LONG-TERM INFLUENCE OF LARGE FOREST FIRE ON GROUND VEGETATION

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Abstract
Fire is a major disturbance in hemiboreal forests; it affects not only trees, but also ground vegetation. Previous studies have analysed the succession of ground vegetation after the fire, but not addressed the impact of the size of the burned area on revegetation of it. Therefore, the aim of our study was to assess the differences in post-fire ground vegetation in relation to the distance from the edge of the affected area. Vegetation data were collected using Braun-Blanquet method in three sites (122 sample plots) affected by forest fire and five clearcuts (not affected by fire) (92 plots), all regenerated by Scots pine 6 – 7 years before the assessment. The number of ground vegetation species (in all sites predominantly birds or wind dispersed) as well as their projective cover was not affected by the distance from the nearest edge of burned or clearcut, except in burned sites on dry sand soil (*Vaccinosa* and *Myrtillosa*), where herbaceous plant and shrub cover was decreasing (from 23.5% to 11.6%) and bryophyte and lichen cover – increasing (from 3% to 13.9%) with an increasing distance from the edge of the area. The total number of plants in burned areas was twice smaller than in clearcut in the same soil conditions but such large difference in projective cover was not observed. There were no significant differences between burned and clearcut areas in respect to Ellenberg's indicator values on both soil types, as well as no trend in Ellenberg's values for soil moisture in relation to distance from the nearest stand edge.
Key words: post-fire regeneration, post-fire colonization, plant dispersal, natural succession, moisture regime.

Introduction

Disturbances – abrupt change in forest (stand), affecting majority of trees – are a major force changing and creating vegetation structures and composition in forested ecosystems (White, 1979). Forest ecosystems are influenced by anthropogenic disturbances as well as by natural disturbances such as forest fire, windthrow, water level fluctuations, desiccation, insect outbreaks, pathogens, browsing damages by large herbivores (Kuuluvainen, 2002).

In Northern Europe forest fire is assumed to be the main natural disturbance, influencing vegetation composition and structure, even thouht during last century the majority (>95%) of forest fires occur due to human activities. In Latvia about 970 ha of pine forests are affected by fire every year (Zadiņa *et al.*, 2015). The influence of forest fires in a particular forest site are dependent on various factors such as site specific factors, stand composition and fire behaviour (Angelstam, 1998).

Fire alters the microclimatic conditions, for instance, light, regime of moisture and temperature changes in the affected area. It is also known that fire affects biogeochemical cycles such as carbon cycle (Flanningan *et al*., 2000). Major post-fire changes are related to invasion of pioneer phase species (De Grandpr´e *et al*., 1993). Post-fire conditions in the affected areas are characterized by thinner soil humus layers, higher pH and more available nutrients in soil for plants (Simard *et al*., 2001). After a high intensity forest fire, soil aggregates lose their stability, therefore enhancing soil degradation (Vacchiano *et al*., 2013). To compare with forest on dry soil, forest on wet soil does not have seed reserves in the ground that would be 'responsible' for gradual change of species or succession after a large-scale disturbance when light and other conditions differ (Priedītis, 1999).

Ground vegetation plays an important role during the early stages of forest stand development. Colonization is rapid (within five to seven years) with communities dominated by fast-growing vascular plants (Greene *et al.*, 1999) which occupy all microsites (De Grandpr´e *et al*., 1993). Species composition of early successional communities are typically dominated by shade intolerant, nutrient demanding species which colonize from seeds or regenerate from underground rhizomes, and can remain dormant for up to 100 years and grow rapidly in response to the abundance of resources (Hart & Chen, 2006). Bryophyte and lichen species are not a large component of vegetation communities during the earlier stages of post-fire succession. Following fire, the number of species, i.e., the species richness, increases quickly, and continues to increase throughout the early stages of post-fire succession, as a large number of plant species colonize growing spaces initially free of competition (Greene *et al.*, 1999). The number of species after forest fire can be remarkable - Rees and Juday (2002) have reported the presence of 80 species on burned stands in Alaska, while Abrams and Dickmann (1982) recorded 89 species on burned stands in Northern Michigan (Hart & Chen, 2006).

Ground vegetation communities following fire and harvesting can be considerably different. Post-logging communities are more similar compositionally to the pre-disturbance communities compared to those resulting from fire (Noble *et al*., 1977; Rees & Juday, 2002). These communities are dominated primarily by tolerant bryophytes and vascular plants, most of which are present in late successional communities prior to clear-cutting. A number of pioneering species is absent in these stands (Hart & Chen, 2006).

Composition of ground vegetation depends not only on the intensity and type of fire, creating various microenvironmental conditions but, presumably, also from the size of the affected area. Large, high-intensity forest fire would stop transpiration of water via trees in a significant area, and, it is assumed, could cause degradation of forest ecosystem: its partial or complete change to swamp ecosystem. Numerous studies have addressed the succession of ground vegetation after forest fire, however, to the best of our knowledge, the influence of forest fire size has not been analysed. Therefore, the aim of our study was to assess the differences in post-fire ground vegetation in relation to the distance from the edge of the fire-affected area.

Materials and Methods

Data collection was carried out in the summer of 2014 in the middle and western part of Latvia in three places affected by forest fire and reforested with Scots pine 6 – 7 years ago. Transects with 122 sample plots (size 1x1m) were established on poor mineral soils with normal moisture regime – further in text referred to as "dry sand soils" (forest types *Vaccinosa* and *Myrtillosa*) and drained mineral soils (forest types *Vaccinosa* mel. and *Myrtillosa* mel.). For control, 92 sample plots were established in five sites in 6 – 7 years old Scots pine stands planted after the clearcut on the same forest types. Relief in all sites was flat. Transects were drawn perpendicular to the edge of the nearest forest stand with height exceeding 10 m. Sample plots were placed systematically (every 30 m) on those transects: 3 m on each side of the transect in each of the points. First sample plot of transect was placed 25 m from the forest stand to avoid direct influence of the trees in neighbouring stand. Ground vegetation data were collected using Braun-Blanquet method (Braun-Blanquet, 1964). Projective cover of each ground vegetation species (%) was assessed as well as the total projective cover of layer herbaceous plants and shrubs (E1) and layer mosses and lichens (E0) with the precision of 1%. In case some species were detected, but projective cover did not reach 1%, it was stated as 0.5%.

All sample plots were divided in four zones according to the distance from the nearest forest stand: zone I: 25 – 50 m, zone II: 51 – 75 m, zone III: 76 – 100 m, zone IV: over 100 m.

Information from databases BioPop, Ecological Flora Database, Bioflora on functional types of plants, types of seed dispersal, need for moisture, Raunkier *life forms* and Ellenberg's indicator values (Ellenberg *et al*., 1992) were gathered and used to compare ground-vegetation between the stated zones. Occurrence of plants was characterized by their constancy, calculated as a proportion of sample plots, where the plant was present from the total number of sample plots. Based on frequency of occurrence constancy a class was assigned to each species (I: occurrence < 21%, II: 21 - 40%, III: 41 - 60%, IV: 61 - 80%, V: 81 - 100%) (Markovs, 1965; Muller – Dombois & Ellenberg, 1974). Significance of differences was calculated using ANOVA.

Results and Discussion

In total, after forest fire on dry sand soils 18 species of herbaceous plants, bryophytes and lichens were found. The number of species per zone varied, in zone I it was 5 (on average 5), in zone II it was 4 – 8 (on average 5.5), in zone III it was 3 – 7 (on average 4.8) and in zone IV it was 2 – 9 (on average 4.3) species. The average number per zone was 4.9 species. Most frequently occurring species (constancy class V) were *Polytrichum juniperinum* Hedw. (characteristic pioneer species of coniferous forests after disturbance) and *Calluna vulgaris* (L.) Hull (characteristic of dry pine forests and after fire on dry, poor soils). Frequently occurring species (constancy class III) were *Carex ericetorum* Pollich (characteristic of pine forest on dry soil) and *Calamagrostis epigeios* (L.) Roth (characteristic of pine forest on dry soil in early-successive plant societies), rarely occurring species were *Chamaenerion angustifolium* (L.) Scop. (typical of early-successive plant societies in dry clearings and burnings) and *Vaccinium vitis-idaea* L. (characteristic of evergreen bush – pine plant society on dry pine forest and clearing) (constancy class II), but 12 species were very rare – constancy class I.

In the control sample plots on dry sand soil 39 species of herbaceous plants, bryophytes and lichens were found. The number of species per zone I, II, III and IV was 5 – 8 (on average 6.7), 2 – 7 (on average 5.3), 6 – 9 (on average 7.5) and 5 – 6 (on average 5.5), respectively. The average number in all zones was 6.2 species. Very frequently occurring species (constancy class IV) were *Dicranum polysetum* Sw., *Pleurozium schreberi* (Brid.) Mitt. (both characteristic of coniferous forest) and *Calluna vulgaris*, frequently occurring species (constancy class III) were *Vaccinium vitis-idaea*, *Vaccinium myrtillus* L. (characteristic of relative dry clearings and burnings of pine forest) and *Polytrichum juniperinum*. The rest of species were relative rare (constancy classes II and I).

The number of species in all our sample plots was lesser than on average stands in *Vacciniosa* and *Myrtillosa* (it varies from 80 to 100 species) (Liepa *et* *al*., 2014). Besides many plants – successful colonizers dominated in our study without important role into early succession (Hart & Chen, 2006). Most often species presented in the area after fire occurred as a result of local colonization from seeds and propagules located in the humus layer (Granstrom, 1982; Rydgren & Hestmark, 1997). Furthermore, in Canadian boreal forests De Grandpr´e *et al.* (1993) found that up to 70% of all species that occurred after fire were present before fire but species dominant before were not usually abundant following fire (Peltzer *et al*., 2000). But domination of typical tolerant bryophytes and brush, as well as a greater number of bryophytes and lichen species, in general, was indicative that in the control sample plots (without influence of fire) composition of species was more similar to the structure of species before disturbance (Hart & Chen, 2006).

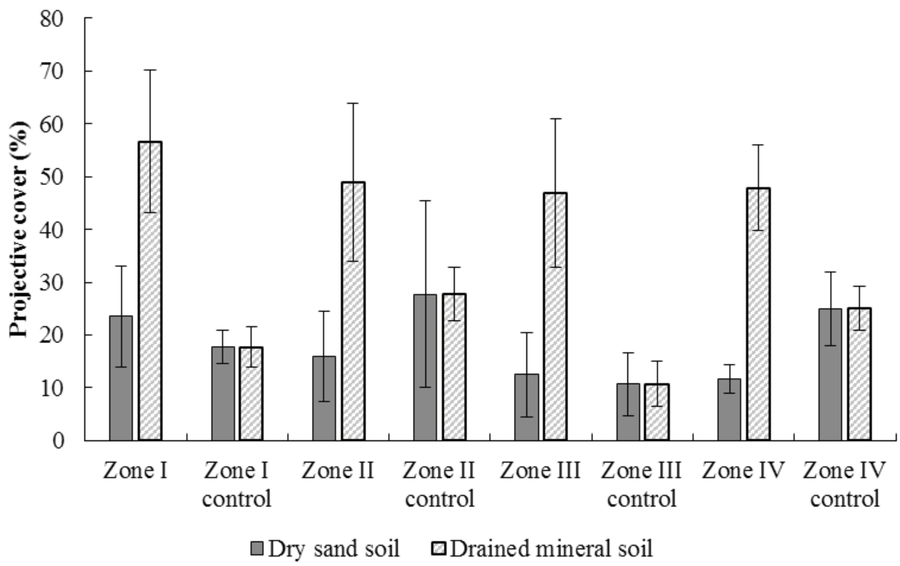
In burned sample plots on drained mineral soil 48 species of herbaceous plants, bryophytes and lichens were detected. Their number per zones I, II, III and IV was 3 – 11 (on average 4.5), 3 – 13 (on average 6.9), 4 – 17 (on average 6.8) and 4 – 11 (on average 6.8) species, respectively. The average number in all zones was 7.1 species. Very frequently occurring species (constancy class IV) were *Vaccinium vitis-idaea* un *Calluna vulgaris*, frequently occurring species (constancy class III) were *Molinia caerulea* (L.) Moench (characteristic of clearings of drained forests on soil with high humidity), *Pleurozium schreberi* and *Vaccinium myrtillus*. The remaining species were detected relatively seldom (constancy classes II and I).

In the control sample plots on drained mineral soil 94 herbaceous plants, bryophytes and lichens were detected. Their number per zone I, II, III and IV was 3 – 11 (on average 8.2), 6 – 19 (on average 13), 8 – 19 (on average 11.2) and 3 – 17 (on average 8.9) species, respectively. The average number in all zones was 10.3 species. Very frequently occurring species (constancy class IV) were *Molinia caerulea* and *Vaccinium myrtillus*. Frequently detected were also *Pleurozium schreberi, Rubus idaeus* (charasteristic of clearings on nitrogen-rich soil), *Polytrichum juniperinum* and *Vaccinium vitis-idaea* (constancy class III). The rest 87 species were found very rarely (constancy class I).

The number of species in all our sample plots was close to average stands in *Vacciniosa* mel. and *Myrtillosa* mel. (it varies from 50 to 110 species) (Liepa *et al*., 2014), that indicated a variety of different conditions and ecological niches in drained forest. In our sample plots dominated tolerant species – bushes, herbaceous plants and bryophytes.

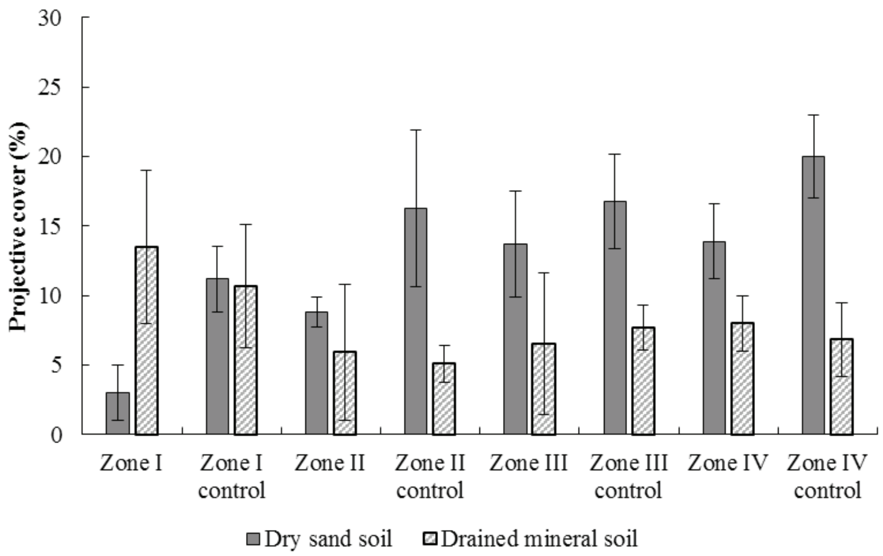
The projective cover of herbaceous plants and shrub layer (E1) in burned areas on sand soil was: 23.5% in zone I, 16% in zone II, 12.5% in zone III and 11.6% in zone IV (Fig. 1). Projective cover of bryophytes and lichen layer (E0) was 3%, 8.8%, 13.7% and 13.9%, respectively (Fig. 2). The projective cover of layer E1 was decreasing but projective cover of layer E0 – increasing by increasing distance from the nearest forest stand edge.

The projective cover of layer E1 in control on sand soil in zones I, II, III and IV was 17.7%, 27.7%, 10.8%, 25%, respectively, and projective cover of layer E0 was 11.2%, 16.3%, 16.8% and 20%, respectively. In



zone I: 25 – 50 m, zone II: 51 – 75 m, zone III: 76 – 100 m, zone IV: over 100 m

Figure 1. The average projective cover of plants and shrub layer (E1) on dry sand and drained mineral soil (± SE) depending on distance from the edge of burned or clearcut (control) area (zone).



zone I: 25 – 50 m, zone II: 51 – 75 m, zone III: 76 – 100 m, zone IV: over 100 m

Figure 2. The average projective cover of bryophytes and lichen layer (E0) on dry sand and drained mineral soil (± SE) depending on distance from the edge of burned or clearcut (control) area (zone).

the control sample plots the projective cover of layer E0 was larger than in burning sample plots, and its projective cover was increasing by increasing distance from nearest forest stands edge. But projective cover of layer E1 was least affected by distance from nearest forest stands edge, the smallest value was in zone III but the greatest in zone IV.

Projective cover of layer E1 in burnings on drained mineral soil in zones I, II, III and IV was 56.6%, 49%, 46.9% and 47.3%, respectively. Projective cover of layer E0 was 13.5%, 15%, 14% and 8%, respectively. The largest projective cover of layer E1 was in zone I and it decreased by distance from the forest edge. The smallest projective cover of layer E0 was in zone IV, in other 3 zones it was similar.

Projective cover of layer E1 in the control plots on drained mineral soil was smaller than in burnings and was quite similar in all zones: 40.2% in zone I, 37.9% in zone II, 35% in zone III and 41% in zone IV. Projective cover of layer E0 was 10.7%, 5.1%, 7.7% and 6.8%, respectively. In control sample plots, the projective cover of layer E0 was smaller than in burning sample plots, the largest value was in zone I close to the forest edge.

Dispersal of seeds or spores in burnings on sand soil in zone 1 was predominantly done by birds (36.7%), to a lesser extent by wind (26.7%) and autochorous (self-dispersal) (26.7%). Only zone I plants were dispersed by ants, determined by closeness of forest. In zones II, III and IV plants mostly were dispersed by wind (61.7%, 57.8% and 63.8%, respectively), but also important was autochorous (21.7%, 30.6% and 17.3%) and dispersal by birds (16.7%, 11.7% and 19.0%, respectively). In the control plot on sand soil in all zones dominated dispersal by birds (53.3%, 58.3%, 41.7% and 33.24% in zones I, II, III and IV) and wind (44.2%, 41.7%, 50% and 11.3%, respectively). Plants dispersed by ants occurred only close to the forest edge, in zone I. Plants dispersed by water were detected in zone 4, which can be explained by increasing moisture more than 100 meters away from the forest edge.

In burnings on drained mineral soil dominated dispersal by wind (57.1%, 42.9%, 40.1% and 31.1%) and birds (40.2%, 41.8%, 32.2% and 48.5%). Plants dispersed by ants and autochorous plants occurred unequally in all zones, and dispersal by water was not notable. In the control on drained mineral soil the dispersal of seeds or spores was determined primarily by birds (46.9%, 32.5%, 35.9% and 44.4% in zones I, II, III and IV), to lesser extent by wind (27.0%, 22.3%, 36.5% and 34.9%, respectively) and also plants with autochorous dispersal type were present (14.9%, 25.8%, 8.7% un 11.3%). Dispersal by water in control was more important than in burnings (9.8%, 10.0%, 7.9% and 5.6%), which can be explained by greater moisture than in burnings.

In all objects were detected species with different life forms – hemicryptophytes, chamaephytes, geophytes and therophytes, but its distribution in zones differed (Raunkiaer, 1934). Therophytes had the lesser proportion in all zones.

In burnings on dry sand soil in all zones the majority of species were geophytes (average proportion 42.5%), but chamaephytes and hemicryptophytes were to a lesser extent (30% and

Table 1

Average Ellenberg's values (± SE) in different distances from the edge (zone) of affected – clearcut (control) or burned – area

Zone*	Moisture in dry sand soil	Moisture in drained mineral soil	pH in dry sand soil	pH in drained mineral soil	Nitrate in dry sand soil	Nitrate in drained mineral soil
Zone I	5.6 ± 0.12	6.1 ± 0.17	2.0 ± 0.39	2.0 ± 0.14	1.2 ± 0.03	1.8 ± 0.09
Zone I, control	5.6 ± 0.17	7.1 ± 0.38	2.2 ± 0.18	3.2 ± 0.44	1.7 ± 0.13	2.7 ± 0.36
Zone II	5.6 ± 0.2	5.9 ± 0.16	2.3 ± 0.58	2.4 ± 0.25	2.2 ± 0.7	2.2 ± 0.28
Zone II, control	5.4 ± 0.13	6.6 ± 0.14	2.0 ± 0.29	4.2 ± 0.28	1.8 ± 0.28	3.3 ± 0.19
Zone III	5.2 ± 0.26	6.0 ± 0.19	3.2 ± 0.8	2.5 ± 0.27	1.8 ± 0.23	2.2 ± 0.25
Zone III, control	5.3 ± 0.09	6.4 ± 0.25	2.4 ± 0.25	3.1 ± 0.43	1.9 ± 0.2	2.5 ± 0.45
Zone IV	5.6 ± 0.07	5.6 ± 0.13	2.3 ± 0.2	2.1 ± 0.13	1.8 ± 0.13	1.6 ± 0.14
Zone IV, control	5.6 ± 0.04	6.7 ± 0.19	2.5 ± 0.01	4.0 ± 0.35	1.6 ± 0.02	2.8 ± 0.25

*zone I: distance 25 – 50 m, zone II: 51 – 75 m, zone III: 76 – 100 m, zone IV: over 100 m from the nearest edge of the affected area

24.3%, respectively). But in the control on dry sand soil hemicryptophytes dominated (average proporton 57.5%), chamaephytes and geophytes to a lesser extent (26.8% and 15%, respectively). In burnings on drained mineral soil in all zones most represented were hemicryptophytes (average proportion 61.5%), but chamaephytes and geophytes were less common (average proportion 20.8% and 11.8%, respectively). In control also dominated hemicryptophytes (56.3%), less represented were geophytes (27.5%) and chamaephytes (15.6%). Analysis of plant moisture requirement showed that in burned areas on dry sand soil only mezophytes were detected (100%). In control on dry sand soil most species in zones I to III were mezophytes (average proportion 97%), the rest were mezohigrophytes, but in zone IV higrophytes had a notable proportion (45.3) that indicated moist soil. The distribution differs in burned areas on drained mineral soil: average proportion of mezophytes was only 55.6%. The proportion of higrophytes increased from 0% to 2.2% and proportion of mezohigrophytes decreased from 15% to 1% by increasing distance from the nearest forest edge. In control, the tendency was the same as in burned areas: mezophytes were 87.2%, the proportion of mezohigrophytes decreased from 15.1% to 1.2% and proportion of higrophytes increased from 3.0% to 6.6%.

Ellenberg's indicator values are arranged in Table 1. Those values show that average moist, acid to very acid, nitrogen-poor soils dominated both in the burned and control areas on dry sand soil. In sample plots on drained mineral soils moist, acid to average acid, nitrogen-poor soils dominated. There were no significant differences between burned and clearcut areas in respect to Ellenberg's indicator values on both soil types.

Conclusions

1. The total number of ground vegetation species both in forest types on dry sand soil (*Vaccinosa* and *Myrtillosa*) as well as in forest types on drained mineral soil (*Vaccinosa* mel. and *Myrtillosa* mel.) in burned areas was twice smaller than in clearcut areas. There was not a clear trend in changes of the number of ground vegetation species in relation to distance from the edge of the affected area in any of the analysed sites after fire or after clearcut.
2. Projective cover of herbaceous plant and shrub layer was almost twice higher in sites on richer (drained mineral) soils in comparison to sites on poorer (dry sand) soils; difference in projective cover of bryophyte and lichen layer was not so pronounced. There was no clear tendency in changes of projective cover in relation to distance from the stand edge in any of the assessed areas except in burned sites on dry sand soil, where herbaceous plant and shrub cover was decreasing (from 23.5% to 11.6%) and bryophyte and lichen cover – increasing (from 3% to 13.9%) with an increasing distance from the edge of the area.
3. In forest types on dry sand soil in burned areas only mezophytes were detected, but in clearcut

areas up to 100 m from the edge – mezophytes (average proportion 97%), but further – also a large proportion (45%) of higrophytes, indicating moist soil. In forest types on dry sand soil in burned and clearcut areas the proportion of higrophytes increased (from 0% to 2.2% and from 3.0% to 6.6%, respectively), but proportion of mezohigrophytes decreased (from 15% to 1%) with increasing distance from the nearest forest edge. No trend in Ellenberg's values for soil moisture in relation to distance from the nearest stand edge was noted.

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