THE EFFECT OF SITE AND AGE ON TREE REGENERATION IN YOUNG UPLAND HARDWOOD CLEARCUTS[1]

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ABSTRACT.--The objective of this paper was to determine the distribution of dominant-codominant and dominant plot tree (DPT) regeneration across site and age variables on 74 clearcuts from 5 to 17 years on the Hoosier National Forest. Data was collected on 1801, 0.01 acre regeneration plots. Multivariate and univariate analyses of variance were used to determine if transformed aspect, slope position and clearcut age were significantly related to transformed percent dominant-codominant regeneration. The dominant-codominant regeneration was dominated by miscellaneous noncommercial species, sassafras and yellow-poplar. The DPT regeneration classified as post harvest regeneration was dominated by yellow-poplar, black cherry and red and black oak species. Black cherry followed by yellow-poplar and red and American elm were the most frequently occurring species in the DPT observations classified as advance regeneration. Species composition was significantly related to clearcut age and site variables.

INTRODUCTION

Clearcutting on the Hoosier National Forest (HNF) has been the harvesting alternative used by the United States Forest Service (USFS) for approximately twenty years. The decision to use clearcutting on the HNF was based on USFS research, completed in the 1950's and early 1960's, and summarized by Roach and Gingrich (1968). This research indicated that if a high priority management objective was to produce high value timber products in a relatively short time, then clearcutting was the most efficient alternative to regenerate most upland hardwood types (Sander and Clark 1971, Roach and Gingrich 1968).

Some foresters and environmental groups have raised concerns that clearcutting is detrimental to the forest. In particular environmental groups suggest that there is a change in species composition from oak dominated stands to a more mixed hardwood regeneration following clear-cutting. The frequency and distribution of regeneration following clearcutting across the array of sites on the HNF is not known and the need for further research in the area of identified in the Hoosier National Forest Land Resource Management Plan (USFS 1986). The specific concern is that foresters cannot predict or control the amount of oak regeneration which will occur following a regeneration harvest. In anticipation of these concerns over clearcutting, Purdue University's Department of Forestry and Natural Resources was contracted by the USFS to evaluate the regeneration of clearcut stands on the Hoosier National Forest (Wayne-Hoosier National Forest, Contract No. 53-52B1-5-01086).

The failure of oak to regenerate successfully after harvesting, especially on more productive sites, is not unique to clearcutting on the Hoosier National Forest (Standiford and Fischer 1980, Heiligmann et. al. 1985, Crow 1988). It appears that regardless of the even-aged management harvesting alternative used, the reproduction of oak follows the trend of little or no reproduction on excellent sites, an occasional occurrence on good sites and moderately plentiful on poorer sites (Trimble and Hart 1961). Mills et. al. (1987) compiled a comprehensive literature review of upland hardwood silviculture with a section especially applicable to the HNF. The reason that current stands on the HNF are

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dominated by oak is not well understood. They concluded that any harvesting activity will reduce the oak component of the future forest with oak regeneration only dominating on poor sites. On better sites they suggest oak will not be a major component of the regeneration and other species will dominate.

Competition among woody stems in young clearcuts is intense with only those trees that can obtain and maintain a dominant crown position surviving to form the overstory of the next forest stand. Once a tree in a young clearcut stand obtains a dominant crown position it has the greatest probability of surviving and maintaining its dominance (Bicknell 1982). Therefore, a seedlings past height growth increment and present crown position are the most significant variables to consider when predicting which seedlings will successfully reach or maintain a dominant crown position (Walters 1963).

This study uses subsets of an empirical data base of 1801, 0.01 acre plots distributed across 74 clearcuts, 5 to 17 years of age on the Hoosier National Forest (Fischer 1987). The purpose of this study was to relate site quality and clearcut age to species composition on the HNF. Specific objectives were to determine the distribution of the dominant-codominant and dominant plot tree species composition in young stands resulting from clearcutting by age and site quality. Dominant-codominant trees were defined as trees with crowns which form the main canopy. Dominant plot trees were the individual tree on each plot with a crown above the main canopy and currently expressing the most height dominance.

STUDY SITES

Clearcuts of mature, upland hardwood stands made prior to 1981 on the Pleasant Run and Lost River Management Units of the USFS Brownstown R.D. and prior to 1982 on the Little Africa and Tell City Units of the USFS Tell City R.D. were identified from HNF office records. Clearcuts made in pine stands and/or tornado damaged stands were not considered representative of mature, upland central hardwood stands and were dropped from further consideration.

Homoya et. al. (1985) has described the natural regions of Indiana. The Pleasant Run Management Unit (Figure 1) is located in the Brown County Hills Section of the Highland Rim Natural Region. The region is unglaciated with well drained acid silt loam soils of the Berks-Gilpin-Weikert association. The natural vegetation is primarily oak-hickory on the uplands with chestnut oak dominating the overstory of the ridge tops and a thick layer of greenbriar in the understory. The ravines of the Brown County Hills Section contain mesic species such as American beech, red oak, sugar maple and white ash.

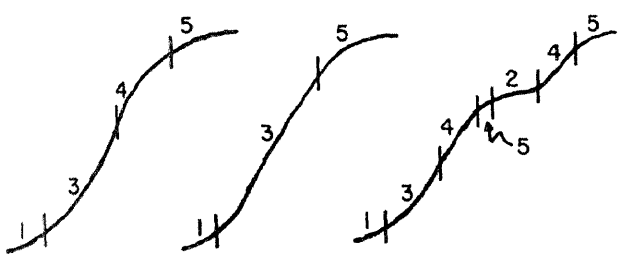
The three remaining units of the HNF, the Lost River, Little Africa and Tell City, Management Units are located in the Crawford Upland and Escarpment Sections of the Shawnee Hills Natural Region. The Crawford Uplands Section's most distinguishing feature is the rugged hills with sandstone cliffs and rockhouses. The major soil association in this section is Wellston-Zanesville-Berks which are well drained acid silt loams. The forest vegetation on the upland slopes are black, chestnut, scarlet and white oaks, and various hickories. The coves contain a mixed mesophytic association represented by species such as American beech, sugar maple, white oak, yellow-poplar and black walnut. Portions of the Lost River and Little Africa Management Units are in the Escarpment Section. The major differences between the Escarpment and Crawford Upland Sections is that the Escarpment section does not contain sandstone cliffs and rockhouses, and post oak along with black oak tends to replace chestnut oak on dry sites. Also, some of the cove species that are found in the Crawford Upland Section are not present in the Escarpment Section.

METHODS

Two hundred twenty-five clearcuts with complete records that included age, acreage, location and sale sawtimber volume by HNF species group were identified as "qualifying" for field sampling. Seventy-four clearcuts representing a distribution of ages and sites were sampled. A systemic distribution of equi-spaced plots (Husch et. al. 1982) was determined to best represent the irregularly shaped clearcuts on the HNF. Sample plot size was 0.01 acre. The distance between plots was determined to be 3.16 chains using a formula from Husch et. al. (1982) where the sampling intensity was 1 percent and plot size was 0.01 acre. The initial point to begin the inventory on each clearcut was determined from topographical maps to ensure all available site characteristics were equally likely to be included in the inventory. Plots overlapping the boundary of the clearcut were not included in the sample. A total of 1801 plots were sampled.

Plot data collection was divided into three sections. Section 1 was the collection of the site variables of aspect and slope position (fig. 1). Aspect was the plot center's azimuth to the nearest 10°. Section 2 consisted of a tree tally for each woody stem greater than or equal to 4.5 feet in height, within the boundary of the plot, by species, crown class and origin. Crown classification was an ocular estimate of crown position. Dominants had crowns above the main canopy, codominants had crowns as part of the main canopy and suppressed trees had crowns under the main canopy. Trees classified as seedlings originated from seed, seedling sprouts originated as sprouts from roots or seedlings, and stump sprouts originated from cut stumps. Section 3 was

a more detailed survey of the dominant plot tree in the tree tally section. The DPT was defined as the individual tree on the plot which was currently expressing the most height dominance. If two or more trees were equal in dominance the tree nearest the plot center was chosen. Dominant plot trees were restricted to species which had the potential to reach the main canopy at rotation age (approximately 80 years) thus miscellaneous noncommercial species were excluded. If a plot was dominated by wild grapevines or contained a large residual tree, no DPT was recorded for that plot. The DPT data included: Species, DBH - to the nearest tenth of an inch, Tree Height - to the nearest two feet, Origin - as defined in the tree tally section, Stump Age (one foot above the ground) and DBH Age. An increment borer was used to obtain a core for stump age within one foot of the ground and 4.5 feet in height for the DBH age. Growth rings were counted in the field and the observed age recorded.



Slope Position Code	Topographic Position
1	Bottom of Slope
2	Bench
3	Mid-Slope
4	Break from ridge top
5	Ridge top

Figure 1. From Bowersox and Ward, 1972; Slope position code numbers for typical topography of the ridge and valley region of Pennsylvania.

ANALYSIS

Univariate and multivariate analyses of variance were used to test for significant differences between the distribution of species across site and age factors. Univariate analysis was used to test for differences between the means of a single variable across site or age variables, whereas multivariate analysis of variance uses a vector of means to test for significant differences across sites and/or ages (Morrison 1976). The model for the univariate analysis tests for the effect of site/age variables separately on each species. The multivariate analysis of variance model was used when all species were designated as dependent variables; site/age variables were used as independent variables. Wilks' lambda was used as the multivariate test. The Wilks' lambda test uses the determinant of two matrices, which had an approximate F statistic distribution, to test for a significant difference between the vector of means of the dependent variables (SAS Institute 1985).

The analyses and subsequent results of this study are from a more extensive investigation of variables which were found to be related to the species composition of young clearcuts on the HNF (Fischer 1987). For consistency with Fischer's study, and since the dominant-codominant regeneration best indicates the species that have become established and will dominate on each plot the suppressed trees were not included in the analyses. Also, Fischer (1987) concluded that the similarities between the Shawnee Hills and the Highland Rim Natural Regions exceeded the differences and would allow for the analysis of the data from the plots on the four management units to be combined.

For statistical analysis of the aspect variable the aspect azimuth for each plot was transformed to a scale using the Beers et. al. (1966) aspect transformation procedure:

$$A' = \text{Cos. } (45 - A) + 1$$

where

A' = transformed aspect value,
Cos. = cosine,
and A = observed azimuth.

This transformation assumes that azimuth 45° (northeast) is the most favorable aspect for tree growth.

To obtain a more balanced distribution of plots by slope position and for comparisons with other central hardwood regeneration studies (Hilt 1985, Heiligmann et. al. 1985), the five slope positions (fig. 1) were reduced to three. Slope positions 1 and 2, bottom and bench slope positions, were combined into a "lower slope position" (251 plots). The "mid-slope position," position 3, was left intact (1101 plots). Slope positions 4 and 5, a break just over a ridge and ridge top slope positions, were combined into an "upper slope position" (449 plots).

The distribution of plots into single year age classes for the clearcut stands inventoried showed an unequal distribution. To obtain a more even distribution of plots with respect to age, plots were divided into four age-class categories: 5-7, 8-11, 12-14, and 15-17 years of age. With the four age groups there are 504 plots in the 5-7 years of age group, 391 plots in the 8-11 age group, 504 plots in the 12-14 age group and 402 plots in the 15-17 years of age group.

Fifteen species/species groups (the term "species" will be used here after to refer to species/species groups) were stratified across aspect codes, slope positions and age groups. The fifteen species are: (1) white oak (white and chinkapin oaks), (2) northern red and black oak, (3) other oak (chestnut, scarlet, pin and post oaks), (4) yellow-poplar, (5) black cherry, (6) black walnut, (7) white ash, (8) hickory (bitternut, mockernut, pignut and shagbark hickories), (9) soft maple (red and silver maples, and boxelder), (10) sugar maple, (11) red and American elms, (12) sassafras, (13) aspen, (14) other commercial hardwoods (basswood, butternut, blackgum, sweetgum, hackberry, locusts and sycamore) and (15) miscellaneous noncommercial (bluebeech, redbud, devil's walking stick, dogwood, hawthorn, ironwood and pawpaw).

RESULTS

Dominant-Codominant Regeneration

For the analysis of the dominant-codominant regeneration importance values were derived by:

$$IV_i = (((D_i/D) + (F_i/F)) / 2)* 100$$

where

$i = 1,12$

IV_i = species importance value,

D_i = density of a species,

D = sum of densities,

F_i = frequency of a species,

and F = sum of frequencies.

The importance value is an "indication of the vegetational importance of a species within the stand" (Curtis and McIntosh 1951). The importance value formula compensates for species which tend to be clumpy and whose presence is then over emphasized when only percentage values are used as a measure of dominance.

The ranking of importance values are: miscellaneous species followed by sassafras and yellow-poplar (table 1). Together these three species have an importance value of 49.9. Surprisingly, the fourth highest ranking species was sugar maple. The combined importance value for the three oak species is 10.2. The other oak (primarily chestnut oak) and black walnut species were the least important of the fifteen species.

Multivariate and univariate analysis of variance using Wilks' lambda and an F statistic (all statistical tests were at the 0.05 level) were used to determine the effect of transformed aspect, slope position and age on the percentage of dominant-codominant trees in a given species. For this analysis the percent of each species on a plot was transformed by the formula:

Table 1.--Density, and frequency of occurrence on 1801, 0.01 acre plots and importance values (I.V.) for dominant-codominant regeneration by species on the Hoosier National Forest clearcuts.

Species	Density	Frequency	I.V.
white oak	599	308	2.9
red and black oak	1361	539	5.6
other oak	536	127	1.7
yellow-poplar	4010	954	12.6
black cherry	1425	678	6.6
black walnut	48	30	0.3
white ash	1514	570	6.1
hickory	374	215	2.0
soft maple	1187	314	3.9
sugar maple	2304	719	8.3
red and Am. elm	1610	498	5.8
sassafras	4591	991	13.8
aspen	6261	171	2.1
other hardwoods	1108	441	4.6
miscellaneous	9115	1348	23.5
Total	30408	7903	100.0

$$TP_i = \text{ARCSIN} \sqrt{\% \ spp_i}$$

where

$i = 1,12$

TP_i = transformed percent by species,

and $\% \ spp_i$ = percent dominant-codominant species on each plot.

The results shown in table 2 reveal that the overall effect of the interaction was significant. Since the three factor interaction of aspect, slope position and clearcut age was significant for all species except black walnut, the effect of the main factors and two-way interactions (not shown in table 2) are not clear. However, slope position appears to be the most important main factor. The two-way interaction of slope position and clearcut age was significant for black walnut indicating that slope position and age interactively effect the distribution of black walnut while aspect did not.

Dominant Plot Tree

For the analysis of the dominant plot trees (DPT) data the species were reduced to 12 instead of the fifteen species used in the dominant-codominant analysis. The adjustments to the species categories were: a) to combine the black walnut and white ash species, b) to combine the hickory species with the other commercial hardwoods, and c) to exclude the miscellaneous species (see methods). Also, time constraints

necessitated a reduction in the sampling intensity of the DPT age on the Tell City Ranger District. On this district the age of the DPT was obtained only on every fifth plot. All other data on the DPT were collected on these plots. This reduction in sampling intensity accounted for 440 of the 1801 plots. These plots were removed from the DPT data base. Also, 39 plots did not have a DPT thus the DPT data base has 1322 plots.

Since the above ground age, at one foot, of each DPT was collected it was possible to determine which trees were advance regeneration. For this study advance regeneration was defined as any DPT that had an age at one foot which was three years or greater than the overall clearcut age. This age was chosen since most HNF cutting contracts ranged over a two or three year period. The observations which were determined to be advance regeneration were sorted into a separate data base. The data base without the advance regeneration (hereafter referred to as "post harvest regeneration") consists of 1071 observations while the advance regeneration data base has 251 observations. Since there was not any attempt to age DPT below stump height (one foot), it is possible that some of the observations that were classified as post harvest regeneration could be advance regeneration. The origin of these misclassified observations could be from trees that had died back or were broken off during the logging operation and then resprouted below one foot after harvest.

Table 2.--Significance of F test by species and Wilk's lambda for the overall effect by aspect, slope position (sl. pos.), age and the three-factor interaction on transformed percentage of dominant-codominant regeneration.

Species	Aspect	Sl. pos.	Age	Aspect x sl. pos. x age
white oak	*[1]	ns	*	*
red and black oak	*	*	ns	*
other oak	*	*	*	*
yellow-poplar	*	ns	*	*
black cherry	ns[2]	*	*	*
black walnut	ns	*	ns	ns
white ash	ns	*	*	*
hickory	*	ns	ns	*
soft maple	ns	*	ns	*
sugar maple	ns	*	ns	*
red and Am. elm	*	*	*	*
sassafras	ns	*	ns	*
aspen	ns	*	ns	*
other hardwoods	ns	*	*	*
miscellaneous	ns	ns	*	*
Overall effect	*	*	*	*

[1]* - significant at the 0.05 level
[2]ns - not significant

The seedling and seedling sprouts origin categories were combined because of the difficulty in distinguishing between the two classifications, especially after a clearcut was ten years of age. Also, since there could only be one DPT per plot, importance values are not possible on a plot basis, therefore, percent values were used.

Post Harvest Regeneration

In table 3 it is evident that yellow-poplar is the dominate species in the post harvest regeneration category. Red and black oak and black cherry are the second and third highest percent species followed by aspen and sassafras. The three oak species together make up 18.8 percent of the DPT post harvest regeneration. The results suggest that the species composition is currently dominated by shade intolerants with the rest of the species relegated to a subordinate role in clearcuts 5 to 17 years of age.

The origin of the species shows that yellow-poplar, black cherry, red and American elm and sassafras trees were primarily from seedling/seedling sprouts. All of the aspen were from seedling/seedling sprouts. The white oak, and red and black oak species are almost equally split between seedling/seedling sprout and stump sprouts. The other oak species had the highest percent of stump sprouts at approximately 67 percent.

Advance Regeneration

The 251 observations which were identified as advance regeneration were analyzed in the same format as the post harvest regeneration data to allow for comparisons between the results of both data bases. For these data black cherry is dominant followed by yellow-poplar (table 4). The percentages of black cherry and yellow-poplar in the advance regeneration (table 4) have almost been reversed from the post harvest regeneration data (table 3). The percent red and black oak is much lower for advance regeneration than post harvest regeneration. The three oak species make up 12.2% of the DPT advance regeneration.

The average percent of seedling/seedling sprouts and stump sprouts are approximately equal from one data base to the other (tables 3 and 4). As in the post harvest data all of the aspen observations are from seedling/seedling sprout origin. However, in contrast to the post harvest data where the majority of the sugar maple observations are from stump sprout origin all of the observations in the advance regeneration data are from seedling/seedling sprout origin.

Table 3.--Percent of dominant plot trees by species group and percent by origin of each species for observations classified as post harvest regeneration. (n = 1071)

Species	Percent	Percent by origin Seedling/ seedling	Stump sprout
white oak	2.7	55.2	44.8
red and black oak	11.6	46.3	53.8
other oak	4.5	33.3	66.7
yellow-poplar	37.7	88.3	11.7
black cherry	10.7	93.9	6.1
walnut and ash	4.7	61.4	38.6
soft maple	3.0	56.3	43.7
sugar maple	1.5	43.8	56.2
red and Am. elm	5.9	85.7	14.3
sassafras	7.0	86.5	13.5
aspen	8.2	100.0	0.0
other hardwoods	3.0	59.4	40.6
Average		77.6	22.4

Table 4.--Percent of dominant plot trees by species group and percent by origin for each species for observations classified as advance regeneration. (n = 251)

Species	Percent	Percent by origin Seedling/ seedling	Stump sprout
white oak	5.6	78.6	21.4
red and black oak	4.4	63.6	36.4
other oak	2.8	57.1	42.9
yellow-poplar	14.8	73.7	26.3
black cherry	31.6	88.6	11.4
walnut and ash	5.2	84.6	15.4
soft maple	5.6	50.0	50.0
sugar maple	6.8	100.0	0.0
red and Am. elm	8.4	95.0	5.0
sassafras	6.4	62.5	37.5
aspen	1.6	100.0	0.0
other hardwoods	6.4	71.6	29.4
Average		80.0	20.0

DISCUSSION AND CONCLUSIONS

The species composition of the dominant-codominant regeneration in clearcuts 5-17 years of age on the Hoosier National Forest is dominated by intolerant species such as sassafras and yellow-poplar as well as many miscellaneous noncommercial species. These results are consistent with other authors' conclusions from similar studies (Standiford and Fischer 1980, Beck and Hooper 1986, Hilt 1985).

Hilt (1985) used multivariate and univariate analysis of variance to test for the effect of site and age on five species groups. He found the overall effect of age, site and the interaction of age and site significant at the 0.05 level. Hilt's univariate results for the effect of age, site and the interaction of age and site for oaks, yellow-poplar, maples, other commercial hardwoods and noncommercial hardwoods were that age was only significant for noncommercial species, while site was significant for the oaks and other commercial species. The interaction of site and age was only significant for the oak species.

A direct comparison between Hilt's results and the results reported here is not possible because Hilt used site index for a measure of site quality, while the site variables used in this study were aspect and slope position. Also, Hilt chose to group species into far fewer classes. In our results the significance of the aspect, slope position and age interaction precludes any attempt to separate the effects of any other the main factors, except for black walnut. The difference results in the two studies may be because Hilt only inventoried stands with at least 60 percent oak sawtimber volume before harvest, while in the HNF study the percent of preharvest oak sawtimber volume averaged only 54 percent (Fischer 1987).

Two conclusions can be made about the species composition of the dominant-codominant regeneration on the HNF. First, since the overall effect was significant (table 2), the species composition of the young clearcuts differs across sites and age. Secondly, no one single factor of aspect, slope position or age can be solely contributed to changes in species composition. These conclusions verify why simplistic, single factor prediction models have not succeeded in aiding foresters to predict regeneration response to clearcutting in the upland central hardwoods.

The dominant plot tree (DPT) represents the tree on each plot that will most likely survive and dominate a plot over time (Bicknell 1982, Fischer 1987). Overall, 81 percent of the DPT observations were classified as post harvest regeneration and only 19 percent as advance regeneration. The order of dominance by species for the post harvest DPT is yellow-poplar followed by red and black oak, and black cherry. In the advance regeneration data black cherry is dominant followed by yellow-poplar and red and American elm. The most obvious difference between the species composition of the post harvest regeneration and advance regeneration data base are the changes in percentages of yellow-poplar

and black cherry. Also, oaks were a higher percentage of the post harvest regeneration than the advance regeneration.

A comparison of the dominant-codominant to the post harvest DPT regeneration reveals that DPT regeneration is more dominated by yellow-poplar and oaks (tables 1 and 3). When comparing dominant-codominant to advance DPT regeneration, the DPT regeneration is more dominated by black cherry (tables 1 and 4). Interestingly, while sassafras has the second highest importance value (13.8) for dominant-codominant regeneration its percentage of dominant plot trees is only 7.0 and 6.4 for post harvest and advance regeneration.

Obviously, these differences in composition between dominant-codominant and DPT are partially the result of not recording miscellaneous species as DPT. However, this difference is also the expression of height domination by species which are emerging above the canopy. As Hilt (1985) suggests in addition to yellow-poplar other species such as black cherry, aspen and white ash indicate the same trend of expressing early height dominance. If the species composition of the DPT regeneration is indeed the better indicator of the future composition as suggested by Bicknell (1982), then several conclusions can be made. First, the next forest will have a large component of yellow-poplar and black cherry. Secondly, although the next forest will apparently have a smaller component of oak than the harvested stands (Fischer 1987), the situation is not hopeless. Based on DPT the oak species will make up approximately seventeen percent of the stems in the next forest instead of the ten percent predicted if percent dominant- codominant stems is used as an indicator.

Finally, several questions on the long-term development trends of these HNF clearcuts remain unanswered. One question that seems to persist is whether, after clearcutting, mesic site species have extended their range on to sites that may not support them in times of stress (Leopold and Parker 1985). Hilt (1985b) noted high mortality of yellow-poplar following drought years in 20+ year-old stands resulting from clearcutting on poor and medium sites in southeast Ohio. Fischer (1987) found that preharvest yellow-poplar saw-timber volumes only averaged seven percent of the total on these HNF clearcuts. Current levels in the dominant-codominant and DPT regeneration are two to five times higher. Also, Fischer (1987) observed that extensive 0.5 to 1 acre patches of aspen and black locust occur on some HNF clear-cuts. Since these species do not generally persist over the entire length of a rotation (80-120 years), it is unclear what species will be present in these patches at rotation age. Obviously long term data from permanent plots would go far in answering many of the questions that remain about the dynamic process of species composition in upland hardwood clearcut stands.

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