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Long-Term Influence of Stump-Removal on Components of Hemiboreal Pine Forest Ecosystem

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Abstract: Use of whole tree biomass becomes increasingly more important due to rising demand for renewable energy and materials to replace fossil resources. Therefore, assessment of influence of this approach on hemiboreal forest ecosystem is essential. The aim of our study was to assess the long-term influence of full biomass removal (FBR) on the ground vegetation and soil chemical composition in Scots pine stands. Study sites were located in *Vacciniosa*, *Myrtillosa*, and *Myrtillosa mel.* forest types. Almost half a century from the FBR, it had no notable or significant influence on number of ground vegetation species. Significant differences in overall vegetation composition between stands established after FBR and conventional harvesting (stem-wood removal) were not found by the detrended correspondence analysis (DCA) and analysis of similarities (ANOSIM). In addition, values of Ellenberg and Düll indicators were similar and, in most cases (determined by forest type and parameter), had no significant differences between FBR and the same age control stands. Similarly, no significant differences were found between these stands in soil carbon and nitrogen pools. Thus, there had not been a negative long-term effect of FBR on the hemiboreal Scots pine ecosystem as indicated by ground vegetation and soil.

Keywords: full biomass gathering; vegetation; long-term effects; soil chemical composition; detrended correspondence analysis

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1. Introduction

The aim of stump harvesting has been, and still is, to ensure additional wood resources. Historically, stumps have been a resource for tar [1,2] or chemical processing [3]; currently, they are viewed as a source for bioenergy. Whole tree harvesting instead of conventional harvesting (stem wood use from clear-cuts) will increase the usable wood production by 30%, depending on trees species and conditions [4,5]. For Scots pine (*Pinus sylvestris* L.), harvestable amount of stumps and coarse roots is about 11% to 18%, and biomass from stem and branches is about from 78% to 83%, and the fine roots and needles are approximately 6% [4,6–8]. For Norway spruce (*Picea abies*), the amount of harvestable stem and branch biomass is from 60% to 72%, the stump and coarse roots are from 18% to 21% of all tree biomass, and needles, cones, and small and fine roots are approximately 22% [5,6]. In Northern Europe, stump harvesting is primarily practiced in Norway spruce forests of Finland. The amount that Finland harvests from stumps and roots is on average 0.76 million m^3 per year, with notable variation between years. It reached a peak from 2010 to 2013 [9]. Factors driving the stump harvesting are the technologies and costs (dependent on the technologies and amount of obtainable material), as well as considerations on the potential influence of this practice to the forest ecosystem.

Stumps can be removed (bulldozed) with the upper layer of soil [10]; however, it creates difficulties to obtain clean wood for further processing. Therefore, in current practice, stumps are lifted with as little soil attached as possible [11,12]. After stump harvesting, the pits are closed by adjacent soil [13]. Studies have shown that stump harvesting mixes soil layers [13], causing faster decomposition of vegetation and litter and loss (leakage) of nutrients and slower vegetation regeneration [14]. In addition, additional activities while removing and collecting the stumps increase the soil compaction This damage can be partly reduced by training operators and using adjusted machinery with lower pressure to forest floor [13,15]. Some nutrients were removed from the forest area with the harvested stumps and roots themselves and/or upper (0–20 cm) soil layer, like Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, Mn^{2+}, N, C, P [16,17]. Stumps have a notable role in carbon and nitrogen circulation: after harvesting, carbon is very gradually released to the atmosphere. Nitrogen accumulates when the stumps decompose [18,19]. By removing all tree biomass from a forest stand, nutrient loss is significantly higher, in comparison to only stump harvesting, since needles/leaves and twigs have the highest nutrient amount and concentration [20,21]. Nutrient removal might affect the growth of next tree generation at early stages [8]. However, it does not necessarily lead to reduced increment over a longer period, as has been seen for Scots pine on fertile soil [22].

Forest management affects soil invertebrates, earthworms, and nematodes: their number is most dramatically reduced after clear-cut, and especially after stump harvesting, because of microclimate change and removal of organic material from the forest floor [12,23]. Similarly, such drastic changes influence ground vegetation; the microclimate changes, new, light-demanding species rapidly spread, but shade tolerance plants species perish [24]. Stump harvesting creates five times more ground disturbance than conventional clearcutting [25]. In such conditions, ingrowth of new vascular plant species is more rapid, since they do not have to compete with much of existing (pre-harvest) vegetation [26]. The stump harvesting did not make a significant impact on ground vegetation in that, 8–13 years after stump removal, the vegetation and mosses had larger field cover [27].

Changes of vegetation, ground disturbance, and decomposition of organic material cause changes in CO_2 flux. No significant differences in this measure had been found between conventional harvesting and stump removal in the first two years [28]. In addition, in the medium-term (20–30 years), the influence had not been significant in mineral soil but had been significant ($p < 0.05$) in humus [29].

There is not much information about the long-term impact of stump harvesting on carbon and nitrogen stock, as well as there is not much information about long term impact on vegetation and forest stand. Even so, short term impact of 0–20 years after stump harvesting [12,23] and medium-term impact of 20–30 years after stump harvesting [17,28,29] is rather well assessed. Almost all studies are located in areas North from latitude 58 and South from latitude 55 [15], leaving the hemiboreal forests out. The aim of this study was to characterize the long-term influence of stump harvesting on hemiboreal pine forest ecosystem, as indicated by ground vegetation.

2. Methods and Materials

2.1. Study Site

Study areas were located in Scots pine stands in western and central part of Latvia: *Vacciniosa* forest type with dry nutrient-poor acidic sandy soil (56°45′ N, 24°35′ E), *Myrtillosa* forest type with nutrient-poor podzolic sandy soil (57°19′ N, 22°03′ E), and *Myrtillosa mel.* forest type with drained peaty soils (56°22′ N, 21°12′ E; Figure 1). Climatic conditions are similar in all sites: mean monthly temperature ranging from −1.2 °C to −6.1 °C in January and 16 °C to 19.4 °C in July, the mean annual precipitation is 725 mm, and vegetation period ~202 days [30].

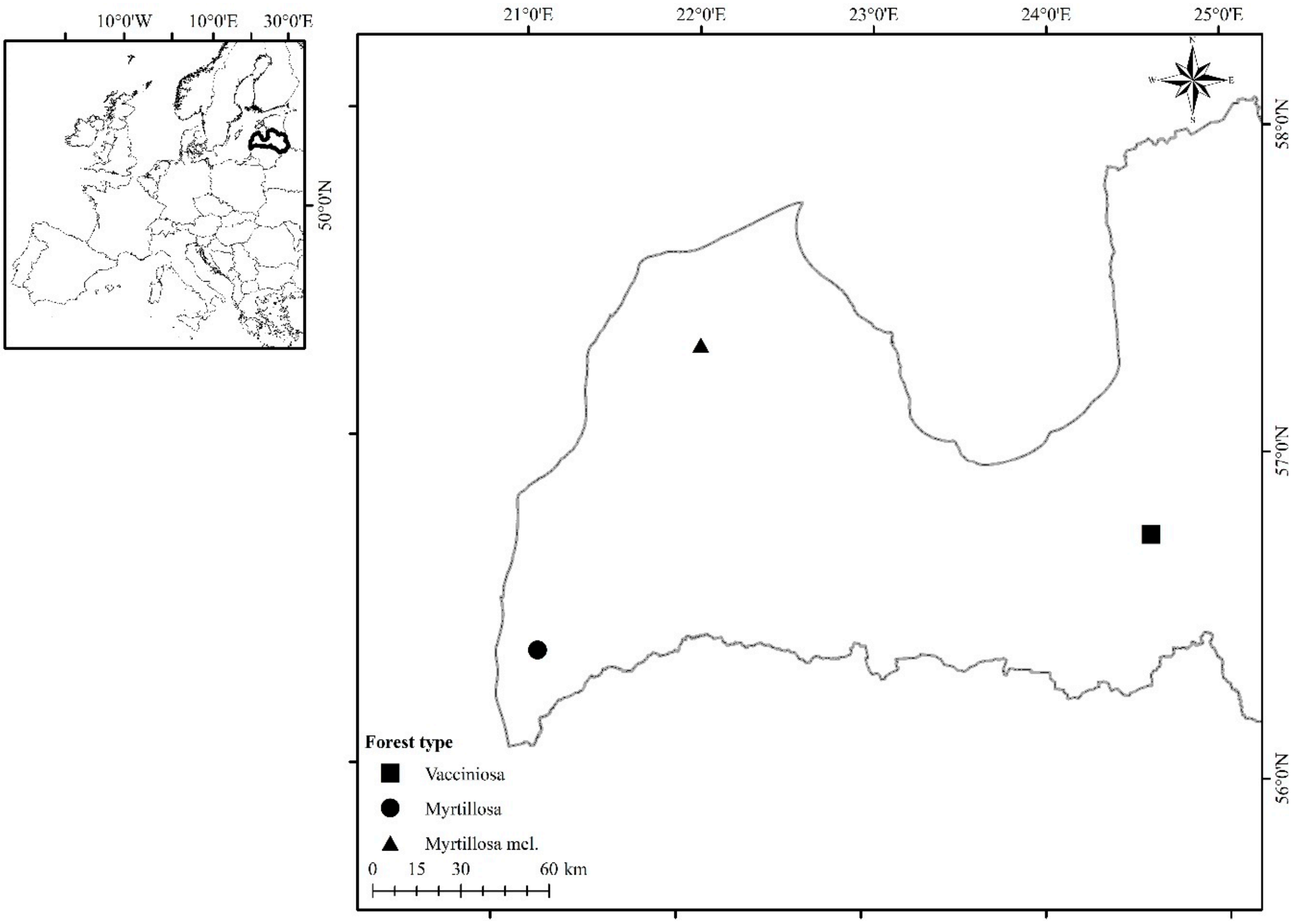

Figure 1. Location of study areas in Latvia. (**Left**) Location of Latvia in Europe. (**Right**) Stand locations in Latvia.

Study areas were selected based on documented information about specific management: in 1968, after a clear-cut, all aboveground and stump biomass, together with the upper soil layer (ca. 8 cm thick) was moved with a bulldozer, resulting in full biomass removal (FBR). The nearby areas in the same forest types were selected for the comparison: young stand (~11 years) and middle age (control) stand (~50 years), both established after conventional harvesting (only stem-wood removed), as well as mature stand (~120 years) and old stand (~160 years) (Table 1, Table S5).

Table 1. Forest inventory data of stands with and without stump harvesting.

Forest Type	Type	Composition Ratio	Age	Stand	H[1], m	DBH[2], cm	Basal Area, m^2 ha^{-1}	Yield, m^3 ha^{-1}
Vacciniosa	FBR stand	10P[3]	50	504-66-11	19	22.6	21.7	198.9
Vacciniosa	Control stand	10P	53	508-110-4	18.6	18.4	19.6	179.5
Vacciniosa	Control stand	10P	48	508-109-16	17.9	20.23	14.6	128.3
Vacciniosa	Control stand	10P	51	504-66-17	18.1	18.2	35.4	311.6
Myrtillosa	FBR stand	10P	40	705-246-2	17.5	20.2	22.4	194.1
Myrtillosa	Control stand	10P	41	710-300-36	19.5	24.2	25.3	240.0
Myrtillosa	Control stand	10P	35	713-300-14	17.7	22.1	28.1	248.0
Myrtillosa	Control stand	8P 2E[4]	40	713-205-19	16.3	22	15.8	127.4
Myrtillosa	Control stand	9P1B[5]	40	705-195-33	15.3	15.3	29.8	229.1
Myrtillosa mel.	FBR stand	10P	41	209-418-10	21.2	24.6	30.3	302.2
Myrtillosa mel.	FBR stand	10P	35	209-419-8	17.8	22.9	24.8	218
Myrtillosa mel.	Control stand	9P1E	41	209-448-17	13.9	18.5	21.8	159.8
Myrtillosa mel.	Control stand	9P1B	43	709-216-1	17.6	19.9	23.5	200.4

[1] H—Mean tree height in the stand; [2] DBH—Mean tree diameter at 1.3 m; [3] P—Scots pine; [4] E—Norway spruce; [5] B—Silver birch. Composition ration—proportion of each tree species in the stand, based on its standing volume.

Data were collected in July of 2015, half a century (48 years) after FBR. Vegetation was evaluated in altogether forty transects (50 m each), placed in the stands not closer than 15 m from the edges. On each transect, 17 sampling plots (total 680), with size 1 m × 1 m, were placed with regular spacing (2 m). In each sampling plot, ground cover vegetation and bare soil cover (including wood residuals and debris) were described by the Braun-Blanquet method [31].

Additionally, approximately in the middle of each FBR and middle age stand transect, soil samples (100 cm^3) were collected from the depth of 0–10 cm; 10–20 cm; 20–40 cm; and 40–80 cm, and one litter sample 10 × 10 cm^2, without any living plant. The samples were transported to Latvian State Forest Research Institute "SILAVA" laboratory where they were analyzed. To measure the total amount of carbon in the soil was used elemental analysis method by [32]. To measure the total amount of N, we used Kjeldahl method by LVS ISO 11261:2002 [33,34] and, to measure the total amount of carbon in forest stand, we used elemental analysis method, accepting that conifers and deciduous trees average carbon values are 50.8% and 48.8% [35].

2.2. Data Analysis

The mean relative cover of every species in each stand was calculated. Species diversity for each stand was described by Shannon (H′) indices $(H) = -\sum_{i=1}^{S} p_i ln\ p_i$, where p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of calculations, and s is the number of species [36]. The similarity of indices was statistically verified using analysis of variance at the significance level $p < 0.05$ in program R 3.4.2 [37]. The Analysis of Similarities (ANOSIM) in program R, using package "vegan" [38,39] was used for the statistical comparison of the composition of vegetation between all the stands in one forest type. The R value (between 0 and 1) $= \frac{(\overline{r_B} - \overline{r_W})}{\frac{1}{2}M}$, where r_B is the average rank of similarities of pairs of samples originating from different sites, r_W is the average of rank similarity of pairs among replicates within sites, $M = n(n-1)/2$, where n is the number of samples, derived from this analysis, characterizes the level of similarity: if R = 0, then stands are same, and, if R = 1, then stands are completely different. The similarity of species composition among the stands was assessed by the Detrended Correspondence Analysis (DCA) based on the relative cover of species [40]. To characterize the growing conditions in all forest types, we used Ellenberg indicator values for vascular plants [41] and Düll indicator values for mosses [42]. Analysis of variance was used to test the similarity of the carbon and nitrogen concentration between all same age control stands and FBR stand.

3. Results

Most undergrowth species were found in stump harvested (FBR) *Myrtillosa mel.* forest type (10 species); in FBR *Myrtillosa* forest type was the second highest undergrowth species (8 species); but, in FBR *Vacciniosa*, there were only five undergrowth species. In the control stand, undergrowth species were less common in all forest types, where such undergrowth species as *Betula pendula*, *Frangula alnus*, *Picea abies*, and *Pinus sylvestris* were in all stands. *Myrtillosa* forest type was with ruderal specie *Amelanchier spicata*, and the *Myrtillosa mel.* forest type was with invasive species *Prunus domestica*, which is gone wild from nearest gardens (Table 2; Table S1).

Table 2. Occurrence of undergrowth and advance regeneration in study areas.

Species	Vacciniosa	Myrtilliosa	Myrtilliosa Mel.
Acer platinoides	-	×	×
Amelanchier spicata	-	×	-
Betula pendula	×	×	×
Betula pubescens	-	-	×
Cerasus avium	-	×	-
Corylus avellana	-	×	-
Frangula alnus	×	×	×
Picea abies	×	×	×
Pinus sylvestris	×	×	×
Populus tremula	×	×	-
Prunus domestica	-	-	×
Quercus robur	-	×	-
Salix sp.	-	-	×
Sorbus aucuparia	-	×	×
Tilia cordata	×	-	×
Viburnum opulus	-	×	-

"-"—species not present; ×—species present.

Vacciniosa FBR and the control stand had the highest number of ground vegetation species (22 and 24), but the lowest number of species were found in a mature stand (14 species). The highest Shannon-Wiener index was in the young stand (1.57), and the lowest was in FBR site (1.05). The FBR stand had statically similar Shannon-Wiener indexes with the control stand and mature stand, but the young stand has no similarities with other stands (Table 3).

Table 3. Number of species and Shannon-Wiener diversity indices in the study area of *Vacciniosa*, *Myrtillosa*, *Myrtillosa mel*.

Variable	Forest Type	FBR [5]	Control Stand [1]	Young Stand [2]	Mature Stand [3]	Old Stand [4]
Number of species	*Vacciniosa*	22	24	17	14	20
	Myrtillosa	41	35	49	20	35
	Myrtillosa mel.	78	46	20	51	43
Shannon- Wiener index	*Vacciniosa*	1.05 [b]	1.22 [bc]	1.57 [a]	1.09 [bc]	1.32 [c]
	Myrtillosa	1.59 [a]	1.59 [a]	1.70 [a]	2.08 [b]	1.95 [b]
	Myrtillosa mel.	1.80 [bc]	1.54 [a]	1.63 [ab]	1.62 [ab]	1.89 [c]

Different letters ([abc]) show statistically significant differences. [1] Control stand—conventional harvested stand at age of ~50 years; [2] Young stand—conventional harvested stand at age of ~11 years; [3] Mature stand—conventional harvested stand at age of ~120 years; [4] Old stand—conventional harvested stand at age of ~160 years, [5] FBR—stump harvested stand at age of 50 years.

Similar trends had been observed in the *Myrtillosa* FBR stand, which had the high number of ground vegetation species (41), but the lowest was in a mature stand (20 species); in this forest type, a young stand had highest number of species—49. The highest Shannon-Wiener index was in a mature and old stand (2.08 and 1.95), but the lowest was in stump harvest and the control stand (1.59 in both). The FBR stand had statistically similar Shannon-Wiener indexes with the control stand and young stand (Table 3). The FBR stand had the highest number of ground vegetation species also in *Myrtillosa mel*. (78), but the lowest was on a young stand (20 species). The highest Shannon-Wiener index was in the FBR and old stand (1.80 and 1.89), but the lowest was in the control stand (1.54). There were no statistical differences between the FBR stand and the young stand, mature stand, and old stand, but the control stand had no significant differences between the young and mature stand (Table 3). The FBR stand had as many or more species than the control stand, and it had almost the same Shannon-Wiener index.

Most common species in *Vacciniosa* forest type in the FBR harvested stand was moss, like *Pleurozium schreberi* (54.47%), and other mosses, like *Hylocomium splendens* and *Dicranum polysetum* (Table S2). At the same age, the control stand's most common species was the same *Pleurozium schreberi* and *Hylocomium splendens* (29.83% and 28.84%). A high percentage of mosses was in *Vacciniosa* forest type in other control stands (mature stand and old stand) (Table S2). In the young stand, the most common species was dwarf shrubs, like *Calluna vulgaris* and *Vaccinium vitis-idea* and *Dicranum polysetum* (Table S2). At the FBR site, protected species *Lycopodium clavatum* was found, and it also was found in the same age control stand (7.06% and 1.17%) (Table S2).

At the *Myrtillosa* forest type, the FBR stand most common species was *Deschampsia flexuosa* (38.35%) and *Pleurozium schreberi* (14.61%); at the same age, the control stand's most common species was the same, *Deschampsia flexuosa* (21.25%) and *Pleurozium schreberi* (16.68%). In the young stand, the most common species was *Calamagrostis canescens* (13.29%), *Deschampsia flexuosa* (19.50%), and *Pleurozium schreberi* (11.62%); in the older control stands, the most common species was *Deschampsia flexuosa* (14.21%), *Hylocomium splendens* (11.03%), and *Vaccinium myrtillus* (10.50%) in the mature stand, and *Oxalis acetosella* (18.74%) and *Hylocomium splendens* (13.38%) (Table S3).

A very similar percentage cover to species was in *Myrtillosa mel*. forest type FBR site; their most common species was *Deschampsia flexuosa* (15.59%) and *Pleurozium schreberi* (11.30%). At the control stand, the most common specie was *Molinia cearulea* (14.60%); at the new stand, the most common species was *Molinia cearulea* (14.29%) and *Vaccinium vitis-idea* (10.06%). In the mature stand, the most common species was *Deschampsia flexuosa* (19.85%), *Oxyrrhynchium hians* (17.58%), and *Molinia cearulea* (12.52%); in the old stand, the most common species were *Pseudoscleropodium purum* (15.27%) and *Calamagrostis arundinacea* (10.06%) (Table S4).

The obtained data from ANOSIM analysis in *Vacciniosa* forest type showed that the FBR site was most similar to the control stand (R = 0.08). The mature stand was also very similar to the FBR site (R = 0.40). The old stand and young stand were more dissimilar to the FBR site. DCA analysis shows similar results, in that the FBR stand mostly overlaps with the control stand and with the mature stand. The results of DCA also follows the logical trend of vegetation development from the young to old stand (Figure 2).

In *Myrtillosa* forest type, the FBR site was similar to the young stand (R = 0.40) and control stand (R=0.44), and the biggest dissimilarities were between the FBR and old stand. The DCA analysis showed that the FBR stand groups together with the mature, control, and young stand. Old stand groups with mature, control, and young stand, but the old stand is the only stand that is dissimilar to the FBR site (Figure 3).

At *Myrtillosa mel.* forest type, the FBR site was similar to the control stand and with the mature stand (R=0.19), but the young stand was the most different from the FBR site (R = 0.48). The DCA analysis showed that the FBR stand overlaps most with the control, mature, and old stand, and the DCA showed similar results to the ANOSIM analysis in all three forest types (Figure 4).

To compare growth conditions in each forest type, we used Ellenberg's indicator values. The FBR stand, in most cases (parameters and forest types), significantly differed from the control stand. In *Vacciniosa* forest type, in FBR stands, light conditions were similar only to the young stand, but, in the control, mature and old stand light conditions were significantly different (Table 4). The FBR stand temperature growth conditions were significantly different only from a mature stand. Moisture growth conditions in FBR site was significantly different from all control stands. And pH growth conditions in the FBR stand was similar to other control stands. At *Myrtillosa* forest type, the FBR stand light growth conditions were similar to the young stand but different than the control, mature, and old stand. The temperature, moisture, and pH growth conditions in the FBR stand have significant differences to all control stands. In *Myrtillosa mel*. forest type, the FBR stand light growth conditions had significant differences only with the old stand. The temperature growth conditions in the FBR stand had significant differences with the control stand and young stand, as Please ensure the meaning has been retained. old stand. The pH growth conditions in FBR stand had significant differences with control, young, and mature stand (Table 4).

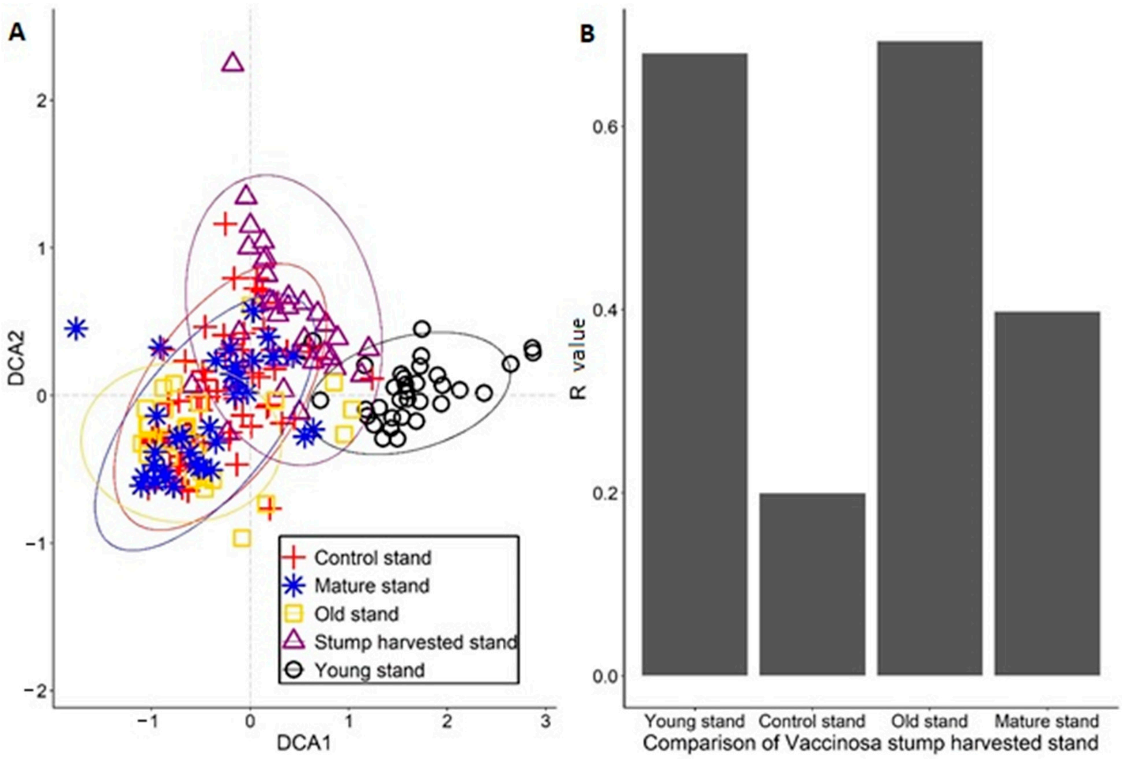

Figure 2. The detrended correspondence analysis (DCA) ordination results in a study area of *Vaccinosa* with ANOSIM results. (**A**) DCA analysis of how *Vacciniosa* forest type plots overlap. (**B**) Similar stands are compared to stump harvested stand.

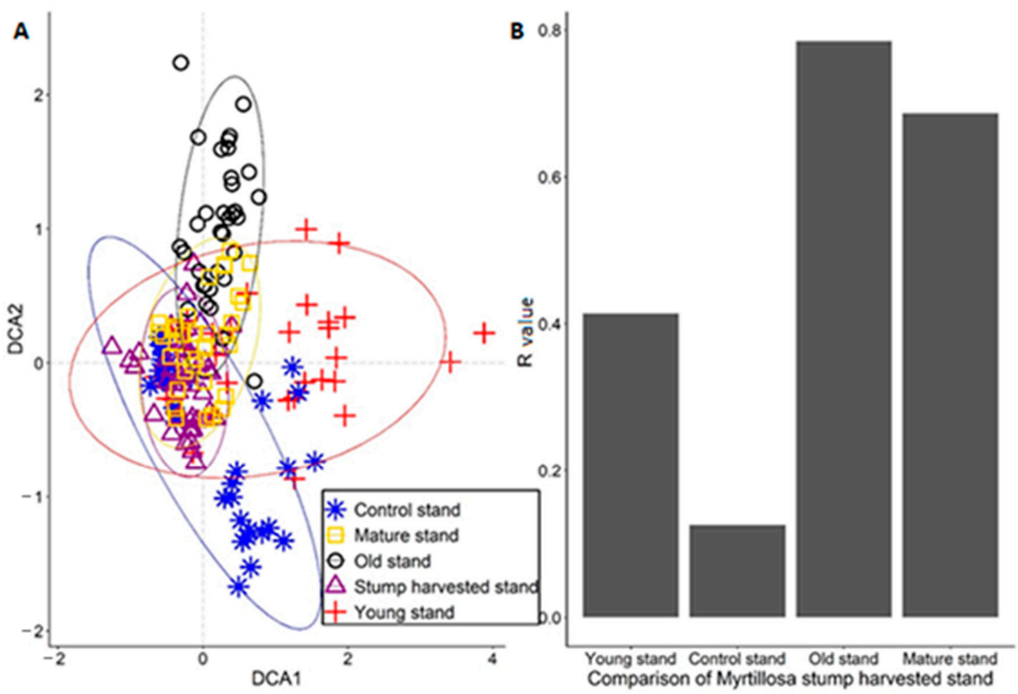

Figure 3. The DCA ordination results in a study area of *Myrtillosa* with ANOSIM results. (**A**) DCA analysis of how *Myrtillosa* forest type plots overlap. (**B**) Similar stands are compared to the stump harvested stand.

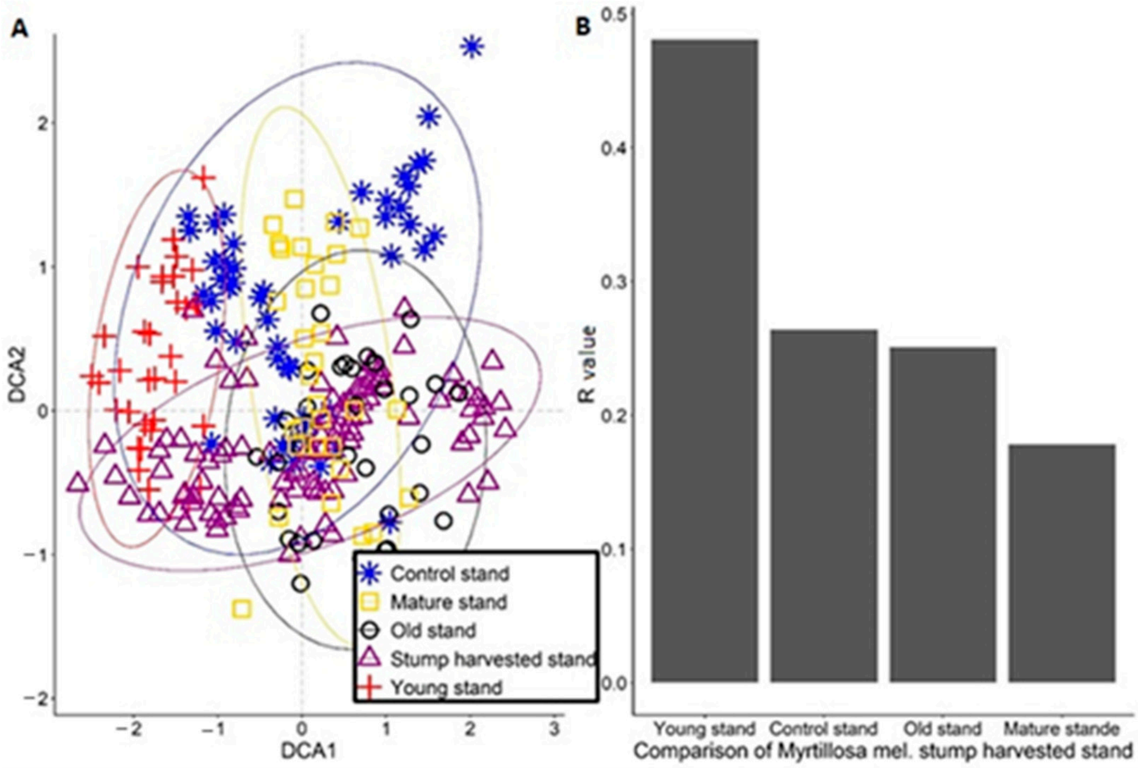

Figure 4. The DCA ordination results in a study area of *Myrtillosa mel.* with ANOSIM results. (**A**) DCA analysis of how *Myrtillosa mel.* forest type plots overlap. (**B**) Similar stands are compared to the stump harvested stand.

Table 4. The Ellenberg values for vascular plants of all forest types.

Forest Type	Territories	Light	Temperature	Moisture	Soil pH
	FBR stand	6.79 ^{a}	4.60 ^{a}	4.71 ^{b}	1.97 ^{ab}
	Control stand	5.66 ^{b}	4.60 ^{a}	4.97 ^{a}	2.09 ^{b}
Vaccinosa	Young stand	6.76 ^{a}	4.66 ^{a}	4.96 ^{a}	1.67 ^{a}
	Mature stand	5.31 ^{b}	4.24 ^{b}	4.97 ^{a}	1.93 ^{ab}
	Old stand	5.38 ^{b}	4.63 ^{a}	4.94 ^{a}	2.04 ^{ab}
	FBR stand	7.37 ^{b}	5.55 ^{b}	3.21 ^{b}	3.92 ^{c}
	Control stand	6.50 ^{a}	5.29 ^{a}	4.57 ^{a}	3.66 ^{b}
Myrtillosa	Young stand	6.97 ^{ab}	5.24 ^{a}	4.58 ^{a}	4.38 ^{a}
	Mature stand	5.85 ^{d}	5.24 ^{a}	4.77 ^{a}	3.53 ^{b}
	Old stand	4.39 ^{c}	5.17 ^{a}	5.16 ^{a}	4.23 ^{a}
	FBR stand	6.07 ^{ab}	5.15 ^{c}	4.39 ^{c}	3.73 ^{c}
	Control stand	5.90 ^{a}	4.91 ^{ab}	5.38 ^{ab}	4.10 ^{b}
Myrtillosa mel.	Young stand	5.59 ^{a}	4.78 ^{a}	5.87 ^{a}	3.33 ^{a}
	Mature stand	6.53 ^{b}	5.08 ^{c}	4.76 ^{cd}	4.23 ^{b}
	Old stand	4.86 ^{c}	4.94 ^{bc}	5.04 ^{bd}	3.84 ^{bc}

Different letters (^{abcd}) show statistically significant differences.

To compare growth conditions for mosses, we used Düll indicator values. Unlike vascular plants, in most cases, mosses and lichens had no significant difference between the FBR and control stand. In *Vacciniosa* forest type, the FBR stand light and temperature conditions were significantly different only with the young stand. The moisture growth conditions in FBR stand were significantly different with the young stand and mature stand. In the FBR stand, pH growth conditions were significant with all control stands (Table 5). In *Myrtillosa* forest type, the FBR stand light growth conditions were significantly different with the mature and old stand, and moisture growth conditions in FBR stand were significantly different with mature and old stands. In *Myrtillosa mel.* forest type, the

FBR stand light growth conditions was significantly different with the young stand and mature stand and had the same significant differences with temperature growth conditions. FBR stand moisture growth conditions was significantly different with control stand and mature stand and pH growth conditions was significantly different with all control stands (Table 5).

Table 5. The Düll values for mosses and lichens of all forest types.

Forest type	Territories	Light	Temperature	Moisture	Soil pH
	FBR stand	5.75 [b]	2.86 [b]	3.95 [b]	2.61 [b]
	Control stand	5.98 [b]	3.00 [b]	4.05 [bc]	3.51 [a]
Vaccinosa	Young stand	5.22 [a]	2.36 [a]	3.63 [a]	3.33 [a]
	Mature stand	5.93 [b]	3.01 [b]	4.21 [c]	3.88 [ac]
	Old stand	5.90 [b]	2.86 [b]	4.11 [bc]	4.18 [c]
	FBR stand	6.05 [a]	2.99 [a]	4.33 [a]	3.56 [a]
	Control stand	6.02 [a]	3.01 [a]	4.34 [a]	3.47 [a]
Myrtillosa	Young stand	5.94 [a]	3.00 [a]	4.28 [a]	3.58 [a]
	Mature stand	5.47 [b]	2.91 [a]	4.99 [b]	3.37 [a]
	Old stand	5.60 [b]	3.04 [a]	4.78 [b]	3.44 [a]
	FBR stand	3.72 [b]	2.16 [ab]	3.00 [b]	3.52 [c]
	Control stand	4.67 [bc]	2.71 [bc]	3.89 [a]	4.57 [b]
Myrtillosa mel.	Young stand	2.32 [a]	1.66 [a]	3.92 [ab]	1.72 [a]
	Mature stand	5.58 [c]	3.36 [c]	4.15 [a]	5.43 [b]
	Old stand	4.43 [bc]	2.65 [bc]	3.60 [ab]	4.14 [b]

Different letters ([abc]) show statistically significant differences.

Analyzing soil parameters as carbon and nitrogen in the soil, there were no significant differences between the FBR and control stand. In all forest types, carbon and nitrogen were more in the FBR stand.

Amount of C in trees have a significant difference ($p < 0.05$) between control stands and FBR stands in *Vacciniosa*. In *Myrtillosa*, the total C in the FBR stand is lower than in the control stand, but there were no significant differences ($p > 0.05$). In *Myrtillosa mel*, total C was higher in the FBR stand, but there was no significant difference between (Table 6).

Table 6. Carbon pools, soil density, and pH in control stands and full biomass removal (FBR) stands.

Forest Type	FBR Stand / Control Stand	Total C	Soil Density	pH
Vacciniosa	FBR stand	112.19	1164.62	5.47
Vacciniosa	Control stand	140.75	754.00	4.85
Myrtillosa	FBR stand	112.96	1597.53	4.64
Myrtillosa	Control stand	120.93	1445.27	3.82
Myrtillosa mel.	FBR stand	142.82	1397.00	4.30
Myrtillosa mel.	Control stand	113.24	1343.88	4.10

4. Discussion

According to results, the FBR stand in *Vacciniosa* forest type had a significant effect on ground cover vegetation between all stands (Table 3), the *Pleurozium schreberi* was dominating in the FBR stand because it favors disturbances [43], and after mechanized forestation, which was mainly used in former Soviet Union to speed up the forestation process, which left large bare soil territories with only spruce seedlings planted [44]. The other reason why *Pleurozium schreberi* dominates in the FBR stand is that it has great anatomy (stable stem and well-placed branches) [45]. But the large dominance of *Pleurozium schreberi* has some negative effects on ground vegetation; it lowers the richness and the number of species in the FBR stand, but the differences were not significant (Table S2). More factors can change vegetation structure in the forest, mostly often anemochory [46] and zoochory [47]. Both large and small scale topographic conditions were flat, which most likely will not influence ground vegetation species. And it might be the reason why, in control and FBR stands, there are so many species.

According to results in forest type *Myrtillosa*, there was *Deschampsia flexuosa* dominance in all stands, but mostly in FBR; this shows the big influence of bare soil after stump harvesting that is because *Deschampsia flexuosa* have a great tolerance to exposure and disturbances [48]. But there were more dominating species in other stands, like *Pleurozium schreberi* and *Calamagrostis canescens*, and these species can spread rapidly [24,49], which is why, in the FBR stand and control stand, there were lower Shannon-Wiener indexes. In *Myrtillosa* forest type, dominance of one specie did not have as much impact as in *Vacciniosa* forest type with *Pleurozium schreberi*, and this is because richness was statistically even in same age control stand and in a young stand. At older stands (mature stand and old stand), there was a dominance of plants *Vaccinium myrtillus*, *Oxalis acetosella*, and *Hylocomium splendens* with a high tolerance of shading [50–52].

Similar dominance was with *Myrtillosa mel*. forest type, but, in younger and same age control stands with conventional harvesting, there was large *Molinia cearulea* dominance, and this is because it has a large and deep root system, which is mostly unaffected after conventional harvesting [53,54]. In addition, the small seeds can more easily spread across the vegetation-covered soil and even get through a dense ground cover of vegetation and litter [55]. Looking at the FBR site, it almost has two times higher number of species, and species richness is statistically different from same-age control stands because of species percentage differences (Table S4). The two most common species were *Calamagrostis canescens* and *Pleurozium schreberi*, which can aggressively spread after stump harvesting [43,49]. It was observed that, in older stands, increasing humidity and shading allowed the mosses to spread in these forests [56].

In *Vacciniosa* forest type, to better compare territories similarity, we used two analyses (ANOSIM and DCA), and these analyses confirmed that FBR site is most similar with same-age control stand, confirmed by other researchers [24]. Both results decline our hypothesis that, in the long term, the impact will be negative on studied forest stand. In addition, the most different stands from FBR stand were young stand and old stand because of the intense of available sunlight and soil fertility [57] (Figure 2). In *Myrtillosa* forest type, the (ANOSIM and DCA) analysis showed almost the same similarities as it was in *Vacciniosa* forest type, except that young stand was more similar than older stands (Figure 3). In *Mytillosa mel*. forest type, there were completely different results in (ANOSIM and DCA) analysis. The results showed that most similar stands with the FBR stand were all stands where stand age was over 40 years (Figure 4). It is because, in all these two stands, there were similar species, like *Deschampsia flexuosa* and mosses, like *Pleurozium schreberi* and *Hylocomium splendens* (Table S4). The young stand was most dissimilar because there was recent conventional harvesting, which changed the growing conditions [58]. These two analyses showed that stump harvesting does not have a negative impact in the long term, and there were all characteristic species, which was typical to *Myrtillosa mel*. forest type [24,59].

The values of Ellenberg and Düll well describe the growing conditions in the forest; each forest type has its own complex of characteristic species that characterize its growing conditions [57]. Thus, if the forest is disturbed, as well as if the amount of light, temperature, humidity, and chemical composition changes, it changes the growing species in the community forest [57]. This might have further consequences to change the forest types or even the forest stand can completely degrade [60]. In *Vacciniosa*, there were different species which better grow in the shade, like *Luzula Pilosa*, and *Vaccinium myrtillus* that better grows in partial shade [57]. According to results, in the FBR stand, there mostly grows plant communities that required well-lit areas to grow [57], and these communities were similar to young stand plant communities (Table 4). The moisture regime in FBR stand differed significantly from other stands, but it was also likely to be affected by adjacent clear-cutting, so additional sunlight came from the side, which may have contributed to soil drying in sunny weather [58,61,62]. The environmental acidity of the FBR stand did not differ significantly from other stands, as there are herbaceous plants that like acidic soils, such as *Vaccinium vitis-idea*, *Vaccinium myrtillus*, and *Calluna vulgaris*. Complexes of plant species in *Vacciniosa* stands, corresponding to herbaceous complexes growing in very acidic to acidic soils [57] (Table 4). The Düll values mostly were similar to Ellenberg values. In the young stand, the Düll indicator values showed that alpine species or species that can withstand large temperature fluctuations are also found in the territories of Latvia, such as *Cetraria islandica* and others that grow there [63]. In other stands were species which adapted to temperate growth conditions in boreal forests, like *Hylocomium splendens* [57]. The soil acidity was significantly different between FBR and other stands because there was removed organic layer with soil and stumps.

In *Myrtillosa*, forest type light and temperature growth conditions were similar to *Vacciniosa* forest type because they are similar in forest types [64]. However, the FBR area did not differ significantly from the young stand according to Ellenberg values for light. Ellenberg's light value was most likely influenced by the frequent occurrence of *Deschampsia flexuosa*, as it grows well in illuminated areas [57]. Due to the fact that, in the *Myrtillosa* forest type, the mature stand and the old stand had thicker undergrowth, this affected the light conditions for herbaceous species and made more difficulties to adapt to [57], which is why both stands differed significantly from other stands. In terms of temperature values, the growing conditions in the FBR stand differed significantly from the other stands, and their growing conditions correspond to a moderate temperature range, as evidenced by the frequent occurrence of *Deschampsia flexuosa* and *Calamagrostis arundinacea* [57]. Ellenberg values for humidity showed that FBR stand differs significantly from other stands. The FBR stand was dominated by arid plants, such as *Deschampsia flexuosa*, but the remaining stands had wetter soil, as indicated by Ellenberg's mean moisture values, as well as some species that were not present in the FBR stand due to drought, such as *Calamagrostis canescens*. The environmental acidity in all stands was close to moderately acidic soil, as evidenced by Ellenberg averages. According to Düll values for mosses and lichens, they did not differ practically in any of the growing conditions, they showed a similar tendency with herbaceous floor stands (Table 5).

In *Myrtillosa mel*. the values of herbaceous Ellenberg floor for the amount of light differed significantly only between FBR and the old stand. The old stand had partial light growth conditions according to Ellenberg averages, as evidenced by the frequent occurrence of *Vaccinium myrtillus*, as this species likes partially shaded areas [57]. Ellenberg average values for temperature for FBR stand differed significantly from the young stand and same-age control stand, but moderate-temperature area plant communities (such as *Calamagrostis arundinacea* and *Vaccinium myrtillus*) grew in all areas [57]. All stands, except FBR, had wet growing conditions, again proving that FBR stand received more light than other stands. In addition, FBR stand had plant communities that grow best in partial shade (*Pseudoscleropodium purum*), which may indicate heterogeneous conditions and a wetter microclimate in some areas. FBR stands had partial acidity growth conditions according to Ellenberg values, and they did not differ significantly from the old stand, these changes in soil pH can be explained by the need of moss species for an acidic soil [65]. From the Düll values obtained in the moss and lichen floor, in the *Myrtillosa mel.* forest type, it can be concluded that the young stand grew plants that grow better in wetter environmental conditions, such as *Oxyrrhynchium hians* [49,57,61]; this is most likely explained by the fact that the young stand has preserved moss species from the previous stand, where there was probably a large undergrowth [66]. According to Düll values, the temperature in the young stand was the lowest and corresponds to the communities of alpine species [63] because *Sphagnum capillifolium* with a high percentage cover was found there, which was probably the reason for this low value (1.66).

This may explain why, in all forest stands, there were some commitments between yields, basal areas, and plants which were growing in those stands. This may be the reason why we did not find similarities between control stand and FBR stand, by Ellenberg and

Düll values in light. So, we think that yield and basal area might affect all vascular plants, bryophytes, and lichens in those stands.

5. Conclusions

Ground vegetation of hemiboreal Scots pine forests, where stump harvesting and full biomass removal (FBR) was carried out, had fully recovered, and almost half a century after the treatment, consists of species characteristic for the particular forest types, including protected species. Similarly, no long-lasting significant influence of FBR on soil carbon nor nitrogen pools had been found. It demonstrates the ability of hemiboreal forest ecosystem to recover after severe disturbances and the potential for more intensive forest management without adverse impact to this ecosystem. Caution must be applied while implementing this approach over a large area, since spatial (forest landscape) effects, not assessed in this study, may have played a role to ensure efficient recovery of ground vegetation. Continuous monitoring of stands after the FBR would provide better understanding on the patterns and causal links of ground vegetation recovery and shifts in soil chemical composition, therefore needing to be addressed in future.

Supplementary Materials: The following are available online at https://www.mdpi.com/2071-1050/13/4/2095/s1, Table S1: Occurrence of underwood and advance growth of control sites, Table S2: The percentage cover of most common species in the Vacciniosa study area, Table S3: The percentage cover of most common species in the Myrtillosa study area, Table S4: The percentage cover of most common species in the pine Myrtillosa mel study area.

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