Effects of prescribed forest burning on carabid beetles (Coleoptera: Carabidae): a case study in south-eastern Norway

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The influence of prescribed burning on ground beetles was studied in a single 12-ha stand that was partially clear-cut, selectively-cut and retained (= standing forest), and was compared to an unburned stand in 2002 in SE Norway. Thirty-two species were collected using Barber pitfall traps. Carabids were more numerous and more diverse in the burned area, compared to the unburned forest. Overall abundance was highest in the selectively-cut treatment, followed by the clear-cut and standing forest. Species diversity tended to increase in the sequence unburned forest – burned standing forest – burned selectively-cut – burned clear-cut. Species composition differed little between the burned treatments. *Pterostichus adstrictus*, a species associated with open habitats and which frequently colonizes burned areas, was the most abundant species collected. It was most common in the burned area, particularly in the selectively-cut treatment. Our results suggest that burning of a single stand may support some carabid species, even endangered ones, although larger forest fires are probably more effective for conservation purposes.

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1. Introduction

Wildfires are among the basic ecological factors that change habitats and initiate the succession of new forest communities (Zackrisson 1977, Niklasson & Granström 2000, Ryan 2002). Burned areas are ephemeral habitats presenting a broad range of ecological niches that many insect species may exploit. Burned areas are attractive for insects because they provide an easily accessible source of nutrients, competition is low or absent, and temperature and moisture regimes are different and often more favourable than the surrounding unburned forests (Wikars 1992, McCullough *et al.* 1998).

Efficient fire suppression has been the rule in many countries during the 20th century, and has led to drastic decreases or even local extinctions of many pyrophilous insects (Gärdenfors 2000). To support these species, controlled burning of

forests or logged-over areas (= prescribed burning) has become a part of modern forest management during the last decades. For example, in Sweden, >1,000 ha of forest are burned annually as a conservation measure (Granström 2001). These areas have often been partly logged before burning.

Recently, the importance of alternative harvesting methods and their effects on soil-living invertebrates has been widely discussed (e.g., Gardner & Usher 1989, Atlegrim & Sjöberg 1996, Koivula 2002). However, the effects of fire in alternatively-harvested stands on invertebrates have been much less studied. Although some logged areas are burned annually, there is very little evidence that such treatments have a conservation function (Wikars 1995a, Saint-Germain *et al.* 2005). Knowledge on the effects of burning harvested areas would help forest managers to optimize the positive effects of controlled burning on threatened species.

Several studies have described the composition of carabid beetle assemblages (Coleoptera: Carabidae) during forest successional cycles, under both natural and burned conditions (e.g., Holliday 1984, 1992, Muona & Rutanen 1994, Butterfield 1997, Rainio & Niemelä 2003). The influx of pyrophilous invaders may depend on the size of the burned area, the amount of burned wood left, competition by open-habitat generalist species that colonize the area between harvest and fire, and other, sometimes unknown, factors (Ahlgren 1974, Kolbe 1981, Wikars 1995a).

A field study was undertaken in SE Norway to investigate the insect assemblages of three burned forest treatments (clear-cut, selectively-cut, and standing forest) and one unburned forest habitat. In this paper, we report the results from the sampling of ground beetles. Results on other beetle groups, sampled using methods other than pitfall trapping and during subsequent post-fire years, will be presented in forth-coming reports.

2. Material and methods

2.1. Study area

The study area is situated in Gravberget, southeastern Norway, ca. 220 km north-east from Oslo (60°58.8' N, 12°06.7' E). Mean annual temperature is ca. +2.1 °C, with monthly averages ranging from –10°C to +14°C. Mean annual precipitation is 795 mm, with monthly averages ranging from 37 to 97 mm (measured at the nearest meteorological station in Trysil, http://met.no). The study area is about 450 m a.s.l. and consists of boreal conifer forests.

In May 2002, a prescribed burning of ca. 12 ha covered three habitat types: clear-cut (CC), selectively-cut (AC), and standing (= retained) forest (SF). A control site with unburned forest (UF) was situated about 100 m from the burned area. Both burned and unburned sites were predominantly covered with Norway spruce (*Picea abies* (L.) Karst.) forest on a hillside with a westerly aspect of approx. 15° down to a small river. This set-up created a large variation in vegetation types, soil wetness and forest production potential within the study area.

On the top of the hill, the environment was dry with pine trees (*Pinus sylvestris* L.) and lichens (*Cladonia* spp.) dominating. Further down the hill, vegetation mainly consisted of Norway spruce and *Calluna vulgaris* (L.) Hull. *Vaccinium* shrubs were abundant on well-drained soils. Along the riverside, Norway spruce was growing on water-logged soils.

The northern end of the study area was a clearcut (CC; completely cleared of trees) with an exception of a strip of poor-quality-timber spruce trees left along the river margin for aquatic biotope protection purposes (approx. 5% of area). The selectively-cut (AC) section was situated south and immediately adjacent to the CC site. The selective cutting was undertaken by harvesting approximately 90% of the trees, which represented a sufficiently large dimension to cover the expenses of the operation and leaving trees that would normally survive a low-intensity forest fire, such as large pines. Thus, approx. 10% of the trees were retained and evenly distributed throughout the area covered by the treatment. As in the CC, a strip of poor-quality-timber trees were left along the riverside. The third treatment, standing forest (SF), represented boreal conifer forest typical of the region, and was situated south of the AC site.

Moist weather preceded the prescribed forest fire, and heterogeneous soil conditions made the

Table 1. Carabids collected during the summer of 2002 in Gravberget, SE Norway, in the four study plots: burned clear-cut (CC), burned selectively cut (AC), burned standing forest (SF), and unburned forest (UF). Group (= ecological groups): H = hygrophilous, F = closed forest, O = open-habitat species. No. spp. = observed number of species; Estim. no. spp. = Chao estimate of total number of species.

	Species	Group	CC	AC	SF	UF	Total
1	*Leistus terminatus* Mellw.	H	–	–	–	1	1
2	*Notiophilus aquaticus* L.	H	1	5	4	1	11
3	*N. biguttatus* F.	F	26	50	17	2	95
4	*N. germinyi* Fauv.	F	1	4	1	1	7
5	*Carabus violaceus* L.	F	2	3	2	–	7
6	*Cychrus caraboides* L.	F	–	1	–	–	1
7	*Cicindela campestris* L.	O	8	1	–	–	9
8	*C. sylvatica* L.	O	2	–	–	–	2
9	*Miscodera arctica* Payk.	F	2	1	–	–	3
10	*Patrobus assimilis* Chaud.	F	–	3	3	4	10
11	*P. atrorufus* Stroem.	H	1	1	–	–	2
12	*Trechus rubens* F.	H	–	–	1	–	1
13	*Bembidion grapei* Gyll.	O	4	2	–	–	6
14	*B. lampros* Hbst.	O	11	2	–	–	13
15	*B. quadrimaculatus* L.	H	1	–	–	–	1
16	*Pterostichus adstrictus* Esch.	O	248	361	170	1	780
17	*P. diligens* Sturm	H	1	–	–	–	1
18	*P. oblongopunctatus* F.	F	3	–	–	–	3
19	*P. strenuus* Panz.	F	2	4	1	–	7
20	*Calathus micropterus* Duft.	F	7	61	61	31	160
21	*Agonum ericeti* Panz.	H	1	–	–	–	1
22	*A. fuliginosum* Panz.	H	–	–	1	–	1
23	*Amara brunnea* Gyll.	F	1	1	–	–	2
24	*A. communis* Panz.	O	1	–	–	–	1
25	*A. lunicollis* Shiødte	O	3	–	3	–	6
26	*A. nigricornis* Thoms.	O	–	6	8	–	14
27	*A. plebeja* Gyll.	O	–	–	1	–	1
28	*Harpalus fuliginosus* Duft.	O	–	1	1	–	2
29	*H. quadripunctatus* Dej.	F	6	15	9	–	30
30	*Bradycellus caucasicus* Chaud.	O	1	–	–	–	1
31	*Dicheirotrichus placidus* Gyll.	F	1	–	–	–	1
32	*Cymindis vaporariorum* L.	O	–	1	2	–	3
	No. of individuals		334	523	285	41	1,183
	No. spp. (S_{obs})		23	19	16	7	32
	Estim. no. spp. (Chao Index; S_{est})		35.5	31.3	25.0	15.0	
	S_{obs} / S_{est}		0.65	0.61	0.64	0.47	

burning very uneven, particularly in the forested part. Due to the high costs required to conduct this kind of experimental study, it was not possible to replicate the experimental set-up.

2.2. Sampling

Carabids were sampled in the three burned site types (CC, AC, and SF) and one unburned site (UF) during the summer of 2002 using Barber pitfall traps (e.g., Baars 1979, Spence & Niemelä 1994). At each site, two groups of pitfall traps were used to reduce sampling variation due to the heterogeneity of the area. The two trap groups were approx. 50–100 m apart at the uphill and downhill locations, respectively. Individual traps within each group were 3–5 m apart and set in a 20-m diameter circle. In each trap group, 10 plastic pitfall traps (mouth diameter 6 cm, depth 8 cm)

were dug into the soil so that the rim of the cup was at the level of the soil surface.

The cups were partly filled with a 1:1 mixture of propylene glycol and water, with a drop of detergent to reduce surface tension. The traps were accompanied with transparent plastic roofs (set on wire "legs") to reduce the risk of flooding of the cups from rainfall (Phillips & Cobb 2005). In total, 80 traps were used, and emptied in four occasions at 3–4 weeks intervals between 1 June and 4 September. Beetles were hand-sorted in the laboratory, and identified using the nomenclature by Kryzhanovskij *et al.* (1995). For analytical purposes, the collected insects from the four sampling periods were pooled to eliminate temporal variation.

2.3. Statistical analyses

The relative abundances of sampled beetle assemblages from the four sites were used in two analysis steps. First, the burned and unburned sites were compared; second, the three logging treatments within the burned area were compared. Differences in relative abundance of carabids among sites and treatments were tested using chi-square analysis.

Canonical correspondence analysis (CCA) with the four types of forest treatments (three logged, one un-harvested) as environmental dummy variables was applied to identify species associations with the treatments. Furthermore, the un-logged forest site was excluded from the analysis and thus only the 60 pitfalls from the burned sites were compared using correspondence analysis (CA). These ordinations were performed using CANOCO 4.0 (ter Braak & Šmilauer 1998).

To evaluate the species diversity within each site, an abundance-based estimator of species richness (S_{est}) was calculated (Chao 1984):

$$S_{est} = S_{obs} + (F_1^2/2*F_2) \qquad (1)$$

where S_{obs} is the observed number of species, F_1 is the number of singletons (species represented by a single individual) and F_2 is the number of doubletons (species represented by two individuals).
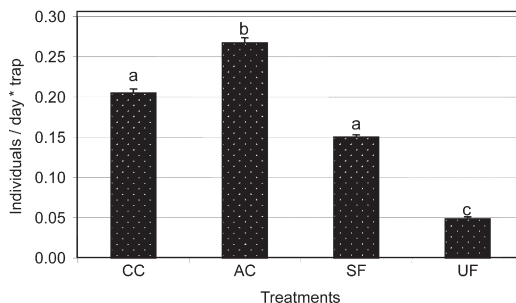

Fig. 1. Mean carabid catch in the four studied plots: burned clear cut (CC), burned selectively cut (AC), burned standing forest (SF), and unburned forest (UF) collected during the summer 2002 in Gravberget, SE Norway. Letters indicate statistically significant differences (*p* <0.05).

Species were assigned to three ecological groups: hygrophilous, forest-associated and open-habitat species, according to their ecological associations (Lindroth 1992). Species accounting for >7% of the catch within a given site were considered dominant.

3. Results

A total of 1,183 individuals from 32 species were collected. The three most numerous species were *Pterostichus adstrictus*, *Calathus micropterus* and *Notiophilus biguttatus* that altogether made up for almost 90% of the total carabid catch (Table 1). The mean carabid catch was 0.17 (± 0.005 SE) individuals per trap per day (Fig. 1).

3.1. Comparison of burned and unburned sites

The average collection efficiency in the burned and unburned forest was 0.21 (± 0.005 SE) and 0.05 (± 0.003 SE) individuals per trap per day, respectively. Chi-square analysis showed significant differences between burned and unburned sites (χ^2 = 994.7, df = 1, *p* <0.001). *Pterostichus adstrictus* made up for 66% of the total catch and was the most abundant species in the burned sites. Only one specimen of *P. adstrictus* was found in the unburned forest. Only 3% of the total catch (seven species) were collected in the unburned forest (Table 1). Of these, *C. micropterus* was the
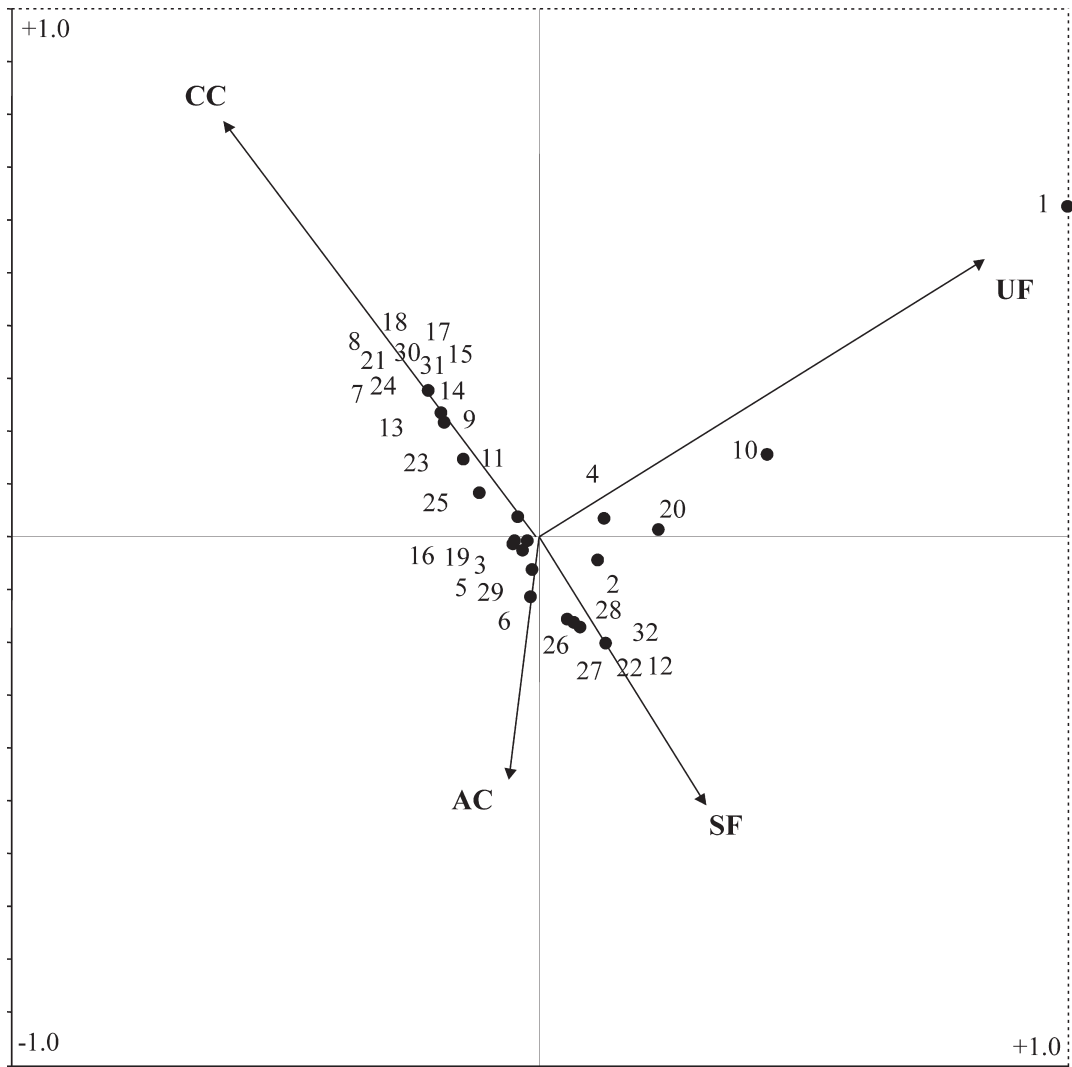
Fig. 2. Canonical correspondence analysis for the 80 pitfall traps with treatments as environmental dummy variables: burned clear-cut (CC), burned alternatively cut (AC), burned standing forest (SF), and unburned forest (UF). Numbers indicate species as shown in Table 1.

most abundant species. *Leistus terminatus* was the only species found exclusively in the unburned forest, but only one specimen was collected. The Chao index indicated that the burned sites hosted approx. two times higher species richness (25–35) than the unburned forest (UF; 15).

The CCA with treatment types as dummy variables revealed that some species were associated with certain types of treatments (Fig. 2). The first two axes in the CCA plot explained 93% of the total variability. For example, the analysis

showed a relatively strong association between the forest site (UF) and *Patrobus assimilis*.

3.2. Effects of burned forest treatments

The beetle catch in the selectively-cut site (AC) was 0.27 ($\pm$ 0.006 SE); in the clear-cut site (CC) 0.20 ($\pm$ 0.005 SE); and in the standing forest site (SF) 0.15 ($\pm$ 0.003 SE) individuals per trap per day. The average beetle catch for the three treatments differed significantly from the expected,
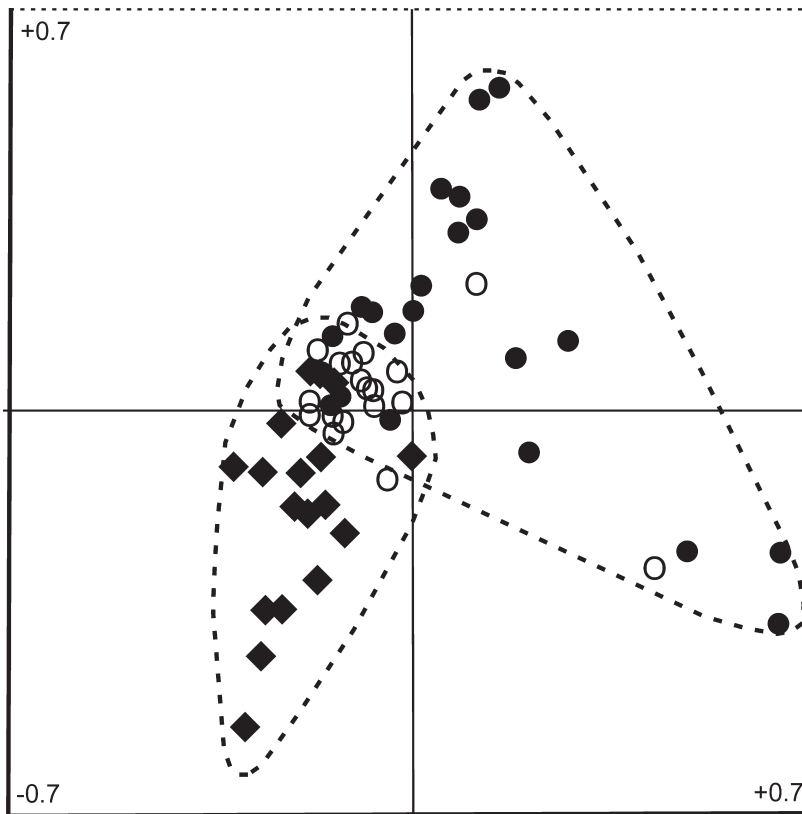
Fig. 3. Correspondence analysis for the 60 pit-fall traps of the burned sites. Filled diamonds = clear-cut (CC), open circles = selective cut (AC), filled circles = standing forest (SF).

i.e. that collected numbers of beetles would be equal for the three treatments ($\chi^2 = 83.0$, df = 2, p <0.001). Species richness was highest in the CC (23 species), followed by AC (19 species), and SF (16 species). The Chao index showed that the estimated numbers of species were higher than the observed number of species, indicating that continued sampling would produce more species than were actually collected.

The CCA showed several species being slightly associated with the CC treatment, and both open-habitat and forest specialists were collected in this site (Fig. 2, Table 1). The open-habitat specialists *P. adstrictus*, *Bembidion lampros*, *Cicindela campestris* and *C. sylvatica* were the most characteristic species in CC, in addition to the forest species *N. biguttatus* that was also relatively abundant in the clear-cut. The CCA did not show clear associations between carabid species and AC or SF habitat types (Fig. 2).

The most abundant species in AC were *P. adstrictus*, *N. biguttatus*, and *C. micropterus* (Table 1). No particular species were more abun-

dant in SF, compared to the other treatments.

Pterostichus adstrictus made up for 60% of the catch in SF, 69% in AC, and 74% in CC. Eleven additional open-habitat species (5% of total catch) were most abundantly caught in the CC site. The proportion of forest species was 27.6% of all specimens (12 species). Forest species decreased from 33% to 16% of treatment totals in the sequence SF-AC-CC. Eight hygrophilous species comprised less than 2% of the total catch.

Three species dominated the catch in CC, AC and SF habitats. In CC, the dominant species were *P. adstrictus* and *N. biguttatus*. In AC, on the other hand, *P. adstrictus*, *N. biguttatus* and *C. micropterus* dominated, whereas in SF the most abundant species were *P. adstrictus* and *C. micropterus*. In UF, there was a single dominating species: *C. micropterus*.

The CA, including the 60 pitfall traps of "burned" treatments, separated CC from SF, while AC scores fell between the scores of the other two habitats (Fig. 3). The first two axes in the CA plot explained 41% of the total variability.

4. Discussion

The carabid assemblages sampled in this study represented a typical set of species characteristic of boreal forests (e.g., Niemelä *et al.* 1988, Lindroth 1992). We found that carabids were more numerous and more diverse in the burned forest, compared to the untouched forest, as earlier shown by Wikars (1992), Gongalsky *et al.* (2003) and Saint-Germain *et al.* (2005). Prescribed burning should potentially attract fire specialists (Wikars 1995b), but we caught no true pyrophilous carabids, such as *Sericoda quadripunctata* Deg. or *Pterostichus quadrifoveolatus* Letz. The reasons for their absence might be related to the relatively small size of the burned area. Wikars (1995b) stated that the size of the burned forest may be an important factor in attracting pyrophilous species. Regarding conservation of pyrophilous carabids, burns should perhaps cover much more than the studied 12 ha, or several burns should be spread over larger geographical areas. Another contributing reason for the lack of pyrophilous carabids could be that these species in this particular region of Norway have become extremely rare or locally extinct. Thus, as south-eastern Norway has been exposed to few forest fires during the last decades, many pyrophilous carabids may already have a distribution too scattered to efficiently colonize a small fire.

The forest fire also apparently attracted other carabids, such as *P. adstrictus*, *N. biguttatus*, *Harpalus quadripunctatus* and *B. lampros* (or at least they were most abundant in burned sites). Such species can be attracted to the newly created habitat, but may not be obligatorily dependent on fires, because they also appear in unburned habitats (Wikars 1997). Wikars and Schimmel (2001) used the term "fire-favoured" for both obligatory and facultative pyrophilous insects and emphasized that distinguishing pyrophilous from fire-favoured species can be difficult, particularly for soil-living species. Our material showed that these fire-favoured species were able to locate this fire, probably as a result of their high abundances in adjacent areas. Burned areas have the quality to support many insect species, often in high abundances, for several reasons. Perhaps the most notable factor is the ash- and burned-wood-covered black ground that is efficiently heated by the sun (Kimmins 1997) and is therefore attractive for thermophilous species (McCullough *et al.* 1998). Forested areas are generally wetter and cooler than open areas, which might negatively affect the abundance of many carabid species. Also, the capturing efficiency of pitfall traps in this type of forests might be reduced by the heterogeneity and rough structure of the soil surface caused by moss and lichen cover (e.g., Koivula *et al.* 2003). This could be the case in our unburned forest samples that had lower species richness than had the burned sites. The actual (observed) number of species (S_{obs}) collected in UF was roughly two times lower than the estimated total number of species (S_{est}) (Table 1). Contrary to the UF habitat, the proportion of observed species richness and the estimated species richness in the burned sites was more than 60%.

Pterostichus adstrictus was the most abundant species in our samples, with two-thirds of the total catch. This species often colonizes recently burned areas in large numbers and also becomes more abundant in the northern areas of Scandinavia than the more southerly distributed pyrophilous *P. quadrifoveolatus* (Wikars 1997). Furthermore, there were no red-listed species in our data set, and only one rare species was collected, viz. *Bembidion grapei*.

The highest carabid catch was found in the selectively-cut (AC) site, and the highest species diversity was observed in the clear-cut (CC) site. As discussed above, the higher capturing efficiency and richness estimates for the burned sites were probably due to the cleared and flat soil surface providing fewer possibilities for beetles to avoid traps. Differences between treatments, though, could potentially be caused by variations in micro-climate, habitat structure, food sources, or other unknown factors. However, the lack of replication in the present study suggests that these findings should be interpreted with caution. We cannot, for example, rule out the possibility of hidden environmental gradients (over the 12-ha area with the three burned treatments) that could partly be driving the results.

Prescribed burns of cut forests were originally planned as a measure against the decrease of abundance of pyrophilous species observed during the last decades in Scandinavia (Granström

2001). Loss of species observed across Europe (Kotze & O'Hara 2003) is thought to be partly reduced by prescribed fires, as they provide a broad range of ecological niches for species inhabiting forests, such as carabids. The relatively high abundance and large biodiversity reported in this study, as well as the presence of at least one rare species and several fire-favoured species, provide biological support for prescribed fires as a valuable conservation measure in boreal forests. We emphasize the importance of undertaking prescribed burning in environmentally heterogeneous areas, including a variety of habitats and forest management regimes, such as those present in this study. Such recommendations have also been made by other authors (e.g., Bohman *et al.* 2004). At present, prescribed burning in at least 5% of large land holdings in Sweden is recommended as a conservation measure for improved biodiversity by the Swedish Forest Stewardship Council (Swedish FSC 1998). Such measures should also be considered in Norway.

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