Investigating the effects of different levels of forest management on carabid beetle richness, abundance and community composition in Fennoscandia

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Swedish University of Agricultural Sciences - SLU
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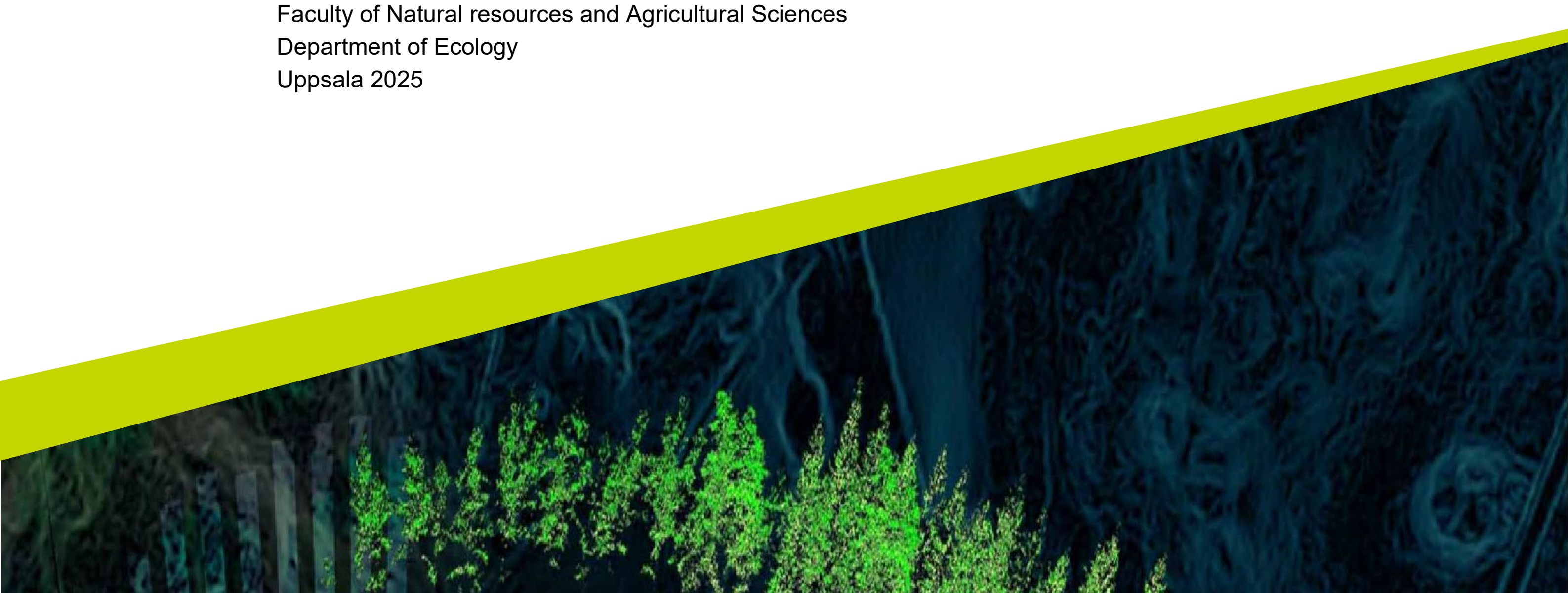

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Abstract

Carabid beetles are one of the most diverse types of insects and reside in most terrestrial habitats on earth. However, the forests they live in have been heavily altered, with different forest management types emerging in an attempt to extract biomass from the forest but still maintain biodiversity.
I analyzed a data set of carabids caught in pitfall traps from three different forest management types. These were forests managed by clearcutting, retention forestry and those set aside for biodiversity. The data set used was from 240 forest plots split equally between the three forest management types and between the two countries surveyed, Finland and Sweden.
The objective of the report was to analyze if richness, abundance and community composition differed among three forest management types (old clearcuts. retention patches in old clearcuts and set-asides), and if the differences found were uniform between the two countries. The report also compared to what extent species were unique and to what degree there was overlap between the forest management types and countries. With the most common species identified for each of the forest management types and countries. The study also had as an objective to describe the extent to which beetle community composition in retention patches were influenced by trap location and therefore edge effects, these being traps placed either in the middle or at the edge of the retention patches. The collected data was then analyzed and visualized by using box plots, ANOVAs with Tukey's tests, t-tests and Venn diagrams. I showed that there were significant differences between the forest management types, with retention plots in Finland having the highest carabid beetle richness but the lowest abundance. In the set-asides in Finland, species richness was the lowest. Abundance was highest in Swedish set-asides than in any of the other forest management types. Trap location in retention patches was shown to be insignificant. The community composition of beetles overlapped among the forest management types, 41% of all species were found in all forest management types for both countries and 50% of all species were found in both countries. Only 1% of species were found in both set-asides and old clearcuts, while 10% of species were found in both old clearcuts and retention patches. These overlaps conclude that the different forest management types influence beetle communities in terms of richness and abundance and that the forest management types can be seen as a form of degradation gradient where habitats more similar share a higher percentage of species.

Keywords: Forest management, Carabidae, Carabid Beetles, Sweden, Finland, Fennoscandia, Retention forestry, Set-asides, Clearcut forestry

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Abbreviations

SE	Standard error

1. Introduction

Since the 19th century, the forests of Fennoscandia have been intensively managed for commercial purposes (Kotilainen & Rytteri, 2011).
The forest landscape today is primarily composed of managed forests intermixed with the occasional set-aside patch for conservation.

In the managed forests, it is possible find areas that have been clearcut and areas where retention forestry has been practised. Retention forestry is a type of environmental concern that was introduced in Northern Europe in the 1980s (Simonsson et al., 2015). However, it wasn't a widespread type of forestry until the late 1990s when forest certification standards were widely introduced (Gustafsson et al., 2010). Retention forestry attempts to mimic natural disturbances by maintaining some trees after final felling (Kuuluvainen et al., 2021). This leads to a variation in stand age, which in turn contributes to a more diverse forested area (Halaj et al., 2008).

The main difference between clearcut and retention forestry, is that some trees in a stand are left untouched within retention forestry. Clearcut forestry aims to obtain the largest possible biomass of timber from the area, often meaning that areas are clear-felled (Gustafsson et al., 2020). These intensive forestry methods have had profound negative effects on biodiversity as they have led to the loss of natural habitats that can sustain a multitude of different life forms (Secretariat of the Convention on Biological Diversity, 2010). The leading reason for the loss of biodiversity in areas that are actively managed is the homogenization of the forest, with trees of the same age and type (Franklin et al., 2000). In contrast to this, set- aside locations host a larger variation of stand age and dead wood per hectare (Skogsstyrelsen, 2023). The three forestry management methods mentioned above can therefore be seen as a form of gradient, going from forested areas with low human impact (set-asides) to areas where human intervention is high (clearcuts). Retention forestry can be seen as an intermediate forest type in this where human management takes place while attempting to minimize the effects forestry has on biodiversity.

A taxon that is often used to examine the effects of forestry on biodiversity are carabid beetles, as they are ecologically diverse and a reliable indicator of changes in their habitat (Langor et al., 2006, Koivula et al., 1999). Carabids are one of the most diverse insect families, with an estimated 40 000 species (Lövei & Sunderland, 1996). It is estimated that 361 species of carabid beetles reside in Fennoscandia (Lindroth, 1993). Carabid beetles reside in almost every terrestrial habitat on Earth. Carabid beetles are relatively long-lived and have little seasonal fluctuation in behavior (Lindroth, 1974). In forested areas, carabid beetles are heavily affected by changes in leaf and needle litter, fragmentation and the presence of edges, and altered sun exposure (Niemelä et al., 1988, Koivula et al., 1999).

After a forest has been harvested, negative changes in the amount and quality of leaf and needle litter biomass and other ground litter (such as branches) take place over time, as available litter is not replenished once the trees are removed. Furthermore, biological changes in the leaf and needle litter biomass through temperature and moisture content may affect forest litter invertebrates that are sensitive to these changes (Bird & Chatarpaul, 1986). This is concluded in a report by Magura et al (2005) focusing on carabid beetles and their relationship with leaf litter. The study showed that plots containing leaf and needle litter biomass had a significantly lower ground temperature than control plots with little to no leaf and needle litter. In addition, there was more prey in plots with higher amounts of leaf and needle litter. It was also noted that carabid larvae were more plentiful in plots containing leaf and needle litter biomass than in the control plots.

A multitude of different edge effects can also affect carabid beetles living in a fragmented landscape (Magura, 2000). These edge effects are most commonly divided into abiotic and biotic factors. These include, but are not limited to, increased risk of predation, altered species interactions, humidity, sunlight and wind (Saunders et al., 1991). The edges of forest fragments tend to be home to a mix of invertebrates that can be found on both sides of the "edge zone" (Kotze & Samways, 1999). An assumption can therefore be made that these edge zones are more easily inhabited by other species from the matrix, leading to this mix of invertebrate community composition. The mix of species found inevitably affects interactions between species, and in turn, can increase the risk of predation (Spence et al., 1996). Previous studies on carabid beetles have shown that habitat fragmentation (through forestry, for example) affects carabid community composition through alterations in abundance and species richness (Niemelä, 2001). It has also been highlighted that the number of carabid species found in a patch was largely affected by its shape, as patches with a higher edge-to-area ratio were shown to have a higher species richness (Usher et al., 1993). Research undertaken by Niemelä et al (1988) reinforces this as it indicated that species richness was higher in smaller (< 5 ha) than in larger (> 30 ha) forested areas. Additionally, areas of continuous forest that were not fragmented had the lowest species richness overall. It was established that a reason for the pattern could be that the fragmented landscape patches had more sunlight – making it more favorable for some carabid species. Thus, leading to an increase of carabid beetle abundance and richness within a given area.

It has been noted that by categorizing carabid species by forest specialists, generalists and other species, it was possible to recognize a significant shift towards forest specialists in areas of increased forest age, while a decrease of other species was observed (Jukes et al., 2000). The colonization of clear-cut sites by carabid beetles can be seen as a vital process that increases species richness in an area, an increase that can be observed in as little as 2 years after clear-cutting (Fahy & Gormally, 1998). According to the report by Jukes et al. (2000), homogeneity within a habitat is often recognized as a reason for decreasing carabid diversity and richness, together with forested areas where little light can penetrate the canopy. These habitats then become unsuitable for the majority of species.

1.1 Objective of the report

This report has three main objectives. Firstly, it seeks to analyze if richness, abundance and species composition of carabid beetles differ among three forest management types (old clearcuts, retention patches in old clearcuts and set-asides), and if the differences are uniform between the two countries, Sweden and Finland. Secondly, the report compares to what degree species are unique and to what degree there is overlap between each of the forest management types and countries together with identifying the most common species for each of the forest management types within the two countries. Thirdly, the study aims to describe to what extent beetle communities in retention patches are influenced by edge effects.

1.2 Questions

1) How does carabid abundance, richness and community composition differ between the forest management types and countries?

2) What are the most common species found in each of the forest management types between the two countries, and what habitats do they reside in?

3) To what degree are species in the different forest management types unique and to what extent is there overlap?

4) Is there a difference between interior and edge trap locations in retention patches regarding beetle community composition?

1.3 Hypothesis

Carabid species richness and carabid community composition
I expect that there will be differences in carabid beetle richness and community composition between the different forest management types and countries, with the lowest richness expected to be found in set-asides. I also expect that it will be possible to observe a natural gradient in the community composition for each of the forest management types for unique and overlapping species. This would reinforce the notion that a diverse array of species thrives in different forest management types and that it is in fact possible to view the forest management types used in this study as a form of gradient based mainly off the species that reside there.

Carabid abundance
The mean abundance is expected to differ between the forest management types and countries. Old clearcuts would be expected to have the highest beetle abundance.
If this is the case, it would illustrate that different forest management types affect the number of beetles able to thrive.

Trap location
The expectation is that the composition of the beetle communities will be affected by trap location in retention patches. As species that thrive in open areas will be caught in edge traps while forest species will be caught in the traps in the middle of the retention patches.

2. Material and method

2.1 Method overview

In this study, a total of 240 circular forest plots with a 20 m radius (0.125 ha) were established. Half of these sites were in Sweden and the other 120 in Finland. The Swedish plots were divided equally between Hälsingland and Värmland. The plots in Finland were scattered across both North Karelia and Kainuu. The characteristics of the plots used were largely the same. For example, pertaining to the tree species composition.

The plots were then divided equally between three different forest management types in both countries. As such, there were 40 sites per management type, per country. These management types being 25–30-year-old clearcuts (with young forest), retention patches surrounded by the aforementioned old clearcuts and mature set-asides. The mature set-asides used did differ between the countries due to small differences in the exact methods of management. The Swedish set-asides used were surrounded by clearcuts while the set-asides in Finland were largely part of a contiguous forest.

To collect carabid beetle specimens in 2022, we used pitfall traps. Four traps (mouth 80 mm, volume 2-3 dl, plastic lid 10 x 10 cm, strong salt-water solution + drop of detergent) were placed in the center and four were placed at the edge of retention patches. These groups were placed approximately 15 m apart, preferably within the 20 m radius plot. There was a similar setup of 4+4 traps in old clearcut and set-aside plots. In the latter two, all traps were placed at least 25 m from the nearest edge to the neighboring stand. While servicing traps (setup, emptying, removal), the groups of four traps were pooled (i.e., emptied into the same storage cup). Traps were serviced approximately once a month, starting in mid-May and ending in August or September. In total, the study, per country, produced (40 sites x 3 plots x 2, 4-trap sets x 3 collecting periods) 720 samples. Trap losses were recorded. Plots with 10 or more lost traps were removed from our analysis. The samples were then sorted in the laboratory and carabids identified. Carabids with an occurrence as low as 1 were counted and noted. The carabid abundance in this study refers to the total number of records from all carabid species found in a plot.

2.2 Data analysis

After the data had been collected, it was analyzed using R version 4.2.1 (R Core Team, 2022). The data was analyzed for patterns in species richness, abundance and carabid community composition.

Two-way ANOVAs were used to analyze the effect of forest management type and country on species richness and total abundance of beetles. Tukey's tests were used to further clarify this data and where these interactions took place. T-tests were used to compare data from edge and middle traps (80 traps for each trap location) in retention patches. Venn diagrams were used to visualize differences and similarities in species composition between the countries and forest management types and illustrated possible overlap in species. They were also used to visualize differences and overlap between edge and middle traps in retention patches.

3. Results

3.1 Carabid beetle species richness

Species richness of beetles ranged from 1 to 19 species in the single plots across all forest management type and country combinations (Figure 1). On average, the species richness did not differ much between the combinations, ranging from 4.88 to 7.38 species (Table 1).

A two-way ANOVA was performed to analyze the effect of forest management type and country on beetle species richness (Table 1). The two-way ANOVA revealed that there was no overall difference in richness between the two countries ($p = 0.3907$) (Table 1). There was, however, a significant effect of forest management type ($p= 0.0027$), but there was also a significant interaction between country and forest management type ($F (2, 226) = 5.18$, $p = 0.0063$). The significant interaction was caused by a difference in species richness but only in set-asides (Figure 1 & Table 1**)**. Set-asides in Sweden had an on average 30% higher species richness then set-asides in Finland. The effect shown was not uniform between the countries and forest management types. When comparing set-asides in Finland with all other forest types it was found that they had the lowest species richness. In retention patches, the species richness in both countries was similar.

This was also supported by the subsequent Tukey's test (Table 2) which found that the mean beetle species richness was significantly different between set-asides in Finland and retention patches in Sweden ($p = 0.003$, 95% CI = [-4.14,-0.55]), set-asides in Sweden ($p = 0.030$, 95% CI = [-3.70,-0.11]), old clearcuts in Finland ($p = 0.04$, 95% CI = [-3.56, -0.04]) and retention patches in Finland ($p = 0.0009$, 95% CI = [-4.26, -00.74]).

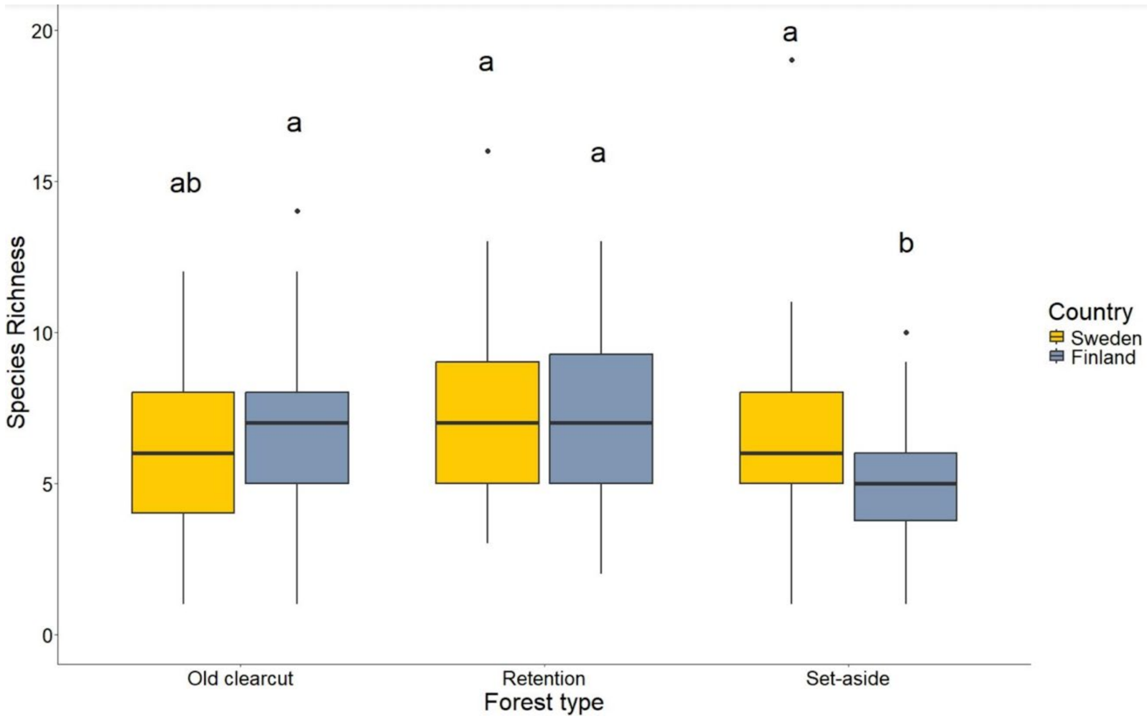

Figure 1: The number of carabid beetle species documented in the different forest management types, compared between Finland and Sweden. Those boxplots marked with the letter "a" are statistically different than those marked with the letter "b", while those boxplots marked with "ab" are statistically the same as both "a" and "b". This is derived from the Tukey's test.

Table 1: Results from the two-way ANOVA conducted to compare the effect of forestry management type and country on species richness.

	Degrees of freedom	Mean square	F value	P value
Forest type	2	91.0	6.07	0.0027**
Country	1	5.5	0.74	0.3907
Forest type: Country	2	77.6	5.18	0.0063**
Residuals	226	1693.4	7.49	

Table 2: Results from a Tukey's test conducted to compare and clarify the effect of forestry management type and country on species richness. All significant results are marked with asterisks.

Comparison between combinations	Mean difference	Lower bound of 95% CI	Upper bound of 95% CI	P value
Retention:Sweden-Old clearcut:Sweden	1.35	-0.4694007	3.16	0.27
Set-aside:Sweden-Old clearcut:Sweden	0.92	-0.9018331	2.73	0.69
Old clearcut:Finland-Old clearcut:Sweden	0.81	-0.9757558	2.59	0.78
Retention:Finland-Old clearcut:Sweden	1.51	-0.2757558	3.29	0.15
Set-aside:Finland-Old clearcut:Sweden	-0.99	-2.7757558	0.79	0.59
Set-aside:Sweden-Retention:Sweden	-0.43	-2.2617028	1.39	0.98
Old clearcut:Finland-Retention:Sweden	-0.54	-2.3358601	1.25	0.95
Retention:Finland-Retention:Sweden	0.16	-1.6358601	1.95	0.99
Set-aside:Finland-Retention:Sweden	-2.34	-4.1358601	-0.55	$p<0.01$
Old clearcut:Finland-Set-aside:Sweden	-0.11	-1.9034276	1.69	0.99
Retention:Finland-Set-aside:Sweden	0.59	-1.2034276	2.39	0.93
Set-aside:Finland-Set-aside:Sweden	-1.91	-3.7034276	-0.11	0.029**
Retention:Finland-Old clearcut:Finland	0.70	-1.0593359	2.46	0.86
Set-aside:Finland-Old clearcut:Finland	-1.80	-3.5593359	-0.04	0.04**

Set-asides:Finland-Retention:Finland	-2.50	-4.26	-0.74	p<0.01

3.2 Carabid beetle abundance

The carabid abundance in this study refers to the total number of records from all carabid species found in a plot. The abundance of carabids ranged from 0 to 320 individuals in a single plot across all forest management type and country combinations (Figure 2). Carabid abundance differed strongly between the combinations, with Swedish set-asides having the highest abundance (87.0 individuals) and retention patches in Finland having the lowest mean abundance (41.9 individuals) (Figure 2).

The two-way ANOVA revealed a significant main effect of country (p=0.02), but this effect was not uniform between countries (F(2, 234) = 3,95, p = 0.02). Set-asides in Sweden had higher beetle abundance than the other forest types, where there were no or small differences among forest types in Finland (Figure 2 & Table 3). Set-asides in Sweden had an on average 44% higher abundance than set-asides in Finland.

This was also shown by the subsequent Tukey's test (Table 4) which revealed that beetle abundance was significantly different between set-asides in Sweden and old clearcuts in Sweden (p = 0.02, 95% CI = [4.27, 76.98]), retention patches in Finland (p = <0.01, 95% CI= [-81.5, -8,79]), and set-asides in Finland (p = 0.03, 95% CI = [-75.36, -2.64]).

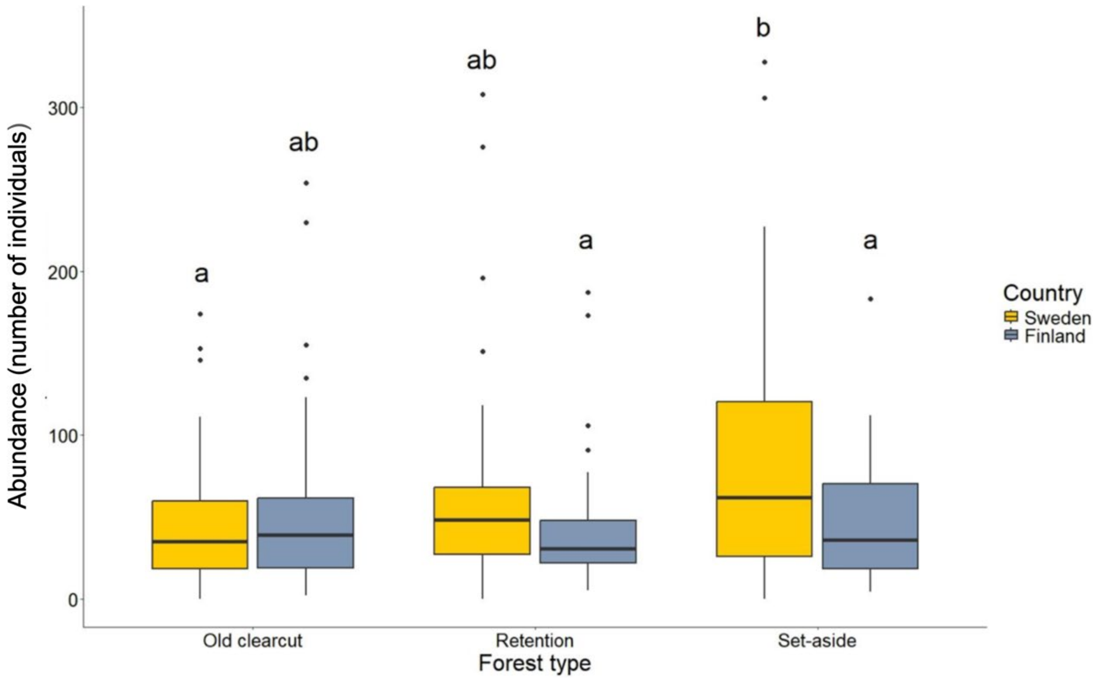

Figure 2: The carabid abundance calculated for each of the forest management types, for both Finland and Sweden.

Table 3: Results from a two-way ANOVA conducted to compare the effects of forest management type and country on carabid beetle abundance.

	Degrees of freedom	Mean square	F value	P value
Forest type	2	6162	1.92	0.15
Country	1	17510	5.47	0.02**
Forest type: Country	2	12650	3.95	0.02**
Residuals	234	3202		

Table 4: Results from a Tukey's test conducted to compare the effect of forestry management type and country on carabid beetle abundance.

Comparison between combinations	Mean difference	Lower bound of 95% CI	Upper bound of 95% CI	P value
Retention:Sweden-Old clearcut:Sweden	18.10	-18.26	54.46	0.71
Set-aside:Sweden-Old clearcut:Sweden	40.63	4.27	76.98	0.019**
Old clearcut:Finland-Old clearcut:Sweden	10.38	-25.98	46.73	0.96
Retention:Finland-Old clearcut:Sweden	-4.53	-40.88	31.83	0.99
Set-aside:Finland-Old clearcut:Sweden	1.63	-34.73	37.98	0.99
Set-aside:Sweden-Retention:Sweden	22.53	-13.83	58.88	0.48
Old clearcut:Finland-Retention:Sweden	-7.73	-44.08	28.63	0.99
Retention:Finland-Retention:Sweden	-22.63	-58.98	13.73	0.48
Set-aside:Finland-Retention:Sweden	-16.48	-52.83	19.88	0.78

Old clearcut:Finland-Set-aside:Sweden	-30.25	-66.61	6.11	0.16
Retention:Finland-Set-aside:Sweden	-45.15	-81.51	-8.79	0.0058**
Set-aside:Finland-Set-aside:Sweden	-39.00	-75.36	-2.64	0.028**
Retention:Finland-Old clearcut:Finland	-14.90	-51.26	21.46	0.85
Set-aside:Finland-Old clearcut:Finland	-8.75	-45.11	27.61	0.98
Set-aside:Finland-Retention:Finland	6.15	-30.21	42.51	0.99

3.3 Trap location in retention patches

A two-sample t-test was conducted to compare trap location and its effect on measured species richness within a retention patch. These locations were either the edge or the middle of a patch. The test shows that there was no significant difference in species richness between traps located at the edge (M= [8.89], SD= [5.24]) and in the middle (M= [8.18], SD= [4.56]); t (149) = [-0.89], p= [0.38].

A two-sample t-test was performed to compare trap location and its effect on measured carabid abundance within a retention patch. The traps were located either at the edge or in the middle of a patch. There was no significant difference in beetle abundance between the traps located at the edge and in the middle (t (149) = [-1.08], p=[0.28].

3.4 Carabid community composition

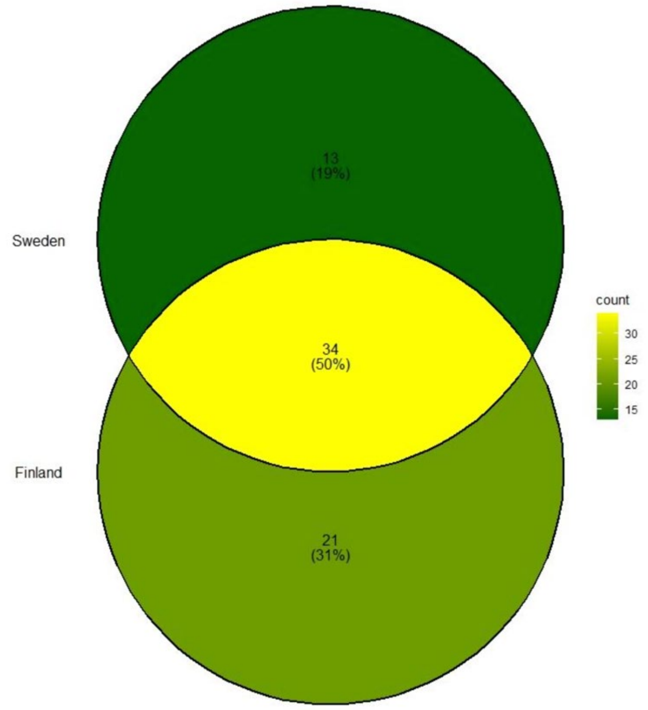

Figure 3: Venn diagram displaying the number of carabid species found in both countries or only in Sweden or Finland.

There were 13 (19%) species only found in Sweden, 34 species (50%) were found in both Sweden and Finland, and lastly, 21 species (31%) were only found in Finland (Figure 3).

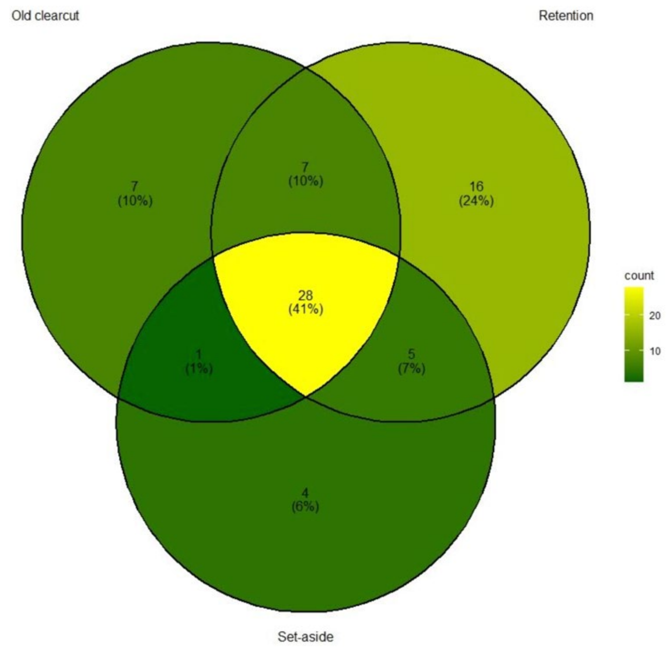

Figure 4: Venn diagram displaying the number of carabid species found in each, or all of the forest management types.

A large overlap was observed in the number of species between the forest management types, with 28 species (41%) being found in all forest management types. Seven species (10%) were found in both old clearcuts and retention patches. Five species (7%) were found in retention patches and set-aside locations. Only one species (1%) was found in both old clearcuts and set-aside patches. Furthermore, within all forest management types, retention patches were shown to contain sixteen (totaling 24%) of all unique species found, old clearcuts contained seven (totaling 10%) and set-asides four (6%) (Figure 4, Table 5). A species found was counted and noted for the forest management types even if the occurrence was as low as one.

Table 5: The species that are uniquely present in a specific forest management type and which have overlapping presence across different forest management types. Note that *Pterostichus nigrita/rhaeticus* could not be identified to species level. In the "Preferred habitat" column, the habitat type was listed alongside the number of species that had a preference for that habitat (shown in brackets). All information regarding habitat preferences was obtained from Bräunicke & Trautner (2009) and various species-specific pages from SLU artdatabanken (2024). The number of species with the same habitat preferences are added together and presented in brackets together with the preferred habitat type.

Forest management type	Species	Number of unique species	Preferred habitat
Clearcut	*Pterostichus diligens, Badister lacertosus, Blemus discus, Calathus melanocephalus, Carabus nitens, Harpalus affinis, Notiophilus aquaticus*	7	Wet forested landscape species (1), Open landscapes and forest species (2), Open landscape species (3), Heathland and open, wet grassland species (1).
Retention	*Amara aenea, Calathus fuscipes, Dicheirotrichus cognatus, Paranchus albipes, Trechus quadristriatus, Trechus rubens, Amara tibialis, Bembidion quadrimaculatum, Bradycellus caucasicus,Carabus cancellatus, Dyschirius globosus, Harpalus latus, Harpalus luteicornis, Harpalus solitaris, Poecilus versicolor, Pterostichus rhaeticus*	16	Open habitat species (9), Water species (2), Forest species (1), Heathland and sandy forest species (2), Open habitat and water species (2).
Set-aside	*Elaphrus cupreus, Sericoda quadripunctata, Amara aulica, Platynus mannerheimii*	4	Wet landscape species (2), Forest fire dependent species (1), Open habitat species (1).

Clearcut / Retention	*Agonum ericeti, Harpalus laevipes, Nothiophilus aestuans, Amara lunicollis, Amara quenseli, Cymindis vaporariorum, Synuchus vivalis*	7	Wet open landscape species (1), Forest species (1), Open habitat species (3), Sandy heathland species (2).
Clearcut / Set-aside	*Pterostichus minor*	1	Wet landscape species.
Retention / Set-aside	*Notiophilus reitteri, Oxypselaphus obscurus, Trechus rivularis, Dromius agilis, Harpalus rufipes*	5	Forest species (1), Wet landscape species (1), Wet open landscapes (1), Forest species (1), Open habitat species (1).
Clearcut / Retention/ Setaside	*Agonum fuliginosum, Amara brunnea, Calathus micropterus, Carabus coriaceus, Carabus glabratus, Carabus hortensis, Carabus nemoralis, Carabus problematicus, Carabus violaceus, Cychrus caraboides, Leistus terminatus, Notiophilus palustris, Pterostichus niger, Pterostichus nigrita, Pterostichus oblongopunctatus, Pterostichus strenuus, Trechus secalis, Dicheirotrichus placidus, Leistus ferrugineus, Loricera pilicornis, Notiophilus biguttatus, Notiophilus germinyi, Patrobus assimilis, Patrobus atrorufus, Poecilus cupreus, Pterostichus adstrictus, Pterostichus melanarius, Pterostichus nigrita/rhaeticus*	28	Wet landscape species (8), Sand heathland species (3), Forest species (10), Open habitat species (6), Species found in all habitats (1), Forest and open habitat species (1).

Table 6: The three most common species among the documented carabid beetle species per country and forest management type with their recorded abundances.

Forest management type	Country	Rank	Species	Abundance
Old clearcut	Finland	1	*Trechus secalis*	873
		2	*Pterostichus oblongopunctatus*	366
		3	*Calathus micropterus*	299
	Sweden	1	*Carabus violaceus*	803
		2	*Pterostichus niger*	194
		3	*Cychrus caraboides*	89
Retention	Finland	1	*Pterostichus oblongopunctatus*	440
		2	*Trechus secalis*	296
		3	*Calathus micropterus*	268

	Sweden	1	*Carabus violaceus*	1066
		2	*Agonum fuliginosum*	325
		3	*Carabus hortensis*	305
Set-aside	Finland	1	*Pterostichus oblongopunctatus*	1068
		2	*Calathus micropterus*	305
		3	*Carabus glabratus*	215
	Sweden	1	*Carabus violaceus*	963
		2	*Pterostichus oblongopunctatus*	604
		3	*Carabus hortensis*	544

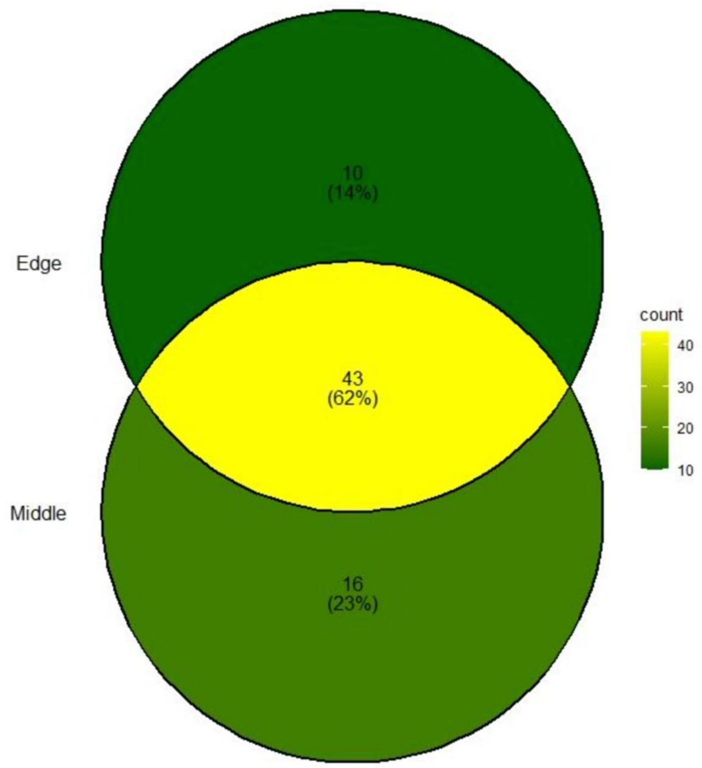

Figure 5: Venn diagram displaying the number of carabid beetle species caught in each or both of the trap locations, for all of the retention patches.

4. Discussion

4.1 Discussion of results

Differences in beetle species richness among the forest management types was in general not that large. The major exception to this trend, however, was found in set-asides in Finland. These had the lowest species richness overall, indicating that the hypothesis of richness differing between forest management types to be somewhat correct. The differences found in set-asides were not universal between the countries. This can be explained by considering that set-aside locations used in Sweden were smaller forested areas surrounded by clearcuts, whilst the set-asides in Finland were part of a larger forested area. The lack of uniformity between the countries could maybe be influenced by the closeness to the edges in Sweden, potentially having affected the species richness in these locations. This, due to an influx of species from the matrix and the edge zones, providing habitats for a more diverse array of species (Spence et al., 1996). The differences in richness between the set-asides in both countries can subsequently be explained by considering that species richness in smaller patches (such as the ones in Sweden) tend to be higher than the richness in larger areas (for example the patch in Finland, that was a small part of a contiguous forested area) (Niemelä et al.,1988). This could indicate that edge effects were at play in the smaller patches in Sweden.

The results of beetle abundance showed that set-aside patches differed from all other forest management types, the most significant result was found in set-asides in Sweden, having the highest carabid abundance of all forest management types and between the countries. Retention patches in Finland instead showed the lowest beetle abundance of all forest management types. This validates the hypothesis that abundance should differ between forest management types and between the two countries but showed that set-asides in Sweden harbour higher beetle abundance than any of the other forest types, including set-asides in Finland. The high abundance of beetles found in set-asides in Sweden could be due to the amount of leaf and needle litter biomass present. A study by Bird & Chatarpaul (1986) identified that after forest management, there were negative changes, not only in the amount but also the quality of ground and leaf litter, which was no longer being replenished. Thus, causing biological changes, such as through temperature and moisture content loss which in turn affects invertebrates such as carabid beetles. It has also been noted that carabid larvae tend to be more plentiful in sites containing leaf litter, than in control sites lacking it, this would contribute to continued higher abundance (Magura et al., 2005). This pattern could be applied to my results, where Swedish set-asides had the highest carabid abundance. However, it is unclear as to why this is not mirrored in the set-asides in Finland. A speculative reason for the differences in carabid abundance between Finland and Sweden could be the distance from the edges. The set-asides used in this study differ somewhat between the countries, as in Finland they were a part of a continuous nature reserve while in Sweden they were largely small areas surrounded by other forest management types. These edge effects include humidity, wind and increased predation risk (Saunders et al., 1991). The larger forested areas (in Finland) could be expected to be home to more forest specialists as the area is dominated by a uniform forest, without the impact of edge effects. Whereas the smaller set-asides (like those in Sweden) could contain a more heterogeneous forest, therefore being more suitable for a multitude of generalist species (Jukes et al., 2000).

The results from carabid community composition also indicate some overlap between the species found in the different forest management types, as 41% of all species identified were found in all of the forest management types. The large overlap may indicate that the majority of species found were generalists and not specialists.

When pooling the species found in the two countries for all forest management types, it was observed that 50% (34 species) were found in both Sweden and Finland. Of all species, 31% (21 species) were found in only Finland and 19% (13 species) were only found in Sweden. This shows that there were some small differences between the countries that may generate differences in species composition. However, the reason behind this is unknown. It is possible to speculate that details in the forest management processes between the two countries could lie behind this. For example, it is known that the set-asides in Finland were part of contiguous forest while the ones in Sweden were small plots set-aside for conservation purposes. This could potentially have an impact on the overall species able to thrive in the different countries leading to the differences in species found in the two countries.

The results show that there is much overlap in carabid species between the forest management types. All forest management types in Sweden have *Carabus violaceus* as the most common species. *Carabus violaceus* is known as being a widespread generalist species, thriving in a multitude of habitats, from forests to grasslands (SLU Artdatabanken, 2024e; Bräunicke & Trautner, 2009). Both set-asides and retention patches in Finland have *Pterostichus oblongopunctatus* as the species with the highest abundance. This species is known to reside in forested areas (SLU Artdatabanken, 2024a). Old clearcuts in Finland have *Trechus secalis* as the most widespread carabid species. However, *Trechus secalis* is the second most common carabid in retention patches in Finland. *Trechus secalis* is known to reside in open environments as well as forests (SLU Artdatabanken, 2024b). This is consistent with characteristics found in clearcut locations as they largely lack continuous canopy cover as all large trees are removed, allowing more sunlight to reach the forest floor.

The three most common species found in the set-asides in Sweden were *Carabus violaceus, Pterostichus oblongopunctatus* and *Carabus hortensis.* With 963, 604 and 544 individuals, respectively. In Finland, the most common species were *Pterostichus oblongopunctatus, Calathus micropterus,* and *Carabus glabratus.* With 1068, 305 and 215 individuals, respectively. *Carabus violaceus* is noted as being predominantly a forest species but can also be found in open grasslands (SLU Artdatabanken, 2024e; Bräunicke & Trautner, 2009). *Pterostichus oblongopunctatus, Carabus hortensis* and *Carabus glabratus* are most commonly found in forested areas (SLU Artdatabanken, 2024a; SLU Artdatabanken, 2024c; SLU Artdatabanken, 2024d; Bräunicke & Trautner, 2009). *Calathus micropterus* is instead mainly a heathland species, commonly found in sandy heathlands and sandy pine forests (Bräunicke & Trautner, 2009). The primary species mentioned above found in the set-asides in both countries were also found in retention patches and old clearcuts. They will therefore be regarded as generalist species. Previous studies have found that there is a shift towards forest specialists in areas with increased stand age (Jukes et al., 2000). Out of all the most common generalist species found in the set-asides, the only one that sticks out is *Calathus micropterus.* It is therefore possible to deduce that the set-asides in Finland were in part made up of sandy pine forests.

When compared to all other forest management types, set-asides contained four species not found anywhere else. Two of the species found have a preference for wetter habitats, which can be found in areas with less continuous canopy cover to intercept rainfall. It is therefore unexpected to find species with this habitat preference within a forest management type that is commonly dominated by large old-growth trees with a dense canopy. The other two species found in set-asides differed somewhat. With one only commonly found in areas that have recently experienced forest fire, and the other thriving in areas of continuous open habitat. This diverse array of species, requiring specific habitats, illustrates the potentially large differences between the set-asides used in this study. Clearcuts were shown to have seven unique species, these largely being species with a preference for open and wetter landscapes with more ground vegetation. This may be explained by the clearcuts used in this study being 30 years old and the establishment of new-growth having taken place. However, these clearcuts still lacked large trees and continuous canopy cover, allowing more rainfall to reach the ground. Out of all management types, retention patches were shown to contain the highest number of unique species. The majority of these species had a preference for open habitats and open wet habitats. There were also species that had a preference for heathland habitats, and those with a preference for forests. The large number of unique species found in retention patches could be explained by a possible influx of species from the matrix, this paired with the retention patch providing a multitude of different habitats allowing a more diverse array of species to thrive there.

There was much overlap found between species within the clearcuts and retention patches, with seven species being found in both management types. There is also a considerable overlap between retention patches and set-asides, with five species being found in both forest management types. Thus, indicating that the forest management types can be seen as a form of gradient where more similar management types have a greater overlap of species than more dissimilar forest management types. The difference in forest management types is most clear when comparing clearcuts and set-asides as these forest management types have the least species overlap, with a total of one species. Note that species were recorded even if they had a noted abundance as low as one individual, meaning that there is a possibility that individuals caught were not necessarily representative of the different forest management types.

The results from trap location in retention patches show that trap location has no effect on beetle community composition. Retention patches were used in the example as they are the only forest management type, out of those analyzed, that has clear edges as they are surrounded by clearcuts. When the results from trap location were visualized in a Venn diagram there was an overlap of 62%. The remaining percentage caught within traps was divided between edge traps (14%) and traps located within the middle of the retention patch (23%). This pattern could indicate that the whole retention patch was possibly influenced by edge effects or that the retention patches used were too small to be influenced by edge effects at all. This has been recognized in a paper by Laurance (1991) where it was shown that edge effects were evident up to 500 m inside the fragment, however, the largest effects were noted within 200 m. These edge effects are expected to influence the retention patches in a number of ways. Ranging from increased wind strength, higher amounts of sunlight and an elevated predation risk, paired with reduced humidity (Saunders et al., 1991). It can be assumed that the retention patches used were small and had irregular edges, as smaller patches with a higher edge-to-core ratio have on average, a less distinct species richness and species composition than larger patches with a lower edge-to-core ratio. The smaller patches have higher ratios of perimeter and therefore the middles of them are affected by multiple edges and therefore edge effects (Malcolm, 1994; Banks-Leite et al., 2010). This may explain why the results did not indicate large differences between edge and middle trap location.

4.2 Conclusion

In conclusion, species richness was noted as being marginally higher in retention patches in Finland, while carabid abundance was lowest here, compared to all other forest management types. Furthermore, species richness was lowest in set-asides in Finland. Abundance was concluded to be higher in set-asides in Sweden than in all other forest management types. There was also significant overlap in carabid community composition for all forest management types with a total of 41% of all species being found in all forest management types and 50% of all species were found in both countries. In Sweden, *Carabus violaceus* was the most common species. In Finland, however, the most common species, found in all forest management types, was *Pterostichus oblongopunctatus*. This was the most abundant species in all forest management types in Finland other than the old clearcuts, where *Trechus secalis* was more common. The different species found, together with differences in abundance and richness, is thought to be because of various edge effects, changes in leaf and needle litter biomass and patch size (Saunders et al., 1991; Bird & Chatarpaul, 1986; Malcolm, 1994; Banks-Leite et al., 2010). Trap location was not significant for beetle community composition in retention patches, showing that edge effects were largely at play in the whole patch. With the majority of species being found in both edge and middle trap locations.

The main conclusion that can be drawn from this study is that human activities through different forest management do influence carabid richness and abundance, together with carabid community composition, but that the differences found varied across the countries. In order to fully understand the effect that forest management has on carabid beetles it is necessary to conduct further studies.

4.3 Future studies & Caveats

In future studies regarding carabid beetle abundance and richness in different forest management types in Fennoscandia, it would be of great interest to incorporate more variables into the study. Mainly in order to see the effect many of these variables actually have on carabid beetles and how changes in their habitat can affect them. For example, measuring light influx in the different trap locations and forest management types could give further insight into the observed patterns for carabid abundance and richness and the effect of trap location. This, paired with measuring humidity, wind and taking photos of the different forest management locations would aid in further understanding the reasons behind some of the patterns found. Studying other invertebrate groups and known predators of carabid beetles could also help to complete the picture as to what affects carabid beetles in the different forest management types.

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