

INVESTIGATION OF HETEROGENEITY OF THE GROUND COVER AND FOREST LITTER IN PINE FORESTS OF THE NORTHERN TAIGA (KOLA PENINSULA, RUSSIA)

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Abstract

The paper considers the specific features of spatial accumulation of organic matter by the ground cover and forest litter in middle-aged pine forests of different types on the territory of the central part of the Kola peninsula (Russia). The main characteristics and peculiarities of biomass accumulation by the components (dwarf-shrubs, mosses, lichens) of the ground cover have been revealed, as well as the specific features of plant waste and forest litter in pine ecosystems in terms of ecotope humidification extent. Upon transition from lichen pine woodlands, occupying the driest habitat, to green-moss type pine forests saturated with moisture to the greatest extent of all considered types of forests, the stock of aboveground and underground biomass of the ground cover increases, their biomass structure changes, along with increment in thickness and biomass of the forest litter. The biomass of mosses and lichens exceeds the stock of aboveground biomass of plants with the root strategy of mineral nutrition (dwarf-shrubs) in all explored types of pine forests.

The estimation of the biomass stock of components of ground cover, plant waste and forest litter in different types of microsites (near-tree-trunk, under-tree-crown and between-tree-crowns) has made it possible to reveal heterogeneity of distribution of the organic matter over the area of biogeocoenoses. The maximum differences in the stock of biomass of the ground cover components are observed in the lichen pine woodland, which apparently is caused by the utmost-contrasting hydrothermal conditions of the habitats. The most levelled spatial distribution of the organic matter is registered in the green-moss type of pine forest where optimal ecotope conditions for green mosses and dwarf-shrubs are formed.

Keywords: Kola peninsula, northern taiga, pine forests, aboveground cover, forest litter, biomass

1. INTRODUCTION

Revealing the mechanisms underlying the formation of ground cover mosaic is necessary for comprehending the principles of structural organisation and functioning of the natural forest ecosystems. In the boreal ecosystems, the ground-layer vegetation functioning is significantly conditioned by woody plants spatial heterogeneity and temporal variability of sun exposure; evapotranspiration, microclimate, distribution of atmospheric precipitation; hydrological, temperature and nutrition regime. Woody plants transform the environment actively, thus affecting the other organisms. The boreal forests are characterised by expressed vegetation cover heterogeneity, being of great importance for functioning of forest communities [1–6]. The vegetation micromosaic conditions spatial soils heterogeneity, which is best mirrored in the structure of their upper horizons. It should be noted that the reasons of intracoenotic heterogeneity of soils and vegetational cover are different, and the role of particular factors defining it is unequable.

One of the most important parameters defining productivity of forest communities is accumulation of the organic matter contained in the aboveground biomass of higher plants, mosses and lichens, as well as in the plant waste and forest litter. The ground cover biomass in forests of the Kola peninsula may reach 25% and more of its total stock, while the yearly yield and involvement in biogeochemical circulation account for 50–60%. Plant waste as a source of organic matter of soil and nutrition elements needed by the biota is one of the key components of biogeochemical cycles in forest communities [2, 7]. The amount and structure of plant waste define the biomass stock of forest litter.

Besides, the plant waste is a source of nutrition, and at the same time a habitat for the majority of invertebrates and microorganisms that provide its mineralization [8].

Forest litter and plant waste have important ecological functions, setting the hydrothermal and nutritional regimes of soils and forming forest-growing conditions. According to some researchers [9], forest litter in the pine forest growing on sandy soils should rather be called a vegetal-detrital ground cover, since it consists of poorly-divisible mixture of defunct organic matter, mineral particles and live stems of mosses, lichen thalli and plant roots. In our research, we distinguish plant waste from forest litter. Plant waste is formed of defunct parts of plants, branches, cones, bark; it is not subject to decomposition and humification processes. Forest litter represents a mixture of half-decayed remainder of higher plants, mosses, lichens and amorphous humified mass of organic matter of dark grey, reddish brown or black colour.

The objective of this research is evaluating accumulation of the above- and underground biomass of the ground cover components (lichens, mosses, dwarf-shrubs) and the assessment of biomass of plant waste and forest litter in different microsites of Northern taiga pine forests.

2. MATERIALS AND METHODS

2.1. Materials

The research was made in the middle-aged pine forests located in the central part of the Kola peninsula, middle course of the Liva river (67°49' N, 31°20' E), vegetating on Al-Fe-humic podzols (Folic/Histic Albic Podzols, according to WRB). The period after the last fire averages 90 years. The main tree species of the stand is *Pinus sylvestris* L. A short taxation characteristic of pine stands is given in Table 1. The dominating species in the dwarf-shrub and herb layer of the explored pine forests are dwarf-shrubs *Vaccinium vitis-idaea* V. *myrtillus*, *Empetrum hermaphroditum*; in the moss-lichen stratum – lichens *Cladonia rangiferina*, *Cl. stellaris*, *Cl. mitis*; green mosses *Pleurozium schreberi*, *Dicranum* sp. are present as well.

Sampling site	Age, yr	Diameter _{1.3m} , cm	Height, cm	Number of the trunks, un/ha
SS1	70	11.8	9.2	455
SS2	70	11.9	11.5	1155
SS3	70	10.9	10.5	2260

Table 1. Brief characteristic of the pine stands

A number of sampling sites (SS) to the size of 30x30 m were singled out in pine forests of different types: SS1 – lichen pine woodland, dominated by lichens, SS2 – lichen/green-moss type of pine forest, SS3 – green-moss type of pine forest. Plots were outlined within every sampling site, with the size of 10x10 cm in the following microsites: near-tree-trunk (a), under-tree-crown (b) and between-tree-crowns (c). In total, 180 plots were marked out.

The live ground cover was cut off in each plot and subdivided into the following components: dwarf-shrubs, lichens and mosses. The forest litter thickness was measured; the plant waste and forest litter were collected, with all plant roots removed. All the samples of vegetational material and forest litter were utmostly dried up and weighed with subsequent conversion to 1 m².

2.2. Methods

The verification of the explored parameters in terms of complying with the normal distribution law has shown that the distribution of most parameters differed significantly from normal distribution. In this connection, in assessing the extent of difference, the nonparametric Kruskal-Wallis criterion (H) was used; in case of extent of difference $p < 0,05$, the distinction was considered significant.

The coefficient of variation (V) is calculated as the ratio of the standard deviation to the mean value and is expressed in percentage. The figures and tables present average values and their standard error.

3. RESULTS

The average value of lichens biomass in the lichen pine woodland (SS1) makes 325 ± 65 g/m², in lichen/green-moss type of pine forest (SS2) – 78 ± 17 g/m², and in green-moss type of pine forest (SS3) – 10 ± 6 g/m². The average values of moss biomass make respectively: SS1 – 2 ± 1 g/m², SS2 – 75 ± 26 g/m², SS3 – 115 ± 10 g/m². It should be emphasized that the maximum value of lichens biomass is almost 3 times more than that of moss. It is necessary to note a substantial variation range of biomass parameters, both for mosses and lichens: the variation coefficient (V) vary from 50 to 350%. The observable trends of change in accumulation of mosses and lichens biomass are quite logical, they are connected with forest type and conditioned by the habitat.

Figures 1–3 present the biomass of lichens and mosses in various microsites of explored sampling sites: SS1 – lichen pine woodland, SS2 – lichen/green-moss type of pine forest, SS3 – green-moss type of pine forest.

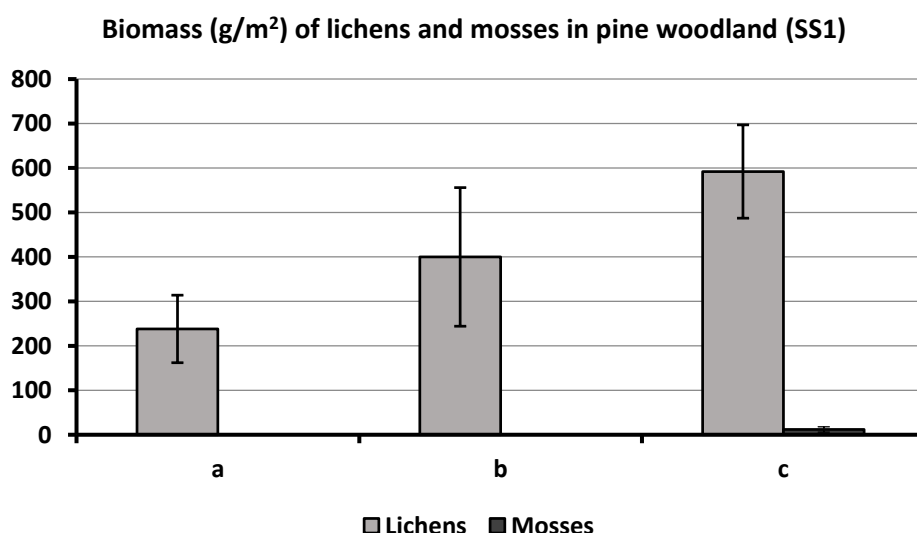


Fig. 1. Biomass of lichens and mosses in pine woodland (SS1)

Here and in figures 2–6: (a) microsites near the trunk of a tree; (b) microsites under the crown of a tree; (c) microsites between the crowns of trees

There is a trend, observed in all explored types of forest communities, towards increase of the lichens biomass, from the near-tree-trunk microsites to the between-tree-crowns ones, but this tendency is not confirmed statistically. Mosses are absent almost completely in all microsites of the lichen pine woodland (SS1) (Fig. 1). The moss biomass at SS2 is significantly higher ($H=13.6$, $p=0.001$) in between-tree-crowns microsites in comparison with (a) and (b) microsites (Fig. 2). The distinctions in moss biomass in the green-moss type of pine forest (SS3) are not important (Fig. 3), i.e. the accumulation of moss biomass is more levelled spatially in this type of pine forest.

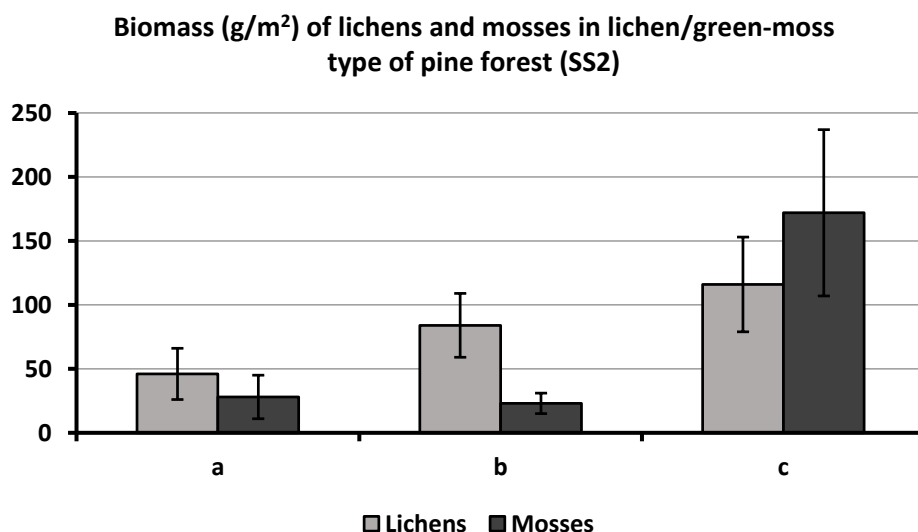


Fig. 2. Biomass of lichens and mosses in lichen/green-moss type of pine forest

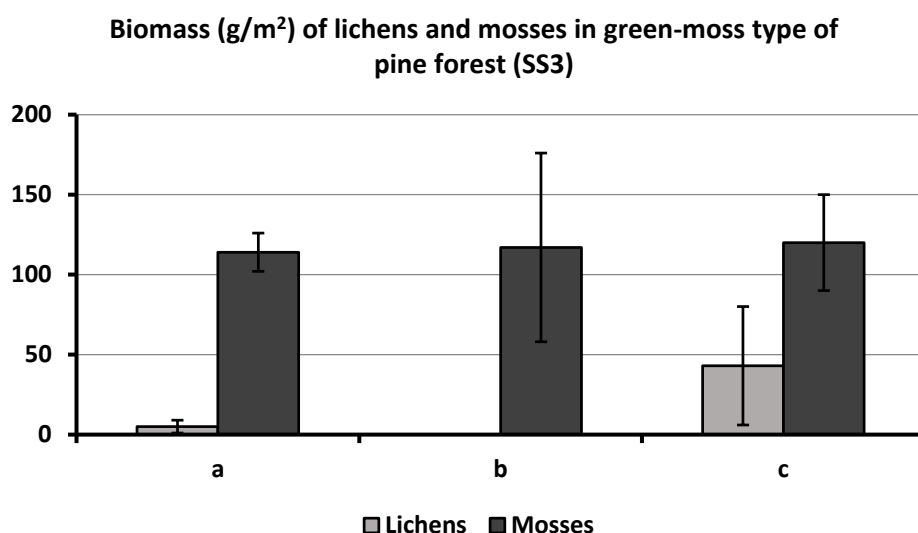


Fig. 3. Biomass of lichens and mosses in green-moss type of pine forest

The maximum biomass of dwarf-shrubs is observed in microsites of lichen pine woodland (SS1) where it makes 124 ± 20 g/m² on the average, while the minimum values of the dwarf-shrubs biomass (the average of 45 ± 8 g/m²) are observed in pine forest of the green-moss type (SS3). The variation range of the dwarf-shrubs biomass in all studied pine communities is much smaller than that of the mosses and lichens; the variation coefficient ranges from 78 to 96%. The distribution of dwarf-shrubs biomass between the microsites differs in the studied pine communities (Fig. 4): the biomass of dwarf-shrubs does not differ appreciably in the lichen pine woodland (SS1) and in the green-moss pine forest (SS3). On the contrary, the biomass of dwarf-shrubs at the between-tree-crowns microsites (c) in the lichen/green-moss pine forest (SS2) is 2.5 times less than at the near-tree-trunk microsites (a).

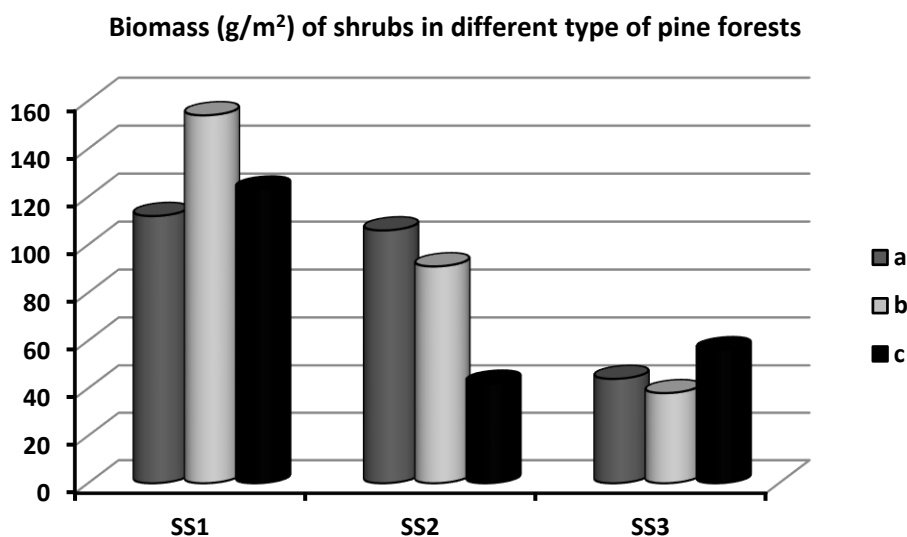


Fig. 4. Aboveground biomass of dwarf-shrubs in lichen pine woodland (SS1), lichen/green-moss type of pine forest (SS2), green-moss type of pine forest (SS3)

Most of the underground sprouts and thin roots of dwarf-shrubs are located in the forest litter. The least values of underground biomass are observed in all microsites of the lichen pine woodland (SS1), and the maximum values – in the green-moss type of pine forest (SS3) (Table 2); at the same time, no directional change in the underground biomass upon transition from the near-tree-trunk (a) to between-tree-crowns microsites (c) was revealed; no significant distinctions are present. The average value of the underground biomass in the green-moss pine forest (SS3) makes 385 ± 67 g/m², which is 2.4 times more than the same for the lichen pine woodland (SS1), exceeding the above value in the lichen/green-moss pine forest (SS2) 1.5 times. According to Kruskal-Wallis test, the distinctions between the underground biomass in the explored types of pine forests are significant ($H=21.9$, $p=0.00001$). The underground biomass variation range is very narrow, the variation coefficients are within the range 43–57%.

Sampling sites	Microsite (a)	Microsite (b)	Microsite (c)
SS1	161±27	191±35	137±21
SS2	289±32	362±40	201±36
SS3	346±44	406±70	400±87

Table 2. Underground biomass of dwarf-shrubs (g/m²) in lichen pine woodland (SS1), lichen/green-moss type of pine forest (SS2), green-moss type of pine forest (SS3)

The comparative analysis of the above- and underground biomass of dwarf-shrubs has shown that in all cases the latter exceeds the aboveground biomass. The least distinctions in the above- and underground biomass are observed in different microsites of the lichen pine woodland (SS1), varying from 1.1 to 1.4 times. The difference of the above- and underground biomass in the lichen/green-moss type of pine forest (SS2) is 2.7–4.8 times. The greatest distinction between the above- and underground parts of dwarf-shrubs is observed in the green-moss pine forest (SS3) where it makes 7–11 times.

The average values of the plant waste mass in the explored pine forests do not differ significantly and constitute 1430 ± 130 g/m² on the average. The variation range of the plant waste mass in different

types of pine forests is considerably smaller in comparison with this parameter for the aboveground biomass of dwarf-shrubs, mosses and lichens; the variation coefficient varies from 40 to 60%. The maximum values of the plant waste mass ($1610\text{--}1885\text{ g/m}^2$) in all explored forest types are observed for the near-tree-trunk microsites, the minimum values – for the between-tree-crowns microsites ($720\text{--}1070\text{ g/m}^2$) (Fig. 5). Upon transition from the near-tree-trunk microsites (a) to between-tree-crowns microsites (c), the plant waste mass significantly decreases, on the average 2 times ($H=6.7\text{--}13.2$, $p=0.001\text{--}0.03$).

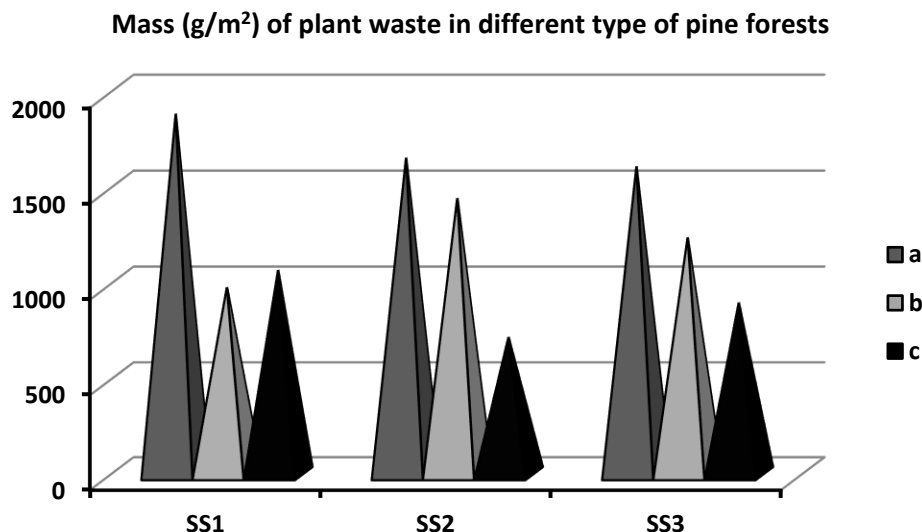


Fig. 5. Mass of plant waste in lichen pine woodland (SS1), lichen/green-moss type of pine forest (SS2), green-moss type of pine forest (SS3)

The minimum average value of the forest litter mass is observed in the lichen pine woodland (SS1), where it makes $2040 \pm 200\text{ g/m}^2$; the maximum value is observed in the green-moss type of pine forest ($4880 \pm 340\text{ g/m}^2$) – i.e. the forest litter mass appreciably increases 2.5 times upon transition from the lichen pine woodland (SS1) to the green-moss pine forest (SS3). The forest litter mass is characterized by quite a narrow variation range ($V=35\text{--}50\%$). It is only in the lichen pine woodland (SS1) that the forest litter mass significantly ($H=7.1$, $p=0.03$) decreases from the near-tree-trunk microsites (a) to between-tree-crowns (c) microsites (Fig. 6). The variation in forest litter mass at different microsites of the two other explored communities is not significant.

The forest litter thickness in the lichen pine woodland (SS1) is minimal in the explored types of pine forests ($3.7 \pm 0.4\text{ cm}$); it is maximal in the green-moss type of pine forest (SS3) ($6.4 \pm 0.5\text{ cm}$). This means that the forest litter thickness substantially increases, almost 2 times, upon transition from the lichen pine woodland to the green-moss type of pine forest. The minimal variation range, among the investigated parameters, is specific of the forest litter thickness, where the variation coefficient makes 40–50%. The forest litter thickness in all types of studied pine forests is 1.5–2.5 more in the near-tree-trunk (a) microsites than in the between-tree-crowns (c) microsites (Table 3), and in all cases these distinctions are significant ($H=8.1\text{--}10.0$, $p=0.007\text{--}0.02$).

The correlation analysis of the forest litter thickness and its mass shown that the correlation between these parameters is significant only for the lichen pine woodland (SS1, $r=0.69$, $p=0.00001$) and the green-moss pine forest (SS3, $r=0.48$, $p=0.007$), while no such correlation is observed for the lichen/green-moss forest type (SS2). It is only in the lichen pine woodland (SS1) that a significant correlation may be traced between the forest litter thickness and the mass at the near-tree-trunk (a) and under-tree-crowns (b) microsites ($r=0.48\text{--}0.65$, $p < 0.05$); this correlation is not significant in all other cases.

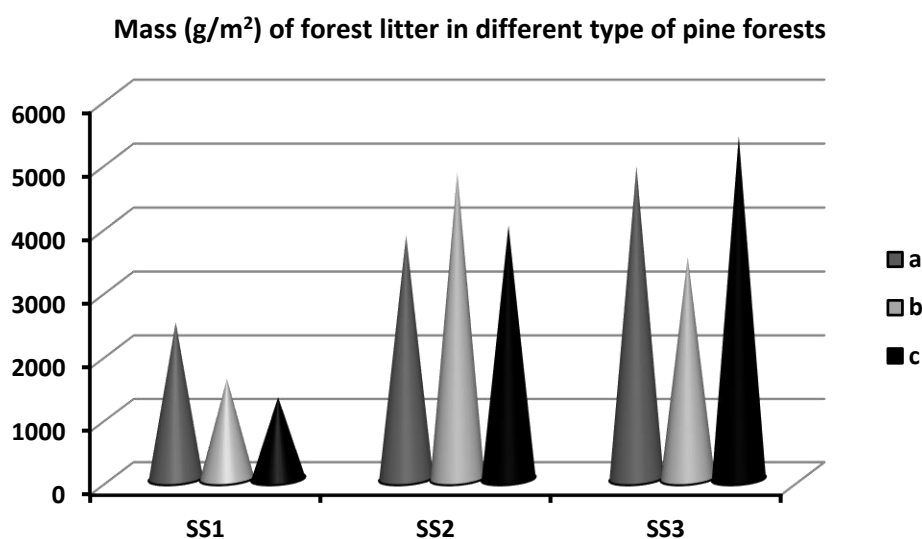


Fig. 6. Forest litter mass in lichen pine woodland (SS1), lichen/green-moss type of pine forest (SS2), green-moss type of pine forest (SS3)

Sampling site	Microsite (a)	Microsite (b)	Microsite (c)
SS1	4.5±0.4	3.3±0.7	1.7±0.3
SS2	5.0±0.6	4.4±0.3	3.4±0.6
SS3	7.1±0.5	3.5±1.5	3.8±0.5

Table 3. Forest litter thickness (cm) in lichen pine woodland (SS1), lichen/green-moss type of pine forest (SS2), green-moss type of pine forest (SS3)

Thus, the effected research has made it possible to evaluate the heterogeneity of the ground cover and the forest litter in different types of middle-aged pine forests of the Northern taiga; to identify the specific features of dwarf-shrubs, mosses and lichens biomass; to reveal the peculiarities of forest litter thickness, plant waste and forest litter mass in different microsites within studied forest types.

4. DISCUSSION

It is well known that pine forests of lichen site type in the boreal forests subzone are formed in the driest habitats. With increasing habitat wetting, the type of pine forests changes from lichen/green-moss to moss site type. In the most humid habitats sphagnum type of pine forests is formed. The conducted studies have revealed the logical changes in both the aboveground biomass of the ground cover components and the underground biomass of dwarf-shrubs, as well as the mass of plant waste and forest litter sequentially from the open lichen–pine woodland to the moss site type forest. The average values of lichens biomass decrease by more than 30 times, on the contrary, mosses, increase more than 50 times. The difference in the aboveground biomass of dwarf-shrubs is about 3 times. Differences in the stock of biomass of underground plant organs do not exceed 2.4 times. It should be emphasized that the biomass of the underground plant organs exceeds the aboveground biomass of dwarf-shrubs in all studied types of pine forests, and these differences increase from 1.1–1.4 times in the lichen pine woodland (SS1) to 7–11 times in the green-moss forest type (SS3). It is interesting to note that the plant waste mass does not substantially differ in the explored types of pine forests, while the forest litter thickness and its mass increases 2–2.5 times in the course of transition from the lichen pine woodland to the green-moss type of pine forest.

The research made for middle-taiga pine forests of post-fire origin has shown that the overall stock of aboveground biomass decreases with increasing tree age, both in *myrtillus* and *sphagnum* type of pine forests [10]. The main producers of organic matter in the ground cover are dwarf-shrubs, accounting for 53–73% of the overall aboveground biomass; the share of mosses is 26–44%; the share of herbs is only 1–3%. In our research, the dominant position in accumulation of organic matter is held by mosses and/or lichens; their share accounts for over 70% of the total aboveground biomass in all explored types of pine forests. The results obtained are consistent with data of other researchers of boreal pine forests [7, 11].

The study of micromosaic, characteristic of the ground cover and the upper soil horizons in the forest biogeocenoses, has been most often conducted in boreal spruce forests or in dark coniferous forests of the middle taiga where intra-coenotic mosaic is expressed most contrastively [1–6]. Much fewer papers explore spatial heterogeneity of the ground cover and of the upper soil horizons in pine biogeocoenoses, which apparently is connected with the fact that light-coniferous pine forests have more uniform sun exposure under the canopy [9, 11].

As a result of comparative evaluation of biomass of ground cover components in different microsites, essential intra-ecosystem variability of this parameter has been established, which made it possible to reveal the main biomass change trends depending on location of the microsite. All of the studied types of pine forests show a tendency towards increase of the lichens biomass ranging from near-tree-trunk microsites to between-tree-crowns ones; however, this tendency is not confirmed statistically. Probably, this specific feature will be important in case of extending the sampling.

The factual absence of mosses in the lichen pine woodland may be explained by the extremely dry conditions of this ecotope. The moss biomass stock in the lichen/green-moss type of pine forest (SS2), which is more wet, expectedly increases 6 times upon transition from near-tree-trunk (a) to between-tree-crowns microsites (c), which is caused by the forest canopy intercepting precipitation. The wettest ecotope of the green-moss pine forest provides maximum moss biomass values; at the same time, the differences between various microsites are not important, which is evidential of sufficient water availability of the whole habitat for successful growth of mosses.

The trends in microsite-specific changes of the aboveground and underground biomass of dwarf-shrubs differ in the explored pine communities. The stock of both aboveground and underground biomass of dwarf-shrubs does not differ significantly in the lichen pine woodland (SS1) and the green-moss type of pine forest (SS3). On the contrary, the stock of aboveground biomass of dwarf-shrubs in the lichen/green-moss type of pine forest (SS2) consistently decreases 2.5 times from the near-tree-trunk (a) to between-tree-crowns microsites (c), while the greatest stock of the underground biomass is observed in the under-tree-crown microsites (b).

It is logical to assume that the maximum amount of plant waste will accumulate in the near-tree-trunk microsites (a) for account of defunct wood fractions (pine needles, branches, bark, cones). Our research has confirmed this assumption. The maximum plant waste mass values are observed in all of the explored types of pine forests in the near-tree-trunk microsites (a), and the minimum values – in the between-tree-crowns microsites (c) where the plant waste mass is on the average 2 times less than in the first microsite type, which is in agreement with the data of the other researchers [2].

A similar specific feature – twofold reduction from the near-tree-trunk to the between-tree-crown microsites is revealed for forest litter thickness in all explored types of pine forests, which apparently is conditioned by the plant waste mass forming forest litter. However, it is only in the lichen pine woodland (SS1) that the forest litter mass significantly decreases from the near-tree-trunk to between-tree-crown microsites; the spatial distribution of the forest litter in the other two explored communities is more uniform, since the difference in the forest litter mass between the different microsites is not appreciable.

In conclusion, we may state that the results of our research basically reflect the major trends in respect of biomass accumulation change in the pine forests' ground cover, as well as regarding the forest litter stock, as revealed by other researchers.

5. CONCLUSIONS

The heterogeneity of the ground cover is a fundamental property of forest ecosystems which is substantially conditioned by the influence of trees, which, in turn, is accounted for by the following factors: (a) nature of influence (through the change of energy and matter flows, root competition etc.); (b) generic affiliation (the species of genus *Picea* affect the ground cover tessellation more pronouncedly in comparison with the species of genus *Pinus*); specific response of ground cover species to the edicator's influence. The undertaken research has made it possible to reveal specific features of biomass accumulation by the ground cover components in different types of middle-aged pine forests of the Kola peninsula (Russia). Upon transition from lichen pine woodlands, occupying the driest habitat, to green-moss type pine forests saturated with moisture to the greatest extent of all considered types of forests, the stock of aboveground and underground biomass of all ground-cover components increases; the ground-cover biomass structure changes, along with increment in thickness and stock of forest litter. A characteristic feature in accumulation of organic matter by the ground cover of all explored types of pine forests is excess of aboveground biomass of plants with atmospheric strategy of nutrition over the biomass stock of plants with root strategy of mineral nutrition.

The evaluation of the biomass stock of components of ground cover, plant waste and forest litter in different types of microsites has made it possible to assess the extent of heterogeneity of organic matter distribution in different types of pine communities. The maximum differences in the stock of biomass of the ground cover components are observed in lichen pine woodland, which apparently is caused by the utmost-contrasting hydrothermal conditions of the habitat. The least differences in the explored parameters of the ground cover are observed in the green-moss type of pine forest where optimal ecotope conditions for existence of green mosses and dwarf-shrubs are formed.

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