FOREST TREE INVASION AND DIVERSITY ON STRIPMINES

W. Clark Ashby, Nelson F. Rogers and Clay A. Kolar[1/]

Abstract.-- Our 1975-77 inventory of tree plantations on stripmines showed a diverse forest cover approximately 30 years after mining. Planted trees outnumbered or nearly equalled volunteer trees in Indiana and southern Illinois deep in mesic forest types. Volunteer trees greatly outnumbered planted trees in northern Illinois, Missouri, Kansas, and Oklahoma, on the edge of the prairie type. The number of invading tree species ranged from 48 in Indiana to 17 in Oklahoma. Invading trees tended to be inversely proportiinal in number to the surviving planted trees on a plot, and were influenced by kind of planted tree.

Black locust, elm, hackberry, ash, black cherry, and box elder were the leading volunteer species in our studies. Red mulberry in Missouri and Kansas, and hackberry in Indiana, invaded much more vigorously under black locust than under other planted trees. Cottonweed and sycamore were the major pioneer invaders on open sites after mining, and had the largest trees. Factors evidently important for tree invasion and forest diversity include spoil physical and chemical features, type of forest cover, and availability of seed or root suckers.

Additional keywords: Interior coal province, central states, midwest, *Robinia pseudoacacia*, *Ulmus americana*, *Celtis occidentalis*.

PLAN OF STUDY

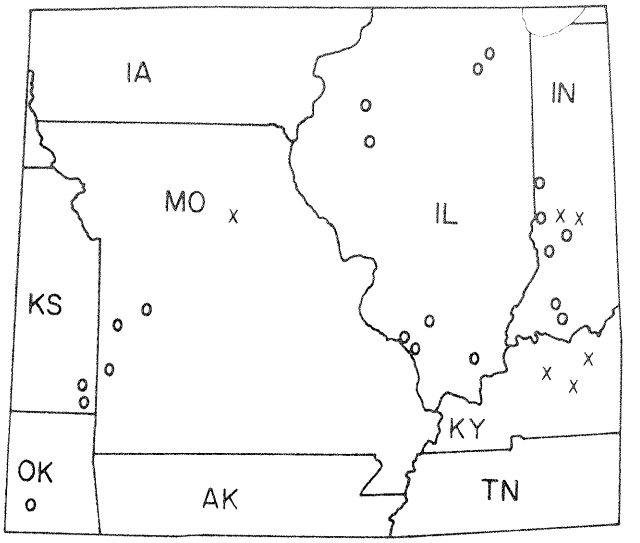
During 1975-77 we inventoried tree numbers and sizes on plots in the Eastern and Western Interior Coal Provinces. Our data base for this paper is the number and kind of planted and volunteer trees on the inventoried plots organized by kind of planted species and by geographic area in which the plots were located (fig. 1). Only limited reference will be made to size of trees because of the mixed and unknown age classes for the several volunteer species.

Our plots had been planted to trees approximately 30 years earlier in an extensive research program of the USDA Forest Service in cooperation with

---

1/ Professor, Department of Botany, Southern Illinois University, Carbondale, Illinois; Silviculturist, Retired, USDA Forest Service, Salem, Missouri; and Researcher, Department of Botany, Southern Illinois University, Carbondale, Illinois. This research was supported by the USDA Forest Service Northeastern Forest Experiment Station, Research Work Unit NE-1605.

Figure 1.--Location of forest tree planting research areas on strip-mines. The Eastern and Western Interior Coal Provinces lie respectively to the east and west of the Mississippi River in the Central States. Counties in which plots were inventoried - O. Some plots were lost by re-mining, land fills, flooding, housing developments, etc. Counties in which all plots were lost - X. Most of these counties had only one set of plots.



several coal companies (Limstrom 1960, Rogers 1951).[2/] Other plantings inventoried were established by Daniel DenUyl at Purdue University in 1949, and by coal companies between 1930-45. A few additional plots included in the inventory were planted as late as 1954.

The planting plan for most USDA Forest Service plots in Indiana and Illinois was a series of 17 to 19 single-species rows, 50 trees per row randomly assigned in a plot, so that no one species formed a canopy. Spacing was 7 X 7 feet (2.1 m by 2.1 m) which gave an initial stocking rate of 889 trees per acre (2268 trees per ha). Other Forest Service plantings were by plots typically 1/4 acre (0.1 ha) usually with one or sometimes two mixed species. The plots were grouped into replicated blocks which earlier had been planted to black locust (Robinia pseudoacacia L.). Company plantings were usually single-species blocks, and the DenUyl plots either single species or a mixture of species in alternating single-species rows.

Plots in Missouri, Kansas and Oklahoma were 70 feet by 70 feet (0.1 acre or 0.04 ha) planted to 100 seedlings or seed of the same age class and species. One study in Kansas with mixed species had plots of variable size depending on the planting mix.

Most plots were established a few years after mining, following initial settling of spoil materials or grading of some plots. Both seedlings and seed were planted using planting bars or mattocks. With a few exceptions no forest management or utilization of the plots subsequently took place. Some plots were grazed or burned or cut to a limited extent for fence posts, and many conifers were cut for Christmas trees. Most hardwood species usually had acceptable to good survival and growth. Initially good growth of pines was followed by high mortality rates, so the kind and amount of tree cover affecting invasion of volunteer species was highly variable.

2/ Ashby, W.C.; C.A. Kolar; and N.F. Rogers. 1980. Results of 30 year old plantations on surface mines in the central states. Trees for Reclamation Conference Proceedings. USDA Forest Service, Lexington, KY. In press.

TREE INVASION

Invasion of volunteer trees, and of a few shrubs included in the inventory, was striking in all areas (table 1). Only in Indiana did the planted trees substantially outnumber the volunteers. Indiana had a much larger number of kinds of invading tree species, and no one species dominated to the extent found in the other areas (fig 2). Southern Illinois was most similar to Indiana.

Table 1.--Number of planted trees and of volunteers in the six geographical areas of the Eastern and the Western Interior Coal Provinces.

	Geographical Area					
Plant Material	IN	so IL	no IL	MO	KS	OK
Planted trees						
Number inventoried	4344	2000	713	1439	1967	259
Approx. survival (%)	26	22	13	24	27	17
No. of species tested	20	18	16	14	14	12
Volunteers						
Number inventoried	2880	1815	2051	3657	3064	576
No. of tree species	48	36	23	20	20	17
No. of shrub species	11	6	11	—	—	—

Black locust, which had been planted in adjacent plots, constituted over half the volunteers in Kansas. Geyer (1971) earlier had found black locust to constitute 47% of volunteer trees, followed by American elm at 18%. Locust was also first in Missouri and northern Illinois, second in Oklahoma and southern Illinois, and fifth in Indiana.

Elm (*Ulmus americana* L., or possibly *U. rubra* Muhl. or *U. alata* Michx.), and hackberry (*Celtis occidentalis* L.) were also found in the ten leading trees of all geographic units (fig. 2). Elm was the predominant species in Indiana and southern Illinois, with hackberry predominant in Oklahoma (elm third). Hackberry was substantially less important in other areas. Only in southern Illinois was ash (*Fraxinus americana* L. or *F. pennsylvanica* Marsh.), the second-ranked volunteer tree in northern Illinois, not among the top ten trees. Black cherry (*Prunus serotina* Ehrh.) was a leading species (third three times) in all geographic areas except Oklahoma where it was not found even though it was planted. Cottonwood (*Populus deltoides* Marsh.), likewise not reported in the Oklahoma plots, was shown

in all other areas except southern Illinois. Box elder (Acer negundo L.) was in the top ten in all areas except Indiana, where it tied with sycamore (Platanus occidentalis L.) for eleventh place. Red mulberry (Morus rubra L.) was shown in all areas except Indiana and southern Illinois.

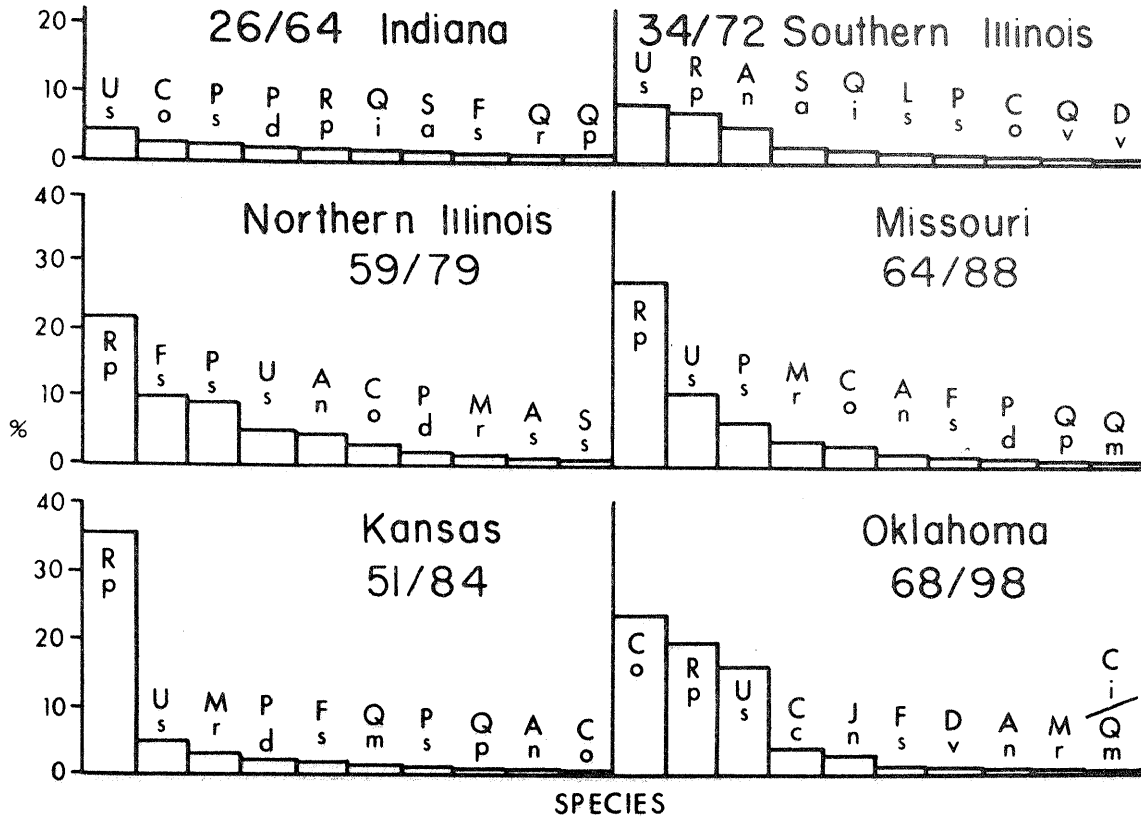


Figure 2.-- The ten leading volunteer tree species in each area. The height of each histogram depicts the percent each species constituted out of all trees inventoried on all plots in that area. For Indiana these total 26% (or 64% of the volunteers only as shown by the fraction 26/64). For Kansas the ten leading volunteer species constituted 51% of all trees inventoried, or 84% on the volunteer trees only as shown by the fraction 51/84. The species designations are:

An	Acer negundo	Pd	Populus deltoides
As	Acer saccharinum	Ps	Prunus serotina
Ci	Carya illinoensis	Qi	Quercus imbricaria
Cc	Cercis canadensis	Qm	Quercus macrocarpa
Co	Celtis occidentalis	Qp	Quercus palustris
Dv	Diospyros virginiana	Qr	Quercus rubra
Fs	Fraxinus spp.	Qv	Quercus velutina
Jn	Juglans nigra	Rp	Robinia pseudoacacia
Ls	Liquidambar styraciflua	Sa	Sassafras albidum
Mr	Morus rubra	Ss	Salix spp.
		Us	Ulmus spp.

Characteristic Volunteer Species

Black locust.--This leading volunteer species likely invaded other planted species both by sprouting and from seed, more so in areas not highly favorable for tree growth. Locust is a nitrogen-fixing and soil building legume with fast early growth and an early demise in the midwest from the locust borer (*Megacyllene robiniae* Forst.), thus making way for invasion of other trees.

Cottonwood and sycamore.--These were the largest trees on the plots and were almost all of one size class. They likely became established soon after mining, and their presence was noted in the plot establishment reports of the USDA Forest Service. Some were removed at that time. Cottonwood was more numerous, more widely dispersed, and larger than sycamore. Neither was observed under the canopy of other planted or volunteer trees.

Site conditions apparently most favorable to cottonwood were the high pH and deep, fresh mineral minesoils found throughout the study area. Near-by bodies of water did not seem to be a factor. Invasion occasionally occurred on acidic sites which, however, also had the fresh mineral minesoils.

Elm, black cherry, ash, and box elder.--All four species commonly invade forest plantings or developing natural stands on a diversity of sites. The size-class range reported indicates these species have invaded throughout most of the 30-year period. Box elder was the only maple to invade in appreciable numbers. Silver, red (*Acer rubrum* L.), and a few sugar (*A. saccharum* Marsh.) maples were found in Illinois and Indiana.

Hackberry and mulberry.-- Invasion typically may be later in forest development than by the previous four species. Though locally important, these two species also were less widely dispersed than the elm, black cherry, ash, or box elder.

Oaks.--Vigorous oak invasion and growth appear to have taken place locally on numerous plots in recent years. The large seeded bur oak (*Quercus macrocarpa* Michx.) in Missouri, Kansas, and Oklahoma likely seeded in from the numerous planted trees, as also seems true for red oak in Indiana.

Pin oak (*Quercus palustris* Muench.), which has a small acorn easily carried by birds, had some of the largest trees on plots in Indiana, Missouri, and Kansas where it was one of the ten leading volunteer trees. Other species with small acorns include shingle oak (*Quercus inbricaria* Michx.), of importance on mine sites in Indiana and southern Illinois. Black oak (*Quercus velutina* Lam.) and an unknown apparent hybrid with southern red (*Quercus falcata* Michx.) or blackjack (*Quercus marilandica* Muench.) oak were also important in southern Illinois. Oaks present in small numbers and not otherwise reported included black, bur, chestnut *Quercus prinus* L.), pin, red, (*Quercus rubra* L.), southern red, and white (*Quercus* alba L.).

Black walnut.--In addition to being one of the top ten in Oklahoma, walnut volunteered in all other areas. Planted trees had substantial nut crops prior to 30 years, thus offsetting problems in transport of this large seed into mined areas.

Sassafras (*Sassafras albidum* (Nutt.) Nees) and persimmon (*Diospyros virginiana* L.).--Although the "classical" old-field successional species in the southern part of the Interior Coal Province, neither species had invaded vigorously on the stripmines. Sassafras in particular tended to be clumped in occasional plots. Most trees of either species were small compared to the species already discussed.

Conifers.--No conifers were among the ten leading species after 30 years in any area. Best representation was Virginia and loblolly pine and red cedar in Indiana and Illinois. Red cedar was the leading volunteer conifer in Missouri. All of these species had been planted on the plots.

Shrubs.--Dogwood (*Cornus racemosa* Lam., some *C. florida* L. and other *Cornus* spp.) was the most important type of shrub or small tree. Its clumped stems were equivalent in number to fifth place in Indiana and fourth in both southern and northern Illinois. Grape (*Vitis* spp.), choke cherry (*Prunus virginiana* L.), buckthorn (*Rhamnus* spp.), and elderberry (*Sambucus* spp.) were relatively important in northern Illinois; sumac (*Rhus* spp.) and grape in Indiana; and grape in southern Illinois.

Species Interactions

Plots where planted species generally failed had more volunteer trees than plots with good survival rates of planted trees. The pines and other plantings which failed prior to 30 years for unknown reasons may have had good cover in earlier years (Ashby, et al. 1966, Geyer 1971). As these planted trees failed the partial cover may have been highly favorable for tree invasion.

Pine stands with residual stocking rates of 200 or more trees per acre had few invaders. Shortleaf (*Pinus echinata* Mill.) and white (*P. strobus* L.) pine had the most volunteers, while red pine (*P. resinosa* Ait.) and red cedar (*Juniperus virginiana* L.) had the fewest. Failures in Indiana-Illinois were chiefly of conifers competing with planted hardwoods so that large open sites were unusual.

Ash, sweetgum (*Liquidambar styraciflua* L.), and tulip tree (*Liriodendron tulipifera* L.) were the least exclusive of the hardwoods. Results were somewhat variable when black locust was one of the mixture. For example, ash, red oak (*Quercus rubra* L.), and most silver maple (*Acer saccharinum* L.) plantings with black locust had relatively few volunteers. Sweetgum or tulip tree as well as other silver maple plots planted with black locust in Indiana had more volunteers than planted survivors.

Most plots in Missouri-Kansas-Oklahoma had more volunteer than planted trees. Tree invasion likely was favored by the 0.1-acre openings

left when a planted species failed. Bur oak (Quercus macrocarpa Michx.) seedlings were more competitive than the volunteer species, and bur oak from seed less so. Red cedar, Virginia pine (Pinus virginiana Mill.) and to a lesser extent loblolly pine (Pinus taeda L.) were the most competitive conifers in the surviving block plantings.

Black walnut mixed plantings had relatively few invaders in Missouri. In most places the planted black walnut developed stately fruit-producing trees, but good stands were few. Those species in Kansas 30 years after planting which had equal numbers of planted and volunteer trees included ash, black walnut, and black locust.

Specific interactions were examined using an 8 by 8 matrix of volunteer and planted species with average number of volunteer trees as the criterion. Mulberry (Morus rubra L.) averaged five or more times as many trees on the planted black locust plots in Missouri and Kansas as on plots of any other planted species. Plots heavily invaded by black locust did not have this association which may develop in time. The locust may provide perches for birds after eating mulberry fruits and/or provide a favorable habitat for mulberry germination and growth.

Hackberry in Indiana-Illinois had a similar large number of individuals under black locust compared to other planted trees. Also in Indiana, black cherry invasion was greater under ash than under other types of cover. In Missouri elm invaded jack (Pinus banksiana Lamb.) or shortleaf pine in greater numbers than did black cherry, ash, or box elder.

SUITABILITY OF STRIPMINES FOR FOREST TREE INVASION

What features of stripmines can explain the vigorous tree invasion reported in our study? One answer relates to site characteristics. Soil types on the 10- to 20- or more feet high spoil banks were commonly silt loams to silty clay loams with an admixture of rocks. Moisture did not seem to be limiting in that elm, hackberry, and box elder, found as leading species in all areas, are more hydric-mesic than mesic-xeric. Presumed xeric species were scarcely evident. Phosphorus and potassium levels were comparable to midwestern forest soils or sometimes higher.

Several comparisons with old-field succession are instructive. Seed sources, litter, microorganisms, shade, and other forest resources are largely absent on large expanses of disturbed ground. On many unplanted mined areas a factor missing initially and still today has been tree cover, whose importance has also been documented in old-field studies (Carmean, et al. 1976).

The plots we inventoried stood out from their surroundings on the landscape and on aerial photographs. Studies on upland old-fields in southern Illinois (Ashby and Weaver 1970) or Missouri (Drew 1942) show that fields distant from a forest edge are invaded slowly. Those field areas near a source of sprouts or seed experience tree invasion comparable in terms of species and numbers to our planted stripmine areas.

As in our studies, vigor of forest development and number of kinds of invading trees after logging, windstorm, or other disturbance of established stands tends to be greatest in Indiana or southern Illinois which lie near where the oak-hickory, the western mesophytic, and the Mississippi embayment divisions of the eastern deciduous forest meet. Northern Illinois, Missouri, Kansas, and Oklahoma lie at the oak-hickory interface of the eastern deciduous forest with the original prairie grasslands. Precipitation is reasonably similar (about 40 in. per year) throughout the areas. Indiana, however, has a much more equable climate than the States further west.

There are no areas in the midwest sufficiently old to predict potential climax forest composition on stripmines. Black locust, elm, hackberry, black cherry, mulberry, and ash were the leading invaders of our study. It seems unlikely they will individually constitute more than a small part of a climax stand.

Assuming the regional oak-hickory climax will prevail, the several presently invading oak species suggest that succession is proceeding rapidly. Tulip tree, basswood (Tilia americana L.) and sugar maple were also represented in Indiana-Illinois as invading species. Seed supply rather than suitable habitat likely was the limiting factor for invasion of these major climax or near-climax species. Possibly planting these species would greatly hasten their importance in the stands. Bur oak can be expected as a climax species in western areas.

Our experience to date shows how planting trees on stripmines not only can realize the potential for forest cover, it can help maximize that potential. Initiating tree cover gives double dividends, for like begets like. The newly planted forests are capable of self-regeneration. Individual species likely function in a continuing, natural process of species replacement (Watt 1947).

A successful planting which needs few volunteers to maintain an adequate stocking rate likely will have few until senescence of the originally-planted trees. Those plantings with higher mortality rates early in the history of a stand typically have high rates of invasion by volunteer trees as the original trees die out. Volunteer trees thus greatly contribute to sustaining desired forest cover. They also may enrich stands by contributing oak, walnut, and other desirable species. The first plantings by man are only the beginning of forest development and enrichment.

LITERATURE CITED

Ashby, W. C. and G. T. Weaver, 1970. Forest regeneration on two old fields in southwestern Illinois. Amer. Midland Naturalist 84:90-104.

Ashby, W. C., M. B. Baker, and J. B. Casteel. 1966. Forest cover changes in strip-mine plantations. Tree Planters' Notes 76:17-20.

Carmean, W. H., F. B. Clark, R. D. Williams, and P. B. Hannah. 1976. Hardwoods planted in old fields favored by prior tree cover. USDA Forest Serv. Res. Pap. NC-134. 16pp.

Drew, W. B. 1942. The revegetation of abandoned cropland in the Cedar Creek area, Boone and Callaway Counties, Missouri. Missouri Agric. Exp. Sta. Res. Bul. 344. 52 pp.

Geyer, W. A. 1971. Reforesting Kansas coal spoils. Kansas Agric. Exp. Sta. Circ. 399. 9 p.

Limstrom, G. A. 1960. Forestation of strip-mined land in the central states. USDA Forest Serv. Agric. Handbook No. 166. 74 pp.

Rogers, N. F. 1951. Strip-mined lands of the Western Interior Coal Province. Missiouri Agric. Exp. Sta. Res. Bul. 475. 55 pp.

Watt, A. S. 1947. Pattern and process in the plant community. Jour. Ecology 35:1-22.