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An Old-Growth Definition for Southern Mixed Hardwood Forests

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Preface

Old growth is widely acknowledged today as an essential part of managed forests, particularly on public lands. However, this concept is relatively new, evolving since the 1970's when a grassroots movement in the Pacific Northwest began in earnest to define old growth. In response to changes in public attitude, the U.S. Department of Agriculture, Forest Service, began reevaluating its policy regarding old-growth forests in the 1980's. Indeed, the ecological significance of old growth and its contribution to biodiversity were apparent. It was also evident that definitions were needed to adequately assess and manage the old-growth resource. However, definitions of old growth varied widely among scientists. To address this discrepancy and other old-growth issues, the National Old-Growth Task Group was formed in 1988. At the recommendation of this committee, old growth was officially recognized as a distinct resource by the Forest Service, greatly enhancing its status in forest management planning. The committee devised "The Generic Definition and Description of Old-Growth Forests" to serve as a basis for further work and to ensure uniformity among Forest Service Stations and Regions. Emphasis was placed on the quantification of old-growth attributes.

At the urging of the Chief of the Forest Service, all Forest Service Stations and Regions began developing old-growth definitions for specific forest types. Because the Southern and Eastern Regions share many forest communities (together they encompass the entire Eastern United States), their efforts were combined, and a cooperative agreement was established with The Nature Conservancy for technical support. The resulting project represents the first large-scale effort to define old growth for all forests in the Eastern United States. This project helped bring the old-growth issue to public attention in the East.

Definitions will first be developed for broad forest types and based mainly on published information and so must be viewed accordingly. Refinements will be made by the Forest Service as new information becomes available. This document represents 1 of 35 forest types for which old-growth definitions will be drafted.

In preparing individual old-growth definitions, authors followed National Old-Growth Task Group guidelines, which differ from the standard General Technical Report format in two ways—the abstract (missing in this report) and the literature citations (listed in Southern Journal of Applied Forestry style). Allowing for these deviations will ensure consistency across organizational and geographic boundaries.

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Introduction

The southern mixed hardwood forest, one of the southernmost mesic temperate forest types in North America, occurs along the southeastern Coastal Plain of the United States from the Carolinas to eastern Texas. These forests contain a diverse mixture of evergreen and deciduous broad-leaved trees combined with evergreen coniferous trees. Typically, they are dominated by American beech *(Fagus grandifolia* Ehrh.), southern magnolia (*Magnolia grandiflora* L.), and *Pinus* spp. (Quarterman and Keever 1962; Monk 1965, 1967, 1968; Marks and Harcombe 1975; Clewell 1985; Godfrey 1988; Platt and Schwartz 1990; Vankat 1990). As the climate of the southeastern Coastal Plain, at least along the coast of the Gulf of Mexico, remained relatively constant during the Pleistocene, present mesic hardwood forests may represent relicts derived from the early Tertiary flora (Axelrod 1958, 1966; Platt and Schwartz 1990). In addition, they would have served as refuges for many northern temperate species during the Pleistocene glaciations (Davis 1981, Delcourt and Delcourt 1987, Webb 1990).

Before European settlement, stands of southern mixed hardwood forests formed narrow bands of vegetation between floodplain forests and upland xeric forests or savannas dominated by longleaf pine (*Pinus palustris* Mill.). These sites were naturally protected from frequent flooding and from growing-season fires initiated in the pine savannas (Williams 1827; Delcourt and Delcourt 1974, 1977; Marks and Harcombe 1981; Schafale and Harcombe 1983; Platt and Schwartz 1990; Ware et al. 1993; Schwartz 1994; Harcombe et al. 1993). After European settlement, virtually all pine savannas were clearcut, and their characteristic growing-season fires were suppressed. Following such disruption, hardwood species and pines, especially loblolly pine (*P. taeda* L.), replaced longleaf pine forming woodlands and forests that replaced most of the savannas. Stands of southern mixed hardwood forests are frequently affected by hurricanes along the Coastal Plain (Jarvinen et al. 1984, Neumann et al. 1992). These disturbances, which recur within the lifespan of most canopy trees, greatly influence the dynamics of these forests (Glitzenstein et al. 1986, Platt and Schwartz 1990).

Preservation or restoration of the southern mixed hardwood forests requires criteria for recognizing the so-called old-growth stands (Thomas et al. 1988). The concept of old growth was originally developed for Pacific Northwest forests, based on the notion that those forests undergo a directional autogenic succession toward a steady-state climax that is disrupted by natural devastations (Franklin et al. 1981, 1986; Franklin and Spies 1984). In this context, old-growth condition becomes essentially synonymous with climax state. Application of the old-growth concept in other regions has tended to result in transferral of this connotation to different forests (e.g., Barnes 1989, Hayward 1991). This created difficulties for characterizing the old-growth condition of forests that, being affected by frequent disturbances (Tyrrell 1992), may not approach a climax or a steady state (Jones 1945, Raup 1964, White 1979, Denslow 1980, Pickett and White 1985, Platt and Schwartz 1990). In these cases, an old-growth forest would be one that has not been recently cleared and whose dynamics are essentially the same as those that historically shaped forest structure and composition ("age" and "disturbance" criteria) (Hunter 1989). The old-growth definition would then contain attributes expected in a forest likely to change under a natural disturbance regime, rather than attributes expected in a steady-state community.

In this report, we characterize the old-growth condition for the southern mixed hardwood forests based on published accounts and on data from five exemplary stands that show no evidence of having been cleared by humans or by natural agents during the last 200 years. The two easternmost stands are located near each other, one (Woodyard Hammock) in northern Florida and the other (Titi Hammock) in southern Georgia; two central stands (Zemurray Forest and Tunica Hills) are in eastern Louisiana, and the westernmost stand (Weir Forest) is in eastern Texas (see appendix for a detailed presentation of the exemplary forests). Structure and composition data were compiled from mapped-plot data bases and published reports related to all five forests. Description of immediate hurricane effects was based on censuses conducted after 1985 Hurricane Kate in Woodyard Hammock and Titi Hammock. Dynamics over a 14-year period were described based on an ongoing long-term study in Woodyard

Hammock. This forest type was defined by Quarterman and Keever (1962) and corresponds to the lower slope hardwood pine forest of Marks and Harcombe (1981), to forest type 66 in Vankat (1990), and partially to Southern Research Station types 31, 37, 46, and 59, as well as Society of American Foresters (SAF) types 82 and 89 (Eyre 1980).

Old-Growth Characteristics

Distribution in the Landscape

Old-growth southern mixed hardwood forests are small stands whose origin predates extensive European settlement in the United States. All of the exemplary forests occupied mesic sites associated with streams or lakes. These sites are moister than the uplands and therefore are relatively protected from the lightning-initiated fires that frequently burned the upland pine savannas (Platt and Schwartz 1990, Harcombe et al. 1993).

Strata and Growth Forms

Southern mixed hardwood forests have an overstory of evergreen and deciduous broad-leaved species and evergreen needle-leaved species, mostly composed of trees 66 to 98 feet [20 to 30 meters (m)] tall, and an understory of trees less than 49 feet (15 m) tall, usually of evergreen and deciduous broad-leaved species (Harcombe and Marks 1977, Platt 1985, Platt and Hermann 1986). Trees support lianas and sometimes fairly abundant epiphytes. Except in gaps, the ground cover of herbs is sparse, probably as a result of the abundance of evergreen trees (Marks and Harcombe 1975, Platt and Schwartz 1990).

Overall Diversity

The exemplary forests averaged 37 tree species ≥1 inch [2 centimeters (cm)] in diameter at breast height (d.b.h.). About 28 of these species reached at least 4 inches (10 cm) in d.b.h. (table 1). The rest were large shrubs and a few species dispersed from nearby environments and present only as juveniles. Diversity index *N1* (= $e^{H'}$) indicates that about 15 of the species in each stand contributed significantly to total density, and *N2* (= *1/D*) that about 11 shared dominance (table 1).

Overstory Species

Dominant species of large overstory trees in the exemplary forests always included American beech, southern magnolia, and sweetgum (*Liquidambar styraciflua* L.); some of the oak species, water oak (*Quercus nigra* L.), white oak (*Q. alba* L.), swamp chestnut oak (*Q. michauxii* Nutt.); and, except in Tunica Hills, either spruce pine (*P. glabra* Walt.), or loblolly pine (tables 2 and 3). In each exemplary forest, there were about 13 species of large overstory trees [d.b.h. ≥20 inches (50 cm)], about one-half of which shared dominance (respectively, *N0* and *N1*, table 1). Thus, the composition of the overstory was fairly constant among the exemplary forests despite some variation in species abundance. American beech was always either the first or the second most abundant species in the overstory. An additional 30 native overstory species were represented in the exemplary forests (table 2).

Understory and Vine Species

The understory of the exemplary forests contained small individuals of overstory species and several species that never reach the overstory (table 2). Among the latter, American holly (*Ilex opaca* Ait.), American hornbeam (*Carpinus caroliniana* Walt.), and eastern hophornbeam [*Ostrya virginiana* (Mill.) K. Koch] frequently shared dominance (table 2). However, species abundance in the understory was variable among sites. The dominant

Table 1—Tree species diversity in five southern mixed hardwood forests

Sizes	Range	Median	Number of sites
D.b.h. ≥2 cm			
N0[a]	28-60	37	4
N1[b]	5-20	15	4
N2[c]	3-12	11	4
D.b.h. ≥10 cm			
N0[a]	25-43	28	4
N1[b]	12-16	14	4
N2[c]	9-11	10	5
D.b.h. ≥50 cm			
N0[a]	8-15	13	5
N1[b]	8-15	7	5
N2[c]	4-12	6	5

[a] N0 is the total number of species.
[b] N1 = $e^{H'}$, where H' is the Shannon-Wiener index, measures the number of nonrare species.
[c] N2 = 1/D, where D is the Simpson index, measures the number of dominant species (Hill 1973). All indices were calculated with overall stand tree-density data.

Table 2—Large and small tree presence (number of sites out of five), density ranges, and density averages (median number of trees per hectare) for common species in five old-growth southern mixed hardwood forests

	Large trees d.b.h. >50 cm			Small trees 10 cm < d.b.h. ≤50 cm		
Species	Presence	Density range	Density median	Presence	Density range	Density median
Overstory[a] species:						
Fagus grandifolia	5	6.0-18.0	9.0	5	3.0-102.0	38.5
Magnolia grandiflora	5	2.0-24.7	5.4	5	10.0- 59.0	19.6
Liquidambar styraciflua	5	0.3- 5.0	3.0	5	10.6- 66.9	36.0
Quercus nigra	4	0.2- 5.0	3.0	5	0.8- 22.0	12.7
Q. alba	4	0 - 5.0	2.0	5	1.5- 40.5	5.0
Q. michauxii	4	0.4- 2.0	0.9	4	1.8- 28.0	6.5
Liriodendron tulipifera	4	0.9- 5.4	2.0	4	1.0- 6.5	1.8
Nyssa sylvatica	4	0.5- 3.5	0.8	4	13.0- 22.4	18.9
Pinus glabra	3	4.4-16.5	4.4	3	10.9- 25.4	10.9
P. taeda	3	1.6-22.0	1.6	4	0.2- 48.0	0.4
Carya glabra	3	0.7- 2.4	0.7	3	1.0- 9.4	1.0
Q. hemisphaerica	3	0.2- 1.8	0.2	4	0.4- 15.8	1.0
Q. shumardii	2	0.4- 9.0	0	2	0.9- 6.0	0
M. virginiana	1	1.4- 1.4	0	4	0.7- 10.6	4.0
C. tomentosa	1	0.4- 0.4	0	3	0.8- 2.2	0.8
C. cordiformis	1	1.0- 1.0	0	2	1.0- 8.4	0
Tilia americana	1	0.8- 0.8	0	2	4.0- 5.2	0
All overstory species:		40.0-70.0	46.0		140.0-275.0	227.0
Understory[b] species:						
Ilex opaca				5	1.0- 59.0	30.4
Carpinus caroliniana				5	1.3- 41.0	21.1
Ostrya virginiana				4	8.0- 69.8	27.0
Cornus florida				4	2.4- 30.0	7.8
Acer rubrum				4	0.8- 32.0	1.0
Symplocos tinctoria				4	0.4- 5.5	1.0
Prunus serotina				4	0.2- 3.0	0.4
Aralia spinosa				2	0.2- 1.0	0
Cercis canadensis				2	0.2- 2.4	0
Halesia diptera				2	5.0- 8.5	0
Oxydendron arboreum				2	5.8- 16.0	0
All understory species:					114.0-163.2	125.0
All species:[c]		40.0-70.0	46.0		304.0-389.0	351.6

[a] Overstory: *Carya illinoiensis, Castanea pumila, Celtis laevigata, Gleditsia triacanthos, Juglans nigra, Magnolia pyramidata, Paulownia tomentosa, Pinus echinata, Platanus occidentalis, Quercus falcata, Q. marilandica, Q. muehlenbergii, Q. nuttallii, Q. pagodaefolia, Q. phellos, Q. stellata, Q. virginiana, Tilia americana, Ulmus alata, U. americana.*
[b] Understory: *Acer negundo, A. saccharum, Bumelia lanuginosa, Fraxinus americana, F. caroliniana, F. pennsylvanica, Lindera benzoin, Morus rubra, Osmanthus americana, Persea borbonia, Planera aquatica, Prunus caroliniana, Sassafras albidum, Ulmus rubra, Viburnum rifidulum.*
[c] Includes additional species found in only one exemplary forest. All nomenclature follows Godfrey (1988).

Table 3—Range and median basal area (m^2/ha) for common overstory species, for all trees, and for small and large trees in five old-growth southern mixed hardwood forests

Group	Basal area Range	Median
Fagus grandifolia	2.6- 9.3	5.4
Magnolia grandiflora	1.5-11.6	4.0
Liquidambar styraciflua	1.1- 4.3	3.7
Quercus nigra	0.7- 3.2	1.9
Q. alba	0.2- 3.0	1.0
Q. michauxii	0.1- 1.1	0.9
Liriodendron tulipifera	0.4- 2.7	0.8
Nyssa sylvatica	0.7- 2.3	1.1
Pinus glabra	3.9- 6.9	3.9
P. taeda	0.1-10.5	0.5
Carya glabra	0.5- 1.8	0.5
Q. hemisphaerica	0.3- 1.0	0.3
Q. shumardii	0.1- 3.1	0
M. virginiana	0.1- 1.2	0.1
C. tomentosa	0 - 0.5	0
C. cordiformis	0.3- 0.3	0
Tilia americana	0.2- 0.6	0
All trees	29.0-40.0	33.0
Small trees (d.b.h. ≥10 cm)	27.0-38.0	33.0
Large trees (d.b.h. ≥50 cm)	12.0-24.0	13.0

Minimum d.b.h. of trees included in the calculation of basal area for common species and for all trees was 2 cm for Woodyard Hammock, Titi Hammock, and Tunica Hills; 1 cm for Zemurray Forest; and 4.5 cm for Weir Woods. All nomenclature follows Godfrey (1988).

understory species were eastern hophornbeam in Woodyard Hammock, flowering dogwood (*Cornus florida* L.) in Titi Hammock, two-wing silverbell (*Halesia diptera* Ellis) and Florida anise (*Illicium floridanum* Ellis) in Zemurray Forest, American hornbeam in Tunica Hills, and American holly in Weir Forest. In stands not recently affected by a hurricane, understory trees may be clumped in localized gaps (Platt and Hermann 1986). Characteristic species of lianas in the exemplary forests were cross-vine (*Bignonia capreolata* L.), wood-vamp (*Decumaria barbara* L.), poison-ivy [*Toxicodendron radicans* (L.) Kuntze], bullbriar (*Smilax rotundifolia* L.), and summer grape (*Vitis aestivalis* Michx.); the main epiphyte was Spanish-moss [*Tillandsia usneoides* (L.)].

Density and Basal Area

Total basal area in the exemplary forests was similar to the 269 to 377 square feet per acre [25 to 35 square meters per hectare (ha) (m^2/ha)] range reported by Parker (1989) for hardwood forests of the central hardwood region (table 3). However, density of trees 4 inches (10 cm) in d.b.h. or larger ranged from 139 to 176 trees per acre (344 to 435 trees per ha) [median 160 trees per acre (396 trees per ha)], while the density range reported for the central hardwood region was 65 to 173 trees per acre (161 to 427 trees per ha) (Parker 1989). In addition, the median tree density in the exemplary forests exceeds the 101 trees per acre (250 trees per ha) reported by Martin (1992) for a mixed mesophytic forest in Kentucky. High density in the exemplary forests resulted largely from the large number of small trees (table 2). Reported density and basal area of large overstory trees [d.b.h. ≥20 inches (50 cm)] were extremely high in Zemurray Forest [28 trees per acre (70 trees per ha)], [258 square feet per acre (24 m^2/ha)] (White 1987). In the rest of the exemplary forests, density of large overstory trees ranged from 16.2 and 19.0 trees per acre (40 and 47 trees per ha) and basal area from 129 to 151 square feet per acre (12 to 14 m^2/ha) (table 2).

Size/Age Distributions

Few overstory trees in the exemplary stands reached 39 inches (100 cm) in d.b.h., but many exceeded 20 inches (50 cm) (table 4). In the overstory of these forests, long-lived species, such as American beech, southern magnolia, and sweetgum, were mixed with short-lived trees, such as spruce pine or loblolly pine (table 4). When all tree species were combined, density of trees in these forests decreased with tree size (Harcombe and Marks 1978, White 1987, Platt and Schwartz 1990). Populations of *Pinus* spp., however, usually had a scarcity of small sized classes, suggesting a single-aged condition. For long-lived dominant overstory species, small trees were scarce in some forests but not in others. For example, southern magnolia had very few juveniles in Woodyard Hammock, but many in Weir Forest (see also Harcombe and Marks 1978, Hirsh 1981, Glitzenstein et al. 1986, White 1987).

Gaps

Expanded gaps (Runkle 1982) in Woodyard Hammock occupied about 30 percent of the area before Hurricane Kate. Before Hurricane Kate, small individuals of hickories (*Carya* spp.), water oak, and swamp chestnut oak in Woodyard Hammock were associated with old gaps (Platt and Hermann 1986). In addition, rapidly growing, short-lived, deciduous understory species (such as eastern hophornbeam, American hornbeam, and flowering dogwood) were associated with new gaps, while the slow-growing, long-lived, evergreen American holly and sweetleaf [*Symplocos tinctoria* (L.) L'Hér.] were associated

Table 4—Ranges and averages (medians) of forest structural characteristics observed in southern mixed hardwood forests

Structural characteristic	Range	Median	Number of sites
	Cm	*Cm*	
D.b.h. of largest tree			
Magnolia grandiflora	72-126	95	5
Fagus grandifolia	77- 98	86	5
Nyssa sylvatica	58- 86	81	4
Pinus glabra	72- 81	80	3
Liriodendron tulipifera	54-116	78	4
P. taeda	47- 80	72	4
Quercus alba	48- 82	71	4
Carya glabra	60- 78	70	3
Q. nigra	31- 79	68	5
Liquidambar styraciflua	54- 91	63	5
Q. michauxii	39- 74	61	5
Q. hemisphaerica	38- 55	54	3
Age of old trees in years[a]			
M. grandiflora		214	1
F. grandifolia		210	1
L. styraciflua		210	1
Q. alba		170	1
P. taeda		94	1
P. glabra			
Variation in tree diameter			
No. of 10-cm d.b.h. classes	8- 11	9	4
Evergreen species			
Basal area (percent of total)	7- 52	43	5
Dead trees			
Standing dead (snags per ha)		11	1
Downed logs (m^3 per ha)		72	1

[a] Percentile 95 of the age frequency distribution. All nomenclature follows Godfrey (1988).

with old gaps (Platt and Schwartz 1990). After Hurricane Kate, many juvenile spruce pine and eastern hophornbeam reached 1 inch (2 cm) in d.b.h. in gaps enlarged by the disturbance.

Dead Component

Density of standing dead trees observed in Woodyard Hammock 7 years after Hurricane Kate [5 snags per acre (11 snags per ha)] was lower than the 8 to 18 snags per acre (19 to 44 snags per ha) range reported for the central region mixed mesophytic forest (Parker 1989). Total volume of dead wood on the forest floor in Woodyard Hammock in 1992 was probably influenced by Hurricane Kate (table 4). Twice as much dead wood per unit area occurred in gaps as beneath closed canopy. It took about 9 years for one-half of the dead trees [d.b.h. ≥4 inches (10 cm)] to disappear (estimated in 1992 from the presence or absence of remains of mapped trees that died in Woodyard Hammock between 1978 and 1990). Logs of spruce pine and eastern hophornbeam disappeared more slowly than logs of southern magnolia, American beech, American hornbeam, and American holly.

Regional and Local Variation

Southern mixed hardwood forest species composition, diversity, and proportion of evergreen and deciduous trees vary throughout the Coastal Plain. The geographical distributions of some tree species terminate or are interrupted within the Coastal Plain, presumably in relation with climatic gradients or geological history. For example, the distributions of spruce pine and sourwood (*Oxydendron arboreum)* do not extend west of the Mississippi River, and the distribution of yellow-poplar (*Liriodendron tulipifera* L.) terminates in central Louisiana (Beck 1990, Kossuth and Michael 1990, Overton 1990). Before European settlement, no pines grew near the Mississippi River (Delcourt and Delcourt 1974), explaining the absence of pines in the Tunica Hills old-growth forest.

The number of evergreen species in the southern mixed hardwood forests decreases to the north, while the number of deciduous species decreases to the south (Blaisdell et al. 1974, Greller 1980, Ware et al. 1993). The northernmost limit of southern magnolia occurs at the southeastern corner of North Carolina (Ware 1970, Ware et al. 1993). This limit has been proposed to be associated with seed and seedling sensitivity to freezing (Evans 1933). American beech and white oak do not grow in southeastern Georgia and the peninsula of Florida (Ward 1967). Ranges of the other temperate tree species terminate progressively from north to south along the central ridge of the peninsula of Florida, and very little mixing occurs with tropical tree species. As a result, tree-species diversity in temperate hardwood forests decreases southward along the peninsula (Greller 1980, Schwartz 1988, Platt and Schwartz 1990). Diversity of epiphytes and ferns, however, increases in this direction by the addition of tropical species (Schwartz 1988, Platt and Schwartz 1990). In mesic hardwood forests of northern Florida, less than one-third of the overstory species are evergreen; but farther south in the peninsula, evergreens are more than one-half of the overstory species (Greller 1980). Located west of the Florida peninsula, the exemplary forests contained less than one-third evergreen species in the overstory, but the basal area of these evergreen species was 43 to 52 percent (table 4) of total basal area of overstory species (except in the Tunica Hills, where it was 7 percent).

Old-growth composition of southern mixed hardwood forests varies with local soil conditions and subtle topographic gradients. In northern Florida, Monk (1965) found that the proportion of evergreen trees in hardwood forests was highest on dry, sterile soils and that maximum community diversity occurred on mesic calcareous soils. In ordination analyses of the original 30 quantitative censuses from Quarterman and Keever (1962), Ware (1978, 1988) found that higher abundance of laurel oak (*Q. hemisphaerica* Michx.) and lower abundance of American beech were apparently associated with relatively low moisture and coarse soil texture. In eastern Texas, Marks and Harcombe (1981) found that species composition varied with changes of soil texture over the landscape. Their lower slope hardwood pine forest, which had the maximum proportion of evergreen species, occurred in the middle of the soil texture gradient. In northwest Florida, Gibson (1992) found that topography accounted for the main compositional differences within a forest dominated by laurel oak.

Both Platt and Schwartz (1990) and Harcombe et al. (1993) suggested that fire occurrence interacts with edaphic factors and topography to determine the distribution of hardwood forest tree species. According to Platt and Schwartz (1990), low intensity, growing-season fires on the uplands may prevent some species from mesic and hydric forests, such as sweetgum, water oak, loblolly pine, and American hornbeam, from invading upslope. A similar situation was proposed for the Kisatchie National Forest in western Louisiana, where fire was hypothesized to play a key role in determining the differences between mesic stands, dominated by American beech, southern magnolia, swamp chestnut oak, white oak, and water oak, and drier stands dominated by post oak (*Q. stellata),* blackjack oak (*Q. marilandica)*, southern red oak (*Q. falcata),* black oak (*Q. velutina),* white oak, *Carya* spp., shortleaf pine (*P. echinata* Mill.), and loblolly pine (Martin and Smith 1991).

Old-Growth Dynamics

Tree recruitment, growth, and mortality in old-growth southern mixed hardwood forests do not seem to have occurred at steady annual rates. Instead, these processes would have had pulses as a result of natural disturbances (Harcombe and Marks 1978, Glitzenstein et al. 1986, Platt and Schwartz 1990). In the past, creeping fires that started in the uplands might have frequently killed seedling and understory trees and damaged adult trees (especially American beech) (Blaisdell et al. 1974). In contrast, crown or devastating fires have not been recorded in these forests. In Woodyard Hammock, a summer drought in 1981 killed many small trees and slowed the growth rate of trees. Intermittent streams, changing their course across the forest, have also caused localized tree mortality in Woodyard Hammock.

The most conspicuous disturbances affecting southern mixed hardwood forests are hurricanes. All of the exemplary forests were exposed to four to six storms with winds over 62 miles per hour [100 kilometers per hour (km/hour)] between 1886 and 1992 (see appendix). In 1985, Hurricane Kate passed near Woodyard Hammock and Titi Hammock with winds of about 100 miles per hour (160 km/hour). In Woodyard Hammock, this storm extensively disrupted the canopy; expanded gaps (Runkle 1982) were increased from 31 to 62 percent of the area, and 58 percent of large hardwood trees and 80 percent of large pines were damaged. However, tree mortality was low; 98 percent of all hardwoods, 95 percent of large [d.b.h. ≥18 inches (45 cm)] hardwoods, 65 percent of all pines, and 61 percent of large pines survived. The effect of Hurricane Kate on species diversity was minor; the number of common species (measured as $N1 = e^{H'}$) was 12.0 in 1984 and 11.7 in 1986. In Titi Hammock, the patterns of tree damage and mortality were similar. None of the hurricanes recorded near the exemplary forests between 1886 and 1992 greatly exceeded the intensity of Hurricane Kate (Jarvinen et al. 1984). Hence, none of these forests has undergone a hurricane of the magnitude of Camille (1969) or Hugo (1991). Such major hurricanes are, however, very unlikely to impact on these forests because they have a low frequency of landfall along the Gulf of Mexico coastline.

In Woodyard Hammock, disruption of the canopy by Hurricane Kate prompted marked changes in tree recruitment, growth, and mortality in subsequent years. Before the disturbance, recruitment rates were low, and thinning of juveniles and small trees was intense. Tree mortality decreased with increasing size, and large tree mortality was very low. Average growth rates of large trees were high, and juveniles were almost completely suppressed (table 5). As a result, total density was decreasing, and basal area was becoming increasingly concentrated in large trees. After the Hurricane, there was a massive recruitment into the juvenile size class [d.b.h. ≥1 inch (2 cm)], which mostly resulted from release of small individuals present at the time of the storm. Juvenile mortality decreased and juvenile annual growth rate more than doubled (table 5). Mortality of large trees increased greatly, and large-tree annual growth rate was halved (table 5). As the result, total tree density (d.b.h. ≥1 inch (2 cm)] increased 36 percent in 6 years, even though total tree basal

Table 5—Average rates of recruitment, tree growth, and mortality observed in Woodyard Hammock during periods before (1978-84), including (1984-86), and after (1986-92) Hurricane Kate

Vital rates	1978-84	1984-86	1986-92
Recruitment (trees/ha/yr)	13.8	43.3	81.0
Annual growth (mm/yr)			
Juveniles	.66 (.02)	1.27 (.04)	1.61 (.03)
Small trees	1.90 (.05)	1.30 (.04)	1.94 (.06)
Large trees	4.07 (.19)	1.64 (.15)	1.96 (.16)
Annual mortality (percent)			
Juveniles	5.58 (.21)	5.31 (.38)	3.41 (.15)
Small trees	2.58 (.15)	4.04 (.33)	1.98 (.14)
Large trees	.71 (.23)	4.73 (.99)	2.03 (.39)

Standard errors shown in parentheses. Juveniles (2 cm ≤ d.b.h. <10 cm); small trees (10 cm ≤ d.b.h. <50 cm); large trees (50 cm ≤ d.b.h.).

area remained stable. As most of the new recruits were spruce pine or eastern hophornbeam, forest species composition [d.b.h. ≥1 inch (2 cm)] changed rapidly in the years that followed Hurricane Kate. In contrast, the rate of change in species composition of trees ›4 inches (10 cm) in d.b.h. declined from the prehurricane period, mainly because ongoing thinning of suppressed spruce pine and American hornbeam ceased.

The Nature of Old Growth

The southern mixed hardwood forests were presented by Quarterman and Keever (1962) as the “climatic climax” in the southeastern Coastal Plain, as part of a long tradition of assigning climax status to the mesic hardwood forests of the region (Gano 1917; MacGowan 1937; Kurz 1944; Braun 1950; Monk 1965, 1967, 1968; Blaisdell et al. 1974; Delcourt and Delcourt 1974, 1977; Ware et al. 1993). The main basis for this argument has been that fire suppression in the upland pine-savannas is followed by hardwood encroachment. This concept was based on the assumption that southern mixed hardwood forests were essentially equilibrium forests that resulted from a directional autogenic succession (Quarterman 1981). However, this concept gave little consideration to hurricanes that frequently impact the Coastal Plain (Jarvinen et al. 1984, Neumann et al. 1992). These disturbances constitute a strong allogenic influence that may prevent these forests from approaching an equilibrium (Glitzenstein et al. 1986, Platt and Schwartz 1990).

The hurricane regime affecting the southern mixed hardwood forests is characterized by high frequency (several per century) of storms that, while extensively damaging the canopy, result in low tree mortality. In contrast, complete forest devastation by natural agents, such as very intense hurricanes or crown fires, appears to be extremely rare. In each site, recurrence time of hurricanes may be highly variable, and patterns of hurricane damage may vary among storms. Frequent, nondevastating hurricanes would account for the larger proportion of the area occupied by gaps, lower density of standing dead trees, and relatively smaller sizes of canopy trees than in northern temperate old-growth forests (Quigley and Platt 1996). High tree density would occur because mortality of suppressed trees is likely to be interrupted by a disturbance. Repeated canopy disruption, with the consequent increases in light in the understory, would account for high rates of recruitment and growth.

Hurricanes can be followed by waves of tree recruitment, growth, and death resulting in changes in the density and structure of tree populations and in consequent fluctuations in forest species composition. Under a regime of frequent low intensity hurricanes, stands of southern mixed hardwood forests are not likely to reach an equilibrium structure and composition. Regeneration in periodic canopy openings would prevent the long-lived, shade-tolerant canopy trees from displacing the short-lived, shade-intolerant pines and the small statured understory species (Connell 1978). However, the nondevastating nature of such disturbances also results in shade-tolerant species surviving frequent disruptions. In addition, since hurricanes may disrupt large proportions of the canopy, changes in disturbed patches are likely to be reflected throughout the stand (O'Neill et al. 1986, Smith and Urban 1988). The classical interpretation of these effects of frequent, nondevastating disturbances, consistent with the directional succession model, is that disturbances produce a retrogression to preclimax seral stages followed by a new autogenic succession toward the climax (MacGowan 1937). However, because hurricanes often occur at intervals shorter than the lifespan of trees, and because their immediate effects can be variable, successional tendencies due to tolerance and competitive displacement would be minor compared to the processes of regeneration and change that result from the timing and immediate effects of the disturbances (Platt and Schwartz 1990). One strong suggestion against the retrogression notion is that spruce pine, a light-demanding species that is recruited into the canopy in gaps enlarged by the hurricanes, does not behave as a pioneer, but instead is endemic to these old-growth forests. As the climate of the southeastern Coastal Plain along the Gulf of Mexico coastline remained relatively unchanged during the Pleistocene age, chronic disturbance of these forests may have selected traits in the life history of the tree species that make them adapted for, or even dependent on, the disturbance (Denslow 1980, Platt and Schwartz 1990).

Disturbances affecting the southern mixed hardwood forests appear to be critical for both regeneration and change in old-growth stands. Allogenic disturbances would have been necessary for recruitment or growth of many of the tree species into the canopy of these forests and, therefore, for their continued coexistence. Wide variation in the frequency of disturbances and probably in their immediate effects would have determined changes in stand structure and composition. As complete stand devastation by natural agents was probably very rare in this forest type, old-growth stands may have existed for many generations of trees under the effects of frequent, nondevastating disturbances. Regeneration and change associated with these disturbances, rather than the hypothesized directional succession (Quarterman and Keever 1962, Bormann and Likens 1979, Quarterman 1981), are likely to have dominated the natural dynamics of these forests over most of their history.

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Appendix

Exemplary Forests

Woodyard Hammock is a 74-acre [30-hectare (ha)] hardwood forest located 20 miles [32 kilometers (km)] north of Tallahassee, Leon County, in northern Florida (30°35' N, 84°20' W). It occupies flat terrain along the northern shore of Lake Iamonia. Part of an antebellum plantation established in the early 1800's, it has been managed as a part of Tall Timbers Research Station since 1959 (Blaisdell et al. 1974, Hirsh 1981, Platt and Hermann 1986, Platt and Schwartz 1990). According to records of the National Oceanic and Atmospheric Administration (NOAA) (Neumann et al. 1992), between 1886 and 1992 four hurricanes with winds over 62 miles per hour [100 kilometers per hour (km/h)] in 1886, 1894, 1941, and 1985 (Hurricane Kate), passed within 62 miles (100 km) of Woodyard Hammock. Even though creeping fires originating in surrounding pine land entered the forest in the past, this has not happened recently, at least since 1959 (Hirsh 1981). During the early 1900's, dead trees were salvaged for firewood and some large loblolly pine (*Pinus taeda*) were cut. In 1978, an 11-acre (5-ha) permanent study plot was established in the middle of Woodyard Hammock (Hirsh 1981, Platt and Hermann 1986). All trees in the plot 1 inch [2 centimeters (cm)] in d.b.h. or larger were measured, mapped, and tagged. Censuses were repeated biennially to record tree recruitment, growth, and death. Gaps were periodically mapped as polygons formed by connecting the bases of their bordering canopy trees (expanded gaps) (Runkle 1982). After Hurricane Kate in 1985, damage to each mapped tree was assessed. Trees that died between 1978 and 1992 and extant dead material were sampled in 1992 to estimate density of snags, volume of downed logs, and rates of disappearance.

Titi Hammock is a 289-acre (117-ha) hardwood forest located in Thomas County, in southern Georgia, 22 miles (14 km) south of Thomasville (30°41' N, 84°00' W). It is part of Springhill Plantation, was established in the early 1800's, and is currently managed by The Nature Conservancy. This forest occupies steep terrain with a 66-feet [20-meters (m)] change in elevation along the bluffs of Titi Creek. Along the slope, three different plant associations can be distinguished (Platt 1985). In the past, dead trees were salvaged for firewood and some large pines may have been selectively cut on the upper slope. A creeping fire entered the forest in 1968 (Blaisdell et al. 1974). The site is near Woodyard Hammock and was exposed to the same hurricanes as that forest. A 12-acre (5-ha) permanent study plot was established in Titi Hammock in 1985 before Hurricane Kate struck the area. All trees in the plot 1 inch (2 cm) in d.b.h. or larger were tagged, measured, and mapped. Damage to mapped trees by Hurricane Kate was assessed in 1986, and in 1990 the whole plot was surveyed for tree growth and survival.

Zemurray Forest is an 87-acre (35-ha) hardwood forest located in Tangipahoa Parish in eastern Louisiana, 50 miles (80 km) north of New Orleans (30°37' N, 90°21' W). It occupies a level site with acid soil, in the floodplain of Chappepeela Creek (White 1987). According to NOAA records (Jarvinen et al. 1984), between 1886 and 1992 four hurricanes passed within 62 miles (100 km) of this location with wind of more than 62 miles per hour (100 km/h). Quarterman and Keever (1962) included this forest in their extensive survey of the southern mixed hardwood forest. In this report, detailed information on structure and composition of this forest was obtained by White (1987), and was based on the analysis of ten 1-acre (0.2-ha) plots.

Tunica Hills is a forest tract located in West Feliciana Parish in eastern Louisiana, 38 miles (60 km) northwest of Baton Rouge and 1 mile (2 km) east of the Mississippi River (30°47' N, 91°29' W). It has second-growth pine forests on the uplands and old-growth hardwood forests on steep ravine slopes (Delcourt and Delcourt 1974). The forest is being managed as a preserve by The Nature Conservancy. According to NOAA records (Jarvinen et al. 1984), between 1886 and 1992 six hurricanes with winds more than 62 miles per hour (100 km/h) passed within 62 miles (100 km) of this site. Data used in this report were obtained by Quigley (1994), who measured, tagged, and mapped all trees that were 0.4 inches (1 cm) in d.b.h. or greater in 16 randomly located hardwood plots of 0.2 acres (1/16 ha) each.

Weir Forest is located 10 miles (16 km) north of Beaumont, in Hardin County in eastern Texas, (30°16' N, 94°12' W). It occupies gently sloping terrain, slightly dissected by intermittent streams near the Neches River (Harcombe and Marks 1977). According to Glitzenstein et al. (1986), this forest was not directly affected by humans before the late 1800's. Around 1917, pines were selectively logged. According to NOAA records (Jarvinen et al. 1984), four hurricanes with winds more than 62 miles per hour (100 km/h) passed within 62 miles (100 km) of this forest. An 8-acre (3-ha) plot in Weir Woods has been mapped and monitored since 1980. Data on species composition and tree sizes were provided by J. Glitzenstein and P. Harcombe. Additional information was taken from detailed analyses of structure and dynamics of this forest (Harcombe and Marks 1978, Glitzenstein et al. 1986).

Batista, William B.; Platt, William J. 1997. An old-growth definition for southern mixed hardwood forests. Gen. Tech. Rep. SRS-9. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 11 p.

This report provides an old-growth definition for the southern mixed hardwood forests based on five exemplary stands that show no evidence of having undergone any natural catastrophe or clearcutting for at least 200 years. This forest type occurs in the U.S. southeastern Coastal Plain from the Carolinas to eastern Texas. The exemplary old-growth stands were restricted to slopes or slightly elevated terraces between uplands and river- or lake-margin floodplains. They had a diverse overstory, typically dominated by *Fagus grandifolia, Magnolia grandiflora, and Pinus* spp., and a particularly diverse woody understory. Observed rates of tree recruitment, growth, and death were rather high. These processes would occur in pulses, associated with the frequent but nondevastating effect of hurricanes, that may result in fluctuations of species composition. We suggest that under this disturbance regime, old-growth southern mixed hardwood forests would not undergo a directional succession.

Keywords: Coastal Plain, conservation, disturbance, *Fagus grandifolia,* hurricane, *Magnolia grandiflora*, old growth, restoration, southern mixed hardwood forests, temperate forest.