Ecological Forces Affecting Reclamation with Trees

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Abstract. Reforestation is a dynamic process highly conditioned by natural ecological forces and by man's activities. Climatic limitations largely govern areas where given kinds of trees can be grown. Other limitations include type of rooting medium, drainage, and herbaceous competition. The large expanse of some mined areas may differentially limit natural invasion, with cottonwood least affected.

Tree establishment greatly accelerates forest development, both by the growth of those trees and because trees beget trees. Often the more successful planted or naturally invading trees on midwestern stripmines are hardwoods found on river floodplains, old fields, or other disturbed sites. Several nitrogen-fixing trees and shrubs are highly adapted to mine sites. Some species of old-growth forests have been planted and grown well on reclaimed lands. Conifers have generally not grown well outside their native range.

Good sites are primary in forest development. Pre-law practices often resulted in successful tree growth. Future success in reclamation with trees is dependent on suitable regulations for good site preparation and on kinds and amount of plant competition and animal use.

THE RECLAMATION RECORD

The nature and importance of reclamation with trees has varied greatly in past years. Up to World War II trees were the major type of reclamation planting in the Appalachian and Interior (midwest) Coal Provinces. In Illinois, for example, the Department of Conservation and the Coal Strippers Association had an agreement to plant an acre in trees for every acre mined. As time went on manpower availability, increasing costs, and the quicker returns and ease of growing pasture in reclamation led to an abandonment of tree planting by most coal companies in the midwest. The shift away from trees was less marked in Appalachia.

With the passage of Public Law 95-87, Surface Mining Control and Reclamation Act of 1977, coal companies found themselves again in the tree-planting business. The pre-mining vegetation was to be restored, with some exceptions. Sites were to be graded, and surface soil materials replaced. How successful the new planting programs may be over the commercial life span of trees under these new conditions will not be known for several more decades.

Most of the pre-law tree plantings in the midwest are now at least 30 years old and some exceed 50 years. The record shows a substantial degree of success with trees. Differences in tree performance, and in invasion of plantings by other kinds of plants, can be substantially related to ecological forces important on non-mined lands.

Nature of the Record. A major concern in the assessment of reclamation with trees, as in other types of studies, is the extent and validity of the record. For most tree plantings the records are scanty. Numbers of trees of different kinds ordered for a given mine, which usually ties the planting to a county, may be found in company files. Other records may show the location of active mining at that time. Trees usually were planted about two years after mining to get better survival by allowing the cast overburden from the shovel or dragline to settle, perhaps to be graded, and to lessen the hazards of damage to plantings from equipment working close to the pit.

Files tend to be "buried", lost, or discarded, and the human element has often been of greatest importance in locating most planting records. New computerized registers of research plots may change this situation. For practical purposes the only entry to company plantings at present is through the memory of some interested person who had contact with the earlier planting programs. As the "old timers" move to other positions or retire the information may be permanently lost. It is possible to locate stands on a mined area, though acreages are large and access often difficult. Tree ages to estimate planting date can be counted on increment cores. These methods of locating stands tend to be biased toward the better stands.

Fortunately there were also reclamation research plots established in earlier times. The USDA Forest Service had a substantial reclamation research program in the decade after World War II, perhaps related to the political expectation of a civilian conservation corps-type program after the war and the need for research findings which would contribute to the greatest effectiveness of such a program. Faculty members at universities with access to mining areas also established plots, for example Daniel DenUyl at Purdue University in Indiana. Much of the record is found in graduate student theses, as well as in the plots themselves, and in publications of early research results.

<u>Choice of Trees for Planting</u>. In all these plantings someone had to make a judgment on what kinds of trees to plant. There would be constraints

of seed or seedling availability, though with assured orders the state nurseries shift their production schedules to some extent. Some species such as white oak, which has strongly cyclic years of abundant and scanty seed production, were not likely to be included in plantings. They could not be counted on to be available, and did not provide many opportunities for gaining experience in how to handle them.

Other species had or were thought to have handling problems and were little used. Black walnut has sometimes been considered in this category because of the large size of seedlings often encountered, though most nurseries and planters have found ways to handle walnut successfully.

Species selection was strongly influenced by experiences with non-reclamation plantings. A love for pine is deeply ingrained in many foresters from regions where pine is native. Widespread success with black locust in erosion-control plantings led to its frequent use in reclamation where it gave a quick cover on spoils too. Its use for "cover-up" or "window dressing", especially along the public roads, was common in early plantings.

The net effect of these influences was that most planters used trees which had easily obtained seed, were easily grown in the nursery and handled in the field, and which gave satisfactory results during the early years in reclamation plantings. The longer-term results are also now having an impact on the post-law resurgence of planting. A different type of rooting medium for tree growth is now required, however, and the early lessons may not be fully applicable.

Little attention was paid during the period of the earlier plantings to seed source, or provenance, of the planting stock. Even if the nursery from which seedlings were obtained was known, the seed may not have been of local origin. White pine is a good example of the importance of seed source. In southern Illinois, where white pine is not native, trees originating from Tennessee or Georgia have grown much better than those from northern areas. Provenance studies with black walnut have shown major differences in tree growth related to moving trees to the north or south of their origin.

In summary, the record provides much information for judging ecological forces affecting reclamation with trees. A bias is evident toward trees expected to do well in reclamation and which are easily handled. The broad outlines of success with trees can be seen.

IMPACTS OF ENVIRONMENT ON REFORESTATION

Vegetation is a product of controlling environmental factors. As formalized by Jenny (1), l, v, a, and s are ecosystem properties, and cl, p, r, o, and t are state factors. For any total system property l, any vegetation property v, any animal property a, and any soil property s, $[l,v,a,s] = f[cl,p,r,o,t,\ldots]$ in which cl = climate, p = parent material, r = relief or topography, o = organisms available to be part of the forest, and t = time or age. It is important to note that both vegetation and soil are dependent variables. The well-known correspondence of grassland soils with grasslands, etc. is not a simple cause-and-effect relationship, but rather the effects of the several independent factors on both the vegetation and the soil systems.

Climate, and more specifically precipitation, is considered to be the controlling factor of greatest importance for forest development, and is under the least control by man. Parent material is of special interest in reclamation because of the large, though ultimately limited, amount of control over its composition in mining. This includes not only what materials are put back as a rooting medium but also how they are put back. For example trees grow very differently on compacted compared to non-compacted soils and spoils.

Land form is also under substantial control by the operator. Overall relief is at most rather minor for trees as found in spoil banks of earlier days, or on landscapes graded to original contour today. The grading probably has much more effect on growth through compaction of the rooting medium than through effects on land form. Flooding and siltation have caused loss of trees in deep troughs between spoil banks. No effects of aspect were found in a 30-year inventory of forest plantings on ungraded spoil in Indiana and Illinois (2). South slopes were more favorable for bur oak planted in Ohio (3). On a broader scale, high elevation reclamation plantings in West Virginia may be more similar to those of Pennsylvania than Virginia.

Species selection for planting and natural invasion have a tremendous impact upon the kind of forest which develops. These factors interact with time as some kinds of trees grow much more rapidly than others to form a forest.

The role of tree invasion on mined lands may differ substantially from that on lands otherwise disturbed because of the size of the areas involved. Natural disturbances--fire, tornadoes, logging, old fields--in the eastern United States commonly affect relatively small areas, and leave substantial amounts of pre-existing biota. A large mining operation may affect 100 ha per year, and 1000 ha over a period of years. Seed sources for natural invasion and habitats for animals which transport seed may be very limited and strongly bias the kinds of volunteer trees.

Climate. The coal areas of the United States include both humid and dry climates. I shall discuss use of trees in the eastern humid regions, which include the Appalachian and the Interior Coal Provinces. Relatively limited recent lignite mining to the south will not be considered.

The Appalachian Coal Province extends from Pennsylvania to Alabama. Its climatic features can be inferred from its major forest types which range from northern hardwoods (maple-beech-birch) to oak-hickory to oak-pine to southern pines (loblolly-shortleaf) (4). Reclamation has been influenced both by selection of trees available locally for planting, and by relatively greater success of those kinds of trees. Although southern hardwoods such as sweet (red) gum grow well on minesoils in Alabama, southern pines are much preferred for use by the local wood-using industry.

Climates of the Interior (midwestern) Coal Province from Indiana to Kansas are chiefly represented by the oak-hickory forest type, with elm-ash-cottonwood along major rivers. Part of the Indiana coal field lies in the maple-beech-birch forest type, and shares features such as successful use of white pine with the northern Appalachian region.

The correspondence of climatic and forest types, which is modified by topographic and soil features, suggests the use of trees from a local forest type in reclamation. In general this has been a good practice. Several introduced hardwoods, especially nitrogen-fixing trees and shrubs and hybrid poplars in northern Appalachia, have also been of value. Trial-and-error is still needed to match species to site conditions when working with new types of site.

Rooting Medium and Drainage. Until recently the rooting medium after mining was a mixture of all overburden layers, both unconsolidated and fractured sedimentary rock. In many respects this material resembled glacial moraine deposits, and like them supported good tree growth. The high degree of variability in overburden from one mine to another is reflected in the variability of rooting-medium composition.

Ungraded cast overburden (spoil) is relatively loose with a large pore volume available for rooting. Soil pans and rock layers which limit rooting on natural soils are eliminated. The large volume contributes to favorable anchorage, nutrient, and water relations. Nutrient supply is also increased by weathering of rock fragments in surface layers. Water supply is enhanced by the substantial water-holding supply of coarse fragments, by free water at low tension between rocks, and by high infiltration and percolation rates on the loose spoil (5).

Tree rooting patterns are not affected adversely by the coarse fragments typical of cast overburden (5). Roots readily go around larger particles and penetrate weathered shales and sandstones. On graded sites with compacted soil fines these weathered rocks are pathways for roots and water.

A few types of pre-law sites had physical limitations for tree growth, for example loess banks, sand, or the almost pure rock found chiefly on anthracite mines. Instability was the major problem. On easily erodable soils trees may be damaged by uncovering the seedling roots (6). Slides are common on rocky areas, leading to breakage of root systems. Moisture seems adequate for trees after they are established (7). High temperatures which may kill tree seedlings are found on barren, dark-colored rocky sites. These types of site would not be found under current regulations. Grading may be beneficial on such sites.

Grading on other sites severely limited growth as trees matured. A walnut planting in Indiana on a graded site grew as well as on adjacent ungraded banks for 18 years. By 42 years trees on the graded site were much smaller, stagheaded, and dying. Growth limitations from grading have been shown by several authors (5).

Chemical limitations were also found on pre-law sites, apparently more so in Appalachia than in the Interior Coal Province judging by the number of publications on the problem. Many barren areas are associated with low pH. Lack of plant cover on extremely acid soils should most often probably be attributed to high levels of soluble aluminum and other toxic elements. The chemical environments on these spoils are complex, variable, and not well understood. Usually extreme acidity is associated with the presence of iron sulfides (pyrite and marcasite) in coal and shale fragments (8).

Another condition associated with the development of extreme acidity is initially low pH favorable for activity of *Thiobacillus ferroxidans* bacteria. Adequate mixture of lime in the overburden, liming of the spoils before acidity worsens, inhibition of the bacteria by materials such as sodium lauryl sulfate, or covering of the sulfides are means to reduce acidity problems. Once the acidification has progressed deeply into spoil, or gob, massive amounts of lime or sludge or other neutralizing materials are required. Mixing these materials into the rooting medium is required, and because that is rarely feasible to an adequate depth the potential for plant growth is limited.

Lack of drainage limits tree growth to a variable extent on mined lands. Willows, sycamores, and cottonwoods grow around the margins of stripmine lakes, ponds, and drainages. Often these wet areas are associated with a remaining highwall in pre-law mining. Tree plantings commonly fail in low areas between strip banks which may flood seasonally. The problem of flooding continues today on land graded to original contour in the midwest which has post-grading settling and formation of temporary ponds on the graded sites.

AVAILABLE ORGANISMS

Successful reclamation calls for suitably adapted plants. The theoretical number of permutations and combinations of environmental factors affecting tree survival and growth is very great. In practice most trees used in reclamation have a broad range of tolerance to commonly encountered reclamation conditions. Shrubs may have even higher survival and growth rates. They are used relatively little in reclamation in the eastern United States.

The choice of trees for planting has varied somewhat related to geographic area, as has the relative performance of species planted in the several areas. The tree plantings serve as a biological assay of stripmine conditions. Seven of 28 total kinds of trees planted in a large-scale USDA Forest Service study were used in all five states (IN, IL, MO, KS, OK) of the Interior Coal Province (2).

Three hardwoods planted in all states represented in the Forest Service studies were black locust, ash (nominally green though likely also white), and black walnut. The black locust documents interest in nitrogen-fixing companion trees. Locust performed least well in Indiana after 30 years, perhaps related to hardwood competition both planted and volunteer. The insect locust borer severely damages most stands after about ten years.

Ash was characterized by high survival, and relatively poor growth in all areas. Black walnut performed relatively better in the eastern than the western section of the Interior Coal Province, as is true also for unmined lands. Because of its high economic value, the occasional mined sites on which walnut has made exceptional growth deserve particular attention. Quality trees are much more important than stands with poor form and low growth rates. This potential of mined sites needs to be developed and exploited.

Four non-native pines (jack, shortleaf, loblolly, and Virginia) were planted in all five states of the midwestern coal-producing region. Pine may have been selected based on perceptions of mined areas as droughty, acidic, or otherwise liable to stress.

None of these pines survived and grew well in Indiana, some in Illinois, and more in Missouri, Kansas, and Oklahoma. The better performance after 30 years in the western section can be associated with less competition from hardwoods in the planting plan used in those states. Of the other five kinds of pine, eastern white grew better in Indiana and Ohio (3) than Illinois. Ponderosa pine grew better in Kansas than Missouri. Few pines are planted for reclamation today in the midwest.

In contrast to the prevailing oak-hickory forest type, few plantings of oak and essentially none of hickory have been made in the midwest. Tremendous numbers of species characteristic of bottomlands and other disturbed sites such as ash, soft maple, cottonwood, and sycamore were planted. These species typically seed abundantly, are relatively easy to grow in nurseries, and often have good survival and/or growth rates.

Ecological features of mined lands can also be characterized by noting what kinds of trees volunteer into forest plantings on stripmines.

These volunteers are predominantly mesic or mesic-hydric species including American elm, boxelder, ash, black cherry and hackberry. Cottonwood and sycamore start growing on fresh spoils before competing plant cover is established. The success of these species documents favorable water relations on many minesoils.

Nutrient relations on mined lands have been evaluated by soil analyses and tree growth. Although levels of exchangeable phosphorus and potassium from soil tests are often low, they do not seem to limit tree growth. Levels of reserve nutrients are rarely determined.

A major response has been found to planting nitrogen-fixing trees. Site-sensitive species such as tulip tree or black walnut grow much better when underplanted under decadent black locust than otherwise. These locust stands also have substantially greater invasion of black cherry, hackberry, and other species than sites without locust (9,10).

FUTURE PROSPECTS FOR FORESTS IN RECLAMATION

The past may well not be prologue to the future in reclamation with trees on mined lands. Today land is graded to original contour and capped with pre-existing surface soil materials. These techniques tend to limit tree growth, probably in part by compaction from traffic by earth-moving machinery. In several studies mixed cast overburden has also been found superior to replaced surface materials in porosity, pH, and nutrient reserves (5).

Because any trees planted on these new types of rooting medium under present regulations are so young, definitive conclusions are not possible. Among the species which had highest 3-year survival in an extensive series of plots by my research group have been black locust, several oak species, black walnut, and ash.

Growth assessments of these plantings are reported only for those species with an adequate number of surviving seedlings. Black locust, sycamore, bald cypress, river birch, and silver maple have made the greatest basal diameter growth on graded spoils. The latter four species are found naturally on lowland soils. The tallest species on the graded sites were sycamore, river birch, and white ash, again species of lowland areas. Trees on ungraded plots had appreciably larger diameters and height.

Tree growth in these studies was also affected by herbaceous ground cover, which became increasingly dense by the second year after planting. All tree plantings were individually treated with herbicides to control herbaceous competition starting with the third year of the study. Differential effects of the herbaceous cover on the several tree species can be noted.

Animal influences may be marked on stripmines. Many areas are sufficiently removed from wooded habitats that squirrels are absent. Direct seeding of walnuts, hickories, and large-seeded oaks becomes practical. Small rodents, however, thrive in the herbaceous cover now required and plantings of small seed will likely fail. Success with small-seeded species has been very limited, perhaps for still other reasons.

During drought periods when the herbaceous cover has dried up voles or similar organisms have girdled virtually all the red oak seedlings in a planting, though black walnut has been little affected. As trees get larger, the biggest (best) trees have been severely damaged by male deer rubbing velvet off their antlers. Deer come into the open, pasture-like areas from appreciable distances at night, and tree plantations are particularly vulnerable.

Future prospects for trees in reclamation over their long life spans depend on many factors which can not at present be fully evaluated. A new generation of researchers will render further judgment on possible needs of trees for changes in our reclamation practices.

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