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THE IMPACT OF FOREST HARVESTING MACHINES ON UNDERSTOREY VEGETATION IN *HYLOCOMIOSA* FOREST TYPE IN ZEMGALE, LATVIA

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Forests are ecologically stable ecosystems that maintain a balanced environment, while wood is one of the most important products of the economy. Forest harvesting technologies are constantly evolving, volumes and intensity of logging increase, as a result the composition and cover of the understorey vegetation changes as well as physical and chemical properties of the soil have been effected. This issue is topical because sustainable forest management options are one of the issues currently being discussed in Europe, so it is important to assess whether logging techniques cause significant understorey cover damage that affects the future development of the forest stand.

The aim of this reseach is to assess the effects of intensity of forest harvesting machines on the diversity of understorey vegetation after the harvesting in the *Hylocomiosa* forest type in Zemgale region, Latvia. In total 70 sampling plots have been established in each of four forest tracts during the vegetation season of 2017. The ground vegetation has been estimated according to Braun-Blanquet approach: the total coverage of herbaceous and moss layer in percentage has been detected and the proportion of each species has been assessed and also plant species has been specified by ecological groups. Results showed that forest harvesting machines do not effect amount of understorey species and their coverage, but change the composition of species and transform the moss layer substantively. Also forest harvesting machines do not affect the species diversity of the herbaceous layer, but change the composition of moss layer. With the increase of intensity of impact of the harvesting machines the species diversity of the moss layer decreases.

Key words: the impact of forest harvesting machines, understorey coverage, changes in species composition.

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INTRODUCTION

Forests are ecologically stable ecosystems that maintain a balanced environment, while wood is one of the most important products of the economy. At the same time logging technologies are constantly evolving, increasing the volume and intensity of logging. Forest management activities affect ground cover, with regard to changes in species composition and projective coverage of understorey vegetation. Sustainable forest management requires the development of methods that can meet the economic, social and ecological needs. As a result of mechanized logging, when trees are felled, cut and pruned, as well as changes in the environment, the diversity of species changes. The forest fragmentation as the result of forest logging creates edge effect, thus increases the diversity of the forest environment (Nelson & Halpern 2005). This issue is topical because sustainable forest management options are one of the issues currently being discussed in Europe, so it is important to assess whether logging techniques cause significant ground cover damage that affects the future development of the forest stand.

More pronounced influence on forest ecosystem was found after fellings, which remove standing trees (final, reconstructive, and sanitary fellings) where forest tends to regenerate, creating stands with structure and species composition similar to the previous one. Thinning and selective felling (final selective felling, reconstructive selective felling and sanitary selective felling) create less disturbance to forest stand, because stand is partially retained (species composition and spatial structure remains, biomass accumulates faster) thus stand can potentially develop old-growth features. Studies show that the increase in forest harvesting intensity during the first decade of the 21st century has promoted forest fragmentation, the increase of clearcut area, number, and edge effects as well as the increase of middle-aged stands due to uneven age group distribution. At the same time, isolation of mature and overmature stands has increased, for example, many of such stands are located inside protected areas (microreserves or protected forest parcels) and thus the gene flows between populations of forest-dwelling species are inhibited (Hanski 1999). Final felling interferes with the stability of forest ecosystem, thus changing sucessional pathways (Bormann et al. 1979). For instance, after felling using skiddering, the projective coverage of herbaceous layer decreases multiple times, and coverage of epigeic lichens and dwarf shrubs like bilberry, increases (Olsson & Staaf 1995). Compared to sites with skiddering, forwarding distributes timber residues in felling, which promotes the development of herbaceous plants and ruderal species few years after the felling (Olsson & Staaf 1995). When comparing vegetational changes between technological processes, the biomass of understorey vegetation doubles after skiddering, but after forwarding mineral nutrient levels in plants increase (Olsson & Staaf 1995). The regeneration of deforested areas is very important for the sustainability of forest management and for biodiversity conservation. In general, the intensity of forest harvesting influences the diversity of understorey plants. For instance, after thinning, selective and regeneration felling, the number of moss species and their projective coverage decreases rapidly, but after selective felling remained unchanged. The number of herbaceous plant species decreased rapidly in areas where selective and regenerative fellings were made, but species projective coverage decreased also after thinning, selective and final fellings. The diversity of understorey species on skid trails increases. A study has found that a larger number of introduced species occurr on skid trails (Jalonen & Vanha-Majamaa 2001).

The aim of research is to evaluate the impact of forest harvesting machines on forest understorey vegetation diversity after logging works in *Hylocomiosa* type forests in Ozolnieki district, Zemgale.

In order to achieve the aim, the following research tasks were set: to determine and analyze the impact of the intensity of forest harvesting machines on the diversity of forest understorey vegetation, to compare and evaluate the changes of forest understorey vegetation depending on the intensity of impact of forest harvesting machines. The hypothesis of the research is that the intensity of the impact of forest harvesting machines causes insignificant changes in the diversity of forest understorey vegetation.

MATERIAL AND METHODS

All research objects are located in Ozolnieki district in Zemgale region (Fig. 1).

The areas studied in this research correspond to the *Vaccinium myrtillus* L. type forests. Such types of forests are found on flat surfaces in wet mild sand or in dusty sand in the soil. The characteristic species of forest ground vegetation are *Vaccinium myrtillus*, *Luzula pilosa* (L.) Willd., *Trientalis europaea* L. and moss *Hylocomium splendens* (Hedw.) Schimp. (Tabaka 2001, Nikodemus et al. 2018).

Field data was collected during the vegetation season of 2017. We analyzed four forest compartments, all in *Hylocomiosa* forest type, one forest compartment with different number of travels (in total 40 sample plots were established), two forest compartments with final fellings and unknown number of travels (20 sample plots were established) and one forest compartment with stand age of 100 years was selected as a control (10 sample plots were established) (Fig. 2). Sample plots were established 20 m from edges to minimize the influence of the edge effect. The size of each sample plot is 1x1 m. In sample plot all plant species and their projective coverage (%) are observed as a total projective coverage (%) by herbaceous and moss layer according to Braun-Blanquet method (Pakalne & Znotiņa 1992).

For each plant species a coefficient of occurence was determined according to the Raunkier formula and a degree of consistency (Markovs 1965, Muller-Dombois & Ellenberg 1974). For each species, the mean projective cover has been determined using the data from 1x1 m sample plots. For plant species, a coefficient of occurrence was calculated according to Raunkier, which describes how frequently a given species is represented in all the investigated plots in total. The occurrence of plant species is equated to the parameter of consistency, determined by attributing it to the occurrence coefficient: I - <21, II - 21 - 40, III - 41 - 60, IV - 61 - 80, V - 81 - 100% (Muller-Dombois & Ellenberg 1974).

The life forms according to Raunkier, dispersal agent and plant strategies by Grime (Grime, 1979)

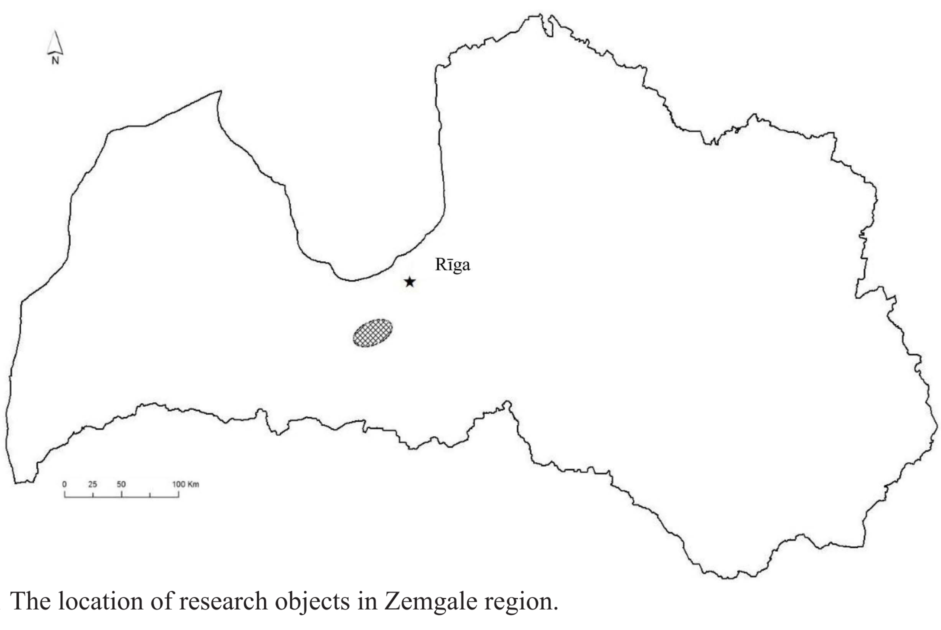

Fig. 1 The location of research objects in Zemgale region.

were assessed using data bases BIRDS EcoFlora and "Flora of vascular plants in central Russia" (База данных...). An ecological assessment of the sample plots was carried out using standard scales of environmental factors (light, moisture, the reaction of soil) by Ellenberg (Ellenberg 1996). The statistical analysis of the data has been performed: one-way single factor ANOVA and a t-test were used to test the significance of travel times on the development of vegetation on skid trails (Arhipova & Bāliņa 2003).

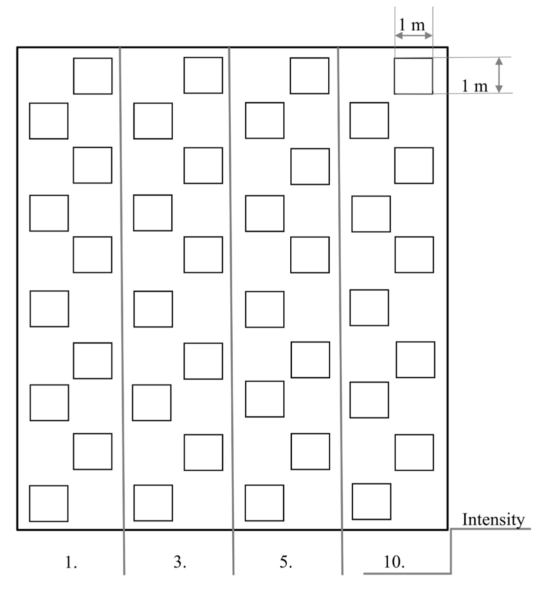

Fig. 2 Design of sample plots.

RESULTS AND DISCUSSION

The changes of number of species in herbaceous and moss layers depending on the number of travels are shown in Fig. 3.

In total 23 vascular plant species and nine moss species are found out in clearcuts (four tree species, two shrub species, two dwarf shrub species, nine herbaceous plant species, three species of pteridophytes, two grass species and one species of sedge. The biggest number of species in herbaceous layer is found in clearcut with unknown intensity of harvesting machines, there are 10 plant species. The number of species decreases with increasing number of travels. The number of species in clearcuts are larger than in the forest interior. Over time, dense herbaceous vegetation develops in forest stands and this prohibits the opportunity for new plants, invasive or alien species and persistent species communities develop in these areas. The number of moss species also decreases with increasing number of travels.

During forest harvesting the conditions of lighting, moisture and temperature change, mosses and ground lichens cannot adapt to these changing conditions and they usually dissapear, opening the space for growth, which will commonly occupied by sedges, herbaceous

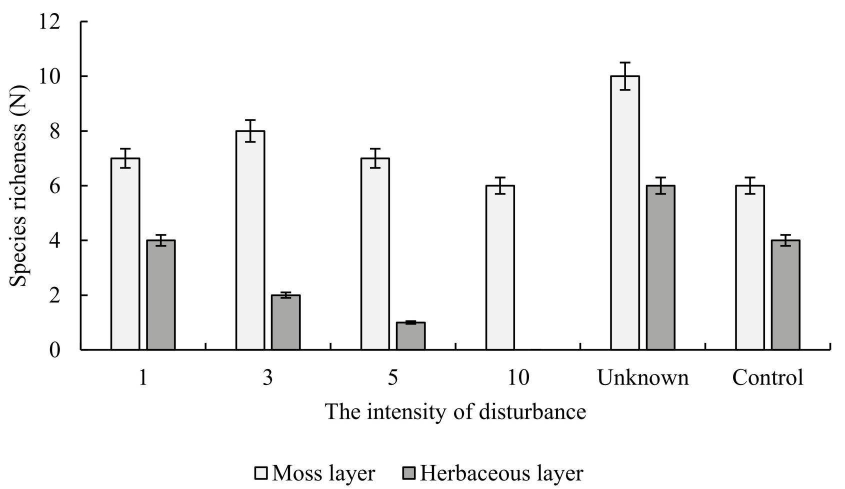

Fig. 3. The number of species of herbaceous and moss layers (mean values are shown ± SE).

plants and other light-demanding species. When comparing the number of herbaceous plants, sedges and moss species in clearcuts with various skid travel intensity, we found that for herbaceous plants the number of travels is not a significant factor ($p > 0.05$), but cover of moss species is destroyed with increasing travel intensity.

The projective coverage of herbaceous' and moss' layers is shown in Fig. 4.

The largest projective coverage for herbaceous plants was found in the clearcut with unknown number of travels – 33% and in control forest compartment – 44%. With travel times increasing from one to five, projective coverage of herbaceous plants increases. In the clearcut with one travel, the largest herbaceous plant projective coverage is consisted of dwarf shrubs like *Vaccinium myrtillus* and *Vacccinium vitis-idaea* L. Similar situation was in clearcut with three travels. Here herbaceous layer is also dominated by *Vaccinium myrtillus* and *Vacccinium vitis-idaea*, but in moss layer *Hylocomium splendens* had the largest projective coverage. In clearcuts with five and ten travels the dominant species are similar - *Carex digitata* L., *Vaccinium myrtillus*, *Vacccinium vitis-ideae* and *Luzula pilosa*, although their projective coverages differed. In clearcuts with unknown number of travels in addition to *Vaccinium myrtillus* also *Lysimachia nummularia* L., *Luzula pilosa* and *Oxalis acetosella* L. were found. Inside forest the largest projective coverage was made up by *Vaccinium myrtillus* and *Vacccinium vitis-idaea*. Data analysis showed that projective coverage decreases during the harvesting, and analyzing the relationship between number of travels and projective coverages indicated that projective coverage of herbaceous layer increases with the intensity of skid trail use.

With the increase of the number of travels from one to ten, projective coverage of moss layer decreased. In clearcut with ten travels mosses were not found at all. The largest projective coverage in moss layer was found inside the forest stand – 48% and in clearcut with unknown number of travels – 45%, where apparent patches of undisturbed understorey had remained (Fenton et al. 2003). In the clearcut with one travel species like *Climacium dendroides* (Hedw.) F. Weber & D.Mohr, *Hypnum cupressiforme* Hedw. and *Rhythidiadelphus triquetrus* (Hedw.) Warnst. dominated. In the clearcut with three travels moss layer was dominated by *Hylocomium splendens*, which was also the only species found in the clearcut with five travels. The largest species diversity was found in the clearcut with unknown number of travels and here the average projective coverage was 44.5%, which is similar to the average projective coverage of moss layer inside

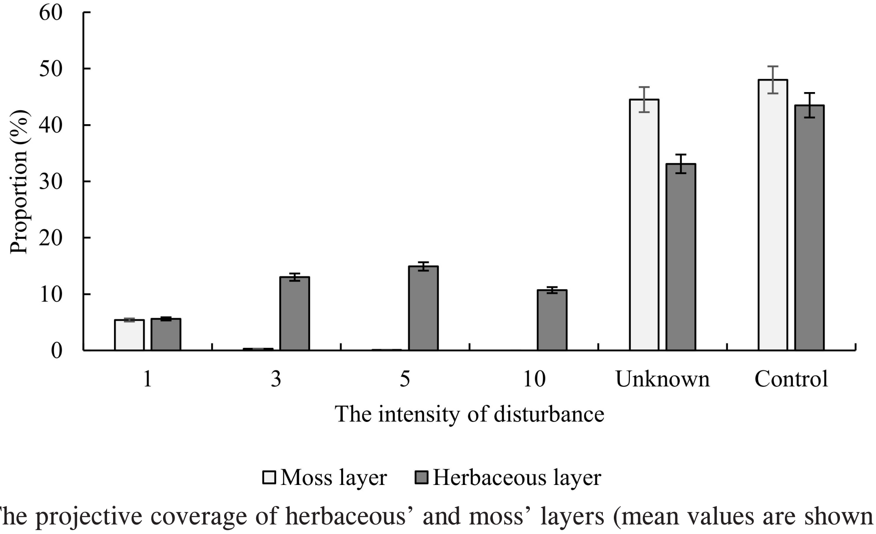

Fig. 4. The projective coverage of herbaceous' and moss' layers (mean values are shown ± SE).

Table 1. The indicator values of ecological factors by Ellenberg

The intensity of forest harvesting machines (the number of travels)	The indicator values of ecological factors		
	Moisture	Nitrogen	Light
1	4.5 ± 0.2	2.3 ± 0.1	6.4 ± 0.3
3	4.6 ± 0.2	2.9 ± 0.1	4.2 ± 0.2
5	4.8 ± 0.2	3.1 ± 0.2	4.1 ± 0.2
10	4.7 ± 0.2	3.4 ± 0.2	3.5 ± 0.2
Unknown	4.7 ± 0.2	3.3 ± 0.2	4.6 ± 0.2
Control	5.1 ± 0.3	2.9 ± 0.1	5.1 ± 0.3

forest (dominated by *Hylocomium splendens* and *Pleurozium schreberi* (Wild. ex Brid.) Mitt.). Overall, differences between moss layer coverages are not significant ($p > 0.05$).

The proportion of species diversity in the herbaceous' layer is shown in Fig. 5.

Dwarf shrub species dominate in all clearcuts and this is explained by the fact that in *Hylocomiosa* forest type dwarf shrubs are indicator species. The majority of dwarf shrub projective coverage is comprised by *Vaccinium myrtillus* and *Vacccinium vitis-idaea. Carex digitata*, which is an indicator species, is common in clearcuts – it indicates soil compaction and general degradation of soil properties (Liepa et al. 2014). With increased number of travels, sedge occurrence in clearcuts increases. Mechanically damaged dwarf shrubs, which previously occupied large proportion of projective coverage, were replaced by plant species, which are better adapted to new conditions i.e. compacted soils.

The proportion of evergreen and summer green plants species in the herbaceous' layer is shown in Fig. 6.

In the first clearcut summer green plants dominate – 70%, and the remaining 30% are evergreen plants. With increasing number of travel times, the proportion of evergreen plants increases, but summer green – decreases. In the clearcut with unknown number of travels the proportion of evergreen plants was 38%, which is similar to the proportion inside the forest stand (36%). This is explained by remaining patches of vegetation, undisturbed by harvesting machinery in this particular sample plot. This shows that evergreen plants are more resistant to mechanic injuries and disturbances.

The proportion of plant species by stem type is shown in Fig. 7.

With increasing number of travels the proportion of woody plants decreases and the proportion of plants with herbaceous stems – increases. In the clearcut with one travel the proportion of woody plants against plants with herbaceous stems was 90% to 10%. In clearcut with three travels this proportion was 74% to 26%, but in clearcuts with five and ten travels – 44% to 57% and 36% to 54%, respectively. In the clearcut with unknown number of travels this proportion was 51% (woody plants) to 49% (plants with herbaceous stems), but inside the forest stand plants with herbaceous stems comprised only 2% and woody plants - 98%. This forest stand corresponds to *Hylocomiosa* forest type, dominated by *Vaccinium myrtillus* and *Vacccinium vitis-idaea* and both of these species have woody stems. With increasing number of travels, the proportion of plants with woody stems decreases, but for plants with herbaceous stems – increases. Plants with woody stems are more vulnerable to mechanical injuries and disturbances, which means that damaged plants can be replaced by plants with herbaceous stems which are more adaptable to such environments.

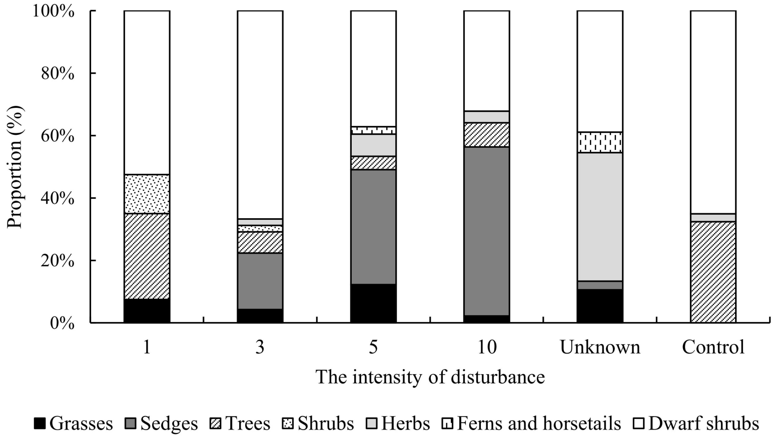

Fig. 5. The proportion of species diversity in the herbaceous' layer.

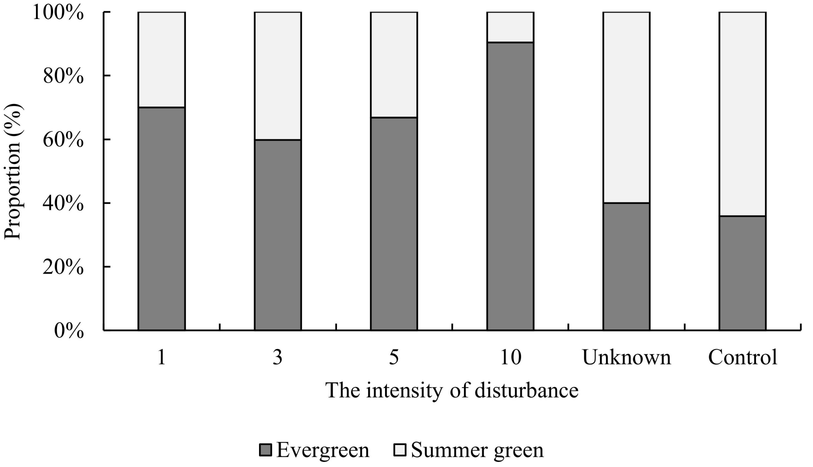

Fig. 6. The proportion of evergreen and summer green plant species in the herbaceous' layer.

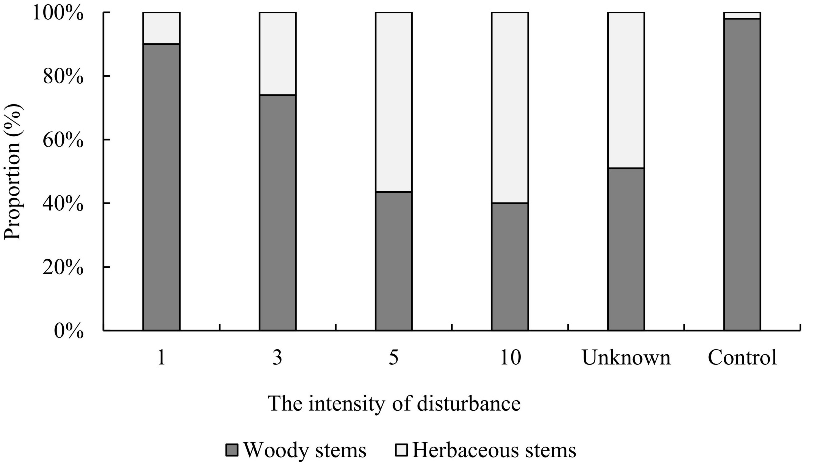

Fig. 7. The proportion of plant species by stem type.

External environmental factors - moisture, nitrogen and light were determined using gradation scores in each sample plot and plants characterized by them in herbaceous layer (Table 1).

All sample plots had light moisture conditions, what might be explained by high projective coverage of dwarf shrubs in all sample plots. However, in managed sample plots, the average moisture value varies from 4.5 to 4.7. Slightly higher moisture value was in control plot (inside forest) – 5.1. In all sample plots soil has low nitrogen levels (values from 2 to 3.9). The lowest nitrogen value was found in a clearcut with the lowest intensity skidding (2.3) – one travel. Ligh values decreased with increasing times of travel. It is explained by the decline of dwarf shrub projective coverage due to increasing intensity of hervesting actions. In clearcut with unknown number of travels average light conditions corresponded to semi-shade level.

In clearcut with one travel competitors-stress tolerant species like *Vaccinium myrtillus* and *Vacccinium vitis-idaea* dominated, reaching proportions of 43% in the clearcut. Species of competitor strategy were also dominant, reaching 38% - these were mainly undergrowth trees like *Populus tremula* L., *Pinus sylvestris* L., *Picea abies* (L.) H.Karst. and *Sorbus aucuparia* L. One plant species that belongs to mixed strategy group (competitors-stress tolerant-ruderal) and had proportion of 20% in clearcuts with one travel was *Calamagrostis arundinacea* (L.).Roth. In the clearcut with three travels, competitor-stress tolerant group had the largest proportion (66%). Species that belong to this group are *Vaccinium myrtillus* and *Vacccinium vitis-idaea*. The proportion of mixed-strategy plant species (*Luzula pilosa* and *Carex digitata*) in the clearcut was 22%. Competitor species like *Populus tremula, Quercus robur* L. and *Padus avium* Mill. as well as other undergrowth trees comprise 9%. *Melampyrum pratense* L. is characterized by competitor-ruderal strategy and it makes up 4% in this particular clearcut. We found that in clearcut with five travels *Luzula pilosa* and *Carex digitata* (mixed strategy) comprise 50%. *Vaccinium myrtillus* and *Vacccinium vitis-idaea* with competitor-stress tolerant strategy makes up 37%. Plant species of two strategies: competitors (*Quercus robur* and *Padus avium*) and competitors-ruderals (*Melampyrum pratense*) comprise identical proportions in clearcut – 7%. In the clearcut with ten travels mixed-strategy plant species were dominant (51%), for instance, *Luzula pilosa* and *Carex digitata*. However, the proportion of competitor-stress tolerant species like *Vaccinium myrtillus*, *Vacccinium vitis-idaea* and *Lysimachia vulgaris* L. comprised 32%. The remaining 7% are made up by competitor species (*Pinus sylvestris*). In the clearcut with unknown number of travels the largest proportion (38%) is comprised by mixed-strategy species, for instance, *Luzula pilosa*, *Carex digitata, Lysimachia nummularia*, *Mycelis muralis* (L.) Dumort., *Calamagrostis arundinacea*, *Oxalis acetosella*, *Trifolium repens* L. and *Equisetum pratense* Ehrh.. The proportion of competitor-stress tolerant species (*Vaccinium myrtillus*, *Vacccinium vitis-idaea* and *Lysimachia vulgaris*) in this clearcut was 37%. Competitor species (*Rubus idaeus* L. and *Pteridium aquilinum* (L.) Kuhn) here comprise 17%. In the clearcut with unknown number of travels we found stress tolerant species (4%): *Maianthemum bifolium* (L.) F.W.Schmidt and *Viola palustris* L. We also found that in forest competitor-stress tolerant group (*Vaccinium myrtillus* and *Vacccinium vitis-idaea*) was dominant – their proportion reached 65%, followed by competitors 33% (*Picea abies*, *Quercus robur* and *Populus tremula*) and only 3% were competitors-ruderals (*Melampyrum pratense*). Overall, the large proportion of competitor-stress tolerant group in clearcuts was due to the high occurrence of *Vaccinium myrtillus* and *Vaccinium vitis-idaea* in the understorey in all clearcuts. Species with competitor strategy was found in all clearcuts. In forest we did not find species with mixed strategy – the proportion of such species increases with the number of travels in clearcuts.

In clearcuts with various levels of influence boreal species are dominant, and this is most pronounced in the tree layer – 65%. Species characteristic to the boreal biome - *Vaccinium* *myrtillus* and *Vacccinium vitis-idaea* were found in all clearcuts. In contrast, the proportion of nemoral species is much lower. The number of boreo-nemoral species (*Picea abies*, *Populus tremula*, *Sorbus aucuparia*, *Calamagrostis arundinacea*, *Luzula pilosa* and *Carex digitata*) increases with the increasing influence on understorey vegetation. In forest stands stable plant communities develop over longer periods, which can adapt to anthropogenic, abiotic or biotic disturbances. When the portion of the previous projective understorey coverage is destroyed, the space for growth opens, and it can be occupied by species that are suitable for survival and colonize in these conditions.

CONCLUSIONS

1. The intensity of forest harvesting machines does not significantly affect the diversity of plant species but changes the composition of the plant species.

2. With the increase of the intensity of forest harvesting machines on skid-trails, the diversity and projective coverage of moss layer decrease.

3. It has been established that with the increase of the intensity of forest harvesting machines, the proportion of woody plants decreases and the proportion of herbaceous plants increases (grasses and sedges). The high proportion of grasses and sedges in clearings can be explained by the degradation of soil structure and soil compaction.

4. With the increase of the intensity of forest harvesting machines, the number of evergreen plant species increases, and the number of summer green plants decreases. The evergreen plants are more resistant to mechanical damage and disturbances.

5. With the increase of the intensity of forest harvesting machines, the proportion of plants with woody stems decreases, but the proportion of plants with herbaceous stems increases.

6. The greatest number of plant species in the herbaceous layer was found in clearcut, where the intensity of forest harvesting machines (the number of travels) on skid-trails is unknown.

7. The total number of plant species in the herbaceous layer is not affected by the intensity of forest harvesting machines.

8. The most homogeneous plant communities are in clearcuts where the effect of the intensity of forest harvesting machines is minimal.

9. With the increase of the intensity of forest harvesting machines, the proportion of plants with mixed-type life strategies (competitor-stress tolerant-ruderal) increases.

10. In clearcuts, where the intensity of forest harvesting machines on skid-trails is stronger (5 and 10 travel times), as well as the unknown intensity, the boreo-nemoral plant species are dominated, but where the intensity is lower (1 or 3 travel times) the boreal species are dominated.

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