Condition and Growth of Scots Pine Seedlings under Strong and Weak Pollution in Kola Peninsula

ALEKSEY FEDORKOV*[1], JUHA KAITERA[2] AND RISTO JALKANEN[3]

[1] Institute of Biology, Komi Science Center, Russian Academy of Sciences, Kommunisticheskaya st., 28, Syktyvkar, 167982, Russia; fedorkov@ib.komisc.ru, tel. +7 8212 24 50 03*

[2]Finnish Forest Research Institute, Muhos Research Unit, Kirkkosaarentie 7, FI 91500 Muhos, Finland;

[3]Finnish Forest Research Institute, Rovaniemi Research Unit, P. O. Box 16, FI 96301 Rovaniemi, Finland

Fedorkov, A., Kaitera, J. and Jalkanen, R. 2007. Condition and Growth of Scots Pine Seedlings under Strong and Weak Pollution in Kola Peninsula. *Baltic Forestry*, 13 (2): 179–183.

Abstract

Anthropogenic stress has affected forest trees for decades and will continue to do so in the foreseeable future. The Scots pine tree condition was evaluated and tree height was measured at age twelve in provenance field trial established on two sites under strong and weak pollution levels in Kola Peninsula, NW Russia. The seedlings of three Finnish origins (Muonio, Ylitornio and Suomussalmi) were used for establishment of the trial. Based on needle, bud and stem observations, the evaluation of the condition was performed. Surprisingly the condition was better and trees were slightly taller on the strongly than weakly polluted site with significant differences among some provenances from northern Finland. The trees had a significantly higher condition ($p<0.05$) in the northernmost provenance (Muonio) than in the more southern ones (Ylitornio and Suomussalmi) under weak pollution. On the strongly polluted site, the differences between provenances were insignificant. Thus the dead forest area around Monchegorsk is most successfully reforested, when using artificial reforestation with local or more northern Scots pine seed sources.

Key words tree condition, height, sulphur dioxide, heavy metals, *Pinus sylvestris*

Introduction

Anthropogenic stress has affected forest trees for decades and will continue to do so in the foreseeable future. The Severonickel smelter complex in Monchegorsk, Kola Peninsula, NW Russia, is the largest pollution source in Europe, causing forest decline over an area of 400 (Mikkola 1996) to 1000 km^2 (Rigina and Kozlov 2000). In recent years, however, sulphur dioxide and heavy metal emissions from the smelter have dramatically reduced (Figs. 1 and 2), allowing forest to start regenerating again. The area is, however, located close to the northern conifer tree line, where good seed years are very rare. Under these conditions, full or almost full seed maturation of the dominant species, Scots pine (*Pinus sylvestris* L.), occur only a few times in a century (Henttonen *et al*. 1986). Thus forest regeneration would benefit from artificial sowing or planting. After artificial regenerations, large among and within-population variation in height growth and field survival have been found in northern Scandinavian Scots pine populations with numerous studies indicating dangers when using non-adapted provenances (Persson and Ståhl 1990, Persson 1994). For example, a southward transfer of seeds in northern Sweden is recommended to receive a satisfied survival and growth of Scots pine (Eriksson *et al*. 1980). As there are no recommendations for the best provenance to be used for regenerating this industrial desert, field trials with provenances should be carried out under different pollution levels. The aim of this study was to investigate the condition and growth of Scots pine provenances at contrasting pollution levels.

Material and methods

Field experiment and measurements

A field trial with one-year-old seedlings of three Finnish Scots pine provenances was established at two sites in Kola Peninsula, NW Russia in early summer of 1992. The sites represented weakly and strongly polluted areas (Fig. 3, Table 1 and 2). The relief, climate and nutritional soil status were similar on both sites. In 1991, 20–25 subsamples were taken from the upper soil layer (about 5 cm depth) on each site (diagonally). Mixed site samples were prepared to analyze the concentrations of heavy metals. Colorimetric methods were used to determine Ni and Cu concentrations in the litter; Ni after complexation with dimeth-

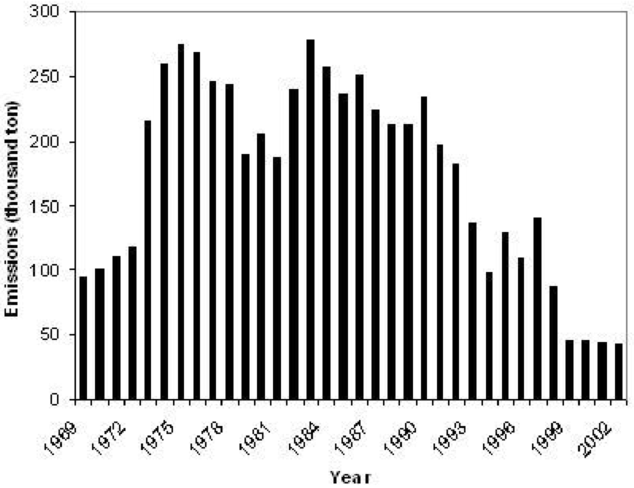

Figure 1. Annual SO_2 emissions in the atmosphere from the Severonikel smelter complex in Monchegorsk, NW Russia (thousands of tons). The official data of the Severonickel smelter complex

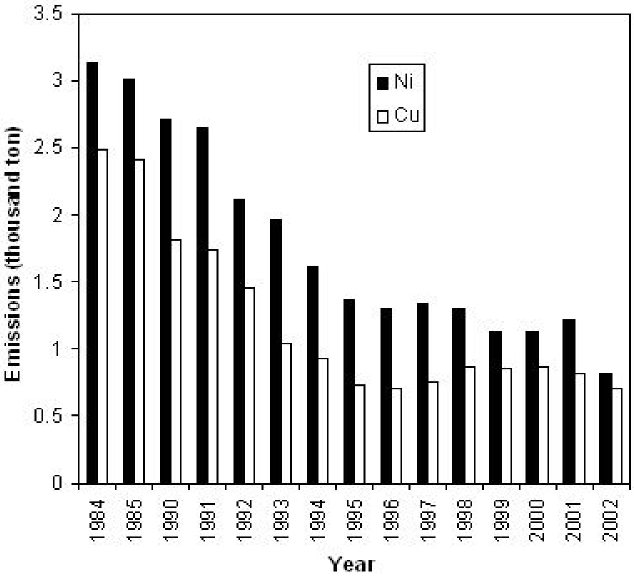

Figure 2. Annual emissions of nickel and copper in the atmosphere by Severonikel smelter complex in Monchegorsk, NW Russia (thousands of tons). The official data of the Severonickel smelter complex

ylglyoxime, and Cu by reaction with lead diethyl carbamate after extraction with chloroform (Barcan *et al.* 1993). Passive lead dioxide absorbers were used to measure atmospheric concentrations of sulphur dioxide in 1990–1992 (Barcan 1992).

On both sites a randomized block design with five replicates of each provenance was employed. The size of each experimental plot was 20×10 m with a spacing of 2×2 m (about 50 seedlings per plot). The initial aim of this experiment was to study the susceptibility of

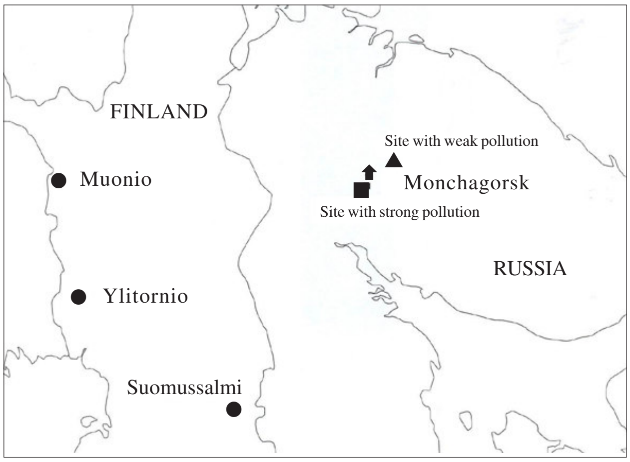

Figure 3. Location of the provenances of *Pinus sylvestris* (●), experimental sites (▲ – weak pollution level, ■ – strong pollution level) and emission source (🡅)

Table 1. Characteristics of the experimental sites

Pollution level	Distance from source of emissions, km	Mean atmospheric SO_2 concentration, µg/m^3 year	Heavy metals in forest litter, g/kg of dry weight Ni	Cu
Strong	15	15.0	1.41	0.98
Weak	40	2.0	0.11	0.057

Table 2. Basic information on the provenances of ***Pinus sylvestris***

Provenance	Latitude N	Longitude E	Altitude m asl	d.d*
Muonio	67°50’	23°50’	250	723
Ylitornio	66°30’	24°30’	120	912
Suomussalmi	65°15’	29°00’	230	864

*The effective temperature sum (threshold +5°C) based on values from Ojansuu, R. and Henttonen, H. (1983)

Scots pine provenances to pine-shoot disease caused by *Gremmeniella abietina* (Lagerb.) Morelet after artificial inoculations. The inoculated seedlings in two plots of each provenance were destroyed in 1995, but the uninoculated seedlings in the three control plots of each provenance were left in the field to grow (Kaitera *et al*. 2001). The height and condition of the trees were estimated after 12 growing seasons in 2004. The tree condition was estimated using slightly modified Huttunen’s (1978) classification: 0 – healthy tree, at least three year’s needle sets intact in the shoots, buds healthy, stem straight and grows vigorously; 1 – slightly damaged, good condition, only some needle damage, terminal and other buds healthy, main stem straight; 2 – seriously damaged tree, in poor condition, over 30% of the needles damaged, terminal bud damaged, bent or dead retarded height growth; 3 – dead tree. The height was analysed for trees that were in good condition at the time of assessment.

Statistical analysis

Prior to the statistical analyses the scores for tree condition were linearized by transformation to normal score (NSC) values according to Gianola and Norton (1981) in order to adjust for non-adequate or variable spacing of classes and to improve the efficiency of subsequent analyses. The scores were thus first transformed to ranks, which were further transformed to the expected values of the order statistics of the normal distribution, expressed in standard deviation (SD) units (Ericsson and Danell 1995).

The statistical significance of the effects of pollution level and provenance on tree condition and height was studied using analysis of variance. The general linear model (GLM) procedure was defined as

$$y_{ijk} = \mu + L_i + P_j + (LP)_{ijk} + e_{ijk}$$

where

y_{ijk} = the condition / height for individual trees on the jth site of the ith provenance

μ = overall mean

L_i = the effect of site (pollution level), j = 1, 2

P_j = the effect of the provenance, i = 1, 2, 3

$(LP)_{ijk}$ = the effect of the interaction between site and provenance

e_{ijk} = the experimental error

The differences between the provenances (northernmost vs. more southern ones) were analyzed by the Scheffe's test. The analysis was performed using the ANOVA and *post hoc* comparisons procedure of the SAS statistical package (SAS/STAT User's Guide 1999).

Results

Pollution level, provenance and their interaction had a significant ($p<0.05$) effect on tree condition (expressed in NSC) and tree height (Table 3). Surprisingly NSC was lower and trees were slightly taller on the strongly than weakly polluted site with significant differences among some provenances (Table 4). The trees had a significantly higher NSC ($p<0.05$) in the northernmost provenance (Muonio) than in the more southern ones (Ylitornio and Suomussalmi) under weak pollution. On the strongly polluted site, the differences between provenances were small and insignificant (Table 4). On the weakly polluted site, pines of the northernmost provenance were taller than those of the southern ones, but the difference was significant ($p<0.05$) only in the case of Ylitornio provenance. On the strongly polluted site, the mean heights of the trees did not differ significantly between the provenances (Table 4).

Table 3. The effect of pollution level and provenance on the condition and height of *Pinus sylvestris* trees after 12 years in the field

Source	df.*	MS**	*F* – value	*p* – value
Transformed tree condition				
Pollution level	1	236.39	21.21	0.000
Provenance	2	19.72	24.71	0.000
Pollution level×Provenance	2	15.47	19.39	0.000
Tree height				
Pollution level	1	1.21	4.93	0.028
Provenance	2	1.41	5.29	0.006
Pollution level×Provenance	2	1.22	4.57	0.011

* - degrees of freedom; ** - mean sum of squares

Table 4. The tree condition expressed in NSC (normal score class) and tree height (in meters) of the provenances of *Pinus sylvestris* saplings with *p*–values after 12 years in the field in Monchegorsk, NW Russia

	Tree condition (NSC)				Tree height			
Provenance	Number of trees	Mean	SD*	*p*–value	Number of trees	Mean	SD*	*p*–value
			Weak pollution level					
Muonio	150	2.88	2.30	–	79	1.39	0.47	–
Ylitornio	139	3.61	2.09	0.017	43	1.09	0.50	0.006
Suomussalmi	150	3.53	2.08	0.033	48	1.24	0.44	0.251
			Strong pollution level					
Muonio	159	2.20	1.95	–	124	1.41	0.51	–
Ylitornio	156	2.23	2.02	0.988	115	1.42	0.51	0.996
Suomussalmi	160	2.21	1.94	0.998	124	1.30	0.53	0.217

* - standart deviation

Discussion and conclusions

The studied sites differed dramatically in their pollution loads (Table 1), thus, offering a good possibility to investigate Scots pine survival and growth at contrasting pollution levels. It also let us speculate about the possibilities for using Scots pine in artificial reforestation in forest decline area in Kola Peninsula. We assessed the experimental status at age twelve years, when the saplings had already reached the snow level. At this age and onwards, the mortality rate of the saplings remains already rather stable (Eiche 1966, Mäkitalo 1999).

It is known that acid pollutants and heavy metals are toxic to *G. abietina in vitro* and *in vivo* (Ranta *et al*. 1994, Kaitera *et al*. 1995, Vuorinen and Uotila 1997). According to the inventory carried out in this trial in 1995, *G. abietina* had caused natural infection in 20% of the seedlings at weak pollution level, while the corresponding infection was totally lacking on the strongly polluted site and general survivals were 86% and 67% on the strongly and weakly polluted sites, respectively (Kaitera *et al*. 2001). The mortality in Scots pine regenerations in harsher areas is seldom caused by a single event, but instead the resulting damage usually develops over several years (Eiche 1966). Evidently the mortality rates in this trial for local pine provenances were higher in a weakly polluted site compared to strongly polluted one and the corresponding values of survival were 84% and 47% in 1998 (Fedorkov 1999), which corresponds well with the rates observed for the Finnish provenances in this study.

Therefore, the differences in tree condition between the sites may firstly be explained by the number of natural infections of *G. abietina*. Secondly, the surface vegetation is poorly developed in the strongly polluted site, reducing competition between Scots pine seedlings and the vegetation for several years after planting, and thus, improving the growth conditions for the seedlings. Thirdly, the temperature regime is more favourable in the strongly polluted area because the metallurgical dust on the snow cover promotes snow melting in spring, and both soil and air temperature are higher in polluted than non-polluted area (Kruychkov and Makarova 1989). Increased temperature relates also to better nutrient availability, resulting in faster growth.

The positive correlation between the latitude of origin of *P. sylvestris* and resistance to *G. abietina* is well documented (Dietrichson 1968, Björkman 1972, Uotila 1985). Further, in Scots pine the general trend exists that slow growing northern provenances are less sensitive than southern provenances to SO_2 pollution (Huttunen 1978, Oleksyn 1987, 1988; Oleksyn *et al*. 1994). Presumably traits such as xeromorphy or thickness of epidermis of Scots pine needles confer tolerance under gaseous pollution (Huttunen 1978, Fedorkov 2002). This is consistent with the results of this study about better condition of the northernmost provenance on the weakly polluted site. It is concluded that dead forest area around Monchegorsk is most successfully reforested, when using artificial reforestation with local or more northern Scots pine seed sources.

Acknowledgements

Many thanks are due to the personnel of the Suonenjoki Research Unit of the Finnish Forest Research Institute for their seedling production and to Dr John Derome for seedling transport to Russia. The experiment could not have been established without the help of the personnel of the Monchegorsk Research Station of the Northern Forest Research Institute of Agency of Forestry of Russian Federation and Mr. Tarmo Aalto from the Finnish Forest Research Institute in Rovaniemi. Dr Seppo Ruotsalainen provided some basic information about the study material. Prof. Jarkko Hantula commented.

References

Barcan, V.S. 1992. Experience of usage of the passive plimbumoxide absorbers to assess sulphurous gas concentrations in the atmosphere. *Russian Journal of Ecology,* 4: 37–44.

Barcan, V., Pankratova, R. and Silina, A. 1993. Soil contamination by nickel and copper in an area polluted by Severonickel smelter complex. In: Kozlov, M. Haukioja, E. & Yarmishko, V. (eds.). *Proceedings of the International Workshop "Aerial Pollution in Kola Peninsula",* St. Petersburg, Russia, April 14–16, 1992. Apatity, Russia, Kola Science Center. p. 119–147.

Björkman, E. 1972. Die Prüfung forstlicher Baumarten auf Resistenz gegen parasitäre Pilze. *European Journal of Forest Pathology,* 2: 229–237.

Dietrichson, J. 1968. Provenance and resistance to *Scleroderris lagerbergii* Gremmen (*Grumenula abietina* Lagerb.). The international Scots pine provenance experiment of 1938 at Matrand. *Reports of the Norwegian Forest Research Institute,* 25: 395–410.

Eiche, V. 1966. Cold damage and plant mortality in experimental provenance plantations with Scots pine in northern Sweden. *Studia Forestalia Suecica* 36. 219 p.

Eriksson, G., Andersson S., Eiche V., Ivfer, J. and Persson, A. 1980. Severity index and transfer effect on survival and volume production of *Pinus sylvestris* in northern Sweden. *Studia Forestalia Suecica,* 156. 28 p.

Ericsson, T. and Danell, O. 1995. Genetic evaluation, multiple-trait selection criteria, and genetic thinning of *Pinus contorta* var. *latifolia* seed orchards in Sweden. *Scandinavian Journal of Forest Research*10: 313–325.

Fedorkov, A. 1999. Федорков А.Л. Адаптация хвойных к стрессовым условиям Крайнего Севера [Adaptation of conifer plants to stress condition in North]. УрО РАН. Екатеринбург. 97 с. (in Russian)

Fedorkov, A. 2002. Variation of anatomical traits of Scots pine needles and resistance to pollution and climatic stress. *Russian Journal of Ecology,* 1: 70–72.

Gianola, D. and Norton, H.W. 1981. Scaling threshold characters. *Genetics* 99: 357–364.

Henttonen, H., Kanninen, M., Nygren, M. and Ojansuu, R. 1986. The maturation of *Pinus sylvestris* seeds in relation to temperature climate in northern Finland. *Scandinavian Journal of Forest Research,* 1: 243–249.

Huttunen, S. 1978. The effects of air pollution on provenances of Scots pine and Norway spruce in northern Finland. *Silva Fennica,* 12(1): 1–16.

Kaitera, J., Fedorkov, A., Jalkanen, R., Krutov, V. and Tsvetkov, V. 1995. Occurrence of *Gremmeniella abietina* damage on Scots pine along a pollution gradient from Monchegorsk nickel smelter to western Lapland. *European Journal of Forest Pathology,* 25: 13–23.

Kaitera, J., Fedorkov, A. and Jalkanen, R. 2001. Sensitivity of Scots pine shoots to infection by *Gremmeniella abietina* var. *abietina* in contrasting conditions of environmental pollution. *Mikologija i Fitopatologija,* 35(2): 48–52. (in Russian)

Kruychkov, V.V. and Makarova, T.D. 1989. Крючков В.В., Макарова Т.Д. Аэротехногенное воздействие на экосистемы Кольского Севера. [Airborne effect on ecosystems of the Kola North Russia]. Апатиты, 1989. 96 с. (in Russian).

Mikkola, K. 1996. A remote sensing analysis of vegetation damage around metal smelters in the Kola Peninsula, Russia. *International Journal of Remote Sensing,* 17(18): 3675–3690.

Mäkitalo, K. 1999. Effect of site preparation and reforestation method on survival and height growth of Scots pine. *Scandinavian Journal of Forest Research,* 14(6): 512–525.

Ojansuu, R. and Henttonen, H. 1983. Kuukauden keskilämpötilan, lämpösumman ja sademäärän paikallisten arvojen johtaminen Ilmatieteen laitoksen mittaustiedoista. Summary: Estimation of local values of monthly mean temperature, effective temperature sum and precipitation from the measurements made by Finnish Meteorological Office. *Silva Fennica,* 17(2): 143–160.

Oleksyn, J. 1987. Air pollution effects on 15 European and Siberian Scots pine (*Pinus sylvestris* L.) provenances growing in a 75-year-old experiment. *Arboretum Kornickie,* 32: 151–162.

Oleksyn, J. 1988. Height growth of different European Scots pine *Pinus sylvestris* L. provenances in a heavily polluted and a control environment. *Environmental Pollution* 55: 289–299.

Oleksyn, J., Prus-Glowacki, W., Giertych, M. and Reich, P.B. 1994. Relation between genetic diversity and pollution impact in a 1912 experiment with east European *Pinus sylvestris* provenances. *Canadian Journal of Forest Research*, 24: 2390–2394.

Persson, B. 1994. Effects of provenance transfer on survival in nine experimental series with *Pinus sylvestris* (L.) in northern Sweden. *Scandinavian Journal of Forest Research,* 9: 275–287.

Persson, B. and Ståhl, E. 1990. Survival and yield of *Pinus sylvestris* L. as related to provenance transfer and spacing at high altitudes in northern Sweden. *Scandinavian Journal of Forest Research,* 5: 381–395.

Ranta, H., Neuvonen, S., Kääriäinen, S. and Vesanto, S. 1994. Copper and nickel pollution: frequency of endophytic fungi in Scots pine shoots and endophytic growth in vitro. *Canadian Journal of Botany,* 72: 93–99.

Rigina, O. and Kozlov, M. 2000. The impacts of air pollution on the northern taiga forests of the Kola Peninsula, Russian Federation. In: Innes, J.L. & Oleksyn, J. (eds). Forest dynamics in heavily polluted regions. Report No 1 of the IUFRO Task Force on Environmental change, CABI Publishing. p. 37–65.

SAS/STAT User's Guide. 1999. Version 8. *Sas Institute Inc., Cary, NC*. 3884 pp. ISBN 1-58025-494-2.

Uotila, A. 1985. On the effect of seed transfer on the susceptibility of Scots pine to *Ascocalyx abietina* in southern and central Finland. *Folia Forestalia,* 639, 12 p.

Vuorinen, M. and Uotila, A. 1997. The effect of acid rain treatments on the susceptibility of *Pinus sylvestris* to *Gremmeniella abietina*. *European Journal of Forest Pathology,* 27: 125 – 135.

Received 06 April 2007
Accepted 30 October 2007

СОСТОЯНИЕ И РОСТ КУЛЬТУР СОСНЫ ОБЫКНОВЕННОЙ ПРИ СИЛЬНОМ И СЛАБОМ ЗАГРЯЗНЕНИИ НА КОЛЬСКОМ ПОЛУОСТРОВЕ

А. Федорков, Ю. Кайтера и Р. Ялканен

Резюме

В географических культурах сосны, заложенных в условиях сильного и слабого загрязнения на Кольском полуострове (северо–западная Россия) были определены состояние и высота деревьев в возрасте 12 лет. Для создания культур были использованы сеянцы трех финских происхождений (Муонио, Илиторнио и Суомиссалми). Удивительно, но состояние деревьев было лучше, и их высота немного больше на участке с сильным загрязнением по сравнению со слабозагрязненным участком. Это связано с ингибирующим действием загрязнения на развитие грибных болезней сосны. Различия между происхождениями были также существенны. При слабом загрязнении деревья самого северного происхождения (Муонио) имели существенно ($p<0.05$) лучшее состояние, чем более южные (Илиторнио и Суомиссалми). На участке с сильным загрязнением различия между происхождениями были незначительны. Таким образом, на техногенных пустошах вокруг Мончегорска могут успешно создаваться культуры сосны при использовании семян северного происхождения.

Ключевые слова: состояние деревьев, высота, сернистый газ, тяжелые металлы, сосна обыкновенная