The R. R. Reynolds Research Natural Area in Southeastern Arkansas: A 56-Year Case Study in Pine-Hardwood Overstory Sustainability

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ABSTRACT. The R. R. Reynolds Research Natural Area is a 32-ha pine-hardwood forest in southeastern Arkansas, U.S.A., that originated from diameter-limit cutting of the virgin forest before 1915. In 1935, these 32 ha were reserved from timber management. Between 1937 and 1993, eight inventories were taken of all living trees > 9-cm DBH, using 2.5-cm DBH classes within three species groups: *Pinus* spp., *Quercus* spp., and other hardwoods. In 1994, all standing dead snags of pines and hardwoods > 9-cm DBH were inventoried by 2.5-cm DBH classes. During 56 years, the overstory pine-hardwood ratio remained stable in terms of relative basal area, but pine density decreased with a commensurate increase in hardwood density. In 1993, pines represented 63% of basal area but only 23% of stem density. Just before the 1993 inventory, a pine bark-beetle infestation developed on the area, and within one year the pines lost about 2.5 m^2/ha in basal area and had 180% more snags than were contributed by hardwoods. The overstory pine component is decreasing in density as a result of natural senescence and the allogenic effects of bark beetles. Hardwood species are expected to eventually dominate the forest because shade-intolerant pine regeneration will

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not dcvclop to maturity beneath the closed hardwood canopy which can be altered only by catastrophic natural disturbances or anthropogenic intervention. *[Article copies available from The Haworth Document Delivery Service: l-800-342-9678. E-mail address: getinfo@haworth.com]*

INTRODUCTION

During an era when public demands for changes in forest practices arc affecting trcc species composition and size-class distributions on public forcsts, there is a need to improvc our understanding of long-term forest dynamics that occur in the absence of silvicultural intervention. That necd can be met by monitoring changc on Rcsearch Natural Areas. If the specific results of performing no silvicultural treatments arc understood, forest managcrs could enhance their decision-making ability in operational situations (Guldin and Baker 1984).

The USDA Forest Service developed the Research Natural Area program to protect small areas of old growth on national forest lands (Devall and Ramp 1992). Consequcntly, Research Natural Areas are intended to be set aside in perpetuity for nonmanipulativc research and educational purposes.

This invcstigation was conductcd within the R. R. Reynolds Research Natural Arca–a 32-ha, second-growth, pine-oak forest situated in thc Southeastern Evergreen Forcst Region of the West Gulf Coastal Plain (Quartcrman and Kccver 1962) in southern Arkansas, U.S.A. Large-scale removal of virgin loblolly pine (*Pinus taeda* L.) and shortleaf pine (*P. echinata* Mill.) timber began in southern Arkansas in the 1890's and was almost completc by thc late 1920's (Reynolds 1980). During this period, lumber companies usually cut only trees that were larger than 36 cm in stump diameter. As time passcd, residual cone-bearing pines naturally regeneratcd these cutover sites resulting in second-growth forest communities dominated by loblolly pine and mixcd hardwoods (Braun 1950).

To maximize yields of forest products from the Southeastern U.S., forest managers oftcn grow southern ycllow pines (*Pinus echinata, P. elliottii* Engclm., *P. palustris* Mill., and *P. taeda*) in short-rotation plantations by relying on intensive silvicultural practices and making use of the region's long growing scason and highly productivc sites. By thc 21st century, a fourth-generation forest will be approaching maturity (USDA For. Scrv. 1988). Bccausc of the widespread usc of intensivc forest management, only remnants of the natural, second-growth, pine-hardwood forests rcmain for investigation. The prcsent 32-ha forest has been protected from anthropogcnic perturbations since 1935, and no catastrophic natural disturhanccs occurred bcforc 1993.

Our objective in this paper is to document the dynamics of the oversto-ry pine and hardwood component between 1937 and 1993 in the absence of catastrophic disturbances or large-scale silvicultutal treatments. We also report on the prevalence of standing snags in 1994, which coincided with an infestation of pine bark beetles (*Dendroctonus frontalis* Zimm., *D. terebrans* Olivier, and *Ips* spp.) that reached epidemic levels in this Research Natural Area during the summer of 1993.

METHODS

Study Area

The 32-ha forest measures 805 m east-west by 402 m north-south and is located at 33°02′N mean latitude and 91°56′W mean longitude in Ashley County, Arkansas, U.S.A. Soil types are oriented in relation to two ephemeral drainages that run north to south and dissect the 32 ha across the eastern and western quarters. Arkabutla silt loam (Acric Fluvaquent) occurs along the drainages (USDA 1979). These somewhat poorly drained alluvial soils have a site index of about 30 m at 50 years for *Pinus taeda*, *Quercus falcata* var. *pagodifolia* Ell., *Fraxinus pennsylvanica* Marsh., *Liquidambar styraciflua* L. and *Q. nigra* L. (USDA 1979). [Species nomenclature follows Little (1979)]. Providence silt loam (Typic Fragiudalf) occurs on side slopes adjacent to the drains. Bude silt loam (Glossaquic Fragiudalf) is found on upland flats between the drains, and this area also contains intermittent Mima mounds (Cox 1984). Providence and Bude soils were formed as thin loessial deposits, and site index is about 26 m at 50 years for *Pinus taeda*, *P. echinata*, and *Liquidambar styraciflua* (USDA 1979).

Elevation of the area ranges from 37.0 to 42.3 m. The growing season is about 240 days, and annual precipitation averages 140 cm, with wet winters and dry autumns. The 32-ha study area is bordered by forest stands that have been managed during the last 50 years for pine timber production using natural reproduction cutting methods (i.e., single-tree selection, seed-tree cuts, or 2-ha block clearcuts).

Historical Background

Preharvest stand conditions are not known, but the virgin forests in southern Arkansas were composed of mixed pine-hardwood stands with > 50% of the volume in pines (White 1984). By 1915, old-growth pines and the better quality hardwoods on the study area had been cut to a 36-cm stump diameter (Reynolds 1959). Since 1935, no silvicultural practices have been used on the area with the exception of fire protection and cut-and-leave measures (≈ 0.5 tree/ha) to control an infestation of southern pine beetles in the early 1970's while minimizing anthropogenic influences within the 32 ha.

Inventory Procedures

All living trees > 9-cm DBH (diameter breast height, taken 1.37 m above the soil surface) were inventoried by 2.5-cm DBH classes within eight 4-ha subunits on the 32-ha study area. Although both midstory and overstory trees were measured, they will herein be referred to as the overstory component to facilitate presentation. [For a detailed discussion of understory, midstory, and overstory components that occurred on the Natural Area in 1993, refer to Cain and Shelton (1994)]. Inventories were conducted in 1937, 1942, 1946, 1952, 1957, 1963, 1983, and 1993. Until 1983, only three species groups were recorded: pines, oaks, and other hardwoods. During the 1983 and 1993 inventories, a fourth group-gums (*Liquidambar styraciflua* and *Nyssa sylvatica* Marsh.)–was also recorded.

During the winter of 1992-93, a supplemental inventory was conducted to determine the species composition of trees > 9-cm DBH using a 2.5 basal area factor prism at the center of sixty sample points. These sample points were systematically established on three parallel line-transects at 60-m intervals, with prism readings taken at 40-m intervals along the transects. By rotating the prism 360" around the center-point of these variable-radius plots, wc selected trees for measurement of DBH to an accuracy of 0.25 cm and identified each species. These data were used to calculate density and basal area for pines and hardwoods by species. Ages of overstory *Pinus* spp. and *Quercus* spp. were determined by counting annual growth rings on increment cores taken at a height of 1.22 m from a subsample of 92 pines and 7 1 oaks. Three years were added to ring counts to adjust age for growth to 1.22 m in height. Age-class distribution was determined for lO-year increments (e.g., 70-year class ranges from 66 to 75 years).

In the summer of 1994, all snags > 9-cm DBH were inventoried by 2.5-cm DBH classes at their widest horizontal axis to compensate for bark loss and rot. Snags were categorized into two species groups (pines or hardwoods) and four stages of decomposition: (1) full tree and limbs intact; (2) main bole present but few or no limbs; (3) crown missing, bole broken but little or no decay; or (4) crown missing with heavily decayed or rotten bole. A snag was defined as a standing dead tree or standing portion from which at least the leaves of hardwoods or needles of pines had fallen (McPherson et al. 1990). Only snags >1.37 m in height were counted.

Photosynthetically active radiation (PAR) was measured beneath the forest canopy at 1.37 m above ground during clear sky conditions using an 80-sensor Sunfleck Ceptometer (Decagon Devices, Inc., Pullman, WA) in accordance with Pierce and Running (1988). Fifty readings were systematically taken within 0.015-ha plots centered around 30 of the previously described permanent points used for prism sampling. Measurements were taken between 1030 and 1330 solar time on July 29, 1994. Several measurements were also made in full sunlight, which permitted the calculation of relative light intensity (PAR beneath the forest canopy expressed as a percent of PAR in full sunlight). At each PAR measurement-location, pine mortality from southern pine beetle infestation was visually classified as: complete, partial, or none.

Data Analysis

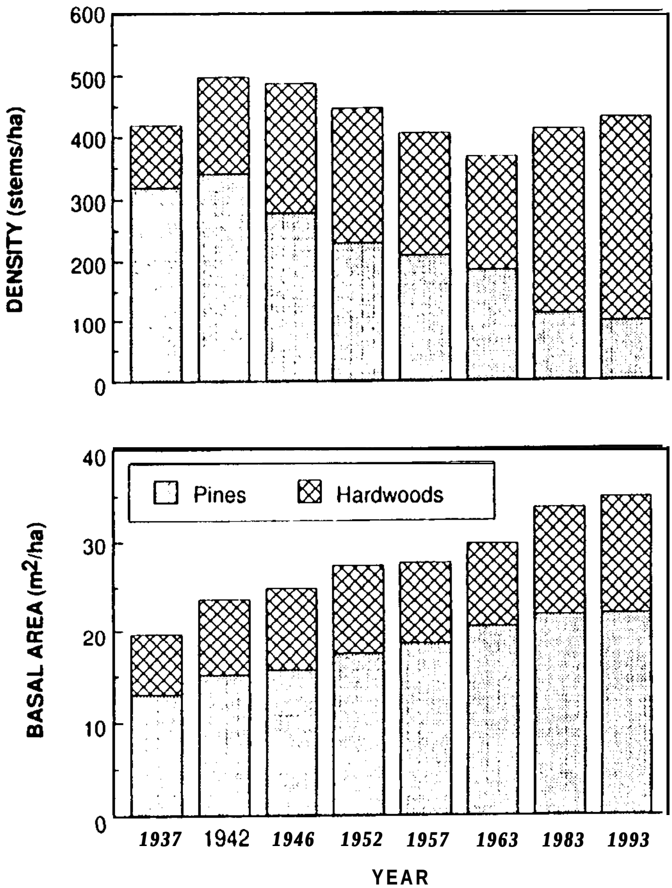
Density and basal area were summed by species groups for the 32-ha forest for each inventory. Quadratic mean DBH was calculated from the number of trees and their basal area. Temporal trends were investigated by regressing density and basal area of pines and hardwoods with the number of years after the initial inventory in 1937. A quadratic model was used, dropping variables that were not significant at $P \leq 0.05$. PAR data were analyzed by analysis of variance at $P \leq 0.05$.

RESULTS AND DISCUSSION

Overstory Density and Basal Area

The total density of trees was fairly stable throughout 56 years, oscillating between 370 and 500 stems/ha (Figure 1). However, the relative proportion of pine and hardwood stems completely reversed with the pines accounting for about 80% of the stems in 1937 but only 20% in 1993. By contrast, the basal area of pines and hardwoods increased steadily throughout 56 years, approaching 35 m^2/ha in 1993. Pine basal area ranged from 65% to 69% of the total, while values for hardwoods ranged from 31% to 35%. In 1993, the pines ranged in age from 50 to 140 years and averaged 82 years, while the oaks ranged from 40 to 150 years and averaged 89 years. The age-class distribution for the pines peaked for the 70-year class, while the distribution for the oaks was bimodal with peaks for the 70- and 120-year classes.

FIGURE 1. Temporal trends in density and basal area for pines and hardwoods > 9-cm DBH on the R. Ft. Reynolds Research Natural Area.



Overstory pine basal area was concentrated in stems 10- to 51-cm DBH in 1937 and averaged 13 m^2/ha, with a mean quadratic DBH of 23 cm. By 1993, overstory pine basal area averaged 22 m^2/ha and had shifted to the larger (48- to 76-cm) DBH classes, with a mean quadratic DBH of 53 cm. Between 1937 and 1993 overstory pine basal area increased 69% while the number of overstory pines decreased 69%, from 320 stems/ha to 99 stems/ha. Because of shade intolerance, there was no ingrowth of pines into the overstory to replace natural mortality that occurred among the old-growth trees (Cain and Shelton 1994).

In 1993, *Pinus taeda* was more important than *P. echinata* by having 65% of total pine density and 77% of total pine basal area. *P. taeda* also had three times as much basal area as any other single overstory species.

In contrast to the pines, hardwood species had a substantial recruitment of stems into the overstory. Consequently, overstory hardwood density increased from 100 stems/ha in 1937 to 33 1 stems/ha in 1993. The major hardwood component in 1937 was mixed oaks, which accounted for 57% of total hardwood density. By 1993, overstory hardwood density was concentrated in other species (44%) rather than in oaks (24%) or in gums (32%). Although the proportion of oaks to all hardwoods declined 33 percentage points between 1937 and 1993, the actual number of overstory oaks increased by about 20 stems/ha during 56 years. In 1993, *Q. alba* L. was the predominant overstory oak with 55% of total oak density. The five most prevalent overstory hardwoods were: *Liquidambar styraciflua* (84 stems/ha), *Nyssa sylvatica* (54 stems/ha), *Ulmus* spp. (52 stems/ha), *Quercus alba* L. (48 stems/ha), and *Ostrya virginiana* (Mill.) K. Koch (28 stems/ha). Other individual species of overstory hardwoods averaged ≤ 2 I stems/ha (Cain and Shelton 1994).

Overstory hardwood basal area increased from 7 m^2/ha in 1937 to 13 m^2/ha in 1993. Oaks maintained basal area dominance with 61% of the hardwood total in 1937 and in 1993. Hardwood basal area was concentrated in *Quercus alba* (5 m^2/ha) which had 51% of total oak basal area and 32% of total hardwood basal area. The second highest concentration of hardwood basal area was in *Liquidambar styraciflua*, with 17% of the hardwood total in 1993. Halls and Homesley (1966) reported similar species composition for hardwoods of sawtimber size (≥ 28-cm DBH) that contributed most to basal area in a mature pine-hardwood forest of southeastern Texas.

In support of the successional trends illustrated in Figure I, regression coefficients for the equations describing temporal trends in density and basal area are provided in Table I.

All terms of the quadratic equation were significant for the pines, indicating that changes in density and basal area were curvilinear through time. By contrast, the squared term was not significant for hardwood density and basal area, indicating a linear relationship with time after the initial inventory. Coefficients of determination were 0.97 and greater for pines, while values for hardwoods were consistently lower (0.58 and 0.83 for density and basal area, respectively).

TABLE 1. Regression coefficients and associated statistics for the density and basal area of pines and hardwoods in the R.R. Reynolds Research Natural Area from 1937 to 1993.

	Regression coefficient*				
Species group	b_0	b_1	b_2	Root mean square error	Coefficient of determination
		Density (numbers/ha)			
Pine	342	−7.63	0.0579	17.7	0.97
Hardwoods	134	2.94	–	50.6	0.58
		Basal area (m^2/ha)			
Pine	13.10	0.360	−0.0036	0.330	0.99
Hardwoods	7.60	0.087	–	0.805	0.83

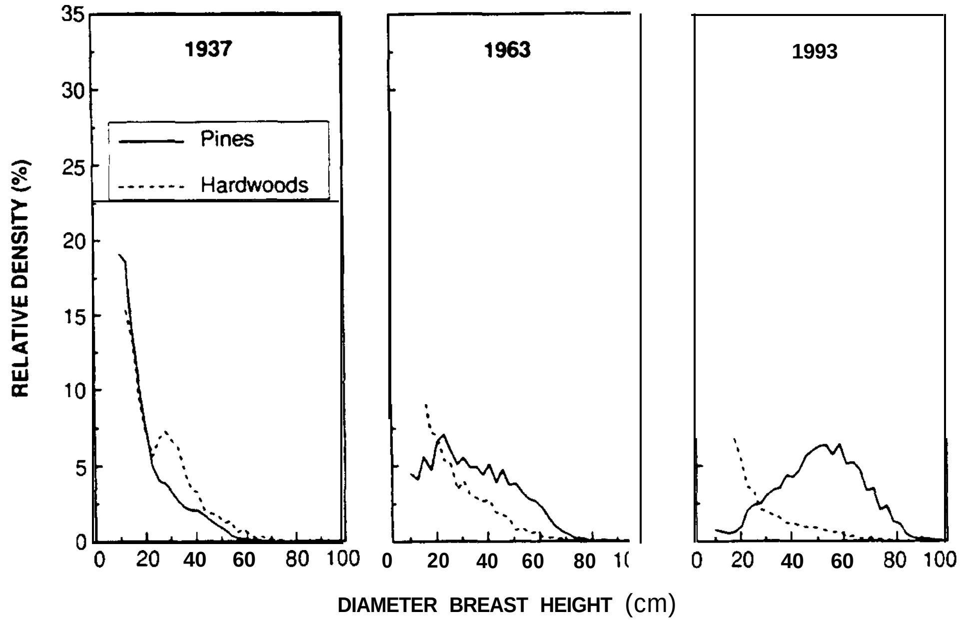
*The equation is. $Y = b_0 + b_1T + b_2T^2$, where: Y is the specified dependent variable and T = (year − 1937). All reported regression coefficients significantly differ from zero at $P \leq 0.05$. There are six degrees of freedom when the squared term is significant or seven otherwise.

Stand Structure

In 1937, DBH classes for both pines and hardwoods followed the negative exponential or reversed-J distribution (Figure 2) that is characteristic of uneven-aged stands (Smith 1986). By 1963, overstory basal area for pines and hardwoods averaged 30 m^2/ha which prohibited the development of juvenile pines in the understory because of a closed canopy, and the reversed-J structure for pines began to disappear (Figure 2).

In 1993, overstory pines exhibited a normal, bell-shaped diameter distribution characteristic of even-aged stands, while overstory hardwoods retained the negative exponential distribution. At that time, total basal area averaged 35 m^2/ha, with 63% of the total in pines. Although there were numerous pine seedlings, Cain and Shelton (1994) reported no pines of sapling size (1-cm to 9-cm DBH). These findings are consistent with Glitzenstein et al. (1986) who reported that *Pinus taeda* exhibited a normal diameter distribution (DBH's ranging from 20 to 65 cm) in an old-growth pine-hardwood forest in East Texas. Two silvicultural requirements for sustaining *P. echinata* and *P. taeda* in an uneven-aged forest structure are that overstory pine basal area should range between 10 and 17 m^2/ha (Cain

FIGURE 2. Diameter-class distributions for live pines and hardwoods >9-cm DBH during three inventories of the RR. Reynolds Research Natural Area. Relative density expresses the number of trees in a DBH class as a percentage of the total number for pines and hardwoods separately.



1993, Shclton and Murphy 1994) and that pine rcgcneration should not be overtopped by hardwoods (Cain 1994).

Snags

In 1994, dcnsity of pinc snags ranged from as few as 8 to as many as 56 per ha in specific 4-ha subunits (Figurc 3). Thc greatcst incidcncc of pine snags was in the three subunits where bark-beetle infestations wcrc highest (i.e., thc northwestern 1/8 and the eastern 1/4 of the 32-ha forest). Where pine snags averaged 40 or more per ha, > 50% of the snags still had their crowns and limbs intact, which indicated that mortality was recent. For pincs in this stage of decomposition, basal-area loss across the 32 ha averaged 2.5 m^2/ha. The diameter distribution for dead pines (Figurc 4) rescmbled that of the live population (Figure 2) except that a higher pcrccntagc of pinc snags were concentrated in the smaller DBH classcs when cornpared to survivors. Since thcsc smaller pines were in subordinate **crown positions,** they were morc likely to be of lower vigor, and thus, more susceptible to bark-beetle attack.

In thc other five 4-ha subunits where bark beetles were not as active, the greatest proportion of pinc snags were judged to be in an advanced stage of decay with missing crowns (Figure 3). This latter stage of decomposition suggested that thcse pines dicd several years earlier. Dcpending on the lcvcl of bark-bcetle activity within the 4-ha subunits, pines had from 9% to 522% more snags than did the hardwoods.

Showalter and Turchin (1993) surmised that hardwoods do not increasc susceptibility of pines to attack by southern pine beetles (*Dendroctonus frontalis*) and may interfere with growth of the insect infestation. Concomitantly, Bclangcr and Malac (1980) proposcd that hardwoods might inhibit southern pinc bcctlc infestations through interference with host discovery. Howcvcr, l-licks (1980) suggested that hardwoods could promote southern pine bcctlc infcstations through competition with host pines.

For hardwoods, thcrc were no fcwcr than 6 but no more than 11 snags/ha in cach 4-ha subunit (Figure 3). Thc greatest proportion of hardwood snags had been dead for sorne tirne because most were in a later stage of decomposition with missing crowns. Since hardwood snags were uniformly distributed across the 32 ha, hardwood rnortality appeared to occur on an individual trce basis rathcr than as a result of a catastrophic natural disturbance such as the one that beset the pines.

Snags arc considered to be cxtrcmcly important ecosystem components (Martin 1992). They serve as reservoirs of stored carbon and nutrients; providc ncsting, fccding, and resting habitats for animals; and arc long-term stablc componcnts of thc forcst detritus food web.

FIGURE 3. Density of pine (P) and hardwood (H) snags >9-cm DBH and the proportional stage of decomposition on eight 4-ha subunits in the R. R. Reynolds Research Natural Area.

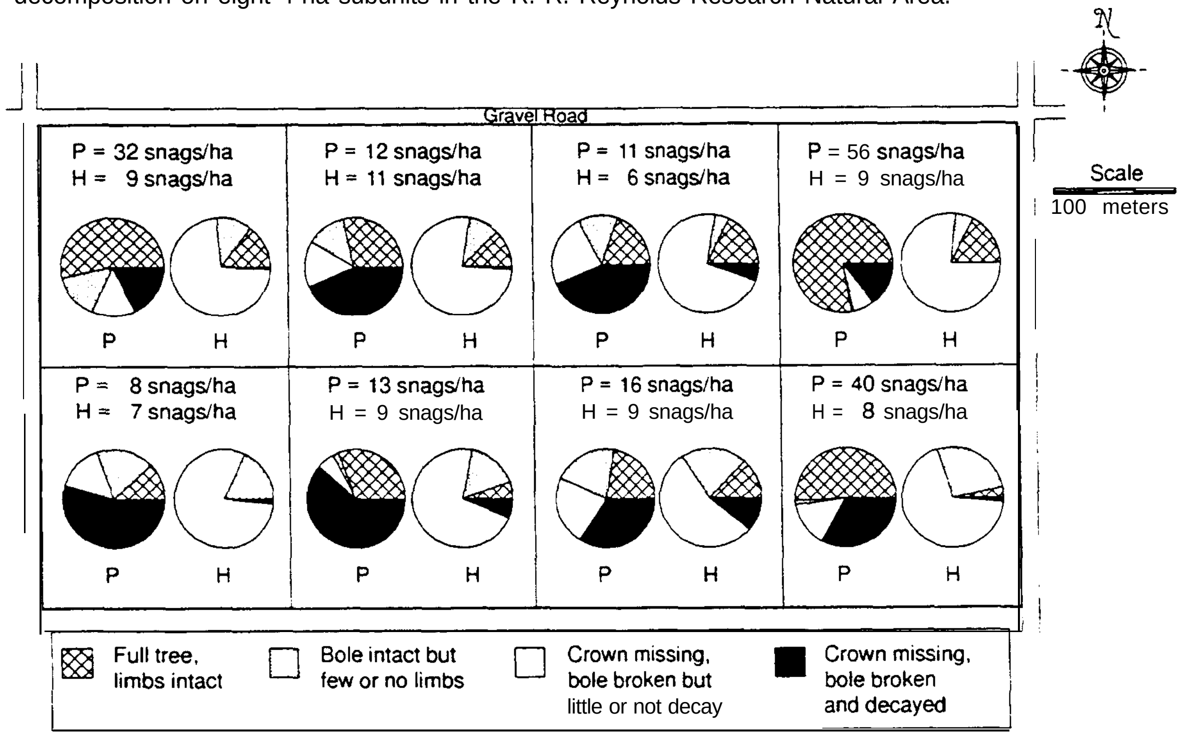
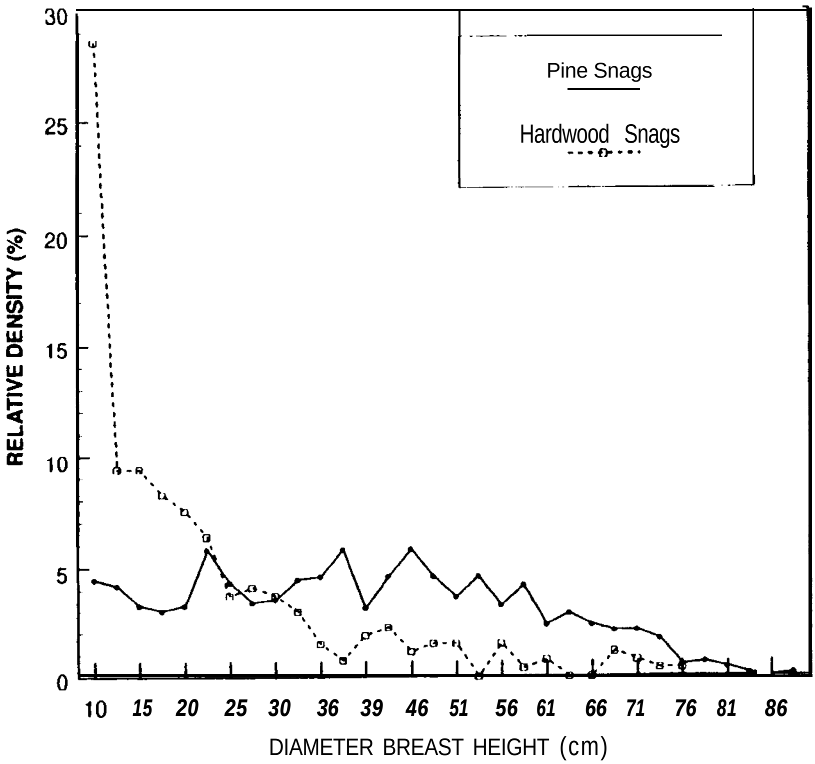


FIGURE 4. Diameter-class distributions for pine and hardwood snags > 9-cm DBH on the R.R. Reynolds Research Natural Area during 1994. Relative density expresses the number of trees in a DBH class as a percentage of the total number for pines and hardwoods separately.



Forest Health

The continuous increase in both pine and hardwood basal area between 1937 and 1993 indicated that growth exceeded mortality for 56 years in this 32-ha forest. In 1993, basal area of trees > 9-cm DBH averaged 22 m²/ha for pines and 13 m²/ha for hardwoods. The density of these trees averaged 430 stems/ha with hardwood species accounting for 77% of the total.

Pine bark-beetle infestations were noted on this Research Natural Area in 1993 following an early-spring wind storm that toppled some pines and damaged other pines in a 16-ha compartment that bordered the south boundary of the Natural Area. Although damaged pines were salvaged outside the perimeter, bark beetles remained active within the Natural Area throughout the 1993 growing season.

In February of 1994, this region was hit by an ice storm of historic significance (Halverson and Guldin [in press]). During 48 hours, accumulated ice caused tree limbs to break and resulted in the collapse of a few old-growth pines and hardwoods whose root systems could not support the extra weight. This catastrophic disturbance stressed the pines and exacerbated the bark-beetle problem which persisted through the 1994 growing season. As a result of the insect infestations and ice storm, overstory pine basal area lost about 2.5 m^2/ha as measured from standing snags, but no record was made of fallen pines. In an assessment of southern pine beetle infestations in southern Arkansas, Ku et al. (1981) reported that high levels of pine basal area (> 22 m^2/ha) were a major factor that increased the susceptibility of *Pinus taeda* and *P. echinata* to attack. On Coastal Plain sites in the Southeastern U.S., overstocked (i.e., high pine basal area) stands of loblolly pine with reduced radial growth and growing on good sites are most often attacked by southern pine beetles (Hicks 1980). In addition, older pines are particularly susceptible to southern pine beetle infestations (USDA For. Serv. 1993). In the present study, older pines and stressed pines most likely provided focal points for initiating southern pine beetle attack while pine vigor and density influenced expansion of the infestation.

In the USDA Forest Service strategic plan on forest health and ecosystem management, the desired state of forest health is a condition where biotic and abiotic influences do not threaten resource management objectives now or in the future (USDA For. Serv. 1993). However, resource management objectives do not necessarily mean commercial products. Objectives should reflect the many uses and values of forests, including recreation, wildlife, wilderness, timber, grazing, and water. Consequently, a desired state of health does not automatically imply that a forest can or should be completely free of damaging pests or dead and dying trees. On the other hand, the ability of forest trees to withstand or recover from the impacts of stressors, such as insects and adverse weather, are important criteria in determining the overall health of a forest (Hyland 1994).

If the allogenic effects of pine bark beetles continue on the R. R. Reynolds Research Natural Area, the overstory component will rapidly change from *Pinus* spp. to one dominated by *Quercus* spp., *Liquidambar styraciflua*, *Nyssa sylvatica*, and *Ulmus* spp. Rather than collapse, large dead pines tend to remain erect and gradually deteriorate as snags over many years (Jones et al. 1981). Such was the case in the present study-the canopy below the dead and dying old-growth pines remained closed during the 1994 growing season because of the combined effect from understory, midstory, and overstory hardwoods. This was confirmed by measuring photosynthetically active radiation (PAR). PAR beneath the forest canopy, taken at a height of 1.37 m, was not significantly related (P = 0.34) to the intensity of the southern pine beetle infestation. PAR averaged 7.9%, 5.4%, and 7.2% of full sunlight for areas where pine mortality was complete, partial, and none, respectively. Since little direct sunlight penetrates to the forest floor under a closed canopy (Cain and Shelton 1994), shade-intolerant pines arc. not likely to become established and achieve overstory status unless large gaps arc created. Stand structure and long-term trends suggest that an overstory dominated by pines will not be sustained in this Research Natural Area in the absence of large-scale, natural perturbations or silvicultural intervention by man.

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