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Natural plant revegetation on reclaimed coal mine landscapes in Agacli-Istanbul

Ender Makineci^{1*}, Beyza Sat Gungor² and Meric Kumbasli³

¹Istanbul University, Faculty of Forestry, Soil Science and Ecology Department
34473 Bahcekoy/Istanbul/Turkey.

²Istanbul Aydin University, Engineering and Architecture Faculty, Architecture Department, Inonu Cad. No:40,
Kucukcekmece/Istanbul, Turkey.

³Forest Entomology and Protection Department, Istanbul University, Faculty of Forestry, Forest Entomology and
Protection 34473 Bahcekoy/Istanbul/Turkey.

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In this study, natural vegetation development was compared on one abandoned open coal mine spoil and three reclaimed coal mine areas with umbrella pine-*Pinus pinea* L., maritime pine-*Pinus pinaster* Ait. and leguminous black locust-*Robinia pseudoacacia* L. in Agacli-Istanbul. Soil data of these sample areas were determined in previous studies. These properties demonstrate physically and nutritionally poor conditions and some rehabilitative effects after tree species were introduced. The plant species composition and total coverage for each species (vertical projection onto the ground) was estimated visually and recorded on each sample plot. Naturally revegetated plant species, species composition, Shannon-Wiener diversity index values, species richness, evenness, total abundance and their cover-abundance scales were evaluated by comparing each other. Generally, the best-represented species belong to Rosaceae in all investigated plots. Shannon diversity index and its components give the different results among sample plots. However, higher values were found on reclaimed sites. Highest Shannon diversity index (H') was found on the sample area reclaimed with maritime pine. Plant species richness (S) was highest under umbrella pine and plant species evenness (J') was highest on black locust sample plot. Despite the sample area reclaimed, black locust has the more fertile soil conditions, it has only the highest plant species evenness (J') value among areas.

Key words: Coal mine, plant composition, reclamation, revegetation, species richness, species diversity

INTRODUCTION

Mined areas exhibit completely modified ecological system. Large spoil piles and pits are main features of a mining land (Martinez Orozco et al., 1993). In particular, open cast, that is, surface mining activities result in a drastic disturbance mining areas become an important man-made components of landscape (Toomik and Liblik, 1998; Hüttl and Bradshaw, 2000). Because of low organic matter contents and other unfavorable physico-chemical characteristics, mine spoils possess very rigorous conditions for plant growth (Banerjee et al., 2004; Singh and Singh, 2006).

Plant succession following the exogenous disturbance associated with surface mining is a subject of both practical and ecological interest (Grant and Loneragan, 2001). Natural plant invasion and succession are important parts of vegetation development as well as nutrient enrichment at this type of disturbed sites (Banerjee et al., 2004). In order to rebuild the resilience of a disturbed ecosystem, it is critical to restore as many aspects of natural vegetation as possible. To do this, the natural vegetation in the site and how it succeeds need to be known (Desmet and Cowling, 1999; Blignaut and Milton, 2005). During plant establishment at different successional stages, colonization of different plant species plays the primary roles in the process of soil formation. Then, once the vegetation is established, the improved soil condition in turn promotes plant succession. The degree

*Corresponding author. E-mail: emak@istanbul.edu.tr. Tel: +90-(212)-2261100, Ext: 25302. Fax: +90-(212)-2261113.

of ecosystem development can be assessed by the level of vegetation recovery and nutrient status of the spoils (Banerjee et al., 2004).

A successful restoration program attempts to accelerate the natural recovery processes to restore the soil fertility and to enhance the biological diversity (Hodačová and Prach, 2003; Singh and Singh, 2006). The establishment of a stable plant cover is considered a suitable option to get long term reclamation (Whiting et al., 2004; Simon, 2005; Conesa et al., 2007a). The natural colonization of mine sites is slow since the physico-chemical characteristics (low pHs, high metal concentration, low water retention capacity, compacted material hindering root elongation, etc.) of these sites are not suitable for most of the plant species (Conesa et al., 2007a, b). Since the exposed surface has lack of seedbank, mined sites needs to be colonized by adjacent species. Reports on the vegetation of spoils emphasize the slow rate of colonization which may be due to either the unfavorable substrate or the lack of suitable pioneer plants, because they have been exterminated to a large extent by man (Jochimsen, 2001). Nevertheless, some tolerant plant species can spread easily in these environments. In this sense, it is useful to search plants that have spontaneously colonized mining sites and therefore, are completely adapted to these polluted environments (Conesa et al., 2007a).

Traditionally, vegetation indicators such as plant species composition and growth rates are monitored on mine sites. These simple vegetation measures meet the criteria for indicators that they are easy to measure and they respond in sensitive, robust and predictable ways over time to stresses and management actions (Dale and Beyeler, 2001; Ludwig et al., 2003). Species richness is only one of various criteria evaluating restoration success but is, nevertheless, a very important one from an ecological point of view (Perrow and Davy, 2002; Hodačová and Prach, 2003). Comparative plant succession studies on derelict sites are providing significant insights into vegetation dynamics to ensure the success of future re-vegetation projects in these areas (Martínez-Ruiz and Fernández-Santos, 2005).

In this present investigation, natural vegetation development on one abandoned open coal mine spoil and three reclaimed mine areas with umbrella pine-*Pinus pinea* L., maritime pine-*Pinus pinaster* Ait. and leguminous plant black locust-*Robinia pseudoacacia* L. in Agacli-Istanbul were compared. The objective of the study was to evaluate resulting vegetation, especially species richness on spoils which have different soil and forest floor proper-ties. The plant composition, Shannon-Wiener diversity index, species richness, evenness, total abundance and their cover-abundances were compared among the sites.

MATERIALS AND METHODS

The study was conducted on reclaimed mine spoils near brown coal

mining district 30 km away Bahcekoy-Istanbul on Catalca Peninsula (Turkey). Mean annual precipitation is 1049 mm and mean annual temperature is 14.0°C. The hottest month is July (23°C) and the coldest is January (4°C). According to Thornthwaite classification system, the study area is considered as humid, mesothermal, oceanic with a moderate soil-water deficit in summer. The study areas are located between 200 to 230 m with an average of 15% slope. The study area consists of randomly selected four sites, one naturally revegetated and three reclaimed planting different tree species in each one with leguminous black locust (*R. pseudoacacia* L.), umbrella pine (*P. pinea* L.) and maritime pine (*P. pinaster* Aiton.) plantations established in 1988 on coal mine spoils without conducting any amelioration practice (Keskin and Makineci, 2009; Sever and Makineci, 2009). And sample plots reclaimed with different tree species were not subjected to any silvicultural treatments such as thinning, pruning or tending, etc. prior to this study. The parent substrate for soil development was loamy and loamy-clay overburden material and detailed data on soil and forest floor properties of reclaimed with maritime pine, umbrella pine and black locust were presented in former studies (Keskin and Makineci, 2009; Sever and Makineci, 2009).

In previous studies in the same research area demonstrated that reclamation with different tree species has given the rehabilitative effects on coal mine soil/spoil (Keskin and Makineci, 2009; Sever and Makineci, 2009). According to the results of the current studies, seventeen years after forestation, maritime pine and umbrella pine have created a larger forest floor. The fast formation of the fermentation layers of forest floor (Table 1) and the significant accumulation of organic carbon and total nitrogen in the upper layers of the soil profile were observed during the development of a maritime pine and umbrella pine plantation on reclaimed spoil (Table 2). The fast formation of the litter and fermentation layers of forest floor and the significant accumulation of N in the soil/spoil profile were observed during the development of leguminous black locust plantation on mine spoil (Keskin and Makineci, 2009). Clearly, all tree species have favorable impacts on initial soil formation. Generally, the umbrella pine and maritime pine generates more forest floor layer. By contrast, black locust litter incorporates into the soil more rapidly. Broad-leaved leguminous black locust may be more beneficial than the umbrella pine and maritime pine because it encourages less acidification and fixes nitrogen (Keskin and Makineci, 2009; Sever and Makineci, 2009). On the other hand, even the open area has no organic layers (forest floor) it has generally not showed significant differences in regarding as soil carbon, total nitrogen and soil pH compared with the sites of maritime pine and umbrella pine (Table 2). This can be interpreted that, possible natural plant succession on open area has also give rehabilitative effects as much as maritime pine and umbrella pine plantations. Likely, more adapted or resistance plant mass exist on open area.

One sampling plot for each sampling site was selected. Each sample plots' size was 400 m². In each sample plot, this study observed and evaluated species composition and cover abundance scales of all naturally revegetated plant species directly within the whole sampling plot. Easily identified plant species reported on the field, undetermined ones clipped and brought to the laboratory to determine by comparing the samples in Istanbul University Faculty of Forestry Herbarium and guide books. The general site characteristics of plant species were reported as described by Davis (1965 to 1985). The plant species composition on the sample areas was characterized by classical phytosociological plots according to Braun-Blanquet cover-abundance values (Braun-Blanquet, 1964) which means that, total coverage for each species (vertical projection onto the ground) was estimated visually and recorded within seven cover classes: r: 1 or 5 individuals; +: few individuals (<20) with cover <5%; 1: many individuals (20 to 100) with cover <5%; 2: 5 to 25% cover; 3: 25 to 50% cover; 4: 50 to 75% cover; 5: 75 to 100% cover (Braun-Blanquet, 1964; Godefroid and Koedam,

Table 1. Forest floor properties of mine spoils reclaimed with maritime pine, black locust and umbrella pine.

Area	Layer (cm)	Mass (kg ha^{-1})	Organic matter (%)	Organic matter Mass (kg ha^{-1})	Nitrogen (%)	Nitrogen mass (kg ha^{-1})
MP	L	7312 ^b	92 ^b	6726 ^b	0.478 ^b	36 ^a
BL		2196 ^a	84 ^a	1857 ^a	1.899 ^a	42 ^a
UP		6050 ^b	92 ^b	5577 ^b	0.474 ^b	30 ^a
Significance		**	***	***	***	NS
MP	F	9267 ^b	79 ^b	7296 ^b	0.696 ^b	69 ^a
BL		3696 ^a	64 ^a	2294 ^a	1.697 ^a	63 ^a
UP		7650 ^{ab}	68 ^a	5179 ^{ab}	0.741 ^b	53 ^a
Significance		*	***	**	***	NS
MP	H	1393 ^a	43 ^a	618 ^a	0.594 ^a	8.75 ^a
BL		214 ^a	57 ^a	122 ^a	1.713 ^a	3.67 ^a
UP		-	-	-	-	-
Significance		NS	NS	NS	NS	NS
MP	Total	17973	-	14641 ^b	-	114 ^a
BL		6107	-	4274 ^a	-	110 ^a
UP		13700	-	10756 ^b	-	83 ^a
Significance		*	-	***	-	NS

Values are mean. Significance levels are NS non significant; *0.05-0.01; **0.01-0.001 and ***0.001>; values within columns followed by the same superscript letter are not statistically different at 0.05 significance level; MP = maritime pine ($n = 14$); L= black locust ($n = 7$); UP = umbrella pine ($n = 5$) and OA = open area ($n = 2$). (Keskin and Makineci, 2009;Sever and Makineci, 2009)

2004). Prior to analysis of Shannon index (Shannon and Weaver, 1949) and its components (richness and evenness), Braun-Blanquet scores were transformed to relative cover (r: 0.01; +: 0.02; 1: 0.04; 2: 0.15; 3: 0.375; 4: 0.625; 5: 0.875) (Fontaine et al., 2007).

RESULTS AND DISCUSSION

Possibly, depending on different soil and forest floor properties on reclaimed sites and open-naturally revegetated area, different results on natural vegetation succession properties were obtained as given further: The sample area reclaimed with maritime pine (*P. pinaster Ait*); the canopy cover of tree layer has been estimated 60% with an average tree height of 9 m; shrub layer cover has been estimated 15% with an average height of 2.5 m; herb layer cover has been estimated 40% with an average height of 0.4 m. Forty-one plant species belonging to 19 plant families were determined (Table 3).

Most of the plants found in the sample area belong to Rosaceae and Asteraceae plant family. *Rubus sanctus* and *Rosa canina* have the highest cover abundance scales in the area, on the other hand, the lower cover abundance scales have been determined on *Arbutus unedo*, *Cornus sanguinea*, *Rhagadiolus stellatus*, *Prunus spinosa*, *Spiranthes spiralis*, *Phillyrea latifolia*, *Carpinus betulus*, *Inula vulgaris*, *Ulmus minor* subsp. *minor*, *Mespilus germanica* and *Rubia peregrina* species (Table 3).

The sample area reclaimed with umbrella pine (*P. pinea L.*); the canopy cover of tree layer has been estimated 80% with an average tree height of 7 m. Shrub layer cover has been estimated 10% with an average height of 3.5 m. Herb layer cover has been estimated 10% with an average height of 0.5 m. 21 plant species belonging to 15 plant family were determined (Table 4). Rosaceae was the most common plant family in this sample area. *Phillyrea latifolia* has the highest cover abundance scale; on the other hand, the lower cover abundance scales have been determined on *Prunus divaricata* subsp. *divaricata*, *Carpinus betulus*, *Mespilus germanica*, *Arbutus unedo*, *Rosa gallica*, *Pyracantha coccinea*, and *Smilax excelsa* species (Table 4).

The sample area reclaimed with leguminous black locust (*R. pseudoacacia L.*); the canopy cover of tree layer has been estimated 70% with an average tree height of 9 m. Shrub layer cover has been estimated 50% with an average height of 2 m. Herb layer cover has been estimated 90% with an average height of 0.5 m. 23 plant species belonging to 11 plant family were determined (Table 5). Primary common plant family was Rosaceae and the secondary were Asteraceae and Poaceae. *Rubus sanctus*, *Robinia pseudoacacia* and *Rosa canina* have the highest cover abundance scales in the area, on the other hand, the lower cover abundance scales has been determined on *Epilobium tetragonum* subsp.

Table 2. Soil properties of mine spoils reclaimed with maritime pine, black locust, umbrella pine and open area.

Area	Depth (cm)	Bulk density (g dm ⁻³)	Fine soil fraction (g dm ⁻³)	Sand (%)	Silt (%)	Clay (%)	Corg (%)	Corg mass (g dm ⁻³)	Nt (%)	Nt mass (g dm ⁻³)	pH
MP BL UP OA	0-1	1435 ^{ab}	1360.71 ^{ab}	56.17 ^a	21.53 ^a	22.31 ^a	1.77 ^a	22.57 ^a	0.096 ^a	1.290 ^a	5.38 ^a
		1095.0 ^a	1026.8 ^a	67.90 ^a	13.00 ^a	19.10 ^a	4.99 ^b	48.47 ^b	0.407 ^b	3.920 ^b	7.36 ^b
		1638.5 ^{bc}	1425.0 ^{ab}	71.50 ^a	13.30 ^a	15.20 ^a	2.74 ^a	33.69 ^{ab}	0.121 ^a	1.540 ^a	5.51 ^a
		1953.75 ^c	1818.75 ^b	65.67 ^a	12.56 ^a	21.76 ^a	2.18 ^a	39.35 ^{ab}	0.045 ^a	0.829 ^a	4.07 ^a
Significance		**	*	NS	NS	NS	**	**	***	***	*
MP BL UP OA	1-3	1290.27 ^a	1220.54 ^{ab}	58.20 ^a	13.83 ^a	27.97 ^a	1.11 ^a	13.27 ^a	0.045 ^a	0.540 ^a	5.43 ^a
		1566.8 ^a	1468.8 ^b	58.50 ^a	13.80 ^a	27.70 ^a	1.64 ^a	24.47 ^a	0.110 ^b	1.610 ^b	7.43 ^b
		1363.0 ^a	1142.5 ^a	69.50 ^a	12.20 ^a	18.30 ^a	1.35 ^a	14.32 ^a	0.060 ^a	0.670 ^a	5.27 ^a
		1306.25 ^a	1256.25 ^{ab}	62.97 ^a	13.62 ^a	23.40 ^a	1.89 ^a	23.71 ^a	0.036 ^a	0.451 ^a	3.97 ^a
Significance		NS	*	NS	NS	NS	NS	NS	***	***	**
MP BL UP OA	3-5	1463.75 ^a	1411.61 ^{ab}	54.98 ^a	13.93 ^a	31.09 ^a	0.95 ^a	12.92 ^a	0.039 ^{ab}	0.550 ^a	5.54 ^{ab}
		1710.5 ^a	1607.1 ^b	56.70 ^a	17.50 ^a	25.90 ^a	1.04 ^a	15.66 ^a	0.054 ^b	0.860 ^b	7.41 ^b
		1462.0 ^a	1237.5 ^a	70.40 ^a	10.20 ^a	19.40 ^a	0.36 ^a	4.18 ^a	0.043 ^b	5.510 ^a	5.06 ^a
		1464.40 ^a	1387.55 ^{ab}	63.33 ^a	13.17 ^a	23.49 ^a	1.77 ^a	24.61 ^a	0.026 ^a	0.363 ^a	3.88 ^a
Significance		NS	*	NS	NS	NS	NS	NS	*	**	*
MP BL UP OA	5-10	1419.29 ^{ab}	1344.29 ^{ab}	53.39 ^a	14.86 ^a	31.75 ^a	0.78 ^a	10.38 ^a	0.032 ^a	0.430 ^a	5.55 ^{ab}
		1639.4 ^c	1517.1 ^b	54.30 ^a	18.10 ^a	27.50 ^a	0.96 ^a	14.94 ^a	0.038 ^a	0.590 ^a	7.41 ^b
		1535.6 ^{bc}	1256.0 ^a	72.10 ^a	9.20 ^a	18.70 ^a	0.13 ^a	1.48 ^a	0.034 ^a	0.420 ^a	4.95 ^a
		1333.0 ^a	1285.0 ^a	57.94 ^a	15.28 ^a	26.77 ^a	1.61 ^a	20.63 ^a	0.029 ^a	0.383 ^a	3.70 ^a
Significance		***	*	NS	NS	NS	NS	NS	NS	NS	*
MP BL UP OA	10-20	1397.43 ^b	1292.86 ^a	56.84 ^a	15.12 ^a	28.05 ^a	0.83 ^a	10.67 ^a	0.033 ^a	0.430 ^a	6.13 ^{ab}
		1414.4 ^b	1302.1 ^a	59.10 ^a	15.80 ^a	25.00 ^a	0.69 ^a	8.79 ^a	0.028 ^a	0.360 ^a	7.50 ^b
		1406.2 ^b	1172.0 ^a	64.70 ^a	12.10 ^a	23.20 ^a	0.60 ^a	6.38 ^a	0.041 ^a	0.480 ^a	4.81 ^a
		1172.0 ^a	1117.5 ^a	60.77 ^a	14.20 ^a	25.02 ^a	1.36 ^a	15.18 ^a	0.023 ^a	0.256 ^a	3.69 ^a
Significance		*	NS	NS	NS	NS	NS	NS	NS	NS	*
MP BL UP OA	20-30	1409.00 ^a	1327.50 ^a	59.69 ^a	13.89 ^a	26.42 ^a	1.01 ^a	13.33 ^a	0.026 ^a	0.340 ^a	5.78 ^{ab}
		1409.7 ^a	1269.3 ^a	60.50 ^a	15.60 ^a	23.90 ^a	0.66 ^a	8.59 ^a	0.024 ^a	0.310 ^a	7.56 ^b
		1413.8 ^a	1204.0 ^a	64.80 ^a	12.50 ^a	22.70 ^a	0.54 ^a	6.32 ^a	0.037 ^a	0.440 ^a	4.54 ^a
		1439.0 ^a	1302.5 ^a	52.92 ^a	15.27 ^a	31.80 ^a	1.325 ^a	17.36 ^a	0.026 ^a	0.345 ^a	3.57 ^a
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	*
MP BL UP OA	30-40	1429.07 ^a	1342.14 ^{ab}	58.70 ^a	15.62 ^a	25.68 ^a	0.69 ^a	9.16 ^a	0.024 ^a	0.320 ^a	5.60 ^{ab}
		1425.4 ^a	1239.3 ^a	59.20 ^a	16.80 ^a	23.90 ^a	0.74 ^a	9.54 ^a	0.021 ^a	0.270 ^a	7.57 ^b
		1360.4 ^a	1234.0 ^a	62.80 ^a	15.80 ^a	21.50 ^a	0.53 ^a	6.36 ^a	0.039 ^a	0.480 ^a	4.45 ^a
		1573.0 ^a	1505.5 ^b	58.06 ^a	13.21 ^a	28.72 ^a	1.005 ^a	15.15 ^a	0.018 ^a	0.276 ^a	5.77 ^{ab}
Significance		NS	*	NS	NS	NS	NS	NS	NS	NS	*
MP BL UP OA	40-50	1382.00 ^a	1311.43 ^a	54.51 ^a	21.44 ^a	24.04 ^a	1.00 ^a	12.53 ^a	0.026 ^a	0.33 ^a	5.48 ^{ab}
		1367.4 ^a	1225.7 ^a	61.40 ^a	13.30 ^a	25.30 ^a	1.12 ^a	14.09 ^a	0.020 ^a	0.250 ^a	7.54 ^b
		1406.6 ^a	1241.0 ^a	64.60 ^a	15.60 ^a	19.80 ^a	0.25 ^a	3.07 ^a	0.036 ^a	0.450 ^a	4.46 ^a
		1542.5 ^a	1435.0 ^a	57.92 ^a	12.74 ^a	29.33 ^a	0.910 ^a	13.03 ^a	0.020 ^a	0.283 ^a	6.42 ^{ab}
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	*

Values are mean. Significance levels are NS non significant. *0.05 to 0.01. **0.01 to 0.001 and ***0.001>. Values within columns followed by the same superscript letter are not statistically different at 0.05 significance level. MP= maritime pine (n= 14); BL= black locust (n= 7); UP= umbrella pine (n= 5); OA= open area (n= 2) (Keskin and Makineci, 2009; Sever and Makineci, 2009).

Table 3. Plant species, their general habitat characteristics and cover-abundance scales on sample area reclaimed with *P. pinaster* Ait.

The plant family	The scientific name of the plant taxa	General habitat characteristic	The cover-abundance scale
Pinaceae	<i>Pinus pinaster</i> Ait	Coastal sand and dunes.	4
Rosaceae	<i>Rubus sanctus</i> Schreber	Open scrub, rocky slopes, banks of rivers, fixed dunes, coastal plains and waste places.	3
Rosaceae	<i>Rosa canina</i> L	Banks, rocky slopes, scrub, hedges forests and clearings limestone places.	2
Ericaceae	<i>Arbutus unedo</i> L.	Macchie often with <i>Erica arborea</i> or under <i>Pinus brutia</i> , often on non-calcareous soils.	r
Cyperaceae	<i>Carex distachya</i> Desf. var. <i>distachya</i> Desf.	Dry stony slopes, open forests and roadsides.	1
Rosaceae	<i>Rosa gallica</i> L.	Dunes, dry meadows, slopes and macchie often on sand.	1
Rosaceae	<i>Pyrus elaeagnifolia</i> Pallas subsp. <i>elaeagnifolia</i> Pallas	Coniferous and deciduous forests and forest remnants fields.	+
Poaceae	<i>Cynosurus echinatus</i> L.	Woodland (usually deciduous), dry hillsides, grassy places, fields and roadsides.	1
Fabaceae	<i>Trifolium campestre</i> Schreb.	Fields, waste places.	1
Fabaceae	<i>Dorycnium rectum</i> (L.) Ser.	Damp and bushy places.	1
Fagaceae	<i>Quercus petraea</i> subsp. <i>Iberica</i>	In <i>Quercus</i> and <i>Fagus</i> forests.	+
Cornaceae	<i>Cornus sanguinea</i> L.	Limestone slopes in woodland.	r
Rosaceae	<i>Sanguisorba minor</i> Scop. subsp. <i>muricata</i> (Spach) Briq.	Waste grounds, fields and slopes.	+
Asteraceae	<i>Rhagadiolus stellatus</i> (L.) Gaertner	Rocky limestone slopes, garigue and waste ground.	r
Asteraceae	<i>Hypochoeris glabra</i> L.	Garigue and fixed sand dunes.	1
Asteraceae	<i>Tussilago farfara</i> L.	Waste and sandy places and damp ground.	1
Fabaceae	<i>Vicia villosa</i> Roth	Rocky places, fields, banks, damp places.	1
Lauraceae	<i>Laurus nobilis</i> L.	Coastal macchie, dense bushes mixed with <i>Myrtus</i> . <i>Phillyrea</i> and <i>Erica arborea</i> , scattered as underwood in <i>Pinus brutia</i> forest, rocky slopes damp gorges.	+
Poaceae	<i>Hordeum bulbosum</i> L.	Rocky limestone or igneous slope, steppe, forest margins, lush meadows.	1

Table 3. Contd.

Asteraceae	<i>Conyza canadensis</i> (L.) Cronquist	In moist conditions often near sea coasts.	1
Pinaceae	<i>Pinus pinaster</i> Ait.	Coastal sand and dunes.	1
Apiaceae	<i>Torilis arvensis</i> (Huds.) Link	Slopes, banks, field, waste places.	1
Fabaceae	<i>Trifolium angustifolium</i> L. var. <i>angustifolium</i> L.	Fallow fields, steppe, sandy places.	1
Poaceae	<i>Piptatherum coerulescens</i> (Desf.) P. Beauv.	Steep ridge, rocky limestone slopes, conglomerate rocks in river and on cliffs, open <i>Quercus</i> and <i>Pinus brutia</i> forests, waste places with rubber.	1
Rosaceae	<i>Prunus spinosa</i> L.	In scrub and forest remnants	r
Cistaceae	<i>Cistus creticus</i> L.	Macchie and griigue.	+
Orchidaceae	<i>Spiranthes spiralis</i> (L.) Chevall.	Grassy places and open pinus forests.	r
Asteraceae	<i>Cichorium intybus</i> L.	Cultivated fields, meadows and waste places.	+
Fabaceae	<i>Medicago lupulina</i> L.	Scrub, meadows, fields, waste places.	+
Poaceae	<i>Dactylis glomerata</i> L. subsp. <i>hispanica</i> (Roth) Nyman	Forests, steppe, rocky slopes, hillsides, fields, roadsides and sand dunes.	1
Oleaceae	<i>Phillyrea latifolia</i> L.	Dry places in macchie. <i>Pinus brutia</i> or deciduous <i>Quercus</i> forest and mixed deciduous scrub forest.	r
Asteraceae	<i>Scolymus hispanicus</i> L.	Waste lands, roadsides and fallow fields.	+
Betulaceae	<i>Carpinus betulus</i> L.	Broad leaved deciduous or mixed forests in pure stands on level ground.	r
Asteraceae	<i>Inula vulgaris</i> (Lam.) Trevisan	Shaded rocky slopes.	r
Fagaceae	<i>Quercus pubescens</i>	Usually associated with <i>Quercus cerris</i> , <i>Fagus</i> , <i>Castanea</i> , rarely in macchie, in anthropogenic steppe or semi-steppe.	+
Ulmaceae	<i>Ulmus minor</i> Miller subsp. <i>minor</i> Miller	Mixed deciduous forest, thickets by rivers and streams, open slopes often in xerothermic communities.	r
Rosaceae	<i>Mespilus germanica</i> L.	Open forests on rocks and in macchie.	r
Lamiaceae	<i>Origanum vulgare</i> L. subsp. <i>vulgare</i> L.	Dry hills and rocky slopes on calcareous and non-calcareous soils, often in partial shade of coniferous or mixed woods Macchie.	+
Fabaceae	<i>Trifolium arvense</i> L. var. <i>arvense</i> L.	Grassy and waste places in open communities generally.	+
Rubiaceae	<i>Rubia peregrina</i> L.	Hedges, thickets and rocky ground	r
Guttiferae	<i>Hypericum cerastioides</i> (Spach) Robson	Siliceous stony places or woodland.	+

Table 4. Plant species, their general habitat characteristics and cover-abundance scales on sample area reclaimed with *Pinus pinea* L.

The plant family	The scientific name of the plant taxa	General habitat characteristic	The cover-abundance scale
Pinaceae	<i>Pinus pinea</i> L.	Coastal areas.	5
Rosaceae	<i>Rubus sanctus</i> Schreber	Open scrub, rocky slopes, banks of rivers, fixed dunes, coastal plains, waste places.	1
Ericaceae	<i>Arbutus unedo</i> L.	Macchie often with <i>Erica arborea</i> or under <i>Pinus brutia</i> , often on non-calcareous soils.	r
Cyperaceae	<i>Carex distachya</i> Desf. var. <i>distachya</i> Desf.	Dry stony slopes, open forests and roadsides.	1
Rosaceae	<i>Rosa gallica</i> L.	Dunes dry meadows, slopes and macchie often on sand.	r
Fabaceae	<i>Dorycnium rectum</i> (L.) Ser.	Damp and bushy places.	+
Fagaceae	<i>Quercus robur</i> L. subsp. <i>robur</i> L.	Scattered in deciduous forest, flood plains steppe often near streams.	+
Cornaceae	<i>Cornus sanguinea</i> L. subsp. <i>Australis</i>	Limestone slopes in woodland.	+
Lauraceae	<i>Laurus nobilis</i> L.	Coastal macchie, dense bushes mixed with <i>Myrtus</i> , <i>Phillyrea</i> and <i>Erica arborea</i> scattered as underwood in <i>Pinus brutia</i> forest rocky slopes damp gorges.	1
Asteraceae	<i>Conyza canadensis</i> (L.) Cronquist	In moist conditions often near sea coasts.	+
Pinaceae	<i>Pinus pinea</i> L.	Coastal areas.	+
Rosaceae	<i>Prunus divaricata</i> subsp. <i>Divaricata</i>	Open woodland steep slopes among rocks.	r
Cistaceae	<i>Cistus creticus</i> L.	Macchie and grigue.	+
Oleaceae	<i>Phillyrea latifolia</i> L.	Dry places in macchie <i>Pinus brutia</i> or deciduous <i>Quercus</i> forest mixed deciduous scrub forest.	2
Betulaceae	<i>Carpinus betulus</i> L.	Broad leaved deciduous or mixed forests in pure stands on level ground.	r
Rosaceae	<i>Mespilus germanica</i> L.	Open forests on rocks and in macchie.	r
Liliaceae	<i>Ruscus aculeatus</i> L.	<i>Quercus</i> forest and scrub and rocky limestone slopes.	+
Scrophulariaceae	<i>Verbascum xanthophoeniceum</i> Griseb.	Pastures, <i>Pinus</i> forest, <i>Quercus</i> scrub, macchie.	1

Table 4. Contd.

Rosaceae	<i>Pyracantha coccinea</i> Roemer	Limestone slopes, sand dunes in open woodland and scrub.	r
Rubiaceae	<i>Rubia peregrina</i> L.	Hedges, thickets and rocky ground	+
Liliaceae	<i>Smilax excelsa</i> L.	<i>Pinus brutia</i> forest with macchie, deciduous forest and scrub on flood plains and in valleys near water.	r

Table 5. Plant species, their general habitat characteristics and cover-abundance scales on sample area reclaimed by *Robinia pseudoacacia* L.

The plant family	The scientific name of the plant taxa	General habitat characteristic	The cover-abundance scale
Fabaceae	<i>Robinia pseudoacacia</i> L.	Oak-hickory forests, well in many different habitats.	4
Rosaceae	<i>Rubus sanctus</i> Schreber	Open scrub, rocky slopes, banks of rivers, fixed dunes, coastal plains and waste places.	3
Rosaceae	<i>Rosa canina</i> L.	Banks, rocky slopes, scrub, hedges, forests and clearings limestone places.	2
Ericaceae	<i>Arbutus unedo</i> L.	Macchie often with <i>Erica arborea</i> or under <i>Pinus brutia</i> often on non-calcareous soils.	+
Rosaceae	<i>Rosa sempervirens</i> L.	Dunes, slopes and scrub at low elevations up to 500 m.	+
Poaceae	<i>Cynosurus echinatus</i> L.	Woodland (usually deciduous) dry hillsides, grassy places, fields and roadsides.	1
Fagaceae	<i>Quercus petraea</i> subsp. <i>Iberica</i>	In <i>Quercus</i> and <i>Fagus</i> forests.	1
Fabaceae	<i>Lotus edulis</i> L.	Waste places, stony ground, dunes,	+
Poaceae	<i>Hordeum murinum</i> L. Subsp. <i>leporinum</i> (Link) Arc.	Steppe, river banks, lake margins, fields and roadsides.	1
Asteraceae	<i>Conyza canadensis</i> (L.) Cronquist	In moist conditions, often near sea coasts.	1
Poaceae	<i>Piptatherum coerulescens</i> (Desf.) P. Beauv.	Steep ridges, rocky limestone slopes, conglomerate rocks in river and on cliffs. Open <i>Quercus</i> and <i>Pinus brutia</i> forests and waste places with rubber.	1
Rosaceae	<i>Prunus divaricata</i> subsp. <i>Divaricata</i>	Open woodland, steep slopes and among rocks.	+
Asteraceae	<i>Cichorium intybus</i> L.	Cultivated fields, meadows and waste places.	1

Table 5. Contd.

Rosaceae	<i>Pyracantha</i> Roemer	<i>coccinea</i>	Limestone slopes, sand dunes and in open woodland and scrub.	1
Asteraceae	<i>Inula vulgaris</i> Trevisan	(Lam.)	Shaded rocky slopes.	1
Liliaceae	<i>Smilax excelsa</i> L.		<i>Pinus brutia</i> forest with macchie and deciduous forest and scrub on flood plains and in valleys near water.	1
Fabaceae	<i>Robinia pseudoacacia</i> L.		Oak-hickory forests and well in many different habitats.	2
Rosaceae	<i>Crataegus</i> Jacq.	<i>monogyna</i>	Hillsides, macchie, <i>Quercus</i> scrub, mixed forests and roadsides.	+
Rosaceae	<i>Crataegus</i> Jacq.	<i>monogyna</i>	Hillsides, macchie, <i>Quercus</i> scrub, mixed forests and roadsides.	1
Rubiaceae	<i>Rubia peregrina</i> L.		Hedges, thickets and rocky ground	+
Polygonaceae	<i>Rumex acetosella</i> L.		Fields, banks and waste places.	1
Onagraceae	<i>Epilobium tetragonum</i> L. subsp. <i>tetragonum</i> L.		Roadsides and fields.	r
Guttiferae	<i>Hypericum cerastoides</i> (Spach) Robson		Siliceous stony places or woodland.	1

tetragonum species (Table 5).

The naturally revegetated area which abandoned after the open coal mining; no tree layer and shrub layer cover has been estimated 5% with an average height of 3.5 m. Herb layer cover has been estimated 90% with an average height of 0.5 m. The lowest number of plant species has been determined in this sample area. 19 plant species belonging to 9 plant families were determined (Table 6). Primary common plant family was Rosaceae and the secondary were Asteraceae and Fabaceae. *Trifolium arvense* var. *arvense*, *Trifolium angustifolium* var. *angustifolium* and *Rumex acetosella* have the high-est cover abundance scales in the area. On the other hand, the lower cover abundance scales have been determined on *Prunus spinosa*, *Cirsium arvense*, *Pyrus elaeagnifolia* subsp. *elaeagnifolia*, *Crataegus monogyna*, and *Ulmus minor* subsp. *minor* species (Table 6).

As shown on Table 7, highest Shannon diversity index (H') was found on the sample area reclaimed with maritime pine. Plant species richness (S) was highest under umbrella pine and plant species evenness (J') was highest on black locust sample area (Table 7). Shannon diversity index and its components gave the different

results among sample areas. However, the highest values were found on reclaimed sites. Despite the sample area reclaimed, black locust has the best soil conditions, it has only the highest plant species evenness (J') value among areas. Primary revegetation on coal-mining spoils in Agacli-Istanbul, the best-represented species belongs to Rosaceae. Similarly, some similar plant species determined in this study show the resistance and survival capability on degraded soils in some research areas close to the Agacli mine spoils (Demir et al., 2008).

Many studies have been published on either spontaneous revegetation of various spoil heaps, especially in North America and Europe or vegetation development after technical reclamation (Hodačová and Prach, 2003). In addition, some authors have recently studied the naturally occurring vegetation that grows on and around mining zones (Melendo et al., 2002; Álvarez-Rogel et al., 2004; Conesa et al., 2007b). However, this study are not aware of many studies in which spontaneously revegetated spoil heaps were directly compared in a quantitative way with those artificially afforested or reclaimed by technical methods (Hodačová and Prach, 2003). Investigations into primary and secondary succession on new

Table 6. Plant species, their general habitat characteristics and cover-abundance scales on open sample area.

The plant family	The scientific name of the plant taxa	General habitat characteristic	The cover-abundance scale
Rosaceae	<i>Pyrus elaeagnifolia</i> Pallas subsp. <i>elaeagnifolia</i> Pallas	Coniferous and deciduous forests and forest remnants and fields.	r
Rosaceae	<i>Rosa sempervirens</i> L.	Dunes, slopes and scrub at low elevations up to 500 m.	1
Rosaceae	<i>Pyrus elaeagnifolia</i> Pallas subsp. <i>elaeagnifolia</i> Pallas	Coniferous and deciduous forests and forest remnants and fields.	1
Rosaceae	<i>Crataegus monogyna</i> Jacq.	Hillsides, macchie, <i>Quercus</i> scrub, mixed forests and roadsides.	r
Asteraceae	<i>Tussilago farfara</i> L.	Waste and sandy places and damp ground.	1
Fabaceae	<i>Lotus edulis</i> L.	Waste places, stony ground and dunes.	+
Polygonaceae	<i>Rumex acetosella</i> L.	Fields, banks and waste places.	2
Rosaceae	<i>Prunus spinosa</i> L.	In scrub and forest remnants.	r
Fabaceae	<i>Melilotus neapolitana</i> Ten.	Waste places.	2
Asteraceae	<i>Cichorium intybus</i> L.	Cultivated fields, meadows and waste places.	1
Asteraceae	<i>Sonchus oleraceus</i> L.	Fields, waste places.	1
Poaceae	<i>Piptatherum coerulescens</i> (Desf.) P. Beauv.	Steep ridges, rocky limestone slopes, conglomerate rocks in river and on cliffs. Open <i>Quercus</i> and <i>Pinus brutia</i> forests and waste places with rubber.	1
Asteraceae	<i>Cirsium arvense</i> (L.) Scop.	Roadsides, river banks, ditches, pastures, cultivated land, wheat and cornfields. Tea plantations and steppe.	r
Apiaceae	<i>Daucus carota</i> L.	Meadows, slopes, sand dunes and fields.	+
Lamiaceae	<i>Calamintha nepeta</i> (L.) Savi	<i>Fagus-castanea</i> forest, sandy rocky limestone slopes, fields and river banks, ruins and sandy beach.	+
Ulmaceae	<i>Ulmus minor</i> Miller subsp. <i>minor</i> Miller	Mixed deciduous forest, thickets by rivers and streams. Open slopes often in xerothermic communities.	r
Fabaceae	<i>Trifolium angustifolium</i> L. var. <i>angustifolium</i> L.	Fallow fields, steppe and sandy places.	2
Fabaceae	<i>Trifolium arvense</i> L. var. <i>arvense</i> L.	Grassy and waste places in open communities generally.	3
Guttiferae	<i>Hypericum cerastoides</i> (Spach) Robson	Siliceous stony places or woodland.	1

Table 7. Shannon index (H'), richness (S) and evenness (J') calculated for sample areas.

Sample area	Shannon diversity index (H')	Plant species richness (S)	Plant species evenness (J')
Maritime pine (<i>Pinus pinaster</i> Ait.)	3.55	41	0.95
Umbrella pine (<i>Pinus pinea</i> L.)	2.83	49	0.93
Black locust (<i>Robinia pseudoacacia</i> L.)	3.03	23	0.96
Open-naturally revegetated area	2.78	19	0.94

anthropogenic 'soils' are revealing significant facets of vegetation dynamics over a large range of environmental conditions (Jochimsen, 2001; Martínez Ruiz et al., 2001; Parrotta and Knowles, 2001; Martínez-Ruiz and Fernández-Santos, 2005). Chambers et al. (1987) interpreted that, available nitrogen in soil fluctuates and is often the most limiting nutrient in mine spoils. They also found that larger pools of organic matter and total nitrogen existed on their reference sites than on naturally revegetated sites. Relatively naturally revegetated sites have high levels of P, K, Ca also fluctuation in NH_4^+ and NO_3^- exhibited smaller in mine spoils (Chambers et al., 1987). In addition, increases in soil nutrients suggest that nutrient retention and the establishment of substantial soil flora is occurring, providing evidence for the sustainability of the soils (Lubke et al., 1996). Spontaneous plant communities that colonize mine tailings in Southern Spain showed different behavior depending on the pH: neutral tailing the plant communities were formed by less number of plant species than in acid tailings (Conesa et al., 2007a). However, substrate pH affects plant growth mainly through its effect on the solubility of chemicals, including toxic metals and nutrients on reclaimed mine sites (Pratas et al., 2005). Conesa et al. (2006) reported pH and electrical conductivity as the main factors that determine the establishment of tolerant plant species in mine tailings.

In this study, significantly higher soil nitrogen and pH values were observed under black locust area. However, suitable soil conditions for plant regeneration are determined under black locust, richness of naturally revegetated plant species was highest under the site reclaimed with maritime pine. Black locust area has only the highest species evenness value. Possibly, the other undetermined factors such as water retention, micro climatic conditions, micro relief changes caused by mining in the landscape, seed banks, adaptation capability of species, etc. can be effective on species richness.

In semi-arid mining zones, the establishment of vegetation also requires plant species adapted to drought (Conesa et al., 2007b). Succession on depositional soils has characteristics of both primary and secondary succession, depending on the fertility of the substrate and the availability of propagules. In any case, the pattern and duration of succession depends not only on climate, physical and chemical properties of the substrate, plant residues or seed stock, but also on the proximity of plant

diaspores (Martínez Ruiz et al., 2001; Martínez-Ruiz and Fernández-Santos, 2005). The results of Hodačová and Prach (2003) indicates that, spontaneous succession should be considered as a reasonable alternative to technical reclamation of spoil heaps in the area, providing more diverse vegetation cover than technical reclamation. They observed that in the studied spoil heaps, a dense herb layer protected slopes better against erosion than dense tree stands with a low herb cover (Hodačová and Prach, 2003).

However, taxonomic (richness) and structural (patchiness and vertical distribution) diversity are both important considerations for reclamation and can be used to monitor the success of rehabilitation as habitat (Smyth and Dearden, 1998). Pratas et al. (2005) described that, some plant species can be used for the purpose of mine restoration and minimization of mining impacts. The plant communities that can be found in mine tailings are frequently formed by few plant species (Conesa et al., 2007b). On the other hand, no single vegetation parameter, for example, cover, abundance, density, biomass, provides the best index of the vegetation condition, so collection of many types of vegetation data is necessary to detect spatiotemporal changes in vegetation (Smyth and Dearden, 1998).

To establish the plant cover on the surface-mined sites, the two most important factors influencing species selection are the soil properties and the tolerance levels of the selected plants. Plant communities that are tolerant to imposed stress conditions on mine spoils can fulfill the objectives of stabilization, pollution control, visual improvement and removal of threats to mankind. The constraints related to plant establishment and amendment of the physical and chemical properties of the toxic metalliferous soils depend upon the appropriate choice that will be able to grow in such hostile. Thus, the plant community tolerant to toxic trace elements play a major role in remediation of degraded mine soils (Pratas et al., 2005). It is known that species-rich vegetation cover is not the only target of reclamation of such deeply altered sites. The technical reclamation (by afforestation) is certainly very important (Hodačová and Prach, 2003).

Among all the techniques that can be used for *in situ* reclamation of mine wastes, revegetation is considered the most suitable to achieve long term reclamation (Tordoff et al., 2000). Vegetation can provide effective protection against wind carried polluted particles, reducing

cing runoff and the overland flow of water and sediments. Vegetation may also improve nutrient conditions in the soil and form the basis for the establishment of a self-sustaining vegetative cover (Conesa et al., 2007b).

In conclusion, the results of the study indicated that plant species on abandoned open coal mine spoils which have no reclamation techniques, show the resistance and survival capability. These species can be selected as target species to success of coal mine restoration.

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