Estonian Journal of Ecology, 2010, **59**, 1, 3–18 doi: 10.3176/eco.2010.1.01

Assessment of vegetation performance on semicoke dumps of Kohtla-Järve oil shale industry, Estonia

Riina Vaht[a], Margus Pensa[b,c✉], Mait Sepp[a], Aarne Luud[d], Helen Karu[e], and Tiina Elvisto[c]

[a] Department of Geography, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia
[b] Institute of Ecology, Tallinn University, Pargi 15, 41537 Jõhvi, Estonia
[c] Institute of Mathematics and Natural Sciences, Tallinn University, Narva mnt. 25, 10120 Tallinn, Estonia
[d] Department of Environmental Protection, Estonian University of Life Sciences, Kreutzwaldi 64, 51014 Tartu, Estonia
[e] Department of Botany, University of Tartu, Lai 40, 51005 Tartu, Estonia

✉ Corresponding author, margus@ecoviro.johvi.ee

Received 18 September 2009, revised 14 December 2009

Abstract. The performance of vegetation was assessed at semicoke dumping sites of Kohtla-Järve oil shale industry in summers 2004 and 2006. The condition of tree species and the presence of herbaceous species were recorded in areas where the vegetation had been planted or had developed naturally. *Betula pendula* and *Populus balsamifera* were the most abundant tree species on the semicoke dumps covering 0.54 and 0.11 km^2, respectively. Herbaceous vegetation had the highest coverage in stands dominated by *Alnus glutinosa*, but the species composition of herbs was homogeneous under different tree species. Most of the herbaceous species were typical of wasteland areas (ruderal strategy type) or adapted to stressful conditions (stress-tolerant strategy type), including seven protected orchid species. The species composition of herbs was affected by the slope of the dump. Our results indicate that planting with *Alnus glutinosa* gives the best result for the reclamation of semicoke dumps as this tree species promotes the growth of herbaceous vegetation.

Key words: biodiversity, industrial waste, oil shale, reclamation, vegetation, semicoke.

INTRODUCTION

As the global supplies of crude oil are decreasing, other fossil fuels (like coal and oil shale) may gain importance. Oil shale, a relatively less known fossil fuel, contains a significant amount of kerogen, from which liquid hydrocarbons can be extracted. The global supply of oil shale was estimated at 411 Gt in 2005 (Andrews, 2006), but oil shale has an economic value only for 33 countries with the USA, Russia, and Brazil accounting for 86% of the world's oil-shale resources (Brendow, 2003). According to the report by EASAC (2007), the world's leading oil shale producer in 2005 was Estonia (70% of the world's total production), where oil shale is used for power generation, oil production, cement production, and by the chemical industry.

Mining and processing of oil shale have caused several environmental problems in North-East Estonia (Raukas & Punning, 2009). When used for oil extraction, approximately half of the oil shale turns into semicoke during pyrolysis. Although the semicoke has been utilized as a building material, road filling material, and growth substrate for plants (Kaar, 2002; Raave et al., 2004; Värnik et al., 2006; Harzia et al., 2007; Mõtlep et al., 2007), it has little value for industry and has therefore been dumped near chemical plants since the beginning of oil extraction in the 1930s. As manmade hills, these semicoke dumps form remarkable landmarks in the landscape of North-East Estonia (Luud et al., 2003).

Freshly deposed semicoke contains a large amount of phenols and has therefore been regarded as a hazardous substance. Phenols and other pollutants seep from the fresh semicoke and pollute the catchment area of creeks and rivers that flow into the Gulf of Finland. Another major problem is the emission of polycyclic aromatic hydrocarbons (PAHs) and dust that comes from the fine-grained material of semicoke dumps (Orupõld & Henrysson, 1999; Raave et al., 2004). Also, various hazardous chemical compounds (e.g., arsenic acid), which were once used in the oil extraction process, have been buried to Kohtla-Järve semicoke dumps. Some of the semicoke dumps have self-ignited and the burning process is still continuing causing the emission of hydrogen sulphide (H_2S), ammonia (NH_3), and heavy metals into the air (Raave et al., 2004; Oja et al., 2007).

Afforestation has been considered to be the most sustainable way of restoring the productivity of land damaged by oil-shale mining and industry (Vaus, 1970; Kaar, 2002). Since 1971, more than 160 thousand trees have been planted to semicoke dumps in North-East Estonia in order to establish a vital plant cover and to initiate soil formation (Kaar, 2003). The most productive tree species have been broadleaved trees such as *Alnus glutinosa* and *Betula pendula*, while conifers do not perform well on the semicoke dumps (Kaar, 2003). Ostonen et al. (2006) showed that the bioaugmentation of semicoke by supplying phenol-degrading bacteria to the substrate might improve the growth of *B. pendula*. The successful establishment of the tree layer on the semicoke dumps reduces significantly dust emissions (Kaar, 2003).

Natural dispersal of vegetation on semicoke dumps has attracted much less scientific attention than afforestation. However, naturally grown areas together with planted areas have proven to be a great success in creating diverse plant communities in wastelands (Lamb et al., 2005; Hobbs et al., 2006). For example, the self-grown vegetation of Kohtla-Järve semicoke dumps includes several protected plant species, which were found by students of a local gymnasium during their school project (Schmidt, 2006).

The aims of this study were (1) to determine the distribution of different vegetation types on the Kohtla-Järve semicoke dumps by creating a digital vegetation map, (2) to compare the performance of vegetation and the formation of organic soil in different vegetation types, and (3) to analyse the significance of semicoke dumps as a habitat for protected plant species.

MATERIAL AND METHODS

Study area

The study was conducted in an area where semicoke is dumped in Kohtla-Järve, North-East Estonia (59°23′N, 27°13′E). The semicoke dumps are located in the Viru Plateau landscape region, which is an Ordovician limestone plateau. The mean monthly temperatures in the area range from –7 °C in January to 16 °C in July; the mean annual precipitation varies between 600 and 700 mm. The absolute altitude of the region is between 30 and 50 m above sea level (Arold, 2005).

Approximately 73 million tonnes of waste material has been deposited on the Kohtla-Järve semicoke dumps since the 1930s. In total, the semicoke dumping site in Kohtla-Järve occupies 2.2 km^2. However, our study area covered only the older part of the sites where semicoke was dumped from the mid-1930s until the mid-1990s. This old dumping area covers 1.3 km^2 and contains seven semicoke hills grown together. The ridge of the hills is more than 100 m long and the hillside slopes may reach up to 60 degrees. The ridges are directed from east to west, so that hillsides are open to north and south (see Fig. 1). The maximum absolute height of the hills is 172 m and their maximum relative height is 127 m (Pae et al., 2005). The landscape in the study area is highly mosaic with ridges and sharp hillsides alternating with small valleys and plains. The semicoke dumping area was previously covered with fields and semi-natural meadows interspersed with moist mixed forests. Today the same landscape surrounds the area in north and west, whereas industrial and residential areas are located in east and south.

As semicoke is black-coloured, the surface temperature of the semicoke dumps may rise to high levels during summer months. The ground texture on the surface of the dumps is mostly coarse-grained, so the topmost layer of semicoke is prone to droughts. However, at a depth of 5–30 cm, the ground is fine-grained and its water holding capacity is much higher. The pH of fresh semicoke is more than 12, but over time the pH of the topmost layers declines (Ostonen et al., 2006). The composition of the mineral matter of semicoke is relatively uniform. Predominant components in the fresh semicoke are calcite, dolomite, quartz, K-feldspar, and clay minerals (Mõtlep et al., 2007). During deposition, the composition of semicoke changes as unstable phases of minerals are replaced by a considerable amount of ettringite (a Ca–Al-sulphate) (Mõtlep et al., 2007). As the growth substrate for plants, semicoke is a relatively poor material with low concentrations of nitrogen and phosphorus but with a relatively high concentration of potassium (Kaar, 2002).

Sampling

In the first phase of vegetation analysis, the vegetated areas of the semicoke dumps were determined on the areal photos issued by the Estonian Land Board. These vegetated areas were studied in some detail in June and July 2004 and

2006, when 76 plots of 10 m × 10 m were established in the study area. The potential locations for the plots were pre-selected on the areal photos. The selection criterion was even distribution of the plots across the vegetated area of the semicoke dumps. In each plot, the vegetation was divided into tree layer (including shrubs) and herbaceous layer. In the tree and shrub layer, the species composition and the performance (number of healthy plants divided by the total number of plants) of different species were assessed. The origin of the tree layer (either planted or natural) was determined, based on the information found from old reclamation projects. In the herbaceous layer, the presence of herbaceous species was recorded and the general coverage of vegetation was assessed. When the herbaceous layer was very poor and sparse (only a few species or plants were present), the occurrence of species was recorded across a whole plot; in the cases the herbaceous layer was prosperous, quadrates of 1 m × 1 m were used to count plant species. The number of quadrates within a plot depended on the heterogeneity of the herbaceous layer and ranged from two to five. The quadrates were located evenly within plots. The forest floor depth (total thickness of the first generic soil horizons: litter, fermentation, and humus) was assessed in triplicates on each plot.

Data analysis

Based on the areal photos and the data of field observations, a vegetation map of the semicoke dumping area was created (using MapInfo Professional version 5). From the created digital map, the areas of different vegetation types and the hill slopes were measured. The vegetation types were arbitrarily distinguished according to the species composition and origin of the tree and shrub layer (see Table 1). For example, 'Betula10 planted' represents the vegetation where 10-year-old planted saplings of *Betula pendula* are dominant in the tree layer, whereas 'Betula10 natural' is a natural vegetation type where the dominating *Betula pendula* is 10 years old.

In the next step of data analysis, it was checked whether the species composition of herbs was affected by the properties of the tree and shrub layer (i.e., whether the herbaceous layer could be divided among the vegetation types distinguished according to the tree and shrub layer). Prior to any further analysis of the herbaceous layer, a species–area curve was plotted to check whether 76 sampling plots gave a sufficient overview of the most common herbs in the study area. All herbaceous species were divided among Grime's (1979) competitive (C), stress-tolerant (S), and ruderal (R) plant strategies. Plants are exposed to stress (resource limitation) and disturbance (biomass removal) to a variable extent, which leads to the S and R strategies. The C strategy characterizes plants that grow in resource rich (no stress) and undisturbed habitats. Besides there are combinations and intermediate strategy types including the indifferent CSR strategy. Additional information on the strategy types was obtained from Grime et al. (1988) and Hunt et al. (2004).

To describe the patterns in the species composition of herbs, we used non-metric multidimensional scaling (NMS; McCune & Grace, 2002). The input data were the presence of herbaceous species in a study plot; only the species that occurred in at least two plots were included in the analysis. Two different data sets were used in NMS: one included all vegetation types, while the other included only the vegetation types where *Betula pendula* dominated in the tree layer (*Betula* chronosequence data). Before running NMS, the presence data of herbaceous species were transformed by using Booleyan smoothing. A random starting configuration and Sørensen's distance measure were applied in NMS. We used PC-ORD version 5 to do NMS. Pearson's correlation *r* was computed between vegetation data and environmental variables using SigmaPlot 10.

RESULTS

Vegetation types

In total, 12 different vegetation types were identified: 11 where trees or shrubs dominated in the vegetation and one where only herbaceous vegetation was present (Fig. 1, Table 1). Together, these 12 vegetation types covered 0.89 km^2, that is about 70% of the study area. The area where trees dominated was 0.55 km^2.

The most common tree species was *Betula pendula*. The population of planted *B. pendula* covered 0.35 km^2 and an extra 0.19 km^2 was covered by naturally grown *B. pendula* stands (Table 1). *Populus balsamifera* was the second most abundant planted tree species on the semicoke dumps. This exotic species had started to spread naturally on the semicoke dumps. Most of the more than 20-year-old *P. balsamifera* trees were not healthy and had dead branches in their canopies, while in the mixed stands where it was not a dominant species, *P. balsamifera* was healthy. In total, *P. balsamifera* stands covered 0.11 km^2 (Table 1). Of other vegetation types, the treeless cover of herbaceous species occupied the largest area (0.21 km^2; 'Grass natural' in Table 1).

In the understory, the dominating species were *B. pendula*, *P. balsamifera*, and *P. tremula*. The naturally grown *Salix* spp. population was abundant (Table 1). The exotic species *Hippophaë rhamnoides* and *Elaeagnus commutata* had renewed well and spread almost everywhere on the semicoke dumps (Table 1). A small set of *Pinus mugo* had also been planted on the semicoke dumps; however, this species did not perform as well as other understory species.

There was no humus layer in the young *B. pendula* and *P. balsamifera* stands. An up to 2-cm-thick humus layer with leaf mould had developed in 20-year-old and older *B. pendula* stands. The thickest forest floor was measured in the 'Alnus30 planted' vegetation type; however, comparison of mean values of forest

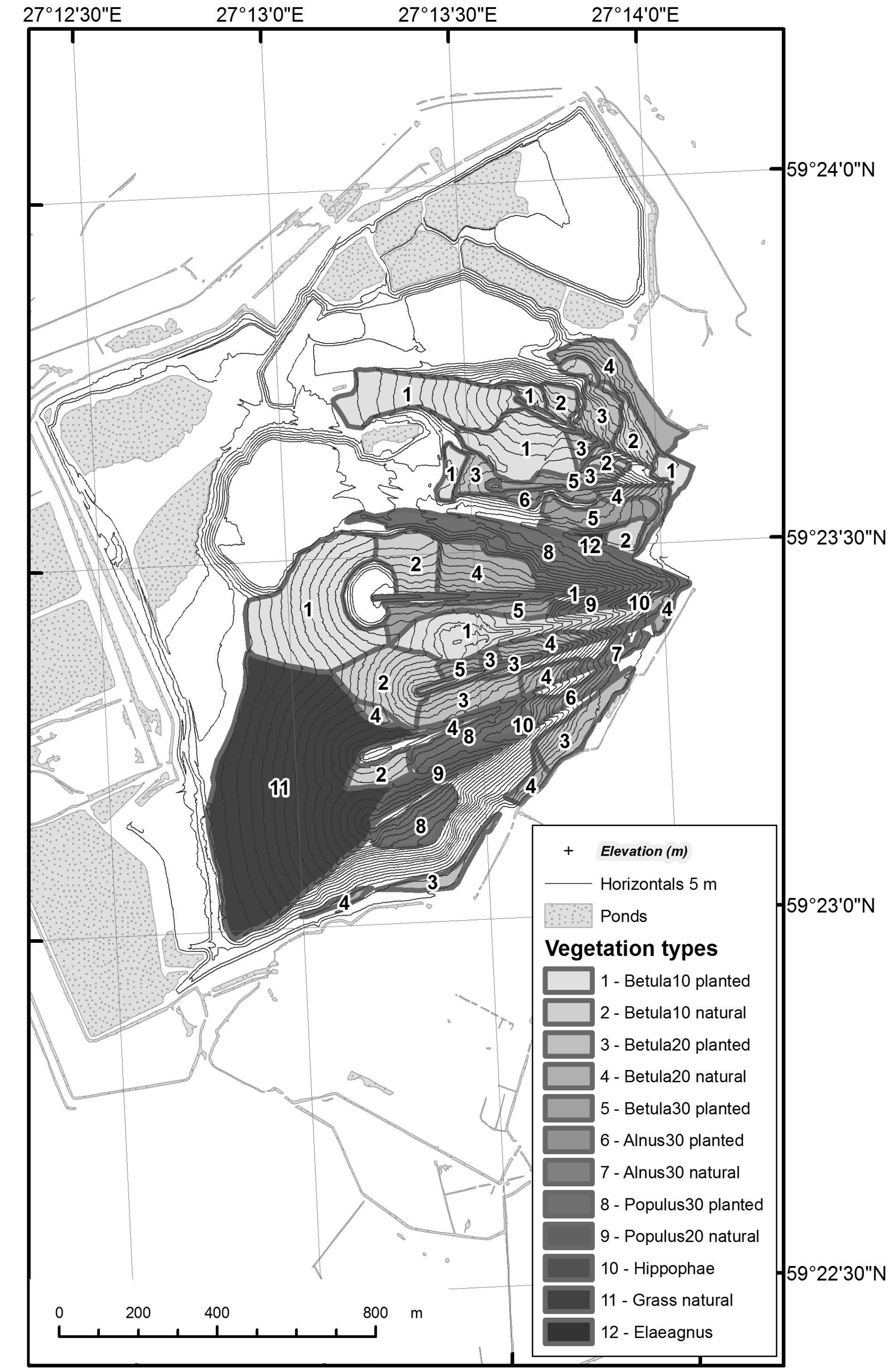

Fig. 1. Map of the distribution of the vegetation types on Kohtla-Järve semicoke dumps.

Table 1. Characteristics of vegetation types distinguished according to the properties of the tree and shrub layers on Kohtla-Järve semicoke dumps

Vegetation type	Planted species	Natural species	Area, km^2	Average forest floor depth, cm (SD)	Coverage of herb layer, %	No. of plots
Betula10 planted	*Betula pendula*, *Populus balsamifera*, *Pinus mugo*	*Elaeagnus commutata*, *Salix* sp.	0.22	0 (0)	5–20	5
Betula10 natural		*Betula pendula*, *Populus balsamifera*, *Salix* sp.	0.09	0 (0)	5–10	11
Betula20 planted	*Betula pendula*, *Hippophaë rhamnoides*, *Swida* sp., *Caragana arborescens*, *Elaeagnus commutata*, *Padus avium*	*Populus balsamifera*, *Populus tremula*	0.08	2.22 (2.54)	50	13
Betula20 natural	*Hippophaë rhamnoides*	*Betula pendula*, *Populus balsamifera*, *Populus tremula*, *Pinus sylvestris*, *Picea abies*, *Salix* sp.	0.10	1.08 (1.50)	10–50	16
Betula30 planted	*Betula pendula*	*Populus balsamifera*, *Populus tremula*, *Pinus sylvestris*, *Salix* sp.	0.05	3 (2.83)	40	12
Alnus30 planted	*Alnus glutinosa*	*Betula pendula*, *Populus tremula*, *Alnus glutinosa*	0.01	7.3 (4.62)	100	4
Alnus30 natural		*Alnus glutinosa*, *Betula pendula*, *Populus balsamifera*, *Populus tremula*, *Sorbus aucuparia*, *Salix* sp.	0.005	2 (0.82)	50	1
Populus30 planted	*Populus balsamifera*, *Hippophaë rhamnoides*	*Populus balsamifera*, *Betula pendula*, *Sorbus aucuparia*, *Swida* sp.	0.09	1.2 (1.30)	10–20	6
Populus20 natural		*Populus balsamifera*, *Betula pendula*, *Sorbus aucuparia*, *Cornus* sp.	0.02	0 (0)	5	4
Hippophaë	*Hippophaë rhamnoides*		0.003	2 (1.8)	0–10	1
Elaeagnus	*Elaeagnus commutata*	*Betula pendula*, *Populus tremula*	0.002	0 (0)	0	1
Grass natural		*Betula pendula*, *Populus balsamifera*	0.21	0	0–5	2

floor thickness indicated that differences among vegetation types were insignificant (one-way ANOVA, $F = 2.5$, $P = 0.06$; only the vegetation types where the forest floor layer occurred at least in one study plot were included in the analysis).

Herbaceous vegetation

The total number of herbaceous species recorded across all stand types was 64. The first order jackknife estimate was 85 species and the second order jackknife estimate was 94 species (see McCune & Grace, 2002 for more information about the jackknife method). Thus, 76 study plots gave a sufficient overview of the species composition of herbaceous vegetation. The highest number of herbaceous species was found in the 'Betula20 natural' vegetation type, the lowest in the 'Grass natural' vegetation type (Table 2). The coverage of herbaceous vegetation was the highest in the 'Alnus30 planted' vegetation type (Table 1). The general coverage of herbaceous vegetation did not correlate with the hill slope ($r = 0.22$, $P = 0.3$), as there were bare plots also in areas with the zero slope. However, no vegetation grew in areas where the slope was more than 50 degrees and no study plots were established in such areas.

The most abundant species in the herbaceous vegetation was *Achillea millefolium*, which occurred in 46 plots, followed by *Tussilago farfara* and *Taraxacum officinale* (both in 41 plots). *Pyrola rotundifolia* occurred in 25 plots (Table 2). The processing of species composition data using NMS ordination resulted in a three-dimensional solution both for all vegetation types (final stress 10.3, final instability <0.001, 250 randomized runs in the Monte Carlo test, $P = 0.004$) and for the *Betula* chronosequence data (final stress 10.0, final instability <0.001, 250 randomized runs in the Monte Carlo test, $P < 0.01$). Cumulatively, the NMS axes explained 90% of the variance in the species composition of all vegetation type data, and 94% of the variation in the species composition of the *Betula* chronosequence data. In both cases, the study plots of different vegetation types were homogeneously distributed across the NMS space, indicating that the species composition of herbs did not differ among vegetation types (Fig. 2). In the case of the all vegetation type dataset, the slope of semicoke dumps correlated significantly with the 3rd NMS axis ($r = 0.41$, $P = 0.04$). Consequently, the species composition of herbaceous vegetation was affected by the hill slope.

Most herbaceous vegetation species were naturally grown and common to wasteland areas with low soil fertility. As regards plant strategy types, generalists (CSR-strategy), stress-tolerant species, and ruderals were dominant in the herbaceous vegetation (Table 2). The presence and abundance of several orchid species (*Dactylorhiza baltica*, *D. fuchsii*, *D. incarnata*, *D. maculata*, *Epipactis atrorubens*, *E. helleborine*, and *Orchis militaris*) in the herbaceous vegetation was somewhat surprising as some of them (e.g., *O. militaris*) did not occur in the areas surrounding the semicoke dumps of Kohtla-Järve.

Table 2. Occurrence of herbaceous species in different vegetation types on the semicoke dumps in Kohtla-Järve. The numbers indicate in how many study plots the species were found within a vegetation type (relative number of the study plots where the species occurred is in parentheses). Protected species are in bold, old forest species (according to Hermy et al., 1999) are marked with an asterisk. Strategy types are according to Grime's (1979) C–S–R plant strategies (C – competitive, S – stress-tolerant, R – ruderal)

Species	Strategy type	Betula10 planted	Betula10 natural	Betula20 planted	Betula20 natural	Betula30 planted	Alnus30 planted	Alnus30 natural	Populus30 planted	Populus20 natural	Hippophaë	Grass natural
Achillea millefolium	CR/CSR	2 (0.4)	5 (0.5)	10 (0.8)	11 (0.7)	8 (0.7)	4 (1.0)	1 (1.0)	4 (0.7)		1 (1.0)	
Agrostis capillaris	CSR			1 (0.1)								
Anthemis tinctoria	R	1 (0.2)	3 (0.3)	5 (0.4)	3 (0.2)	2 (0.2)		1 (1.0)	1 (0.2)	1 (0.3)	1 (1.0)	
Artemisia absinthium	CR/CSR	1 (0.2)	1 (0.1)									
Artemisia campestris			1 (0.1)		5 (0.3)				1 (0.2)			
Artemisia vulgaris	C/CR		1 (0.1)	2 (0.2)	1 (0.1)			1 (1.0)	2 (0.3)			
Barbarea vulgaris	R/CR	2 (0.4)										1 (0.5)
Calamagrostis epigeios	C/SC	3 (0.6)	4 (0.4)	1 (0.1)	7 (0.4)			1 (1.0)	2 (0.3)		1 (1.0)	1 (0.5)
Campanula rotundifolia	S							1 (1.0)				
*Campanula trachelium**	CSR							1 (1.0)		1 (0.3)		
Carduus crispus	CR	1 (0.2)	1 (0.1)									
Centaurea jacea		1 (0.2)						1 (1.0)	1 (0.2)		1 (1.0)	
Cerastium holosteoides		2 (0.4)		1 (0.1)								
Cerastium sp.				1 (0.1)	1 (0.1)							
Cirsium arvense	C								1 (0.2)		1 (1.0)	
*Convallaria majalis**	S/SC							1 (1.0)				
Crepis sp.			4 (0.4)	4 (0.3)	4 (0.3)	3 (0.3)	2 (0.5)		3 (0.5)			
Dactylis glomerata	C/CSR				1 (0.1)		2 (0.5)	1 (1.0)	1 (0.2)			
Dactylorhiza baltica	S/CSR		1 (0.1)	2 (0.2)	3 (0.2)	1 (0.1)			1 (0.2)			
Dactylorhiza fuchsii*	S/CSR			1 (0.1)	1 (0.1)				1 (0.2)			

Continued overleaf

Table 2. *Continued*

Species	Strategy type	Betula10 planted	Betula10 natural	Betula20 planted	Betula20 natural	Betula30 planted	Alnus30 planted	Alnus30 natural	Populus30 planted	Populus20 natural	Hippophaë	Grass natural
Dactylorhiza incarnata	S/CSR			1 (0.1)								
Dactylorhiza maculata	S/CSR	1 (0.2)		1 (0.1)	3 (0.2)	2 (0.2)						
Daucus carota	SR/CSR				1 (0.1)							
Deschampsia cespitosa	SC/CSR	1 (0.2)	2 (0.2)	2 (0.2)	1 (0.1)	3 (0.3)	2 (0.5)		1 (0.2)	2 (0.5)		
Echium vulgare	R/CSR		1 (0.1)		6 (0.4)				2 (0.3)	1 (0.3)	1 (1.0)	
Epilobium angustifolium			4 (0.4)	3 (0.2)	6 (0.4)	1 (0.1)			4 (0.7)			1 (0.5)
Epilobium sp.									1 (0.2)			
Epipactis atrorubens	S	1 (0.2)	2 (0.2)	3 (0.2)	3 (0.2)	4 (0.3)	3 (0.8)	1 (1.0)	2 (0.3)	1 (0.3)		
Epipactis helleborine	S			1 (0.1)								
Erucastrum gallicum			1 (0.1)	2 (0.2)					1 (0.2)			
Erysimum cheiranthoides	R				1 (0.1)							
Festuca pratensis	CSR		4 (0.4)	1 (0.1)	2 (0.1)	5 (0.4)			1 (0.2)	2 (0.5)		
Festuca rubra	CSR		1 (0.1)	6 (0.5)	7 (0.4)	2 (0.2)		1 (1.0)	2 (0.3)	2 (0.5)	1 (1.0)	
Galium album					1 (0.1)							
Leucanthemum vulgare	C/CSR										1 (1.0)	
Medicago lupulina	R/SR			1 (0.1)	6 (0.4)	2 (0.2)					1 (1.0)	
Medicago sativa	C/CSR			1 (0.1)		2 (0.2)						
Medicago × varia	C/CSR			2 (0.2)								
Melilotus albus	CR			3 (0.2)	5 (0.3)	3 (0.3)						
Orchis militaris	S/SR			3 (0.2)	1 (0.1)	2 (0.2)	1 (0.3)		3 (0.5)			
Orthilia secunda						1 (0.1)						
Pastinaca sativa			2 (0.2)	6 (0.6)	8 (0.5)	4 (0.3)		1 (1.0)	4 (0.7)	1 (0.3)	1 (1.0)	
Pilosella officinarum	S/CSR		2 (0.2)		3 (0.2)				2 (0.3)			
Pilosella sp.			1 (0.1)	1 (0.1)	1 (0.1)	1 (0.1)						

Table 2. *Continued*

Species	Strategy type	Betula10 planted	Betula10 natural	Betula20 planted	Betula20 natural	Betula30 planted	Alnus30 planted	Alnus30 natural	Populus30 planted	Populus20 natural	Hippophaë	Grass natural
Pimpinella major	CSR										1 (1.0)	
Poa angustifolia	S/CSR		1 (0.1)			2 (0.2)						
Poa compressa	S/CSR		3 (0.3)	3 (0.2)	7 (0.4)	1 (0.1)		1 (1.0)	1 (0.2)			
Poa palustris	CSR				4 (0.3)							
Poa pratensis	CSR	1 (0.1)		4 (0.3)								
Poa trivialis	CR/CSR				2 (0.1)	2 (0.2)	4 (1.0)					
Potentilla heidereichii			1 (0.1)									
Potentilla intermedia		1 (0.2)										
Pyrola rotundifolia	S		3 (0.3)	3 (0.2)	9 (0.6)	4 (0.3)		1 (1.0)	3 (0.5)	2 (0.5)		
Reseda lutea	SR/CSR	3 (0.6)	2 (0.2)		3 (0.2)					1 (0.3)	1 (1.0)	2 (1.0)
Sagina nodosa	S/SR	1 (0.2)										
Silene pratensis			1 (0.1)						1 (0.2)			
Solanum dulcamara	C/CSR			1 (0.1)	1 (0.1)				2 (0.3)			
Solidago virgaurea	S/CSR		1 (0.1)		6 (0.4)	1 (0.1)		1 (1.0)	4 (0.7)			
Sonchus oleraceus	R/CR		2 (0.2)	1 (0.1)	1 (0.1)				1 (0.2)			
Taraxacum officinale	R/CSR	2 (0.4)	6 (0.6)	6 (0.5)	9 (0.6)	6 (0.5)	4 (1.0)	1 (1.0)	5 (0.8)	2 (0.5)		
Trifolium pratense	CSR				1 (0.1)							
Tussilago farfara	CR	4 (0.8)	7 (0.7)	5 (0.4)	5 (0.3)	3 (0.3)	4 (1.0)	1 (1.0)	5 (0.8)	4 (1.0)	1 (1.0)	2 (1.0)
Valeriana officinalis	CSR								1 (0.2)			
Vicia cracca	C/CSR			1 (0.1)	1 (0.1)							
Total number of species		17	29	34	38	24	9	17	31	12	13	5

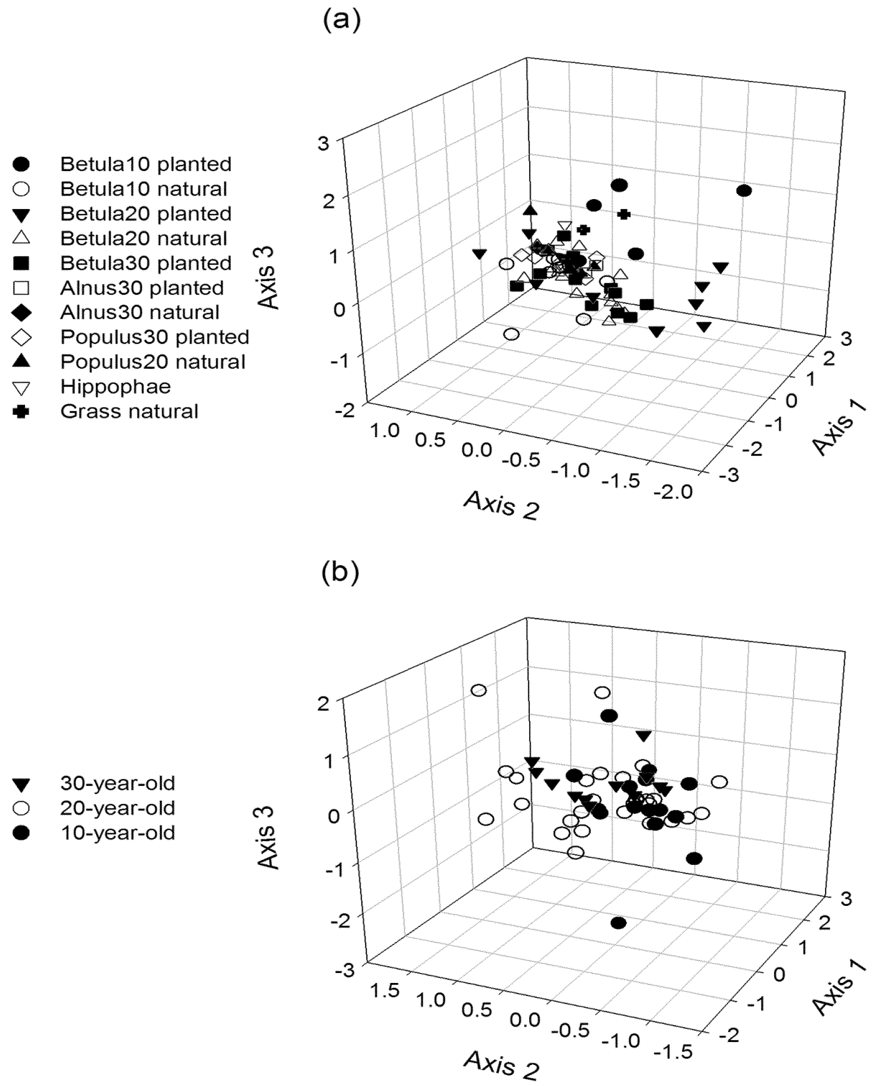

Fig. 2. Nonmetric multidimensional scaling (NMS) ordination of the herbaceous vegetation data from different vegetation types. (a) Dataset of all vegetation types; (b) *Betula* chronosequence dataset. Axis 3 in (a) shows the increase in the dump slope; the other axes did not correlate with the measured environmental variables.

DISCUSSION AND CONCLUSIONS

The assessment of the success of reclamation depends on the initial goals of the project. The aim of the re-establishment of vegetation is often just to prevent erosion and to add economic value to the degraded lands. This involves planting fast-growing trees, which often results in the establishment of mono-specific plantations of exotic species on the degraded landscapes (Hunter et al., 1998). However, as the loss of biodiversity has become more serious, ecologically sound restoration of degraded ecosystems challenges environmental scientists. Thus, it has become particularly important to achieve the same biodiversity in degraded landscapes that was present before degradation or that is characteristic of surrounding non-degraded areas (Palik et al., 2000). For that reason, the selection of planting material has a crucial significance as tree species that may fulfil the less difficult goal of reclamation may have negative effects on the recovery of biodiversity (e.g., Holl, 2002; Pensa et al., 2008).

The Kohtla-Järve semicoke dumping area has been reclaimed by planting approximately 34 different tree and shrub species (26 of them exotic) (Kaar, 2003). From the economic point of few, *Betula pendula* has been the optimal choice for planting as this species survives well under the conditions prevailing on the semicoke dumps (Kaar, 2003). As our results indicate, the formation of a substantial humus layer in the stands dominated by *B. pendula* takes about 20 years. The coverage of herbaceous vegetation is variable but increases with the age in *Betula* stands. As compared to *B. pendula*, *Alnus glutinosa* enhances the growth of herbaceous species and the formation of a soil layer. Thus, if the performance of herbaceous vegetation is prioritized, then planting with *A. glutinosa* should be preferred to *B. pendula* in flatter areas. The species of *Alnus* form symbiotic relationship with N_2-fixing actinomycetes (Huss-Danell, 1997) and influence soil fertility and vegetation productivity through nitrogen-rich leaf litter (Huss-Danell, 1986; Rothe et al., 2002; Uri et al., 2002). For example, in reclaimed oil-shale opencasts, the presence of *A. glutinosa* in the tree layer affects positively the productivity of herbaceous species and soil formation (Pensa et al., 2004, 2008).

High percentage of *Populus* stands on the Kohtla-Järve semicoke dumps is connected to the wide use of these species in creating green belts in industrial towns in the former Soviet Union. However, except for *P. tremula*, all other *Populus* species are alien to the Estonian flora and cause problems at the time of seed dispersal. As compared with *B. pendula*, *Populus* spp. do not thrive on semicoke dumps, and thus, their use as a planting material is not justified. From the exotic species that had started to spread on the semicoke dumps, *Elaeagnus commutata* and *Hippophaë rhamnoides* suppressed almost all other plant species in areas where they dominated. Hence, although both of them help to prevent erosion, their use in reclamation projects has a negative influence on the recovery of biodiversity.

The composition of herbaceous vegetation did not show any distinctive characteristics in different vegetation types. Most of the species were common for wastelands or were generalists without any specific habitat requirements. This indicates that irrespective of the traits of the tree layer, the herbaceous vegetation is in the initial stages of its development and has not yet diverged according to properties of the tree layer. The dominance of ruderals and generalists is typical of areas that are in the first stages of the recovery from a disturbance (Grime et al., 1988). From the 64 recorded herbaceous species, only one, *Festuca rubra*, was sown; others had spread naturally to the dumps. Only three herbaceous species recorded are old forest species according to Hermy et al. (1999) (Table 2).

Although several protected orchid species were abundant in the study area, the value of the vegetation as the habitat for protected species was low. None of these protected orchid species is rare or endangered in the Estonian flora (Kukk & Kull, 2005) and the law does not require the protection of their habitats. However, the higher abundance of orchids on the semicoke dumps as compared with surrounding forests indicates that the conditions on the dumps are especially suitable for these species. One reason might be the high abundance of fungi, which are essential for the germination of orchid seeds; another reason might be the low abundance of competitive plant species, which might suppress the growth of orchids (which are mainly stress-tolerant species; Grime et al., 1988). This explains why only one orchid species was present in the *Alnus* stands, where the coverage of herbaceous vegetation was the highest.

The vegetation cover of disturbed ecosystems depends also on geomorphology, especially the slope gradient. The steep hillsides are open to soil erosion, although a dense vegetation cover with a humus layer can reduce it (Robichaud, 2005). In our study sites, the topsoil texture was gravelly and not solid. Therefore the young vegetation cover on dumps with no humus layer is vulnerable to erosion, especially on steep hillsides. So, the slope of the dump tended to affect the species composition of herbaceous vegetation. Although there was no firm correlation between the slope and vegetation cover, we found almost no vegetation in the steepest parts of hillsides near the ridges, particularly on the southern slopes. Extra activities are needed for the reclamation of those slopes. While microorganisms are essential for reducing the toxicity of semicoke (by biodegrading phenols) (e.g., Juhanson et al., 2007; Truu et al., 2007), the vegetation reduces topsoil erosion and the emission of semicoke dust into the air. Thus, the full coverage of the Kohtla-Järve semicoke dumps with vegetation is an essential task, which, however, cannot be achieved without levelling the dumps.

In conclusion, our results confirm that the planting of *Betula pendula* in order to reclaim the semicoke dumping area has been a successful option, while the use of *Populus* spp. is not justified. *Alnus glutinosa* can give even better results than *B. pendula* in terms of promoting the formation of diverse herbaceous vegetation. The exotic species *Elaeagnus commutata* and *Hippophaë rhamnoides* tend to suppress ground vegetation and planting with these species should be avoided if the recovery of herbaceous diversity is among the targets of reclamation. The significance of the Kohtla-Järve semicoke dumping area as habitat for protected species is low, thus, there are no restrictions for re-shaping the dumps in order to reduce the slopes of the hills.

ACKNOWLEDGEMENTS

Mr Harry Sonford checked the language of the manuscript. The fieldwork was conducted and the vegetation data were collected within a project supported by the Estonian Science Foundation (grant No. 5764) and project 0282119s02 financed by the Ministry of Education and Research, Estonia.

REFERENCES

Andrews, A. 2006. Oil Shale: History, Incentives, and Policy. Congressional Research Service. http://www.fas.org/sgp/crs/misc/RL33359.pdf (visited 2008-08-15).

Arold, I. 2005. *Eesti maastikud*. Tartu University Press, Tartu.

Brendow, K. 2003. Global oil shale issues and perspectives. *Oil Shale*, **20**, 81–92.

EASAC. 2007. *A Study on the EU Oil Shale Industry – Viewed in the Light of Estonian Experience. A Report by EASAC to the Committee on Industry, Research and Energy of the European Parliament*. European Academies Science Advisory Council, London.

Grime, J. P. 1979. *Plant Strategies and Vegetation Processes*. John Wiley & Sons, New York.

Grime, J. P., Hodgson, J. G. & Hunt, R. 1988. *Comparative Plant Ecology. A Functional Approach to Common British Species*. Unwin Hyman, London.

Harzia, H., Orupõld, K., Habicht, J. & Tenno, T. 2007. Leaching behavior of oil shale semicoke: sulphur species. *Oil Shale*, **24**, 583–589.

Hermy, M., Honnay, O., Firbank, L., Grashof-Bokdam, C. & Lawesson, J. E. 1999. An ecological comparison between ancient and other forest plant species of Europe, and the implications for forest conservation. *Biol. Conserv.*, **91**, 9–22.

Hobbs, R. J., Arico, S., Aronson, J., Baron, J. S., Bridgewater, P., Cramer, V. A., Epstein, P. R., Ewel, J. J., Klink, C. A., Lugo, A. E., Norton, D., Ojima, D., Richardson, D. M., Sanderson, E. W., Valladares, F., Vilà, M., Zamora, R. & Zobel, M. 2006. Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecol. Biogeogr.*, **15**, 1–7.

Holl, K. D. 2002. Long-term vegetation recovery on reclaimed coal surface mines in the eastern USA. *J. Appl. Ecol.*, **39**, 960–970.

Hunt, R., Hodgson, J. G., Thompson, K., Bungener, P., Dunnett, N. P. & Askew, A. P. 2004. A new practical tool for deriving a functional signature for herbaceous vegetation. *Appl. Veg. Sci.*, **7**, 163–170.

Hunter, I. R., Hobley, M. & Smale, P. 1998. Afforestation of degraded land—pyrrhic victory over economic, social and ecological reality. *Ecol. Eng.*, **10**, 97–106.

Huss-Danell, K. 1986. Nitrogen in shoot litter, root litter and root exudates from nitrogen-fixing *Alnus incana*. *Plant Soil*, **91**, 43–49.

Huss-Danell, K. 1997. Actinorhizal symbioses and their N_2 fixation. *New Phytol.*, **136**, 375–405.

Juhanson, J., Truu, J., Heinaru, E. & Heinaru, A. 2007. Temporal dynamics of microbial community in soil during phytoremediation field experiment. *J. Envir. Eng. Landscape Manage.*, **15**, 213–220.

Kaar, E. 2002. Coniferous trees on exhausted oil shale opencast mines. *For. Stud.*, **36**, 120–125.

Kaar, E. 2003. *Viru Õlitööstus AS I, II ja IV poolkoksimäe haljastamine 2003. a*. EPKAR Grupp OÜ, Tartu.

Kukk, T. & Kull, T. 2005. *Atlas of the Estonian Flora*. Estonian University of Life Sciences, Tartu.

Lamb, D., Erskine, D. P. & Parrotta, J. A. 2005. Restoration of degraded tropical forest landscapes. *Science*, **310**, 1628–1632.

Luud, A., Liblik, V. & Sepp, M. 2003. Landscape evaluation in industrial areas. *Oil Shale*, **20**, 25–32.

McCune, B. & Grace, J. B. 2002. *Analysis of Ecological Communities*. MjM Software, Gleneden Beach.

Mõtlep, R., Kirsimäe, K., Talviste, P., Puura, E. & Jürgenson, J. 2007. Mineral composition of Estonian oil shale semi-coke sediments. *Oil Shale*, **24**, 405–422.

Oja, V., Elenurm, A., Rohtla, I., Tali, E., Tearo, E. & Yanchilin, A. 2007. Comparison of oil shales from different deposits: oil shale pyrolysis and co-pyrolysis with ash. *Oil Shale*, **24**, 101–108.

Orupõld, K. & Henrysson, T. 1999. Biological treatment of oil shale ash heaps leachate containing phenolic compounds by biofilm reactors with suspended carriers. *J. Resour. Environ. Biotechnol.*, **2**, 219–233.

Ostonen, I., Lõhmus, K., Alama, S., Truu, J., Kaar, E., Vares, A., Uri, V. & Kurvits, V. 2006. Morphological adaptations of fine roots in Scots pine (*Pinus sylvestris* L.), silver birch (*Betula pendula* Roth.) and black alder (*Alnus glutinosa* (L.) Gaertn.) stands in recultivated areas of oil shale mining and semicoke hills. *Oil Shale*, **23**, 187–202.

Pae, T., Luud, A. & Sepp, M. 2005. Artificial mountains in North-East Estonia: monumental dumps of ash and semi-coke. *Oil Shale*, **22**, 333–343.

Palik, B. J., Goebel, P. C., Kirkman, L. K. & West, L. 2000. Using landscape hierarchies to guide restoration of disturbed ecosystems. *Ecol. Appl.*, **10**, 189–202.

Pensa, M., Sellin, A., Luud, A. & Valgma, I. 2004. An analysis of vegetation restoration on opencast oil shale mines in Estonia. *Restor. Ecol.*, **12**, 200–206.

Pensa, M., Karu, H., Luud, A., Rull, E. & Vaht, R. 2008. The effect of planted tree species on the development of herbaceous vegetation in a reclaimed opencast. *Can. J. For. Res.*, **38**, 2674–2686.

Raave, H., Kuldkepp, P., Leedu, E. & Merivee, A. 2004. Recultivation substance and composts produced from semi-coke: the effect on soil characteristics, the yield of field crops and the environment. *Oil Shale*, **21**, 59–73.

Raukas, A. & Punning, J.-M. 2009. Environmental problems in the Estonian oil shale industry. *Energ. Envir. Sci.*, **2**, 723–728.

Robichaud, R. P. 2005. Measurement of post-fire hillslope erosion to evaluate and model rehabilitation treatment effectiveness and recovery. *Int. J. Wildland Fire*, **14**, 475–485.

Rothe, A., Cromack, K., Resh, S. C., Makineci, E. & Son, Y. 2002. Soil carbon and nitrogen changes under Douglas-fir with and without red alder. *Soil Sci. Soc. Am. J.*, **66**, 1988–1995.

Schmidt, M. 2006. Orchid species in Kohtla-Järve industrial area. In *Nature of Oil Shale Region* (Puura, I. et al., eds), pp. 107–109. Estonian Naturalists' Society, Tartu.

Truu, J., Heinaru, E., Vedler, E., Juhanson, J., Viirmae, M. & Heinaru, A. 2007. Formation of microbial communities in oil shale chemical industry solid wastes during phytoremediation and bioaugmentation. *NATO Science Series* IV: *Earth and Environmental Sciences*, **76**, 57–66.

Uri, V., Tullus, H. & Lõhmus, K. 2002. Biomass production and nutrient accumulation in short-rotation grey alder (*Alnus incana* (L.) Moench) plantation on abandoned agricultural land. *For. Ecol. Manage.*, **161**, 169–179.

Värnik, R., Karp, K., Pihelgas, E., Merivee, A. & Lehtsaar, J. 2006. Effect of semicoke-based compost mixtures on gross margin of horticultural crops. *Oil Shale*, **23**, 39–52.

Vaus, M. 1970. *Eesti põlevkivikarjääride pinnaste metsakasvatuslikud omadused*. Ministry of Forestry and Nature Conservation, Tallinn.

Kohtla-Järve poolkoksimägede taimkatte seisund

Riina Vaht, Margus Pensa, Mait Sepp, Aarne Luud, Helen Karu ja Tiina Elvisto

Kohtla-Järve poolkoksimägede taimkatte seisundit uuriti 2004. ja 2006. aasta suvel. Puu- ja põõsarinde olukorda ning rohttaimeliikide esinemist registreeriti aladel, kus oli toimunud metsastamine, ja samuti aladel, kus taimkate oli arenenud looduslikul teel. Kõige levinumateks puuliikideks olid arukask (*Betula pendula*) ja palsamipappel (*Populus balsamifera*), mis hõivasid vastavalt 0,54 ning 0,11 km^2 suuruse ala. Rohttaimede kõrgeimad katvused registreeriti sanglepa (*Alnus glutinosa*) domineerimisega kasvukohtades, kuid rohttaimede liigiline koosseis oli kogu uuritaval alal sarnane ega sõltunud valitsevast puuliigist. Enamik uurimisalal kasvavatest rohttaimeliikidest olid tüüpilised jäätmaadele (ruderaalid) või kohastunud stressirohketele keskkonnatingimustele (stressitalujad). Viimane rühm hõlmas ka seitset kaitsealust käpaliste liiki. Uuringu tulemused näitavad, et poolkoksimägede rekultiveerimine sanglepa istutamise teel soodustab rohttaimede kasvu ja ühtlast levikut.