Managing Forests to Maintain Populations of Gray and Fox Squirrels

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Illinois Natural History Survey

Illinois Department of Conservation Technical Bulletin 5
June 1987

Illinois Department of Conservation Technical Bulletin 5
Printed by authority of the State of Illinois
Springfield, Illinois
James R. Thompson, Governor
Mark Frech, Director, Department of Conservation

This report is a contribution (in part) of Federal Aid in Wildlife Restoration Project W-66-R, with the cooperation of the Illinois Department of Conservation, the United States Fish and Wildlife Service, and the Illinois Natural History Survey. The Illinois Department of Conservation and the United States Fish and Wildlife Service have no responsibility for the form and content of the data in this report or for the conclusions reached.

The acrylic painting of a fox squirrel used on the cover was painted especially for this publication by Beverley C. Sanderson, Champaign, Illinois.

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Composition: Patty L. Duzan and Eva Steger

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Contents

THIS management guide is designed to maintain populations of fox and gray squirrels (*Sciurus niger* and *S. carolinensis*) in the forests of Illinois and adjacent states, an area that includes the western portion of the central hardwood forest region of the Ohio and middle Mississippi river valleys. It is intended for managers of public forests and for those who provide technical assistance to the owners of private forests.

The possibilities of continuous production of forest products from trees of high market value are not always perceived by woodland owners, who often equate a "woodsy" condition with potential forest income regardless of tree composition and condition. Managers are further constrained by the requirements of the current wood market and by institutional or personal biases that limit timber management prescriptions to some form of selection cutting. For example, a recent followup study of 23 timber sales on private lands in southern Indiana revealed that single-tree selection cutting (diameter limit cutting) had left most of the stands seriously understocked with high quality trees (Callahan & Fischer 1982). Single-tree selection cutting often accelerates the successional trend toward such shade-tolerant, moist-soil species as sugar maple, a trend that is already occurring in many oak-dominated forests (Schlesinger 1976; Merritt 1979; Sawtelle 1984). We believe that private landowners must be offered alternative management plans for their woodlands and informed of the consequences of those alternatives in terms of the future production of wood products and the maintenance of wildlife. Although timber products are important reasons for owning woodlands, many owners appreciate the aesthetic and recreational values of a diverse wildlife population and are willing to forego financial gain to provide wildlife habitat. Timber managers, therefore, must consider recreational and residential uses of woodlands as well as their market value.

We also recognize that the management of tree crops may not be a viable alternative on some public and private forest lands in Illinois because of public opposition to timber cutting or because intensive recreational use precludes it. Often such forests are excellent producers of squirrels. When hunting is prohibited, these forests serve as refuges for squirrels, thereby providing emigrants that will disperse to adjacent forests and ultimately help to maintain squirrel numbers within heavily hunted public forests.

Scientific names for all trees mentioned in the text are given in Appendix 1. Technical terms used in the text are defined in the glossary.

Acknowledgments

We wish to thank the following for their helpful reviews: Mr. R.K. Landes, U.S. Department of Agriculture (USDA) Forest Service, Hoosier National Forest; Mr. L. Casey, USDA Forest Service, State and Private Forestry; Mr. J. Ellis, Illinois Department of Conservation; Mr. F. Loomis, Illinois Department of Conservation; Mr. R. Stoll, Ohio Division of Wildlife; Drs. G.C. Sanderson and W.R. Edwards, Illinois Natural History Survey; and Mr. G. Hubert, Illinois Department of Conservation. Mr. L. Le Mere and Mrs. Molly Hardin Scott, Illinois Natural History Survey, provided the figures; Mrs. Audrey Hodgins, also of the Survey, edited the manuscript.

Physiographic Divisions of Illinois

Of the estimated 15.3 million acres of forest present in Illinois in 1800, only about 4.1 million acres remain (USDA Forest Service, unpublished data 1986). Based on physiography and land use, Illinois can be divided into the three regions shown in Figure 1: the Prairie Region (60 counties), the Claypan Region (26 counties), and the Southern Region (16 counties). Squirrel habitats in these regions differ in nature and extent.

Prairie Region

Approximately 7.9 percent of the Prairie Region was forested in 1985. The landscape is nearly level, and the soils, derived from loess over calcareous glacial drift, have been enriched over time by prairie vegetation. Today this region is one of the world's most productive and intensively farmed areas, and remnant forests are confined almost exclusively to areas too rough or too poorly drained to farm. Forests persist as small, scattered wood lots or as narrow belts along rivers and streams. Major forest types are oak-hickory (49%), stands dominated by sugar maple (33%), and bottomland hardwoods (14%) (USDA Forest Service, unpublished data 1986).

Claypan Region

South of the Prairie Region on soils of Illinoian age, the uplands are level with more dissected stream courses. These soils of the Claypan Region are more extensively leached and not as fertile as those in the Prairie Region. Here the upland soils developed under prairie vegetation; the bottomland soils developed under hardwood forests. Forests covered 15.4 percent of this region in 1985 and are found primarily on rough slopes, in bottomlands along creeks and rivers, and in thousands of small farm woodlands. Major forest types include oak-hickory (55%), bottomland hardwoods (20%), and stands dominated by sugar maple (20%).

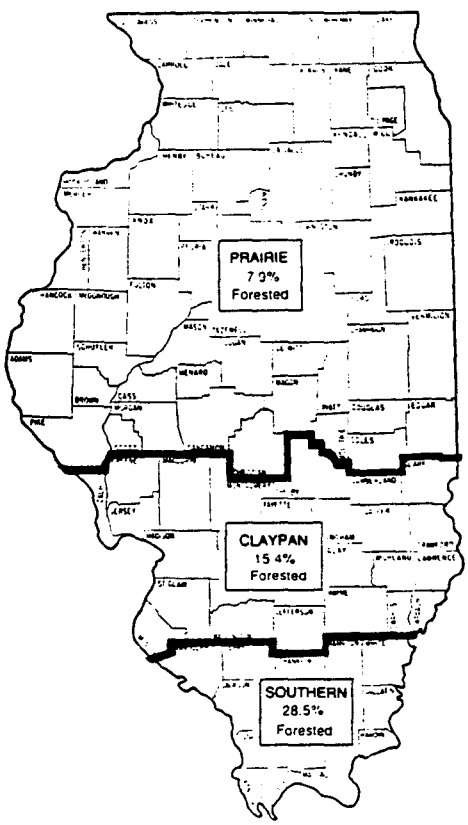

FIGURE 1. Physiographic regions of Illinois.

Southern Region

Some of the 16 southernmost counties of Illinois were never glaciated. As a result, forest types in the Southern Region are more varied than those in the Prairie and Claypan regions because the rougher topography creates a mix of sites that offers variable soils and microclimates that affect tree growth and composition. Extensive pine plantings on public lands have also created artificial and naturally seeded pine stands. More bottomland sites are also located in the Southern Region than in the other two regions. In 1985, 28.5 percent of the Southern Region was forested. Forests dominated by oak-hickory made up 46 percent of the total forest; bottomland forest types made up 25 percent; types dominated by sugar maple contributed 21 percent; and pine forests, 6 percent (USDA Forest Service, unpublished data 1986).

Forest Characteristics and Ownership

Ninety percent of Illinois woodlands are privately owned, principally by farmers (45%) and homeowners whose incomes are not derived from farms (38%) (Table 1). Most of these forests have not been disturbed in recent years (Table 2) and are approaching economic maturity (Table 3). Recent trends toward more mesic soils and microclimates that followed the cessation of uncontrolled wild fires and livestock pasturing have created conditions under which such mesic species as sugar maple have increased greatly throughout the state (Table 3). The implications for squirrels in the successional shift from oak-hickory to more mesic forests are presently unknown, but reduction in the production of winter-storable foods will reduce squirrel numbers.

Forest Types and Squirrel Populations

In Illinois, gray squirrels are most common in large (>100 acres) forested tracts along rivers and streams where at least 20 percent of the area is forested, where a diverse woody understory is found, and where at least two nesting cavities per acre can be identified (Nixon et al. 1978). Such tracts are scarce or absent over extended portions of central and northern Illinois, where wood lots are small (<100 acres) and scattered (Fig. 2). Fox squirrels are found throughout the state but prefer upland forests with sparse, woody understories that offer abundant "edge" between field and forest.

Forest types that support significant numbers of squirrels in Illinois are listed in Table 4. At present, the uplands are dominated by various oak types. Where site index exceeds 70, forests are usually mixtures of oak, maple, tuliptree, basswood, and beech but are increasingly dominated by sugar maple. These sites occur on lower slopes, in coves, and on many north- and east-facing middle slopes where surface soils are relatively deep and well drained. On average sites (site index 55–70)—such as those found on most midslopes, upper north slopes, lower south slopes, and

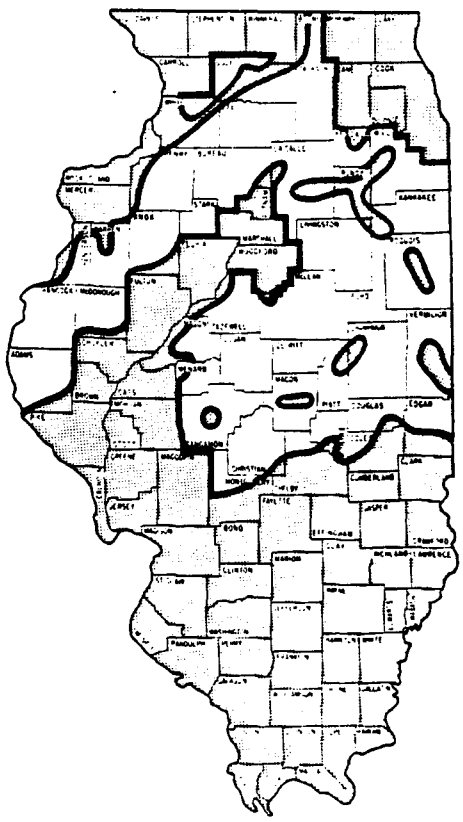

FIGURE 2. Distribution of gray squirrels in Illinois. Gray squirrels are scarce in or absent from unshaded areas.

TABLE 1.—Ownership of Illinois forest land in 1985 (USDA Forest Service, unpublished data 1986).

Ownership	Percent
Private	
Farmers	45
Homeowners	38
Corporations	7
Subtotal	*90*
Public	
Federal	7
State	2
City and county	1
Subtotal	*10*

TABLE 2.—Estimated percentages of disturbed and nondisturbed forest land by ownership, 1962–1985 (USDA Forest Service, unpublished data 1986).

	Farmers	Homeowners	Corporations
No disturbance	84	84	83
Timber sales	10	11	7
Other disturbances (fire, mining, etc.)	6	5	10

TABLE 3.—Estimated percentages of principal forest types by size in Illinois in 1985 (USDA Forest Service, unpublished data 1986).

Size	Oak-Hickory	Maple Types	Elm-Ash-Cottonwood
Sawtimber (11+ inches dbh)	72	47	67
Pole (5–10 inches dbh)	18	20	22
Saplings (<5 inches dbh)	10	33	11

TABLE 4.—Forest types in Illinois that support significant numbers of squirrels. Numbers in parentheses indicate forest-cover types of the Society of American Foresters (Eyre 1980).

Forest Type	Description and Successional Trend
UPLAND TYPES	
Northern hardwoods	
Sugar maple–basswood (26)	Well-drained, moist soils and ravines throughout Illinois. This type is increasing as forest succession currently favors these shade- tolerant species. Considered climax forest.
Beech–sugar maple (60)	Moist, well-drained soils on north and east lower slopes and ravines in southern and east-central Illinois. Considered climax forest.
Central hardwoods	
Post oak–blackjack oak (40)	Dry sites, upper south and west and ridges in southern Illinois; claypan soils in south-central Illinois and sand soils in western Illinois. Climax type on very dry sites.
Bur oak (42)	Associated with many sites, including dry uplands and moist bottomlands throughout Illinois. Not considered climax and succeeds to other oak types (52, 53, & 55).
White oak–black oak–red oak (52)	The most abundant upland type in Illinois, found on both glaciated and unglaciated soils throughout the state. Climax on dryer sites. Succeeds to sugar maple, basswood, or beech-maple on mesic sites.
White oak (53)	Moderately moist, well-drained soils throughout the state. Climax on dryer sites. Succeeds to sugar maple, basswood, or beech-maple on mesic sites.
Black oak (110)	Moderately dry to dry sites, most common on sandy soils in central and southern Illinois. Climax on dry sites.
Northern red oak (55)	Moist sites such as coves, north- and east-facing slopes in central and southern Illinois. Succeeds to sugar maple, basswood, or beech maple.
BOTTOMLAND TYPES	
Central hardwoods	
Silver maple–American elm (62)	Well-drained sites along floodplains throughout Illinois. Frequently flooded sites are almost entirely silver maple. Dutch elm disease has reduced the elm component. Succeeds itself where floods are frequent. Changes in flood regimes and soil moisture will change tree composition to other types.
Pin oak–sweetgum (65)	Pure pin oak is found on poorly drained sites on the Illinoian till plain in south-central and southern Illinois. Found on clay soils where water accumulates during winter. An early successional type that succeeds to swamp chestnut oak–cherrybark oak as soils dry out.
Swamp chestnut oak–cherrybark oak (91)	Highest first bottom ridges on the best sandy loams in the bottoms along the Ohio and Mississippi rivers and their tributaries in southern Illinois. Climax type.
Hackberry–American elm–green ash	Low ridges, flats, and sloughs in first bottoms along the major rivers in southern Illinois. Succeeds to swamp chestnut oak–cherrybark oak or sweetgum–willow oak.
Sycamore–sweetgum–American elm (94)	River fronts in the first bottoms of major rivers, banks of smaller rivers, and large creeks that flood. Rich soils with moderately good drainage in southern Illinois. Succeeds to swamp chestnut oak–cherrybark oak or sweetgum–willow oak.

many broad ridges with deep, well-drained soils—oaks and hickories are dominant. Poor sites (site index <55) are occupied almost exclusively by oaks and hickories. These sites are found on upper south slopes, dry rocky ridges, and sandy, droughty soils in Illinois; here post oak–blackjack oak or black oak–blackjack oak frequently dominate the forest overstory.

Flooding largely dictates species composition in bottomland forests, but composition at any site is also in part a product of past history (fire, flood, grazing, and cutting intensity), soil types, and natural succession. Cottonwood-willow pioneer wherever sufficient light and bare, moist soils are available. These species in turn are succeeded by mixtures of silver maple, elm, ash, sycamore, and hackberry. As soil drainage improves, the composition changes to types that include various oaks (Prairie and Claypan regions) and such types as pin oak–sweetgum, pure pin oak, and swamp chestnut oak–cherrybark oak (Southern Region). Because of past cutting practices, silver maple–elm, or a variant thereof, dominates many of the river bottoms of Illinois.

How productive of squirrels are the forest types listed in Table 4? We have compiled information from live captures of squirrels in mature stands for many of these types (Fig. 3). The key element for the production of squirrels appears to be abundance of winter-storable foods (foods that can be stored either above or below ground and retrieved in sound condition as long as 6 months later). Forest types that produce little or no winter-storable food (silver maple–elm) or are intermittent seed producers (beech-maple) support few squirrels. Forest types composed of only a few species (for example, post oak–blackjack oak or black oak types) typically support fewer squirrels than do stands of mixed species. This low population may result from the uncertain nature of seed yields where only one or two tree species are present. The presence of oaks in stands dominated by beech-maple and sugar maple–basswood greatly increases the capacity of these stands to support squirrels (Fig. 3).

Requirements of Gray and Fox Squirrels

Managers who wish to use forest management strategies to benefit gray and fox squirrels must be familiar with the life-history requirements of the two species (Table 5). Because gray squirrels are more social (they tolerate one another better) than fox squirrels, grays are more likely to increase in numbers when resources (food and shelter) increase (Nixon et al. 1984). Densities of one or two

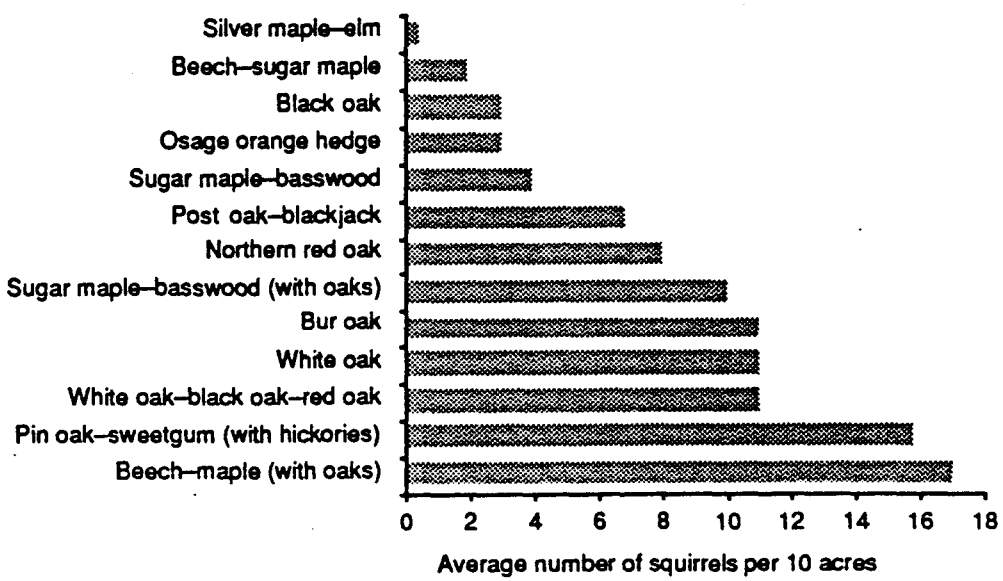

FIGURE 3. Average squirrel densities in fall found by live trapping in selected forest types in the Midwest.

squirrels per acre are commonly reported for fox squirrels; higher densities are seldom found (Baumgartner 1940; Allen 1943; Jordan 1971; Adams 1973) and when they occur, they represent temporary increases usually observed only in the fall months. Gray squirrels, however, frequently exceed two per acre on protected sites where food is abundant (Flyger 1960; Mosby 1969).

Habitat Preferences

Each of the two species has habitat preferences not shared by the other. Gray squirrels are usually found where forest understories are quite dense, but fox squirrels are found where forest understories are relatively open. This difference in habitat preference means that management activities that tend to increase the density of the forest understory, periodic selection cutting, for example, can be expected to create a forest structure more favorable to gray than to fox squirrels where both species coexist (Nixon, Havera, and Hansen 1980).

Food Habits

To maintain body weight in winter, both gray and fox squirrels need to metabolize approximately 150 to 160 kilocalories of energy per day per kilogram of body weight (Lud-

TABLE 5.—Attributes of gray and fox squirrels.

Attribute	Gray	Fox
Age structure[a] (adult:young)	Hunted 52:48 Protected 60:40	Hunted 35:65 Protected 75:25
Annual survival[b]		
Adults	Hunted:20–40%; protected:50–60%	Same as gray
Young	Hunted:<40%; protected:20–30%	Same as gray
Breeding period[c]	December–September, peaks in December–January and May–June	Same as gray
Breeding age[d]	Females: 10–12 months Males: 9–12 months	Hunted: same as gray Protected: males same as gray; females < 40% at 10–12 months
Litter size[e]	Winter: 2–3; summer: 3–4	Same as gray
Food requirement[f]	1–1.5 pounds/week (450–680 grams)	1.5–2 pounds/week (680–900 grams)
Shelter requirements[g]	Tree cavities: 2–3/acre Nest boxes: 2–3/acre Grapevines for leaf nests: 2–3/acre	Tree cavities: same as gray Nest boxes: 1–2/acre Grapevines for leaf nests: 3–4/acre
Average home range[h]	2–20 acres, varies with size of wood lot	2–30 acres, varies with size of wood lot
Average squirrel density for mature stands[i]	0.5–1/acre, occasionally up to 6/acre in protected parks	1–2/acre
Social structure[j]	Males dominate females; adults dominate young; both sexes frequently den together; young may or may not disperse after weaning; adult female may tolerate presence of her young up to breeding age and occasionally longer; breeding females intolerant of one another.	Males dominate females; adults dominate young; adults largely solitary throughout the year; adult females intolerant of one another, of their young, and of immigrants; young usually disperse after weaning.

[a] Fouch 1961; Barkalow et al. 1970; Eveland 1974; Nixon et al. 1974; Nixon et al. 1975; Nixon et al. 1986. [b] Barkalow et al. 1970; Eveland 1974; Nixon et al. 1975; Hansen et al. 1986. [c] Brown & Yeager 1945; Nixon & McClain 1975. [d] Brown & Yeager 1945; Nixon & McClain 1975; Nixon et al. 1986. [e] Brown & Yeager 1945; Nixon & McClain 1975. [f] Nixon et al. 1968; Short & Duke 1971; Havera & Smith 1979; Korschgen 1981. [g] Barkalow & Soots 1965; Sanderson et al. 1980; McComb & Noble 1981; Nixon et al. 1984. [h] Geeslin 1970; Donohoe & Beal 1972; Adams 1973. [i] Baumgartner 1940; Flyger 1960; Mosby 1969; Eveland 1974; Nixon et al. 1986. [j] Bernard 1972; Benson 1975.

wick et al. 1969; Husband 1976; Havera & Smith 1979). To meet that requirement, squirrels need to eat approximately the number of acorns, hickory nuts, or black walnuts per day shown in Table 6.

The seasonally important foods of both species of squirrels are shown in Table 7. Because no substantial differences in food habits between species have been observed, a single list is given. Hickory nuts are the preferred food in late summer, but acorns are the leading winter food, presumably because acorns ripen later than hickory nuts, because oaks are more abundant than hickories, and perhaps because of the ease with which squirrels open acorns compared with hickory nuts, a factor that may be important for energy conservation in winter (Smith & Follmer 1972). These food habits indicate that forest managers should provide mixtures of seed-producing oaks and hickories. Although squirrels eat the seeds of all oaks and hickories native to Illinois, they tend to avoid those of red oak and bitternut hickory unless these are the only winter-storable foods available.

Seed production by trees is cyclic, with good seed years followed by 1 or 2 years with little or no seed production. The results of 28 years of continuous observations of the seeding habits of many of the trees important to squirrels in the Midwest are shown in Table 8. Oaks never produced a heavy crop during that period, although black and red oaks were somewhat better seed producers than white oaks. Hickories, on the other hand, were more dependable producers than any of the oaks, another indication that mixtures of oaks and hickories are needed to sustain squirrels from year to year.

The amount of winter-storable food available for squirrels is the key to sustained squirrel abundance. We feel that winter-storable tree seed should exceed 150 pounds per acre (Nixon et al. 1975) if the needs of all wildlife species, including squirrels, are to be met. Data from yield-measurement studies suggest that increases in sound seed production can be expected as diameter at breast height (dbh) increases for the important oaks and hickories and for black walnut in Illinois

TABLE 6.—Number of nuts or acorns eaten per day by gray and fox squirrels in winter when feeding exclusively on a single species.[a]

Tree Species	Gray[b]	Fox
White oak	9	10[c]
Black oak	18	20[c]
Red oak	5	6[c]
Blackjack oak	18	20[d]
Post oak	18	20[d]
Bur oak	3	3[c]
Shagbark hickory	9	10[c]
Mockernut hickory	9	10[c]
Black walnut	14	16[c]

[a] Developed from diets of captive squirrels.
[b] Gray squirrel data extrapolated from Short & Duke 1971.
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TABLE 7.—Foods of gray and fox squirrels in Illinois in order of importance by season.

Spring	Summer	Fall	Winter
Oak buds, flowers, and acorns	Hickory nuts	Acorns[a]	Acorns
Black walnut flowers and nuts	Acorns	Hickory nuts[a]	Black walnuts
Elm flowers, buds, and seeds	Black walnuts	Black walnuts[a]	Osage orange seeds
Hickory flowers and nuts	Mulberries	Osage orange seeds[a]	Corn seed
Corn seed	Grapes	Grapes	Hickory nuts
Maple buds, flowers, and seeds	Fungi	Corn seed	Elm buds
Osage orange seeds	Maple seeds	Fungi	Soybeans
Fungi	Corn seed	Maple seeds	
	Hackberry seed	Dogwood seeds	

[a] Winter-storable foods.

(Table 9). From these production figures and from the number of seeds eaten by squirrels per day during winter (Table 6), we have developed a crude stocking guide that would provide squirrels with 80 percent of their annual diet (30% oak, 40% hickory, 10% walnut) (Table 10). We base this recommendation on studies of food habits done in the Midwest (Nixon et al. 1968; Korschgen 1981).

The stocking guide shown in Table 10 works as follows. The allowable maximum number of trees of all species from, for example, the 14-inch dbh class is 119 per acre; the allowable minimum is 68. Forest managers, therefore, may harvest down to 68 trees. These trees should come from the three categories shown in Table 10: oaks, hickories, and black walnut. The oak requirement (30% of the annual diet) may be filled at 14-inch dbh by 4 white oaks or by the number given in Table 10 for any of the other oak species. The hickory requirement (40% of the annual diet) may be filled by 18 shagbarks or 8 mockernuts. One black walnut is required to fill the final 10 percent. If these requirements are met in each category, other trees in those categories may be removed without threatening the diet we recommend for squirrels.

This stocking guide can be modified for stands that are composed of only a few species. If, for example, the seed-producing trees in a given stand are composed solely of white oak, the minimum number required to meet the needs of squirrels will be higher than that shown in Table 10. To calculate, for example, the number of 10-inch white oaks that would be required to provide 100 percent of the annual diet, divide the number shown in Table 10 (13) by the proportion of the annual diet provided by oaks in oak-dominated stands (30%). That number equals the number of white oaks that would be needed if they were to provide 100 percent of the diet ($13 \div 0.30 = 43$). When white oaks are expected to provide less than 100 percent of the diet but more than 30 percent, multiply the anticipated proportion by 43. If, for example, 10-inch dbh white oaks were expected to provide 75% of the annual diet of squirrels, 32 white oaks would be required ($43 \times 0.75 = 32$).

TABLE 8.—Relative seed production by trees important to squirrels over a 28-year period in the Midwest (Den Uyl 1961).

Tree Species	Number of Years			
	No Crop	Light Crop	Medium Crop	Heavy Crop
White oak	5	17	6	0
Red oak	1	19	8	0
Black oak	1	17	10	0
Hickories	0	20	4	4
Beech	6	14	5	1
Sugar maple	0	11	9	8
White ash	1	18	7	2
Elms	0	13	11	4
Basswood	0	10	12	6
Tuliptree	1	15	10	2

TABLE 9.—Seed production for species of oak and hickory and for black walnut by dbh class.

Average dbh (inches)	Average Number of Sound Nuts or Acorns per Tree								
	Oak					Hickory			Walnut
	White[a]	Black[b]	Red[b]	Blackjack[a]	Post[a]	Shagbark[c]	Mockernut[c]	Pignut[c]	Black[d]
8	52	—[e]	—	—	454	16	12	—	478
10	278	260	40	40	626	45	56	48	830
12	505	405	200	746	778	88	155	139	1,181
14	742	550	510	1,107	907	132	254	230	1,533
16	968	695	900	1,492	1,102	176	350	319	1,884
18	1,195	840	1,310	1,876	1,253	220	449	411	2,236
20	1,421	985	1,560	2,137	1,426	264	548	502	2,584
22	1,658	1,130	1,540	2,599	1,578	307	646	592	2,939
24	1,885	1,275	1,400	2,983	1,728	351	744	683	—

[a]Goodrum et al. 1971. [b]Downs 1944. [c]Nixon, McClain, and Hansen 1980. [d]Zarger 1946. [e]No information.

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(Table 9). From these production figures and from the number of seeds eaten by squirrels per day during winter (Table 6), we have developed a crude stocking guide that would provide squirrels with 80 percent of their annual diet (30% oak, 40% hickory, 10% walnut) (Table 10). We base this recommendation on studies of food habits done in the Midwest (Nixon et al. 1968; Korschgen 1981).

The stocking guide shown in Table 10 works as follows. The allowable maximum number of trees of all species from, for example, the 14-inch dbh class is 119 per acre; the allowable minimum is 68. Forest managers, therefore, may harvest down to 68 trees. These trees should come from the three categories shown in Table 10: oaks, hickories, and black walnut. The oak requirement (30% of the annual diet) may be filled at 14-inch dbh by 4 white oaks or by the number given in Table 10 for any of the other oak species. The hickory requirement (40% of the annual diet) may be filled by 18 shagbarks or 8 mockernuts. One black walnut is required to fill the final 10 percent. If these requirements are met in each category, other trees in those categories may be removed without threatening the diet we recommend for squirrels.

This stocking guide can be modified for stands that are composed of only a few species. If, for example, the seed-producing trees in a given stand are composed solely of white oak, the minimum number required to meet the needs of squirrels will be higher than that shown in Table 10. To calculate, for example, the number of 10-inch white oaks that would be required to provide 100 percent of the annual diet, divide the number shown in Table 10 (13) by the proportion of the annual diet provided by oaks in oak-dominated stands (30%). That number equals the number of white oaks that would be needed if they were to provide 100 percent of the diet ($13 \div 0.30 = 43$). When white oaks are expected to provide less than 100 percent of the diet but more than 30 percent, multiply the anticipated proportion by 43. If, for example, 10-inch dbh white oaks were expected to provide 75% of the annual diet of squirrels, 32 white oaks would be required ($43 \times 0.75 = 32$).

TABLE 8.—Relative seed production by trees important to squirrels over a 28-year period in the Midwest (Den Uyl 1961).

Tree Species	Number of Years			
	No Crop	Light Crop	Medium Crop	Heavy Crop
White oak	5	17	6	0
Red oak	1	19	8	0
Black oak	1	17	10	0
Hickories	0	20	4	4
Beech	6	14	5	1
Sugar maple	0	11	9	8
White ash	1	18	7	2
Elms	0	13	11	4
Basswood	0	10	12	6
Tuliptree	1	15	10	2

TABLE 9.—Seed production for species of oak and hickory and for black walnut by dbh class.

Average dbh (inches)	Average Number of Sound Nuts or Acorns per Tree								
	Oak					Hickory			Walnut
	White[a]	Black[b]	Red[b]	Blackjack[a]	Post[a]	Shagbark[c]	Mockernut[c]	Pignut[c]	Black[d]
8	52	—[e]	—	—	454	16	12	—	478
10	278	260	40	40	626	45	56	48	830
12	505	405	200	746	778	88	155	139	1,181
14	742	550	510	1,107	907	132	254	230	1,533
16	968	695	900	1,492	1,102	176	350	319	1,884
18	1,195	840	1,310	1,876	1,253	220	449	411	2,236
20	1,421	985	1,560	2,137	1,426	264	548	502	2,584
22	1,658	1,130	1,540	2,599	1,578	307	646	592	2,939
24	1,885	1,275	1,400	2,983	1,728	351	744	683	—

[a]Goodrum et al. 1971. [b]Downs 1944. [c]Nixon, McClain, and Hansen 1980. [d]Zarger 1946. [e]No information.

At present in Illinois, 74 percent of the white oaks, 81 percent of the black oaks, and 94 percent of the hickories are ≤ 10 inches dbh and therefore are not producing large seed crops (Table 11).

Winter Feeding

No evidence indicates that the use of corn to supplement the winter diet of squirrels is necessary in mixed hardwood forests (Havera & Nixon 1980); indeed, an exclusive diet of corn causes weight loss in both gray and fox squirrels (Havera & Smith 1979). However, in forests composed of only one or two species, for example, black oak on sandy uplands or pin oak in the bottoms, tree seed failures are fairly common. In years of seed failure, we suggest supplemental feeding with a 70:30 mixture of shelled corn and shelled soybeans. Soybeans provide a more balanced diet; however, some squirrels will not eat them initially (Havera & Smith 1979). Feeders (roofed wooden boxes placed on legs) should be spaced about one per 10 acres. Feeding should begin in late August and continue into late March or April, or until spring foods become abundant. Squirrels begin dispersing as early as August when food crops fail and will already have dispersed if feeding is delayed until November or December. Managers should note that in most winters feeding may have limited value in reducing the emigration of fox squirrels and in attracting immigrants. Winter feeding, however, is more likely to increase gray squirrel numbers.

Natural Shelters

Both fox and gray squirrels prefer tree cavities over leaf nests for shelter. Preferred cavities have entrance holes 2–4 inches in diameter, are 12–20 inches deep, are situated in the trunk of a tree or in a large limb, and offer protection from wet and cold weather. Fox squirrels are more likely to use leaf nests in winter than are grays, although both species use them in summer, presumably to escape the heat and the parasites that build up in tree cavities.

The importance of tree cavities to gray squirrels is shown in our Illinois study of cavity abundance and gray squirrel distribution (Nixon et al. 1978). We found grays present only where we found at least two tree cavities suitable for all-weather shelter per acre. We examined 279 leaf nests in late February in Vermilion County, Illinois, and found that 13 percent were occupied by fox squirrels. No use of leaf nests by grays was observed,

TABLE 10.—Number of trees required for stocking at levels A and B in oak-dominated stands and the minimum number of dominant or co-dominant oaks, hickories, and black walnut needed at level B to supply 80 percent of the annual squirrel diet (30% oak, 40% hickory, and 10% walnut). Squirrel densities are assumed to average one per acre. Site index is ignored here because the position of the tree canopy is more important to seed production than the quality of the site.

Average dbh (inches)	Trees per Acre[a]		Number of Trees to Be Retained per Acre at B-level Stocking[b]							
			Oak					Hickory		Walnut
	Level A	Level B	White	Black	Red	Post	Blackjack	Shagbark	Mockernut	Black
8	308	177	73	—[c]	—	9	—	—	—	3
10	212	122	13	16	29	7	19	97	79	2
12	155	88	5	10	5	5	5	26	14	2
14	119	68	4	6	3	5	3	18	8	1
16	93	53	4	4	2	3	2	9	5	1
18	75	43	2	3	2	3	2	7	4	1
20	63	35	1	3	2	3	1	6	3	1
22	52	30	1	2	1	3	1	5	3	1
24	45	25	1	2	1	3	1	5	2	1

[a] Gingrich 1967. A and B levels represent the range of tree stocking that will fully utilize an available growing space. A-level stocking represents the upper limit of full utilization; B-level stocking represents the lower limit of full utilization.

[b] Corrected for trees that do not produce seed.

[c] No Information.

although they comprised about 15 percent of the squirrel population. Radio-tracking studies in other states (Geeslin 1970; Donohoe & Beal 1972; Adams 1973) showed that individual squirrels of both species used up to nine different shelters on an annual basis; two or three of these were tree cavities offering all-weather shelter. On the basis of these findings, at least two or three cavities that provide all-weather shelter should be available per acre if reasonably high squirrel densities are to be sustained (Table 12). The location of these cavities (trunk or limbs) makes no difference if the entrance hole is 2–4 inches in diameter, thus excluding larger predators.

In Illinois, unmanaged forest stands >50 years old usually contain an abundance of cavities suitable for squirrels (Table 13). Cavities are most abundant in trees ≥12 inches dbh. Figure 4 illustrates a typical distribution of cavity trees by size. Black oak, sugar maple, basswood, cottonwood, beech, elms, ashes, and sycamore are more likely to form one or more suitable cavities; hickories are least likely to do so.

Leaf nests are usually built in or near favored-food trees in late summer. On a study area in Vermilion County, Illinois, we found that fox squirrels selected white oak and beech as sites for leaf nests more often than expected; black oak, the tight-bark hickories (mockernut, pignut, and bitternut), sugar maple, black walnut, ash, and red oak in proportion to their abundance in the woods; and shagbark hickory less often than expected. Of the trees in which leaf nests were built, white oak and beech contained more usable (still weathertight when examined) nests than expected on the basis of tree frequency; sugar maple, red oak, the tight-bark hickories, and shagbark hickory had expected numbers of usable leaf nests; black oak, black walnut, and ash had fewer usable nests than expected. No significant relationship was found between the longevity of usable leaf nests and tree species. We also compared the number of leaf nests built in trees 6–10 and 12–20+ inches dbh and found that trees in the larger dbh group had significantly more leaf nests than expected on the basis of numbers of trees present.

Of particular interest to forest managers is the high proportion of leaf nests built in trees supporting grapevines. Observations of locations of 3,799 leaf nests on six study areas in three states revealed that 35–85 percent of the nests were anchored to grapevines where <24 percent of the trees examined supported grapevines (Sanderson et al. 1980). As determined from average densities of leaf nests, we recommend that gray squirrels have access to two or three trees with grapevines per acre; fox squirrels, because of their greater use of leaf nests, should have access to three or four trees with grapevines per acre (Table 12). Although grapevines can become a threat to tree growth in openings on hardwood forest sites (Smith & Smithson 1975), we believe that leaving two to four

TABLE 11.—Distribution by dbh class of principal producers of winter food for squirrels in Illinois (USDA Forest Service, unpublished data 1986).

Average dbh (inches)	Percent			
	Black Walnut	White Oaks[a]	Black Oaks[b]	Hickories[c]
<6	52	45	55	69
6	17	11	10	12
8	12	10	9	8
10	7	8	7	5
12	5	7	6	3
14	4	6	4	1
16	2	4	3	<1
18+	1	9	6	1

[a]White oaks = white, bur, chestnut, post, chinquapin, swamp white, and swamp chestnut.
[b]Black oaks = scarlet, northern pin, pin, black, blackjack, Spanish, northern red, shingle, overcup, cherrybark, and willow.
[c]Hickories = shellbark, shagbark, mockernut, pecan, pignut, and bitternut.

vines per acre poses no serious threat to tree growth, particularly if the vines are allowed to remain on trees of low commercial value.

Man-made Shelters

Nest structures are not regularly occupied by squirrels in upland forest types <25 years old, probably because of the scarcity of winter-storable foods in such stands (Table 14). For stands >30 years old, with fewer than two or three nesting cavities per acre, nest structures can benefit squirrels (Table 12).

For gray squirrels, nest structures should be placed 18–20 feet high in trees without cavities. The entrance should face away from the prevailing wind. McComb and Noble (1981) recommended that the entrance face the ground to maximize use by gray squirrels. A density of two to four structures per acre is adequate, and grays should begin to use these structures almost immediately (Barkalow & Soots 1965).

For maximum use by fox squirrels, particularly females, nest structures must be carefully placed. Structures are most likely to be used when they are securely anchored well up in the tree canopy. Use by adult females will increase if nest structures are positioned in trees close to a field edge. Ideally, a tree limb should be located above the nest struc-

TABLE 12.—Shelter needs of gray and fox squirrels in Illinois.

Shelter Need	Number
Tree cavities per acre [a]	2–3 (up to 7 if other cavity nesters are present)
Nest structures per acre	2–3 for gray squirrels 1–2 for fox squirrels
Grapevines per acre (for leaf nests)	2–3 for gray squirrels 3–4 for fox squirrels

[a]Entrance 2–4 inches in diameter, offering good protection from weather.

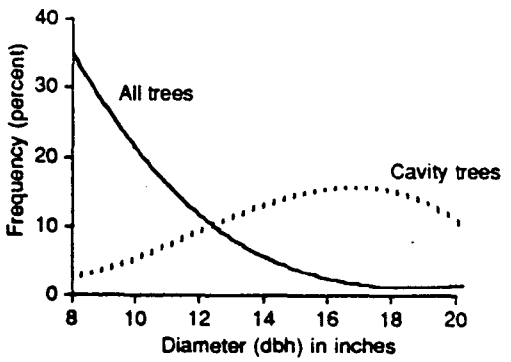

FIGURE 4. Distribution by diameter at breast height of all trees examined and of trees with cavities in an oak-hickory forest in Vermilion County, Illinois.

TABLE 13.—Numbers of tree cavities per acre suitable for nesting (all-weather shelter) and for escape only for squirrels in selected unmanaged forests in central and northern Illinois.

County	Number of 26′ × 130′ Transects	Average Number of Nesting Cavities per Acre	Average Number of Escape-only Cavities per Acre
Northern Illinois			
DeKalb	34	6.0	1.3
Jo Daviess	50	4.2	6.4
Winnebago	31	11.0	0.6
Central Illinois			
Edgar	79	0.8	0.9
Henderson	20	13.0	1.0
Livingston	19	8.0	1.5
Mason	40	6.3	2.3
Peoria	20	14.0	1.5
Piatt	79	4.4	3.4
Schyler	40	8.7	7.3
Vermilion	35	5.5	3.0
Woodford	40	8.0	2.3

ture (Nixon et al. 1984; McComb & Noble 1981). Sub-adults of both sexes and adult males will use structures placed somewhat below the canopy and away from the forest edge because they are not as particular concerning shelter characteristics as are adult females. Structures should not be placed in trees with existing cavities. We recommend one or two properly placed structures per acre for fox squirrels; additional structures are unlikely to be used because of the intolerant social behavior of adult female fox squirrels (Table 5). Although nest structures are commonly made of wood, those made from used rubber tires or old ammunition boxes work well and are cheaper to construct. Designs for two nest structures are given in Appendix 2.

The best management strategy is to provide man-made structures (two or three per acre) along with natural cavities (two or three per acre). This combination will accommodate the array of cavity nesters that inhabit Illinois woodlands, particularly those species that do not readily accept artificial structures—such as some woodpeckers and barred owls (*Strix varia*). Additions of man-made nesting structures may also reduce interspecific competition for natural cavities.

Management for Squirrels by Forest Type

Managers must develop the silvicultural program that best meets a landowner's objectives tempered by present forest conditions and market demands. They should begin by inventorying the vegetation in the woodland. This inventory may be extensive—that is, mapping existing stands into such broad categories as oak-hickory and northern hardwood, including age and general condition classes—or intensive, using plots of various sizes to count woody vegetation. Intensive surveys, however, will be needed before accurate prescriptions for timber management can be prepared, and guidelines for conducting such an inventory are presented in Appendix 3. When conducting an inventory and preparing a management plan, managers should always consult an Illinois Department of Conservation (IDOC) service forester since management plans must be approved by the IDOC before landowners can qualify for financial assistance in carrying them out.

TABLE 14.—Production of food for squirrels in less mature clear-cuts (<25 years) in forests dominated by oak-hickory compared with production in more mature clear-cuts (≥50 years). All are medium sites (site index 55–70).

	Percent of Total Food Production			
	Years after Clear-cutting			
Food	7	15	20	50+
Acorns[a]	0	12	52	97
Fungi	4	37	32	<1
Flowering dogwood seeds	1	49	7	1
Blackberries	95	2	0	0
Grapes	0	0	9	0

[a] Winter-storable foods.

General Management of Oak Types

Unmanaged Stands over 50 Years Old

The majority of oak-hickory stands in Illinois are approaching maturity (Table 3) and usually support one or two squirrels per acre. Winter-storable food and cavities for shelter are usually abundant in these stands. In general, if the number of trees is below level C (Table 10 gives levels A and B. Level C represents the tree stocking necessary if a stand is to reach level B in about 10 years.), the stand should be cut using large-group selection or clear-cutting as soon as adequate advance reproduction of oaks and hickories exists in the understory. If 80 percent or more of the trees are of the desired diameter for the site (Table 15), whether to cut depends on the stocking level and on the adequacy of oak and hickory reproduction. In stands with 60–80 percent of full stocking, thinning should not be scheduled because not enough trees would be cut to benefit the stand.

Clear-cutting

On medium (site index 55–70) or poor (site index <55) sites, the perpetuation of oaks and hickories is not difficult if sufficient advance reproduction of oaks and hickories has occurred before cutting is undertaken. However, if numbers of young oaks and hickories in the understory do not meet the standards defined above (see also Appendix 3), harvest cutting should be delayed until adequate numbers are present. Unfortu-

nately, the cultural techniques necessary to ensure the successful reproduction of these species are not completely understood; at present, some form of shelterwood cutting seems best. Ten or more years may be required before enough oak and hickory stems reach a size and density that will permit large-group selection or clear-cutting. Sander (1977) recommends that overstory density be kept at about 60 percent until oak and hickory stems average 3 feet in height, that intermediate and suppressed trees be removed, and that holes in the canopy be kept small and scattered. If a dense understory is present, it will have to be removed or reduced to allow adequate light to reach oak and hickory seedlings. Techniques for the removal of dense understories are not yet well documented, but cutting understory stems and applying herbicide (IDOC foresters can recommend effective herbicides) to the cut stump is apparently the most cost-effective method and one that protects existing oak and hickory seedlings (Mark Thomas, University of Missouri, personal communication 1986). With the shelterwood-system, the overstory should be cut to 50 percent of full stocking (full stocking = level A as shown in Table 10) when oak and hickory stems in the understory average 3 feet in height. This level of stocking (50%) should include the number of trees needed for squirrel food production (Table 10). Two or three suitable tree cavities per acre should also be maintained.

When adequate advance reproduction of oaks and hickories has occurred, total removal of the shelterwood using even-aged silviculture based on clear-cuts or large-group selection cuts (at least two tree-heights in width) are the recommended procedures (Sander 1977); however, forest management for squirrel populations places several constraints on this practice. Clear-cuts should be less than 20 acres in size and less than 500 feet wide. Cuts should not be adjacent to one another for at least 30 years or until the stand cut earlier has begun to produce seed (Nixon, McClain, and Donohoe 1980). Finally, from 40 to 60 percent of the total area under management should be retained in a seed-producing stage.

On good sites (site index 70+), oak and hickory stems have a difficult time keeping up with intolerant species that spring up after clear-cutting. We therefore recommend the use of one or more of three options to ensure that at least a few oaks and hickories reach seed-bearing age in a co-dominate or dominant crown position. (1) Either before or after the merchantable timber is cut, 15–20 suppressed hickory poles per acre (3–6 inches dbh) should be selected for retention. About half of these young trees die within 5 years, but the remainder will have a good chance of reaching seed-bearing size in at least a co-dominant crown position (Nixon et al. 1983). Vigorous young trees with intact, upright terminal buds that show no obvious disease or injury should be chosen. When young oaks are scarce, a similar number of pole-sized oaks should be retained. (2) Oaks and hickories <2 inches in diameter found in openings should be cut close to the ground during or immediately after the logging operation. These cut stems will sprout vigorously and should be able to keep up with the growth of

TABLE 15.—Recommended intervals and tree diameters for harvest cutting of oak types in Illinois (Sander 1977).

Site Index (feet)	Tree Stocking per Acre[a]	Harvest Cutting Interval (years)	Desired Average Tree dbh (inches)
Poor (40–54)	75–90	90–120	16–18
Average (55–70)	45–60	75–90	20–24
Good (70+)	40–45	60–75[b]	24–28

[a] Level-A stocking.
[b] An interval of at least 70 years should be used for squirrel production.

the shade-intolerant species that will dominate the site after both group selection and clear-cutting. (3) Vigorous seedlings of oaks, black walnut, or shagbark hickory should be planted on good sites (site index 70+). Such plantings frequently prove successful when seedlings are kept free of competition. If the seedlings are not protected from competition, planting is a waste of money. Planting is also a good way to ensure that a few black walnut trees will be present in the stand during the next rotation. To improve the survival of spring-planted stock, the procedures outlined for red oak seedlings by Johnson et al. (1986) should be followed (root collars ≥0.5 inch in diameter, root pruned 8 inches below the collar, top pruned 8 inches above the collar). When weed control is used on good sites, the survival of oak and walnut seedlings for the first 5 years or so can approach 50 percent (Hilt 1977).

Early weeding or crown-release cutting is essential around oaks and hickories in openings created by timber harvest. Cutover stands should be entered when trees are about 10 years old. Crown-release cutting is discussed further in the section that follows. Enough oaks or hickories should be selected for crown release to provide the minimum numbers of trees needed for the production of squirrel food, that is, the minimum number shown in Table 10 for each species available plus an additional 10–20 percent to compensate for mortality.

Thinning

Generally, oak-hickory stands should be thinned to leave residual stands at about 60 percent of full stocking. If stands are thinned when less than 20 years of age, however, stocking should be reduced to 50 percent of full stocking (Sander 1977). Stands should be thinned from below, that is, intermediate and suppressed trees of low vigor should be removed. Thinning stands of seed-producing age should be done in the fall. Trees that are poor seed producers should be removed first. The thinning of oak stands should be stopped when trees are 60–70 years old on average sites (site index 55–70) and 50–60 years on good sites (site index 70+), or at about ¾ of the rotation age for the site.

Cultural work may begin when stands are as young as 10 years old. Mast-producing trees should be thinned on a spacing of 15 to 20 feet (Table 16). This spacing should provide an acceptable stocking of crop trees by the time tree diameters are large enough for commercial thinning. Crowns of oaks and hickories should be released whenever necessary (Sander 1977), but release cutting should allow light to only about ¾ of the crown. Too much light reduces height growth and allows faster-growing intolerants (such as tuliptrees) to outgrow the more shade-tolerant oaks and hickories (Nixon et al. 1983). Stump sprout clumps should be reduced to one or two stems. The crowns of five to seven beeches, two to four maples, and two to four elms per acre should also be released if these species are present.

Rotation Age and Cutting Schedules

A desirable distribution of trees by age class is shown in Table 17. When this information is combined with the information shown in Figure 5 for oak-dominated forests, man-

TABLE 16.—Optimum spacing between seed-producing trees for full utilization of the site.

Average dbh (inches)	Maximum (feet)	Minimum (feet)	Average (feet)
8	17	13	15
10	20	16	18
12	24	18	21
14	27	21	24
16	30	24	27

TABLE 17.—Desirable distribution of trees by age class in forests managed for squirrel populations and for forest products through large-group selection cuts or clear-cuts (adapted from the wildlife habitat management guide for the Mark Twain National Forest, Missouri, mimeo).

Rotation Age When Cut (years)	Percent of Total Forest in Each Age Class			
	>50 Years	30–50 Years	11–29 Years	≤10 Years
80	38	25	25	12
90	45	22	22	11
100	50	20	20	10
110	55	18	18	9

agers can estimate the distribution of huntable (forests supporting ≥4 squirrels per 10 acres provide good hunting) squirrel range in a forest under management. For example, about 38 percent of a forest with a rotation age structure of 80 (Table 17) would typically provide good hunting, 25 percent would provide variable hunting success from year to year dependent on the abundance of food and on squirrel reproduction, and about 37 percent of the forest would provide little or no squirrel hunting.

For wood lots ≤100 acres in size, the proportion of a stand that will support huntable populations of squirrels (at least 4 squirrels per 10 acres) depends strongly on the cutting interval (Table 18). For example, under a 60-year rotation, as little as 33 percent of a 60-acre unit would contain huntable populations compared with 67 percent under a 100-year rotation (Fig. 6). These differences peak when the age of the first cut equals the minimum age at which a stand can support a huntable squirrel population (40–50 years as shown in Fig. 5) and remain constant thereafter. The size of the stand and the size of the cut have minimal effects on the proportion of the stand that supports huntable squirrel populations during the first 40 years and no effect thereafter (Fig. 7, 8). These observations assume that cutting intervals vary depending on cut size, length of rotation, and stand size as outlined by Roach and Gingrich (1968).

Nearly optimal habitat conditions for squirrels can be maintained if clear-cuts are kept small and are surrounded by plots old enough to support huntable squirrel populations. The optimal pattern for cutting a stand or wood lot for squirrels, therefore, includes well-dispersed cuttings (Fig. 9). Depending on the size of the stand, the size of the cut, and the length of rotation, even small clear-cuts may have to be deferred once during each rotation and only after 50 percent of the stand has been cut in order to avoid creating adjacent plots both of which would be less than 40 years of age. Length of deferral can be short where units are large, the length of rotation is long, and the size of the cut is small (Table 19). Table 18 can be used to determine intervals for cutting the first 50 percent of the stand. After 50 percent of the stand has been cut over, the next cutting interval must be deferred for the number of years shown in Table 19, if cuts are not to be adjacent to one another in less than 40 years. For example, the cutting interval for a 20-acre woodland managed on a 60-year cutting rotation using 2-acre clear-cuts, would be lengthened by 16 years after 50 percent of the 20-acre tract had been cut. Instead of the initial 6-year

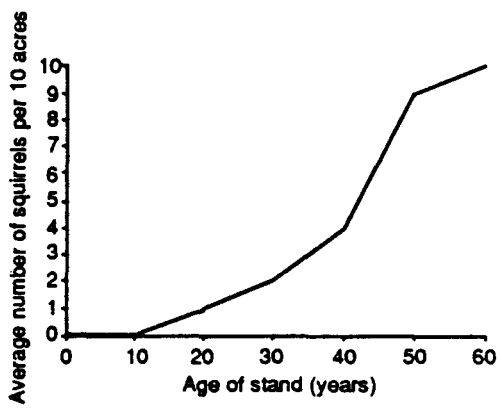

FIGURE 5. Relationship between age of stand and resident squirrel density in oak-dominated forests.

TABLE 18.—Minimum clear-cutting intervals in years for various cut sizes, rotation lengths, and woodland acreages (modified from Roach & Gingrich 1968).

Size of Cut (acres)	Rotation Length (years) for 20–acre Woodland			Rotation Length (years) for 40–acre Woodland			Rotation Length (years) for 60–acre Woodland		
	60	80	100	60	80	100	60	80	100
2	6	8	10	3	4	5	2	2	3
3	9	12	15	4	6	7	3	4	5
4	12	16	20	6	8	10	4	5	6
5	15	20	25	7	10	12	5	6	8

cutting interval (Table 18), the interval would now be 22 years (Table 19). After a single 22-year cutting interval, the cutting schedule would again revert to 6-year intervals.

Firewood and the Removal of Cull Trees

Managers should consider the tradeoffs between the economic value of firewood and the quality of wildlife habitat when considering large-scale cuttings of dead, dying, cull, or injured trees. Some of the trees scheduled for removal that are not commercially usable should be killed in place and left for cavity production and as a feeding area for birds that consume bark-dwelling insects. As an aid in selecting trees for firewood, Table 20 rates the principal Illinois species in terms of their value to wildlife and their value as firewood.

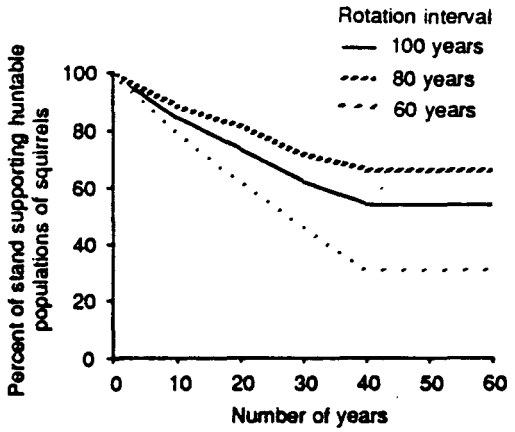

FIGURE 6. Effect of rotation interval on percent of stand that will support huntable populations of squirrels over a 60-year period. If the rotation interval remains constant, after 60 years no appreciable change will occur in the percent of a stand that will support huntable populations of squirrels. Stand size and cut size were held constant at 60 and 2 acres, respectively.

Selection Cutting

On privately owned woodlands, landowners are frequently reluctant to use clearcutting or large-group selection cuts to harvest trees. In that event, managers may suggest that some type of selection cutting be used, but the consequences of such cuttings in terms of future tree quality (often the poorer quality trees are left) and tree reproduction (increases in shade-tolerant sugar maple) should be pointed out to the landowner. In general, selective cutting in stands dominated by oak-hickory will not materially reduce squirrel numbers provided that removals total less than 40 percent of the merchantable trees over 14 inches dbh and that minimum densities of food-producing trees (Table 10) remain after cutting (Nixon, Havera, and Hansen 1980). When cutting removes squirrel nest sites, these should be replaced with nest structures to maintain two or three sites per acre. If cull-tree or firewood removal is part of the recommended treat-

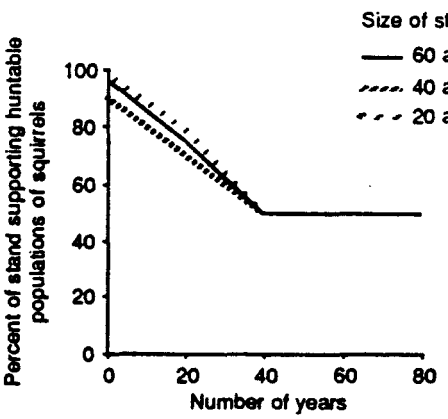

FIGURE 7. Effect of size of stand on percent of stand that will support huntable populations of squirrels during an 80-year period. Cut size and rotation length were held at 2 acres and 80 years, respectively.

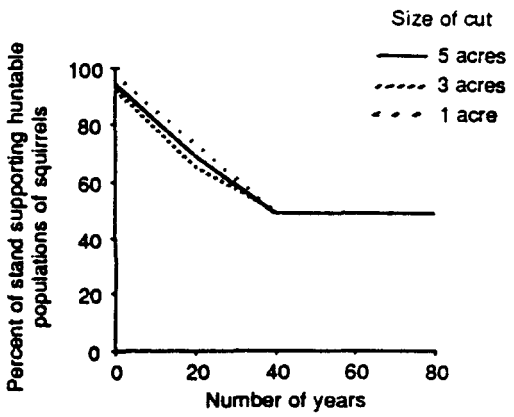

FIGURE 8. Effect of size of cut on percent of stand that will support huntable populations of squirrels during an 80-year period. Stand size and cutting interval were held at 60 acres and 80 years, respectively.

ment during or following selection cutting, up to seven cavity-prone trees per acre should be retained.

Shelter

Because nest structures are expensive to build, place, and service, they are not feasible for large tracts. Their use in the small cuts recommended for woodlands managed for squirrels after age 30 does not require a large outlay of money or time and can be promoted as a service project for such organizations as sportsmen's clubs, scouts, and youth conservation corps. To benefit a variety of cavity nesters, structures in a range of sizes should be used: large (about 24 × 12 × 12 inches), medium (about 18 × 8 × 8 inches), small (about 12 × 6 × 6 inches); entrances should range from 2–5 inches in diameter (McComb & Noble 1981).

In clear-cuts or large-group selection cuts, up to seven cull trees per acre should be killed and left in place to provide cavities for wildlife during the early years of new stand development. In previously clear-cut areas >30 years old but <60 years old, two or three nest structures per acre should be erected. In addition, trees killed in place around the outside of the cut (two or three per 400 feet of edge) or nest structures placed about every 200 feet around the periphery of the cut, would increase the use of openings by squirrels and help provide squirrels to restock the new stand when seed production allows them to locate there.

Trees likely to develop cavities are those infected with heart-rot fungi. They may be detected by observing (1) fungal-fruiting bodies, (2) dead-branch stubs, (3) old wounds or scars, (4) discolored or soft wood in increment borer corings, or (5) obvious dead portions of the tree.

Studies of the incidence of rot associated with branch death in midwestern forests indicate that managers can increase the likelihood of cavity formation by stub-pruning branches that are 4–6 inches in diameter or slightly larger (Toole 1961). Stubs 5–7 inches long should be left to reduce the probability that the wound will heal before rot begins to form a suitable cavity (Sanderson 1975). Cull trees or those of low commercial value should be chosen for future den sites and retained during all subsequent thinnings and cleanings. A total of 10–20 branches pruned per acre for future den sites is ample when such cavity-prone species as sycamore, cottonwood, basswood, black oak, elms, sugar maple, and

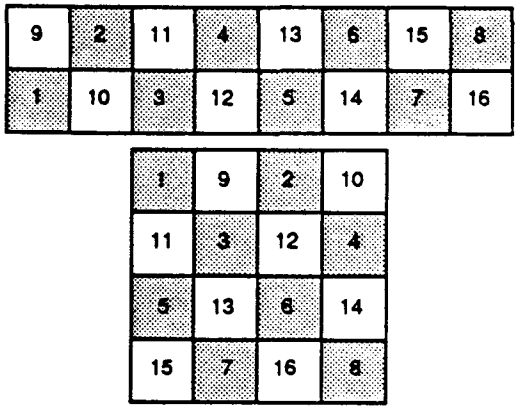

FIGURE 9. Cutting sequences to avoid adjacent clear-cuts on square and rectangular units. The cutting sequence is designated numerically.

TABLE 19.—Deferred cutting interval in years required to avoid adjacent plots, both of which are <40 years of age. The deferral is required only once during each rotation, after 50 percent of the plots (none adjacent) in the unit have been cut. In all instances here, the shape of the cut is square and the shape of the unit is rectangular.

Size of Cut (acres)	Rotation Length (years) for 20–acre Woodland			Rotation Length (years) for 40–acre Woodland			Rotation Length (years) for 60–acre Woodland		
	60	80	100	60	80	100	60	80	100
2	22	16	10	16	8	0	16	8	4
3	31	28	25	24	16	12	16	8	0
4	28	24	20	22	16	10	20	15	10
5	25	20	15	19	10	4	20	16	8

TABLE 20.—Values of principal Illinois tree species to wildlife and as firewood (Carey & Gill 1980). Scientific names are not provided.

Tree	All Wildlife	Songbirds	Game Birds	Fur & Game Mammals Including Squirrels	Firewood	Remarks
Oaks	Excellent	Excellent	Excellent	Excellent	Excellent	Retain a variety of species.
Black cherry	Excellent	Excellent	Good	Good	Good	May have high timber value when mature.
Apples	Excellent	Good	Good	Good	Excellent	Rare; attractive to grouse.
Pines	Excellent	Excellent	Fair	Good	Fair	Good as kindling.
Flowering dogwood	Excellent	Excellent	Good	Fair	Excellent	High aesthetic qualities.
Maples	Good	Good	Fair	Excellent	Excellent	High aesthetic qualities in fall.
American beech	Good	Fair	Fair	Excellent	Excellent	High aesthetic qualities in the fall; important to squirrels.
Alders	Good	Good	Good	Fair	Good	Locally important to songbirds and game birds.
Aspens	Good	Fair	Good	Excellent	Fair	Especially attractive to grouse.
Birches	Good	Fair	Good	Good	Excellent	Important to wildlife in areas north of Illinois.
Hackberry	Fair	Good	Fair	Fair	Excellent	Important winter food for songbirds.
Hickories	Fair	Fair	Fair	Good	Excellent	Especially attractive to squirrels.
Ashes	Fair	Fair	Fair	Fair	Excellent	Supply mast in the fall.
American basswood	Fair	Fair	Fair	Fair	Fair	Good as kindling.
Black walnut	Fair	Fair	Fair	Fair	Excellent	May have high timber value when mature.
Black tupelo	Fair	Fair	Fair	Fair	Fair	Locally important to songbirds and game birds.
Eastern cottonwood	Fair	Fair	Fair	Fair	Fair	Good as kindling.
Elms	Fair	Fair	Fair	Good	Fair	High water content when green; difficult to split; cut if diseased.
Black locust	Fair	Fair	Fair	Fair	Excellent	Low value for wildlife, high for firewood; a nitrogen-fixer.
Eastern red cedar	Fair	Good	Fair	Fair	Fair	Good as kindling; attractive to songbirds.
Sassafras	Fair	Fair	Fair	Fair	Good	Berries eaten by insectivorous birds.
Sweetgum	Fair	Fair	Fair	Fair	Fair	High water content when green; high aesthetic value.
Sycamore	Fair	Fair	Fair	Fair	Fair	Aesthetic value; high water content when green; difficult to split.
Tuliptree	Fair	Fair	Fair	Fair	Fair	Good as kindling; aesthetic value.
Willows	Fair	Fair	Fair	Fair	Fair	Attractive to wildlife in areas north of Illinois.

beech are selected. Stub pruning should be done in stands <40 years old because up to 30 years may be required to produce a suitable nesting cavity (Baumgartner 1940).

Special Considerations for Specific Oak Types

Mixed Oak Types

A mix of fall-germinating, same-year fruiting (white oak) and spring-germinating, following-year fruiting (black and red oaks) species in oak woodlands means that squirrels have a relatively dependable food supply. Managers should try to obtain a 50:50 mix of red/black and white oaks during thinnings and during release cuttings undertaken after clear-cutting or group selection. In general, the management of mixed oak types to maintain squirrel populations should follow the recommendations previously made for oak forests. We strongly recommend planting 10–15 black walnuts per acre in clear-cuts on good sites (site index 70+). Vigorous seedlings (oaks, black walnut, shagbark hickory) should be planted in the spring and periodic clearings undertaken to control competition.

Red Oak Type

The red oak type generally occurs only on good sites (site index 70+) in Illinois. When cut, this type tends to convert to a mixed species stand with fewer oaks and hickories. If the stand is <60–70 years old, managers should release the crowns of white or black oaks and hickories during thinnings to increase the food supply of squirrels. If a stand is approaching maturity, the manager can do little to alter its composition. When a stand is marked for cutting, 15–20 hickory poles (3–6 inches dbh) and a few white oak poles should be retained and preserved through the next rotation. Adequate numbers of red oaks probably would derive from stump sprouts. We also recommend planting 10–15 black walnuts per acre in this type, again using vigorous seedlings planted in the spring followed by measures to control competition.

White and Bur Oak Types

Managing the white oak type is similar to managing the red oak type except that more trees of the black oak group are needed, and those present in the stand should be crown released during thinning. Managers should try to increase the number of seed-bearing black oaks and hickories to at least 20 percent of a stand after intermediate cutting (thinnings) is initiated.

Bur oak tends to favor calcareous soils (Fowells 1965) and often forms nearly pure stands on poorly drained upland soils where the culture of other oaks and hickories may be difficult or impractical. Management practices that will help squirrels include releasing crowns to encourage seed production, providing den sites where needed, and using large-group (1–3 acres) selection tree cuts or clear-cuts for regeneration. Because bur oak sprouts readily after a fire, burning can provide it with a competitive advantage over such species as sugar maple and basswood. Not much is known, however, about how often fires are needed to promote bur oak reproduction. Managers should monitor the response after each fire and stop burning when advance reproduction is adequate (Appendix 3). Early thinnings should also be used as needed to release oaks or hickories from competition.

Post, Blackjack, and Black Oak Types

Because post, blackjack, and black oak types grow on poor sites (site index <55) where competition from other trees is minimal, they are often fairly easy to culture after cutting. Group selection or small (1–2 acres) clear-cuts will produce new stands from a mixture of oak stump sprouts and seedlings. If hickory poles are present, up to 15–20 per acre should be retained during cuts in new stands. Post oak responds to thinnings, but the diameter growth rate is reported to be slow (Dyksterhuis 1948). Because post and blackjack oaks are slow to decay and slow to produce suitable nest cavities, managers may need to add up to three nesting structures per acre after stands reach 30 years of age.

On the poorest sites (site index <45), managers should consider these post, blackjack, and black oak types as protection forests (protection of soil and water resources) with lumber products as a bonus. Conversion of these types to pines is not recommended when wildlife production is an objective.

The black oak type often lacks diversity of species and therefore is not as valuable to wildlife. The key to squirrel maintenance lies in increasing the diversity of oaks and hickories and thus the breadth and stability of the food base. Retaining white or bur oaks and hickories during thinnings (Table 10) increases squirrel numbers, but pure stands of black oak are not very productive of squirrels (Fig. 3). This forest type can be reproduced through group selection or clear-cuttings. In addition, 15–20 hickory poles and a similar number of white or bur oak poles should be retained if present to ensure the presence of these species in new stands. If only one thinning is to be made, it should occur when the stand is about 30 years old (Kurtz et al. 1981), reducing basal area to 65–70 square feet. However, where squirrels are important, managers should enter new stands when trees are about 10 years old and select hickories and white or bur oaks for crown release. Species diversity is an important management objective if squirrel populations are to thrive in black oak types.

Black oak readily forms cavities in trees ≥60–70 years old, and stands of that age should not require nest structures. In stands from 30–60 years of age, up to three nest structures per acre should be added. The black oak type is susceptible to failures of tree-seed crops, and supplemental feeding of squirrels may occasionally be necessary in winter.

Northern Hardwoods

Sugar maple–basswood and beech-maple types are the most common northern hardwoods in Illinois and relative to other forest types are becoming more extensive (Table 3). Managers, therefore, should protect and enhance the canopy position of whatever oaks and hickories are found in these northern hardwood types. If the retention of wildlife species that depend on acorns is an important objective, oaks and hickories should not be removed during a timber sale unless they make up more than 20 percent of the stand.

Clear-cutting

The problem of creating a mix of species in northern hardwoods in Illinois is caused by the combination of rapidly growing intolerant species (black cherry and tuliptree) and slowly growing tolerant species (oaks, hickories, sugar maple, and beech) (Roach 1977). The best solution seems to be the use of clear-cutting to harvest these types. Cuts should be small (2–5 acres). Managers should retain 10–20 sugar maples, 10–20 beech, and any oaks or hickories of pole size (3–6 inches dbh) that are suppressed in the understory. The pole-sized trees that are retained should be of good vigor (at least moderate crowns and clean, straight boles) to reduce the incidence of epicormic branching (Marquis 1981).

Both before and after clear-cutting, dense stands of sugar maple may spring up in the understory, thereby reducing the opportunity for other species to survive and grow. These sugar maple understories should be cut or mowed and the stumps treated with herbicide to allow mixed species stands to develop.

Thinning

Pole-sized stands should be thinned from below to about 60 percent of full stocking if they are <60 years old or to about 70 percent of full stocking if they are older and previously unthinned (Roach 1977). Poor seed producers should be removed, and crown development around good seed producers enhanced by release cutting following the spacing shown in Table 16. Whatever oaks and hickories are present should be retained as co-dominant trees. Unfortunately, red oak is the common oak encountered in these types and its acorns are not favored by squirrels. Indeed, fox squirrels lose weight eating them in winter (Havera & Smith 1979).

Planting

If a clear-cut site is suitable for black walnut and white oak, the manager may consider planting a few vigorous seedlings of these two species to provide squirrels with an alternative food source. If the objective is primarily to feed wildlife, 10–20 seedlings per acre will suffice. The planted seedlings must be kept free of competition by using mulches or herbicides to control herbaceous and other woody stems. A radius of 4 or 5 feet around each seedling should be cleared and maintained free of competition until seedlings are able to compete with the developing stand (Hilt 1977).

Shelter

The addition of two or three nest structures per acre to sugar maple-basswood stands between 30 and 60 years old helps to increase squirrel abundance. In Illinois these stands are frequently occupied by gray squirrels that readily use nest boxes (Barkalow & Soots 1965; Burger 1969). After 60 years, natural tree cavities should be abundant in this forest type.

Managers should realize that squirrels will be less abundant in northern hardwood types than in types with higher complements of oaks, hickories, or walnuts. Significantly increasing the number of these species is expensive and difficult, however, because this near-climax forest type tends to exclude desirable mast species if left unmanaged. On the basis of information in Figure 3, an oak component of ≥25 percent is necessary to promote a significant increase in squirrel numbers in northern hardwood types.

Bottomland Hardwoods

The several moist bottomland forest types in Illinois (silver maple–elm, cottonwood, hackberry–American elm–green ash, sycamore–sweetgum–American elm) are often grouped under the general elm-ash-cottonwood type and are similarly managed. They occur throughout Illinois on alluvial soils that are subject to periodic flooding along rivers and other streams.

If stands of bottomland hardwoods are <500 feet wide, adjacent to oak types, and contain virtually no oaks or hickories, managers should not attempt to manage them for squirrels. The necessary release cuttings, the retention of suppressed poles, the control of a rank herbaceous understory, and other requisite practices would mean a high cost for a relatively low return in increased numbers of squirrels. Sufficient diversity in topographic relief is usually found in stands wider than 500 feet, and species that grow on better drained sites—such as bottomland oaks (swamp white, pin, shingle, cherrybark, and overcup) and hickories (shellbark and pecan)—occur in fair numbers. These species must be carefully cultured, however, both as part of extant stands and as advanced reproduction in understories.

Clear-cutting

When left alone and when a seed source is present, bottomland hardwood types often eventually convert to oak types if flooding is infrequent and soils are well drained. If a source of oaks and hickories is present in the overstory but no seedlings are yet established, stands should at most be cut very lightly so that herbacious competition is not encouraged. Large-group selection or clear-cutting is the recommended harvest method for bottomland hardwood forest types when dominant/co-dominant trees reach an average dbh of 24 inches (Myers & Buchman 1984).

Thinning

Weeding and thinning of stands on bottomland sites are needed to concentrate growth on crop trees. Oaks and hickories should be rigorously protected as crop trees during these thinnings. A stocking guide for bottomland sites is presented in Table 21.

Planting

When oaks and hickories are not present, managers should consider planting them immediately after a timber harvest on better-drained sites that are not prone to flooding. Sites for planting must be cleared of competing vegetation and debris and kept free of competition for several years or until seedlings achieve dominance. Vigorous seedlings (30–40 per acre) of pin, swamp white, or

TABLE 21.—Stocking guide for bottomland hardwood types (Myers & Buchman 1984).

Average dbh (inches)	Number of Trees per Acre	
	Maximum Number to Utilize Site Fully Level A	Minimum Number to Utilize Site Fully Level B
6	475	202
8	375	160
10	202	112
12	152	97
14	112	71
16	100	60
18	71	49
20	60	42
22	49	36
24	45	33

shingle oaks and similar numbers of pecans or shellbark hickory should be used.

Shelter

Where the stocking of oaks and hickories exceeds 20 percent of the total number of dominant trees, nest structures (two or three per acre) should be added to stands 25–50 years old. If these stockings total less than 20 percent of bottomland hardwood stands, the addition of nest structures is unlikely to increase squirrel numbers significantly. When oaks and hickories are present, bottomland forests can be very productive of squirrels, as documented by live trapping in the Mississippi valley, where stands often support two or more squirrels per acre throughout the year.

Pin Oak–Sweetgum and Pure Pin Oak Types

Pure pin oak stands are more common in Illinois than mixed pin oak–sweetgum stands. Because of its physiology, pin oak persists on shallow, often flooded, heavy-textured soils (Fowells 1965). Because of their relatively early decadence (at about 80 years), pin oak stands are usually managed for regeneration before that age either by large-group selection cutting (cuts at least two tree-heights wide) or by small clear-cuts (<5 acres). Because pin oaks sprout vigorously, stump sprouts are abundant after cutting. On poorly drained sites, pin oaks occur in nearly pure stands, and managers should retain any other seed-producing species that occur naturally in these stands in an effort to diversify the food supply for squirrels. Managers should also consider planting seedlings if the soils allow such species as swamp white oak and pecan to grow. In immature stands (<35 years), stocking levels should be kept high (basal area = 90 ft^2 per acre) after thinning in order to maximize acorn production; subsequent thinnings should be made every 10 years or so (McQuilkin & Musbach 1977). Stands should be thinned in the fall, larger trees should be retained at each thinning, and trees that are not potential producers of seed should be removed.

Food failures are relatively common in pin oak–sweetgum and pure pin oak types, and supplemental feeding is often desirable during winter when drastic food-related declines in squirrel numbers can be expected. Because pin oaks do not form cavities readily, the addition of two or three nesting structures per acre for stands >25 years of age is desirable.

Management for squirrel populations is not appropriate in bottomland hardwood forests that are managed as greentree reservoirs. The 3- to 4-month fall and winter flooding prevents squirrels from storing or retrieving nuts from the forest floor, and squirrels produced in these flooded stands should be considered a bonus.

On sites with better drainage, pin oak exists in mixed stands, usually with sweetgum but also in mixtures with other bottomland hardwood species native to the region. On better-drained sites, culture favoring mixed stands produces high numbers of squirrels (Fig. 3). Succession is toward more sweetgums and fewer pin oaks; however, the number of pin oaks or other oak species should remain fairly high, at least 30 percent of the stand, if squirrel populations are to be encouraged.

Appendix 1

Common and Scientific Names of Plants Mentioned in Text (from Fowells 1965)

Common Name	Scientific Name
Ash, green	*Fraxinus pennsylvanica*
Ash, white	*Fraxinus americana*
Basswood	*Tilia* spp.
Beech, American	*Fagus grandifolia*
Blackberry	*Rubus* spp.
Blackgum	*Nyssa sylvatica*
Cherry, black	*Prunus serotina*
Cottonwood	*Populus deltoides*
Dogwood, flowering	*Cornus florida*
Elm, American	*Ulmus americana*
Grape	*Vitis* spp.[a]
Hackberry	*Celtis occidentalis*
Hickory, bitternut	*Carya cordiformis*
Hickory, mockernut	*Carya tomentosa*
Hickory, pignut	*Carya glabra*
Hickory, shagbark	*Carya ovata*
Hickory, shellbark	*Carya laciniosa*
Maple, silver	*Acer saccharinum*
Maple, sugar	*Acer saccharum*
Mulberry	*Morus* spp.
Oak, black	*Quercus velutina*
Oak, blackjack	*Quercus marilandica*
Oak, bur	*Quercus macrocarpa*
Oak, chestnut	*Quercus prinus*
Oak, cherrybark	*Quercus pagodaefolia*
Oak, chinquapin	*Quercus muehlenbergii*
Oak, northern pin (jack oak)	*Quercus ellipsoidalis*[a]
Oak, northern red	*Quercus rubra*
Oak, overcup	*Quercus lyrata*
Oak, pin	*Quercus palustris*
Oak, post	*Quercus stellata*
Oak, scarlet	*Quercus coccinea*
Oak, shingle	*Quercus imbricaria*
Oak, shumard	*Quercus shumardii*
Oak, Spanish	*Quercus falcata*
Oak, swamp chestnut	*Quercus michauxii*
Oak, swamp white	*Quercus bicolor*
Oak, white	*Quercus alba*
Oak, willow	*Quercus phellos*
Osage orange	*Maclura pomifera*[a]
Pecan	*Carya illinoensis*
Sweetgum	*Liquidambar styraciflua*
Sycamore	*Platanus occidentalis*
Tuliptree	*Liriodendron tulipifera*
Walnut, black	*Juglans nigra*
Willow	*Salix* spp.

[a]Scientific name as given in Gleason 1968.

Appendix 2

Construction Plans for Nesting Structures for Squirrels

Directions for two types of nesting structures are given below—box construction (adapted from Barkalow & Soots 1965) and tire nests (adapted from Maryland Game and Inland Fish Commission 1966). Rot-resistant wood such as redwood or cypress should be used to construct a nesting box (Fig. A); lumber that has been treated with creosote should not be used. When completed, boxes are attached to the tree with two nonferrous (aluminum) nails, one inserted in the hole at the top of the galvanized strip and the other inserted in the niche at the bottom of the wooden hanger. Finally, the box is positioned firmly by encircling it and the tree with 12-gauge wire as shown in the inset.

The steps in constructing a nest for squirrels from a tire are shown in the five photos that make up Figure B. Begin by removing the steel bead from the inner rim of the tire (1); a saber saw will make the task easier. Cut the tire in half (2); then cut a notch from each side of the tire wall at one end (3). Cut a 3-inch slit at the center of each wall of the

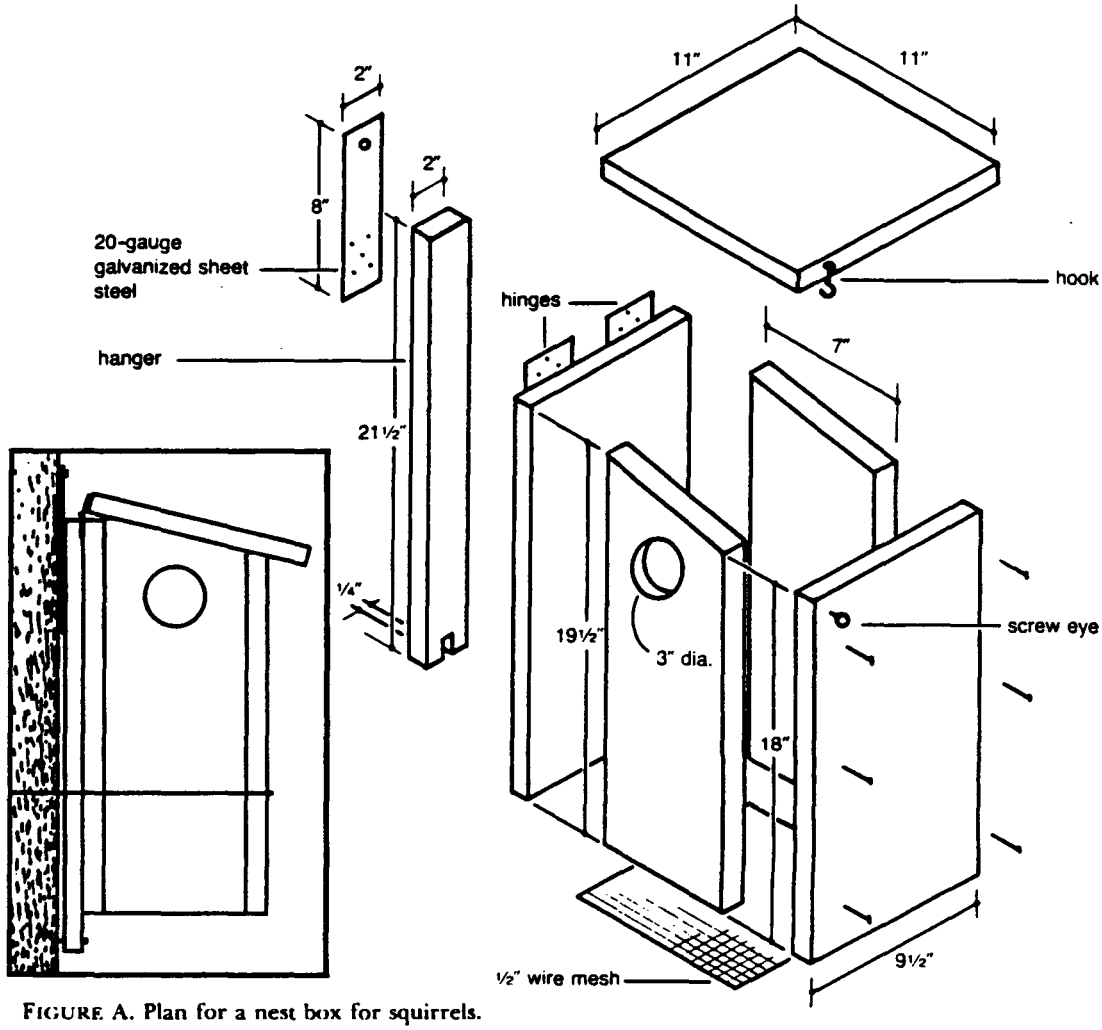

FIGURE A. Plan for a nest box for squirrels.

tire (4). Cut another 3-inch slit to the left of each center slit (5). At the unnotched end of the tire, cut a 3-inch slit parallel to the tread (6). All of these cuts are shown in photo a.

Photo b shows the positions of the roofing nails that are needed to shape the nest. Pierce the tire with an ice pick at these positions.

Fold the tire at the center slits (photo c). Insert a roofing nail from the inside of the tire to attach the two ends at position 1 on the right and again at position 1 on the left. Insert a nail through the three number-2 positions on one side of the center of the tire to shape the base of the nest. Bend over the excess nail on the outside of the tire. Repeat this step for the number-2 positions on the other side of the tire. Squeeze the top two edges of the tire together, and attach by inserting nails at position 3 on the right and again at position 3 on the left.

Make sure the upper side overlaps sufficiently to keep out rain by attaching nails at position 4 on the right and again on the left. Photos c and d show all of these attachments.

Insert a steel rod or heavy wire about 2½ inches from the end of the tire and shape it to form a hanger as shown in photos d and e. Hang the tire nest at least 15 feet from the ground. Make sure that the hanger encircles the limb. Face the throat of the nest toward the tree trunk.

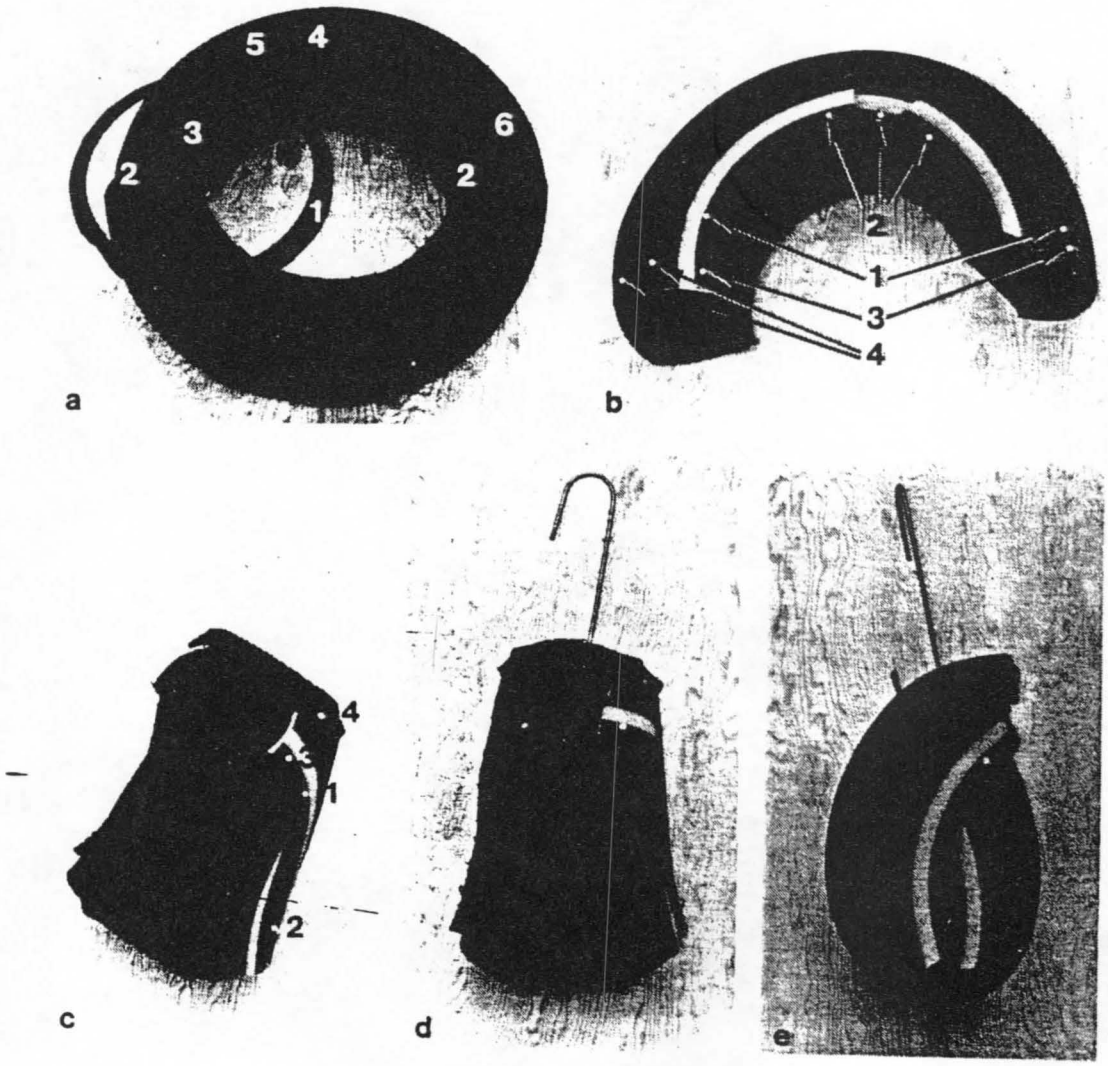

FIGURE 8. Constructing a tire nest for squirrels.

Appendix 3

An Inventory for Evaluating the Probabilities of Successful Reproduction of Oaks and Hickories in the Midwest (Modified from Sander et al. 1984)

This inventory is based on the minimum area—about 1/735 acre—required for good growth by a tree that is approximately 20 years old and has a diameter (dbh) of about 3 inches (Gingrich 1967). For the advance reproduction of oaks to be adequate, oaks of this size and age should equal or exceed 30 percent of the stems on an acre, or approximately 221 stems ($735 \times 0.30 = 221$). For the advance reproduction of hickories to be adequate, hickories of this size and age should equal or exceed 10 percent, or approximately 73 stems per acre ($735 \times 0.10 = 73$). Sprouts from stumps of overstory oaks and hickories, however, can be used to compensate for deficiencies in advance reproduction, and their anticipated rate of success can be computed when the inventory is complete. This number of oaks and hickories can then be combined with the expected number of successful stump sprouts to determine if their combined numbers will be adequate to replace the old stand in 20 years.

Design a form similar to the one in Figure A. Conduct the inventory as follows:

1. Complete columns 1–5 by tallying oaks and hickories by species and grouping all other species 1.6 inches dbh and larger on 10 or more 1/20-acre plots by crown position (dominant, co-dominant, or suppressed) and by diameter. Check each tree over 5 inches dbh in each plot for tree cavities and record this information in columns 6 and 7. Record a cavity as all-weather when its entrance is 2–4 inches wide, when the cavity appears to have a solid roof, and when its sides offer good protection. All other cavities should be recorded as offering squirrels escape cover only.

If a species valuable as food for squirrels, such as American beech, is present, it, like the oaks, should be tallied separately. Such species could be substituted for oaks or hickories or cultured in addition to the oak-hickory requirement. Managers should consult silvicultural guidelines for these species.

2. Determine the totals per acre for columns 1–7. In Figure A, therefore, totals have been doubled because only ten 1/20-acre plots were used.

3. Determine an average age for dominant and co-dominant oaks and hickories and compute the site index. Determine an average age for lower story (suppressed) oaks and hickories that are at least 1.6 inches dbh. Record this information in the appropriate blanks at the top of the form.

4. Select the number of 1/735-acre plots (4.3 feet in radius) to be used in the inventory from the following:

Stand size (acres)	Number of 1/735-acre plots to be used
<10	25
10–30	40
31–50	60

The number of plots should be distributed uniformly throughout the stand.

5. Measure the height and the diameter at ground level of the tallest stem of advance oak and hickory reproduction on each 1/735-acre plot (columns 3 and 4 under Advance Reproduction). Record these measurements by height class (2-foot increments) and by ground diameter class (½-inch increments) as shown in Table A. Use a 6-inch caliper graduated in tenth or in quarter inches for measuring diameters at ground level. Measure only trees 1.5 inches dbh or less; stems larger than this have already been inventoried. If no oak or hickory advance reproduction is present, record zeros for height and for diameter at ground level.

6. Record the aspect of each plot by quadrant (NE, SE, SW, or NW) and its slope position (upper, middle, or lower third). For plots on narrow ridge tops, record RI (ridge); for plots on level topography (all slopes less than 15%), record LE (level); for bottoms, record BO under slope position and use the stocking values (SV) shown in Table A for southeast/northwest aspects. For RI, use the values given for upper slope; for LE, use the values given for middle slope; for BO, use the values given for lower slope.

7. Record the SV for each plot by referring to Table A. For lack of comparable data, use Table A for hickory also. Calculate the average SV, rounding it off to the nearest whole number. If the average SV for oaks is ≥30 percent, advance reproduction is adequate. If the average SV is ≥10 percent for hickory, advance reproduction is adequate. No further calculations are necessary, and the stand may be harvested.

8. When the average SV is <30 percent for oak and ≤10 percent for hickory, advance reproduction is inadequate to reproduce the stand. The stand, however, can still be cut if enough stumps of overstory oaks and hickories sprout after they are cut. To compute the expected contribution to reproduction stocking from stump sprouting, see Table B for selected species; consult similar tables for other species.

9. Referring to the hypothetical data recorded on the form in Figure A, note that there are 26 black oaks 2–5 inches in diameter per acre. Refer next to Table B. Because the site index for the example in Figure A is 60 and the stand age is 80, approximately 42 percent of the stumps of black oaks (2–5 inches dbh) are likely to produce at least one co-dominant stem at age 20. Going back to Figure A, note that 11 (26 × 0.42 = 11) is the number of stump sprouts likely to reach the canopy by age 20. Calculate the anticipated

TABLE A. — Stocking value in percent for advance reproduction inventory plots (1/735 of an acre).[a]

Size of Tallest Tree per Plot		Southwest Aspect			Southeast/Northwest Aspect			Northeast Aspect		
Height Class in Feet (range)	Ground Diameter Class in Inches (range)	Upper Slope	Middle Slope	Lower Slope	Upper Slope	Middle Slope	Lower Slope	Upper Slope	Middle Slope	Lower Slope
≤1	All	1	1	0	1	2	0	1	1	0
2	0.5 (0.3–0.7)	5	6	1	8	9	2	4	5	1
(1.1–3.0)	1.0 (0.8+)	14	17	3	22	26	6	13	15	3
4	0.5 (0.3–0.7)	10	11	2	15	18	4	8	10	2
(3.1–5.0)	1.0 (0.8–1.2)	22	25	6	32	37	9	19	22	5
	1.5 (1.3+)	37	42	11	51	56	18	34	38	10
6	0.5 (0.3–0.7)	19	22	5	28	32	8	16	19	4
(5.1–7.0)	1.0 (0.8–1.2)	32	36	9	45	50	14	29	33	8
	1.5 (1.3+)	45	50	15	59	65	23	41	46	13
8	1.0 (0.8–1.2)	44	49	14	59	64	22	40	45	12
(7.1–9.0)	1.5 (1.3–1.7)	54	59	19	68	73	28	49	54	17
	2.0 (1.8+)	62	67	24	76	80	35	57	62	21
10	1.0 (0.8–1.2)	58	63	22	72	77	32	54	59	14
(9.1+)	1.5 (1.3–1.7)	62	67	24	76	81	35	58	63	16
	2.0 (1.8–2.2)	66	71	27	79	84	38	61	66	19
	2.5 (2.3+)	69	74	29	82	86	41	64	69	21

[a]Stocking value (SV) is the projected contribution in percent of a single stem to stand stocking at age 20. Numbers in the table, therefore, are probabilities that a stem will be co-dominant or dominant in the stand at age 20.

Date 11/12/86 Compartment 1 Stand Size (in acres) 20

Stand Age (dominants) 80 Site Index 60 Stand Age (lower story) 80

Stems ≥ 1.6 inches dbh (1/20-acre plots)

Plot Number	dbh class (inches)	Black Oak D	Black Oak C	Black Oak S	White Oak D	White Oak C	White Oak S	Northern Red Oak D	Northern Red Oak C	Northern Red Oak S	Shagbark Hickory D	Shagbark Hickory C	Shagbark Hickory S	Other Species D	Other Species C	Other Species S	All-weather cavities D	All-weather cavities C	All-weather cavities S	Escape-only cavities D	Escape-only cavities C	Escape-only cavities S
1	2–5			••			••			•						••			•			
	6–11					•									•							
	12–16													•								
	17+										•						•					
2	2–5			••			::															
	6–11		•			•									••							
	12–16					•																
	17+																					
3	2–5			•			•			••						•							
	6–11																					
	12–16				•									•			•					
	17+																					
4	2–5						••									••						
	6–11								•													
	12–16	••						•						••								
	17+																					
5	2–5						::			••												
	6–11		•			••																
	12–16																					
	17+				•												•					
6	2–5			•			••			••						••							
	6–11														•							
	12–16	••			•									•								
	17+																					

Advance Reproduction of Oaks and Hickories (1/735-acre plots)

Plot Number	Aspect	Slope Position	Height Oak	Height Hickory	Diameter at Ground Level Oak	Diameter at Ground Level Hickory	Stocking Value Oak	Stocking Value Hickory
1	SE	LO	0	0	0	0	0	0
2	SE	|	10	0	2.0	0	38	0
3	SE	|	0	0	0	0	0	0
4	SE	|	2	4	.5	1.0	2	9
5	SE	BO	2	0	.5	0	2	0
6	SE	LO	0	0	0	0	0	0
7	SE	|	6	0	1.5	0	23	0
8	SE	|	4	6	.5	1.5	4	23
9	SE	|	8	0	1.5	0	28	0
10	SE	|	0	0	0	0	0	0
11	|	|	6	0	.5	0	8	0
12	|	|	0	0	0	0	0	0
13	|	LO	2	2	.5	.5	2	2
14	|	MI	4	0	.5	0	18	0
15	|	|	8	0	1.5	0	73	0
16	|	|	4	0	.5	0	18	0
17	|	|	8	0	1.5	0	73	0
18	|	|	0	0	0	0	0	0
19	|	|	4	0	1.0	0	37	0
20	|	|	1	10	—	2.0	2	38
21	|	|	8	0	1.0	0	6.4	0
22	|	|	0	0	0	0	0	0
23	|	|	6	0	1.5	0	65	0
24	|	|	4	0	1.5	0	56	0

Plot Number	dbh class (inches)	Black Oak			White Oak			Northern Red Oak			Shagbark Hickory			Other Species			All-weather cavities			Escape-only cavities		
		D	C	S	D	C	S	D	C	S	D	C	S	D	C	S	D	C	S	D	C	S
7	2–5			••			••			••												
	6–11					•									••							
	12–16													•								
	17+	•															•					
8	2–5			••						•			••			••						
	6–11		•																			
	12–16	•									•											
	17+																					
9	2-5						••									••						
	6–11		•									•			•							
	12–16		••		•			•						•								
	17+																					
10	2–5			••			••			•												
	6–11					•						•			•							
	12–16	••															•					
	17+																					
Number per acre	2–5	0	0	26	0	0	60	0	0	24	0	0	4	0	0	26	0	0	1			
	6–11	0	8	0	0	12	0	0	2	0	0	4	0	0	16	0	0	0	0			
	12–16	14	4	0	6	2	0	4	0	0	2	0	0	14	0	0	2	0	0			
	17+	2	0	0	2	0	0	0	0	0	2	0	0	0	0	0	3	0	0			
	Total	16	12	26	8	14	60	4	2	24	4	4	4	14	16	26	5	0	1	0	0	0
Number of stump sprouts per acre	2–5	0	0	11	0	0	11	0	0	12	0	0	4									
	6–11	0	1	0	0	1	0	0	1	0	0	3	0									
	12–16	1	0	0	0	0	0	2	0	0	1	0	0									
	17+	0	0	0	0	0	0	0	0	0	0	0	0									
	Total	1	1	11	0	1	11	2	1	12	1	3	4									

Plot Number	Aspect	Slope Position	Height		Diameter at Ground Level		Stocking Value	
			Oak	Hickory	Oak	Hickory	Oak	Hickory
25		MI	8	0	1.5	0	73	0
26		MI	0	0	0	0	0	0
27		UP	10	10	2.0	2.5	79	82
28		UP	0	0	0	0	0	0
29		UP	0	0	0	0	0	0
30		UP	8	0	1.5	0	68	0
31		RI	1	0	—	0	1	0
32		UP	10	0	2.0	0	79	0
33			0	2	0	.5	8	0
34			0	0	0	0	0	0
35			6	0	1.5	0	59	0
36			0	0	0	0	0	0
37			0	4	0	1.0	0	32
38			8	0	1.5	0	68	0
39			6	0	1.5	0	59	0
40			1	8	—	1.5	1	68

	Stocking value	
Stocking value average	25	6
Is advance reproduction adequate?	NO	NO
Is advance reproduction + stump sprouts adequate?	YES	NO

Total number of stump sprouts per acre	
Oak	Hickory
40	8

FIGURE A. Inventory for calculating expected number of stump sprouts, advance reproduction, and tree cavities. The following abbreviations are used on this form: D (dominant), C (co-dominant), and S (suppressed). This inventory has been modified from Sander et al. 1984.

number of stump sprouts for other oak species in this fashion and combine the totals for oaks. Repeat the process for hickories.

10. Determine from Table C the number of oak stump sprouts that are required in combination with advance reproduction stocking to meet minimum stocking requirements. The stocking value of 25 that is shown in Figure A, for example, will require 37 stump sprouts to make up the deficiency in advance reproduction of oaks. For hickories, the stocking value of 6 shown in Figure A will require 29 stump sprouts as shown in Table C. In our example, the addition of stump sprouts is adequate for oaks but is inadequate for hickories.

11. Remember that suppressed and intermediate oaks and hickories in the 2–5 inch class may be younger than the stand dominants. For example, if the 60 white oaks (2- to

TABLE B.—Expected proportion of stumps that will produce, at probability 0.8 or greater, at least one co-dominant or larger stem at age 20.

Species	Site Index	dbh Class (inches)	Age of Parent Tree (years) 40	60	80	100	All Ages
Black oak[a]	50	2–5	0.36	0.34	0.32	0.30	—
		6–11	0.13	0.11	0.10	0.08	—
		12–16	0.06	0.05	0.04	0.03	—
		17+	—	0.02	0.02	0.01	—
	60	2–5	0.47	0.45	0.42	0.40	—
		6–11	0.16	0.15	0.13	0.12	—
		12–16	0.07	0.06	0.05	0.04	—
		17+	—	0.03	0.02	0.02	—
	70	2–5	0.61	0.59	0.56	0.54	—
		6–11	0.21	0.19	0.17	0.16	—
		12–16	0.10	0.08	0.07	0.06	—
		17+	—	0.05	0.04	0.03	—
White oak[a]	50	2–5	0.47	0.25	0.12	0.05	—
		6–11	0.18	0.10	0.06	0.03	—
		12–16	0.06	0.04	0.03	0.02	—
		17+	—	0.02	0.01	0.01	—
	60	2–5	0.63	0.38	0.19	0.08	—
		6–11	0.26	0.16	0.09	0.05	—
		12–16	0.09	0.07	0.05	0.03	—
		17+	—	0.03	0.02	0.02	—
	70	2–5	0.81	0.55	0.31	0.15	—
		6–11	0.36	0.25	0.16	0.09	—
		12–16	0.15	0.11	0.08	0.06	—
		17+	—	0.05	0.04	0.04	—
Northern red oak[a]	60+	2–5	0.86	0.86	0.49	0.49	—
		6–11	0.86	0.86	0.46	0.46	—
		12–16	0.86	0.86	0.38	0.38	—
		17+	—	0.86	0.24	0.24	—
Shagbark hickory[b]	50+	2–5	—	—	—	—	1.00
		6–11	—	—	—	—	0.90
		12–16	—	—	—	—	0.50
		17+	—	—	—	—	0.25

[a] Adapted from Sander et al. 1984.
[b] Adapted from Boisen & Newlin 1910.

5-inches dbh) shown in Figure A had been 40 years old instead of 80, the number of expected stump sprouts would be 38 per acre ($60 \times 0.63 = 37.8$, as calculated from Table B)—sufficient to compensate for the deficiency in advance reproduction. Consequently, the average age of lower-story oaks and hickories should always be determined.

12. If the average SV is ≥30 percent for oaks but <10 percent for hickories, the stand may be harvested for oak and selectively harvested for hickory. Deficiencies in hickory reproduction can be made up by preserving enough hickory poles (3–6 inches dbh) per acre to compensate for inadequate advance reproduction and insufficient stump sprouts. Calculate the number of poles needed from Table C. In the example in Figure A, 21 hickory poles will be required: with the SV of 6, 29 poles would be required; however, 8 stump sprouts are present, therefore, only 21 poles are needed. Because about half of these poles will die, that number should be doubled to 42 hickory poles (Nixon et al. 1983).

Trees can be selected for preservation either before or after clear-cutting removes the large trees and before clean-up crews cut or kill stems >2 inches dbh. Hickories <160 feet from the uncut forest and growing on lower slopes and in coves are most likely to survive. Trees selected for preservation should have an upright, actively growing terminal leader and no obvious disease or injury (Nixon et al. 1983).

13. At least 7 trees with all-weather cavities are desirable per acre. Other trees with cavities may be cut. In the example shown in Figure A, 6 trees had cavities; therefore, none should be removed.

TABLE C.—Number of stump sprouts required per acre to compensate for stocking deficiencies of advance reproduction of oaks and hickories.

Mean Stocking Value for Plots (1/735 of an acre)	Oaks	Hickories
≥30	0	—
29	8	—
28	15	—
27	23	—
26	30	—
25	37	—
24	45	—
23	52	—
22	59	—
21	67	—
20	74	—
19	81	—
18	89	—
17	96	—
16	103	—
15	111	—
14	118	—
13	125	—
12	133	—
11	140	—
≥10	148	0
9	155	7
8	162	15
7	170	22
6	177	29
5	184	36
4	192	44
3	199	51
2	206	58
1	214	66
0	221	73

Glossary of Terms

Definitions given here are adapted from Ford-Robertson (1971).

advance reproduction Young trees that have become established naturally before regeneration cuttings are begun or a clear-cutting is made.

basal area A measure of tree density based on the diameter of each tree at breast height. The diameters for all trees per acre provide the basal area measurement, for example, 90 ft^2.

canopy The more or less continuous cover of branches and foliage formed collectively by the crowns of adjacent trees and other woody growth. Layers of canopy may be distinguished.

clear-cutting Strictly, the removal of the entire standing crop of trees.

climax forest A community that represents the culminating stage of a natural forest succession for a given locality.

co-dominant Species in a mixed crop that are about equally numerous and vigorous.

crown release Removal of competing trees the crowns of which shade the crowns of the crop tree.

diameter limit cutting A selective cutting system that removes only those trees that exceed a stipulated diameter, usually 14 inches and larger.

dominant Generally, an individual or species of the upper layers of the canopy.

epicormic branching A shoot arising spontaneously from an adventitious or dormant bud on the stem or on a branch of a woody plant.

greentree reservoir Wooded bottomlands that are flooded each fall and drained each spring to provide feeding areas for waterfowl.

intermediate cutting Removal of trees from a regular crop or stand between the time of its formation and the harvest cutting.

regeneration cutting Removal of trees intended to assist regeneration already present or to make regeneration possible.

rotation age The age when trees are large enough to provide acceptable lumber products and when growth rates begin to slow.

selection and group selection cutting Annual or periodic removal of trees (particularly mature trees), individually or in groups. The size of the group may vary. Large-group selection would cover an area approximately two tree-heights wide; small-group selection would cover a smaller area.

shelterwood cutting A partial removal of the tree canopy using one or more cuttings, designed to establish a new crop under the protection (overhead or side) of the old.

site index A measure of site quality, taken as the total height that a dominant tree of a given species attains at a given age, usually 50 years. On good sites, trees exceed 70 feet; on average sites, heights range from 55–70 feet; on poor sites, tree heights are less than 55 feet after 50 years.

suppressed Trees that have their crowns in the lower layers of the canopy. The leading shoots are not free, and the trees grow very slowly.

stand A relatively uniform group of trees created by a homogenous environment, including soils, topography, aspect, and past treatment.

stocking Number of trees per unit of area, usually an acre or hectare (2.47 acres); a measure of tree density. Full stocking refers to the maximum number of trees that can most efficiently utilize the space and is referred to as A-level stocking. Fewer trees per unit are referred to as a percent of full stocking or to a specific density such as B- or C- level stocking.

thinning A felling made in an immature stand primarily to accelerate diameter increment but also, by suitable selection, to improve the average form of the trees that remain without permanently breaking the canopy.

thinning from below Removing a varying proportion of trees whose crowns are overtopped by the dominant trees in the stand. This type of thinning particularly favors trees whose crowns form the forest canopy or, in heavier thinning grades, selected dominants that are more or less evenly distributed over the stand.

tolerance The ability of trees to grow satisfactorily in the shade of and in competition with other trees.

References Cited

Adams, C.E. 1973. Population dynamics of fox squirrels, *Sciurus niger*, in selected areas in Seward County, Nebraska. Ph.D. Thesis. University of Nebraska, Lincoln. 116 p.

Allen, D.L. 1943. Michigan fox squirrel management. Michigan Department of Conservation Game Division Publication 100. 404 p.

Barkalow, F.S., Jr., and R.S. Soots, Jr. 1965. An analysis of the effect of artificial nest boxes on a gray squirrel population. Transactions of the North American Wildlife Conference 30:349–360.

Barkalow, F.S., Jr., R.B. Hamilton, and R.F. Soots, Jr. 1970. The vital statistics of an unexploited gray squirrel population. Journal of Wildlife Management 34:489–500.

Baumgartner, L.L. 1940. The fox squirrel: its life history, habits, and management. Ph.D. Thesis. The Ohio State University, Columbus. 257 p.

Benson, B.N. 1975. Dominance relationships, mating behavior, and scent marking in fox squirrels (*Sciurus niger rufiventor*). Ph.D. Thesis. Southern Illinois University, Carbondale. 96 p.

Bernard, R.J. 1972. Social organization of the western fox squirrel. M.S. Thesis. Michigan State University, East Lansing. 41 p.

Boisen, A.T., and J.A. Newlin. 1910. The commercial hickories. U.S. Department of Agriculture Forest Service Bulletin 80. 64 p.

Brown, L.G., and L.E. Yeager. 1945. Fox squirrels and gray squirrels in Illinois. Illinois Natural History Survey Bulletin 23(5):449–536.

Burger, G.V. 1969. Response of gray squirrels to nest boxes at Remington Farms, Maryland. Journal of Wildlife Management 33:796–801.

Callahan, J., and B. Fischer. 1982. Economic and silvicultural potentials of 23 harvested Indiana woodlands. Purdue University Agricultural Experiment Station, Station Bulletin 362. West Lafayette, Indiana. 23 p.

Carey, A., and J. Gill. 1980. Firewood and wildlife. U.S. Department of Agriculture Forest Service Research Note NE–299. 5 p.

Den Uyl, D. 1961. Natural tree reproduction in mixed hardwood stands. Purdue University Agricultural Experiment Station Research Bulletin 728. Lafayette, Indiana. 19 p.

Donohoe, R.W., and R.O. Beal. 1972. Squirrel behavior determined by radio-telemetry. Ohio Department of Natural Resources, Ohio Fish and Wildlife Report 2. 20 p.

Downs, A.A. 1944. Estimating acorn crops for wildlife in the southern Appalachians. Journal of Wildlife Management 8:339–340.

Dyksterhuis, E.J. 1948. The vegetation of the western cross timbers. Ecological Monographs 18:325–376.

Eveland, C.G. 1974. The dynamics of a protected population of fox squirrels (*Sciurus niger*). M.S. Thesis. Southern Illinois University, Carbondale. 99 p.

Eyre, H. 1980. Forest cover types of North America. Society of American Foresters, Washington, D.C. 110 p.

Flyger, V.F. 1960. Movements and home range of the gray squirrel, *Sciurus carolinensis* in two Maryland woodlots. Ecology 41:365–369.

Ford-Robertson, F.C., ed. 1971. Terminology of forest science, technology, practice, and products. Society of American Foresters, Washington, D.C. 349 p.

Fouch, W.R. 1961. Mast crops and fox squirrel populations at the Rose Lake Wildlife Experiment Station. Michigan Department of Conservation Game Division Report 2332, Lansing. 4 p.

Fowells, H.A. 1965. Silvics of forest trees of the United States. U.S. Department of Agriculture Forest Service Agriculture Handbook 271. 762 p.

Geeslin, H.G., Jr. 1970. A radio-tracking study of home range, movements, and habitat uses of the fox squirrel (*Sciurus niger*) in east Texas. M.S. Thesis. Texas A&M University, College Station. 118 p.

Gingrich, S.F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the central states. Forest Science 13:38–53.

Gleason, H.A., ed. 1968. The new Britton and Brown illustrated flora of the northeastern United States and adjacent Canada. Hafner Publishing Co., New York and London. 3 vols.

Goodrum, P.D., V.H. Reid, and C.E. Boyd. 1971. Acorn yields, characteristics, and management criteria of oaks for wildlife. Journal of Wildlife Management 35:520–532.

Hansen, L.P., C.M. Nixon, and S.P. Havera. 1986. Recapture rates and length of residence in an unexploited fox squirrel population. American Midland Naturalist 115:209–215.

Havera, S.P., and C.M. Nixon. 1980. Winter feeding of fox and gray squirrel populations. Journal of Wildlife Management 44:41–55.

Havera, S.P., and K.E. Smith. 1979. A nutritional comparison of selected fox squirrel foods. Journal of Wildlife Management 43:691–704.

Hilt, D.E. 1977. Introduction of black walnut and northern red oak seedlings in an upland hardwood forest in southeastern Ohio. U.S. Department of Agriculture Forest Service Research Note NE–241. 5 p.

Husband, T.P. 1976. Energy metabolism and body composition of the fox squirrel. Journal of Wildlife Management 40:255–263.

Johnson, P., C. Dale, K. Davidson, and J. Law. 1986. Planting northern red oak in the Missouri Ozarks: a prescription. Northern Journal of Applied Forestry 3:66–68.

Jordan, J.S. 1971. Yield from an intensively hunted population of eastern fox squirrels. U.S. Department of Agriculture Forest Service Research Paper NE–186. 8 p.

Korschgen, L.J. 1981. Foods of fox and gray squirrels in Missouri. Journal of Wildlife Management 45:260–266.

Kurtz, W., H. Garrett, and R. Williams. 1981. Young stands of scarlet oak in Missouri can be thinned profitably. Southern Journal of Applied Forestry 5:12–16.

Ludwick, R.J., J.P. Fontenot, and H.S. Mosby. 1969. Energy metabolism of the eastern gray squirrel. Journal of Wildlife Management 33:569–575.

Marquis, D.A. 1981. Survival, growth, and quality of residual trees following clearcutting in Allegheny hardwood forests. U.S. Department of Agriculture Forest Service Research Paper NE–477. 9 p.

Maryland Game and Inland Fish Commission. 1966. Tire nests for squirrels. Annapolis. 6 p.

McComb, W.C., and R.E. Noble. 1981. Nest-box and natural-cavity use in three mid-south forest habitats. Journal of Wildlife Management 45:93–101.

McQuilkin, R.A., and R.A. Musbach. 1977. Pin oak acorn production on green tree reservoirs in southeastern Missouri. Journal of Wildlife Management 41:218–225.

Merritt, C. 1979. An overview of oak regeneration problems. Pages 1–10 *in* H.A. Holt and B.C. Fischer, eds. Regenerating oaks in upland hardwood forests. Proceedings 1979 John S. Wright Forestry Conference. Purdue University Research Foundation, West Lafayette, Indiana.

Mosby, H.S. 1969. The influence of hunting on the population dynamics of a woodlot gray squirrel population. Journal of Wildlife Management 33:59–73.

Myers, C., and R. Buchman. 1984. Manager's handbook for elm-ash-cottonwood in the north central states. U.S. Department of Agriculture Forest Service General Technical Report NC–98. 11 p.

Nixon, C.M., R.W. Donohoe, and T. Nash. 1974. Overharvest of fox squirrels from two woodlots in western Ohio. Journal of Wildlife Management 38:67–80.

Nixon, C.M., L.P. Hansen, and S.P. Havera. 1986. Demographic characteristics of an unexploited population of fox squirrels (*Sciurus niger*). Canadian Journal of Zoology 64:512–521.

Nixon, C.M., S.P. Havera, and R.E. Greenberg. 1978. Distribution and abundance of the gray squirrel in Illinois. Illinois Natural History Survey Biological Notes 105. 55 p.

Nixon, C.M., S.P. Havera, and L.P. Hansen. 1980. Initial response of squirrels to forest changes associated with selection cutting. Wildlife Society Bulletin 8:298–306.

Nixon, C.M., S.P. Havera, and L.P. Hansen. 1984. Effects of nest boxes on fox squirrel demography, condition, and shelter use. American Midland Naturalist 112:157–171.

Nixon, C.M., and M.W. McClain. 1975. Breeding seasons and fecundity of female gray squirrels in Ohio. Journal of Wildlife Management 39:426–438.

Nixon, C.M., M.W. McClain, and R.W. Donohoe. 1975. Effects of hunting and mast crops on a squirrel population. Journal of Wildlife Management 39:1–25.

Nixon, C.M., M.W. McClain, and R.W. Donohoe. 1980. Effects of clear-cutting on gray squirrels. Journal of Wildlife Management 44:403–412.

Nixon, C.M., M.W. McClain, and L.P. Hansen. 1980. Six years of hickory seed yields in southeastern Ohio. Journal of Wildlife Management 44:534–539.

Nixon, C.M., M.W. McClain, R.K. Landes, L.P. Hansen, and H.R. Sanderson. 1983. Response of suppressed hickories to release cutting. Wildlife Society Bulletin 11:42–46.

Nixon, C.M., D.M. Worley, and M.W. McClain. 1968. Food habits of squirrels in southeast Ohio.Journal of Wildlife Management 32: 294–305.

Roach, B.A. 1977. A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings. U.S. Department of Agriculture Forest Service Research Paper NE–373. 30 p.

Roach, B.A., and S.F. Gingrich. 1968. Even-aged silviculture for upland central hardwoods. U.S. Department of Agriculture Forest Service Agriculture Handbook 355. 39 p.

Sander, I.L. 1977. Manager's handbook for oaks in the north central states. U.S. Department of Agriculture Forest Service General Technical Report NC–37. 35 p.

Sander, I., P. Johnson, and R. Rogers. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. U.S. Department of Agriculture Forest Service Research Paper NC–251 16 p.