FORESTRY IDEAS, 2020, vol. 26, No 2 (60): 549–557

OPTIMIZATION OF THE COMPOSITION OF FOREST STANDS INCLUDING NORWAY SPRUCE ACCORDING TO THEIR RESISTANCE TO ADVERSE CLIMATIC FACTORS

Denis E. Rumyantsev*, Leonid V. Stonozhenko, Ekaterina V. Naidenova, and Anna A. Sirotova

Mytishchi branch of Bauman Moscow State Technical University (National Research University), 1st Institutskaya Str., 141005 Mytischi, Moscow region, Russia. *E-mail: dendro15@list.ru

Received: 02 May 2020 Accepted: 27 November 2020

Abstract

The article considers the issue of establishment and formation of new plantations in forest areas, passing continuous sanitary logging. The evaluation of the reaction of European spruce in stands of various species composition to the different climatic factors impact by analyzing dendroclimatic information has been carried out. It was found out that the least meteosensitivity of spruce is observed in lime stands. Predicting the conditions of Norway spruce trees (*Picea abies* (L.) Karst.) and spruce stands in general after catastrophic drought of 2010 followed by eight-toothed bark beetle (*Ips typographus* L.) invasion is of immediate interest now. On the practical side optimization of stand composition according to the reaction to climatic factors is advantageous.

Key words: Norway spruce, Moscow region, drought resistance, tree rings, stand composition.

Introduction

Probably the first fundamental work about regularities of radial growth variation of Norway spruce trees was that of Norwegian dendrochronologist B. Eklund (Eklund 1957). Patterns, identified in it are of immediate interest now; for example the strong correlation between early wood width and late wood width oscillation requires further ecophysiological interpretation. In recent times the possibilities for research work in this domain have become much wider thanks to the introduction of new modern specialized equipment and software. Among the works of recent years many contain promising results (Ditmar and Elling 2004, Koprowski and Zielski 2006, Ribnicek et al. 2010, Hartl-Meier et al. 2014, Rumyantsev et al. 2016, Solomina et al. 2017).

For forestry practice in Norway spruce forests the main problem is the periodical death of the stands triggered by the effects of droughts. Drought resistance of spruce and predicting the conditions of Norway spruce trees and stands in general after catastrophic droughts followed by bark beetle (*Ips typographus* L.) invasion has been of particular interest then and now (Sukachev 1928, Tkachenko 1939, Pravdin 1975, Vorontsov 1978, Ditmar and Elling 2004, Rybníček et al. 2010). On the practical side optimization of stand composition according to their reaction to climatic factors is advantageous. Dendroclimatological investigations can help in achieving this goal.

Radial increment can be an indicator of a tree condition to some extent. It should be expected that short-time variation of radial increment will differ depending on forest stand composition where the recorded trees of a certain species grow (Ellenberg 1952). It is interesting to analyze the specific character of the influence of climate factors on the radial growth of spruce depending on the composition of the plant community. Stand-forming species have different ecological requirements. In the process of interspecific competition in Spruce stands, fluctuations in radial growth should take place differently depending on which species is the main competitor of spruce in the plant community. Competition for abiotic resources of the environment, as shown above, modifies the nature of fluctuations in radial growth from year to year.

The aim of this work was to assess the reaction of Norway spruce in stands of different species composition to the impact of different climatic factors.

Materials and Methods

To check the hypothesis about difference of Norway spruce radial growth fluctuations in stands differing in species composition, as initial objects we chose 13 forest stands with various species composition of Shcholkovsky Training and Experimental Forest Range (TEFR) belonging to Mytishchi branch of BMSTU.

The Scholkovsky TEFR is situated in the Moscow region, not far from Moscow (less than 50 km) (55.948165 °N, 38.127995 °E). The climate of the region is moderately continental and typical for the southern taiga zone of the Russian plain.

A core sampling was organized in the stands selected for investigation. One core was taken from each tree at a height of 1.3 m. The number of cores taken from each permanent sample area (PPP) varied from 7 to 13. The Inventory characteristics of experimental plots are presented in Table 1.

Lintab 5 equipment was used for tree ring measuring and Tsap-Win program was used to control the accuracy of measurement by the cross-date procedure (Palchikov and Rumyantsev 2009, Matveev and Rumyantsev 2013). Individual tree-ring chronologies were indexed by rationing radial annual increment to average radial increment over the past 5 years. On the basis of the indexed chronologies average chronologies for each sample plot were built.

To conduct the first part of our research we have selected forest stands with the following species composition: pure spruce (10 units), stands with spruce predominance (7 units), stands with aspen predominance (5 units), stands with birch predominance (7 units), stands with pine predominance (5 units), stands with lime predominance (7 units). We have conducted the analysis of the climatic factors impact on radial increment of spruce depending on plant community composition.

Table 1. Inventory characteristics of experimental plots.

Plot No	Year of last inventory	Species composition by tree layers		Average diameter by tree layers, cm	Average height, m	Cross-sectional area sum, m²/ha	Relative density	Average age, years	Growing stock, m³/ha	Site quality	Understory trees, thousands of individuals/ha (2013–2016)
10	2013		8S1As1B+O	19.2	15.5	23.3	0.54	58	181	II	5O4As1L (2.66)
	2016		8S1As1B+O	20.2	16.9	24.7	0.54	61	206	II	
100	2001		7S1As1B1L+P	20.3	21.4	33.3	0.65	47	341	Ia	9L1O (4.29)
	2013		7S1As1B1L+P	23.9	24.5	32.8	0.6	60	379		
106	2002		10S	14.2	15.2	40.6	0.96	44	310	I	8L2S+O (2.67)
	2013		10S	17.1	15.8	52.2	1.0	55	412	II	
119	2013	I	5L3As1B1S	26.1	25.0	32.5	0.9	55–65	364	Ia	7L2S1Al+O (5.7)
		II	9L1S+B	11.6	16.7	4.2	0.1	40–45	33		
120	2013	I	9S1B+As	21.5	20.4	25.9	0.72	127	242	III	6O4S (0.65)
		II	8S2B+O,As	12.7	16.5	10.0	0.29		78		
	2016	I	9S1B+As	22.4	23.1	29.2	0.66	130	273	III	
		II	8S1B1O+As	12.7	18.3	10.5	0.27		80		
121	2013		9S1B+O	19.8	15.4	38.6	0.89	55	298	II	10O (0.12)
	2016		9S1B+O	21.1	17.7	38.0	0.82	58	330		
122	2013	I	5As3L1B1S	24.5	23.0	35.6	1.0	60–75 (122*)	370	I	9L1S (7.31)
		II	7L3S	12.7	14.0	7.7	0.3	35–50	52		
123	2014		6L3S1B + P, O	32.2	28.7	40.3	1.0	75–90	511	Ia	9L1S+O, M (4.25)
127	2014	I	7L2S1B+O	23.6	25.0	29.5	0.9	65–70 (125*)	330	Ia	7S3L+O (5.74)
		II	8L2S+B, O	10.4	13.4	3.8	0.1	30–45	25		
129	2014	I	7B3L+As, S	16.1	23.3	12.7	0.5	30–35 (65*)	134	Ia	10L+As, O, S (4.14)
		II	5S5B+As, S	9.6	16.1	3.7	0.1	20–35	28		
131	2014	I	5P5B+S, L	26.1	27.3	31.3	0.7	65–80	379	Ia	9L1S+O (6.8)
		II	5S4L1B+P, M, O	11.2	13.7	8.3	0.3	30–55	55		
135	2015		4L3S3B+O, As	20.1	18.7	37.5	1.0	75	342	Ia	5L3S1B 1As+O (3.83)
140	2015		9S1B+O	21.4	24.8	45.7	0.83	66	534	I	10O (0.23)

Note: * – age of individual trees. Legend: S – Norway spruce (*Picea abies* (L.) Karst.); L – Small-leaved linden (*Tilia cordata* Mill.); As – Common aspen (*Populus tremula* L.); O – Common oak (*Quercus robur* L.); B – Silver birch (*Betula pendula* Roth.); P – Scots pine (*Pinus sylvestris* L.); Al – Grey alder (*Alnus incana* (L.) Moench.); M – Norway maple (*Acer platanoides* L.). Numbers symbolize the share out of 10.

Results and Discussion

The example of radial growth dynamic in spruce stands are shown in Fig. 1. Visual analysis of graphs says that the radial growth has significant variability from year to year and between different plots.

Tables 2 and 3 show the results of correlation analysis of the conjugacy of radial growth fluctuations and fluctuations in meteorological parameters of the current and previous year. Reliable values of correlation coefficients are shown in bold in the tables. At degrees of freedom = 53 and α = 0.05, the correlation coefficient values from 0.27 and higher are significantly different from zero. The example chronologies from stands with spruce predominance more than 7 units are shown in Figure 1.

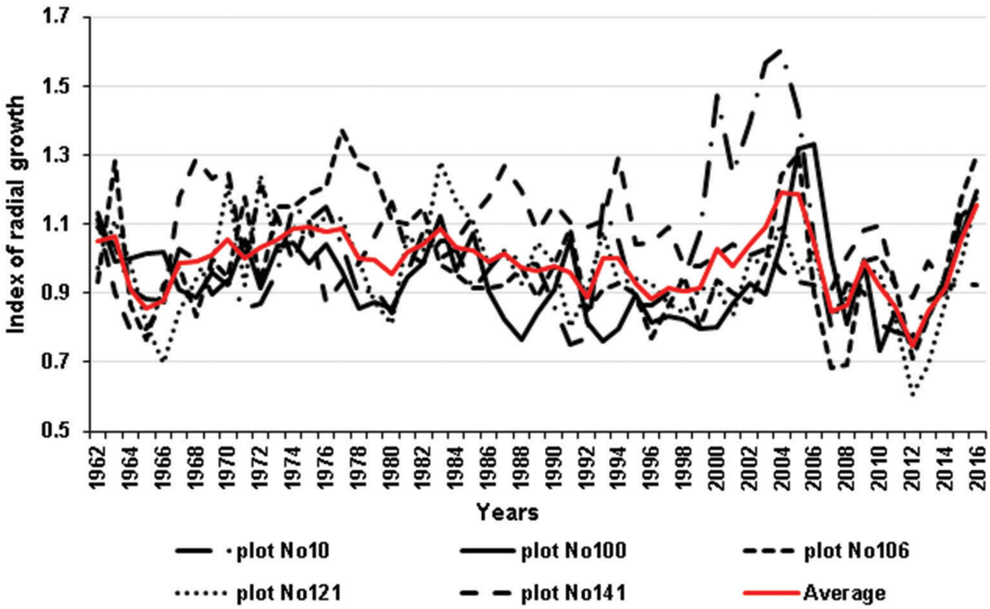

Fig. 1. Example chronologies from stands with spruce predominance more than 7 units.

Table 2. Correlation coefficients between increment indices and meteorological parameters of the current year.

Meteorological parameter	Chronology					
	Pure spruce stands	Stands with spruce predo-minance	Stands with aspen predo-minance	Stands with birch predo-minance	Stands with pine predo-minance	Stands with lime predo-minance
W in January	-0.01	0.15	-0.02	-0.08	**0.31**	-0.10
W in February	-0.05	-0.06	0.21	**0.30**	-0.13	-0.05
W in March	-0.19	-0.18	0.05	0.08	-0.06	0.05
W in April	0.03	0.20	-0.19	-0.18	-0.02	-0.17
W in May	0.17	0.18	0.22	**0.32**	-0.20	0.09
W in June	0.22	-0.05	0.08	0.22	**0.29**	0.00
W in July	0.16	0.10	0.19	0.21	-0.01	0.11

Meteorological parameter	Chronology					
	Pure spruce stands	Stands with spruce predo-minance	Stands with aspen predo-minance	Stands with birch predo-minance	Stands with pine predo-minance	Stands with lime predo-minance
W in August	-0.14	-0.14	-0.09	-0.01	0.15	-0.18
W in September	-0.12	-0.15	**-0.34**	-0.25	0.16	**-0.30**
W in October	-0.15	0.01	-0.02	0.04	-0.18	-0.11
W in November	0.21	0.00	0.01	-0.07	-0.13	0.09
W in December	0.16	-0.03	0.07	0.01	0.19	0.03
T_{av} in January	-0.14	0.06	0.12	0.13	0.19	-0.11
T_{av} in February	-0.01	-0.20	**0.37**	**0.37**	0.03	0.02
T_{av} in March	-0.14	-0.17	**0.32**	**0.29**	-0.03	0.03
T_{av} in April	-0.22	-0.10	0.06	0.15	0.09	0.01
T_{av} in May	0.06	0.03	-0.22	**-0.36**	-0.10	0.02
T_{av} in June	-0.24	-0.22	-0.07	-0.13	0.10	**-0.28**
T_{av} in July	-0.18	**-0.31**	-0.09	-0.14	0.08	-0.17
T_{av} in August	-0.22	-0.08	-0.21	**-0.32**	-0.04	-0.19
T_{av} in September	0.02	0.26	0.19	0.02	-0.07	0.07
T_{av} in October	**-0.30**	0.07	-0.05	-0.16	**0.29**	-0.04
T_{av} in November	0.18	0.16	-0.17	-0.06	-0.19	0.19
T_{av} in December	-0.09	0.24	0.17	0.03	-0.01	-0.14

Note: the correlation coefficients in bold are significantly different from zero; *W* – rainfall, T_{av} – average temperature.

Table 3. Correlation coefficients between increment indices and meteorological parameters of the previous year.

Meteorological parameter	Chronology					
	Pure spruce stands	Stands with spruce predo minance	Stands with aspen predo-minance	Stands with birch predo-minance	Stands with pine predo-minance	Stands with lime predo-minance
W in January	0.01	0.18	-0.03	-0.03	**0.36**	-0.08
W in February	-0.07	-0.11	0.01	0.18	-0.16	0.22
W in March	-0.06	-0.07	-0.12	-0.03	-0.04	0.06
W in April	0.08	0.15	0.05	-0.07	-0.08	0.09
W in May	**0.32**	**0.27**	**0.27**	0.24	-0.13	0.24
W in June	0.15	0.01	0.05	0.01	0.18	0.00
W in July	0.26	**0.28**	0.10	0.17	0.15	**0.34**
W in August	-0.04	-0.16	0.16	0.16	0.03	0.15
W in September	0.02	0.02	-0.14	-0.25	0.26	-0.04
W in October	-0.02	-0.15	-0.16	-0.06	-0.21	-0.05
W in November	0.10	-0.16	-0.24	-0.08	-0.13	0.21
W in December	0.13	0.09	0.10	0.00	0.07	0.19

Meteorological parameter	Chronology					
	Pure spruce stands	Stands with spruce predo minance	Stands with aspen predo-minance	Stands with birch predo-minance	Stands with pine predo-minance	Stands with lime predo-minance
T_{av} in January	-0.10	0.03	0.12	0.21	0.12	0.03
T_{av} in February	**0.29**	0.06	0.21	**0.45**	-0.08	0.16
T_{av} in March	0.14	-0.09	0.03	0.25	-0.07	0.08
T_{av} in April	-0.10	-0.01	-0.05	0.19	-0.11	0.15
T_{av} in May	-0.16	-0.04	-0.18	-0.20	-0.06	-0.07
T_{av} in June	**-0.33**	**-0.31**	-0.06	0.07	0.06	-0.18
T_{av} in July	-0.18	-0.07	-0.10	-0.11	-0.14	-0.23
T_{av} in August	-0.25	0.04	**-0.29**	-0.24	-0.13	**-0.41**
T_{av} in September	-0.15	0.25	-0.09	-0.10	-0.12	-0.22
T_{av} in October	**-0.37**	0.04	-0.05	0.05	0.05	-0.16
T_{av} in November	0.17	0.14	-0.14	-0.17	**-0.30**	0.06
T_{av} in December	0.03	**0.31**	**0.30**	0.25	0.00	-0.12

Note: the correlation coefficients in bold are significantly different from zero. *W* – rainfall, T_{av} – average temperature.

Based on the data in tables 2 and 3, it should be concluded that a specific set of reliable correlation coefficients was observed in chronologies or from stands of different species composition. However, the values of correlation coefficients were small and indicated only the presence of weak links. The maximum value of the correlation coefficient was observed for average temperature of February of the previous year (0.45) and spruce radial growth in stands with birch predominance. There was a relatively high correlation between spruce radial growth in stands with birch predominance and aspen predominance and average temperature of February of current year, too. The temperatures above average have positive effect for spruce radial growth. It may explain their influence on snowmelt and more rapid onset of the growing season. As a whole, even the particular ecophysiological mechanisms of the significant correlations are not understood, they are a biological fact, which was established by scientific methods and need further investigations. For example, the negative effect of high temperatures in May for radial growth of Spruce in the stands with birch predominance (correlation coefficient -0.36) may be related to the high reflective properties of birch bark for sun light, high light transmission capacity of the birch canopy in this period, and intensive cambial activity of the Spruce at that time, because the cambium of spruce is considered very sensitive for thermal damage (Tkachenko 1939, Vorontsov 1978, Hacura et al. 2011).

The results of correlation analysis of radial increment fluctuations and meteorological parameters (precipitation and monthly temperature) fluctuations for the current and previous year show that in the Spruce stands chronologies of various species composition revealed a specific set of significant correlation coefficients (scaling factors) (Table 4). Drought signal is the author's term introduced by D. E.

Table 4. Numbers of the significant correlation coefficients of the relationships between radial increment and meteorological parameters of current and previous year.

Chronology	Pure spruce stands (10 units)	Stands with spruce predominance (7 units)	Stands with aspen predominance (5 units)	Stands with birch predominance (7 units)	Stands with pine predominance (5 units)	Stands with lime predominance (7 units)
Drought signal	5	5	6	7	5	4

Note: Drought signal – the number of sound correlation coefficients values of radial increment and meteorological parameters (Solomina et al. 2017).

Rumyantsev (Solomina et al. 2017). It is defined as the sum of reliable correlation coefficients during the current and previous growing season. Each reliable value is assigned a score of ‘1’, but only positive correlation coefficients with precipitation and negative correlation coefficients with temperatures were taken into account.

The results of our research show that the highest sensitivity to climatic factors (meteosensitivity) of spruce was in small-leaved species stands (the majority of significant correlation coefficient values with meteorological parameters were observed at stands with birch predominance). Meteosensitivity of spruce in pure spruce stands and stands with spruce predominance was the same, that makes it possible to combine them into a generalized chronology (Fig. 2). In contrast, the lowest meteosensitivity of spruce was observed in lime stands. Based on the obtained results, for the next stage of our research we have chosen sample plots including 6 or more units of spruce and minimum 6 or more units of lime in species composition of a stand. The dynamics of radial increment indices for the last 15 years (in the considered chronology) is presented in Fig. 2.

During the studied period a well-defined drought was present in 2010. The

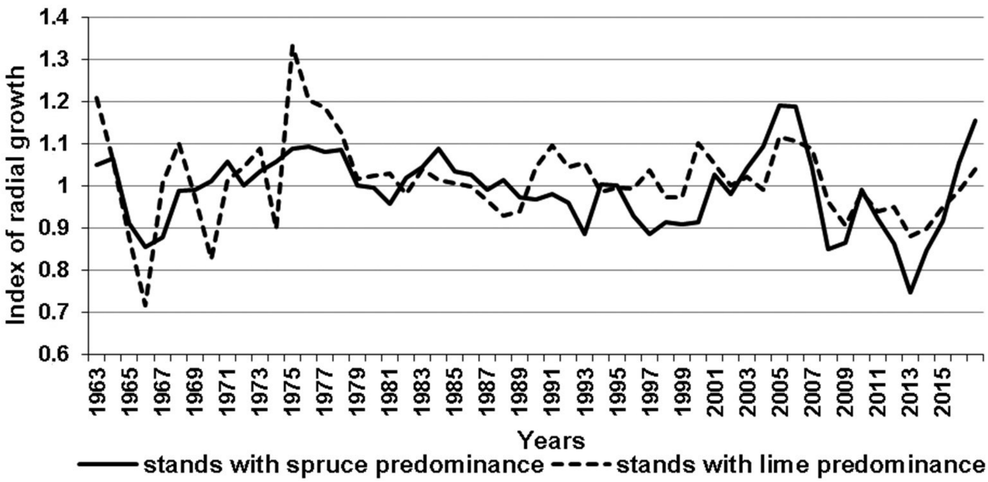

Fig. 2. Dynamics of radial increment indices of spruce in various species composition stands.

analysis of its impact on spruce increment in stands with totally different species composition is of some interest. Precipitation in July 2010 were significantly below the average (86.1 % less than long-term average annual rate). Moreover, July temperatures exceeded long-term average rates by 37.5 %. Analyzing the variation of radial increment indices for two selected groups of trees (Fig. 1), we should emphasize that in 2010 this indicator for the groups was the same, while in the following 2011 it went down dramatically for the group 'stand with spruce predominance' in comparison with the group 'spruce in stands with lime predominance'. In 2012, 2013, 2014 there was still an excess of 'spruce in stands with lime predominance' over the group 'stands with spruce predominance' in terms of radial increment index. Thus, the 2010 drought probably has had more negative effect on the spruce growth in pure stands than in stands with lime predominance.

Conclusion

The increment value of spruce in stands with lime predominance turned to be less dependent on the climatic factors, which could be the evidence of higher spruce resistance in mixed lime-spruce stands in comparison to monocultures. Lower stability of homogeneous ecosystems is noted, and therefore, the establishment of pure spruce plantations, especially in protective forests, seems to be impractical. In the formation of mixed stands, it is necessary to select species that would be complementary to each other and compensate for the impact of certain environmental factors. As a secondary and satellite species, or in the zone of mixed coniferous-broad-leaved forests, the lime is proposed because of possessing natural mechanisms to withstand the dry periods, to which the spruce is vulnerable. Consequently, establishment of mixed lime-spruce plantations in Moscow Region could be recommended in order to increase spruce resistance to drought.

References

Dittmar C., Elling W. 2004 Radial growth of Norway spruce (*Picea abies* (L.) Karst.) at coulissenhied site in relation to environmental conditions and comparison with sites in the Fichtelgebirge and Erzgebirge. Ecological Studies 172: 291–311.

Eklund B. 1957 Om granens arsrings variationner inom mellersta norland och deras samband. Statens Skogsforskingsinstitut. Band 47. Nr. 1. 63 p. (in Swedish).

Ellenberg H. 1952. Landwirtschaftliche Pflanzensoziologie. II. Wiesen und Wieden und ihre standörtliche Bewertung. Stuttgart, Ulmer. 143 p.

Hacura J., Vavrcík H., Urban J., Gebauer R. 2011. Monitoring of xylem formation in *Picea abies* under drought stress influence. Dendrobiology 67: 15–24.

Hartl-Meier C., Zang Ch., Dittmar Ch., Espen J., Göttlein A., Rothe A. 2014. Vulnerability of Norway spruce to climate change in mountain forests of European Alps. Climate Research 60(2): 119–132.

Koprowsi M., Zielski A. 2006. Dendrochronology of Norway spruce (*Picea abies* (L.) Karst.) from two range centers in lowland Poland. Trees 20: 383–390.

Matveev S., Rumyantsev D. 2013. Dendrochronology. Voronezh: Voronezh State Forestry Academy. 140 p. (in Russian).

Palchikov S., Rumyantsev D. 2009. Timber logging legality control based on tree-ring information. Sustainable Forest Use 2(2): 12–16 (in Russian).

Pravdin L.F. 1975. Norway spruce and Siberian spruce in the USSR. Moscow, Nauka. 176 p. (in Russian).

Rumyantsev D.E. 2010. History and methodology of forestry dendrochronology. Moscow, Moscow State University of Forestry. 107 p.

Rumyantsev D.E., Kuhta A.E., Puchinskaya D.V. 2016. Climate signal of droughts in the chronology of spruce from the acidic forest type of the Central forest reserve. Forestry Bulletin 2: 36–43 (in Russian).

Rybníček M., Cermak P., Zid T., Kolar T. 2010. Radial growth and health conditions of Norway spruce (*Picea abies* (L.) Karst.) stands in relation to climate (Silesian Beskids, Czech Republic). Geochronometria 36: 9–16.

Solomina O.N., Bushueva I.S., Dolgova E.A., Zolotokrylin A.N., Kuzneczova V.V., Lazukova L.I., Lomakin N.A., Maczkovskij V.V., Matveev S.M., Mihajlov A.Yu., Mihajlenko V.N., Pozhidaeva D.S., Rumyantsev D.E., Sakulina G.A., Semenov V.A., Hasanov B.F., Cherenkova E.A., Chernokulskij A.V. 2017. Droughts of the Eastern European plain according to hydrometeorological and dendrochronological data. Geography institute of Russia Academy of Sciences, Moscow. 360 p. (in Russian).

Sukachev V.N. 1928. Forest species: their systematic and phytosociology. Coniferous. Moscow Novaya derevnya. 81 p. (in Russian).

Tkachenko M.E. 1939. General silviculture. Leningrad, Goslestechizdat. 746 p. (in Russian).

Vorontsov A.I. 1978. Forest pathology. Moscow. Forest industry [Lesnaya promyshlennost’]. 270 p. (in Russian).