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SOME RESULTS OF THE AFFORESTATION OF CLOSED OIL SHALE OPENCASTS WITH EXOTIC CONIFERS

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The growth and survival of exotic coniferous tree species on closed oil shale opencasts during the last decade was studied, and their suitability for afforestation of plained opencast areas was estimated. The study was carried out in 2001–2003 on experimental plantations on exhausted and recultivated oil shale opencast mines of Narva, Sirgala and Viivikonna. In seventeen experimental plantations a sample plot was established. As for pines, only the growth of shore pine (Pinus contorta Dougl. ex Loud.) was satisfactory. The observed spruce species are unsuitable for afforesting these mines as the substrate is too poor in nutrients, and trees are damaged by frosts in open areas. The afforestation by spruces may be more successful if the seedlings are planted under the shelter of higher deciduous trees. Our tests showed the European, Russian, Siberian and Kurile larch to be most suitable for afforestation of leveled oil shale opencast sites. These species have grown better than other larch species and even better than native tree species. The diameter growth of balsam fir was more or less equal to that of the native tree species, but its height growth was less due to poor nutrient supply in the substrate.

Introduction

The increase in industrial activity connected with the production and processing of mineral resources causes generally disorders in the ecosystem functioning and deterioration of environmental conditions. The mining of raw materials, especially opencast mining, changes the natural landscape to a great extent. In many industrial regions associated with important raw materials the area of the spoiled landscapes was remarkable [1].

In Estonia waste materials of oil shale mining and processing cover thousands of hectares, there are waste heaps with relative heights exceeding

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100 m [2]. After World War II in many countries, particularly in Europe, attention was directed to the restoration of spoiled areas. This usually entailed reinstating some type of vegetation cover, grassland or forestry because this was the simplest and cheapest solution [1].

Kukersite oil shale is the most important mineral resource in Estonia. Oil shale mining started in 1916 in the area of Kohtla-Järve, NE Estonia. In spite of the small depth of the oil shale bedding underground mining spread instead of opencast mining because excavators were quite a rarity at that time [3]. The more economical opencast mining intensified after World War II when walking excavators of dragline type came into use. Reclamation of exhausted mining areas was started in 1959 in the *Kohtla* opencast site. The first experiments on afforestation of the graded overburden dumps were carried out in 1959 in the same mine [4]. As of January 1, 2002, the area of devastated land was 12,319 ha of which 10,572 ha were rehabilitated with the aim of the re-establishment of woodland ecosystems. At that date 9,246 ha of the rehabilitated area was afforested [5].

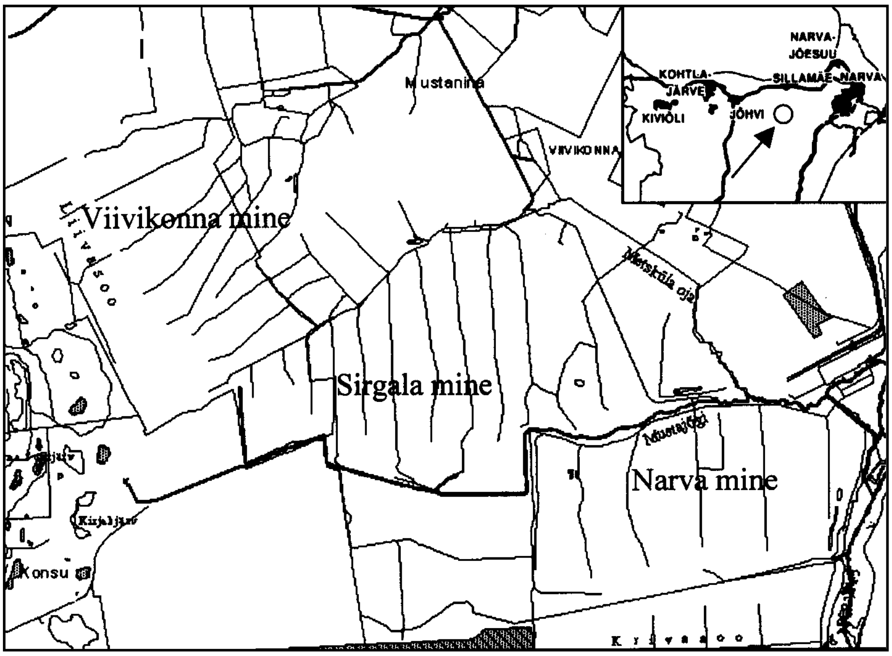
A variety of tree species both spontaneous and foreign were selected for experiments, and different methods of cultivation were checked. To compare the growth of trees grown from seeds obtained from different provenances, in 1979 a geographical experimental plantation was established on the *Sirgala* leveled opencast mine. Analysis of the growth conditions and growth dynamics of the selected tree species was part of the investigations carried out in production plantations and on experimental plots [4–8]. The results showed good to very good growth of indigenous tree species Scots pine (*Pinus sylvestris* L.), silver birch (*Betula pendula* Roth), and black alder (*Alnus glutinosa* (L.) Gaertn.) [4–6]. Norway spruce (*Picea abies* (L.) Karst.) showed poor growth because of the shortage of nutrients in soil and frost damages. Use of the other investigated pine and spruce species for the afforestation of the exhausted opencast mines is not promising. Of other conifers some larch species grow well on leveled opencast sites.

The goal of the present study was to obtain new, up-to-date field data and to evaluate the growth and survival of exotic coniferous tree species on oil shale opencast mines during the last decade.

Study Area and Methods

The growth of exotic tree species was studied on experimental plantations and geographical experimental plantations on exhausted oil shale opencast mines of *Narva*, *Sirgala* and *Viivikonna* (Figure). The data about the experimental plantations including dates of the establishment, localities and areas of the experimental plots, the methods of cultivation, species, provenance, age, quantity and spacing of planted seedlings, and data about the tending and filling in of seedlings on plots were obtained from the Ahtme

Forest District. In 2001–2003, 25 experimental plantations established in 1965–1998 with a total area of 60.8 ha were studied.



Location of the study area

In seventeen experimental plantations a sample plot was established. Its position was selected so that the plot would represent the site conditions, stand structure and species composition. Each sample plot had at least one hundred trees. The breast height diameter and the height were measured for each tree and the species composition on sample plot was determined. The diameter of trees was measured with a caliper and recorded in diameter classes with class interval 1 or 2 cm. The height of trees was measured to the nearest 0.1 m using a Suunto clinometer. In the rest of the plantations the average parameters of trees were estimated visually.

Data processing was performed with the help of the computer program PROTA developed by L. Mihkelson at Estonian Agricultural University. The taxation parameters of the stands on the sample plots including the mean height and diameter, basal area, degree of stocking, site index, stand density and growing stock were computed. The computed values were estimated using standard error of the mean, confidence interval for mean at 95% probability level and coefficient of variation.

Taxation Data of Stands by Tree Species on Sample Plots (H – Height, DBH – Diameter at Breast Height, ± – Standard Error)

Sample plot	Mine	Compartment/ subcompartment	Layer	Species composition*	Age, years	Quality class	Crop density	Tree species	Mean		Basal area, m^2	Density, trees/ha	Growing stock, scm/ha
									Height, m	DBH, cm			
1	*Sirgala*	209/6	I	81*Ps*19*Ls*	38	Ia	0.9	*Ps*	15.1±0.7	15.1±1.6	25.9	1450	201
								Ls	16.4±1.3	15.8±2.2	5.3	270	46
2	*Sirgala*	209/5	I	100*Ls*	38	Ia	0.54	*Ls*	17.3±0.8	23.3±1.9	17.9	420	153
			II	97*Pa*3*Ps*	38		0.63	*Pa*	10.6±1.1	9.7±1.5	14	1900	92
3	*Viivikonna*	176/2	I	100*Ll*	37	Ib	0.8	*Ll*	21.5±0.7	20.2±1.6	28	875	289
			II	100*Pa*			0.04	*Pa*	9.1±1.6	9.1±1.6	0.8	130	5
4	*Sirgala*	223/4	I	100*Ld*	34	Ib	1.25	*Ld*	22.5±1.0	24.1±1.5	44.1	968	466
			II	100*Tc*	34		0.18	*Tc*	8.7±1.4	8.6±1.6	3.3	582	14
5	*Viivikonna*	176/7	I	25*Bp*24*Ab*22*An* 21*Ai*8*Ps*	32	I	1.02	*Bp*	15	10.1	5.4	670	41
								Ab	11.3	12.2	6	520	37
								An	12.1	9.5	4.8	680	34
								Ai	14.6	11.8	4.9	450	34
								Ps	14.6	16.8	1.8	80	13
			II	100*Pa*			0.02	*Pa*	6.5	8.3	0.3	50	1
6	*Sirgala*	236/5	I	87*Ld*13*Ps*	25	I	0.75	*Ld*	12.1±0.6	14.5±1.2	18,7	1138	124
								Ps	10.4±0.5	11.0±1.6	3.1	323	18
			II	100*Pa*			0.02	*Pa*	5.4	5.7	0.3	100	1
7	*Sirgala*	236/5	I	75*Lk*21*Ps*4*Bp*	25	Ib	0.71	*Lk*	12.5±0.7	14.2±1.2	14.2	893	97
								Ps	10.3±0.8	11.6±1.8	4.7	447	27
								Bp	10,6	10,9	0.9	100	5
8	*Sirgala*	236/5	I	74*Lj*24*Ps*2*Bp*	25	I	0.51	*Lj*	10.4±0.4	12.7±0.9	9.2	722	54
								Ps	7.7±0.5	11.0±1.3	3.6	378	17
								Bp	8.2	7.3	0.3	72	1
			II	100*Pa*			0.01	*Pa*	5.4	5.1	0.2	100	1

Taxation Data of Stands by Tree Species on Sample Plots (H – Height, DBH – Diameter at Breast Height, ± – Standard Error) (ending)

Sample plot	Mine	Compartment/ subcompartment	Layer	Species composition*	Age, years	Quality class	Crop density	Tree species	Mean		Basal area, m^2	Density, trees/ha	Growing stock, scm/ha
									Height, m	DBH, cm			
9	*Sirgala*	236/5	I	44*Ll*52*Ps*4*Bp*	25	Ia	0.51	*Ll*	11.4±0.7	12.9±1.3	5	380	32
								Ps	8.9±0.8	12.2±2.1	7.1	610	37
								Bp	8.8±1.8	6.6±3.2	0.7	200	3
			II	100*Pa*			0.01	*Pa*	5.9	5.6	0.2	78	1
10	*Sirgala*	256/8	I	77*Lr*6*Bp*17*Ps*	24	I	0.5	*Lr*	9.7±0.6	12.6±1.5	9	731	51
								Bp	9.7±0.7	8.0±1.7	0.9	181	4
								Ps	8.0±0.6	12.6±1.7	2.3	188	11
11	*Sirgala*	256/7	I	81*Pc*17*Lj*2*Bp*	23	II	0.33	*Pc*	7.3±0.3	10.0±0.9	5.4	687	24
								Lj	6.9±0.5	10.1±1.2	1.2	147	5
								Bp	6.8	5.2	0.2	107	1
12	*Sirgala*	256/8	I	56*La*43*Ps*1*Bp*	24	II	0.28	*La*	7.3±0.5	7.7±0.7	2.9	630	13
								Ps	6.3±0.3	11.0±0.9	2.5	260	10
								Bp	7.4	5.4	0.1	40	0
13	*Narva*	329/2	I	100*Pc*	20	I	0.53	*Pc*	7.8±0.3	8.5±0.7	12.1	2117	57
14	*Narva*	329/4	I	100*Pc*	19	I	0.84	*Pc*	8.2±0.3	10.6±0.6	19.9	2263	98
15	*Narva*	329/3	I	100*Ld*+*Ps*	20	Ib	0.48	*Ld*	11.1±0.4	13.3±1.0	13.2	942	82
								Ps	8.2	10.4	0.2	25	1
16	*Narva*	358/2	I	*Pc, Ps*	5			*Pc*	0.56±0.03				
								Ps	0.63±0.03				
17	*Narva*	371/1	I	**Pc, Ps**	3			*Pc*	0.24±0.01				
								Ps	0.28±0.01				

* *Ab – Abies balsamea, Ai – Alnus incana, An – Acer negundo, Bp – Betula pendula, La – Larix laricina, Ld – Larix decidua, Lj – Larix kaempferi, Lk – Larix kurilensis,* Ll – Larix lubarskii, Lr – Larix russica, Ls – Larix sibirica, Pa – Picea abies, Pc – Pinus contorta, Ps – Pinus sylvestris, Tc – Tilia cordata.

Results

Pines

Along with Scots pine some other pine species were used in the afforestation experiments. In 1979 and 1980 the experimental cultures of black pine (*Pinus nigra* Arnold) and its subspecies, eastern white pine (*P. strobus* L.), Siberian cedar pine (*P. sibirica* (Rupr.) Mayr), ponderosa pine (*P. ponderosa* Dougl. et Laws.), and hard pine (*P. resinosa* Ait.) were established on the *Sirgala* opencast mine [7]. Our inventory as well as some earlier inventories [6, 7] indicated that most of them are unsuitable for afforestation of leveled oil shale opencast mines. By 2001 many trees were died or were in a poor condition due to frost injuries, deficiency of nutrients and different diseases. Only the growth of hard pine was more or less satisfactory.

Large-scale experiments were accomplished with shore pine (*Pinus contorta* Dougl. ex Loud.) on the *Sirgala* and *Narva* opencast mine sites. On the *Sirgala* site (sample plot *11*) shore pine was planted together with Japanese larch (*Larix kaempferi* Sarg.). Some young silver birches settled the plantation naturally. By the average height and breast height diameter shore pines grew more or less equally with Japanese larch but outgrew the birches (Table). However, the shore pines exhibited higher survival rate. The younger shore pines in sample plots *13* and *14* on the *Narva* opencast mine have larger mean height and diameter than those on sample plot *11* but are surpassed by European larch (*Larix decidua* Mill.) on the neighboring sample plot. The survival rate was high reaching 85–90%. The growth of shore pines is satisfactory on the plantations established in 1996 and in 1998 on the *Narva* mine (sample plots *16* and *17*) but are still surpassed by local Scots pines.

In the geographical experimental plantation seedlings of shore pine from nineteen provenances from North America and from two Estonian provenances (Luunja and Kambja) were planted [7]. The inventories made in 1984 showed the highest survival of seedlings from Kambja seeds (84%), with Alaska (74%) and Montana (71%) coming next [7]. The observations made in 2001 indicated that the survival of trees grown from local seeds was the highest. The trees on the Kambja plot have breast diameter 17–22 cm and the biggest tree is 9.0 m high. In 2003 the mean height and diameter at breast height of trees on the Luunja plot was 9.7 ± 0.3 m and 15.2 ± 1.1 cm, respectively. The shore pines originating from Montana seeds showed a good growth as well, having mostly 10–16 cm diameter at breast height and being on average 6–7 m high. The trees from these three provenances have rather good cone production.

As result of the high germinative capacity of seeds natural regeneration of satisfactory condition was observed in the vicinity of the sample plots. Growth of shore pines in the geographical experimental plantation from the other provenances was unsatisfactory. By the autumn of 2001 most of them were dead or had turned into bushes. Numerous trees are damaged by cancer fungus of pine (*Brunchorstia pinea* (Karst.) Höhn). These results show that from the tested pine species only shore pine grown from local seeds can be successfully used along with Scots pine for the afforestation of leveled oil shale opencast mines.

Spruces

From the beginning of the afforestation of leveled oil shale opencast mines attempts have been made to cultivate the indigenous spruce species, Norway spruce, in these sites. As already mentioned in the chapter "Introduction", the results were not promising. In 1979 and 1980 several exotic spruce species were planted in the geographical experimental plantation on the *Sirgala* opencast mine. During the first years after outplanting several species, among them blue spruce (*Picea pungens* Engelm.), Sitka spruce (*P. sitchensis* (Bong.) Carr.) and white spruce (*P. glauca* (Moench) Voss), exhibited survival rates over 90% [9].

In 2001–2003 the authors estimated the growth of exotic spruce species on the experimental plantation. Some of the tested species had grown well. The best growth was shown by white spruce. The trees on the plot have the highest average height and breast height diameter (7.9 m and 13.5 cm, respectively) of all the species. Some 8.5 m high trees were found. The specimens of black spruce (*P. mariana* (Mill.) B. S. P.) that had survived by 2001 did well. The mean height of black spruces on the plot was 6.8 m and their breast height diameter was 9.3 cm. The trees have plenty of cones. Because of the narrow columnar crown, which looks quite blue from a distance, these trees are decorative.

Also the growth of blue spruce, Engelmann spruce (*P. engelmannii* (Parry) Engelm.) and specimens of Sitka spruce that were still alive was satisfactory. The average height of the trees by species varied from 4.7 to 5.2 m. The survival rate was low for Schrenk's spruce (*P. schrenkiana* Fisch. et Mey.), Yezo spruce (*P. jezoensis* Carr.), Chinese spruce (*P. asperata* Mast.) and Sitka spruce. By 2001 most seedlings of these species had died. The few trees but Sitka spruces that are still alive are short or have turned into bushes and are in poor condition. The spruce species have commonly higher demands to soil fertility than pines. Besides they suffer frost damages, especially in open areas. For these reasons most of the above-listed spruce species are considered unsuitable for the afforestation of open leveled oil shale opencast mine sites. The afforestation using spruces may be more successful if the seedlings are planted under the shelter of higher deciduous trees.

Larches

Larch species, mainly Siberian larch (*Larix sibirica* Ledeb.), have been used since the 1960s for the afforestation of leveled oil shale opencast mines. Many larch species grow well in spontaneous areals (ranges) on dry carbonaceous soils, which are similar to soils of the recultivated oil shale opencast mines. This is the main reason why so much attention has been paid to experiments with larch species. Several production plantations have been established in different forest districts [4]. Since 1965 a series of comparative investigations concerning the suitability of the different larch species for afforestation were carried out on experimental plantations in the *Viivikonna*, *Narva* and *Sirgala* mines [4, 6]. In 1969 a geographical experimental plantation of European larch from fifteen provenances in Germany was established in the Sirgala recultivated opencast mine.

Good results were obtained with several larch species. In mixed plantations, where Siberian larch grows together with native Scots pine (sample plot *1*) and Norway spruce, (sample plot *2*) it surpasses both local species in height and diameter (see the Table). In the geographical experimental plantation of European larch (sample plot *4*) the average height of the trees grown from Rheinland-Pfalz seeds was 22.5 ± 1.0 m and their average breast height diameter was 24.1 ± 1.5 cm in 2001 (see the Table). At the same time the average height of small-leaved lime (*Tilia cordata* Mill.) planted between the rows of larch was 8.7 ± 1.4 m with breast height diameter of 8.6 ± 1.6 cm. In the younger experimental plantation (sample plots *6* and *15*) European larch has grown better compared with Scots pine and Norway spruce.

Tests have been carried out also with several larch species originating from eastern Asia. The experimental plantations with Lubarski larch (*L.* × *lubarskii* Suk.) were established in 1967 on the *Viivikonna* mine and in 1978 on the *Sirgala* mine. By 2001 the trees in the *Viivikonna* plantation (sample plot *3*) had survived well and showed good growth. Their average height and breast height diameter exceeded considerably those of Norway spruce of the same age (see the Table). In the plantation on the *Sirgala* opencast mine (sample plot *9*) the survival of Lubarski larch was worse. Over 50% of the trees planted have died. Still the stand is of high quality class. By the height larches surpass the native spruce, pine and birch.

However, the difference in the average breast height diameter between larch and Scots pine is not large. In 1978 seedlings of Kurile larch (*L. kurilensis* Mayr) and Japanese larch (*L. kaempferi* (Lamb.) Sarg.) were planted in the test plantation on the *Sirgala* opencast mine. In addition to larches Scots pine and silver birch seedlings were planted into the larch cultures during the next two years. The study made in autumn 2001 proved that the growth of Kurile larch (sample plot *7*) was significantly better than that of spontaneous species and was equal to the growth of European larch in the adjacent plantation (see the Table). The survival rate and growth of Japanese larch were worse compared to Kurile and European larch. Still the growth of Japanese larch was better than that of mixed native trees on this plot. On sample plot *11* Japanese larch grows more or less equally with shore pine. In several production forest cultures established earlier on recultivated oil shale opencast mines Japanese larch has suffered from frost because of its longer vegetation period [10].

In the test plots of Russian (*L. russica* (Endl.) Sabibe ex Trautv.) and American larch (*L. laricina* (Du Roi) K. Koch) on the *Sirgala* opencast mine (sample plots *10* and *12*, respectively) Russian larch has been more successful. Its average height and breast height diameter surpass considerably these parameters of American larch and spontaneous tree species (see the Table). As also Scots pines and silver birches on the Russian larch plot have greater average height and breast height diameter than the same species on the American larch sample plot have, it may be assumed that site conditions may be more favorable on the Russian larch plot.

The tests made so far with larch species show that for the afforestation of leveled oil shale opencast sites European, Russian, Siberian and Kurile larch are more suitable that other larch species. Moreover, these species have grown even better than our native tree species.

Firs

Balsam fir (*Abies balsamea* (L.) Mill.) is native North American tree species. It is frost hardy in Estonia, but grows well only on nutrient-rich substrates [11]. In 1969 a balsam fir and ash-leaved maple (*Acer negundo* L.) mixed plantation was established on the *Sirgala* leveled opencast mine (sample plot *5*). Scots pine, silver birch and gray alder (*Alnus incana* (L.) Moench) penetrated into the plantation later. By 2001 the survival rate of balsam fir was 74.3%. Measurements made in 2001 on the sample plot showed that balsam fir trees were overgrown by other tree species (see the Table). The average breast height diameter of balsam fir was larger than that of other tree species but silver birch on the sample plot, however. This indicates that the nutrient pool in the substrate, essential to height growth, is scanty for balsam fir.

Conclusions

The growth and survival of exotic coniferous tree species on recultivated oil shale opencast mines during the last decade was studied. The study was carried out in 2001–2003 on experimental plantations on exhausted oil shale opencast mines of *Narva*, *Sirgala* and *Viivikonna*. In seventeen experimental plantations a sample plot was established.

The earlier investigations showed good to very good growth of indigenous tree species Scots pine, silver birch, and black alder. Of exotic conifers some larch species grow well on recultivated opencast sites.

Several pine species were tested in afforestation experiments. Inventories indicated that trees of most pine species were in a poor condition due to frost injuries, deficiency of nutrients and diseases. Only the growth of shore pine was satisfactory. For the afforestation of recultivated oil shale opencast mines seedlings grown from local seeds should be preferred.

The test with spruces indicated that the observed species are unsuitable for the afforestation of the open leveled oil shale opencast mines. The substrate is too poor for spruces and trees are damaged by frosts in open areas. Spruces may do better if the seedlings are planted under the shelter of higher deciduous trees.

Good results were obtained with several larch species. The tests show that for the afforestation of recultivated oil shale opencast sites the most suitable larch species are European, Russian, Siberian and Kurile larch. These species have grown better than other larch species and even better than our native tree species.

The diameter growth of balsam fir was more or less equal to the native tree species but it is overcome in height growth due to the poor nutrient supply in the substrate.

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