FORESTRY IDEAS, 2015, vol. 21, No 2 (50): 375–383

RADIAL GROWTH OF SCOTS PINE (*PINUS SYLVESTRIS* L.) IN VARIED ENVIRONMENT INFLUENCED BY AIR POLLUTION IN THE EUROPEAN NORTH OF RUSSIA

Vasiliy T. Yarmishko

Komarov Botanical Institute, 2 Prof. Popova str., St. Petersburg, 193376, Russia.
E-mail: vasiliyarmishko@yandex.ru

Received: 29 April 2015 Accepted: 18 January 2016

Abstract

The paper presents results of a study on the radial growth of Scots pine (*Pinus sylvestris* L.) in lichen-green moss pine forests of III–IV age class in natural conditions and in varied environment influenced by air pollution in the European North of Russia. We found that the growth of pine in young age depends more on intrapopulation interactions than on climatic factors, which is confirmed by the data on dynamics of radial growth of overripe pines. It is observed that while radial increment of pine has natural fluctuations, its dynamics changes significantly induced by atmospheric pollutants. The significant negative correlation between radial growth of pine and volume of pollutants emitted by 'Severonickel' smelter is determined.

Key words: atmospheric pollution, competition, growth, North of Russia, Scots pine.

Introduction

The in-depth study of the growth and development of dominant forest species is important both for evaluation of biological efficiency of forest ecosystems, and estimation of intrapopulation relations effects as well as understanding reasons of individual variability and stability in woody species influenced by natural and anthropogenic factors (Fritts 1976, Hustich 1978, Shiyatov 1986, Yarmishko 1997, Malkonen 2000, Yarmishko and Lyanguzova 2013).

Studies on anthropogenic dynamics of northern taiga suggest that regeneration of disturbed forest communities has different patterns in different localities (Zyabchenko 1984; Tsvetkov and Semenov 1985, Listov 1986; Kryuchkov 1991, Gromtzev 2000, Chernen'kova 2002; Tsvetkov and Tsvetkov 2003, Yarmishko, 1990, 1993, 1997, 2009; Yarmishko and Yarmishko 2015). These local patterns depend on a number of factors that altogether are described as habitat conditions. However, the above publications provide little information on the effect of intrapopulation interactions on growth and development of single trees and forest stands.

In the European North of Russia, where the numerous industrial enterprises are located ('Severonickel', 'Pechenganickel', 'ANBP-Apatity', 'Olenegorsk GOK' and others), atmospheric pollution remains one of the major anthropogenic factors causing damage and even destruction of vegetation. The central area of Kola Peninsula serves in our research as representative pilot region for the as-

sessment of impact of powerful source of long-lasting industrial pollution ('Severonickel' Cu-Ni smelter) on forest vegetation at the northern limit of its distribution. The region is characterized by relatively severe climatic conditions substantially limiting growth rate and efficiency of plant reproduction processes, as well as intensity of biological matter cycles. Primary pollutants of the territory are sulphur dioxide and heavy metal compounds.

One of the main goals of current study was to evaluate Scots pine individual trees and tree stands reactions to the pollution with sulphur dioxide and heavy metal compounds (Ni, Cu) especially with the significant decrease of emission in recent years. The radial growth is used as basic integrated quantitative indicator for evaluation of the sates of Scots pine trees in the studied conditions.

Materials and Methods

The long-term integrated researches were held at Kola Peninsula in lichen-green moss pine forests of III–IV age classes at various distances from the major emission source of the studied territory 'Severonickel' smelter (Monchegorsk, Murmansk oblast) in prevailing winds directions within the limits of three zones: impacted, buffer and background (Yarmishko 1997, 2009). The types of communities that are of the same forest type but have different level of disturbance were determined by their landscape position, characteristics of forest communities and their components, types of parent rock material and soil types.

Table 1. Brief characteristics of the studied stands.

Sample plot, number	Distance to the emission source, km	Coordinates and altitude, m	Stand composition, ratio	Average height, m	Average diameter, cm	Stand density, ha^{-1}	Age, years
Background area							
31	70	67°33'227" N 31°04'751" E, 180 m	10 P	7.1	9.4	2800	65
32	65	67°35'356" N 31°39'159 " E, 161 m	10 P	6.9	7.6	5150	55
33	60	67°33'334" N 32°07'326" E, 181 m	10 P	7.3	7.9	4500	60
Area of moderate atmospheric pollution							
3	35	67°38'168" N 32°42'234" E, 165 m	10 P+B	9.1	9.1	2120	65
Area of heavy atmospheric pollution							
29	10	67°41'216" N 32°46'447" E, 166 m	10 P	3.9	4.5	4220	60
29-a	12	68°00'384" N 32°55'540" E, 198 m	10 P	4.3	6.1	3150	65

The series of permanent sample plots (PSP) of 0.1–0.15 hectares each were set within each zone. PSPs were selected and set according to commonly recognized and clearly described approaches (Zagreev et al. 1992, Yarmishko 1997, Sanitary rules… 1998, Yarmishko and Lyanguzova 2002). Table 1 gives brief characteristic of tree layer of PSPs. Special at-

tention was given to the studies of Scots pine communities in the background area, where effects of air pollutants were negligible or absent.

To obtain quantitative data on the specificity of radial growth of Scots pine 15–20 sample trees were selected in each PSP within the working zones. The chosen trees were drilled by Pressler borer. The increment cores were taken from two sides of the trunk – northern and southern – at height of 1.3 m from root collar. The age of the trees was identified by cores sampled from the root collar of the studied trees. The annual rings width was measured with LINTAB 6 measuring system. The SAS/Stat program was used for statistical analysis of the data and calculation of correlation factors (SAS/Stat 1990). The methodical specifics of the carried research was comparison of the obtained data on the annual radial increment of Scots pine growing in natural conditions and in the communities influenced by different volumes of pollution.

The major source of industrial pollution in the area is Cu-Ni 'Severonickel' smelter (Monchegorsk, 67°55' N, 32°48' E), which is in operation since 1939 (Pozdnyakov 1999). At the peak of emission in 1973 – 1992 (Fig. 1) the average annual emission was about 230,000 t of SO_2 and 15,000 t of fine heavy metal polymetallic dust of mainly Ni and Cu sulphides and oxides. Between 1993 and 1999 the factory's treatment facilities were improved, that lowered emission of sulphur dioxide eight times, and polymetallic dust five times compared to their maximum values. Since 1999 onwards, annual emission is relatively stable and makes on the average 40,000 t of sulpfur dioxide and 5,000 t of a polymetallic dust (Kola MMC 2007).

Results

The pinewoods in the European North of Russia are intensively utilized for a long time. In the middle of the last century, forest harvesting was especially active in the studied region. Long-term observation over the second growth and formation of tree stands in lichen and lichen-green moss pine forests with insignificant or zero anthropogenic impact upon forest phytocoenosis allowed us to suggest generalized approach to disturbed forests recovery.

The pine seedlings appeared in amount of 12,000–15,000 (sometimes 30,000–35,000) per hectare on new fellings, and on fellings damaged by surface fires. However, significant number of seedlings and saplings died in the first years (soil drought, diseases, etc.). It is has been known that in further years of growth and development, competition between individual trees increase, both in above-ground parts, and in root systems (Zyabchenko 1984, Tsvetkov and Semenov, 1985, Listov 1986). As a result, an intensive differentiation occurs in juvenile growth: the strongest occupy leading positions, the weakest – die, and some persist as suppressed juveniles for a long time in the understorey of the young forest.

Lichen-green moss pine forests studied in three PSPs in the background area are characterized by good growth and development, the upperstorey trees are in regular distribution and there are about 4000–4500 trees per 1 ha on average. There are about 2000–3000 trees per 1 ha of strongly suppressed alive and dry trees in the understorey. The analysis of the data on radial wood growth of Scots pine suggests (Fig. 2) that in first 12–15 years of tree life, when there was almost no competition, the annual radial wood

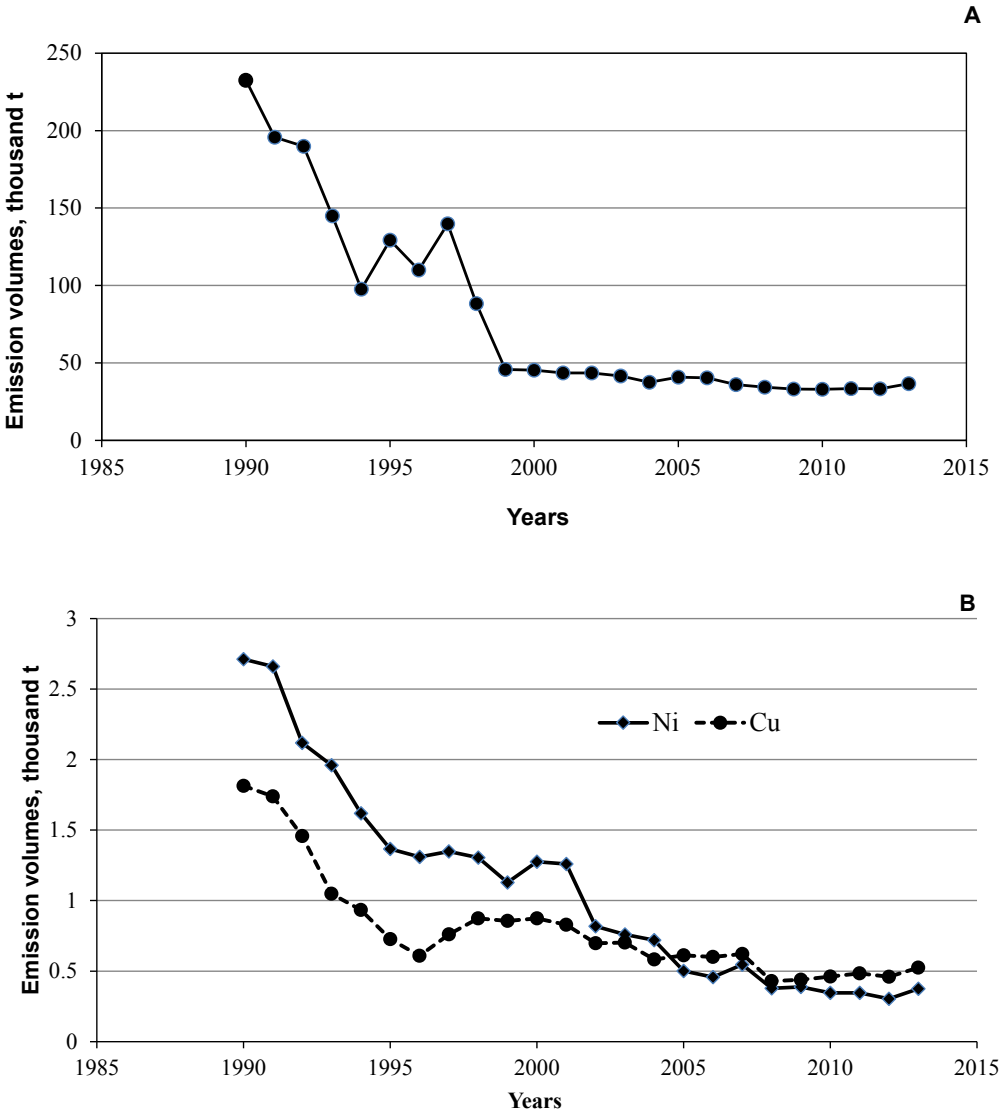

Fig. 1. Dynamics of atmospheric emission of sulphur dioxide (A) and Ni and Cu compounds (B).

increment was active (about 1.2–1.5 mm/year). Later, as juvenile pines grew bigger and the associated ground cover developed, the intensity of radial wood growth decreased by 23–25 % to little more than 1 mm/year. In the beginning of 1980s radial increment reached the minimum of 0.6–0.7 mm/year and has been stable for almost 30 years by now. It proves that competition in intrapopulation interaction in this stage is less than in the earlier phases of community formation. It is possible to predict further extension of differentiation process as based on the data on

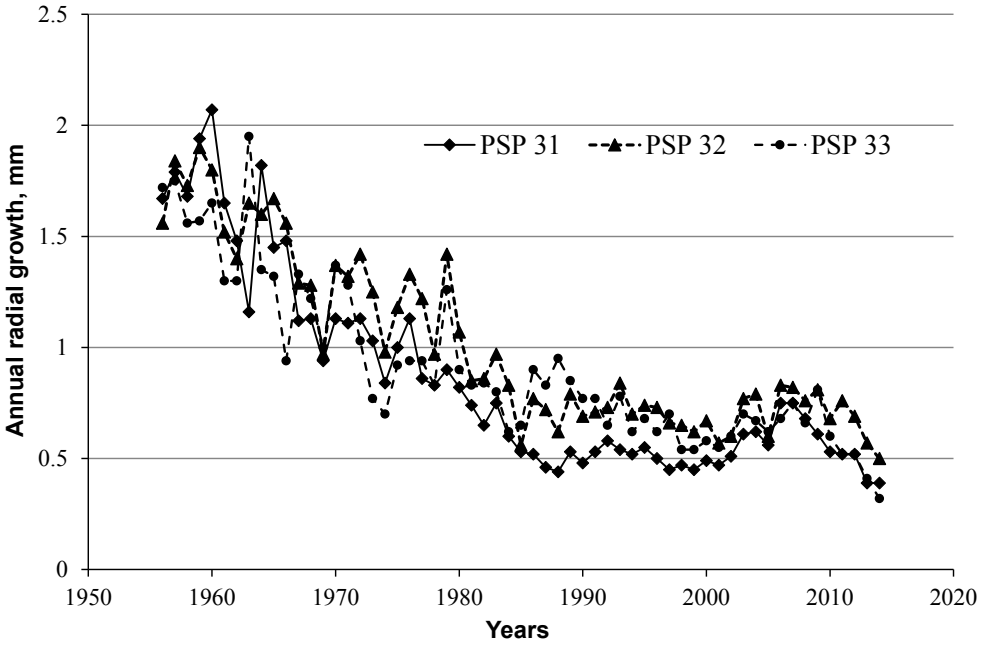

Fig. 2. Dynamics of annual radial growth of Scots pine of III–IV age class in lichen and lichen-green moss pine forests in three sample plots of the background area.

the pine forest density (trees per hectare), existence of thin stems and severely suppressed tress. Fig. 2 shows definite short-term fluctuation cycles of radial wood increment registered for each of three studied PSPs. These cycles are probably related to the changing weather conditions. They are generally synchronous though the fluctuation amplitudes of radial growth slightly differ. Within several last years the annual radial growth after some short-term increase again decreased on all studied plots (Fig. 2), we think this is associated with increasing competition within the maturing communities.

Of a special interest is Fig. 3 demonstrating data on radial growth of individual 300-year-old overripe pines growing in young secondary pine stands of III–IV age class. Trunk and crown morphometric characteristics of old trees demonstrate their good state. There are no signs of mechanical or fire injuries on the trunks. No heart rot was seen in the core samples collected for measuring annual radial growth and age at root collar or at breast height. These old pines that survived logging and fires were the mother trees for the disturbed forests.

Information obtained from the core samples shows that in young age, during the first 35–40 years of tree life the annual radial growth of now overripe trees, was 2–3 mm/year and decreased for up to 0.9–1.3 mm/year later (Fig. 3). The reason for such decrease in wood growth was increasing plants' competitive interactions in developing young community. Further, during next 160–170 years, the radial growth was relatively stable on the average of 0.6–0.7 mm/year with some fluctuations that obviously are related to the changing

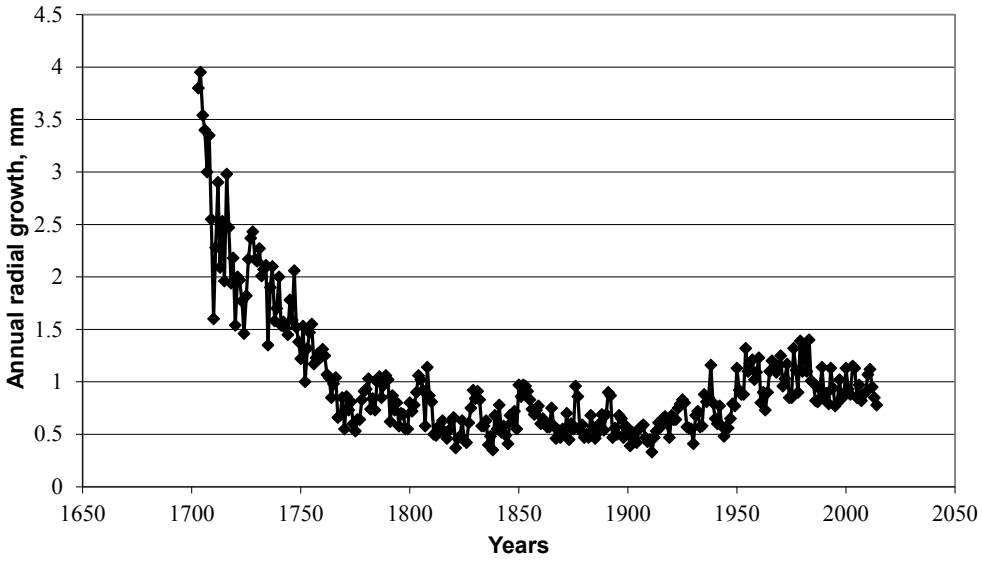

Fig. 3. Dynamics of the annual radial growth of Scots pine of XVI age class in lichen and lichen-green moss pine forests of the background area in the north of European Russia.

weather. In the mid-1950s a notable increase in radial wood increment occurred (Fig. 3). At that time intensive logging for highly valued Scots pine timber begun in the studied part of Kola Peninsula (Tsvetkov and Semenov 1985, Kryuchkov 1991). Hence, the plants competition essentially weakened after logging, fires frequently arising on fellings and significant destruction of ground cover. The remaining mother trees (sort of seed banks) demonstrated positive response increasing annual wood growth 1.3–1.5 times (1.0–1.1 mm/year). This indicator did not vary for almost 50 years (Fig. 3). Over the last years, the decline of wood increment in mature trees due to increasing competition from the intensively developing young Scots pine stands was observed (5,150 trees/ha).

Previous correlation analysis (Yarmishko 1997) demonstrated no significant association between radial growth of a pine in background area and basic climatic indices (average temperature and precipitation of July, total temperature and precipitation for growing season). Analysis of meteorological conditions in the years of maximum and minimum radial wood increment allows only in general determine most basic trends of Scots pine wood increment in the background areas of Kola Peninsula (Yarmishko 1997). This means that observed decrease in intensity of radial growth of young pine stands is connected with strong competition in developing communities (for light, nutrients, etc.).

Annual dynamics of Scots pine radial growth in young stands of III–IV age class at the territories with various degree of pollution in the central part of Kola Peninsula is shown in Fig. 4. The intensity of wood increment of Scots pine at the zone of moderate air pollution (buffer zone, within 35 km radius from the emitting source) was similar to the controls until early 1990s. Later the annual radial

growth curve demonstrated notable descending character. That to our opinion, is related to the pollutants accumulated in the soil and continuous intrapopulation competition processes. The correlation analysis of data series of radial increment of Scots pine from the areas of moderate pollution with volumes of emitted air pollutants demonstrates negative association (r = –0.47; n = 24; P < 0.05). Here we should note that the pine responded to decrease of toxic emission with increasing wood growth of 10–15 % in early 2000s as compared to the previous period. The recent years are characterized by decrease in wood increment in the studied region.

The radial growth of Scots pine in a zone of heavy pollution (impacted zone, within 8–12 km radius from emitting source) in the early stages of tree stands formation was moderate and did not exceed 0.8–0.9 mm/year. No matter there is visible similarity of the curves of young community growth in impacted zone (descending character) with those in background area and buffer zone, the pollutants had sufficient negative effect on the pine from the moment of its germination. In early 1970s the annual pine wood increment essentially decreased (as low as 0.3 mm/year). This is seen as a direct response to the 1970s 'Severonickel' smelter combine capacity boosted and started importing Norilsk ore that is characterized by increased content of sulphur (Fig. 4).

The intensity of Scots pine wood increment in the heavily contaminated territories have been gradually increasing form early 1990s and by 2000s was similar to the growth rate in background communities and in the areas with low contamination. The correlation analysis of data series on Scots pine radial wood increment in the areas of heavy pollution and volumes of emitted pollutants provides reliable negative association. There is significant correlation of the radial growth with amount of sulphur dioxide emitted to the

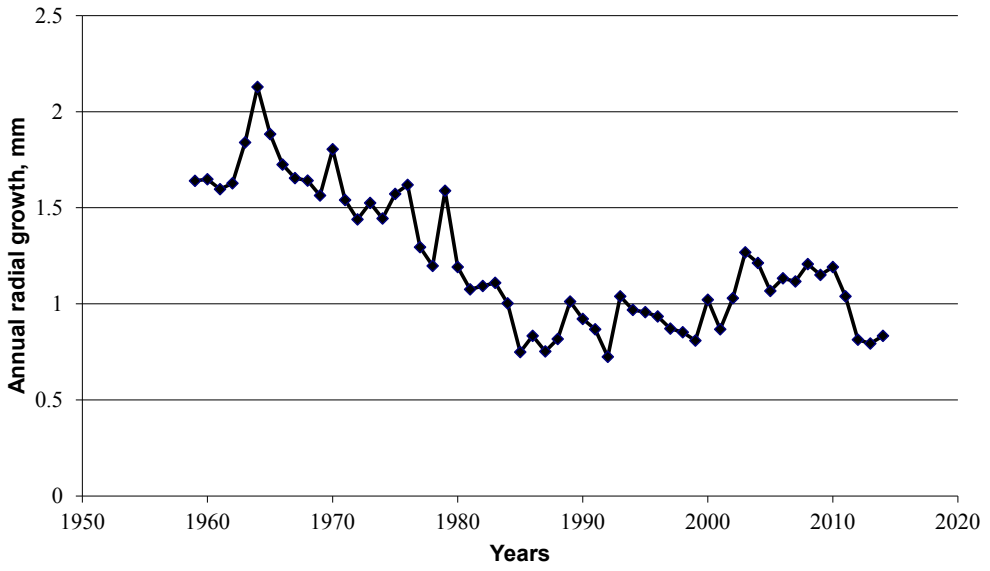

Fig. 4. Dynamics of annual radial growth of Scots pine in the areas with different levels of pollution.

atmosphere (r = –0.80; n = 24; P < 0.05) and amount of solid particles (r = –0.85; n = 24; P < 0.05). It is necessary to note, that the established association is much stronger in heavily polluted area, than in the moderate one. In more affected territories the growth and development of individual trees and tree stands of Scots pine depend rather on intensity of environment pollution with sulphur dioxide and oxides of heavy metals, than on changing climatic factors. Though even in this affected territories the factor of intrapopulation competition is to be taken in account, as the tree density is still high (3,500–4,200 trees/ha) although trees are damaged.

Discussion

The high uniformity of spatial structure and similarity of tree age are the features of young forests due to specificity of forest formation on the logged and burned areas in the European North of Russia. Until the formation of stand canopy, young forests differs in stand density, closeness and state. It is in young forests that the disproportion between these characteristics is more obvious. The uniformity of tree distribution and narrow crowns of pine explains this phenomenon. One more feature of the dense young forests is the slow natural mortality.

Intensive annual radial increment of Scots pine in the north of Kola Peninsula lasts for 45–50 years, and according to Tsvetkov and Tsvetkova (1985) even longer, for 50–60 years. In dense young forests (12,000–15,000 trees/ha) the radial growth notably reduces from the age of 25–30. According to downfall trend, radial growth of pine in young age depends in a greater degree on intrapopulation interactions, than on climatic factors. The data on radial increment of overripe pines, as well as on communities affected by atmospheric pollution proves this observation. Fig. 4 demonstrates recent decrease in radial growth of Scots pine in all studied territories. To our opinion, this is related to the global environmental changes and continuous intrapopulation processes characteristic to developing young forest communities.

Conclusion

In conclusion, it is necessary to say that the growth of Scots pine (*Pinus sylvestris* L.) in the European North of Russian in young age depends more on intrapopulation competition than on climatic factors. This conclusion is confirmed by the data on dynamics of radial increment of the overripe pines. Essential changes of annual radial growth of Scots pine influenced by atmospheric pollutants are registered, while natural fluctuations exist. The significant negative correlation between annual radial increment of Scots pine and volume of toxic substances emitted by ‘Severonickel’ combine is established. Synergetic effects of various natural and anthropogenic factors have significant influence on formation, growth and vitality of Scots pine communities at the northern limit of its distribution.

Acknowledgments

The studies were carried out in the frame of the approved research topic of the Laboratory of the ecology of plant communities of Komarov Botanical Institute RAS (No 01201458800) and with the financial support from the program ’Biological Resources of Russia: Dynamics under Global Climatic and Anthropogenic Effects‘ of the Department of Biological Sciences of RAS.

References

Chernen'kova T.V. 2002. Response of forest vegetation to industrial pollution. Moscow, Nauka 191 p. (in Russian).

Fritts H.C. 1976. Tree rings and climate. London, New York and San Francisco, Academic Press. 567 p.

Gromtzev A.N. 2000. Landscape ecology of taiga forests: theoretical and applied aspects. Petrozavodsk. 144 p. (in Russian).

Havas P., Huttunen S. 1972. The effect of air pollution on the radial growth of Scots pine (*Pinus sylvestris* L.). Biological Conservation 4(5): 361–368.

Hari P., Raunemaa T. 1985. The effect of changing environmental factors of forest growth. Proc. of the symp. 'Air pollution and ecosystems' (October 1–5, 1984. Ostrevice, Czech.) Brno: 249–261.

Hustich I. 1978. The growth of Scots pine in northern Lapland, 1928–1977. Annales Botanici Fennici 15: 241–252.

Kola MMC 2007. Yearbook 5: 87 p. (in Russian).

Kryuchkov V.V. 1991. Critical Anthropogenic Loads and the Status of the Ecosystems of the North. Ekologiya 3: 28–40 (in Russian).

Listov A.A. 1986. White-moss pine forests. Moscow: Agropromizdat. 182 p. (in Russian).

Malkonen E. (Ed.) 2000. Forest Condition in a Changing Environment. The Finnish Case. Kluwer Academic Publishers 65. 378 p.

Nöjd P., Kauppi P. 1995. Growth of Scots pine in a changing environment. Kola peninsula pollutants and forest ecosystems in Lapland: Final report of the Lapland forest damage project: 61–65.

Pozdnyakov V.Ya. 1999. Severonickel (Pages of history of 'Severonickel' combine). Moscow, Ore and Metals. 429 p. (in Russian).

Sanitary rules for forests of the Russian Federation 1998. (Approved by the order of Russian Federal Forest Service of 15.10.1998.) No 10: 18 p. (in Russian).

SAS/Stat 1990. User's guide. Version 6.0. SAS Institute, Cary N.C. 572 p.

Shiyatov S.G. 1986. Dendrochronology of the forest upper border in the Urals. Moscow. 136 p. (in Russian).

Tsvetkov V.F., Semenov B.A. 1985. Pine forests of the Far North. Moscow, Agropromizdat. 116 p. (in Russian).

Tsvetkov V.F., Tsvetkov I.V. 2003. Forest in the conditions of aerotechnogenic pollution. Arhangel'sk: ASTU Publ. 354 p. (in Russian).

Tsvetkov V.F., Tsvetkova V.I. 1985. Laws of formation of annual growth layer and radial growth of a pine in the Kola Peninsula. Botanical researches beyond the Arctic Circle. Apatity: 82–88 (in Russian).

Yarmishko V.T. 1990. State of pine stands. Influence of industrial atmospheric pollution on pine forests of Kola Peninsula. Leningrad, BIN: 104–109. (in Russian).

Yarmishko V.T. 1993. The analysis of morphological structure and crown state of *Pinus sylvestris* L. under different levels of air pollution in Kola Peninsula. Aerial pollution in Kola Peninsula (April, 14–16, 1992, St. Petersburg): Proceedings of the International Workshop. Apatity: 236–251.

Yarmishko V.T. 1997. Scots pine and atmospheric pollution in the European North. St. Petersburg. 210 p. (in Russian).

Yarmishko V.T. (Ed.). 2009. Dynamics of forest communities of Northwestern Russia. St. Petersburg. 276 p. (in Russian).

Yarmishko V.T., Lyanguzova I.V. (Eds.). 2002. Methods of study of forest communities. St. Petersburg. 240 p. (in Russian).

Yarmishko V.T., Lyanguzova I.V. 2013. Long-term dynamics of parameters and state of needles of *Pinus sylvestris* L. affected by aerotechnogenic pollution in the European North. Bulletin of Saint Petersburg Forest Technical Academy 203: 137–148 (in Russian).

Yarmishko V.T., Yarmishko M.A. 2015. State of the forest communities in conditions of changing environment on the European North of the Russia. Book of Abstracts, International Scientific Conference 'Forestry: Bridge to the Future' 6–9 May 2015, Sofia, Bulgaria: 155–156.

Zagreev V.V., Sukhikh V.I., Shvidenko A.Z., Gusev N.N., Moshkalev A.G. 1992. All-Union standards for forest inventory. Moscow, Kolos. 495 p. (in Russian).

Zyabchenko V.V. 1984. Pine forests of the European North. Leningrad, Science. 274 p. (in Russian).