DEVELOPMENT OF UNDERGROWTH PHENOLOGICAL SPRUCE FORMS IN DIFFERENT SPECIES COMPOSITION OF FOREST STANDS

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Abstract
The aim of research was to determine peculiarities of relations between mature layer of the stand with distribution of spruce (*Picea abies.* Kr.) regeneration according phenology forms and growth specifics.
The study examined the success of the resumption of spruce in the Leningrad region under the canopy of the parent stand. In stands with different share of spruce and in various forest-typological conditions, the features of the relationship between the maternal canopy of the stand, the distribution of the natural resumption of spruce by phenological forms and its course of growth were investigated. The account of the undergrowth was carried out by two methods: continuous reading and selective-statistical method.
Regardless of the state of viability of spruce undergrowth, the increase in success of regeneration goes from a late vegetation season growth start form to an early one. Under the canopy of the maternal tree stand, young spruce of the early form has the best growth and development indices. In general, under the canopy of spruce stands, the annual height increment in spruce undergrowth, regardless of the phenological structure, the size categories and the state of viability, is greater than under the canopy of pine, pine-spruce and birch-spruce stands. The best characteristics of spruce undergrowth, regardless of phenological forms in vaccinio-myrtillo-pinetum type of forest. When analyzing the characteristics of spruce undergrowth under the canopy of the stand, taking into account the phenological and altitudinal structure, and the state of viability, it was revealed that at the average age prevailing in the spruce undergrowth of the transitional form, the best parameters of growth have small and medium forms and growth in the early form.
Analyzing the characteristics of spruce undergrowth under the canopy of the stand, taking into account the phenological and height structure, as well as vitality status, it was revealed that at average age, dominating for the spruce undergrowth of transitional form, the best parameters of small and medium groups of undergrowth has early vegetation season growth start form. The best parameters of the growth have a large group of undergrowth of late vegetation season growth start form.
Key words: young growth of spruce, phenological forms, the composition of the stand.

Introduction

There are many morphologic, phenological and other forms of spruce (Münch, 1923; Barton, 1988; Holzer & Schultze, 1988; Rohmeder, 1952; 1963; Akakiev, 1960; Ronis & Veveris, 1964; Martynov *et al.*, 1994). The singling out of these forms is essential to forestry and selection (Alekseev, 1974; Kharitonov, 1937; Golikov, 2007). Spruce has three phenological forms: early start of vegetation season, transitional and late start of vegetation season. The basic difference among them lies in start dates of vegetation. In its turn, the economic value of singling out the phenological forms is associated with differences in the rapidity of their growth and in the length of vegetation period. For some authors, the phenological structure of spruce undergrowth is genetically conditioned (Golikov, 2007; Popov *et al.*, 1985). According to others, the phenological structure of spruce undergrowth is influenced by environmental conditions: the degree of luminance, thermal regime, growing season length, site class and others (Tarkhanov & Shchekalev, 2007; Krasnobaeva, 2013; Belyaeva, 2013). Some researchers believe that the average height increment in different phenological forms is the same. Some have arrived at a conclusion that spruces coming out early have a greater increment in height than spruces coming out late (Milyutin, 1963; Milenin & Arbuzov, 2011; Makarov & Druzhinin, 2013). Acknowledgement of the fact that phenological forms of spruce growing differently can be found in a research work by V.Ya. Popov *et al.* (1985), P.G. Melnik and S.M. Savistin (1995) take the view that the growth course of spruce's different phenological forms depends largely on weather conditions in a specific year. A.M. Paltsev (1986) came to similar results when considering geocultures of spruce. S.N. Tarkhanov (2007) reported on the different growth of phenological forms of fir spruce in individual years. It is also reported on differences in productivity of various phenological forms of spruce in its different distribution areas (Ronis & Veveris, 1964; Melnik & Savostin, 1995; Krasnobaeva, 2013). Summing up the above, it is to be noted that the influence of mother stand upon the growth course of spruce undergrowth having different phenological forms is under-investigated.

The purpose of this paper was to expose peculiarities of interconnections among the mother

stand's canopy, the distribution of spruce's natural regeneration by phenological forms and the growth course under conditions of the Leningrad region.

Materials and Methods

The natural regeneration of fir spruce under the forest canopy was registered within the territory of Siversky Les experimental forestry enterprise in the Karashevsky, Orlinsky, Druzhnoselsky and Ontsevky forest districts of the Gatchina forest division in the Leningrad region (59°34'35"(59°34' 58) N&30°7'41"(30°7'69) E) on the permanent sample plots ranging in size from 0.25 to 0.5 ha.

Methods of singling out the phenological forms of fir spruce differ with different researchers. In our research we made use of techniques proposed by A.V. Gryazkin (1997). As an early form, we designated spruce biotypes whose terminal bud starts breaking prior to the efflorescing of European bird cherry. As a late form, we designated spruce biotypes whose terminal bud starts breaking after the efflorescing of European mountain ash or after the beginning of Scotch pine's pollen dispersion under conditions of the Leningrad region, with the transitional form being in-between these two forms.

From 600 to 3000 of spruce undergrowth trees per ha were counted on the sample plots. Phenological signs of spruce's young generation were investigated in thick stands of spruce trees, pine trees and birch trees in a pleurocarpous moss group of forest types. The natural regeneration of fir spruce was registered in the spring 2011, 2014 and 2015 under the canopy of stands. This registration was carried out by two methods: a complete enumeration approach and a statistical sampling method. Use was made of research techniques presented in depth in the paper by A.V. Gryazkin and N.V. Belyaeva (2013). The age of undergrowth was determined according to the annual increment of branches for each example of spruce undergrowth and was calculated as an average from total amount of undergrowth. The complete enumeration was carried out on bands, 5 m wide, divided into squares 5 x 5 m. The registration by statistical sampling method was carried out on circular plots, 10 m^2 each, established at equidistance from each other in free running.

Results and Discussion

In previous investigations, regenerative processes of spruce were researched in homogenous spruce stands (Ronis & Veveris, 1964; Gryazkin & Belyaeva, 2013). Influence of mature layer of mixed stand on regeneration of new generation of spruce was not studied. Under the stand canopy in forest types being investigated, the spruce undergrowth of early form has got better indices of growth and development (see Table 1). When comparing basic characteristics of spruce undergrowth by its phenological forms, it is evident that the specimens of early form, which are of about the same age (with a difference of no more than two years), have a greater height. The average height of the spruce undergrowth of an early form is one and a half as much as that of the spruce undergrowth of a late form. The average increment in the spruce undergrowth of an early form is 1.5 to 2 cm above the average increment in the spruce undergrowth of transitional and late forms. It is being noted that, under the canopy of spruce stands, the spruce undergrowth of an early form has the best parameters of growth and development (see Table 1), with its average increment being 3 to 4 cm greater than that of the spruce undergrowth of transitional and late forms. Under the canopy of pine stands, the best indices are with the spruce undergrowth of a transitional form, with its average increment being 1 to 3 cm greater than that of the spruce undergrowth of early and late forms. Under the canopy of pine-spruce and spruce-birch stands, all the forms of spruce undergrowth have approximately the same indices in terms of average increment.

In general, under the canopy of pine and spruce stands, the indices of the spruce undergrowth, independently of its phenological structure, are higher than those under the canopy of pine-spruce and spruce-birch stands. The average increment is 3 to 7 cm greater in the spruce undergrowth growing under the canopy of pine and spruce stands.

While analyzing characteristics of spruce undergrowth with different phenological forms versus a relative density of the stand, its age, and growing stock, it was revealed that, with an increase in phenological forms, the indices of spruce undergrowth go down without regard to its phenological structure (see Table 1). An average increment of spruce undergrowth decreases by a factor of 2 to 4 with an increase in relative density of the stand, its age, and growing stock. This suggests that there is a close relationship among the composition of mother stand and the degree of luminance under it as well as the growth course of spruce undergrowth of different phenological forms.

It was further noted that the vaccinium forest type has the best characteristics of spruce undergrowth irrespective of its phenological forms (see Table 1).

It was revealed that, with a comprehensive tending of forest, an average increment of spruce undergrowth of different phenological forms decreases by a factor of 1.5 to 2 (see Table 2), which can be explained by the fact that the application of fertilizers improves the nutritional conditions for the grass layer and nether vert. resulting in an extreme competition.

Table 1

Character of spruce undergrowth with different phenological forms

Dominant species	Stand composition	Height (H_{av}), cm	Age (A_{av}), years	Increment (Z_{av}), cm year^{-1}
Early coming-out phenological form				
Spruce	9S1P	52.1	12.9	4.0
	9S1P	123.8	17.7	7.0
	8S2P	69.5	13.7	5.1
	10S+P	117.0	23.0	5.0
	8,7S1,1P0,1B0,1As	114.7	12.7	9.0
	6,5S3,1P0,3As0,1B	66.3	11.9	5.6
	9,1S0,9B+Al	176.4	9.4	18.7
	7,8S1,6P0,6B	147.3	12.6	11.7
	6,6S3,2P0,2B	164.2	10.3	15.9
	Average	*132.0*	*13.7*	*10.5*
Pine	10P	134.4	11.4	11.8
	10P	203.7	20.5	9.9
	10P	170.0	12.5	13.6
	7,8P1,3S0,9B	158.5	23.8	6.7
	5P2S2B1As	92.1	22.1	4.2
	6P2S2B	119.5	21.3	5.6
	Average	*146.4*	*18.6*	*8.6*
Pine + Spruce	I 10P / II 9S1B	99.9	23.4	4.3
	I 10P / II 5S5B	140.6	14.6	9.6
	4,9S4,1P0,8As0,2B	56.2	23.5	2.4
	5,4S4,2P0,4As+B	65.2	13.2	4.9
	I 10P / II 7S2B1As	105.3	22.0	4.8
	4P4S2B	80.8	14.4	5.6
	Average	*91.3*	*18.5*	*5.3*
Spruce + Birch	I 10B+As+P / II 10S	87.9	23.8	3.7
	Average	*87.9*	*23.8*	*3.7*
Average across all sampling areas		***123.2***	***16.7***	***8.4***
Transitional phenological form				
Spruce	9S1P	40.7	10.7	3.8
	9S1P	84.3	14.2	5.9
	8S2P	76.0	15.2	5.0
	10S+P	116.0	32.4	3.6
	8,7S1,1P0,1B0,1AS	104.5	12.9	8.1
	6,5S3,1P0,3AS0,1B	49.7	9.6	5.2
	Average	*82.4*	*14.8*	*6.3*
Pine	10P	257.0	19.4	13.2
	10P	233.5	22.5	10.4
	10P	210.0	13.0	r6.2
	7,8P1,3S0,9B	129.7	18.4	7.0
	5P2S2B1AS	131.2	24.8	5.3
	6P2S2B	112.8	17.9	6.3
	Average	*179.0*	*19.3*	*9.7*
Pine + Spruce	I 10P / II 9S1B	122.0	21.8	5.6
	I 10P / II 5S5B	189.2	16.1	11.7
	4,9S4,1P0,8AS0,2B	31.2	15.3	2.0
	5,4S4,2P0,4AS+B	46.1	11.3	4.1
	I 10P / II 7S2B1AS	107.6	22.7	4.7
	4P4S2B	36.2	8.2	4.4
	Average	*88.7*	*15.9*	*5.4*

Dominant species	Stand composition	Height (H_{av}), cm	Age (A_{av}), years	Increment (Z_{av}), cm year^{-1}
Spruce + Birch	I 10B+AS+P / II 10S	116.8	32.0	3.6
	Average	*116.8*	*32.0*	*3.6*
Average across all sampling areas		***115.0***	***17.3***	***6.9***
Late coming-out phenological form				
Spruce	9S1P	40.7	11.9	3.4
	9S1P	49.9	8.1	6.2
	8S2P	47.4	13.1	3.6
	10S+P	40.4	13.2	3.1
	8,7S1,1P0,1B0,1AS	56.7	8.9	6.4
	6,5S3,1P0,3AS0,1B	45.0	9.5	4.8
	9,1S0,9B+AL	100.0	8.1	12.4
	7,8S1,6P0,6B	101.0	10.1	10.0
	6,6S3,2P0,2B	81.8	9.1	9.0
	Average	*71.7*	*10.2*	*7.5*
Pine	10P	113.0	16.5	6.8
	10P	164.0	22.0	7.5
	10P	188.7	14.0	13.5
	7,8P1,3S0,9B	81.4	16.3	5.0
	5P2S2B1AS	101.0	30.8	3.2
	6P2S2B	56.3	15.3	3.7
	Average	*117.4*	*19.2*	*6.6*
Pine + Spruce	I 10P / II 9S1B	108.4	21.4	5.1
	I 10P / II 5S5B	103.7	15.8	6.6
	4,9S4,1P0,8AS0,2B	30.7	13.9	2.2
	5,4S4,2P0,4AS+B	40.9	11.3	3.6
	I 10P / II 7S2B1AS	79.1	19.2	4.1
	4P4S2B	57.1	12.8	4.6
	Average	*70.0*	*15.7*	*4.4*
Spruce + Birch	I 10B+AS+P / II 10S	98.1	30.3	3.2
	Average	*98.1*	*30.3*	*3.2*
Average across all sampling areas		***84.3***	***14.8***	***6.3***

Note: “P” – pine; “S” – spruce; “B” – birch; “AS” – aspen; “AL” – alder; “I” – first level of the stand; “II” – second level of the stand.

When comparing phenological forms of spruce undergrowth according to its state, it is evident that, on the whole, the spruce undergrowth of early form, both viable and unviable, has better parameters under the canopy of stands (see Table 2). An increase in these indices goes from the late phenological form to the early one, irrespective of the state of viability. The average height of spruce undergrowth of an early form is twice as much as that of spruce undergrowth of a late form. The average increment of viable spruce undergrowth of early form exceeds the average increment of spruce undergrowth of transitional and late forms by 20 – 30% and the average increment of inviable spruce undergrowth by 30 – 35%. The undergrowth of an early form is 2 to 3.5 years older than the undergrowth of transitional and late forms. It was revealed that the canopy of spruce and spruce-birch stands provides better indices in terms of an average increment to the spruce undergrowth of an early form, while the canopy of pine and pine-spruce stands provides such indices to the spruce undergrowth of a transitional form.

Factor ANOVA analysis of influence of tree species composition on the number of undergrowth trees determines the undergrowth amount at the level 24% from the sum of all factors (Ft=3.0 (p=5%) and Ff=3.9). The influence of pure pine stand on the amount of spruce undergrowth was not proved by statistics. But conducted ANOVA analysis of influence of layer factor of pine-spruce stand on the amount of spruce regeneration more than 30% from the sum of all factor influencing on this parameter.

As a whole, under the canopy of spruce stands, an average annual increment in height in the spruce undergrowth, irrespective of its phenological structure and category of size, is greater than that under the canopy of pine, pine-spruce and birch-spruce stands. Irrespective of the phenological structure and category of size, the spruce undergrowth is older under the canopy of birch-spruce stands.

Table 2

Character of spruce undergrowth with different phenological forms according to its state

Dominant species	Number of sampling area	Viable			Inviable		
		Height (H_{av}), cm	Age (A_{av}), years	Increment (Z_{av}), cm year^{-1}	Height (H_{av}), cm	Age (A_{av}), years	Increment (Z_{av}), cm year^{-1}
Early coming-out phenological form							
Spruce	9S1P	50.7	12.5	4.1	63.3	16.2	3.9
	9S1P	320.0	44.0	7.3	84.6	12.4	6.8
	8S2P	68.7	13.8	5.0	73	13.3	5.5
	10S+P	117.0	23.0	5.0	-	-	-
	8,7S1,1P0,1B0,1AS	120.9	14.4	8.4	93.0	7.0	13.3
	6,5S3,1P0,3AS0,1B	87.8	13.1	6.7	57.0	11.4	5.0
	9,1S0,9B+AL	180.0	9.4	19.1	123.3	9.5	12.9
	7,8S1,6P0,6B	147.9	12.5	11.8	140.8	13.4	10.5
	6,6S3,2P0,2B	162.6	10.2	15.9	191.0	12.5	15.3
	Average	*154.4*	*16.5*	*10.7*	*103.3*	*12.0*	*9.2*
Pine	10P	161.0	13.0	12.4	28.0	5.0	5.6
	10P	203.7	20.5	9.9	-	-	-
	10P	170.0	12.5	13.6	-	-	-
	7,8P1,3S0,9B	189.7	27.0	7.0	65.0	14.0	4.6
	5P2S2B1AS	71.2	18.3	3.9	106.1	24.6	4.3
	6P2S2B	77.8	17.3	4.5	150.8	24.3	6.2
	Average	*145.6*	*18.1*	*8.6*	*87.5*	*17.0*	*5.2*
Pine+ Spruce	I 10P / II 9S1B	113.7	21.3	5.3	89.5	25.0	3.6
	I 10P / II 5S5B	155.0	24.5	6.3	131.0	8.0	16.4
	4,9S4,1P0,8AS0,2B	52.4	21.6	2.4	77.5	34.0	2.3
	5,4S4,2P0,4AS+B	62.5	12.5	5.0	69.0	14.2	4.9
	I 10P / II 7S2B1AS	78.7	19.3	4.1	185.0	30.0	6.2
	4P4S2B	70.2	13.3	5.3	93.8	15.8	5.9
	Average	*88.8*	*18.8*	*4.7*	*107.6*	*21.2*	*6.6*
Spruce + Birch	I 10B+AS+P / II 10S	96.0	24.0	4.0	56.9	22.1	2.6
	Average	*96.0*	*24.0*	*4.0*	*56.9*	*22.1*	*2.6*
Average across all sampling areas		***132.4***	***17.8***	***8.3***	***98.9***	***16.5***	***7.1***
Transitional phenological form							
Spruce	9S1P	40.5	10.6	3.8	44.0	13.5	3.3
	9S1P	97.5	15.3	6.4	73.6	13.3	5.5
	8S2P	76.4	14.7	5.2	75.2	14.8	5.1
	10S+P	82.7	23.7	3.5	166.0	45.5	3.7
	8,7S1,1P0,1B0,1AS	107.5	13.4	8.0	83.2	9.9	8.4
	6,5S3,1P0,3AS0,1B	59.4	9.2	6.5	45.6	9.8	4.7
	Average	*81.4*	*13.6*	*6.6*	*81.3*	*17.8*	*5.1*
Pine	10P	274.4	19.9	13.8	100.0	15.0	6.7
	10P	233.5	22.5	10.4	-	-	-
	10P	230.0	12.6	18.3	110.0	15.0	7.3
	7,8P1,3S0,9B	132.1	18.5	7.1	124.0	18.3	6.8
	5P2S2B1AS	57.0	17.0	3.4	152.4	27.0	5.6
	6P2S2B	47.9	13.6	3.5	183.0	22.6	8.1
	Average	*162.5*	*17.4*	*9.4*	*133.9*	*19.6*	*6.9*

Dominant species	Number of sampling area	Viable			Inviable		
		Height (H_{av}), cm	Age (A_{av}), years	Increment (Z_{av}), cm year^{-1}	Height (H_{av}), cm	Age (A_{av}.), years	Increment (Z_{av}.), cm year^{-1}
Pine + Spruce	I 10P / II 9S1B	143.6	22.3	6.4	93.1	21.2	4.4
	I 10P / II 5S5B	246.8	19.4	12.7	65.7	9.1	7.2
	4,9S4,1P0,8AS0,2B	31.2	15.3	2.0	-	-	-
	5,4S4,2P0,4AS+B	44.0	10.5	4.2	49.2	12.5	3.9
	I 10P / II 7S2B1AS	114	22.7	5.0	91.2	22.9	4.0
	4P4S2B	19.6	5.6	3.5	75.0	14.2	5.3
	Average	*99.9*	*16.0*	*5.6*	*74.8*	*16.0*	*5.0*
Spruce + Birch	I 10B+AS+P / II 10S	96.5	24.7	3.9	82.5	25.6	3.2
	Average	*96.5*	*24.7*	*3.9*	*82.5*	*25.6*	*3.2*
Average across all sampling areas		***112.0***	***16.0***	***7.0***	***94.9***	***18.2***	***5.5***
Late coming-out phenological form							
Spruce	9S1P	36.9	10.8	3.4	56.8	16.8	3.4
	9S1P	65.5	10.8	6.1	45.1	7.3	6.2
	8S2P	56.1	14.5	3.9	39.1	11.7	3.4
	10S+P	40.4	13.2	3.1	-	-	-
	8,7S1,1P0,1B0,1AS	53.1	9.0	5.9	73.4	8.5	8.7
	6,5S3,1P0,3AS0,1B	50.8	9.2	5.5	42.4	9.6	4.4
	9,1S0,9B+AL	101.8	8.2	12.4	91.9	7.5	12.2
	7,8S1,6P0,6B	101.9	9.9	10.3	96.8	11.1	8.7
	6,6S3,2P0,2B	82.6	9.0	9.2	77.8	9.6	8.1
	Average	*74.3*	*10.4*	*7.6*	*65.4*	*10.3*	*6.9*
Pine	10P	170.0	15.0	11.3	56.0	18.0	3.1
	10P	164.0	22.0	7.5	-	-	-
	10P	188.7	14.0	13.5	-	-	-
	7,8P1,3S0,9B	85.4	17.0	5.0	59.8	12.9	4.6
	5P2S2B1AS	86.5	29.0	3.0	105.8	31.3	3.4
	6P2S2B	43.4	14.8	2.9	72.9	15.9	4.6
	Average	*123.0*	*18.6*	*7.2*	*73.6*	*19.5*	*3.9*
Pine + Spruce	I 10P / II 9S1B	120.0	21.3	5.6	97.8	21.4	4.6
	I 10P / II 5S5B	123.3	19.7	6.2	76.5	9.2	8.4
	4,9S4,1P0,8AS0,2B	30.4	13.7	2.2	38.0	20.0	1.9
	5,4S4,2P0,4AS+B	44.6	11.8	3.8	36.6	10.7	3.4
	I 10P / II 7S2B1AS	69.0	19.0	3.6	80.4	19.3	4.2
	4P4S2B	40.6	9.7	4.2	65.2	14.3	4.5
	Average	*1.3*	*15.9*	*4.3*	*65.8*	*15.8*	*4.5*
Spruce + Birch	I 10B+AS+P / II 10S	68.5	19.6	3.5	60.0	22.5	2.7
	Average	*68.5*	*19.6*	*3.5*	*60.0*	*22.5*	*2.7*
Average across all sampling areas		***86.0***	***14.4***	***6.4***	***67.0***	***14.6***	***5.3***

Note: "P" – pine; "S" – spruce; "B" – birch; "AS" – aspen; "AL" – alder; "I" – first level of the stand; "II" – second level of the stand.

Conclusions

1. In general, in investigated forest types in conditions of the Leningrad region, the spruce undergrowth of an early form has better indices of growth and development under the canopy of mother stand. Irrespective of the state of the undergrowth's viability, an increase in these indices goes from the late phenological form to the early one.
2. Being approximately at the same age, the specimens of an early phenological form are higher and have a greater average increment in height. An average increment of viable spruce undergrowth of an early form is greater by 20 – 30% than that of spruce undergrowth of transitional and late forms, and greater by 30 – 35% than that of inviable spruce undergrowth.

3. Irrespective of the phenological structure and state, the spruce undergrowth's average increment decreases by a factor of 2 to 4 with an increase in its relative normality, age and growing stock. This is associated with a decrease in the degree of light intensity under the stand's canopy. With a comprehensive tending of forest, an average increment of spruce undergrowth of all phenological forms decreases by a factor of 1.5 to 2.
4. Generally speaking, the canopy of spruce stands provides a greater average annual increment in height to spruce undergrowth, irrespective of its phenological structure, categories of size and the state of viability, than the canopy of pine, pine-spruce and birch-spruce stands. The vaccinium forest type has the best characteristics of spruce undergrowth, irrespective of its phenological form.
5. When analyzing characteristics of the spruce undergrowth under the stand's canopy with due regard to the phenological and height structure as well as to the state of viability, it was revealed that, at the dominant average age of spruce undergrowth of a transitional form, the best indices of small and medium-sized undergrowth are with an early phenological form, while the best indices of large undergrowth are with a late phenological form.

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