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Edge Effect in Pine Stands in the Northern Taiga

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Abstract. The studies are carried out in pine stands situated on the forest boundaries, which are in between the open space locations and forest growth areas. The investigations were made on the territory of the Kholmogorskiy and Primorskiy districts in the Arkhangelsk region. The purpose of the research is to identify the characteristics of meteorological factors at different distances from the edge of phytocenosis as well as their influence on the undergrowth and ground vegetation in the ecotone zone. For this purpose, the vegetation, which grew on the transects at different distances from the edge of the phytocenosis, is described in layers. The transects were positioned perpendicular to the forest boundary. The following parameters were described and measured, such as undergrowth, ground vegetation, luminance, air temperature, wind speed, air humidity. The taxation of the stand was accomplished by using relascopic circular platforms. It is found that luminance, air temperature, and wind speed naturally decrease with distance from the edge of the phytocenosis deeper into the forest. The decrease in luminance can be revealed to 8 m, temperature to 8–15 m, wind speed to 30 m. However, air humidity increases up to 8 m. A correlation between meteorological factors and the distance from the edge of the phytocenosis is determined. The distribution of the undergrowth according to the edges of phytocenosis has a consistent pattern. The undergrowth of heliophytes of pine, birch, and aspen is most abundant at the edge of phytocenoses, and their numbers decrease with distance from the edge. The undergrowth of sciophytes either increases or its quantity does not change. Such distributions are confirmed by correlation analysis. The resulting figures are rated as significant or high. They are reliable at the significance level

of 0.05. The number of plants in the grass-shrub tier decreases with the distance deep into the forest. Any define conclusion can't be made regarding the moss-lichen tier. In general, it can be concluded that the size of the ecotone zone in terms of meteorological factors and indicators of vegetation is 12–14 m.
Keywords: pine forests, northern taiga, edge of phytocenosis, edge effect, ecotone zone, meteorological factors, undergrowth of coniferous species, undergrowth of deciduous species, ground vegetation
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Научная статья

Краевой эффект сосновых древостоев северной тайги

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Аннотация. Исследование выполнено в сосновых древостоях, расположенных на границах «лес – открытое пространство» на территории Холмогорского и Приморского районов Архангельской области. Цель – выявление особенностей метеорологических факторов на разных расстояниях от края фитоценоза, а также их влияния на подрост и напочвенный покров в экотонной зоне. На трансектах, заложенных перпендикулярно границе леса, на разном расстоянии от края фитоценоза (полосами) производилось

описание подроста, растений живого напочвенного покрова, выполнялась таксация древостоя с использованием реласкопических круговых площадок, измерялись освещенность, температура и влажность воздуха, скорость ветра. Установлено, что освещенность, температура воздуха и скорость ветра закономерно уменьшаются по мере удаления от края фитоценоза в глубь леса. Снижение освещенности проявляется до 8 м, температуры – до 8–15 м, скорости ветра – до 30 м. Влажность воздуха, наоборот, возрастает на расстоянии до 8 м. Обнаружена тесная корреляционная связь метеофакторов с удаленностью от края фитоценоза. Размещение подроста по площади имеет закономерный характер. Подрост светолюбивых видов – сосны, березы, осины – наиболее представлен на краях фитоценозов, по мере удаления от них его количество уменьшается. Подрост теневыносливой ели на расстоянии от опушки, напротив, или начинает встречаться чаще, или его число не меняется. Такое размещение по площади подтверждается корреляционным анализом. Полученные показатели связи значительные или высокие, достоверные при уровне значимости 0,05. Представленность видов растений травяно-кустарничкового яруса также уменьшается по мере удаления в глубь лесных массивов. В отношении мохово-лишайникового яруса однозначного заключения сделать нельзя. В целом можно констатировать, что размер экотонной зоны по метеофакторам и индикаторам растительности составляет 12–14 м.
Ключевые слова: сосняки, северная тайга, край фитоценоза, краевой эффект, экотонная зона, метеорологические факторы, подрост хвойных пород, подрост лиственных пород, живой напочвенный покров
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Introduction

A fragmentation of forest area into separate structures is the division of a single forest massif into separate fragments by roads, sifting, meadows, fields, gas pipelines, etc. This process cannot be stopped. It may only increase. As a result, separate fragments are formed that are in contact with free space. An edge effect is observed at the boundaries [16]. The edge locations are characterized by fluctuations in luminance levels, temperature, humidity, and wind speed [8, 21]. The phenomenon of fragmentation is observed in the literature [18], where the disappearance of unified forest areas in England is described, as well as an invasion of invertebrate species about 250 m inside the tropical forests deep. In general, this process is considered as negative. There is no information in the literature on the natural regeneration of forest-forming tree species in the boarding ecotone zone, which are edifiers and form the ecosystem. However, it is obvious that this process depends mostly on the geographical position of the area. Inside one region, it is influenced by the characteristics of the forest, such as composition of types, age of stands, density, or completeness of trees, growing environment and other factors.

The occurrence and presence of ecotones and ecotone zones are often considered rather comprehensively without the designation of boundary conditions for research, changes in environmental factors, characteristics and productivity of plant assemblages [1, 4, 10–13, 20].

In total, the process of fragmentation is extensive, but at the same time, it is insufficiently investigated. Although, it must be mentioned that the phenomenon was examined in the implementation of hydroforesty. The drainage canals were placed on the prepared glades with a fairly large width. The canals were about 1 m wide at the top. These factors created an edge effect both in growing forest stock and in emerging stands on drained swamps. However, the boundary impact was more often analyzed according to the influence of the drainage channel on the hydrological regime, root anoxia, physiological processes, wood growth, natural regeneration, etc. The main studies of such type are given in the following references: [3, 5, 17, 26]. Although, the articles that describe the drained locations are few and they are about Altai [14], the Southern Urals [25], and the Arkhangelsk region [6, 23]. Therefore, the goal of the study is to investigate the edge effect in the pine forests of the northern taiga in the Arkhangelsk region.

Research objects and methods

The research was conducted in the pine forests of the Kholmogorskiy district forestry near the village of Matigora. In the Primorskiy region, the investigation was performed in different locations of the Isakogorskiy district forestry. In the experimental areas, the transects were perpendicular to the border of the phytocenosis and with a length sufficient for studying the edge effect (150 m) and considering the known facts on the range of the edge effect [18].

On the transects, description of vegetation was made by layers (at different distances from the edge of the phytocenosis), which are undergrowth and vegetation cover. The tree stand was taxed using relascopic circular platforms [2, 19]. The Field Forest Inventory Guide [7, 23] was used in the material processing. The diameters of the trees were measured at chest height with a tree caliper (accuracy ±1 cm). The heights were measured with a VUL-1 altimeter, which gives an accuracy of ±0.5 m. To determine the average age of the stand, core samples were taken with a Pressler borer.

All pine forests are either pure or with a prevalence of pine in the composition (table 1). The type of the forest is blueberry pine. The emerging stands are of 4–6 age classes.

To measure air temperature, air humidity, wind speed an MES-200 device was used. Besides, for a more detailed study a portable weather station WS-3600 was applied. The luminance was measured with a Yu 116 luxmeter.

Results and discussion

To study the edge effect, we analyzed the change at different distances from the edge of the phytocenosis of the most important environmental factors for plants, and then the reaction of the plants themselves. Luminance is one of the most important factors for the existence of the plants. The luminance in ecotone zones does not remain constant. In an open area, it has a maximum value and does not change before the edge of the forest. At this point, it depends on a certain time of the day, cloudiness, the nature of the clouds, and some other factors. As it penetrates the forest stand, it sharply decreases (Fig. 1). In fact, 50 m from the edge of the forest phytocenosis, it does not change. Such characteristic is typical for measurements at different times during the vegetation season. Similar results were obtained for all transects in the Kholmogory region.

Table 1

Forestry-taxation characteristics of forest stands on transects in blueberry pine forests

Direction of transects	Number	Stand composition	Tree species	Average diameter, cm	Average height, m	Relative normality	Growth class	Age class
Primorskiy district (adjacent to branch trails and roads)								
East-west (94)	1	8P1As1B+S	P	18.7	18.3	0.74	IV	VI
			S	9.1	8.5	0.12	–	–
			B	12.4	16.0	0.13	–	–
			As	23.3	19.8	0.10	–	–
	2	8P1As1B+S	P	18.1	17.8	0.80	IV	VI
			S	8.9	11.0	0.06	–	–
			B	12.8	20.5	0.06	–	–
			As	26.3	23.3	0.08	–	–
	3	8P1As1B+S	P	17.1	17.4	0.80	IV	VI
			S	8.5	9.0	0.09	–	–
			B	10.1	18.3	0.08	–	–
			As	22.1	20.7	0.09	–	–
North-south (95)	4	9P1B+S, sin.As	P	17.4	18.4	0.84	IV	VI
			S	7.6	8.8	0.05	–	–
			B	11.2	12.7	0.10	–	–
			As	9.0	14.5	0.00	–	–
	5	9P+B,As, sin.S	P	16.5	18.0	0.78	IV	VI
			S	8.7	6.5	0.05	–	–
			B	13.1	16.8	0.07	–	–
			As	17.7	19.3	0.03	–	–
	6	9P+As,B,S	P	16.3	17.2	0.76	IV	VI
			S	8.6	7.7	0.05	–	–
			B	9.9	17.2	0.07	–	–
			As	19.0	16.2	0.05	–	–
North-south (91)	7	6P3B1As	P	19.2	17.8	0.71	IV	VI
			S	13.4	17.8	0.43	–	–
			B	14.0	18.5	0.16	–	–
	8	6P3B1As, sin.S	P	18.9	17.8	0.68	IV	VI
			S	7.0	8.8	0.01	–	–
			B	14.7	17.9	0.55	–	–
			As	13.7	18.3	0.07	–	–
	9	7P3B+S, sin.As	P	19.5	18.3	0.73	IV	VI
			S	23.0	20.5	0.03	–	–
			B	14.3	17.5	0.24	–	–
			As	11.0	16.0	0.02	–	–

The end of Table 1

Direction of transects	Number	Stand composition	Tree species	Average diameter, cm	Average height, m	Relative normality	Growth class	Age class
North-south (91)	10	9P1B	P	19.6	19.4	0.74	IV	VI
			B	16.4	16.6	0.14	–	–
	11	9P1B, sin.As,S	P	18.8	19.0	0.68	IV	VI
			S	20.6	19.4	0.01	–	–
			B	14.3	20.0	0.08	–	–
			As	10.0	15.0	0.01	–	–
	12	8P1B+As, sin.S	P	19.2	19.0	0.67	IV	VI
			S	7.0	9.0	0.02	–	–
			B	12.9	21.5	0.12	–	–
			As	15.7	19.0	0.03	–	–
Primorskiy district (adjacent to the field)								
Northwest-southeast	3	1P2S3B4As	P	19.0	17.4	0.50	IV	V
			S	18.5	17.4		IV	V
			B	19.4	19.2		–	7
			As	21.3	22.3		–	V
Northwest-southeast	1	1P3S3B3A	P	18.5	17.0	0.50	IV	V
			S	18.0	17.0		IV	V
			B	19.4	19.0		–	7
			As	22.3	22.5		–	V
Kholmogory district (adjacent to the field)								
North-south	1	8P2As+S,B	P	19.8	14.7	0.73	IV	IV
Northeast-southwest	2	8P1B1As+S	P	17.5	13.9	0.69	IV	IV
Northeast-southwest	3	7P1B1As1S	P	19.7	14.8	0.72	IV	IV
North-south	4	6P2S2B+As	P	18.4	14.7	0.69	IV	IV

Note: P – pine; As – aspen; B – birch; S – spruce; sin. – singly in the array.

The revealed pattern was also confirmed about 80 km from this location in the field-forest border in the Primorskiy region. It should be noted that the stands adjoining fields are usually mixed, with the presence of a significant number of deciduous species (table 1). The obtained results showed that the initially selected measurement interval (measurements were taken every 50 m, and they were chosen based on the literature data) is not entirely correct. Further, we took the measurements more frequently, every 10 m, and then even every 2 m. This made it possible to clarify the size of the ecotone zone. A more detailed study (Fig. 2) at another location (Primorskiy district) revealed that starting from 8 m from the edge of the stand, the luminance remains approximately at the same level. Thus, this factor forms an ecotone zone about 8 m wide from the forest edge. The degree of connection between the luminance and the distance from the edge of the phytocenosis ranges from significant to high ($r = –0.57–0.80$; $\eta = 0.61–0.85$).

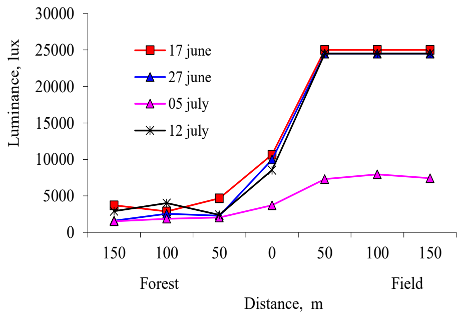

Fig. 1. Luminance change in the ecotone zone from the field and forest sides (4 transects, Khomogorsky district)

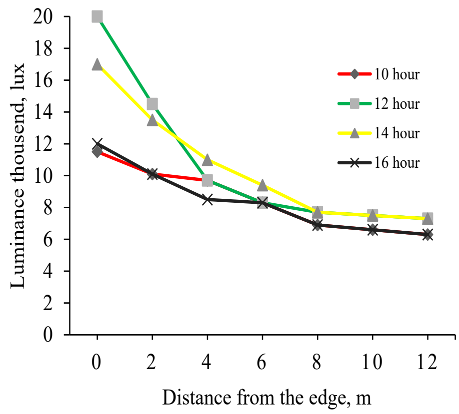

Fig. 2. Luminance in blueberry pine forests at different distances from the edge of the phytocenosis (Primorskiy district, 95)

It is interesting to trace the change in the wind speed when it enters the forest stands. In order to exclude the influence of the dates of the measurements on the obtained results, the wind speed was estimated as a percentage of its speed in an open space. It turned out that on different days of the vegetation season, the damping of the wind when entering the stand is almost the same. It is maximum at the edge and then sharply decreases at a distance of 30 m (Fig. 3).

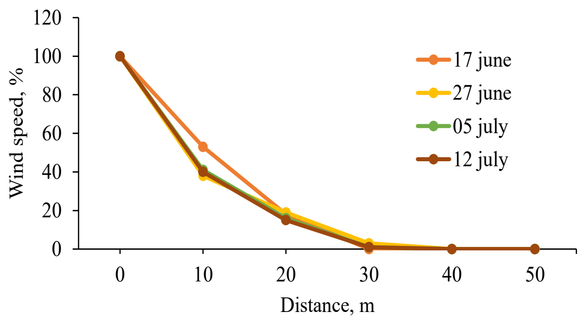

Fig. 3. Change in wind speed from the edge to the forest (Kholmogorskiy district, 4 transects)

The wind speed and the luminance on different transects have the same character. However, the air temperature and the humidity have some variety. Most often, the temperature naturally decreases with distance from the edge of the stand. The air temperature decreases gradually with distance from the edge of the phytocenosis to 8–15 m into the forest deep. The difference between the temperatures is 2–10 %. This measurement pattern can be traced both at the height of 1.3 and at 0.15 m. However, at the height of 0.15 m in daytime hours, the air temperature is always

3–6 degrees higher than at the height of 1.3 m. The correlation analysis shows that the relationship lays in the range between significant and high ($r = –0.43–0.59$; $\eta = 0.48–0.65$), with reliable indicators at the significance level of 0.05. At first glance, in some cases, insignificant differences in temperature may not affect the growth and development of the plants. However, it should be noted that, for the passage of life cycles in poikilothermic organisms, which include plants, the sum of effective temperatures is important [9]. Consequently, the daily summation of temperature that rises above the critical value can ultimately amount to a significant value during the vegetation season.

The air humidity has a general tendency to increase with distance from the edge of the phytocenosis into the forest deep. The increase occurs up to 8 m. The difference reaches 3–4 % at the height of 1.3 m and 3–6 % at the height of 0.15 m, in comparison with the edge of the stand. It should be noted that air humidity is usually higher at 1.3 m, compared to surface air at 0.15 m, and is 4–6 %. Only on some sunny days is the humidity in the surface layer higher than 1.3 m. Correlation analysis showed that the dependenices in general have significant or high connections. The correlation coefficients ranged from 0.58 to 0.62, and the correlation ratios were 0.69–0.83. All indicators are reliable at a significance level of 0.05.

It is better to trace the influence of the edge effect on plant life using the example of undergrowth and ground vegetation, since they are affected by it. In the undergrowth of all types of woody plants a connection was discovered between the quantity and the location due to the edge of phytocenosis the pine undergrowth under the canopy of blueberry pine forests is not found on all trial plots. It can be that the light conditions for its settlement and growth are unfavorable. For example, A.V. Veretennikov [24] indicated that a luminance of 3000 lux, is critical for the process. In the ecotone zone, undergrowth of pine, spruce, birch and aspen was observed, so these species were investigated further. For this purpose, we divide them into the groups of heliophytes (pine, birch, aspen) and sciophytes. This division is traditional and widely included in articles on forestry and forest ecology [15, 22].

The correlation analysis of the relationship between the amount of undergrowth and the distance from the edge of the phytocenosis showed the following. The dependencies are fundamentally different for the heliophytes species and sciophytes spruce. If the relationship is positive for spruce, consequently, the further away from the edge, the more undergrowth. That for pine, birch and aspen, on the contrary, is negative, the further from the edge, the less undergrowth (table 2). The level of the correlation measured varies from significant to high or very high. Most of the correlations are non-linear. The correlation ratios are in the range from 0.79 to 0.95. The obtained correlation indicators are reliable at all levels of significance.

Near the edge of the phytocenosis, the amount of undergrowth ranges from 3000 pcs/ha for aspen to 5700 pcs/ha for birch. As the distance from the edge increases, the amount of undergrowth is almost zero for pine, birch, and aspen (Fig. 4). On some transects, as already noted, there was no pine undergrowth. Consequently, in the undergrowth of heliophyte types, the edge effect extends to 12–14 m.

Table 2

Values of the correlation measured between the density of the undergrowth and the distance from the edge of the phytocenosis

Tree species	Attitude to light	Transect direction	Correlation rate, $r \pm m_r$*	Validity, t_r	Correlating ratio, $\eta \pm m_\eta$**	Validity, t_η
Spruce	Sciophytes	East-west	0.66±0.224	5.47	0.95±0.127	14.27
		North-south	0.92±0.139	18.68	0.95±0.129	22.17
Aspen	Helio-phytes	East-west	–0.84±0.164	13.06	0.94±0.136	14.29
		North-south	–0.84±0.166	13.20	0.89±0.145	17.30
Birch		East-west	–0.54±0.258	3.54	0.79±0.181	9.73
		North-south	–0.80±0.187	10.02	0.89±0.115	15.49
Pine		East-west	–0.79±0.181	9.63	0.88±0.148	13.81

*m_r – error correlation rate; **m_η – error correlating ratio.

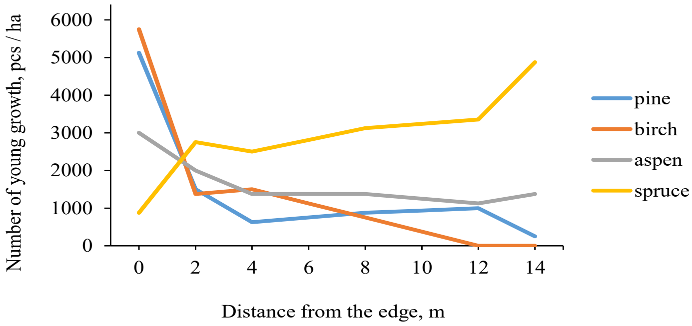

Fig. 4. The amount of undergrowth at different distances from the edge of the phytocenosis

The size of the ecotone zone can be determined not only by changes in meteorological factors, but also by changes in the amount of undergrowth of different tree species at different distances from the ecotone, using the equations obtained (table 3). The width of the ecotone zone is 8–12 m for aspen, 12–16 m for birch, and 14–16 m for pine. For spruce, the edge effect is not manifested.

The number of species of ground vegetation in the studied pine forests is small. They are distributed unevenly in the marginal zone of the phytocenosis. In the grass-shrub tier, the largest number of species is concentrated near the edge of the phytocenosis. More deeply into the forest, their number decreases to 5 and remains at this level (Fig. 5). In relation to the moss-lichen teir, such patterns are not manifested. In some cases, there are more of them at the edge; in others, they are at different distances. Thus, the edge effect affects only the plants of the grass-shrub tier and manifests itself up to 8 m.

Table 3

Dependence between the number of undergrowth (pcs/ha) to the distance from the edge of the phytocenosis (m)

Tree species	Transect direction	The equation	Ecotone zone size, m
Pine	East-west	$y = 74.67 + 3135.57/x$	14–16
Birch	East-west	$y = 411.47 + 900.75/x$	12–16
	North-south	$y = 496.04 + 10462.02/x$	12–16
Aspen	East-west	$y = 553.59 + 3660.22/x$	8–12
	North-south	$y = 553.59 + 3660.22/x$	8–12
Spruce	East-west	$y = 516.62 + 34.60x$	Does not depend on the edge of the phytocenosis
	North-south	$y = 425.77 + 227.19x$	

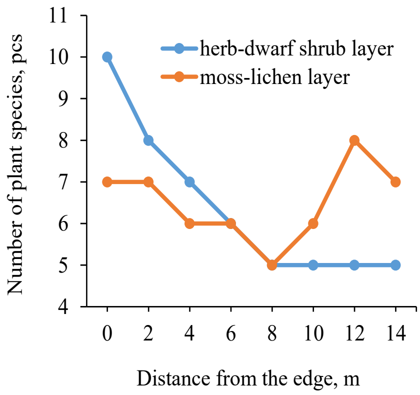

Fig. 5. The number of species of ground vegetation at different distances from the edge of the phytocenosis

Conclusions

1. The marginal effect is manifested in changes of meteorological factors and quantitative indicators of undergrowth of tree species and plants of the grass-shrub tier. Luminance varies to 8 m; temperature to 8–15 m, air humidity to 8 m, wind speed to 30 m. On average, the width of the ecotone zone according to meteorological factors is 14 m. The marginal effect on undergrowth and grass-shrub teir is manifested on average up to 12 m. There were no differences in the impact of the field-forest, road-forest ecotone species.

2. A close correlation was established between meteorological factors and the distance to the edge of the phytocenosis.

3. The placement of undergrowth over the area is associated with the edge of phytocenoses. The amount of undergrowth decreases with distance from the edge for heliophytes species of woody plants (pine, birch, aspen) and does not change or increase for sciophytes.

4. The number of species of the grass-shrub teir naturally decreases with increasing distance from the forest edge.

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