Tree Species Response to Release from Domestic Livestock Grazing

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Introduction

Grazing of domestic livestock has long been a factor which has greatly influenced forest structure and composition in the Central Hardwood Region, and the quality and quantity of timber produced. Approximately sixty-six percent of the forests in the Central Hardwoods Region were subjected to grazing as late as 1947 (4). Prior to the passage of the Indiana Forest Classification Act in 1921, nearly all of the farm woodlots in Indiana were grazed (3). Currently, approximately thirty percent of the forest land in Indiana is grazed (8).

Although many of the farm woodlots in northern Indiana have been protected from grazing since the passage of the Forest Classification Act in 1921, questions concerning the long-term effect of grazing remain unanswered. The purpose of this report is to present recent findings of an extensive research project that was initiated in 1930 to monitor the recovery of Central Hardwood forests from grazing by domestic livestock. Daniel Den Uyl, Department of Forestry and Natural Resources, Purdue University, established permanent plots in the early 1930s, throughout central and northern Indiana, and remeasured the plots at approximately five year intervals until the early 1960's. These plots were established to elucidate recovery processes of these woodlots from grazing. Den Uyl's initial project and early results are detailed in several publications (3,4,5,6,7 and 8). The foresight of Den Uyl has provided a unique opportunity to study the long-term effects of domestic livestock grazing. Research to be reported will focus on changes in species composition, size-class distributions, and basal area and density values over the past 50 years on several of Den Uyl's grazed and ungrazed plots.

Study Area

Some of Den Uyl's original plots had been visited from 1970 to 1984; however, due to recent disturbances in these stands (selective logging) and/or missing data from past inventories, only a small number of quadrats were suitable for remeasurement. Four plots were selected and are located in the Deam, Hoffman and Romey (two plots) woods in the northeastern Indiana counties of Wells, Allen and Adams, respectively (Figure 1). Each varied in forest type, silvical condition, density of canopy, and grazing history when they were established in 1931-32 (Table 1). All plots are level to slightly rolling and have had some selective cutting prior to plot establishment.

Table 1. Characteristics of Plots at time of establishment, 1931-1932 (Diller and Medesy, unpublished report, Purdue University).

Woods	Forest Type	Silvical Condition	Canopy Density	Gazing Intensity[a]	Last Year Grazed
Deam	Upland-Swamp	Fair-poor	70%	Medium-Heavy	1930
Hoffman	Oak-hickory	very good	90%	none	—
Romey	Oak-hickory	good	80%	heavy	1927

[A]See Day and DenUyl (1932) for grazing-intensity criteria.

FIGURE 1. County map of Indiana showing location of Deam (1), Hoffman (2), and Romey (3) woods.

Methods and Materials

In 1931-1932 Den Uyl and associates established 70 plots in 16 northern Indiana counties. Plot size varied from 0.1 to 1 acre (0.04-0.4 ha), most being 0.5 acre (0.2

ha) in size (7). Diameter at breast height (dbh; about 1.37 m above ground) was measured on every tree 0.6 inches (1.5 cm) or larger. Tree species, height and crown class were also determined for each stem. All stems were numbered with metal tags or paint and were mapped by location and crown shape. Each plot was remeasured at approximately five year intervals. Photographs were taken of each plot, and general plot descriptions were made which included: silvical condition, drainage, topography and density of crown cover. Grazing history and evidence of disturbance such as fire and cutting were also recorded when this information was available.

In the fall of 1984 four 0.5 acre (0.2 ha) plots were remeasured. The original plots were located by maps made in 1931 and 1932. Maps which provided directions and distances from nearby towns were utilized to locate properties; those which designated plot locations by distances in chains (1 chain = 20.1 m) and bearings were used to determine the general plot locations.

Once the plot locations were determined, a staff compass and 100 foot (30.5 m) tape were employed along with remnant tree tags, crown maps and records of distances and bearings to relocate quadrat boundaries. At least one metal corner stake from the original plot was found on three plots, and was used as a reference point. However, when no corner stakes were found, tagged trees from the original study that were on or near the boundary in conjunction with crown maps provided adequate information to estimate boundary positions.

Several of the stems near the western edge of of plot no. 66 in the Romey woods were cleared for agricultural purposes. In order to eliminate the edge effects, 25 percent of the original plot was not included in the newly established plot, resulting in a 0.38 acre (0.15 ha) plot. Results for all plots have been expressed in relation to one hectare for ease of comparison. The data from both Romey plots are presented together since these plots were very similar.

All of the trees present at the time of the initial inventory were remeasured (dbh), and the original numbers were recorded. When tree tags were no longer present or readable, crown maps and dbh measurements from the previous survey were used to determine original tree numbers. All stems greater than or equal to 1.0 cm dbh that were not present at the time of the previous survey were classified as ingrowth. Ingrowth stems were identified as to species, measured (dbh) and recorded.

Diameters were recorded for all stems that forked at or below dbh, and all stems were measured to the nearest 0.1 cm (dbh). A metric caliper was used to measure dbh of stems less than 6.0 cm, and a metal diameter tape was used for stems larger than 6.0 cm.

Data from Den Uyl's research (species, crown class and diameters from each measurement period) were stored, with the newly acquired data, on magnetic tape for analysis on the University's computer system. Computer programs were written by the senior author.

Density (stems ha,$^{-1}$), basal area (m^2ha^{-1}), and Importance Values ((relative density + relative basal areas)/2) were calculated for each species by plot. Stems were also separated into 5.0 cm size-classes by species and all species combined.

Results

After grazing, some species which were not present in the initial survey had become established in the plots. At the Romey woods, two species (*Carya tomentosa* and *Acer rubrum*) colonized the plots with the cessation of grazing (Table 2). *Celtis occidentalis, Fraxinus americana, F. nigra* and *Prunus serotina* were new species to the plot in Deam woods following grazing (Table 3). Two new species, *C. occidentalis* and *Liriodendron*

TABLE 2. Changes in density ha^{-1}(D), basal area m^2ha^{-1} and Importance Values[a] (IV) from 1932 to 1984 on plots #66 and #67, combined, in Romey's woods.

Species	1932			1947			1984		
	D	BA	IV	D	BA	IV	D	BA	IV
Acer rubrum	0.0	0.0	0.0	5.0	0.1	1.0	3.3	0.0	0.1
Acer saccharum	64.2	2.2	12.2	27.2	1.0	6.6	644.2	3.0	22.3
Carpinus caroliniana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carya cordiformis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carya glabra	74.2	2.4	13.6	66.8	3.2	18.2	32.2	4.2	10.3
Carya ovata	212.5	5.0	34.0	192.8	6.4	44.4	169.6	10.1	24.9
Carya tomentosa	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.1
Celtis occidentalis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fagus grandifolia	27.2	1.4	6.7	19.8	0.6	4.4	31.3	1.2	3.3
Fraxinus americana	7.4	0.1	1.2	7.4	0.3	1.8	11.6	0.2	0.7
Fraxinus nigra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Juglans nigra	2.4	0.2	1.0	2.4	0.3	1.2	0.0	0.0	0.0
Liriodendron tulipifera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ostrya virginiana	22.2	0.2	2.6	17.3	0.2	2.6	778.4	1.8	21.3
Populus deltoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prunus serotina	2.4	0.1	0.5	2.4	0.1	0.6	69.2	0.2	1.7
Quercus alba	19.8	1.5	6.0	14.8	1.0	5.2	14.8	1.0	2.5
Quercus bicolor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quercus macrocarpa	5.0	0.4	1.6	5.0	0.6	2.4	0.0	0.0	0.0
Quercus muehlenbergii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quercus rubra[c]	24.7	3.0	10.6	9.9	1.0	4.2	93.9	1.5	4.4
Tilia americana	2.4	0.1	0.4	2.4	0.1	0.6	65.9	0.4	2.0
Ulmus americana	14.8	0.9	3.8	14.8	1.0	5.0	145.8	0.5	4.4
Ulmus rubra	17.3	0.5	3.2	7.4	0.2	1.7	18.2	0.1	0.8
Others[b]	27.2	0.1	2.8	0.0	0.0	0.0	56.0	T[b]	1.4
TOTAL	523.9	18.0		394.4	16.1		2139.1	23.8	

[a]IV = (relative density + relative basal area)/2.

[b]T ≤ 0.05

[c]may include individuals of *Quercus shumardii*.

[d]includes *Asimina triloba*, *Cornus* spp., *Crataegus* spp., *Lindera benzoin*, *Staphylea trifolia* and *Viburnum prunifolium*.

TABLE 3. Changes in density ha^{-1} (D), basal area M^2 MA^{-1} (BA) and importance values[a] (IV) from 1931 to 1984 on plot #49 in Deam's woods.

Species	1931			1951			1984		
	D	BA	IV	D	BA	IV	D	BA	IV
Acer rubrum	4.9	0.7	3.0	4.9	1.0	3.4	14.8	1.6	0.0
Acer saccharum	19.8	1.4	8.4	19.8	1.8	9.0	1,724.8	4.1	0.0
Carpinus caroliniana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carya cordiformis	44.5	2.3	16.7	19.8	1.3	7.8	24.7	1.5	0.0
Carya glabra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carya ovata	54.4	3.5	22.4	54.4	4.6	23.9	54.4	6.1	0.0
Carya tomentosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Celtis occidentals	0.0	0.0	0.0	0.0	0.0	0.0	14.8	T_B	0.0
Fagus grandifolia	4.9	0.7	2.9	4.9	0.8	3.0	0.0	0.0	0.0
Fraxinus americana	0.0	0.0	0.0	0.0	0.0	0.0	9.9	T	0.0
Fraxinus nigra	0.0	0.0	0.0	0.0	0.0	0.0	93.9	0.3	0.0
Juglans nigra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liriodenron tulipifera	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ostrya virginiana	4.9	0.8	1.4	0.0	0.0	0.0	207.6	0.8	0.0
Populus deltoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prunus serotina	0.0	0.0	0.0	0.0	0.0	0.0	19.8	T	0.0

TABLE 3.—Continued

	1931			1951			1984		
Species	D	BA	IV	D	BA	IV	D	BA	IV
Quercus alba	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quercus bicolor	9.9	1.3	5.9	9.9	1.7	6.3	9.9	2.7	0.0
Quercus macrocarpa	9.9	1.6	6.7	9.9	2.4	7.6	9.9	4.1	0.0
Quercus muehlenbergii	4.9	0.6	2.8	4.9	0.9	3.2	4.9	1.6	0.0
Quercus rubra[C]	14.8	3.1	11.7	14.8	4.4	13.2	14.8	8.6	0.0
Tilia americana	9.9	1.7	6.9	29.6	2.1	12.1	158.1	1.8	0.0
Ulmus americana	19.8	2.0	10.0	19.8	2.5	10.5	29.7	0.2	0.0
Ulmus rubra	4.9	T[B]	1.2	0.0	0.0	0.0	499.2	1.7	10.0
Others[D]	0.0	0.0	0.0	0.0	0.0	0.0	207.6	0.2	0.0
TOTAL	207.6	19.0		192.7	23.5		3,098.7	35.4	0.0

[A]IV = (relative density + relative basal area)/2.

[B]T ≤ 0.05.

[C]may include individuals of *Quercus shumardii.*

[D]includes *Asimina triloba, Cornus,* spp., *Crataegus* spp., *Lindera benzoin, Staphylea trifolia* and *Viburnum prunifolium.*

tulipifera, also colonized the Hoffman woods, although this stand supposedly had not been grazed (Table 4).

Some species disappeared from each plot. For example, *Fagus grandifolia* no longer exists in the plot at Deam woods. *Juglans nigra* and *Quercus macrocarpa* disappeared from the Romey plots, undoubtedly in part due to selective cutting of the former species. *Carya glabra, Juglans nigra* and *Populus deltoides* were not tallied during the 1984 inventory in the Hoffman plot. However, most if not all of these species still exist outside of these plots within the respective woodlots.

Densities have increased from 1931-1932 to 1984 for all species combined on all plots measured; however, increases are greatest on the plots that had been previously grazed. Overall density increased from 523.9 to 2139.1 stems ha^{-1} on the Romey plots, an increase of 308% (Table 2). Density changes were the greatest on the Deam plot; stem numbers increased from 207.6 to 3098.7 ha^{-1}, an increase of 1392% (Table 3). Density values for all species combined on the ungrazed plot increase 86% (from 953.8 to 1774.2 stems ha,$^{-1}$; Table 4).

On all plots surveyed there was a decrease in density from the first measurement (1931-1932) to the second (1947-1951). This decrease was greatest on the ungrazed Hoffman plot (Table 4); however, the density for this plot was much greater than that of the grazed Romey and Deam plots at the time of the initial survey (Tables 2 and 3). Records kept by Den Uyl indicate that some selective logging occurred in stands after 1931-1932, but most of the decrease in density was due to natural mortality. Since natural regeneration following grazing requires 3 to 15 years to establish (8), seedlings which colonized previously grazed plots were too small to be enumerated during the intermediate period.

The two species that contributed to the greatest increase in density from 1931-1932 to 1984 on the combined Romey plots were *Acer saccharum* and *Ostyra virginiana.* Densities increased from 64.2 to 644.2 stems ha^{-1} and from 22.2 to 778.4 stems ha^{-1} for *Acer saccharum* and *Ostrya virginiana,* respectively. These two species accounted for nearly 83% of the density on the Romey plots in 1984.

Acer saccharum increased from 19.8 to 1724.8 stems ha^{-1} on the Deam plot; this increase accounts for nearly 59% of the total plot increase. Increases in density of

TABLE 4. Changes in density ha^{-1} (D), basal area $M^2 ha^{-1}$ (BA) and Importance Values[A] (IV) from 1931 to 1984 on plot #26 in Hoffman's woods.

	1931			1951			1984		
Species	D	BA	IV	D	BA	IV	D	BA	IV
Acer rubrum	24.7	0.6	2.3	14.8	0.6	2.4	4.9	0.2	0.4
Acer saccharum	118.6	0.7	7.4	93.9	1.2	10.1	207.6	2.2	8.8
Carpinus caroliniana	44.5	0.2	2.6	4.9	T[B]	0.5	192.7	0.2	5.7
Carya cordiformis	24.7	0.8	2.7	0.0	0.0	0.0	14.8	T	0.4
Carya glabra	29.7	2.2	5.3	0.0	0.0	0.0	0.0	0.0	0.0
Carya ovata	9.9	T[B]	0.6	4.9	T	0.4	4.9	T	0.1
Carya tomentosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Celtis occidentalis	0.0	0.0	0.0	0.0	0.0	0.0	4.9	T	0.2
Fagus grandifolia	89.0	0.5	5.5	59.3	0.7	6.3	74.1	1.4	4.0
Fraxinus americana	24.7	0.9	2.8	14.8	1.1	3.0	123.6	2.0	6.2
Fraxinus nigra	89.0	1.4	7.0	19.8	1.0	3.3	19.8	T	0.6
Juglans nigra	9.9	0.7	1.7	9.9	1.2	2.7	0.0	0.0	0.0
Liriodendron tulipiefera	0.0	0.0	0.0	0.0	0.0	0.0	14.8	0.3	0.8
Ostrya virginiana	123.6	0.4	7.2	74.1	0.4	7.2	232.3	1.4	8.4
Populus deltoides	4.9	0.4	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Prunus serotina	0.0	0.0	0.0	0.0	0.0	0.0	84.0	0.1	2.4
Quercus alba	74.1	2.2	7.5	44.5	2.3	7.6	34.6	3.5	5.7
Quercus bicolor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quercus macrocarpa	14.8	0.8	2.2	9.9	1.3	2.9	9.9	2.4	3.6
Quercus muehlenbergii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quercus rubra[C]	93.9	8.4	18.8	89.0	12.9	23.6	84.0	21.0	31.0
Tilia americana	93.9	6.8	16.2	74.1	6.4	16.8	237.2	1.7	9.0
Ulmus americana	4.9	0.1	0.5	4.9	0.2	0.7	64.2	0.1	1.9
Others[D]	4.9	T	0.3	4.9	T	0.5	286.6	0.2	8.0
TOTAL	953.8	30.2		568.3	31.1		1,774.2	36.7	

[A] IV = (relative density + relative basal area)/2.
[B] T ≤ 0.05.
[C] May include individuals of *Quercus shumardii*.
[D] Includes *Asimina triloba, Cornus* spp., *Crataegus* spp., *Lindera benzoin, Staphylea trifolia* and *Viburnum prunifolium*.

Ostrya virginiana, Tilia americana, Ulmus spp. and species in the "other" category (mostly species that do not attain large size, e.g., *Lindera benzoin, Asimina triloba* and *Viburnum prunifolium*) account for another 37% of the increase.

Several species (*Acer saccharum, Carpinus caroliniana, Fraxinus americana, Ostyra virginiana* and *Tilia americana*) have contributed greatly to the increase in the density of the ungrazed plot from 1931 to 1984. However, species in the "other" category, particularly *Lindera benzoin*, have contributed the greatest to this value. Thirty-four percent of the total increase is attributable to these species.

Density values for *Carya* spp. and *Quercus* spp. on both grazed and ungrazed plots from 1931-1932 to 1984 have either decreased or remained fairly constant in most cases. Again, selective logging removed a portion of these stems (many of which had been previously injured) although most had died naturally. However, *Quercus rubra* density increased from 24.7 to 93.9 stems ha^{-1} on the combined Romey plots.

Basal area for all species combined has increased from 1931-1932 to 1984 on all plots sampled; however, as with density, relative increases were greatest on the grazed plots. Basal area decreased at the intermediate inventory only in the Romey woods.

Basal area values increased 32% (from 18.0 to 23.8 m^2ha^{-1}) on the combined Romey plots (Table 2). The largest increase in basal area was on the Deam plot; basal area increased from 19.0 to 35.4 m^{2-1}, an increase of 86% (Table 3). Basal area on the ungrazed Hoffman plot increased from 30.2 to 36.7 m^2ha^{-1}.

Carya glabra and *C. ovata* increased in basal area by 6.9 m²ha'M' on the Romey plots. This increase exceeds the total increase for these plots, because some species exhibited a net decrease in the basal area (e.g., *Quercus* spp. which decreased in basal area by 2.9 m^2ha^{-1}).

In contrast to the Romey plots, *Carya* spp. do not account for the greatest increase in basal area on the Deam plot. Only 1.8 m^2ha^{-1} of the basal area increase of 16.8 m^2ha^{-1} is attributable to *Carya* spp. *Quercus* spp. added 10.40 m^2ha^{-1} of basal area; *Q. rubra* was responsible for over one-half of this increase by 0.9 and 2.7 m^2ha^{-1}, respectively, whereas *Ulmus* spp. basal area totals remained nearly constant.

Quercus rubra increased in basal area by 12.6 m^2ha^{-1} on the ungrazed plot, which is nearly double the increase for the entire plot. Concurrently, *Tilia americiana, Ulmus rubra*, and *Carya glabra* decreased in basal area by 5.1, 2.7 and 2.2 m^2ha^{-1}, respectively.

In 1932 on the combined Romey plots, *Carya ovata, C. glabra, Acer saccharum* and *Quercus rubra* had Importance Values (IV's) of 34.0, 13.6, 12.2 and 10.6%, respectively (Table 2). The IV of *Carya ovata* dropped to 24.9% in 1984; however, *C. ovata* still has the highest IV. *Carya glabra* and *Quercus rubra* IV's also decreased in 1984, while the IV of *Acer saccharum* increased to 22.3% (mainly due to an increase in density). *Ostrya virginiana* IV increased the most from 1932 to 1984 of any species present, with an increase from 2.6 to 21.3% (mainly due to an increase in density).

Carya ovata and *C. cordiformis* had the highest IVs of all species in 1931 on the Deam plot (combined IVs 39.1%; Table 3). Only two other species (*Quercus rubra* and *Ulmus americana*) had IVs of 10.0% or greater in 1931. In 1984, the IV for *Carya* spp. was 12.0%; less than one-third of what it was in 1931. *Quercus rubra* showed a slight increase in IV over this 53 year period. *Ulmus* spp. IV has remained the same; however, the density for this genus has increased from 24.8 to 528.9 stems ha^{-1}. *Ulmus americana* and *U. rubra* seedlings were combined in the *U. rubra* category due to the difficulty in distinguishing between the two species at this early age. *Acer saccharum* had the greatest IV increase from 1931 to 1984 (25.3% increase).

Only two species (*Quercus rubra* and *Tilia americana*) found on the ungrazed Hoffman plot in 1931, had Importance Values greater than 10.0% (18.8 and 16.2%, respectively; Table 4). Both of these species exhibited larger changes in IVs from 1931 to 1984; however, *Quercus rubra* IV increased to 31.0%, while *Tilia americana* IV decreased to 9.0%. *Fraxinus nigra* also decreased in IV from 7.0 to 0.6%.

Size-class distributions for all species combined on grazed and ungrazed plots appear similar in 1931 and 1984 (Figure 2). Stem numbers in most size-classes on the ungrazed plots were greater than those on the grazed plots in 1931. In 1931, both the grazed and ungrazed plots have a notable depletion of stems in the smallest size-class and again in the 15.0-19.9 cm size-class. By 1984 this latter underrepresentation of stems is prominent in the 25.0-29.9 cm size-class.

The size-class distribution for *Acer saccharum* and *Ostrya virginiana* combined on the grazed plot for 1984 (Figure 3) is quite distinct from that of 1931, primarily due to tremendous ingrowth of these species. Differences between these two yeas is less striking on the ungrazed plot, although stem numbers are currently greater in the smallest size-class. These two species made up nearly all of the stems in the lower four classes, all species combined (Figure 2) in 1984.

Quercus spp. size-class distribution is similar for the grazed and ungrazed plots in 1931, in that both distributions roughly resemble a bell-shaped curve (Figure 4). In both cases no stems were found in the 1.0-4.9 cm size-class in 1931; however, there were more stems in the classes from 5.0 to 49.9 cm on the ungrazed plot than on

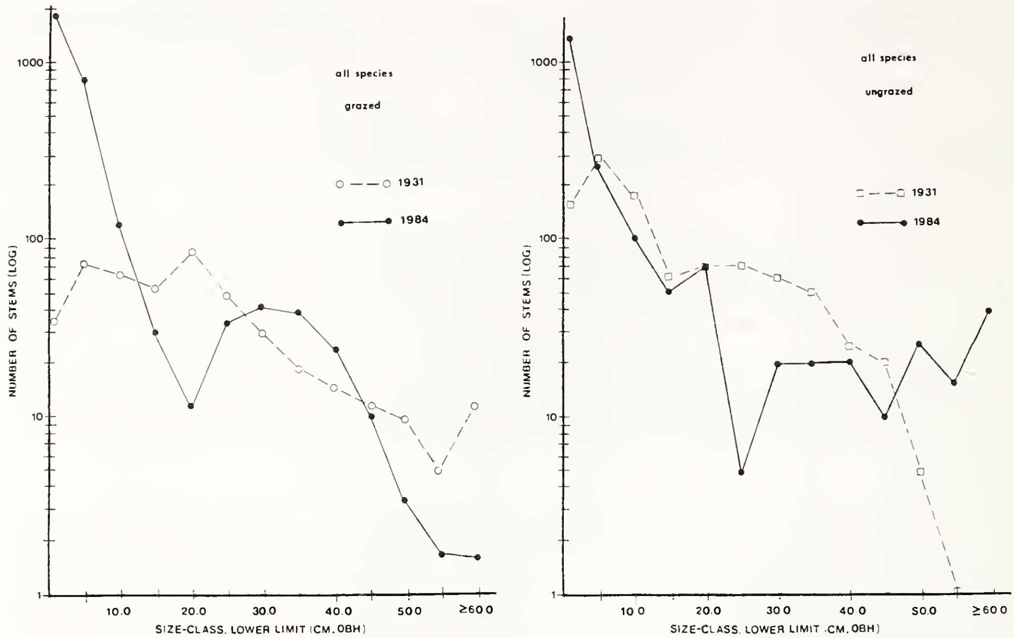

FIGURE 2. Size-class distribution (stems ha^{-1}) of all species combined in 1931 (and 1932) and 1984 for grazed and ungrazed plots.

the grazed plot. There were approximately 70 stems ha^{-1} of *Quercus* spp. in the 1.0-4.9 and 5.0-9.9 cm size-classes combined on the grazed plots in 1984. This increase is due to *Quercus rubra* ingrowth on Romey plot no. 66; *Quercus* spp. regeneration was absent on the other plots.

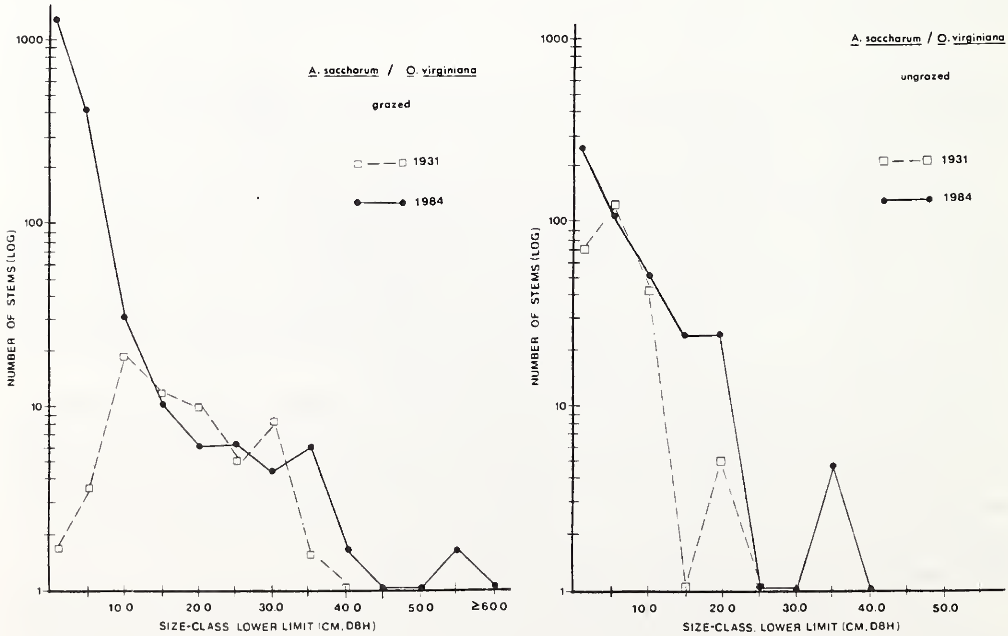

FIGURE 3. Size-class distribution (stems ha^{+1}) of *Acer saccharum* and *Ostrya virginiana* in 1931 (and 1932) and 1984 for grazed and ungrazed plots.

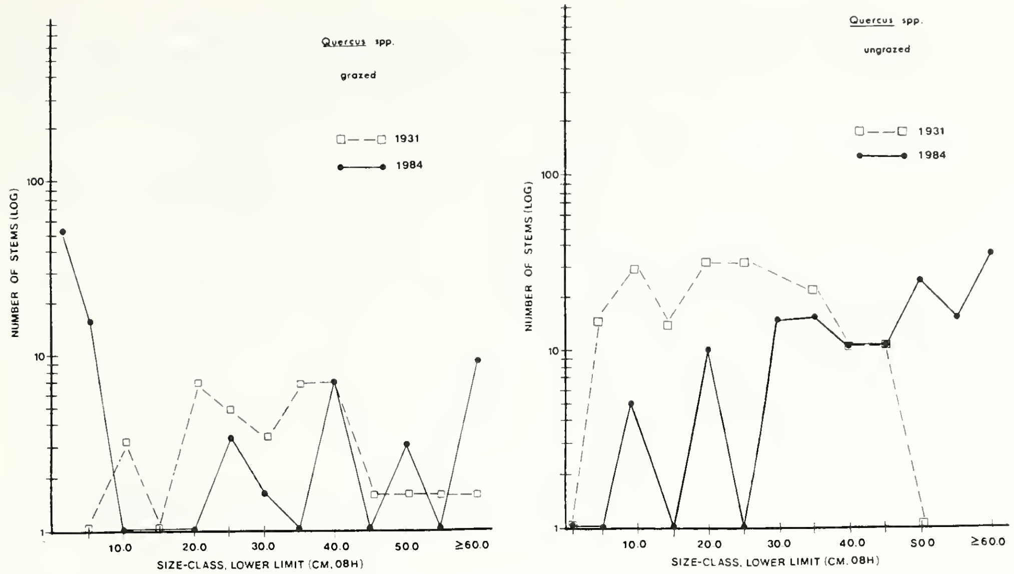

FIGURE 4. Size-class distribution (stems ha^{-1}) of *Quercus* spp. in 1931 (and 1932) and 1984 for grazed and ungrazed plots.

Discussion

Lowered forest productivity is a known consequence of grazing (5). The effect of grazing on various soil properties has been documented in many publications. Soil physical properties (e.g., porosity and permeability) are especially affected (2 and 17). Destruction of the forest floor, a vital part of the forest mineral and hydrologic cycles, is also a consequence (3).

The current basal area of Deam woods (grazed) of 35.4 m^{2}ha^{-1} is relatively high compared to that for mature forests in the Central Hardwoods Region (1, 10 and 14), although this woods had been grazed somewhat heavily in the early 1900s. But, such comparisons are not entirely valid because of differences in the lower stem diameter limit among studies (i.e., all stems) $\geq$ 1 cm in present study versus 10 cm in others). This disparity in lower diameter limit leads to even more dubious comparisons of stem densities. For example, the density in Deam woods of 3099 stems ha^{-1} is substantially higher than the average density of 284 stems ha^{-1} for old-growth forests in Indiana (14). However, if only those stems $\geq$ 10.0 cm dbh are counted at Deam woods the resulting density is 143 stems ha^{-1}. Another reason for such discrepancies in basal area and density between the present study and others cited is differences in stand age. Natural thinning has probably occurred to a greater degree in the old-growth forests previously mentioned compared to the younger Deam woods.

Basal area and density values are much lower at Romey woods partly because site quality may be lowest of the three woods studied. Therefore, it appears that grazing may have a longer and more detrimental effect on forest processes (reduced tree species colonization, less growth, greater mortality, etc.) at Romey woods, although the grazing intensity and/or high-grading may have also been severe enough to cause such differences. Economically, less desirable timber species apparently have been favored by the combination of poor site quality and past grazing. However, more research is needed to evaluate site quality on all stands in this study.

Comparisons between plots at Deam and Romey woods are likewise difficult because of initial differences in location, forest type, silvical condition, soils, etc.

Although we initially believed that the ungrazed plot (Hoffman woods) would serve as a reasonable control, the 1931-32 compositional and structural data suggest that this woods was also disturbed prior to plot establishment. Written records indicate that this woods has been protected from grazing since the 1870s, but other disturbance factors could have affected this woods.

Some authors (11, 14) have claimed that periods of stand disturbance could be determined based on the size-class distribution of stems as depicted in Figures 2, 3, 4 (i.e., the size-class is plotted on the abscissa, the log of the number of stems in that class is plotted on the ordinate; a plot of these values constitutes the negative exponential distribution). Large deviations from the constantly decreasing straight line supposedly indicate periods of disturbance; however, others (13 and 20) have objected to such an affirmation. If this assumption is allowed, at least two major disturbances are apparent in all plots prior to 1930, as shown by the substantial underrepresentation of stems in the 1.0-4.9 and 15.0-19.9 cm classes for the species combinations shown.

Although the lack of stems in the smallest size-class in 1931-1932 could be attributed to grazing effects, this same phenomenon exists for the ungrazed plot. Possible reasons for this parity include: (1) the ungrazed plot had actually been grazed in the late 1800s to early 1900s; and/or (2) severe disturbance affected all stands similarly during the same years. Photographs of the ungrazed plot in 1931 reveal that few small stems existed in the understory, as in the grazed plots. Selective logging in all plots during this period could have contributed to depletion of larger stems, but a more likely factor is drought since the smallest trees seem to have been particularly susceptible. Climatic records at the nearest weather station (Fort Wayne, Indiana) indicate that severe droughts occurred periodically in the late 1800s to early 1900s (19). Such a climatic aberration could explain some of the similarities in the size-class distributions between grazed and ungrazed plots. There is also evidence that small fires had occurred in some of these stands, according to Den Uyl's unpublished data.

The size-class distribution of *Quercus* spp. in both grazed and ungrazed plots suggests that at least this component of these stands established within a relatively narrow time period, i.e. the *Quercus* spp. are even-aged. This belief is based on a comparison of the present results with *Quercus* size-class distributions of Schnur (15) which represent even-aged stands at various ages over a range of site quality.

Initially, the increase in *Ulmus* spp. IV in all woods may seem surprising, considering the effect that Dutch elm disease and elm yellows has had on this genus in Indiana (16). This increase results despite mortality of larger individuals because of substantial ingrowth of *U. americana* and *U. rubra*. Similar density increases in these species have been noted elsewhere (12).

Results from the 1981 survey reinforce some of Den Uyl's (8) findings. For instance, he stated that *Acer saccharum, Ulmus* spp., *Ostrya virginiana* and *Prunus serotina* colonization frequently occurred following grazing. These species are primarily light-seeded or bird-dispersed and produce some seed each year to provide a constant supply of propagules (8). These species are also fairly shade tolerant; therefore they can establish under a dense canopy and persist, at least while in the seedling stage (9). Day and Den Uyl (3) also state that unpalatable, 'weed' species (such as *Ostrya virginiana*) remain on the site and regenerate prolifically following grazing which excludes establishment of more desirable timber species.

Openings of 0.10 to 1 acre (0.04-0.4 ha) are required for the reproduction of most desirable tree species. Canopy densities of 70, 80 and 90% were present on Deam, Romey and Hoffman plots, respectively at establishment (Table 1) which did not allow sufficient sunlight to reach the forest floor for these shade intolerant species to establish and persist. *Quercus* spp. probably did not reproduce on most of the plots for this reason; furthermore, the *Quercus rubra* seedlings present on plot no. 66 were presumably the same individuals that Den Uyl noted in 1957 within openings created by the removal of six large overstory trees in 1942 (8). Also, Den Uyl (8) showed photographs of abundant *Fraxinus americana* reproduction on plot no. 67 of Romey woods. In 1984 only two individuals of this species were tallied on the entire 0.5 acre (0.2 ha) quadrat. This decline in *Fraxinus americana* density is probably attributable to a decline in shade tolerance as this species ages.

Due to site and historical differences among plots it is difficult to make specific conclusions about long-term species response to release from grazing. Site quality is an important factor to consider, since it undoubtedly affects the recovery of different species to release from grazing. In order to better ascertain the effects of grazing on forest composition and structure, it would be necessary to reestablish many more plots with similar characteristics. Ideally, woodlots which contain contiguous grazed and ungrazed plots should be utilized; however, rarely is such a condition available. Den Uyl did establish some plots in woodlots that were divided by fence into both grazed and protected sections; but, unfortunately these plots are no longer intact or they have been severely perturbed since their establishment.

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