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Short Communication

Impacts of Coal Mining on the Aboveground Vegetation and Soil Quality: A Case Study of Qinxin Coal Mine in Shanxi Province, China

The exploitation and utilization of coal resources have been lasting for thousands of years, resulting in a series of ecological environmental problems in China. So far, the mining area has changed into severe and typical damaged ecosystem locally and globally. The coal exploitation history is long in Shanxi province, but goafs are distributed widely. In this study, we addressed this point and took a coal mine, located in Shanxi province where the coal mining has a long exploitation history with goaf densely distributed, as an example. The growth patterns of above ground plant communities, succession characteristics of vegetation community and soil quality characters in the goafs, which could provide theoretical basis for the sustainable development of coal resources and ecological reconstruction in this region, have been studied.

Keywords: Coal mining; Goaf; Ground vegetation; Soil quality; Sustainable development

Received: July 1, 2010; *revised:* July 20, 2010; *accepted:* July 27, 2010

DOI: 10.1002/clen.201000236

1 Introduction

The exploitation and utilization of coal resources have been lasting for thousands of years, resulting in a series of ecological environmental problems locally and globally [1–3]. So far, the mining area has become severe and typical damaged ecosystem in China and the world [4, 5]. In the last three decades, ecological environmental problems induced by coal exploitation in mining areas together with subsequent ecological restoration have steadily become hot issues and absorbed wide concerns of researchers at home and abroad [4–7]. A lot of research findings have been achieved on problems caused by coal mining such as geological hazard, water resource destruction, environmental pollution, and land resources destruction as well as corresponding consequences [8–10]. However, less attention was paid to the changes of the aboveground vegetation features and soil quality in mining areas [11, 12]. The coal exploitation history is long in Shanxi province, which is a typical mining area in China, but goafs are distributed widely. In this study, we addressed this point and took a coal mine, located in Shanxi province where coal mining has a long exploitation history with goaf densely distributed, as an example and representative. The growth patterns of surface plant communities, succession characteristics of vegetation community, and soil quality indicators in the goafs, which could provide theoretical basis for the sustainable development of coal exploitation and ecological reconstruction in this region, have been studied.

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2 Materials and methods

2.1 Physical geography overview of the studying area and research approach

The Qinxin coal mine was selected as the study site with about 24 0469 km^2 and is located in the west part of Qinyuan County, Shanxi province and lies between the longitudes (112°10′06″–112°14′01″E, 36°31′32″–36°34′48″N, 1491–1160 m above sea level).This coal mine was constructed in 1967, and annual coal output reached 1.2 million tons by 2008.

This area belongs to a temperate monsoon climate with the annual average temperature of 8.6°C and about 180 days of frost-free period. Average annual precipitation is 634.0 mm and rainfall is often in July and August in this area. The soil types are mainly composed of brown, cinnamon, and chestnut soil. This region is located in warm temperate deciduous broadleaved forest zone with *Pinus tabulaeformis* and *Quercus liaotungensis* forests as its typical vegetation. Natural secondary forests and artificial forests are dominant in the forest land, while a combination of arbor–shrub–herb accounts for large percentage in the vegetation. In the region, *Pinus tabulaeformis* and *Quercus liaotungensis* are major arbor species. *Ostryopsis davidiana*, *Forsythia suspense*, and *Cotoneaster acutifolius* are major shrub species. *Carex lanceolata* and *Artemisia brachyloba* are major herb species. Additionally, some forest lands of strip and massive block form are mainly distributed in north and southeast of this area.

Based on the contrast comparison between aboveground and underground graph of mine well, a set of surfaces with different mined-out ages are chosen as sample sites, and the sites in non-exacted area were taken as control. The following sampling steps were used for vegetation survey. First, two neighboring quadrats with size 10×10 m^2 are set in each plot, and then two quadrats with

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size $4 \times 5\,m^2$ for shrub and three quadrats with size $1 \times 1\,m^2$ for herb are separately placed along the diagonal lines of these two plots. The following data are recorded during survey. (1) Species names, height, diameter at breast height (DBH), basal diameter and crown width of each arbor plant. (2) Species names, height, abundance, coverage of shrubs (arbor plants with the height in range from 0.3 to 3 m are grouped into shrub). (3) Species names, average height, and herb coverage. (4) The biotope features, i.e., total cover-degree, layer coverage, altitude, slope angel, slope aspect, latitude and longitude and depth of ground litter. Sample plants were also collected at each plot for species identification and classification. The main environmental features of different plots are listed in Tab. 1.

2.2 Statistical analysis

Statistical analysis was made on the families and genera of seed plants both in gob area and non-excavated area to analyze their change trends and the reasons.

The investigated plants are taxonomically grouped into five categories, namely, phanerophytes, chamaephytes, hemicryptophytes, Cryptophytes, and therophytes according to Rauntkiær life-form classification system [7]. The life-forms of aboveground vegetation species with different mined-out ages and in non-excavated area were statistically calculated, and the community structure was represented by a life-form spectrum, including the calculation of percentage contribution of each species with a specific life form to the whole community. It was shown as the following:

$$\text{The percentage of a life-form} = \frac{\text{species numbers of a specific life-form in community}}{\text{total species numbers in community}} \times 100$$

Importance values of individual species in arbor–bush–herb plant community were obtained using the following formula:

$$\mathrm{IV} = \frac{H_r + D_r + P_r}{3}$$

where IV is the tree layer importance value, H_r stays for the relative height, D_r is the relative abundance, and P_r the degree of comparative advantage.

$$\mathrm{IV} = \frac{H_r + C_r}{2}$$

where IV is the importance value of shrub layer, H_r stays for the relative height, and C_r for the relative cover.

$$\mathrm{IV} = C_r$$

where IV is the importance value of vegetation layer and C_r stays for the relative cover.

Three indices, i.e., richness index, evenness index, and diversity index, were chosen to measure the features of plant community. Three kinds of indices were calculated by:

- Richness Index:

$$R = S \quad (1)$$

- Diversity Index:

Simpson Index:

$$\lambda = \sum_{i=1}^{s} \frac{N_i(N_i - 1)}{N(N-1)} \quad (2)$$

Shannon–Wiener Index:

$$H' = -\sum_{i=1}^{s} \frac{N_i}{N} \ln\left(\frac{N_i}{N}\right) \quad (3)$$

- Evenness Index:

$$E_1 = \frac{H'}{\ln S},\ E_5 = \frac{1/\lambda - 1}{e^{H'} - 1} \quad (4)$$

S is total data of species in each plot. N is the sum of importance value of all S species. N_i is an important value of species.

Table 1. The main environmental features in different plots

Plot no.	Mined-out age (a)	Latitude and longitude	Altitude (m)	Community type	Slope aspect	Slope angle (°)	Slope location	Depth of litter (cm)
1	31	36°34′23.5″N and 112°10′41.4″E	1328	Carpinus	South	40	Middle	6.5
2	28	36°34′26.7″N and 112°10′34.8″E	1323	Pine	East	30	Middle	7
3	25	36°34′39.6″N and 112°11′20.1″E	1216	Pine	South	30	Middle	5
4	20	36°34′19.8″N and 112°10′50.9″E	1344	Pine s	Northwest	35	Middle	8
5	16	36°34′31.4″N and 112°11′24.7″E	1229	Pine	East	40	Middle	7.5
6	13	36°34′31.7″N and 112°10′56.3″E	1293	Pine	Southeast	35	Middle	5
7	10	36°34′25.9″N and 112°11′30.1″E	1246	Pine	West	35	Middle	5
8	7	36°33′30.0″N and 112°10′39.2″E	1325	*Quercus liaotungensis*	Southeast	40	Top	8
9	6	36°33′58.6″N and 112°13′01.5″E	1239	Pine	West slope	19	Top	5
10	5	36°33′54″N and 112°13′02.4″E	1213	Pine	Northeast	25	Middle	4
11	4	36°34′18.3″N and 112°12′01.9″E	1275	*Cotinus coggygria*	East	25	Top	5
12	3	36°33′40.2″N and 112°13′00.3″E	1253	Pine	Northeast	28	Top	10
13	2	36°34′31.9″N and 112°10′56.5″E	1212	*Quercus liaotungensis*	Northeast	30	Bottom	8
14	1	36°33′21.3″N and 112°10′24.4″E	1228	*Quercus liaotungensis*	West	30	Middle	5
15	Not excavated areas 1	36°33′33.4″N and 112°10′43.5″E	1343	Pine	East	35	Middle	7
16	Not excavated areas 2	36°33′27.5″N and 112°12′48.4″E	1255	Pine	South	30	Top	5
17	Not excavated areas 3	36°33′22.1″N and 112°12′45.8″E	1289	Pine, oak mixed forest	Northeast	30	Middle	4
18	Not excavated areas 4	36°33′20.1″N and 112°12′44.4″E	1314	Pine, oak mixed forest	East	20	Middle	4.5

3 Results and analysis

3.1 Influence of coal mining on families, genera and species of seed plants

3.1.1 Composition characteristics of families, genera and species of seed plants

One hundred eight species seed plants, belonging to 82 genera and 36 families, are recorded in the survey. Five classical families including rosaceae (19 species, 12 genera), compositae (17 species, 13 genera), leguminosae (8 species, 5 genera), umbelliferae (5 species, 5 genera), and ranunculaceae (5 species, 4 genera) constituted 54 species from 38 genera, accounting for 13.8, 47.56, and 50.0% of total families, genera, and species, respectively. It means that plant species of these five families had the most significant effect on natural vegetation restoration, and also they hold the dominance in the local vegetation system. Liliaceae (4 genera, 5 species), caprifoliaceae (3 genera, 4 species), betulaceae (3 genera, 3 species), and gramineae (2 genera, 3 species) hold the second position, followed by families containing 2 genera and 2 species such as oleaceae, scrophulariaceae, labiatae, and rubiaceae. In addition, violaceae, fagaceae, cyperaceae, campanulaceae, and crassulaceae include 1 genus for each and 4, 3, 2, 2, 2 species, respectively. The rest 19 families, namely anacardiaceae, elaeagnaceae, rhamnaceae, cornaceae, pinaceae, salicaceae, aceraceae, dioscoreaceae, celastraceae, polygalaceae, berberidaceae, wintergreen, cephalotus, asclepiadaceae, geraniaceae, orchidaceae, iridaceae, papaveraceae, and araliaceae were presented as a single species and genus only.

3.1.2 Comparison of families, genera and species of seed plants in gob area and non-excavated area

Fewer arbor species were distributed in non-excavated area (control plots) except *Quercus aliena*, *Pinus tabulaeformis*, and *Quercus liaotungensis*. More arbor species were present in gob area including *Pubescent hornbeam*, *Fraxinus chinensis*, *Cotinus coggygria*, *Quercus variabilis*, and so on. The relatively lower numbers of families, genus and species of seed plants were recorded in shrub layer in non-excavated area with the most 8 genera and 8 species and the least 6 genera and 7 species. Therefore, arbor and shrub species in gob area are found to be relatively abundant, which could be considered as the result of moderate disturbance of coal mining.

The abundant distribution of herb species was in control plot no. 16 (non-excavated area) with a total of 24 genera and 25 species in 15 families. Taxonomically well-represented families are compositae (6 genera and 7 species) and rosaceae (5 genera and 5 species), whereas the rest families are represented by one species, respectively. The reasons of the richness of herb species in this plot may be as follows. The crown density is lower in non-excavated area as a result of less distribution of arbor plants and amount of light, heat and rainfall absorbed by arbor plants. Consequently, majority of these valuable growth resources (light, heat, and rainfall) are more available to herb plants, which leads to the abundant distribution in this area.

3.1.3 Comparison of families, genera and species of seed plants with various mined-out ages

Control plot no. 4 with mined-out age of 20 years has the greatest number of arbor species, a total of 7 genera and 7 species belonging to 6 families. The dominant family is rosaceae (2 genera and 2 species), while the others are presented as 1 species in this plot. Control plot no. 1 with mined-out age of 31 years holds the second position, where 5 species belong to 4 genera, 4 families. Fagaceae (1 genus and 2 species) is the dominant family whereas the remaining families are presented as 1 species, respectively. The third one is control plot no. 2 (mined-out age of 28 years) with 4 species belonging to 4 genera and 4 families. The last one is control plot no. 5 (mined-out age of 16 years) with *Pinus tabulaeformis* as the single species.

Control plot no. 11 (mined-out age of 4 years) has the most shrub species with a total of 11 genera and 11 species belonging to 7 families. The dominant family is rosaceae (5 genera and 5 species) and the others are presented as 1 species, respectively. Control plot no. 5 (mined-out age of 16 years) holds the second position in the number of shrub species, where 10 species belonging to 9 genera, and 7 families are found, and rosaceae (2 genera and 3 species) is the dominant family followed by betulaceae (2 genera and 2 species). The third position is control plot no. 1 (mined-out age of 31 years), where 10 species belonging to 9 genera and 6 families are found with the dominant family, rosaceae (2 genera and 3species), followed by betulaceae and caprifoliaceae (2 genera and 2 species each).

Control plot no. 11 (mined-out age of 4 years) has the most herb species with a total of 21 genera and 22 species belonging to 15 families. The dominant family is rosaceae (5 genera and 5 species) followed by asteraceae (3 genera and 3 species). Control plot no. 2 (mined-out age of 28 years) holds the second position in the number of herb species with a total of 20 species belonging to 20 genera and 14 families. Among them ranunculaceae (3 genera and 3 species) is the dominant family followed by Sedges, leguminosae, gramineae, and rosaceae (2 genera and 2 species each). 19 species belonging to 19 genera and 9 families are observed in control plot no. 3 (mined-out age of 25 years). Among them, asteraceae (8 genera and 8 species) holds the dominance followed by rosaceae (4 genera and 4 species). The minimum number of herb species is the fewest in control plot no. 1 (mined-out age 31 years), where only 6 species belonging to 6 genera and 5 families are recorded.

Theoretically, the longer mined-out ages were, the better vegetation restoration was on the surface of coal gob, as continuous increase of organic content in upper soil layer and the nutrients in soil layers increase gradually as time goes on and thus will improve the vegetation restoration. Obviously, the conclusion drawn from our survey was contrary to the above theoretical expectation theory. In our opinion, this discrepancy may be the consequence of the fact that other factors such as mining depth, altitude, slope aspect and location, human activities, etc., rather than only coal mining, affected the vegetation restoration process.

In addition, rosaceae family holds dominance in shrub layers in all plots. It is worthy to note that most rosaceae plants on the surface of coal gob are drought-tolerant. The seldom presence of non-drought tolerant plants in this region may be the result of worse conditions for them to survive, caused by mining operation, which is usually regarded to lead to lower level of shallow water in mining area. Drought-sensitive plants were rarely distributed in this region, as mining operation can decrease the level of shallow water [13–16]. The rosaceae species in surface shrub layer account for 77.8, 57.1, 50 and 50% in plots 7, 16, 4, and 14, respectively. Grosa, cotoneaster, spiraea, and cerasus are widely distributed in the study area. In addition, the plant habits of cotoneaster are inconsistent, i.e., erect tabor tree and shrub due to different ecological environment.

3.2 Impact of coal mining on life-form of seed plants

Life-form is based on the position and protection mode of resuscitation buds or reproductive organs during adverse periods. It reflects the adaptive mode of species to ecological environment. The species with same life-form have the similar properties in body forms and climate adaptability, and thus life-form is the symbol of regional bioclimate and soil quality [5, 6, 10, 17]. The plant living environment in the study region could be obtained by calculating the life-form spectra in various plots.

3.2.1 Comparative study on life-forms of seed plants in gob and non-excavated area

According to Raunkiær's classification system, statistical analysis is conducted on the life-forms of aboveground vegetation in gob and non-excavated area and the results are shown in Fig. 1.

Figure 1 shows that chamaephyta and hemicryptophyte alternatively predominates the surface vegetation in non-excavated area, and they are the major constituents of undergrowth herbage layer and shrub, such as *Carex lanceolata*, *Sanguisorba officinalis*, and *Atractylodes lancea*. Most arbor and shrub species such as *Quercus aliena*, *Pinus tabulaeformis*, *Lespedeza bicolor*, and *Forsythia suspense* belong to phaenerophyte. Despite the little number of annual plants and geophyte, they are the important components of the plant community. *Erigeron acer*, *Corydalis bungeana*, *Melampyrum roseum*, and *Bidens pilosa* are typical annual plants. *Polygonatum odoratum* and *Agrimonia pilosa* are common geophyte in the studied region. Hemicryptophyte, accounting for 45.85% of the surface vegetation, dominates in gob area, and its life form is characterized by temperate spectrum, indicating that the regional climate is arid and cold. Phanerophyte and chamaephyte account for 21.04 and 18.93% of the vegetation, respectively. The same trend is found in gob area, where annual plants and geophyte are relatively less.

The life-form spectrum not only reflects that it is frigid and dry in winter season in this region and dormant buds of perennial herb locate on the surface or underground to live through winter with fallen leaves and snow as cover, but also suggests that coal mining did not have significant effects on the life-form of surface vegetation.

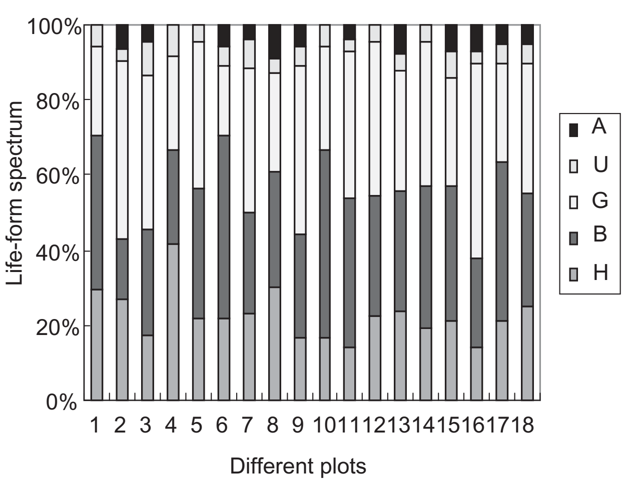

Figure 1. Life-form spectrums of different plots.

3.2.2 Comparison of life-forms of seed plants in gob area with different ages

Life-forms of ground vegetation are different under different mined-out ages. Generally, hemicryptophyte occupies larger proportion than other plants in gob area. Only in plots 1, 6, and 10 (with mined-out ages of 31, 13, 5 years, respectively) chamaephyte holds superiority, but in plot 4 (mined-out age of 20 years) phanerophytes is in pyramid type. In Fig. 2 and Fig. 3, it can be seen that life-form encountered small influence rather than developed to climax community with gob age increasing. This phenomenon could be attributed to the definite influence of coal mining on ground surface, as Qinxin coal mine has a larger mining depth (480 m) and height (1.9 m).

3.3 Effect of coal mining on biospecies diversity index of seed plants

3.3.1 Comparative study of diversity index of seed plants in gob and non-exacted area

There are only 3 arbor species in non-excavated area. In gob area there are 7 arbor species and the average is 3. Thus, no obvious difference was observed in *R*-value between gob area and non-excavated area.

As shown in Fig. 2, *R*-value ($R = 7$) of shrub layer is lower in unexploded area than in gob area, and the maximal value ($R = 11$) is found in plot 11 (mined-out age of 4 years). And *R*-value of shrub

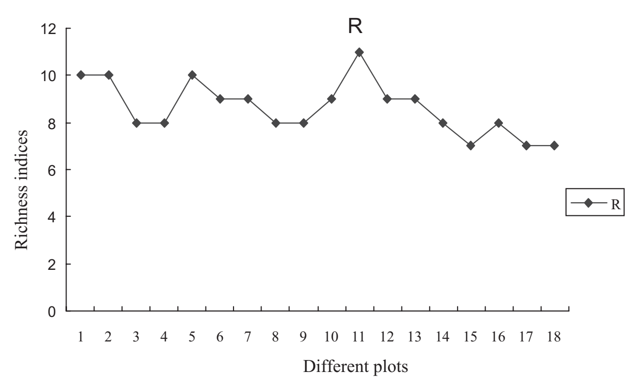

Figure 2. Richness indices of different plots for shrub layer.

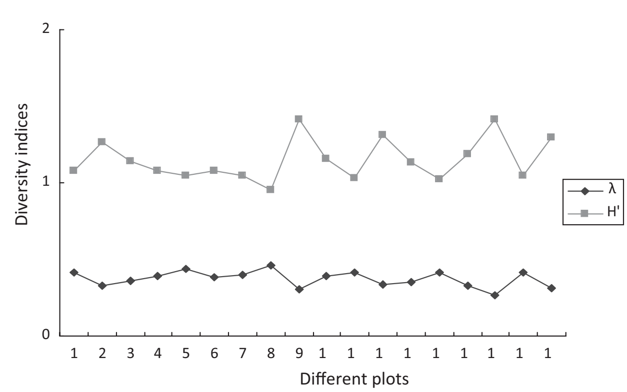

Figure 3. Diversity indices of different plots for shrub layer.

layer is also higher in gob area than in unexploded area (control plots), clearly demonstrating that coal mining operation did not induce the decrease of shrub diversity in study plots. Surface vegetation in gob area only suffers from intermediate disturbance from coal mining. However, species diversity also may decrease if surface vegetation was destroyed by the dewatering of shallow water layer or roof falling in the long run.

Figure 3 shows that λ and H' have opposite change trends, since these indices reflect different eco-information, i.e., λ mainly denotes the species dominance in plant community while H' is a comprehensive measure index of species number and evenness. Consequently, larger H' value is always parallel with smaller λ, displaying opposite changing trend. Three peak values, 1.4135 in plot 16, 1.4113 in plot 9, and 1.3125 in plot 12, are found in Fig. 3. It may be interpreted as follows. First, lower crown density of arbor absorbed less light, heat, and rainfall, leaving more resources available to shrub layer. Besides, these control plots are located at slope crest, and hence they have deeper mining depth, which weakens the influence of coal mining on shallow groundwater. Due to these two facts, a higher H' value comes out as a consequence.

3.3.2 Comparison of diversity index of seed plants with different mined-out ages

Figure 2 indicates the richness of shrub layer in gob area with different mined-out ages are in the range of 8–10, and the average is 9, so mean richness of shrub layer was lower in this region. Highest richness index of shrub layer is 11 in control plot 11, it may be the result of lower crown density and less human disturbance, as this plot is located at slope crest.

It could be found that *R* and *E* of shrub layer in different plots almost have the identical trend as H' (Figs. 2–4). There are abundant shrub species in study quadrats without obvious dominant species. Thus, the importance value indices are nearly identical values of *E* and H'. While, for shrub layer with lower species diversity, species with higher λ value is absolutely dominant in study quadrats, which hence leads to the lower values of *E* and H'.

Richness index of herb varies between 10 and 19 with an average value of 16, as shown in Fig. 5. And the lowest value is only 6 in plot 1, indicating rare presence of herbs, which may be caused by higher crown density of arbor and richness of shrub species.

In Figs. 6 and 7 four peak values, 1.6930 in plot 9, 1.5935 in plot 16, 1.5639 in plot 5, and 1.4755 in plot 12, emerge on the curve of H' of herb layer. The plots where peaks are found in this figure are almost the same as those in Fig. 4 (for shrub layer). However, variation trend of the curve in Figs. 3–7 is contrary to that in arbor layer, which could be attributed to the effects of arbor layer diversity and crown density in shrub layer and herb layer. The less species diversity and the lower crown density lead to higher value of H' index for shrub layer and herb layer, and vice versa.

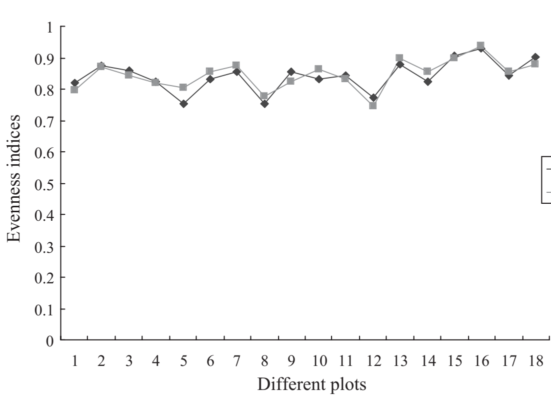

Figure 4. Evenness indices of different plots shrub layer.

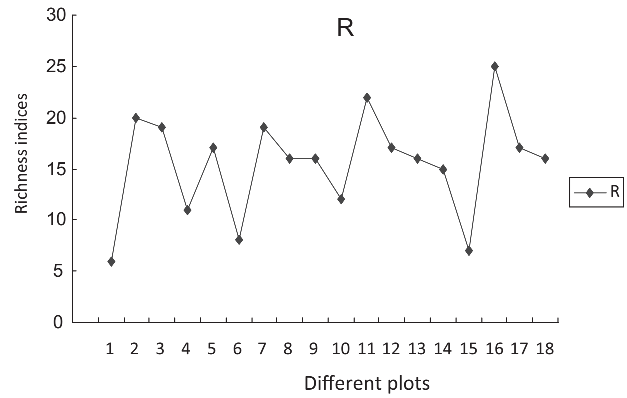

Figure 5. Richness indices of different plots herb layer.

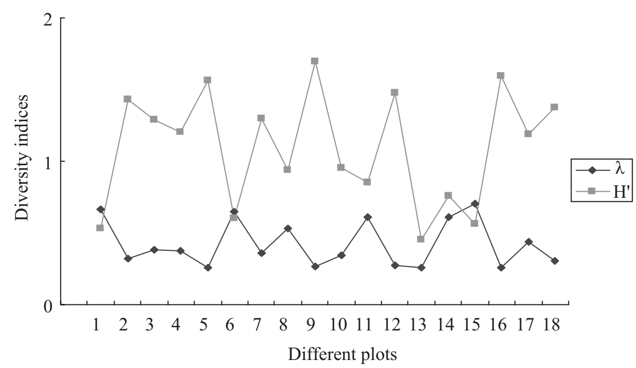

Figure 6. Richness indices of different plots herb layer.

3.3.3 Comparison of diversity index between shrub layer and herb layer

Based on the analysis and calculation of diversity in shrub layer and herb layer, the variation range of richness index for shrub layer and herbs layer are different. Specifically herb layer has the largest

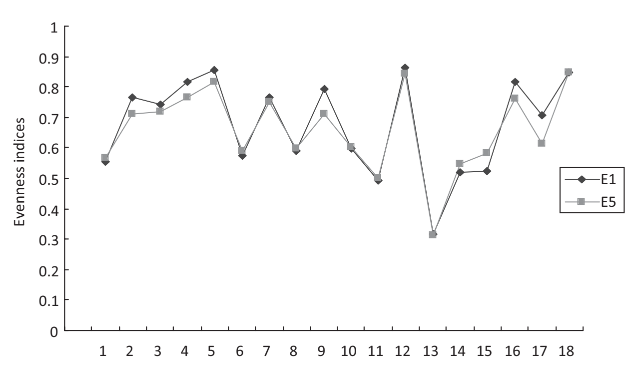

Figure 7. Evenness indices of different plots herb layer.

variation range with an average of 16, followed by shrub layer with an average of 9 and arbor layer with an average value of 3. The diversity index of herb layer also shows steep change trend in the range 0.6–1.6 with an average of 1.10, while shrub layer exhibits mild change trend in the range 1–1.5 with an average of 1.15.

The diversity index curve has the opposite change trend to that of importance value of species in plots. For example, arbor species has the maximum importance value while its diversity index is the minimum. Hence, the diversity index is correspondingly lower, while the dominance degree of dominant species communities is higher. *E*, the evenness degree, is larger in shrub layer than that in herb layer, indicating the structure and organization level of surface vegetation. Given the constant numbers of species, *E* is only related to the evenness degree of individual tree or biomass index of various species. Lower *E* value will be present in the community with constructive or dominant species as the dominance. Hence, the difference of importance value in herb species is larger, and dominant species are apparent. The contrary phenomena is found for shrub species as dominant species are less apparent, indicating that both the extremely rich and scarce species of shrub layer are less, and thus the difference between common and rare species is slight. Our study area is under influence of coal mining perennially, and many factors including mined-out ages and the extent of shallow water loss affect the diversity of surface vegetation, and create remarkable fluctuation [13–16].

According to the comparable analysis on plant community diversity in different synusia, it can be found that the diversity index of herbs is larger than that of shrubs surface vegetation in different plots. It is due to the fact that species of small life-form can make full use of resources (even those with small scale) in local environment and are more sensitive to special heterogeneity, and then can survive more species (Figs. 1–7).

4 Discussions, Conclusions and Implications

Coal gob is an inevitable outcome of coal mining, so comprehensive investigation and detailed understand are necessary for the promotion of healthy development of coal industry, and it has become one of the significant research subjects now. In the present paper, families, genera, species, life-form, and diversity of ground vegetation in both gob and non-exacted areas with different mined-out ages were compared and the effect of coal mining on surface vegetation was investigated. The results provide some insights for sustainable utilization of coal mine, and restoration of ecological environment.

4.1 Discussions

(1) Long time is needed to investigate the succession and evolutionary characteristics of plant communities. However, it is impractical to observe changes of communities for hundred or more years. Therefore, the method of "spatial sere substituting for time sere" is used in present study. In other words, spatial series was used to infer time series. This method pays more attention to finding evidence in present communities, and it is commonly used by botanist to study the succession of communities [1, 5, 8]. However, "spatial sere substituting time sere" method has limitations when used to study vegetation succession. Vegetation succession is a nonlinear process in space, and the communities have much ways to develop due to spatial heterogeneity and provenance disparity. Hence, succession sequence can not be identified directly in the communities of the same space. Time needed in each succession stage, and the time needed to reach the climax is also uncertain. Community succession is a linear process in time and it develops towards a specific direction. Hence, permanent study plots should be set up in suitable sites and long term orientation research could be carried out to investigate the effect of coal-mining on surface vegetation and provide scientific basis for vegetation restoration [9–12, 14–16].

(2) Comparative study shows that species diversity of different layers in gob and non-excavated area has slight discrepancy in study plots. This may be attributed to different vegetation type and succession stages (mainly caused by diverse habitat and mined-out ages) as well as anthropogenic disturbance in various degrees. Via identifying and analyzing, the diversity index of different layers, many aspects including the structure of surface vegetation, organization level, succession, and ecological characteristics were illustrated. As for the relation between diversity index and environmental factors, further quantitative analysis is still needed [12].

4.2 Conclusions

(1) A total of 108 species seed plants belonging to 82 genera and 36 families are recorded during this survey. In non-excavated area arbor species include *Pinus tabulaeformis*, *Quercus liaotungensis*, and *Quercus aliena*, while more arbor species present in gob area including *Pubescent hornbeam*, *Fraxinus chinensis*, *Cotinus coggygria*, *Quercus variabilis*, etc. Less numbers of families, genus, and species of seed plants are recorded in shrub layer in non-excavated area, which may be the result of moderate disturbance induced by coal mining. The abundant distribution of herb species is observed in control plot no. 16 (non-excavated area) with a total of 24 genera and 25 species in 15 families. The reasons of the richness of herb species in this plot may be as follow. The crown density is lower in non-excavated area (as a result of less distribution of arbor plants) and only a little amount of light, heat, and rainfall is absorbed by arbor plants, but majority of these valuable growth resources (light, thermal, and rainfall) are available to herb plants, which leads to the abundant distribution of herb species.

(2) Theoretically, vegetation restoration gradually becomes better along with the increase of organic content in upper soil layer and the nutrients in soil layers. However, our investigations are contrary to this theoretical conclusion. The discrepancy may be the consequence of the fact that other factors such as mining depth, altitude, slope aspect and location, human activities, etc., rather than only coal mining, affected the vegetation restoration process.

(3) Rosaceae family takes absolute dominance in shrub layers in both gob and non-excavated areas. Rosaceae species in surface shrub layer plants account for 77.8, 57.1, 50, and 50% in plots 7, 16, 4, and 14, respectively. In this area, genus of rosa, cotoneaster, spiraea, and cerasus were distributed widely. Above the gob area, plants in rosaceae family are almost drought-enduring species, as coal mining decreased the level in the shallow layer water.

(4) Chamaephyta and hemicryptophyte alternatively predominates the surface vegetation in non-excavated area, while in gob area hemicryptophyte is obviously dominant (up to 45.85%) and characterized by life-form spectrum of temperate plants, indicating this regional climate is arid and cold. Second is phanerophyte (21.04%) and the third is chamaephyte (18.93%). The same trend is found in gob area, where annual plants and geophyte is relatively less. Hence, coal mining had no significant influence on the life form of surface vegetation.
(5) Woods in the study area are natural secondary forest with poor diversity of arbor species. This forest originated from natural growth after artificial fell and had no close relation to coal mining.

R-value of shrub layer is higher in gob area than that in non-excavated area. The reason may be that surface vegetation only suffer intermediate disturbance from coal mining, and *R*-value thus increases as a result. However, species diversity also has the probability to decrease once surface vegetation is destroyed by the dewatering of shallow water layer or roof falling. The plots where peaks are found for herb layer are primarily the same as those in shrub layer. However, the variation trend of herb is contrary to that in arbor layer, which could be attributed to the impacts of arbor layer diversity and crown density to shrub layer and herb layer. The less species diversity is the lower crown density with subsequent higher value of H' index will be in shrub layer and herb layer, and vice versa.

4.3 Implications

Ecological environmental destruction is inevitable, which is closely related to both mining process and planning before mining. Besides, most ecological environment damage can be predicted in advance. Therefore, the ecological environment rehabilitation strategy in mining area should be active and dynamic, and carried out throughout the whole process of coal exploitation, replacing the old and passive strategy characterized by ''destroyed first, controlling followed'' [13–18].

Ecological restoration in mining area indicates that possible environmental damages during or after exploitation are predicted to decrease or avoid them in the mining process as more as possible rather than taking action after being damaged. The major object of ecological restoration in mining area is to reconstruct a high-level and sustainable developmental ecosystem according to the developing sequences of coal mining and the need and value orientation of humankind, rather than simply restore to the previous status. Predicting possible environmental damages during or after exploitation and thereby decreasing or avoiding damages to the environment as much as possible is the nature of ecological environment restoration, rather than taking action after being damaged. What the ecological environment restoration in mining area pursues eventually is to rebuild a high-level, sustainable development ecological system according to the developing sequences of coal mining and the need and value orientation of humankind, rather than a simple copy of environment before exploitation. Restoration of ecological environment in mining area is from the point of view of the complex ecosystem, i.e., including society, economy, and nature, highlighting the relationship between human and environment, and pursues overall coordination, symbiotic coordination and development coordination rather than restricts, repairs, and invest in the pollution [13, 18].

Acknowledgments

This work was supported jointly by the grant from Ministry of Environmental Protection of the People's Republic of China and Onehundred Talent Plan of Chinese Academy of Sciences.

The authors have declared no conflict of interest.

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