J. Ecol. Field Biol. 30 (1): 75~80, 2007

An Evaluation of the Effects of Rehabilitation Practiced in the Coal Mining Spoils in Korea 1. An Evaluation Based on Vegetation

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ABSTRACT: This study evaluated the effects of rehabilitation of existing coal mining spoils on species composition and species diversity. The species composition of most rehabilitated stands differed from that of the reference stands, and thus did not suggest successful rehabilitation. However, stands subjected to restorative treatment many years ago showed higher species diversity than the reference stands and thereby met the goals of rehabilitation. Our results demonstrate that restorative treatments practiced in the past created a heterogeneous ecological space with regard to the surrounding areas. Therefore, even though species diversity increased several years after rehabilitation, this does not indicate that the treatment achieved true rehabilitation success. The treatment did result in temporary stability through increased species diversity, but it could not be described as successful rehabilitation in terms of biological integrity with the surrounding ecosystems.

Key words: Coal mining spoils, Reference stands, Rehabilitation, Species composition, Species diversity

INTRODUCTION

Coal mining activities in Korea have been conducted by deep mining, as coal deposits are deep underground. Therefore, coal mining activities usually lead to the production of large quantities of waste material, or spoils. Such coal mining debris has been piled up on mountains or discarded in the mountain valleys. Therefore, acid mine drainage, barren unvegetated areas and steep unstable piles of mining waste are frequently left behind after mining. Even when the damaged areas are re-vegetated, exotic or non-local species were usually employed for rehabilitation of those areas. Consequently, most rehabilitated mine areas form an ecological space dissimilar with the surrounding habitat.

This problem has occurred because the ecology of the mined area is not well-understood by rehabilitation practitioners. In fact, untreated deep mining debris does not by itself function as soil because it does not include sufficient organic matter. Therefore, ecosystem development in these areas must progress in the same manner as primary succession: the process of ecosystem development on barren surfaces where severe disturbances have removed most vestiges of biological activity. Succession progresses as a result of interactions among plants growing in a given area. The facilitation of growth of new plant species by early colonizers promotes species compositional change to the next successional stage (Connell and Slatyer 1977, Van Andel et al. 1993).

Succession is a directional, cumulative change in the species that occupy a given area through time. Most plants modify their immediate environment in some way that can impact establishment and growth of both other species and other individuals of the same species. Differential species responses to these environmental changes can drive succession (Wright and Muller-Dombois 1988).

Rehabilitation is closely linked to succession theory. Under natural conditions, successional processes or normal ecosystem development will provide an appropriate trajectory for recovery of damaged areas (Dobson et al. 1997; Zedler and Callaway 1999). But natural recovery such as succession occurs very slowly. So, human intervention to accelerate this process, through rehabilitation efforts that facilitate the successional process, is often necessary.

This study aims to evaluate the effects of rehabilitation on existing coal mining spoils based on restoration ecological principles. A properly planned restoration project attempts to fulfill clearly stated goals that reflect important attributes of the reference ecosystem. Goals are attained by pursuing specific objectives. Objectives are evaluated on the basis of performance standards, also known as design criteria or success criteria. These standards or criteria are conceived in large part from an understanding of the reference ecosystem. In this study, we selected nearby forested areas beyond the coal mining spoils as reference sites for comparative purposes. Three strategies exist for conducting an evaluation: direct compari-

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son, attribute analysis and trajectory analysis. In direct comparison, selected parameters are determined or measured in the reference and restoration sites. The parameters considered include aspects of both the biota and the abiotic environment. In attribute analysis, attributes such as species composition, percentage of indigenous species, stability of the system, the physical environment, the presence of normal developmental processes, harmony with the larger ecological matrix, potential threats to the habitat, resilience, and capacity for self-sustenance are used to judge the degree to which each goal has been achieved. Trajectory analysis is an evaluation of trends in restoration area to determine whether the restoration is following its intended trajectory towards the reference condition (SERI 2004). Evaluation in this study was focused on direct comparison of species composition and species diversity.

MATERIALS AND METHODS

Study Area

Field surveys were carried out in three areas of Dogye-eup (the first area) and Gohan-eup (the second area) in Gangwon province, and Mungyung city (the third area) in Gyungbuk province. The first area, which ranged vertically from 200 m to 400 m above sea level, was chosen to obtain information about restoration of coal mining spoils in lowland. We found two reclaimed sites in the first study area. The first site was reclaimed about 30 years ago by introduction of black locust (*Robinia pseudoacacia*) and the second site was recently reclaimed by the introduction of birch (*Betula schmidtii*). Exposed outcrops are common and soil development is poor in most areas of the forest around the first area. Local environmental conditions led to the establishment of Korean red pine (*Pinus densiflora*) forest. This naturally occurring Korean red pine stand contributed to the natural restoration of nearby coal mine spoils. Oak (*Quercus variabilis*) forest, which is common in dry and sterile sites, has also become established in surrounding area.

The second area, which ranged vertically from 800 m to 1,000 m above sea level, was chosen to obtain information about restoration of coal mining spoils in upland areas. Two reclaimed sites were found in the second area. The first site was reclaimed about 30 years ago by the introduction of larch (*Larix leptolepis*), and the other site was reclaimed about 10 years ago by introducing alder (*Alnus hirsuta*). Surrounding forests chosen as reference sites are primarily covered with Mongolian oak (*Quercus mongolica*) forest, but birch forest dominated by *Betula costata* also appears in some nearby ravines.

The third area has an ecological condition similar to that of the first area. We found several types of reclaimed sites in the third area. Two sites were reclaimed about 30 years ago by the introduction of black locust and pitch pine (*P. rigida*), respectively. Another site was reclaimed about 20 years ago by the introduction of black locust. The other two sites were incompletely reclaimed: one was reclaimed by introducing bush clover and the other just by introducing grasses. Surrounding forests chosen as reference sites are primarily covered with Korean red pine forest but a partial oak (*Q. variabilis*) forest also appears on the southern slope.

The rehabilitation history was determined by counting tree rings collected using an increment borer and by interviews with the project makers.

Methods

Field vegetation surveys were conducted from June to September 2004. 97, 56, and 92 randomly chosen plots were investigated in the first, second, and third areas, respectively. The plot sizes for each site were selected based on vegetation stature: 2 m × 2 m, 5 m × 5 m, and 20 m × 20 m in herb, shrub, and forest levels, respectively. All plant species occurring in each plot were identified, following Lee (1985), Park (1995), and KPNI (Korean Plant Names Index, 2006).

Dominance of each species in each plot was estimated on an ordinal scale (1 for <5% to 5 for >75%), and each unit in the ordinal scale was then converted to the median value for percentage cover in each cover class (Braun-Blanquet 1964). The importance value of each species was then determined by multiplying 100 by the cover for that species divided by the total cover of all species in each plot (i.e. the percentage of total cover consisting of that species). A matrix of importance values for all species in all plots were constructed and used for Detrended Correspondence Analysis (DCA) for ordination (Hill 1979). As a measure of species diversity and dominance, a rank abundance curve (Magurran 2004; Kent and Cocker 1992; Lee et al. 2002) was constructed and the Shannon Wiener's Diversity Index (H') was calculated for each stand type.

The effects of rehabilitation were evaluated by comparing the similarity of species and the species diversity between rehabilitated sites and the reference site.

RESULTS

Species Composition

To compare the effects of rehabilitation among stands that differed in introduced plant species and reclamation methods, vegetation data obtained from both the reclaimed and the natural sites were treated by applying the ordination method (Figs. 1~3). In the first area, the sites were composed of stands rehabilitated by introduction of black locust (abbreviated as BL hereafter) and stands rehabilitated with white birch (abbreviated as BR hereafter), respectively and a naturally restored site (abbreviated as NR hereafter). Reference sites consisted of Korean red pine (abbreviated as PI hereafter) and oak (abbreviated as QV hereafter) forests, respectively. As the result of ordination, stands were arranged in the order of BL, NR-BR-PI, and QV on AXIS I (Fig. 1).

In the second area, the rehabilitated sites were composed of stands rehabilitated by introduction of *Alnus hirsuta* (abbreviated as AH hereafter) and *Pinus densiflora* (abbreviated as PIR hereafter), respectively, and BR. Reference sites consisted of *Quercus mongolica* (abbreviated as QM hereafter) and *Larix leptolepis* - QM (abbreviated as LO hereafter) forests. As the result of ordination, stands were arranged in the order of QM, LO, PIR, BR and AH on AXIS I (Fig. 2). On AXIS II, stands of PIR and the other stands tended to be divided into the upper and the lower parts, respectively.

In the third study area, stands were composed of BL, stands rehabilitated by introduction of *P. rigida* (abbreviated in PR), *Lespedeza cyrtobotrya* (abbreviated in LC), and herbaceous plants (abbreviated in GR). Reference stands for the third area were PI and QV. As the result of ordination, stands were arranged in the order of PI - QV, PR, BL, LC and GR on the AXIS I (Fig. 3). On AXIS II, PI and QV occupied the lowermost and the uppermost parts, respectively, and the others were concentrated on a place between the two extremes.

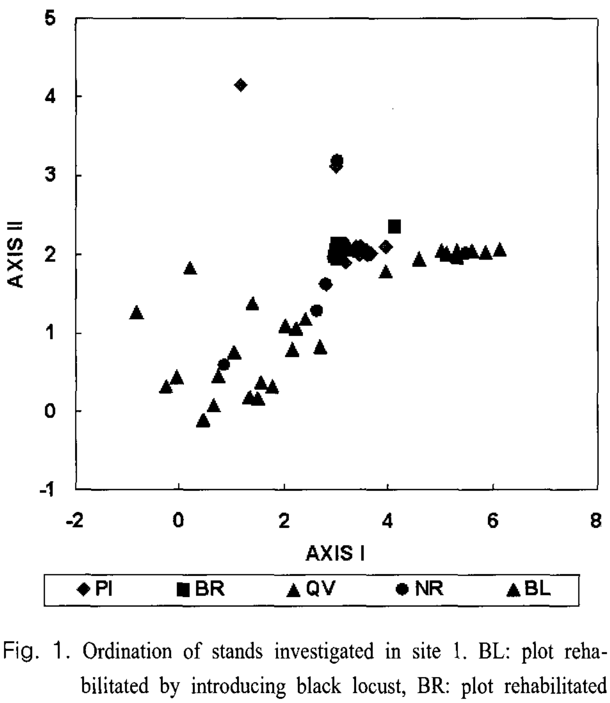

Fig. 1. Ordination of stands investigated in site 1. BL: plot rehabilitated by introducing black locust, BR: plot rehabilitated by introducing birch, PI: reference stand dominated by *Pinus densiflora*, QV: reference stand dominated by *Quercus variabilis*, NR: plot restored naturally

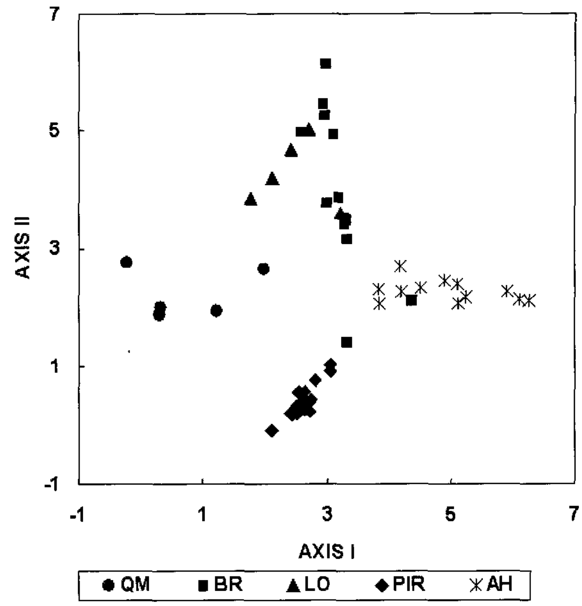

Fig. 2. Ordination of stands investigated in site 2. QM: reference stand dominated by *Quercus mongolica*, LO: plot rehabilitated by introducing *Larix leptolepis* and many oaks were established of the forest floor, AH: plot rehabilitated by introducing *Alnus hirsuta*, BR: plot rehabilitated by introducing birch, PIR: plot rehabilitated by introducing by *Pinus densiflora*

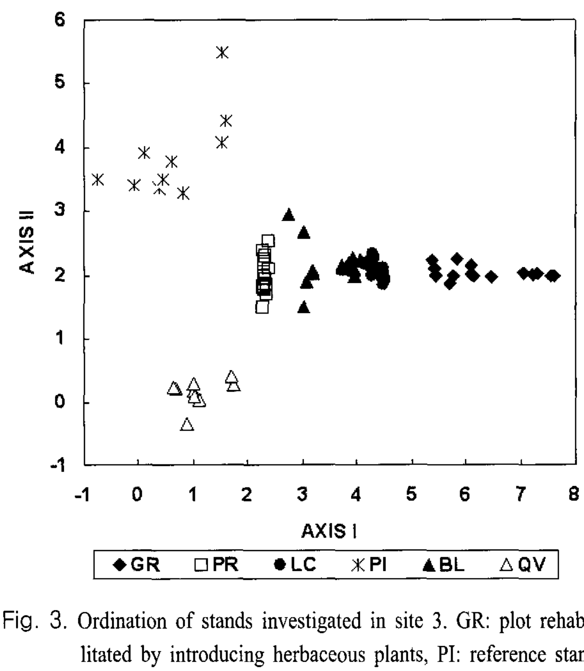

Fig. 3. Ordination of stands investigated in site 3. GR: plot rehabilitated by introducing herbaceous plants, PI: reference stand dominated by *Pinus densiflora*, PR: plot rehabilitated by introducing by *Pinus rigida*, BL: plot rehabilitated by introducing black locust, QV: reference stand dominated by *Quercus variabilis.*

Species Diversity

In the first area, the species rank - dominance curves indicated that the number of species increased in the order of BL, PI, QV, NR, and BR. Slopes of the curves became flatter in the same order (Fig. 4).

In the second study area, the number of species increased in the order of QM, AH, PIR, and BR. The order of species diversities, which was evaluated from the slope of the species rank - dominance curves, was similar (Fig. 5).

In the third area, species richness and diversity estimated from species rank - dominance curves were in the order of PI, BL, QV, and PR-GR (Fig. 6).

DISCUSSION

Effects of Rehabilitation on Species Composition

In the first area, species compositions of the NR and BR were similar to that of the PI reference stand, a result that suggests that those stands display satisfactory effects of rehabilitation. However, the species composition of the rehabilitated stands was dramatically different from that of the QV reference stand (Fig. 1). This difference in species composition is related to the seed dispersal capacities of dominant species in both stands. For example, seeds of the Korean red pine can be dispersed far from the parent tree due to their wings

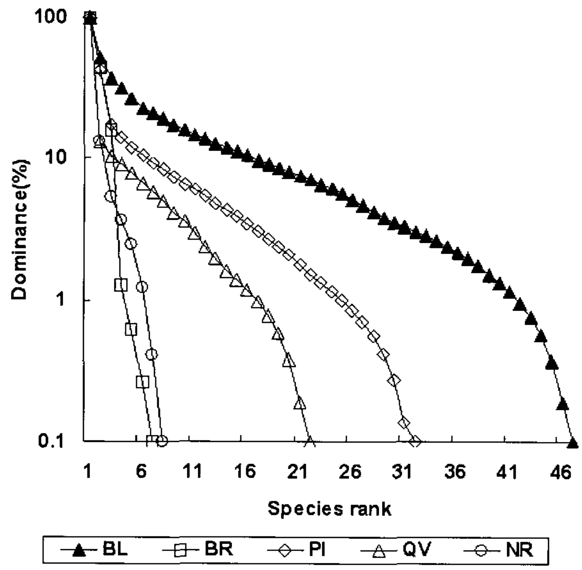

Fig. 4. A comparison of species rank-dominance curves among the plots rehabilitated by different methods in site 1. BL: plot rehabilitated by introducing black locust, BR: plot rehabilitated by introducing birch, PI: reference stand dominated by *Pinus densiflora*, QV: reference stand dominated by *Quercus variabilis*, NR: plot restored naturally

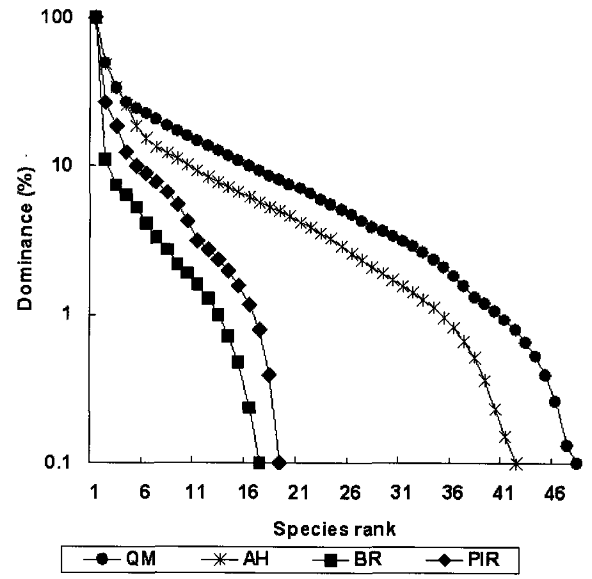

Fig. 5. A comparison of species rank-dominance curves among the plots rehabilitated by different methods in site 2. QM: reference stand dominated by *Quercus mongolica*, AH: plot rehabilitated by introducing *Alnus hirsuta*, BR: plot rehabilitated by introducing birch, PIR: plot rehabilitated by introducing by *Pinus densiflora*

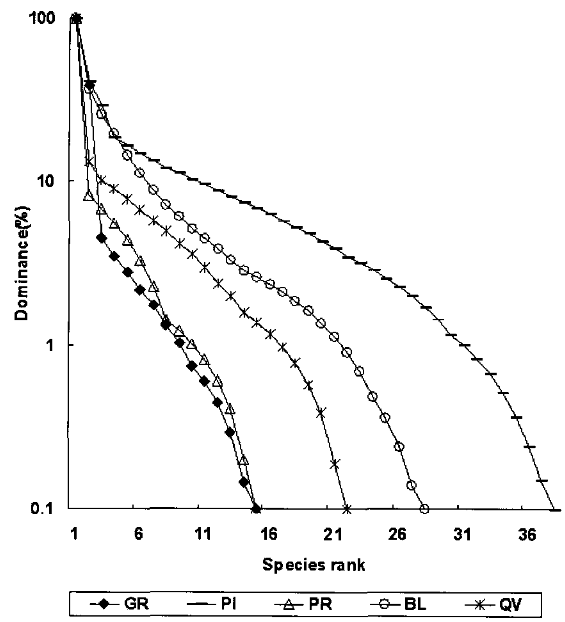

Fig. 6. A comparison of species rank-dominance curves among the plots rehabilitated by different methods in site 3. GR: plot rehabilitated by introducing herbaceous plants, PI: reference stand dominated by *Pinus densiflora*, PR: plot rehabilitated by introducing by *Pinus rigida,* BL: plot rehabilitated by introducing black locust, QV: reference stand dominated by *Quercus variabilis*

(Lee et al. 2004) and thus they can easily invade nearby rehabilitated stands. But in the case of oak (*Q. variabilis*), seed dispersal depends on the action of animals and seed production is not only lower compared with the Korean red pine but also peaks only during mast years.

Meanwhile, the species composition of the black locust rehabilitated stands differed from those of both reference stands. That is, species composition of those stands revealed heterogeneity with that of surrounding natural vegetation.

In the second area, BL showed a relatively similar species composition to that of the reference stands, whereas those of PIR and AH differed from those of reference stands. The differences are probably related to the following facts: 1) this area is located in an upland area about 1,000m above sea level, which corresponds to the boundary of the altitudinal distribution range for Korean red pine stands (Lee 1989). 2) The rehabilitated stands were recently planted, and thus are still in an early successional stage. 3) Strong winds at the site inhibits vegetation establishment.

In addition, dense cover of *Dactylis glomerata* and *Festuca arundinacea*, exotic species, which were introduced artificially for rehabilitation purposes, inhibited invasion of other plant species in AL stands, leading to a different species composition from that of the reference stands.

In the third area, BL, PR, LC, and GR showed different species compositions from that of the reference stands. Those differences are due to the fact that those sites did not experience significant ecological development and change after the initial rehabilitation. For example, in case of PR, although about 30 years had passed after restorative treatment, soil development had hardly progressed, probably because the planting bed is too steep and the decomposition of pitch pine needles is slow. In BL and LC, excessively high densities of the introduced plants inhibited establishment of the other plant species. On the other hand, the GR had received restorative treatment only two years prior to the study and therefore, insufficient time may have passed for accurate evaluation of the effects of restoration.

Effects of the Restorative Treatment on Species Diversity

In the first area, stands for which a long period of time had passed since restorative treatment showed higher species diversity than that of the reference stands, whereas the reverse was true for the site with a relatively short rehabilitation history. In the second area, which has a short rehabilitation history, all the rehabilitated stands showed lower diversity than that of the reference stands. Patterns of species diversity in the third area were similar to that of the first area except for PR. Although PR in this area had a rehabilitation history of about 30 years, the species diversity of this stand was lower than that of the reference stands. As these results suggest, the rehabilitated stands required many years to stabilize after restorative treatment in terms of species diversity.

Synthetic Assessment of Past Rehabilitation Projects

The species compositions of most rehabilitated stands were different from the reference stands. From a viewpoint of species composition, therefore, they did not display an adequate rehabilitation effect.

However, stands that underwent restorative treatment a few decades ago showed higher species diversity than the reference stands. Increased diversity implies that the rehabilitated stands were stabilizing ecologically, if we assume that species diversity means ecological stability (Barbour et al. 1999). In this respect, the rehabilitated stands achieved the rehabilitation goal.

The different results for the species composition, as opposed to the species diversity, is due to the past introduction of exotic species such as *R. pseudoacacia*, *P. rigida*, *D. glomerata,* and *F. arundinacea* to the rehabilitation areas without any consideration of their ecological effects. The use of aliens should be avoided in reclamation of disturbed lands such as this coal mine spoil because it often leads to inhibition of colonizing natives (Densmore 1992). This result emphasizes the importance of careful species selection for future restoration projects.

As the results show, the past restorative treatments created ecological spaces heterogeneous with the surrounding habitat. Therefore, even though species diversity increased in the years following rehabilitation treatments, we cannot conclude that the treatments achieved rehabilitation success. Even though the treatments resulted in increased species diversity, they did not necessarily result in successful rehabilitation in terms of restoration of the biological integrity of the affected area (Karr 1998, Lee et al. 2005, 2006).

ACKNOWLEDGEMENTS

This study was supported by the Korean Ministry of Environment as "The Eco-technopia 21 project titled: "Ecological restoration of the abandoned coal mining spoils and development of technology to ameliorate waste water pollution discharged from the abandoned coal mining spoils".

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(Received February 5, 2007; Accepted February 16, 2007)