Approaches to Rehabilitation of lands in the surroundings of Cu-Ni smelters in the Kola Peninsula, Russia

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Abstract

The effect of Ni-Cu smelters ”Pechenganikel” and «Severonikel» on the adjacent landscape has been to severely damage the forest ecosystems in the Kola Peninsula. Comprehensive investigation around this most powerful in the Northern Europe source of air pollution indicated that forest decline is associated with nutritional disturbances. Treatment of soil with limestone and Mg-P fertilizers in defoliating forests resulted in improvement of nutritional status of spruce. Limestone Mg-P fertilizer application in barren lands caused a decrease in total, exchangeable and active acidity in soil, whereas concentrations of nutrients, cation exchange capacity and base saturation significantly increased. The treatment of soil with fertilizers promoted colonization by native plant species: mosses, herb plants, willows in the areas subjected to air pollution. In order to promote of area colonization by native plants, development of facilitation stages is necessary. Two ways for development of facilitation stages have been tested: 1 – minimal amelioration; 2 - establishment of an herbaceous cover. In order to contribute to rapid development of tree layer, seeding and planting of tolerant to pollution woody plants (*Betula pubescens, Alnus incana., Populus tremula, Salix sp.*), which are not alien in these sites, could be useful.

Introduction

The effect of «Pechenganikel” and “Severonikel” smelters on the adjacent landscape have been to severely damage the forest ecosystems. From two examples, in Sudbury and in the Kola peninsula, it follows that the limiting factors for vegetation cover development in lands subjected to air pollution are unfavourable soil conditions, such as high soil acidity, deficiency of nutrients, soil toxicity because of high content of heavy metals, and low availability of plant seeds (Winterhalder, 1996, Lukina and Nikonov, 1996).

Taking into account that in the case of decrease or even discontinuance of air pollution self-recovery of lands will take a very long time due to unfavorable soil conditions, the rehabilitation works on these lands should be carried out now, despite the existing air pollution, if appropriate soil amendments and corresponding to environment plant species are used. What is more, nowadays, accordingly the official data of Murmansk Environment Protection Committee the level of pollution significantly decreased (1993- 1998).

The goal of this work was to propose the approaches to rehabilitation of defoliating forests and barren lands in the surroundings of Cu-Ni smelters in the Kola Peninsula.

Materials and methods

Ameliorative substance application, treatment of soil with fertilizers, seed mixtures

Prior the treatment sites were not subjected to a process called site improvement – removal of dead material and stones. A treatment rate of fertilizers and ameliorative substances, presented in Table 1, was similar on all experimental plots. In defoliating forests treatment rates of limestone and Mg-P- fertilizer were 0.7 and 0.2 tonnes per hectare correspondingly.

Limestone and fertilizers are applied manually from a bag. It was not necessary to try to distribute them in a homogeneous fashion because the distribution of ameliorative substances in a patchy fashion results in creation an environmental mosaic that will promote higher diversity.

The dosages of fertilizers and limestone were not high. The podzol soils are predominant in

the area. These soils are characterized by coarse texture. In addition, the major part of areas is not covered by plants and by the organic layer, acting as barriers against the downward movement of element compounds. By this is meant that high dosages of ameliorative substances and fertilizers could result in pollution of ground and surface waters.

Seed mixtures and seeding rate are presented in Table 2. Seeding was carried out in the beginning of the growing period (June) of 1998 and 1999.

Soil sample pre-treatment and chemical analysis

The soil samples were taken in June 1998 and 1999 prior the treatment and in the end of vegetation period (August) of 2001 from the uppermost layers of the mineral and organic soils, air-dried, sieved over 1.0 mm sieves and fraction of 1mm stored in paper bags in cool room. Soil pH was measured potentiometrically in water extract using a soil: water ratio of 1:25 for the organic samples and 1: 10 for mineral samples. For determination of extractable concentrations of elements the soil samples were extracted by 1M ammonium acetate (pH=4.65). Exchangeable acidity (EA) and aluminium (EAl) were determined by extraction with 1N KCl, followed by titration. Total acidity (TA) was estimated by extraction with 1M ammonium acetate, pH = 7, followed by titration.

Atomic absorption spectrometry was used to determine the concentrations of metals in the soil, using Perkin Elmer 360, 460 and 5000 with HGA-400 AA spectrophotometer. For preparation of AA standards and blanks the standards of " J.T.Baker Holland" and "Merck Germany" and purification system water "Millipore" have been used. Phosphorus was determined colorimetrically.

Potential cation exchange capacity (CECp) has been calculated as the sum of total acidity and base cations, effective cation exchange capacity (CECe) has been calculated as the sum of exchangeable acidity and base cations. Potential base saturation (BSp) was estimated taking into account CECp, effective base saturation (BSe) – with taking into account CECe.

Results and discussion

Approaches to rehabilitation of defoliating forests

Comprehensive investigation into the so called "new type" forest damage in central Europe and North America indicated that these declines are more ore less frequently associated with acute nutritional disturbances. (Huettl, 1989). From experiments with fertilisers it became evident that specific nutrient supplementation is an appropriate tool for revitalization and restabilization of declining forests. For classical fumigation damages (we have close to the smelter) it was found that an optimal nutritional status increases the resistance of trees and stands against the impact of SO_2 even when very high sublethal dosages are present. Besides the direct phytotoxic impact of SO_2 indirect damage pathways owing to soil acidification were observed.

When exposed to air pollution the dominant forest plants in the Kola Peninsula accumulated large amounts of S, Ni, Cu, Fe, and K whereas the concentrations of Ca, Mg, Mn, Zn decreased (Table 3). The application of ameliorative substances and fertilisers was useful tool for improvement of the nutritional status in declining plant communities and plant vitality supporting. Accordingly our results treatment of soil with limestone and Mg-P- fertilisers in the appropriate amounts (2 t/ha and 0.75 t/ha) resulted in improvement of spruce nutritional status in defoliating forests. The concentrations of nutrients, such as Ca, Mg and Mn in the needles significantly increased.

This approach can be also proposed for supporting of plant vitality in sparse forests.

Approaches to rehabilitation of industrial barrens

In order to promote colonization by native plants, development of facilitation stages is necessary. We consider two ways for development of facilitation stages: 1 – minimal amelioration; 2 - establishment of an herbaceous cover.

Minimal amelioration

The role of manual surface liming of soils in the initiation of colonization became known as a

trigger factor (Winterhalder, 1983). Application of limestone to barren lands triggers colonization by native plant species, through germination both of the existing small seed bank and the incoming wind-disseminated seed rain.

Prior the treatment, sites were not subjected to a process called site improvement – removal of dead material. Dead material and also debris can be considered as source of the organic matter and wildlife habitat.

The application of calcitic limestone + N-P-K-fertilizers improved the soil conditions for development of native plant species. The significant ($p<<0.05$) decrease in total, exchangeable and active acidity has been found (Table 4). Concentrations of nutrients, Ca, Mg, K, P, cation exchange capacity and base saturation significantly increased (Tables 5, 6). This approach was especially effective in the areas where there were single alive trees and some patches of even strongly damaged but still alive ground vegetation.

The simple act of limestone application and treatment the soil with fertilizers promotes colonization by native plant species (mosses, herb plants, willows) (Figure 1).

Treatment of soil with ameliorative substances and fertilizers resulted in the first stages of succession in barren lands. Plants on these figures are typical representatives of pioneer stages of succession in the Kola Peninsula.

Establishment of an herbaceous cover

The goal was to establish plant cover in order to contribute to the development of ecosystem. It is apparent that the introduction of alien species, such as some introduced species of grasses, is not desirable but there are some advantages of this seeding step (Winterhalder, 1996): a) rapid establishment of plant cover, which stabilizes erosion-prone sites and also gives aesthetic improvement); b) improvement of nutritional status of soil for succeeding colonization by native plants species; c) the seed rain is made more effective by the presence of a herbaceous cover that creates turbulent air flow over the surface, leading to the deposition and trapping of seeds. The whole concept of the nurse crop is based on the idea of one species facilitating the establishment of another more desirable.

This seeding step involves manual application of ameliorative substances and fertilizers, grass seed mixtures. The application of calcitic limestone + N-P-K- fertilizers improved the soil conditions for development of native plant species. The significant ($p<<0.05$) decrease in total, exchangeable and active acidity has been found (Table 7). By contrast, concentrations of Ca, Mg, K, P, cation exchange capacity and base saturation significantly increased (Tables 8, 9).

Referring to Figures 2 and 3, good patterns of grass cover development have been demonstrated by all seed mixtures of herbaceous plants growing on the soils treated with $CaCO_3$ + NPK and Mg-P-fertilizer + NPK. Spontaneous colonization by native plants, mosses and willows, has been observed in the areas covered by grasses (Figure 4).

Tree seeding and planting

Because we have small resident bank of seeds, spontaneous colonization of the limed barrens and grassed land by woody plants is so far confined to willow. In order to contribute to rapid development of tree layer seeding and planting with woody plants, which are not alien in these sites, could be useful (Figures 5, 6). Seeding with alder (*Alnus incana*) and birch (*Betula pubescens*) was carried out in 1997. Seeding rate was about 10 –15 kg/ha. Planting by birch (Betula pubescens), willow (*Salix borealis, Salix caprea*) and aspen (*Populus tremula*) has been conducted in autumn 2002**.** Seeding and planting steps involved manual application of limestone + NPK.

Conclusions

Relying on Sudbury and our experiment results we can confirm the hypothesis that soil properties are a more critical factor in the suppression of vegetation cover development than air quality. Treatment of soil with limestone and Mg-P fertilizers resulted in improvement of nutritional status of soil: total acidity, exchangeable aluminium and protons, and active acidity significantly decreased, whereas concentrations of nutrients, cation exchange capacity and base saturation significantly increased.

The simple act of limestone application and treatment of soil with fertilizers promoted colonization by native plant species: mosses, herb plants, willows in the areas subjected to air pollution.

In order to promote of area colonization by native plants, development of facilitation stages is necessary. Two ways for development of facilitation stages have been tested: 1 – minimal amelioration; 1 - establishment of an herbaceous cover.

Minimal amelioration of soil resulted in spontaneous colonization by native plants, mosses and willows. Though the introduction of alien species, such as some introduced species of grasses, is not desirable but there are some advantages of this seeding step: rapid establishment of plant cover and improvement of nutritional status of soil for succeeding colonization by native plants species.

In order to contribute to rapid development of tree layer, seeding and planting of tolerant to pollution woody plants (*Betula pubescens, Alnus incana., Populus tremula, Salix sp.*), which are not alien in these sites, could be useful.

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Table 1. Dosage of fertilizers and ameliorative substances, treatment of barren lands

Fertilizers and ameliorative substances	t/ha
Limestone	2,00
NPK	0,75
Mg-ferilizer	0,60

Table 2. Seed mixtures

Plant, species		P, kg/ ha
Seed mixture 1	Poa pratensis	8
	Bromus inermis	20
	Festuca pratensis	12
Seed mixture 2	Poa pratensis	10
	Alopecurus pratensis	8
	Festuca rubra	20
Seed mixture 3	Bromus inermis	15
	Festuca pratensis	20
Seed mixture 4	Bromus inermis	20
	Phleum pratense	10
	Alopecurus pratensis	10
Seed mixture 5	Festuca rubra	24
Seed mixture 6	Festuca rubra	20
	Phleum pratense	10
	Alopecurus pratensis	10
Seed mixture 7	Poa pratensis	10
	Phleum pratense	10
	Festuca rubra	20

Table 3. Chemical elements in spruce current needles

Trial	N	P	S	K	Ca	Mg	Mn	Fe	Al	Zn	Cu	Ni
	g/kg	mg/kg										
Current needles												
Background	11.10	1663	1093	9398	6473	1085	604	27	82	44.39	3.26	13.31
Control	10.98	2237	1375	13160	1051	718	80	41	98	20.32	13.91	40.32
CaCO3	12.38	2456	1423	12772	2313	901	328	35	84	27.57	15.82	50.63
Mg-P	8.63	1827	1319	10609	1737	752	61	17	87	16.01	12.3	27.99
Needles of previous years												
Background		992	1173	5238	12622	1022	1031	45	199	32.83	2.74	11.87
Control	8.58	1208	1459	8031	1877	331	144	194	212	11.29	11.65	37.51
CaCO3	8.30	956	1480	5935	6756	469	613	13	170	15.9	14.39	47.76
Mg-P	7.31	860	1932	5223	6555	489	379	15	168	8.89	14.21	36.08

Table 4. Soil acidity, treatment of soil on the areas with patches of natural vegetation

Trial	Parameter	pH	TA	EA	EAl	EH
Control, A_0 n=3	Mean	5,15	104	3,60	2,86	0,74
	SE	0,12	3,75	0,49	0,47	0,04
Grass compartments						
$CaCO_3$+NPK A_0 n=3	Mean	5.65	130.84	2.17	1.21	0.96
	SE	0.58	18.33	1.11	0.70	0.41
$CaCO_3$+NPK 0–10cm n=2	Mean	6.22	9.09	0.18	0.07	0.10
	SE	0.45	0.55	0.07	0.05	0.02
$CaCO_3$+NPK 0–20cm n=2	Mean	6.27	8.95	0.17	0.08	0.08
	SE	0.36	0.56	0.04	0.04	0.00003
Dwarf-shrub-grass compartment						
$CaCO_3$+NPK n=2	Mean	5,83	104	1,33	0,94	0,40
	SE	0,08	7,17	0,07	0,12	0,19

Table 5. Bio-available concentrations of elements, mg/kg, treatment of soil on areas with patches of natural vegetation cover (numerator – mean; denominator – standard error)

Trial	Ca	Mg	K	Na	Al	Fe	Mn	Zn	Ni	Cu	P	S	Cd	Pb	Cr	Co
Control, n=3	2650	142	50	16	nd	464	30	9	686	639	5	202	nd	nd	nd	н/о
A_0	812	7	2	2	nd	76	15	4	172	70	2	12	nd	nd	nd	н/о
Grass compartment																
$CaCO_3$+NPK	21147*	812	391	127	68	8,3	237	41	815	22	157	92	0,98	2,38	0,6	20,98
n=3 A_0	5479**	82	91	22	26	4,3	216	7	32	14	84	25	0,2	0,68	0,09	2,69
CaCO3+NPK	921	51	11	10	153	101	12	1,3	39	1,23	3,36	13,52	0,04	0,36	0,44	1,20
n=2; 0–10см	25	21	1,27	0,64	0,10	21	5	0,3	7	0,07	0,54	1,65	0,001	0,03	0,01	0,09
$CaCO_3$+NPK	608	25	12,85	10,39	247	135	11	2,2	36	3,79	2,49	8,92	0,04	0,88	0,57	1,34
n=2; 0–20см	153	1,2	2,26	0,94	70	31	6	1,4	10,65	1,64	1,86	1,82	0,001	0,45	0,06	0,07
	154	0,85	1,77	7,84	29	28	0,9	0,54	15	4	1,14	2,7	0,01	0,01	0,01	0,07
Dwarf shrub-grass compartment																
$CaCO_3$+NPK	9876	681	304	69	331	184	12	9	528	365	34	226	0,6	8,1	1,89	18,2
n=2;	4711	256	127	20	193	170	3	3	211	356	20	2	0,01	0,06	0,97	3,94

Table 6. Cation exchange capacity, mgeqv/100g and base saturation, %, treatment of soil on the areas with patches of natural vegetation cover (numerator – mean; denominator – standard error)

Trial	CECp	CECe	BSp	BSe
Control, n=3	119	18	12	78
	6	4	3	5
Grass compartment				
$CaCO_3$ + NPK, A_0 , n =3	245	116	46	97
	11	27	10	2
$CaCO_3$ + NPK, 0-10 cm, n=2	14	5	36	97
	0,6	0,1	1	1
$CaCO_3$ + NPK 0-20 cm, n=2	12	3	27	95
	0,2	1	6	2
Dwarf shrub- grass compartment				
$CaCO_3$ + NPK, A_0, n =2	161	57	33	97
	19	26	12	1

Table 7. Acidity of mineral and organic soil, plots with grass seeding

Trial	Parameter	pH	TA	EA	EAl	EH
	Mineral soil					
Control, n=7	Mean	3,98	14,84	2,49	2,11	0,38
	SE	0,10	1,01	0,34	0,32	0,04
$CaCO_3$+NPK, n=10	Mean	5,75	11,05	0,65	0,53	0,12
	SE	0,30	0,72	0,19	0,18	0,02
Mg-P fertilizer +NPK, n=5	Mean	5,10	13,32	1,39	1,17	0,22
	SE	0,15	1,26	0,53	0,46	0,07
	Organic soil					
Control, n=2	Mean	4,39	115,6	7	5,5	1,53
	SE	0,48	25	5,3	4	1,32
$CaCO_3$+NPK, n=2	Mean	5,2	103	2,6	2,1	0,48
	SE	0,06	0,13	1	0,99	0,05
Mg- P fertilizer+NPK n=3	Mean	4,99	94	2	1,5	0,4
	SE	0,14	2	0,3	0,3	0,06

Table 8. Bio-available concentrations of elements in soil on plots with seeding of grasses, mg/kg (numerator – mean; denominator – standard error)

Trial	Ca	Mg	K	Na	Al	Fe	Mn	Zn	Ni	Cu	P	S	Cd	Pb	Cr	Co
Mineral soil																
Control, n=7	33	10	12	12	126	664	0,31	0,45	48	121	13	61	0,04	1,06	1,66	0,82
	4	1,2	3	2	47	119	0,02	0,09	7	17	3	7	0,01	0,16	0,24	0,21
$CaCO_3$+NPK, n=10	681	56	26	8	253	243	0,97	0,51	32	95	26	47	0,04	0,83	0,95	0,29
	274	23	4	1,25	78	46	0,36	0,17	15	20	5	10	0,01	0,12	0,14	0,06
Mg-P fertilizer+NPK, n=5	253	58	48	10	537	344	1,24	0,37	25	113	33	60	0,04	0,88	1,39	0,51
	41	9	15	1	240	107	0,43	0,08	6	26	3	16	0,01	0,15	0,31	0,10
Organic soil																
Control, n=2	124	42	34	18	272	1372	1,4	2	175	631	34	158	0,17	7,58	5	1,5
	86	33	21	12	58	1203	0,9	1,5	131	447	17	121	0,08	4,7	3	1
$CaCO_3$+NPK, n=2	933	106	53	10	203	991	1,4	1,5	103	332	162	107	0,09	1,44	3	0,58
	107	7	0,31	2	12	284	0,12	0,1	15	41	29	60	0,01	0,03	1,5	0,2
Mg-P fertilizer+NPK, n=3	382	139	70	17	171	624	2,3	0,72	67	206	185	106	0,09	1,5	1,7	1,4
	98	46	18	4	37	322	0,73	0,07	10	21	23	32	0,003	0,18	0,26	0,5

Table 9. Cation exchange capacity in soil on plots with seeding of grasses, mgeqv/100g and base saturation, **%** (numerator – mean; denominator – standard error)

Trial	CECp	CECe	BSp	BSe
mineral soil				
Control, n =7	15,17	2,81	2	12
	1,03	0,36	0,2	1,4
$CaCO_3$ + NPK n =10	15	4,62	22	83
	1,82	1,67	5,1	4,3
Mg-P fertilizer + NPK, n =5	15,23	3,3	13	62
	1,17	0,50	2,4	9
organic soil				
Control, n =2	117	8	0,86	15
	26	6	0,5	2
$CaCO_3$ + NPK n =2	109	8	5	69
	0,61	0,56	0,42	10
Mg-P fertilizer + NPK, n =3	97	5	3	60
	1	1	1	11

Figure 1. Development of native plants, treatment of soil with $CaCO_3$+NPK in 1997

Figure 2. Seed mixture 1, 2, treatment of mineral soil with $CaCO_3$+NPK, seeding step in 1998

Figure 3. Seed mixture 1, 2, treatment of organic soil with $CaCO_3$+NPK, seeding step in 1998

Figure 4. Development of native plants on grassed area, treatment of soil with $CaCO_3$+NPK, seeding in 1998

Figure 5. Seeding of Alnus incana on mineral soil in autumn 2000, treatment of soil with CaCO3 + NPK

Figure 6. Seeding of birch on organic soil in 1997, treatment of soil with CaCO3 + NPK