Forest management for multiple goals: decadal effects of ecological restoration on insect diversity and regeneration in pine forests

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Summary

Sustainable forest management includes the fulfilment of environmental objectives and certification requirements and mean that the forest need to be managed for multiple goals. More varied forest management options are also requested by private forest owners. The fulfilment of some goals, including goals for biodiversity conservation, requires restoration of important stand structures, such as dead wood, and reintroduction of natural disturbance regimes, such as fire. However, as prescribed burnings are risky and labour demanding there is large interest to develop alternative restoration methods that has the potential to benefit fire associated species. Old pine forests harbor many specialized species but our knowledge regarding effects of ecological restoration other than burning in these stands is very limited. In this project we revisited of an already established large scale field experiment in Effaråsen, Dalarna that was initiated in 2012 to evaluate how green tree retention, dead wood creation and prescribed burning can improve conservation values in pine forests but also maintain sustained yield. To assess biodiversity effects we focused on saproxylic insects because they respond fast to changes in their environment and they are an important part of biodiversity in pine forests. In addition, we sampled insects in emergence traps to evaluate the importance of the created substrates for biodiversity conservation and conducted surveys of emergence holes that were subjected to a base line inventory in 2014 meaning that insects now have had 6 years to respond to the treatments. To pin point the rare pine associated beetle *Tragosoma depsarium* used newly developed methods with species specific pheromones to estimate habitat use and dispersal among stands. We also estimated plant recruitment and growth at different levels of retention. The results show that beetle assemblages used the deadwood created and that the assemblage composition differed between standing and lying wood. Retention levels in the stand impacted assemblages only marginally but burning greatly changed assemblage composition of beetles. For *Tragosoma depsarium* we could not find direct effects of retention levels or burning so for this species historical distribution in the landscape is probably important and the species is expected to colonise the created deadwood in the future. Plant recruitment was most successful in stands with low retention and with soil scarification. Here a potential conflict between biodiversity conservation and forest production occur. If conservation of saproxylic organisms is in focus soil scarification should be avoided.

Background

Swedish silviculture is among the most efficient and technically developed in the world. The implementation of even aged forestry has during a few decades changed the forest landscape with consequences for flora and fauna (Axelsson and Östlund 2001). Many forest associated specie are negatively affected by forestry, especially the following lack of dead wood and old trees (Siitonen 2001, Gibb et al. 2005). In pine forests many nature values are associated with forest fire and although prescribed burning is used to reintroduce fire in the managed landscape there is a need to develop alternative methods to restore nature values in large areas of pine forests where burning is hard to perform or where restoration for nature conservation and timber production occur in the same stand.

Long term conservation of forest biodiversity is part of sustainable forest management and the Swedish environmental goals and despite the introduction of general considerations and certification schemes (FSC, PEFC) that has resulted in that some important substrates and habitats are set aside for conservation there is also a need for restoration i.e. active creation of substrates and reintroduction of natural disturbances (Hägglund et al. 2015). The new FSC-standard demands that forest owners set aside areas to be managed by alternative methods e.g. selective fellings or increased considerations in combination with some timber harvest. There is also demands from private forest owners and agencies to increase the variation in management regimes and adapt them to the goals of the specific owner. Many owners want to manage the forest for multiple goals. The development and evaluation of such methods are thus highly demanded by forest owners and the society.

In Sweden conservation measures in forest management has been implemented since the mid 1990´s and a significant number of studies has evaluated the efforts (Johansson et al. 2013) there are still knowledge gaps especially considering which amounts of considerations are needed, their spatial distribution and the long term effects on biodiversity. Most studies have been conducted in spruce forest and pine forests remain in need of further studies. Old pine forests conservation values depend on management history, continuity and landscape context but most stands have been impacted by selective fellings, forest fires and/or cattle grazing. Pines can become hundreds of years old and survive several forest fires. However, fire suppression and final felling at moderate age has reduced the area of pine forest with high conservation values (Niklasson and Granström 2000, Nitare 2000). Also dead pines can stand for centuries and burned wood, slowly grown trees and tar impregnated wood are important substrates in old pine forest – a forest type that has been pointed out as nationally important and care demanding and that host many associated species. Some of these insects, birds, fungi mosses and lichens are nowadays rare and habitat restoration including is necessary for their survival (Nitare 2000). Few studies have explored how to restore nature values in pine forest. While there is a large interest from forest companies to develop methods that potentially can replace prescribed burnings very few studies has tried to evaluate this in controlled experiments. In this study we will take advantage of a large scale field experiment that was initiated in 2012 and evaluate the effects of different levels of tree retention and prescribed burning on saproxylic insect biodiversity and plant recruitment and growth.

Aim

The aim of this project is to assess the effects of green tree retention, dead wood creation and prescribed burning on conservation values and plant recruitment in pine forests. To assess biodiversity effects we will focus on saproxylic insects because they are likely to exhibit a relatively fast response to restoration efforts and they are an important part of the biodiversity in pine forest. We will use a large scale field experiment and combine emergence trap sampling for the whole insect assemblage with new methods using species specific pheromones to pin point the rare pine associated beetle *Tragosoma depsarium*. We will address the questions:

1. How does the insect assemblage composition respond to a) prescribed burning and b) retention felling and how does the level of tree retention impact the assemblages?
2. Can conservation measures like partial ring barking, creation of high stumps and lying dead wood create substrates that resembles substrates created by burning for fire adapted insects?
3. How does population sizes of the rare *Tragosoma depsarium* vary depending on stand type (burned or retention felled) and retention levels?
4. How is plant recruitment and growth impacted by the different restoration treatments?

Methods

Study area and experimental design

The study will be conducted in the Effaråsen field experiment that was initiated in 2012 by The Forestry Research Institute of Sweden (Skogforsk), the Swedish Forest Agency, Stora Enso Skog AB and the landowner Bergvik Skog AB. Effaråsen is located close to Mora in the province of Dalarna in the southern boreal vegetation zone of Sweden (central point 60° N, 14° E, 350-400 m above sea level). The overall aim with the field trial was to evaluate trade-offs between biodiversity conservation and forest production in old pine forests. Effaråsen is a relatively homogeneous forest area dominated by Scots pine (*Pinus sylvestris* L.), with a tree age of approximately 120 years and with some much older trees. The 24 forest stands included in the project, constitute a total area of 140 hectares, were treated with different levels of clear-felling and extent and type of conservation. The forest stands therefore demonstrate a gradient of management practices, ranging from a commonly practiced level in Sweden to a very high level of retention. Burnt areas are also included, with or without partial cutting, as well as untreated (i.e. without burning or cutting) areas control areas. Base line data on harvested volume and dead wood as well as species occurrence for wood-inhabiting fungi, mycorrhiza fungi, lichens and insects (including pest insects) have been collected. For this project base line data on insects, harvested volume and dead wood are of particular importance.

The treatments included in the study were each replicated in 3 stands. The treatments were:

- Stands with different levels of retention (3, 10, 30, 50 and 100 %) (15 stands)
- Untreated reference stands (3 stands)
- Prescribed burnings with 100 % retention (3 stands)
- Prescribed burned stands with 50 % retention (3 stands)

The retained trees in each stand were allocated in equal portions to the following measures:

- Retention trees
- High stumps
- Partial bark peeling (here after snags)
- Cut trees (left on site as dead wood)

Data collection

To address our study questions we sampled insects in 3 different ways focusing both on aimed search for rare species and sampling of the whole insect community.

How does the insect assemblage composition respond to a) prescribed burning and b) retention felling and how does the level of tree retention impact the assemblages?

Can conservation measures like partial ring barking, creation of high stumps and lying dead wood create substrates that resembles substrates created by burning for fire adapted insects?

To address our first two questions we used a combination of two methods 1) inventory of deadwood and emergence holes and 2) emergence traps.

Deadwood volume and composition and emergence holes of species with characteristic emergence holes and galleries like the rare *Tragosoma depsarium* and the potential pest species *Tomicus piniperda/T. minor* were sampled in four transects of 100 m length. For each dead wood object diameter, length, age, decay class, fire scars and type (standing or lying, snag or branch) was noted (Santaniello et al. 2017).

We used emergence traps on five high stumps, partially bark peeled trees, and cut logs in each stand which resulted in 256 emergence traps. The emergence traps cover a 30 centimeter section of the log in fabric and the emerging insects are caught in a semi-transparent vial filled with propylene glycol (Johansson et al. 2017) (Figure 1). Beetles were be sorted out from the samples and determined by experts.

How does population sizes of the rare Tragosoma depsarium *vary depending on stand type (burned or retention felled) and retention levels?*

We used traps baited with specific pheromones to estimate population sizes of the rare long horn beetle *Tragosoma depsarium* (Figure 1). The use of aggregation pheromones has proven very effective to attract beetles from a limited area and the method is thus be suitable for stand level estimates of population sizes and movement of beetles among stands. Here we will use traps with aggregation pheromones to measure differences in population size among the different stand types. We used live traps (emptied every second day) and mark-recapture techniques (beetles was individually marked with colour and released) to gain knowledge about the movement of this rare beetle in the landscape (Figure 1).

How is plant recruitment and growth impacted by the different restoration treatments?

We will measure all tree saplings in 100 m^3 plots. For each sapling we noted height, basal diameter, age (for conifers) and tree species.

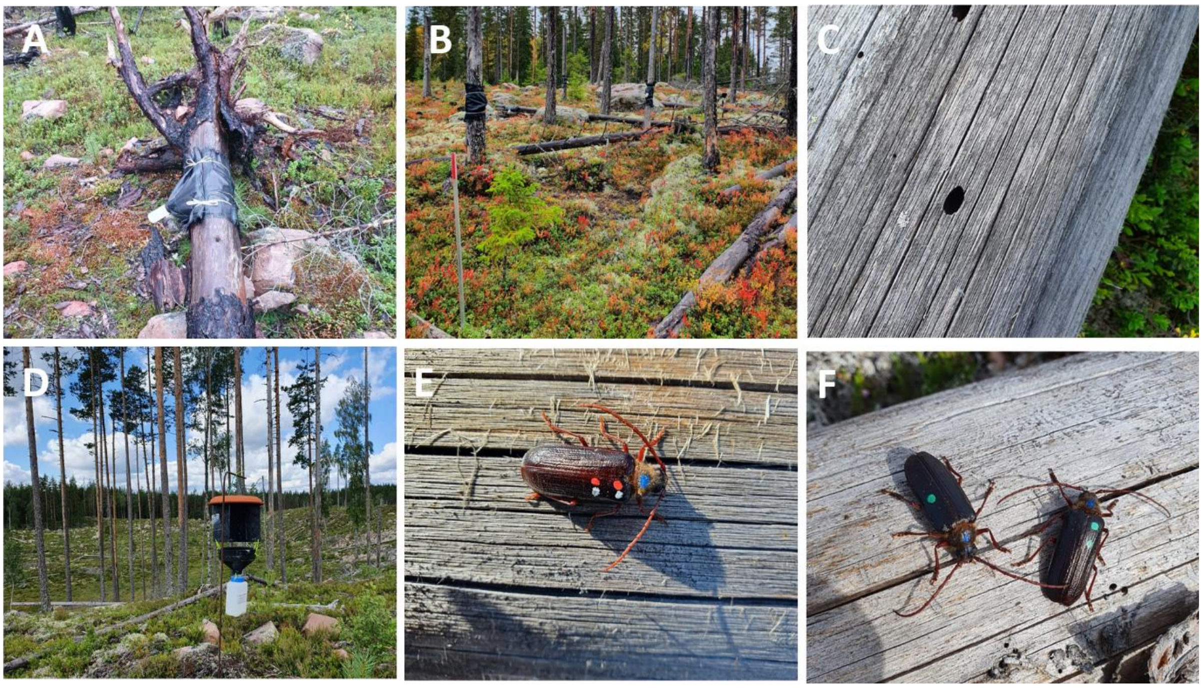

Figure 1. Beetle collection in Effaråsen. A. Emergence trap on log, B emergence traps on snags and highstumps, C. Emergence hols from Tragosoma depsarium, D. Pheromone trap for Tragosoma depsarium, E and F. Marked T. depsarium males caught in the pheromone traps.

Results and discussion

In total we caught 1423 individual representing 102 beetle species. Of those 24 individuals of 5 species were red-listed (*Danosoma fasciatum*, *Nepachys cardiacae, Stagetus borealis, Stephanopachys linearis, Tragosoma depsarium*).

In the phereomone traps we caught 147 individuals of *T. Depsarium*.

Beetle assemblages in retained deadwood in stands with different levels of retention and burned stands

Rarefaction curves showed that species richness was higher in unburned substrates than in burned substrates. Standing deadwood had higher species richness than created snags and logs but diversity was similar between created snags and logs. Stand treatments, i.e., retention levels and burning did not affect species richness nor diversity (Figure 2). Our results are consistent with previous studies in that burned substrates had lower species richness. However, most previous studies evaluate deadwood enrichment the first few years after creation (Hjalten et al. 2007, Hägglund et al. 2020) where mainly cambium consumers are affected. In this study it seems like burning reduce species richness also on a decadal scale, possibly as a result of that wood fungi and fungivores as negatively affected by burning. The fact that stand treatment did not affect richness or diversity in the traps suggest that deadwood enrichment is beneficial for pine associated beetles in all stand types.

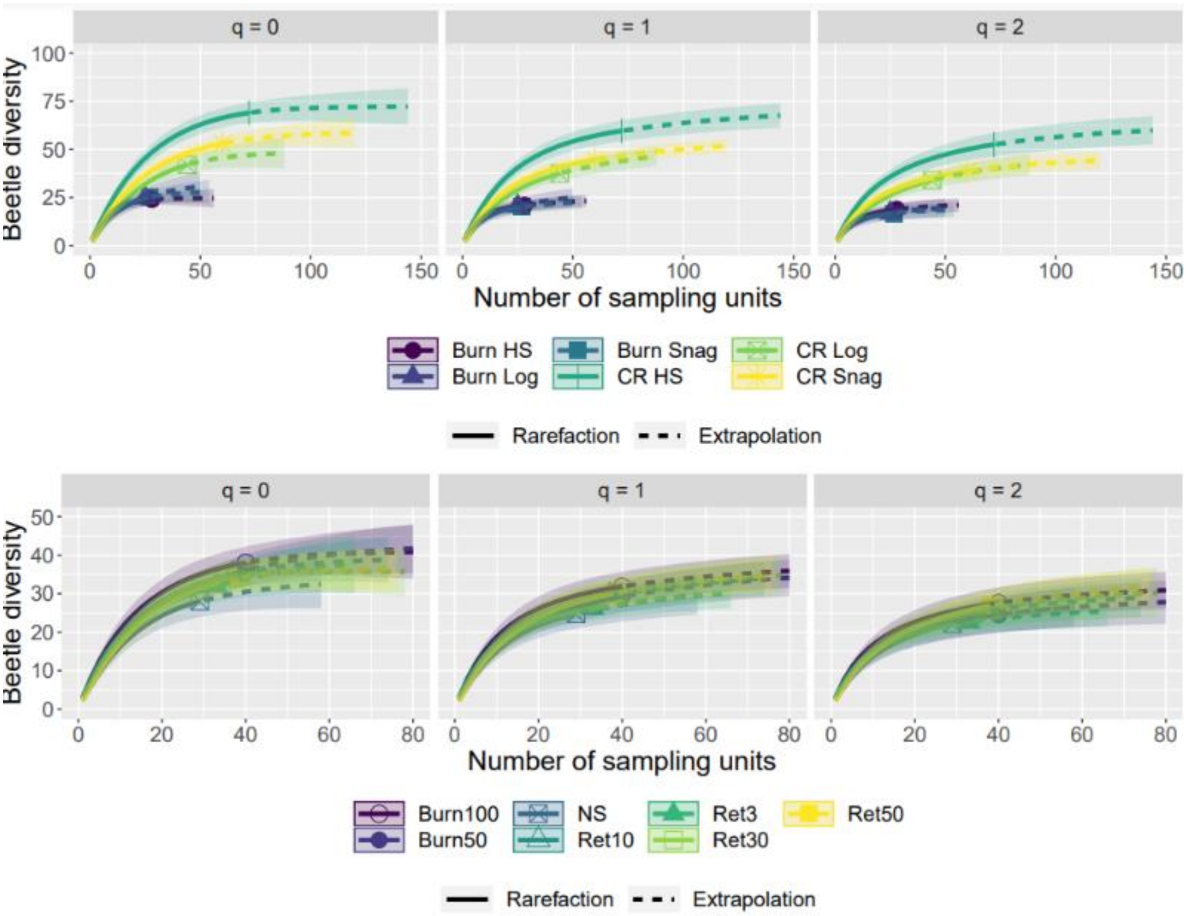

Figure 2. Rarefaction curves for the different substrate types and stand treatments where Q=0 is Richness, q=1 is Shannon diversity, q=2 is Simpson diversity

Beetle assemblage composition differed significantly among the different substrate types with logs supporting assemblages that were different from those on snags and high stumps. Snags and high stumps were also different from each other but burning did not affect assemblage composition on the created deadwood (Figure 3).

These results are to a large extent similar to previous studies that have compared beetle assemblages on spruce deadwood (Hjalten et al. 2012) and pine (Hägglund and Hjälten 2018). Also in those studies the most apparent effect of treatment was the difference between standing and lying deadwood. The result that the beetle assemblage on burned logs, snags and high stumps differed from unburned substrates is also consistent with previous studies (Gibb et al. 2006, Hägglund and Hjälten 2018). The explanation is probably that burning dries out the cambium and reduce its value for cambium consumers. After eight years this impact seems to still be present. This indicate that fire mimicking measures like partial bark peeling of trees is not likely to fully substitute prescribed burning.

The assemblage composition were similar among all treatments and there were no indication that retention levels or burning affected beetle assemblages on created deadwood after 8 years (Figure 3). This result is not consistent with previous studies where stand type (clear-cut vs closed forest) were of major importance and assemblages were clearly different between open clear-cuts and closed forest in spruce dominated forest (Hjalten et al. 2007, Hjalten et al. 2012). Studies that compared gap-cutting (80% retention) with prescribed burning in mixed coniferous forest found that assemblage composition changed after prescribed burning but not after gap-cutting (Hjälten et al. 2017, Hägglund et al. 2020). The results from this study suggest that retention levels is less important for pine associated beetles maybe because pine dominated forest is more open so the change after clear-cutting is less drastic. However, it is important to notice that the stands with high levels of retention contain much more deadwood and thus have the potential to support larger populations of the deadwood associated beetle assemblage.

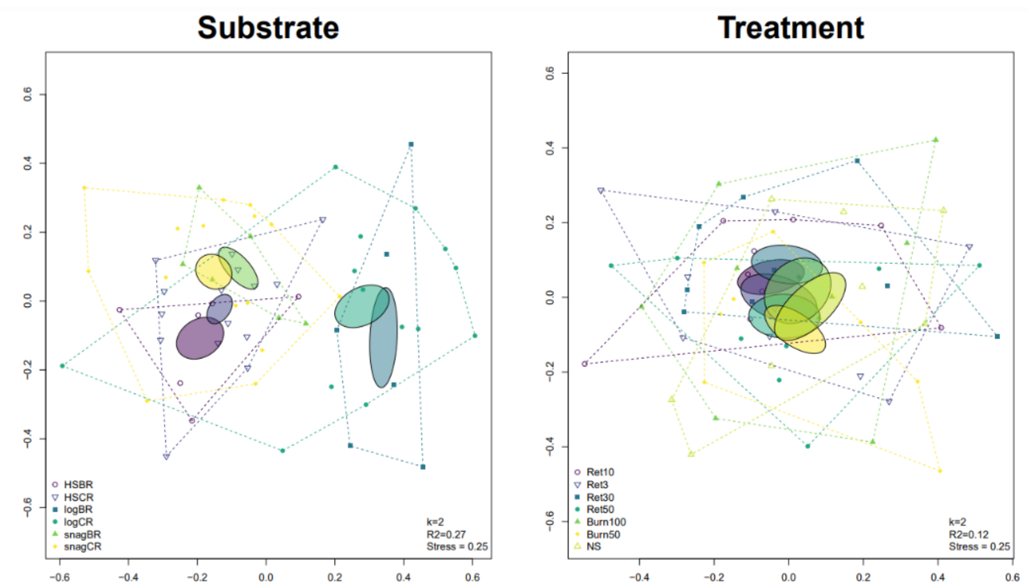

Figure 3. NMDS plots of the assemblage composition in the different substrate types and stand treatments. HS=high stump, BR=burned, Re=retention, NS=only deadwood creation

Tragosoma

We caught in total 147 individuals of *Tragosoma depsarium* and 107 recaptures which gives 254 catches in total. All individuals were caught between the July 12 and August 7. Traps were active until August 25. Most individuals were caught in the second half of July (Figure 4).

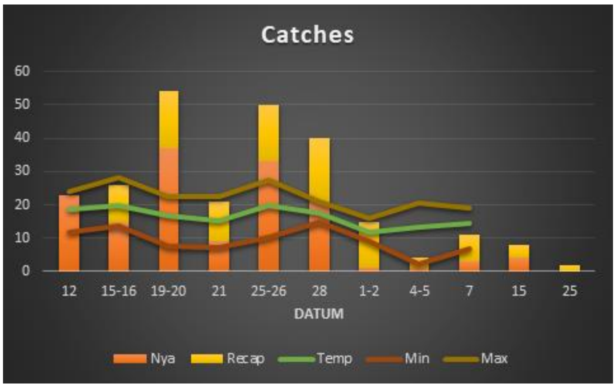

Figure 4. Catches of Tragosoma depsarium in Effaråsen and weather data from Mora.

Individuals of T. depsarium were cought in all different stand treatments and there was no obvious connection between stand treatment and number of catches. However, some areas within Effaråsen seems to be more beneficial for T. Depsarium (Figure X). This indicate that there is something in the landscape except for retention levels or burning that explain the distribution. These could be landscape features such as aspect or slope or the historical availibility of suitable deadwood i.e., sun exposed logs with ground contact. To sort out what is behind the distribution of *T. depsarium* complementary inventories of landscape features and deadwood will be performed in 2024. Our data show that T. depsarium move between the different stands indicating that it can spread to suitable substrates (Figure 5). However, few individuals dispersed over longer distances suggesting that it is important to ensure continuous availability of suitable substrates in areas where the species is present.

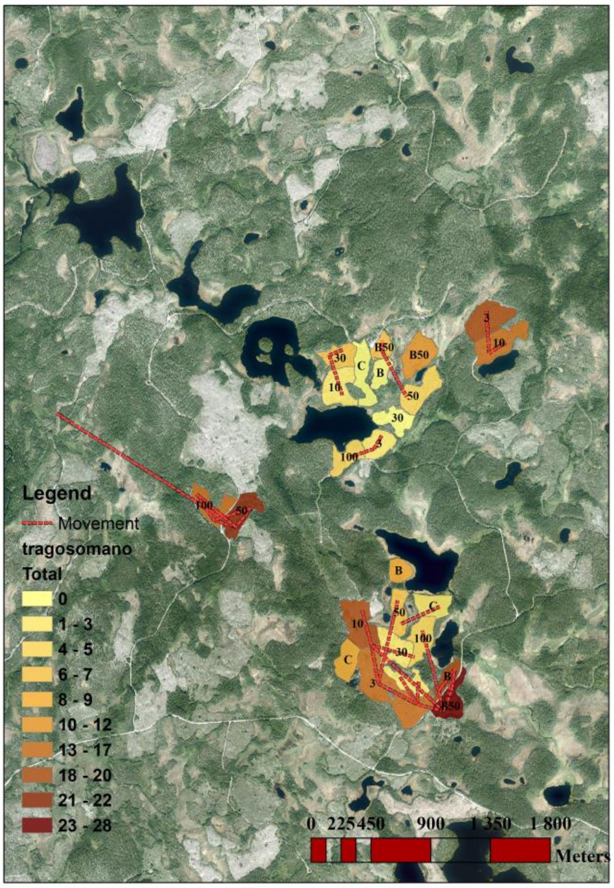

Figure 5. Occurrence and movements of Tragosoma depsarium in Effaråsen. Numbers in the stands are retention levels, colors indicate T. depsarium abundance.

Regeneration

Plant survival of both planted and sown plants were higher in soil scarified plots compared with unscarified plots. For sown plants the survival decreased over time in scarified plots but was stable on around 10 % in plots with 10 or more % retention but was around 15% in plots with 3% retention. The number of plants originating from natural regeneration was clearly higher in soil scarified plots and burning and tree retention increased the number of naturally regenerated plants (Figure 6). These results show that compromises are needed to provide sustainability both in terms of wood production and biodiversity. While soil scarification is positive for regeneration of trees it is negative for deadwood associated biodiversity. Here there is a need to develop more flexible soil scarification methods to not destroy natural values.

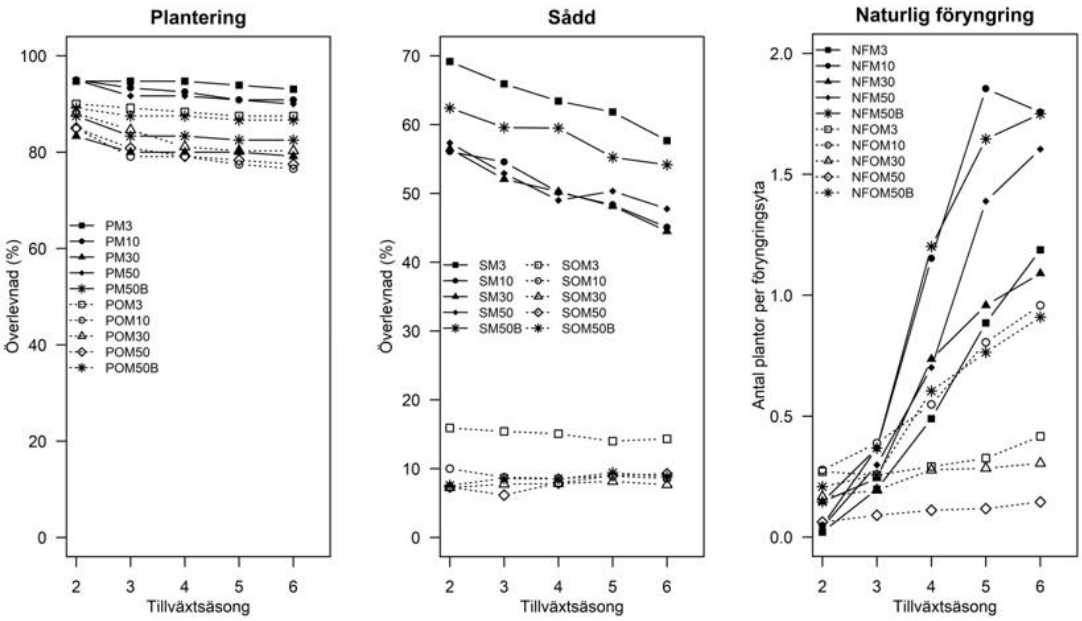

Figure 6. Proportion survival of plants for planted plants (P) and sown plants (S) and the number of plants per plot in natural regeneration (NF) for scarified (M) and non scarified (OM) treatments in the five different retention classes; 3% (3), 10% (10), 30% (30), 50% (50) och 50% + prescribed burning (50B) after the six first years after treatment.

Publications and outreach

The project was part of a larger collaboration project between SLU and Stora Enso and both are co-financing the project through the employment of a PhD student that is financed 50 % by SLU and 50 % by Stora Enso. This project covered the running costs for the PhD project and made it possible to add detailed analyses of insect communities to the project through the resources to species identification and performance of pheromone trials with rare species.

We plan to publish four scientific articles and in for each scientific publication a popular scientific news item will be published on the SLU and Skogforsk web pages. In addition we plan to publish a summary of the project results in Fakta Skog. Preliminary titles and status of each publication is listed below:

Scientific publications:

Ekström-Larsson, A. et al. 2024. Retention level interact with restoration methods in shaping insect assemblages after restoration. Manuscript, data analysed, planned submission in 2024.

Ekström-Larsson, A. et al. 2024. Priority effects determine the ecological function of beetle and fungi assemblages in deadwood. Data analysed, planned submission in 2025.

Ekström-Larsson, A. et al. 2025. Resource use of *Tragosoma depsarium* in a restored landscape. Draft, complementary data will be collected in 2024.

Lariviere et al. 202x. Combining retention and pine regeneration. *Submission spring 2024*

Popular science/reports:

Löfroth et al. 2025. Hänsyn i tallskog kan gynna sällsynta arter. Fakta Skog.

Bachelor thesis:

Amneus, A. & Hjelström, S. (2023) Beetle Diversity – Land Sparing or Land Sharing? the effects of timber extraction and restoration method on saproxylic beetle assemblages in mature managed pine forests.

Presentations at conferences/seminars/excursions

Ekström-Larsson, A. Differing species assemblages of beetles in created deadwood types. Excursion within a research collaboration between SLU and Stora Enso, Spring 2023.

Löfroth, T. Effects of restoration on biodiversity. Forskning för framtidens skogsbruk, Umeå, October 4, 2023.

Economy

The project has been performed according to the budget in the application. Details of the costs in the project are found below.

Kostnader	
Löner	302 034
Material	132 369
Resor	96 468
Övrigt	45 375
Overhead	154 455
Totalt	730 700

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