Research Article
doi: 10.1590/01047760202329013107
vol(29), 2023

CERNE

Influence of clear-cutting on ground vegetation biomass and dwarf shrubs increment in the Scots pine forests of the European North-East

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FOREST ECOLOGY

ABSTRACT

Background: In spite of important functions the ground vegetation performs, the research on global change and human impact on forests has traditionally focused on tree layer. We have analyzed the influence of clear-cuttings on ground vegetation biomass (GVB), fractional structure and annual increment of dwarf shrubs (bilberry and cowberry) shoots. The investigation was carried out at clear-cut areas of the Scots pine forests in the European North-East of Russia.

Results: The GVB value after clear-cutting increased by 1.9−2.4 times. The GVB values at particular technological elements of clear-cuts (apiaries, skidding tracks) were obtained. On skidding tracks, the biomass was by 1.2–1.7 time less than that on apiaries. Among individual species, *Vaccinium vitis-idaea* L., *Pleurozium schreberi* (Willd. ex Brid.) and *Dicranum polysetum* Sw. demonstrated a positive reaction to clear-cutting but mosses of the *Sphagnum* L. genus reacted negatively. Invasion of *Epilobium angustifolium* L. and *Avenella flexuosa* (L.) Drejer increased the grass biomass, especially on skidding tracks. The linear model was applied for describing the relationship between above- and underground dwarf shrub biomass. The clear-cutting had a negative effect on shoot age and mass of both bilberry and cowberry. However, comfortable light conditions raised the role of foliage in biomass and heightened the increments of studied dwarf shrubs by 1.2–1.3 time.

Conclusion: Clear-cutting had a positive effect both on GVB and increment of dwarf shrubs in Scots pine forests on the European North-East.

Keywords: biomass, ground vegetation, clear-cutting, Vaccinium myrtillus, Vaccinium vitis-idaea

HIGHLIGHTS

Clear-cutting has a positive effect on ground vegetation biomass in boreal pine forest.
Biomass of ground vegetation is lower on skidding tracks.
The underground biomass of dwarf shrubs exceeds their aboveground biomass.
Increment of bilberry and cowberry shoots increases after clear-cutting.

OSIPOV, A.F.; KUZNETSOV, M. Influence of clear−cutting on ground vegetation biomass and dwarf shrubs increment in the Scots pine forests of the European North−East. CERNE, v.29, e−103107, doi: 10.1590/01047760202329013107.

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Received: May, 23 2022 Accepted: September, 16 2022

CERNE
ISSN 0104-7760
UNIVERSIDADE FEDERAL DE LAVRAS

INTRODUCTION

The ground vegetation (GV) that included dwarf shrubs, mosses and lichens is an important component of boreal forests performing significant functions (Nilsson and Wardle, 2005). First, in spite of little biomass it has high contribution to net primary production and net ecosystem production (Dirnböck et al., 2020; Osipov et al., 2021) and its short lifespan and richness in nutrients provides the more intense turnover of matter (Gilliam, 2007; De Groote et al., 2018). This effect increases after disturbances (Zehetgruber et al., 2017). Second, the ground vegetation makes a significant contribution to biodiversity that influences the ecosystem functions and services in the boreal forests (Bukvareva et al., 2019; Van der Plas, 2019). After disturbances, the GV becomes a limiting factor for reforestation due to its competition with young trees (Pröll et al., 2015). The plants of GV can be used as an indicator when analyzing the consequences of climate change, the increased anthropogenic pressure on forest ecosystems, studying the issues of biodiversity conservation and terrestrial ecosystems resistance against catastrophic natural and anthropogenic disturbances (Bakkenes et al., 2006; Rumpff et al., 2010; Errington et al., 2022). However, the global change research in forests has traditionally focused on the overstorey (Bradshaw and Warkentin, 2015; Shapoff et al., 2016) that is possibly explained by difficulties in estimating the role of GV in these processes (Gonzales et., 2013; Frolov et al., 2020).

Clear-cutting largely affects forests and may cause considerable changes to physical and chemical forest soil properties and ground vegetation. Forest restoration processes are strongly dependent on the level of these disturbances (Česonienė et al., 2019). The GV succession starts immediately after clear-cut, while reforestation successfulness may be measurable only after several years (Økland et al., 2016). The influence of clear-cutting on GV biodiversity and biomass have been relatively well studied for the Eastern (Woziwoda et al., 2014, Česonienė et al., 2018; 2019) and Northern Europe (Palviainen et al., 2005; Miina et al., 2009; Økland et al., 2016, Hamberg et al., 2019). It has been shown that the response of ground vegetation at clear-cut areas varies and is expressed as an increase or decrease in cover, biomass and biodiversity.

The clear-cut area is a heterogeneous territory represented by alternating apiaries, plots with relatively slightly disturbed soil cover, and skidding tracks (ST), along which logging equipment moves and where logging residues (branches, tree canopies, etc.) are piled. An analysis of the above studies showed that the role of technological elements is not represented, despite the fact that the space of the ST in boreal forests reaches 18 – 30% of the cut over area (Dymov, 2017). Therefore, the assessment of the particular technological elements (apiaries and STs) and their role in the accumulation of ground cover biomass is necessary for predicting reforestation and the cycle of matters after industrial logging.

Bilberry (*Vaccinium myrtillus* L.) and cowberry (*Vaccinium vitis-idaea* L.) are common and often co-dominant dwarf shrubs in boreal forests and important non-wood forest products in the Nordic countries (Kilpaläinen et al. 2016). Berries are used as a source of nutrients and raw materials for the food industry, and leaves - in the pharmaceutical industry. In the Scots pine forests of *Myrtillus* type, cowberry often does not bear fruit while abundant fruiting is observed on clear-cuts where it actively develops. However, clear-cutting has a negative effect on bilberry yields and leads to changing of these shrubs average cover with bilberry decreasing and cowberry increasing (Česonienė et al., 2018). The investigation on role and increment of dwarf shrubs components (shoots, leaves) is important because plants significantly affect both the quantitative composition of forest floor and the rate of its formation, owing to short life span (Frolov et al., 2021). As noted by Lehtonen et al. (2016) it is especially true for high latitude ecosystems where ground vegetation can produce more litter than overstorey. Therefore, obtaining experimental data on the role of separate organs in shrubs biomass (especially belowground parts) continues to be an urgent task. Consequently, the response of shrubs fractional composition and increment to clear-cutting is necessary to study for understanding the turnover processes in the post cutting community and further reforestation.

Forest ecosystems of the Russian Federation comprise about 20% of the area of the world's forests (FAO 2010). According to Zamolodchikov et al. (2013), cutting area was 1.2×10^6 ha in 2009 and volume of harvested wood was about 175×10^6 m^3. The data presented in annual report of the Ministry of Natural Resources and Environment of the Russian Federation (State report, 2020) showed that annual timber cutting over the past decade peaked in 2018 (238×10^6 m^3 in 2018 with slightly decreasing to 219×10^6 m^3 in 2019). Consequently, industrial logging in this territory can have a significant impact on the turnover of matter in the Northern Hemisphere and should be taken into account in a changing climate (Schapoff et al., 2016). However, in this country there is little info characterizing the influence of clear-cutting on cycle of matter and GV biomass in particular (Panov et al. 2013; Osipov et al. 2018) that require an additional investigations. The region of investigation (Komi Republic) is a large massive of forests on the East-European plain with area about 30×10^6 ha where pine forests occupy about 25 % and the annual cutting area varies from 40 to 60 $\times10^3$ ha (Dymov, 2017).

Summarizing the above, we hypothesized that the GV biomass increases after clear-cutting of Scots pine forest on the European North-East, and the skidding tracks play a significant role in the GV biomass, despite soil damage. The fractional composition of dwarf shrubs is relatively constant with leaves share increasing after clear-cutting. The study tasks were: (1) to evaluate the influence of clear-cutting on GV biomass in the Scots pine forests taking into account technological elements of clear-cuts; (2) and to estimate the inter-annual response of bilberry and cowberry shoots to clear-cutting depend of study year.

MATERIAL AND METHODS

Site

The investigations were carried out in the Komi Republic located in the north-eastern part of the East-European Plain (Russia) (Figure 1) in 2018–2021.The climate of the territory is moderate continental with a mean temperature of July +17.5 °C and January −14.2 °C. The total precipitation is 620 mm. The growing season lasts for about 141 days from mid-May to late September, and the period without stable snow cover - from early May to late October.

The objects of study were mature Scots pine forest (control) and clear-cut areas of pine forest logged in 2008 (C-2008) and 2015 (C-2015) (Table 1) located on the same territory at a distance of no more than 1.5 km from each other, which indicates similar climatic and soil conditions. The clear-cut at C-2015 was performed in winter with harvesting machines. Cut trees were transported with forwarders that provided the minimal soil cover disturbances on apiaries. The clear-cut at C-2008 was carried out in winter with chainsaws, and cut trees were transported by a skidder. However, we have not fixed any soil disturbances at C-2008 apiaries during the study period. At both sites, logging residues (canopies, crowns) were bundled on skidding tracks (STs). The stump harvesting was not performed.

Data collection

The GV aboveground biomass (AGB) determination was carried out in early August 2019 at sample plots with size 1/16 m^2 (25×25 cm). Sampling in this period aimed at estimating the maximum biomass accumulation of all species during the growing season (Woziwoda et al. 2014). All above-ground parts of plants (shrubs, grasses, mosses and lichens) were cut out and divided into species. The total number of sample plots was 110 which were distributed as follows: 30 at the control site, 40 sample plots at the clear-cuts each. Due to the structural heterogeneity of clear-cuts, sampling was carried out considering its technological elements (apiaries and skidding tracks) in a 50/50 proportion. As GV underground (UGB) organs of vascular plants we understood rhizomes of bilberry and cowberry and roots of grasses that were collected by a drill from the area of 98 cm^2 at the aboveground biomass sampling point. The sample plots were located randomly at a distance of 4–5 m from each other.

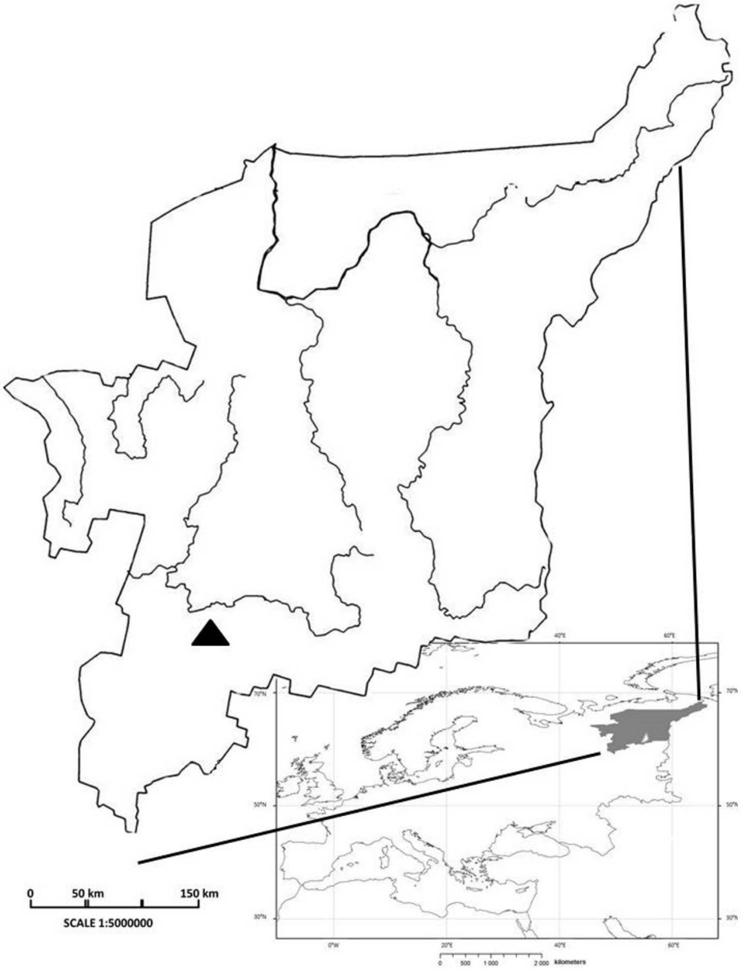

Figure 1. Location of the research area.

Table 1. Characteristic of study sites (description of sites made in 2018).

Species	Tree density (ind.×10^3/ha)		Mean	
	stand	undergrowth	DBH (cm)	Height (m)
Control (N 61°35´37.0´´ E 51°02´27.6´´)				
Pine	1.01±0.05[1]	no[2]	18.5±0.7	18.8±0.3
Spruce	0.27±0.04	3.85±0.54	9.4±0.3	9.7±0.9 / 1.8±0.1[3]
Birch	0.17±0.03	0.42±0.06	11.6±0.3	14.0±1.3 / 3.1±0.6
C-2015 (N 61°35´33.1´´ E 51°02´22.6´´)				
Pine	no	3.78±1.00 / 1.83±0.64[4]	nd[5]	0.51±0.07 / 0.50±0.05
Spruce	single	1.09±0.25 / 0.50±0.15	nd	1.45±0.16 / 0.99±0.13
Birch	single	1.21±0.39 / 1.28±0.58	nd	0.72±0.07/0.54±0.02
C-2008 (N 61°35´12.6´´ E 51°01´08.2´´)				
Pine	0.03±0.01	4.21±0.93 / 2.64±0.74	14.5±1.0	0.7±0.03 / 0.7±0.1
Spruce	0.88±0.05	1.95±0.23 / 0.27±014	9.4±0.4	1.8±0.1 / 1.3±0.05
Birch	0.05±0.02	0.46±0.17 / 9.27±3.79	15.5±0.5	1.0±0.1 / 1.2±0.1

[1] ± SE; [2] not observed; [3] For control site: stand/undergrowth (undergrowth is defined as trees with diameter at breast height (DBH) less than 6 cm); [4] For clear-cuts: apiaries/skidding tracks; [5] not determined.

For 2018–2021, we collected 334 shoots of *V. vitis-idaea* and 159 of *V. myrtillus* for estimating their AGB structure, increment and inter-annual variability of these parameters. The aboveground part of dwarf shrubs was cut at the forest floor level. The shoots of *V. myrtillus* were taken in mid-August and shoots of *V. vitis-idaea* – in early September. The shoots were partitioned into leaves, stems and first-year parts. The shoots age was determined by number of annual growths on the main trunk. All samples were dried at 105°C to an absolutely dry weight. The Latin names of species were given according to www.worldfloraonline.org.

Data analysis

We compared the control site and apiaries because the apiaries are not disturbed and thus more similar to the control plot. In our opinion matching control site and skidding tracks aren't correct because significant disturbances of skidding track by logging equipment and existence of logging residues. Compare of apiaries and skidding tracks was carried out in order to assess the role of individual technological elements. The increment of shoots we calculated as a ratio of first-year organs (leaves and shoots) to the total weight of shoots expressed in percent. With age, *V. myrtillus* and *V. vitis-idaea* form their lateral shoots on the main trunk. As a result, it lies down onto the forest floor and takes root (Efimova, 2003). To assess this process, we introduced the concept of relative annual fall of shoots (RFS) and calculated it using the formula [1], where RFS is a relative fall of shoots [%]; M is the mass of shoots [g]; A – is the age of shoots [years].

$$RFS = \frac{(M / A)}{M} \times 100\% \qquad [1]$$

Statistical analyses

The normality of the variables and linear model residuals were checked with the Shapiro-Wilk's test. We used the t-test (p_t) for pair-wise comparison in case of normal data distribution and the non-parametric Wilcoxon-Mann-Whitney test (p_w) for non-normal distribution. The Kruskal-Wallis test (p_{kw}) was performed to evaluate differences between the studied parameters in case of non-normal distribution of the initial data. The one-way ANOVA (p_A) was used if distribution was normal and variances were homogenous. The homogeneity of variances was tested with the Bartlett test. We performed the regression analysis to assess the relationship between the mass of underground and aboveground dwarf shrubs. Before performing the regression analysis, the initial data were log-transformed to achieve the normal distribution of linear models residuals and the homoscedasticity. The homoscedasticity was checked by the Breusch-Pagan test. The software packages Microsoft Excel 2010 and R 4.03 (R Core Team, 2020) were used and the significance level at α = 0.05 was accepted in all cases.

RESULTS

Influence of clear-cutting on ground vegetation biomass

As show in Table 2, clear-cutting has a positive effect both on total ground vegetation biomass on apiaries ($p_A<0.001$) and on particular groups of species ($p_{kw}<0.001$). The GV biomass at the control site with the Scots pine forest was by 1.9 and 2.4 times less compared to C-2015 and C-2008, respectively. However, this situation did not repeat for particular groups or species. For instance, biomass of grasses was low at C-2008 ($p_w<0.001$) and high at C-2015. Biomass of bilberry had no differences between the control and C-2015 ($p_w=0.107$) but cowberry had biomass higher at C-2015 ($p_{kw}<0.001$). The great diversity of grasses (*Carex globularis* L., *Avenella flexuosa* (L.) Drejer, *Luzula pilosa* (L.) Willd., *Galium boreale* L. and *Epilobium angustifolium L.*) led to their high biomass at C-2015 ($p_{kw}<0.001$). The lowest mass of mosses was fixed for the control site being by 3.4 – 4.1 times less than that at the clear-cut plots ($p_{kw}<0.001$). The reliable impact of clear-cutting on biomass of particular moss species was observed only for the dominant *Pleurozium schreberi* (Willd. ex Brid.) (increased by 5.9–8.6 times, $p_{kw}<0.001$) and *Sphagnum* L. mosses (declined by 2.2–2.8 times, $p_{kw}=0.002$).

The underground biomass (UGB) of dwarf shrubs exceeded their aboveground biomass (AGB) by 1.9–2.8 times at all studied sites. At the same time, a positive effect of clear-cutting on the biomass of dwarf shrubs underground organs was noted ($p_{kw}=0.001$). We noted a positive relationship between the above- and underground biomass of dwarf shrubs (Table 3). The equations describing this relationship in dependence of the element of clear-cut plots (apiary + control, skidding tracks) were characterized by more errors of coefficients, in contrast with the model that includes all data without division into sites and technological elements. So, the errors of the coefficient *a* were 26–45%, and the error of the coefficient *b* was 17%, while in the generalized equation they were 23 and 9%, respectively. The heterogeneity of variances for the "apiary + control" model (p=0.011) should also be taken into account.

Table 2. Biomass of ground vegetation at the control site and apiaries of clear-cuts, g/m^2.

Species	control	C-2008	C-2015	Kruskal-Wallis test (df=2)
Dwarf shrubs incl.:	76.1±6.5[1]	129.9±12.8	125.8±14.4	χ^2 =13.02, p=0.001
V. myrtillus	49.7±5.9	79.5±12.6	41.2±9.6	χ^2 =7.24, p=0.027
V. vitis-idaea	26.4±4.4	50.4±10.7	84.6±11.7	χ^2 =20.26, p<0.001
Grasses[2]	0.3±0.3	0.04±0.04	23.3±10.2	χ^2 =35.23, p<0.001
Mosses incl.:	61.1±8.4	248.5±23.4	206.3±18.0	χ^2 =41.47, p<0.001
Bryopsida incl.	35.2±6.6	236.7±24.6	196.9±20.5	χ^2 =43.20, p<0.001
Pleurozium schreberi (Wild.ex Brid.)	23.1±5.1	197.6±26.7	135.6±17.1	χ^2 =40.41, p<0.001
Hylocomium splendens (Hedw.) Schimp.	5.4±2.8	14.6±7.1	4.7±1.7	χ^2 =4.02, p=0.134
Aulacomnium palustre (Hedw.) Schwägr.	0.2±0.1	0.4±0.2	no[3]	χ^2 =0.01, p=0.939
Ptílium crísta-castrénsis (Hedw.) De Not.	0.04±0.03	1.4±1.2	0.3±0.2	χ^2 =2.18, p=0.336
Polýtrichum commúne Hedw.	4.8±2.3	8.1±4.2	14.8±14.4	χ^2 =3.23, p=0.199
Dicranum polysetum Sw.	1.6±0.6	14.6±4.4	41.5±11.3	χ^2 =22.64, p<0.001
Sphagnum L.	25.9±8.5	11.8±9.4	9.4±9.4	χ^2 =12.39, p=0.002
Equisétum sylváticum L.	no	no	1.0±0.7	no
Lichens[5]	no	0.2±0.1	no	no
Aboveground[6]	137.5±9.1	378.6±24.4	356.4±19.4	χ^2 =48.86, p<0.001
Underground parts of shrubs and grasses	174.6±18.5	358.6±42.5	238.5±21.7	χ^2 =13.44, p=0.001
Total	312.1±22.5	737.2±49.0	594.9±39.0	F=33.58, p<0.001[4]

[1] – Mean ± standard error; [2] – For control site and C-2008 grasses included only *Carex globularis* and at C-2015 included *Carex globularis*, *Luzula pilosa*, *Galium boreale* and *Epilobium angustifolium*; [3] – not observed or not performed; [4] – Results of the one-way ANOVA (df=2); [5] – lichens: *Cladonia arbuscula* (Wallr.) Flot., *Cladonia gracilis* (L.) Willd., *Cladonia botrytes* (K.G.Hagen) Willd. [6] – Include all aboveground parts of dwarf shrubs, grasses, mosses and lichens.

Table 3. Characteristics of linear models (logBG=a+b×logAG) for predicting biomass of belowground dwarf shrub organs (logBG, g/m^2) on aboveground biomass (logAG, g/m^2) data.

Model[1]	Coefficients		R^2	p-value	Residuals[2]	Homoscedasticity[3]
	a (SE)[4]	b(SE)				
FS+control	0.481 (0.125)	3.327 (0.573)	0.31	0.001	0.883	0.011
ST	0.316 (0.143)	3.845 (0.652)	0.22	0.041	0.940	0.426
Total[5]	0.352 (0.083)	3.842 (0.378)	0.25	<0.000	0.802	0.061

[1] – Characteristics of linear model on combined data for forest apiaries and control site (FS + control); for skidding tracks (ST) and total data without sites dividing (Total). [2] – p-value for estimating of residuals distribution normality. [3] – p-value for homogeneity of variances estimating. [4] – SE – standard error of coefficient. [5] – Model that includes all data without division into sites and technological elements.

Ground vegetation biomass for the elements of clear-cuts

The ground vegetation biomass at skidding tracks (STs) was 422.5±33.8 and 492.7±49.1 g/m^2 at C-2008 and C-2015, respectively (Figure 2). The obtained values were by 1.2–1.7 times lower than those at on apiaries of C-2015 and C-2008. More than half of ST biomass at C-2008 (59 %) was located in AGB and the main species were *V. vitis-idaea* (87 g/m^2) and *Pleurozium schreberi* (89 g/m^2). The declining biomass of mosses by 3.3 times (p_w=0.0001) at ST of C-2015 decreased both aboveground and total biomass at this clear-cut element whereas the mass of belowground parts was similar (p_w=0.852). AGB at ST was largely formed by *V. vitis-idaea* (42 %).

Influence of clear-cutting on bilberry and cowberry shoots

Table 4 presents data describing the response of bilberry and cowberry aboveground parts at undisturbed apiaries of clear-cut plots. Clear-cutting affected weight and age of both *V. myrtillus* and *V. vitis-idaea* shoots. After disturbance, the mass of bilberry decreased by 1.5–1.9 times (p_{kw}<0.000) and that of cowberry - by 1.1 time (p_{kw}=0.014). At the clear-cuts, we observed intensification of total increment and RFS in comparison to the control site by 1.2–1.5 and 1.4–1.6 time, respectively for *V. myrtillus* and *V. vitis-idaea*. However, comfortable light conditions at clear-cuts caused the rising role of leaves in biomass and increment of studied dwarf shrubs by 1.2–1.3 (p<0.05) and 1.04–1.2 (p<0.05), respectively. The studied parameters of bilberry and cowberry shoots didn't differ between elements of clear-cuts except for the contribution of leaves in biomass and increment for cowberry and RFS of bilberry at C-2015.

Inter-annual differences of bilberry and cowberry increments

The annual aboveground increment of bilberry changed from 40 to 53 % of total biomass. Despite its increment slightly decreased to the end of observation period, we didn't detect any reliable inter-annual differences both at the control site and apiaries of clear-cut plots (Figure 3A). There were also no true variations in annual growth between plots in same years (p>0.05). Leaves formed more than a half (51–67 %) of bilberry increment with a higher share at C-2015 (p_t<0.05). At the control Scots pine forest, their part was by 1.2–1.3 less in comparison to clear-cut plots (p_w<0.05).

Within the studied period, the aboveground increment of cowberry varied from 37 to 45 % of total biomass at the control site (Fig 3B). There were no differences between 2018 and 2019 (p_t=0.5617) and between 2019 and 2020 (p_t=0.2984) but there were some between 2018 and 2020 years (p_t=0.0453). The most intensive (64–79 %) cowberry increment was revealed at the all clear-cut elements at C-2015 in 2018 and 2019 and at C-2008 in 2019. The cowberry increment at apiaries of C-2008 in 2018 and 2020 was close to control site. The increment on skidding tracks was usually comparable with at the same period of observation (p>0.05). Leaves were the main fraction in cowberry increment and formed 75–85 % of biomass of first-year aboveground organs.

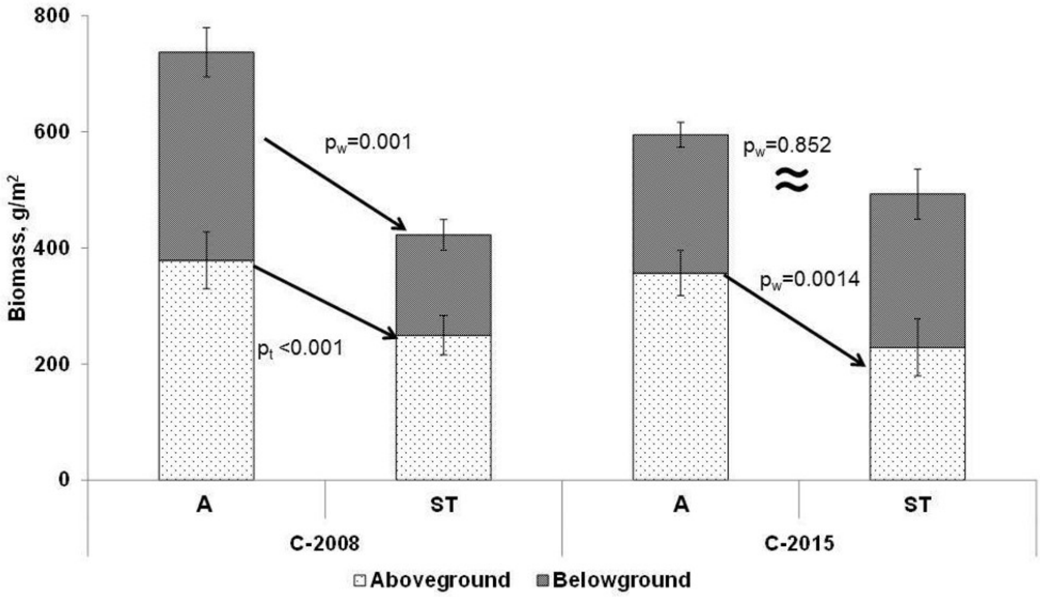

Figure 2 Biomass of ground vegetation on the elements of clear-cuts. A– apiaries, ST – skidding tracks. The "Belowground" includes grasses roots and rhizomes of dwarf shrubs. The "Aboveground" is an aboveground biomass of all species.

Table 4 Response of shoots *Vaccinium myrtillus* and *Vaccinium vitis-idaea* on clear-cutting.

Parameter	Control	C-2008		C-2015		Site differences[1]
		apiary	ST	apiary	ST	
Vaccinium myrtillus						
W, g	1.70±0.25[2]	0.92±0.09	0.71±0.16	0.77±0.10	0.84±0.21	χ^2 =22.61, p<0.001
SFW, %	24.5±0.7	29.3±0.8	28.2±2.2	31.7±0.8	31.4±1.5	F=18.83, p<0.001
I, %	45.3±1.5	50.3±1.6	44.0±4.1	48.4±1.3	52.1±3.1	F =2.99, p=0.053
SFI, %	55.3±1.1	59.1±1.0	65.3±2.0	66.1±1.0	61.2±2.6	F=36.60, p<0.001
RFS, %	26.6±0.9	31.3±1.1	26.5±1.6	31.4±0.9	31.8±2.2	χ^2 =15.43, p<0.001
Age, years	4.0±0.1	3.4±0.1	3.9±0.2	3.3±0.1	3.3±0.2	χ^2 =15.43, p<0.001
Vaccinium vitis-idaea						
W, g	0.49±0.03	0.45±0.05	0.34±0.03	0.44±0.03	0.59±0.06	χ^2 =8.47, p=0.015
SFW, %	57.6±1.0	68.1±1.1	67.3±0.9	67.4±1.0	61.3±1.9	χ^2 =60.36, p<0.001
I, %	40.5±1.7	55.5±2.9	63.0±2.8	64.8±2.3	60.7±2.7	χ^2 =48.36, p<0.001
SFI, %	78.2±1.0	81.1±0.7	79.9±0.9	83.9±0.8	79.6±1.5	χ^2 =20.80, p<0.001
RFS, %	32.5±1.3	47.9±3.4	49.3±3.7	44.8±2.9	39.0±2.2	χ^2 =18.18, p<0.001
Age, years	3.3±0.1	2.5±0.2	2.5±0.1	2.6±0.1	2.8±0.1	χ^2 =18.79, p<0.001

W – mean weight of shoot; SFW - share of foliage in weight of shoot; I – annual aboveground increment; SFI – share of foliage in increment; RFS – relative annual shoot fall off. [1] –Presented differences between control site and apiaries of clear-cuts that were tested by Kruskal-Wallis test or ANOVA (df=2 for *Vaccinium myrtillus* and df=4 for *Vaccinium vitis-idaea*); [2] – mean ± SE.

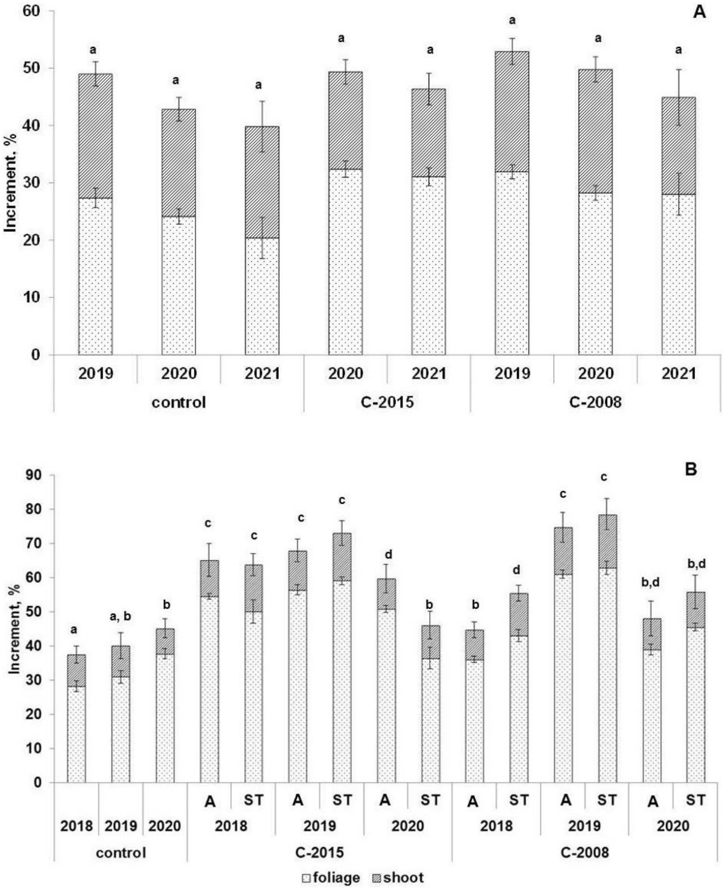

Figure 3. Aboveground increment of dwarf shrubs in years of observations (mean ± SE), % from total mass of shoot A – *V. myrtillus;* B - *V. vitis-idaea*. The error bars on the "shoot" histogram are the standard error of the total increment for the year of observation. Letters on X-axis; A – apiary; ST – skidding track. The same letters indicate absence of differences between treatments.

DISCUSSION

The species composition of the studied communities is typical for pine forests and clear-cuts in the territory of investigation. Grasses invasion is characteristic of the first stages of post-cutting succession in boreal forests (Palviainen et al., 2005; Vanha-Majamaa et al., 2017). The emergence of new species that can be considered as an indicator of climate change has not been identified. It should be noted that long-term observations (Rumpff et al., 2010; Stapper and John, 2015; Errington et al., 2022) or research in mountain regions, where climate change manifests itself faster (Hohenwallner et al., 2011), are needed for this purpose which were not carried out in our case. Therefore, it is not possible to give an unambiguous assessment of the role of climate change based on the data obtained. However, the presented results can be considered as a reference at long-term monitoring of the disturbed lands restoration, including under climate change.

The ground vegetation biomass is known to change along with tree layer development as result of changes in resources and time available for GV species to colonize (Kumar et al. 2017). As noted by Landuyt et al. (2019), the light and nitrogen availability are the main drivers of GV biomass. However, the response of ground vegetation to clear-cutting is different. The negative influence of stand removal on GV biomass was detected by Palviainen et al. (2005) that reasoned by drought, direct sunlight, mechanical damages induced by the logging machinery and logging residues. In our case, the tree layer harvesting caused more comfortable light conditions that favor development of some species at clear-cuts and lead to biomass increasing. However, soil injuries and existence of logging residues on skidding tracks call a less GV biomass on this technological element. As noted by Tonteri et al. (2016) the ground vegetation biomass change after clear-cutting is a different response of separate species to this process induced by their various light sensitivity. Some researchers have presented the data about a positive reaction of bilberry to clear-cutting that is expressed by the increasing cover and biomass (Nielsen et al., 2007; Nybakken et al., 2013). Our results showed a similar trend. The bilberry AGB at the control site was comparable with that of apiaries of C-2015 and by 1.6 time less than that of apiaries of C-2008 (p_w=0.046). However, clear-cutting usually has a negative effect on *V. myrtillus* that is expressed by the decreasing biomass, percentage cover and height. This effect was detected for forests in Finland (Palviainen et al., 2005; Miina et al., 2009; Vanha-Majamaa et al., 2017; Hamberg et al., 2019), Sweden (Bergstedt and Milberg, 2001; Hedwall et al., 2013) and Lithuania (Česonienė et al., 2018). The soil cover disturbances at STs decreased it by 1.9–3.8 times. The low (20.7 g/m^2) bilberry AGB at ST of C-2008 indicates low-intense recovery in 10 years after clear-cutting that explained by damages of soil and underground parts of plants with dormant buds during skidding. As shown by Palviainen et al. (2005), the biomass of *V. myrtillus* after cutting attained its initial levels in 3–4 years.

The response of *V. vitis-idaea* to clear-cutting is ambiguous too. For the Finish and Swedish forests it was negative (Bergstedt and Milberg, 2001; Palviainen et al., 2005; Vanha-Majamaa et al., 2017) but in Lithuania (Česonienė et al., 2018) - positive. We detected a 1.9–3.2-fold increase in cowberry biomass at clear-cut plots. This is possibly caused by a fast activation of dormant buds of *V. vitis-idaea* which produce new rhizomes and shrubs after soil damages (Hautala et al., 2008). Also, *V. vitis-idaea* has thick-skinned leaves and is therefore relatively resistant to intensive illumination and drought (Palviainen et al., 2005) that can explain the foliage share rising in AGB after stand removing (Table 4). These facts in combination with additional nutrients from logging residues can respond for cowberry biomass and increment rate increase especially at skidding tracks of investigated clear-cuts. As noted by Hamberg et al. (2019), the cover of cowberry at clear-cut plot exceeded that at control site approximately by 20 % in six years after cutting activities. The same tends of recovering were detected by Palviainen et al. (2005).

As noted by Frolov et al. (2021), the main fraction of bilberry includes rhizomes (≈71 %) and shoot stems (≈22%). Leaves form about 3 %. The underground parts of *V. myrtillus* and *V. vitis-idaea* exceed the aboveground organs in mature Scots pine forest and at clear-cuts in Lithuania except for cowberry at clear-cuts (Česonienė et al., 2018). According to our data the part of UGB in dwarf shrub biomass was 65–73 % that is comparable with the results of Frolov et al. (2021) and slightly higher than those of Česonienė et al. (2018) due to unfavorable growing conditions (low temperatures, excessive soil moisture, short growing season) in the study area that lead to decreasing shrub height and, respectively, mass of shoots.

The percentage cover and biomass of most common bryophytes (*Pleurozium schreberi, Hylocomium splendens)* decreased after clear-cutting (Palviainenet al., 2005; Tonteri et al., 2016; Vanha-Majamaa et al., 2017; Hamberg et al., 2019). But, we observed the increase in biomass of light-adapted *P. schreberi* and lack of differences for *H. splendens* (p_w>0.05) at apiaries of investigated clear-cut plots. The time gone since clear-cutting has a positive effect on the overgrowth of ST with bryophytes. Thus, the *P. schreberi* biomass at ST of C-2008 was by 3.2–3.8 times higher than that at ST of C-2015 and the control site, respectively. However, the *H. splendens* biomass at ST of both clear-cut plots was significantly (by 6–39 times) less than that at apiaries that indicates a slow recovery of this species on disturbed soils. As noted by Tonteri et al. (2016), the light-adapted *Dicranum polysetum* showed no respond to clear-cutting. By our results, the biomass of *D. polysetum* substantially increased (by 26 times, p_w<0.001) at apiaries of C-2015 but at C-2008 it increased by 9.1 times compared with the control site (p_w<0.001). This species also well-restored at skidding tracks of C-2008 where its biomass was 39.3 g/m^2 that exceeded the biomass at apiaries by 2.7 times (p_w<0.001) and is comparable with C-2015 (p_w=0.166). Plants of the *Sphagnum* genus are semi-shade plants (Tonteri et al., 2016) which biomass and percentage cover decreased after stand removal both at the studied clear-cut plots and their separate technological elements ($p_w < 0.05$ in all cases). The similar reaction of *Sphagnum angustifolium* to clear-cutting was detected by Hamberg et al. (2019).

The biomass increase of grasses is a character of clear-cuts in boreal forests that survive *Epilobium angustifolium* invasion in first years after clear-cutting (Palviainenet al., 2005). It was especially true for C-2015 where *C. angustifolium* biomass reached 21.3 g/m^2. However, this species was not observed at C-2008 possibly due to active regeneration of trees (12.18 inds.×10^3/ha, Table 1) on skidding tracks in ten years after clear-cutting. *Avenella flexuosa* and *Luzula pelosa* are species that actively cover clear-cut surfaces along with *E. angustifolium*, especially at skidding tracks. Thus, their AGB on ST of C-2015 were 13.0 and 9.9 g/m^2, respectively, but on ST of C-2008 4.6 and 1.6 g/m^2. Speaking about the technological elements of clear-cuts, grasses actively inhabit disturbed STs. This is probably due to the lack of competition from mosses. Also the activated soil seed bank of the species after the disturbance can also be the cause of the rapid colonization. The biomass of grasses decreases on ST in 10 years after clear-cutting, simultaneously with the surface overgrowth by mosses ($p_w < 0.001$).

CONCLUSIONS

The ground vegetation biomass at clear-cuts of pine forest changed from 595 to 737 g/m^2 which was by1.9 – 2.4 times higher than that in undisturbed mature Scots pine forest. The biomass on skidding tracks also exceeded the values for control site by 1.4–1.6 time and varied from 423–493 g/m^2. The main species that formed aboveground biomass in control site were bilberry (36 %), cowberry (19 %), mosses of *Sphagnopsida* genus (19%) and *P. schreberi* (17%). After clear-cutting, the role of species changed, especially cowberry, *P. schreberi* and *D. polysetum* that increased significantly. The clear-cutting measures had a negative effect on biomass of shoots both for bilberry and cowberry that decreased by approximately 46–58 and 8–31 %, respectively. The smaller decrease for *V. vitis-idaea* is explained by strong branching of its shoots. The comfortable light conditions caused the increase of cowberry shoot increment but not for bilberry. Also, the intense illumination increased the role of foliage in biomass and increment of studied dwarf shrubs by 1.2–1.3 time. The obtained data will be useful for predicting forest regeneration and modeling the turnover of matter response to industrial logging.

AUTHORSHIP CONTRIBUTION

Project Idea: OFA
Database: OFA, KMA
Processing: OFA, KMA
Analysis: OFA, KMA
Writing: OFA
Review: OFA

AKNOWLEDGEMENTS

The work was carried out within the framework of the research topic of the Institute of biology of the Federal Research Center of the Komi Scientific Center of the Ural Branch of the Russian Academy of Sciences "Zonal patterns of the dynamics of the structure and productivity of primary and anthropogenically modified phytocenoses of forest and marsh ecosystems in the European North-East of Russia" state registration number 122040100031-8.

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