Bachelor thesis

Wildfire decadal and short-term effects on beetle community composition in a boreal, old-growth forest

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Abstract

Fire suppression and forest management implemented over the last 150 years have had profound effects on biodiversity in Fennoscandia. Albeit prescriptive burnings have become a more frequently used tool for conservation purposes, little is known about their qualitative, long-term differences from natural fires.

I studied the short- and long-term effects of a severe wildfire in Northern Sweden, comparing a burned and an unburned area one, two and twelve years after the fire by using data previously collected by the Swedish University of Agricultural Sciences. My analyses show that the beetle species composition changed after the wildfire and differences in abundance and richness could be seen between the burnt and the unburnt area. The proportional abundance of fire-favored species was higher in the burned forest each year, while the proportional abundance of strongly fire-favored species differed between areas during the first two years. Total beetle and saproxylic abundance were larger in the burned area during the first two years, as well as the index of diversity. In contrast to previous studies examining the impact of prescriptive fires, no differences in red-listed species abundance or richness could be observed. This report emphasizes that fire-severity is likely the major factor determining the longevity of legacy materials such as deadwood and that conservation attempts should be directed to both burned and unburned habitats in a dynamic approach.

Keywords: Conservation, Fire ecology, Disturbance, Biodiversity, Boreal forest, Saproxylic.

1. Introduction

Fire as a disturbance has been a recurring event in boreal ecosystems throughout history, altering available resources and reshaping habitats on both temporal and spatial scales (Koltz et al., 2018; Wikars, 1997). Together with windstorms and insect outbreaks, wildfires is the most severe natural, cyclic disturbance, widely considered to maintain long-term stability and diversity in ecosystems (McCullough et al., 1998; Swanson et al., 2011). These large-scale events change the dynamics of the landscape and cause a high structural and vegetational damage (Swanson et al., 2011). Within a wildfire, different areas suffer different levels of fire intensity and therefore shifting rates of mortality (Swanson et al., 2011), creating different levels of tree retention and leaving legacy materials that make for variability in biotic and abiotic factors. These biological legacies unlock niches and create heterogeneous habitats for survivors, opportunists and early successionists to settle in (Swanson et al., 2011; Wikars, 1997).

Many animal species are adapted to these changing environments, possessing morphological characteristics, behavioral strategies and life histories for both surviving and exploiting these new conditions (Koltz et al., 2018; Wikars; 1997). These specializations suggest that there has been an immense evolutionary pressure on organisms to adapt to fire (Granström, 2001). For instance, over 379 species of the order *Coleoptera* (beetles) in Swedish boreal forests are associated – directly or indirectly – with the presence of fire (Wikars, 2006). Considering that pyrophilia in insects has evolved independently several times in a large variety of taxa, it indicates that fire has had a strong evolutionary role through history (Wikars, 1997).

From a historical perspective, forests in northern Sweden have been used for reindeer husbandry by the indigenous Sami population, where burned land have been of great importance for winter grazing (Cogos et al., 2019). Recent studies conducted in Northern Sweden suggest that wildfires have been rare or absent in this area since the introduction of modern fire suppression and large natural fires in productive forests in Fennoscandia have become infrequent and smaller in size (Cogos et al., 2019; Granström, 2001). An area of approximately 1% of all productive forests in Sweden burned annually 150 years ago, a rate that has declined to proximately 0.01% in the year 2000 (Granström, 2001). Suppression arrangements such as removal of dead trees and reduced production of deadwood and other fire-legacy materials, in combination with modern forestry techniques, contribute to the loss of key elements for many species (Östlund, 2004). The disappearance of burned terrain and components associated with fire has caused many pyrophilic and red-listed species to decrease in numbers, whereas some have been driven towards extinction (Wikars, 1997).

During the 13th to 18th centuries, Swedish forests were heavily exploited, supporting an increasingly growing timber industry which left large areas deforested (The Royal Swedish Academy of Agriculture and Forestry, 2015). When the Swedish parliament passed the Forestry Act in the early twentieth century, a regeneration process was initiated - marking the beginning of what is known as the modern Swedish forestry model (The Royal Swedish Academy of Agriculture and Forestry, 2015). Although new trees were planted, from this time until the middle of 1990s, old-growth forests diminished at a fast rate (Naturvårdsverket, 2020). About 70 years ago, new timbering methods such as clear-cutting were introduced, pretending to mimic large-scale natural disturbances but resulted in an even-aged stand management as well as a limitation of early successional stages through stimulated tree plantation (Lundmark et al., 2013; The Royal Swedish Academy of Agriculture and Forestry, 2015; Swanson et al., 2011). Prior to clear-cutting, managed forests still carried high ecological values, with the decline in biodiversity most likely starting after 1950 (Östlund, 2004). The implementation of these fundamental changes has altered ecosystems and generated a more homogeneous landscape in Swedish productive forests which today comprise 57% of the total national land use (The Royal Swedish Academy of Agriculture and Forestry, 2015; Ehnström, 2017; Östlund, 2004).

Beetles are a highly diverse insect group including red-listed, pyrophilic and saproxylic species with an extensively studied life-history. Many beetle species possess rapid reproduction, short lifespans and respond correspondingly to habitat change, which give indications of the current state of ecosystems (Ehnström, 2013; Ehnström, 2002). Together with high dispersal abilities and specific habitat demands, beetles are a suitable group for monitoring changes in biodiversity over time (Ehnström, 2002).

A majority (54%) of red-listed beetle species found in Sweden are bound to forests (Artdatabanken, 2015). Many of these are associated with legacy materials and resources such as decaying wood and enhanced light exposure along with other new habitat conditions which develop after a wildfire (Pausas et al., 2018; Swanson et al, 2011). Other rare species are closely linked to forests older than 140 years that show similar heterogeneity to those of naturally burned forests, with high levels of biodegradable materials favoring specialist species rather than generalists (Naturvårdsverket, 2020). Old-growth forests have increased since 1994, with an area equivalent to 12 percent of the total national forested area (Swedish University of Agricultural Sciences, 2018). One of the main threats to red-listed species in Swedish forests is the absence of decaying wood and habitat destruction (Berg et al., 1995). An estimated 3000-4000 species in Sweden are dependent on deadwood,instan and this is probably the most important component for maintaining biodiversity in managed forests (Ehnström, 2017). The decline of species has been correlated with habitat degradation as a result of the transformation seen in forests during the last seventy years, with recent studies suggesting that the degeneration of unburned habitat is also linked with the disappearance of pyrophilous species (Saint-Germain et al., 2008; Östlund, 2004). In absence of fire, the unburned habitat works as a refuge for pyrophilous species making it important for conserving fire-favored species (Saint-Germain et al., 2008; Östlund, 2004). These two factors, the loss and degeneration of the unburned habitat in combination with dwindling natural fires and disturbances are most likely responsible for the diminishing numbers of many red-listed and pyrophilous species.

Prescriptive fire is presently included as a part of the FSC certification and states that managers of major holdings shall take all reasonable measures to burn an extent equivalent to at least 5 % of the regeneration area on dry and mesic forest land over a five-year period (FSC, 2010). This management has shown positive effects on biodiversity, for example experiments in Finland have shown short-term, positive effects on saproxylic beetle diversity when combining prescriptive fire with tree retention (Heikkala et al., 2016). Another study performed in southern Finland showed that the reintroduction of fire in boreal forests can help threatened species to recover (Kouki et al., 2012). Although prescriptive fire has become a more frequently used tool for managing forests for conservation purposes, the qualitative differences compared with natural fire is not studied. Fire regime components such as severity, intensity and seasonality may cause a complex disturbance which could be hard to imitate with prescriptive fires. In the absence of large-scale natural fires in Fennoscandia during the 20th and 21st-centuries, there is a need for research on how these events impact boreal ecosystems and their response to post-fire conditions.

In this case study, I aimed to evaluate the decadal and short-term effects that natural wildfire may exert on beetle communities in an old-growth boreal forest in northern Sweden. My main purpose was to investigate how fire affects beetle abundance, richness and diversity in different relevant groups one, two and twelve years after the fire and determine whether different groups benefited from the fire and what impact it had on local biodiversity.

2. Material and method

2.1 Study area and design

The studied area is located approximately 66°9´N, 20°49´E in Norrbotten County in northern Sweden, 9 km northwest of the village Bodträskfors. The area is situated in the middle-boreal vegetation zone with pine-dominated, old-growth, coniferous forest ranging from 140 to 170 years of age.

The wildfire started on August 11th, 2006 and continued for 28 days, burning an area of approximately 1900 ha (Bodens kommun, 2008). The fire was severe, leaving patches of surviving pines and stands in different levels of retention. In some areas, the fire burned down to 50 cm into the ground layer, which resulted in a 100% mortality rate of ground vegetation (Johansson et al., 2011). An area of 250 ha was set aside for research and was left unsalvaged, leaving a high amount of deadwood.

In this area, beetles were trapped and collected in 2007 and 2008 by Sweden's University of Agricultural Sciences in Umeå. The trapping period spanned from 31st May to 21st September during 2007 to 2008. In total, 12 sites were sampled - six within the wildfire area and six sites in the unburned forest. Three traps were settled in each sample site, which is referred to as a block. In total 36 traps were settled out each year.

In 2018 another sampling was conducted by SLU, this time with ten single-traps in the unburned sites and ten in the burned area. The trapping period was from 31st May to 4th September. Traps were set up along a transect between two randomly chosen points with a length of approximately 1.6 km and a distance of 140-300 meters apart. I used the data from these previous samplings conducted by SLU. The whole material was used.

Both the unburned and burned areas are situated on two rocky slopes, stretching from 200-280 meters above sea level with moist sections at lower elevation and drier further up. The unburned area is a managed forest consisting of 60% Scots pine (*Pinus sylvestris*), 25% Norway spruce (*Picea abies*) and 15% mixed deciduous trees. The field layer is dwarf-shrub and lichen dominated (94%) with a moderate amount of deadwood. In 2019, one year after the last sampling - early pioneering, deciduous trees like birch and aspen dominated the field layer while many pines were in different levels of retention.

The sites in the unburned area was chosen to resemble the sites in the burned site before the wildfire with regard to stand-age and density, topography, moisture levels, ground layer and vegetation as well as tree-species composition. The unburned area was placed 3 km west of the burned area. Both burned and unburned sites are representative of forests in the area.

Note that this case study only includes one burned and unburned area and therefore, the replicates (sampling sites) within burned and unburned forests are not spatially independent. With that said, the sampling took place over a large area and measurements were taken to make the plots representative.

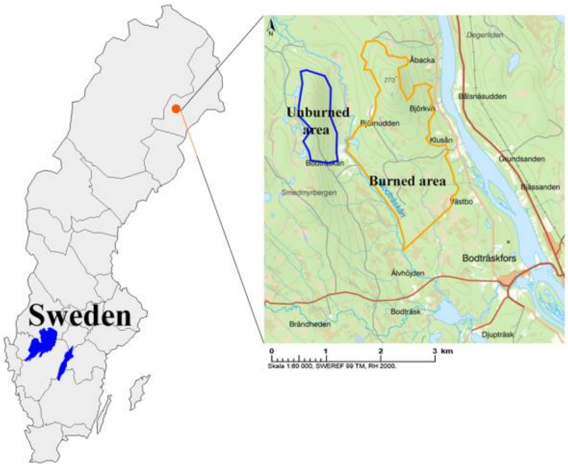

Fig. 1. Map over the geographical location of the wildfire. Orange lines represent the burned area and blue unburned area.

2.2 Sampling of beetles

Each year, beetles had been collected using IBL2 flight-interception traps (CHEMIPAN, Warszawa, Poland). In 2007 and 2008, three traps were placed in each of the 12 sites. Traps were hung on strings between trees in a triangle-shape, 50 m apart from each other, covering all flight directions. In 2018, only single-traps were used.

The IBL2-trap consists of a transparent plastic pane connected by three plastic arms. This creates a triangle-shaped window with an area of 0.35 m^2. A funnel is located under the panes with a mechanism to divert rainwater and is fed into a 7.25 dm^3 plastic container in the bottom. This container was filled to a third with 80% propylene glycol to preserve the collected beetles and a small amount of detergent to reduce surface tension.

2.3 Species characterization and analyses

Beetles had been counted and identified to species level, with the exception of eight species that had been classified to family level. These eight species were not categorized to any specific group. The identifications were done by expert, external taxonomists. Beetle species had been divided into groups; saproxylics, categorized into facultative, obligatory and non-saproxylics by SLU in accordance to their database (Dahlberg & Stokland 2004). Red-list status (Westling, 2015) and pyrophilous species were categorized as fire-favored, fire dependent or strongly fire-favored (Wikars, 2006). Because of low sampling numbers in the fire dependent category, these have been included in the strongly fire-favored category. Taxonomy and nomenclature of the beetles follow Dyntaxa (2019). Some species are classified to more than one group and can therefore be part of more than one analysis. To complement the category assignment from 2018 which was partly incomplete, the online resource Artfakta (Dyntaxa 2019) was used, with the overlook of experts at SLU.

2.4 Data analysis

I analyzed species richness and abundance of all groups and categories in the burned- and unburned forests using independent t-tests for the data that met requirements of parametric tests. For the data that did not meet assumptions, I used Mann–Whitney U-tests. All tests were performed using SPSS 21.0 software (IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp).

Indicator indexes were calculated by dividing the abundance and species richness of a group or category by the total amount of beetles found in the same trap. Indexes were calculated for fire-favored, strongly fire-favored and red-listed species. Since indicator indexes show a proportion bound between 0 and 1, non-parametric tests were used for these analyses.

To visualize differences in beetle

assemblages between years and sample sites I used a non-metric multidimensional scaling (NMDS, function 'metaMDS') in the "vegan" package in the statistical software R (R-Core-Team 2015). Indexes were calculated for Shannon's diversity index (function 'diversity') using the "vegan" package in R while performing a one-way analysis of variance (ANOVA) to check for significant differences in Shannon's diversity between the burned and unburned sites.

3. Results

3.1 Species richness and abundance

From three years of trapping, the data-set contained records of 16751 beetles specimens from 545 different species. Of these species, 99% were categorized in accordance with their dependence on deadwood (obligate, facultative and non saproxylics) and 28% how they benefit from burnings (fire-favored and strongly fire-favored/fire-dependent).

During the first and second year of sampling, abundance was significantly higher in the burned forest compared with the unburned (Fig. 2. year 1: F = 3.372, p-value = 0,007, year 2: F = 3.836, p-value = 0.003). Twelve years after the fire, species richness was nearly significantly higher in the unburned forest (Fig. 2. year 12: p = 0,052).

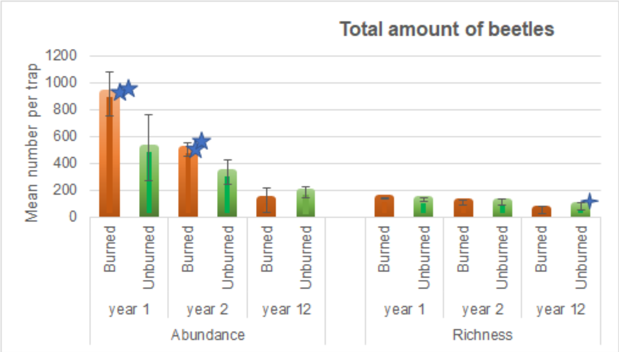

Fig. 2. Comparing burned and unburned sites for all beetles in different years after the wildfire. Year 1 and 2, n=6, year 12 n=12. Stars indicate significant differences * = p<0.05, ** = p<0.01, *** = p<0.001 and + = p<0.055. Error bars represent the standard deviation of means.

3.2 Diversity index

Shannon's diversity index was higher in the burned area one and two years after the wildfire (Fig. 3. year 1 F = 8.484, p-value = 0.0155, year 2: F = 0.0266, p-value = 0.0266) and nearly significant (Fig 3. year 12: F = 4.24, p-value = 0.054) in the unburned area twelve years post-fire.

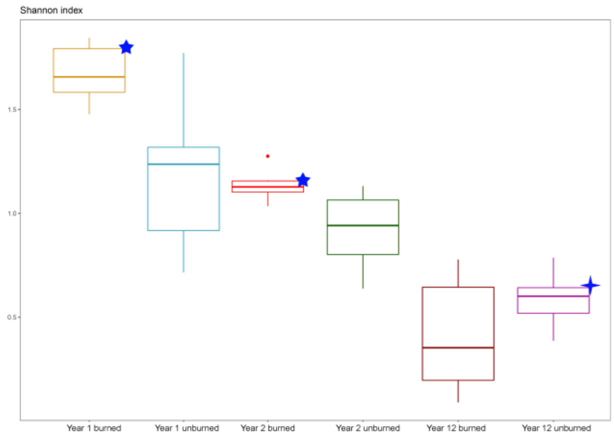

Fig. 3. Diversity index comparing the burned and unburned sites three years after the wildfire for all species. Year 1 and 2, n=6, year 12 n=12. Stars indicate significant differences * = p<0.05, ** = p<0.01, *** = p<0.001 and + = p<0.055.

3.3 Community composition

The first year after the wildfire, communities in the burned and unburned forests were clearly different as suggested by their separation in the multivariate analysis (Fig. 4a). While community composition did not change in the unburned area the first two years after the fire – the composition in the burned area started to diverge after the first year to form a new and different community. Twelve years after the fire, the burned and unburned forests were basically identical in their community composition (Fig. 4b).

3.4 Pyrophilous species

The data-set contained records of 7435 pyrophilous beetles from 153 species. The proportion of fire-favored specimens was higher in burned areas during all years, (Fig. 5a. year 1: U = 0, Z = -2.882, p-value = 0.002,

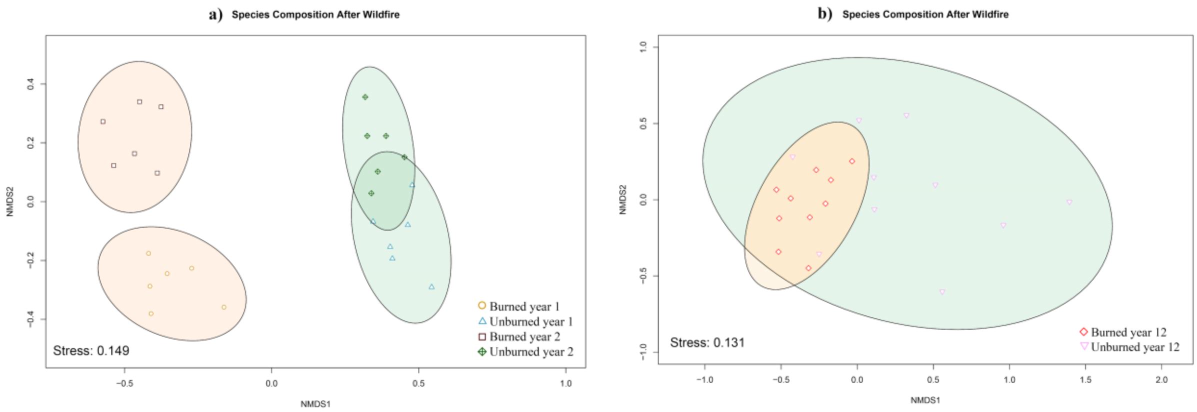

Fig. 4. Two-dimensional visualization of the NMDS ordination for the whole beetle community the first two years (a) and 12 years (b) after the wildfire. Each symbol represents the assemblage in one trap. The ellipse was drawn based on the standard deviation of means within each year.

year 2: U = 0, Z = -2.882, p-value = 0.002, and year 12: U = 16, Z = -2.570, p-value = 0,009) while the proportion of strongly fire-favored species in the burned forest was higher one and two years after the fire (Fig. 5b. year 1: U = 0, Z = -2,882, p-value = 0,002, year 2: U = 1, Z = - 2,741, p-value = 0,004). During the first year, the proportion of strongly fire-favored specimens was higher in burned areas, even though the species *Henoticus serratus* comprised 89.6% of the category (Fig. 5b. year 1: U = 0, Z = -2,882, p-value = 0.002). No difference in abundance or species richness could be seen between the burned and unburned forests for any group twelve years post-fire.

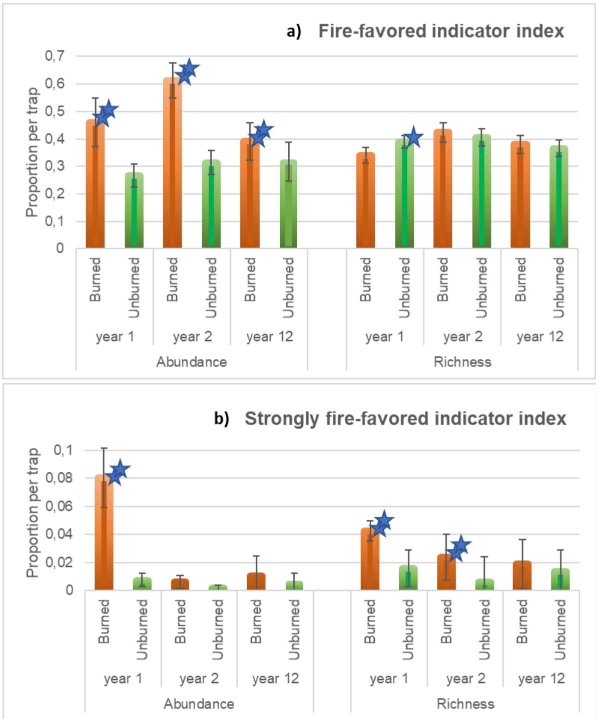

Fig. 5. Indicator index for pyrophilous categories comparing burned and unburned sites in different years after the wildfire. Year 1 and 2, n=6, year 12 n=12. Stars indicate significant differences * = p<0.05, ** = p<0.01, *** = p<0.001. Error bars represent the standard deviation of means.

3.5 Saproxylics

The most abundant and species-rich category was obligatory saproxylic beetles with 246 species (45% of total species) and 11761 specimens trapped. Together, facultative and obligate saproxylics (referred to as saproxylics) constitute 70% of the entire beetle assemblage. The abundance of saproxylics was significantly higher in the burned forest the first two years after the fire (Fig. 6. year 1: F = 3.402, p-value = 0.007, year 2: F = 5.06, p-value = <0,001). Twelve years post-fire saproxylics differed significantly in species richness, which was greater in the unburned forest (Fig. 6. year 12: p-value = 0.043).

3.6 Red-listed species

In total, 207 red listed beetles were trapped from 32 different species. 82% of these were obligate saproxylics. 28 are considered near threatened (NT) and 4 vulnerable (VU) (Westling, 2015). Red-listed species showed no significant proportional differences between forests, except for a significantly higher

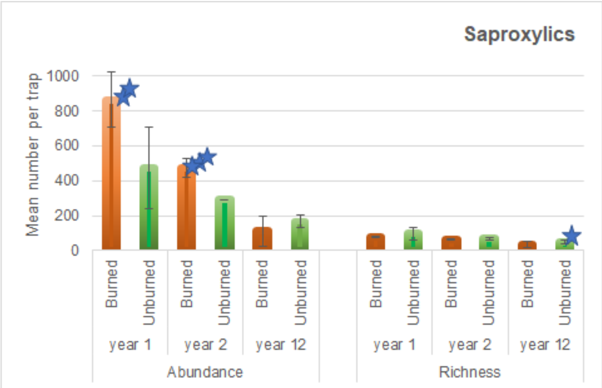

Fig. 6. Comparing burned and unburned sites for the group saproxylics in different years after the wildfire. Year 1 and 2, n=6, year 12 n=12. Stars indicate significant differences * = p<0.05, ** = p<0.01, *** = p<0.001. Error bars represent the standard deviation of means.

abundance in the unburned forest 2 years post-fire (p-value = 0,015).

4. Discussion

Previous studies performed in boreal forests in Fennoscandia have focused on short-term responses to fire, showing temporal shifts in beetle assemblages (Heikkala et al., 2016; Hekkala et al, 2013; Hjältén, 2017; Hyvärinen et al., 2005). One study in Finland showed a drastic change in beetle composition comparing burned and unburned plots right after prescriptive burning (Hyvärinen et al., 2005). Another experimental study showed an increase in pyrophilic species on the first post-fire year, but this effect disappeared 10 years later (Heikkala et al., 2016).

My results are consistent with previous studies, showing that community composition changes on the first two years after the wildfire which is illustrated by the differences in total abundance (fig. 1), diversity (fig. 2) and beetle community composition (fig. 3a). This pattern indicates short-term and annually declining positive effects on local beetle diversity after a natural fire. Twelve years post-fire, little differences in beetle community composition could be observed between burned and unburned areas (fig. 3b).

The differences in proportion among strongly fire-favored species in the burned forest, indicates that even after 150 years of successful fire suppression - these beetles still occur in the region, although in small numbers. Similar to Heikkala et al. (2016), strongly fire-favored species benefit from short-term effects of fire (fig. 4a). The proportion of fire favored beetles in my study was higher every post-fire year and it was the only category that was more abundant in the burned area twelve years after fire (fig. 4b). This pattern implies that at least the latter group enjoys long-lasting benefits from disturbances such as wildfire.

The study of Hekkala et al. (2014) showed an increase in saproxylic species richness one and two years after being treated with prescriptive fire while five years later returning to pre-treatment levels. Similarly, another study showed that from one to ten years after prescribed burnings, saproxylic species richness decreased below pre-treatment levels in burned, harvested stands while richness in burned, unharvested stands remained high (Heikkala et al., 2016). In the latter study, albeit with very low tree mortality, the unharvested control was intended to replicate natural fire. I could observe no difference in saproxylic species richness among treatments in my results, although abundance was higher in burned sites during the first two years (fig. 5). A possible explanation is that the immense severity of this wildfire compared with prescriptive fire has a negative impact on the quality of the deadwood debris, as the time for decomposition is shortened (Heikkala et al., 2016; Hekkala et al, 2013; Johansson et al., 2011).

Prescriptive fire has been proved to have positive effects on red-listed and rare saproxylic species (Heikkala et al., 2016; Hekkala et al, 2013; Hyvärinen et al., 2005). One study examined a 30-year-old boreal forest treated with prescribed fire and saw an increase in the number of red-listed species over two years (Hekkala et al, 2013). In the study of Heikkala et al. (2016), harvested and unharvested stands in different levels of retention were monitored one year before, one year after and ten years after being treated with prescription fire. In harvested stands, red-listed species followed the same pattern as saproxylics in general, with a positive short-term response, followed by a decline back to pre-treatment levels a decade later. In the study, Heikkala et al., (2016) suggests that a constant supply of deadwood in different stages of decay is more important for red-listed species than the legacies created by fire. This suggestion is supported by my findings since no difference in species richness for red-listed species was observed between burned and unburned areas over twelve years. It is possible that given the reproductive success among saproxylics in my study during the first two years, red-listed species could capitalize on the same resources if they were present in the region.

A majority of red-listed species were found by Jonsell et al. (1998) in the stages between 5-15 years of wood decay, with the lowest amount found under 2 years, which could explain the low amount of red-listed species in my study. The scarcity of red-listed species may also indicate that many species were not present in the region, most likely due to a lack of proximity to source habitats in a landscape dominated by productive forests (Heikkala et al., 2016; Hyvärinen et al., 2005; Johansson et al., 2011). An increase of early-successional forest ecosystems such as those ravaged by wildfires on a landscape scale could be a way of linking pyrophilous and red-listed species to favorable habitats, as well as increasing local biodiversity.

5. Conclusion

Since this study was performed in a single burned area, the results are only representative for these sites, nonetheless improving our understanding of natural fire and its effect on old-growth forests in boreal, managed ecosystems.

The unburned forest seems to maintain species richness (fig. 1) and diversity (fig. 3) better than burned sites, twelve years after the fire. This pattern indicates that the unburned habitat is very important for preserving biodiversity in productive forests (Saint-Germain et al., 2008), which demands conservation efforts and a continuous input of deadwood in both burned and unburned habitats (Heikkala et al., 2016; Hjältén et al., 2017). While prescriptive fire is positive for overall biodiversity, it might not be a technique for conserving red-listed species, given the absence of source habitats.

While it is difficult to estimate the qualitative differences between wildfire and prescriptive fire, severity is arguably the biggest factor separating them. Little is still known about wildfire effects in productive forests and more long-term studies would be needed in order to understand natural fire regimes in boreal, managed landscapes.

Acknowledgements

I thank the Swedish University of Agricultural Sciences for providing the data necessary to perform this study and my supervisors Pål Axel Olsson and Therese Löfroth for their expertise. I am grateful for all the help and guidance from Emelie Fredriksson and Antonio Rodriguez with their excellent technical and linguistic advice. A special thanks to Andreas Nord for his unyielding support throughout this project and to all who have read and given feedback on the report.

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