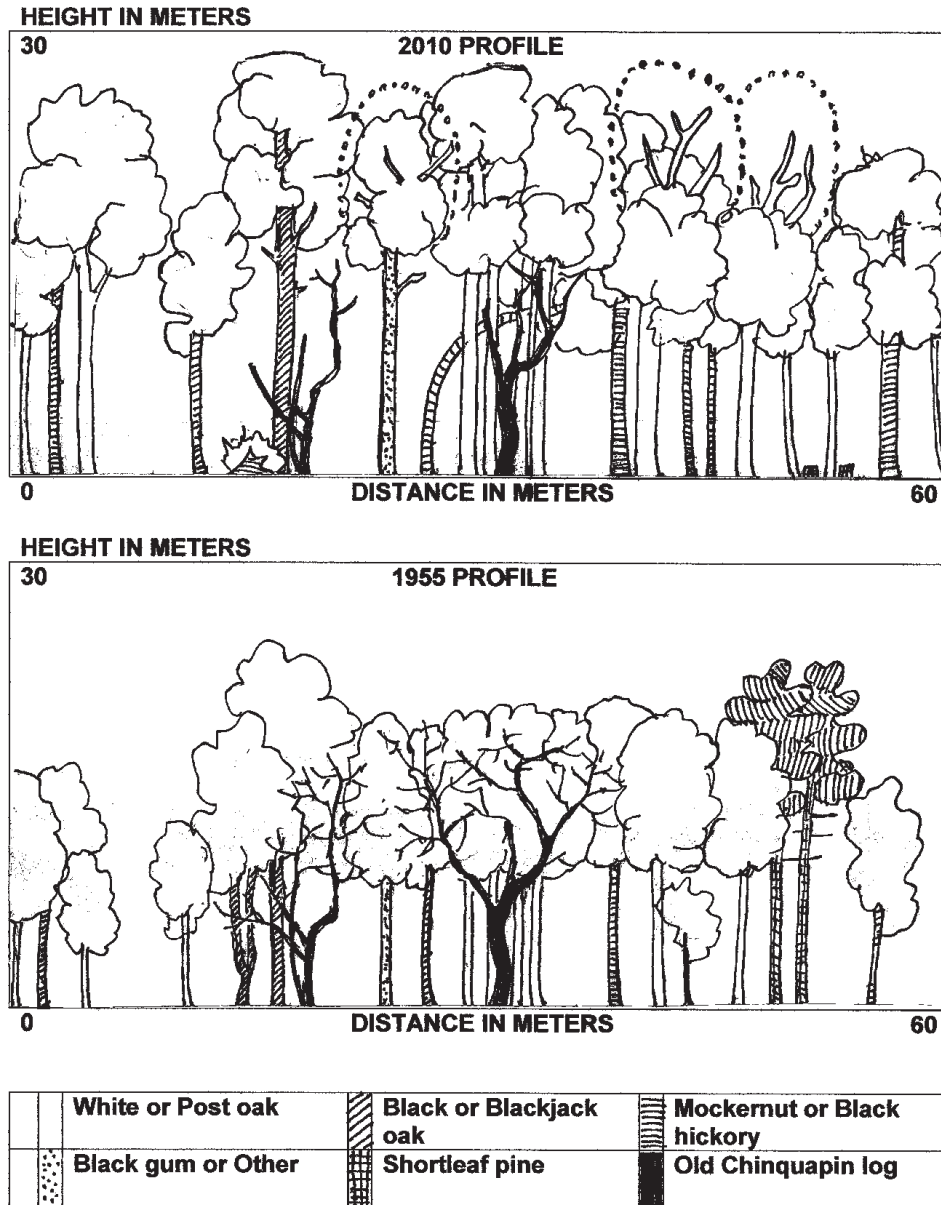|	White or Post oak		Black or Blackjack oak		Mockernut or Black hickory
	Black gum or Other		Shortleaf pine		Old Chinquapin log

FIG. 10.   Cross-section of the forest in 2010 compared to a cross-section inferred in 1955 on the basis of 1955 year diameters identified on tree cores and reconstruction of chinquapins killed by blight in 1957 for area A at Hobbs.

found no saw-cut stumps from salvaged blight kill with which to test this theory. It is curious that both chestnut and Ozark chinquapin have heavily suppressed basal sprouts attached to the base of large and healthy trees. These basal sprouts would be so small as to be hard to detect fifty years after trees die, but such remains are present on many well-preserved logs of the original blight kill and may have

been present on many other logs in earlier years.

The abundance of single-stemmed trees among the original blight kill at Hobbs and Wedington may indicate something about chinquapin ecology. Multiple stemmed trees with as many as 6 large trunks in a clump do occur on our study sites, and especially at Wedington. The distinct separation of living

HEIGHT IN METERS

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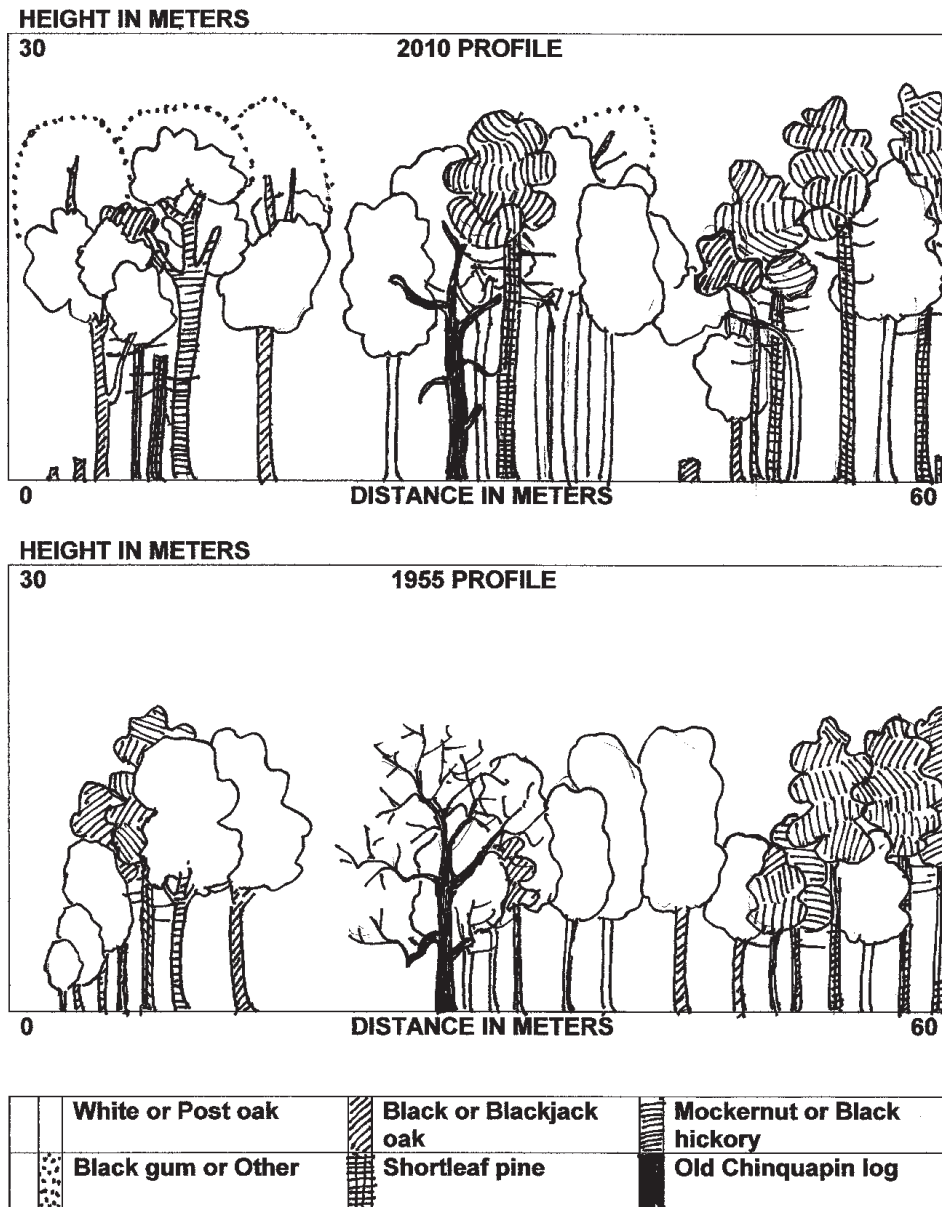|	White or Post oak		Black or Blackjack oak		Mockernut or Black hickory
	Black gum or Other		Shortleaf pine		Old Chinquapin log

FIG. 11. Cross-section of the forest in 2010 compared to a cross section inferred in 1955 on the basis of 1955 year diameters identified on tree cores and reconstruction of chinquapins killed by blight in 1957 for area C at Hobbs.

sprout clone populations into multi-stemmed clumps after fire or blight, and single stemmed little understory trees after long, disturbance-free periods in the understory may say something about the disturbance regime in early forests. The predominance of single-stemmed trunks among pre-blight chinquapin in our study may indicate that these trees originated by release of long suppressed but otherwise undisturbed clones. Multiple stemmed logs were slightly more abundant at Wedington where disturbance was probably more frequent as a result of ongoing subsistence agriculture in the area, and some locations adjacent to the Wedington study site proper had clusters of large old chinquapins that were all multi-stemmed. Our evidence indicates that stands where single-stemmed chinquapin trees

predominated had been free from fire and mechanical disturbance for an extended period, whereas locations with many multi-stemmed trees had been subjected to fire or some other disturbance likely to have produced vigorous basal sprouting. This hypothesis might be verified by identifying inner cylinders of suppressed growth in the chinquapin logs. Unfortunately, the lower part of almost all such logs was hollow, and the few intact cross-sections were obtained 5 or 6 m above the base of the original tree. Inspection of the cross-sections may reflect the distinction between sapwood and heartwood. The vessels in the sapwood remain open after the tree dies and thus quickly drain moisture from rainfall and snowmelt. In contrast, the heartwood has vessels plugged with resins so that moisture is retained and decay is enhanced. We have also noticed that in the case of the few modern sprouts that represent suppressed single-stemmed trees subject to abrupt release are marked by stumps where the wood separates at the radial surface where the transition from slow to fast growth occurs. This separation could act to enhance deterioration of the interior cylinder of wood, as it appears to be doing today on these more recent examples of blight kill. These mechanisms may account for the inability to detect inner years of suppressed growth in the remains of single-stemmed trees. But the consistent association of vigorous, multi-stemmed clones with fire today may make blight-killed chinquapin remains a useful indicator of earlier disturbance regimes.

Measurements of the diameter and height of the original blight kill at Hobbs and Wedington leave no doubt that Ozark chinquapin was once a large forest tree as indicated by Moore (1992) who reported that trees "attained a height of 50 feet or more and a diameter of more than two feet". The diameters of many of these old logs are as large as the diameters of some of the largest trees on the sites today, and were larger than most of the surrounding trees when chestnut blight killed them in 1957. Height-diameter projections back to 1955 indicate that chinquapin was growing as a canopy tree at that time. Site history indicates that chinquapin and the surrounding oaks, hickory, and pine were part of a forest regenerating from more intense disturbance by either commercial (Hobbs) or local subsistence (Wedington) logging. Chinquapin recruitment appears to have been somewhat in advance of oak and hickory recruitment after disturbance, providing another indication that chinquapin trees originated by the release of previously suppressed understory trees.

Comparison of the remains of pre-blight chinquapin logs with the diameters of surrounding trees at the time when blight arrived clearly shows that the chinquapins were growing as canopy dominant trees. This observation applies to relatively young woodlands that were responding to a series of logging disturbances in preceding decades. The general structure of the Ozark chinquapin trees as reconstructed from remains found on the forest floor indicate a crooked and low branching structure different from large canopy trees on the site today. This generates a suspicion that chinquapin might have failed to increase in height to keep pace with competing trees as the forest aged. Paillet (1993) noted that Ozark chinquapin released by wildlife clear-cuts showed diameter and height increases identical to those of released chestnut spouts, but the trees seemed to broaden out and begin to generate a large mast crop after four or five years rather than to continue concentrating resources into upward growth. This conjecture is hard to investigate in much of the Arkansas Ozarks today because of previous land use activities. We will continue to search for rare locations with suitable substrate and protection from frequent burning where we might locate chinquapin logs that indicate a century or more of growth before the arrival of blight.

Although this study focuses on reconstructing the nature of Ozark chinquapin trees in northwest Arkansas in the years before chestnut blight removed chinquapin from the forest canopy, some of our results have applications in regard to restoring this chestnut species to American forests. Chinquapin was a significant component of Ozark forests and restoration of that species would clearly have a beneficial effect. Our results show that chinquapin often attained a canopy position through release of formerly suppressed stems. The trees occurred in local clusters separated by substantial areas without chinquapin, suggesting that out-plantings of blight resistant trees should also be made in clusters within existing forest. Furthermore, this cluster approach can allow blight resistant chinquapin to be planted in locations away from local clusters of native chinquapin sprouts so

that blight resistant genes are not diluted by those of non-resistant trees. Chinquapin clusters on our study sites were most often found on the edges of ridges at positions at the upper edge of steep slopes into ravines. Even if chinquapin can be successfully established elsewhere, our observations indicate that natural reproduction would be most effective in these specific locations where reproduction was effective in pre-blight forests.

Conclusions. A survey of living Ozark chinquapin clones and the remains of original blight-killed chinquapin trees in northwest Arkansas showed the species to be widespread but uncommon. Chinquapin was locally concentrated on sandstone benches and upper slopes in karst terrain developed on the Boone Limestone. The remains of pre-blight chinquapin trees were mapped and measured on two 2 ha sites in Benton (Hobbs Conservation Area) and Washington (Wedington block of the Ozark National Forest) Counties. Tree density was estimated at about 1 tree per ha, consistent with published upland witness tree surveys where chinquapin comprised slightly less than 1% of all witness trees. One hundred-eight logs that were intact enough to describe in detail were documented, representing about half of the total large chinquapins estimated to have grown on the two sites. Most of these grew as single-stemmed trees up to 20 m in height and 40 cm in diameter. The predominance of single-stemmed trees may indicate the relative importance of fire in pre-blight forests because modern surface fires produces clumps of several large and vigorous sprouts from the base of fire-killed chinquapin stems. The larger proportion of multiple-stemmed trees at Wedington is consistent with the higher level of disturbance associated with that location. The lack of subsequent sprouts from the base of large trees and the abundance of living sprout clones that are not associated with old trees indicates most sprouts represent old seedlings that never attained large tree size. Tree rings used to reconstruct stand history on six 20 × 60 m plots demonstrate that blight arrived in these locations in 1957. Stand recruitment was concentrated in an extended period from 1920 to 1940, with a few older trees dating to the mid 1800s. Estimated ages for chinquapin logs seem to pre-date oak and hickory recruitment, suggesting their origin by release of suppressed understory stems. Tree rings were used to show that the diameter of oaks and hickories on the plots were generally less than those of the chinquapins on those plots in 1955. Height-diameter projections were used to compare the stature of the stand with reconstructed remains of chinquapin logs, demonstrating that Ozark chinquapin was growing as a canopy-dominant tree in relatively young forests at the time when blight arrived. However, the crooked and low-branched shape of most chinquapin logs indicates that they might not have been able to maintain their canopy status as the forest continued to age. The height and diameter figures given for Ozark chinquapin in the literature (Ashe 1923, Morre 1992) likewise suggest a large diameter tree with a height somewhat less than that achieved in later age by competing oak and hickory species.

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