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ORIGINAL PAPER

Responses of eight boreal flat bug (Heteroptera: Aradidae) species to clear-cutting and forest fire

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Abstract Boreal flat bugs include a high proportion of species that are considered negatively affected by forestry. Knowledge on the biology and habitat demands of individual species is generally limited. We examined the influence on flat bugs of stand-age and clear-cutting, comparing five classes of spruce stands. The five classes were: clear-cut, unthinned, and thinned (all three products of current clear-cutting forestry), mature managed and old-growth stands (these two had never been clear-cut). We also compared unburned and recently burned mature pine forest. Fire, but not stand age, had a pronounced effect on species richness and total abundance. *Aradus depressus* showed a significant association with older forest stands. *Aradus betulae* occurred only in clear-cuts and burned forest indicating that this species is favored by disturbance in general. *Aradus lugubris*, *Aradus crenaticollis* and *Aradus brevicollis* were found only in the burned forest. *Aradus brevicollis* has not previously been shown to be associated with fire.

Keywords Aradidae · Forest fire · Stand-age · Forest management · Clear-cutting · Habitat demands

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Introduction

A reduction in the quality and quantity of suitable habitat as a consequence of human resource use has had negative influences on the populations of many species worldwide (Harrison and Bruna 1999; Gu et al. 2002; Aune et al. 2005). In Fennoscandian (the Scandinavian and Kola peninsulas plus Finland and Karelia) boreal forests, management focusing on timber production covers almost all forest land. Natural old-growth forests have been replaced with selectively cut stands and during the last ~60 years by even-aged stands developed after clear-cutting (Linder and Östlund 1998). Today, about 95% of these boreal forests are commercially used and, of the 5% set aside for conservation less than half is virgin forest, i.e., forest hardly affected by human activity (Berg et al. 1994; Fridman 1999). Many managed stands lack structural and functional heterogeneity because of the loss of structures (e.g., dead wood) and processes (e.g., natural disturbances) that characterise naturally developed forests (Kuuluvainen et al. 2002; Bengtsson et al. 2003). In the natural boreal forests, fire was the most important stand-replacing disturbance (Zackrisson 1977; Esseen et al. 1992; Weber and Stocks 1998) and approximately one percent of the forest burned each year (Zackrisson and Östlund 1991). Many species have adapted to fire or the habitats created by fire, which include large areas with large amounts of dead wood and successional forests dominated by deciduous trees (Zackrisson 1977; Engelmark 1999). Nowadays, forest fires are heavily suppressed, and in Sweden less than 0.02% of the forest burns each year (Zackrisson and Östlund 1991). Instead, clear-cutting has become the dominating stand-replacing disturbance. Forestry has also severely reduced the amount of dead wood in the forest and, since dead wood has been identified as one of the most important structures for biodiversity, this can explain many of the negative effects of forestry on biodiversity (Esseen et al. 1992; Siitonen 2001; Grove 2002).

In recent years, conservation oriented measures have been implemented in many parts of the boreal biome. In Sweden, the forestry act of 1994 (giving environmental goals the same importance as production goals), environmental certification of forestry and environmental goals on national and EU-level have together driven this development (Anonymous 1994, 2000, 2006). The measures include the creation of snags on most clear-cuts and prescribed burnings on 5% of the certified clear-cuts each year. However, stands established before the implementation of conservation-oriented measures are extremely poor in dead wood, have low proportions of deciduous trees and lack structures that are important for many species (Östlund et al. 1997; Linder and Östlund 1998). Few studies have assessed these young even-aged stands for their importance for species negatively affected by forestry (but see Caruso et al. 2008; Dynesius et al. 2009). Organisms that are difficult to survey, such as the flat bugs (Heteroptera: Aradidae) studied here, are even less known in this respect. Very few studies have made quantitative comparisons of the habitat use of flat bugs (but see Gossner et al. 2007 who provide some quantitative data for three species). We examined the flat bug fauna in stands of different ages and disturbance histories in Swedish boreal forests to provide data on effects of clear-cutting forestry and forest fire on this little known group. More specifically, we asked the following questions:

1. What is the distribution of flat bugs in spruce forest stands of different ages and management histories?
2. How common are flat bugs in a recently burned mature pine forest compared to a similar, but unburned forest?

Materials and methods

Study areas and experimental design

The study was performed in the middle and northern boreal zones of northern Sweden (Ahti et al. 1968). The influence of stand-age and history was evaluated in spruce (*Picea abies*) dominated stands in nine study areas in the provinces of Ångermanland and Åsele lappmark. Pine (*Pinus sylvestris*) and deciduous trees, such as birch (*Betula pubescens* and *B. pendula*), also occurred in the stands. The effect of fire was assessed in pine (*P. sylvestris*) dominated forest in one study area in the province of Norrbotten. Each of the nine stand-age study areas included three stands that had been clear-cut, a recent clear-cut (5–6 years after logging), a pre-thinning stand (mean age 30 years, hereafter referred to as unthinned although most of them have been pre-commercially thinned), and a thinning stand (mean age 53 years, commercially thinned relatively recently). Each study area also included two stands that had never been clear-cut: one mature stand (mean age 108 years) and one old-growth stand (mean age 151 years). Latitude ranged between 63°37′ and 64°14′N, longitude between 16°54′ and 19°32′E, and elevation ranged between 100 and 550 m a.s.l. among the nine areas.

The burned area is the result of a large scale natural forest fire in the province of Norrbotten in August 2006. The fire was intense and killed many trees and consumed most of the bottom and field layers, even in the higher elevated parts, which were dominated by boulders and flat rocks. Approximately 250 ha on Stora Klusåberget (66°10′N, 20°50′E) of the 1,700 ha burned area was not salvage logged and will be set aside for conservation. The area is dominated by pine stands of various ages on dry to mesic ground. Within the conservation area, we located six sampling sites, approximately 350 m apart, and with a 2 km distance between the sites that were furthest apart. All sites were in 140–170 year old pine-dominated, relatively open stands ranging in elevation from 200 to 280 m a.s.l. In an unburned area approximately 3 km to the west, six control sampling sites were selected to be as similar as possible to the burned sites regarding stand-age, stand density and tree species composition, soil factors and topographical location. These control sites were between 300 m and 1 km apart and with 3 km between the sites furthest apart.

We sampled insects using triangular flight intercept/window traps (Polish IBL2-traps) attached between trees or wooden poles (clear-cuts) approximately 1.5 m above the ground (for illustration of the trap see Pettersson et al. 2007). In each site we set up three traps with different flight direction intercepts at least 50 m apart from each other. The total number of traps in the stand-age study was thus 9 study areas × 5 stand-ages × 3 traps = 135 traps and in the fire study 2 study areas (burned area and control area) × 6 sampling sites × 3 traps = 36 traps. The IBL2-traps consisted of a thin, semi-transparent plastic sheet tightened between three thicker plastic parts, making a triangular, window-like flight intercept with a surface of approximately 0.35 m^2. The sides prevented the insects from falling to the ground and instead funnelled them to the bottom tip of the triangle and further down a plastic funnel into a 725 ml collecting bottle. The collecting bottle was filled up to 1/3 with 70% propylene glycol and a small amount of detergent to kill and preserve the trapped insects. The funnel was equipped with an extra funnel draining rain water through a pipe on the side, preventing water from filling the bottle and diluting the glycol.

We caught insects in the stand-age study areas between late May and late September 2006. These traps were emptied twice, in late July and late September. In the fire study area insects were caught between late May and late September 2007, i.e., the first summer after the fire, and emptied once. After collection the insects were separated from the samples and sorted into orders in the lab for subsequent determination to species by experts.

Study organisms

Flat bugs (also called fungus bugs) occur worldwide and include about 1,900 species usually found in litter, in crevices in dead or dying trees, or under loose bark (Anonymous 2008; Heiss and Pericart 2007). In temperate and boreal forests most species are found under the bark of dead or burned trees or on polypore fungi (Heliövaara and Väisänen 1983). They occur on both conifers and/or broadleaves and most species are considered mycophagous (Usinger 1936; Matsuda 1977; Heliövaara and Väisänen 1983; Froeschner 1988; Taylor 1988; Deyrup and Mosley 2004). Some species occur almost exclusively in burned forest (Heliövaara and Väisänen 1983; Coulianos 1989; Wikars 1992; Hjältén et al. 2006). Generally *Aradus* species are good or very good at flying and many disperse over long distances. Fire associated species are particularly good flyers (CC Coulianos personal communication). For many species, however, knowledge about their habitat requirements is anecdotal or lacking (Heliövaara and Väisänen 1983; Coulianos 1989; Wikars 1992). Most flat bugs in Fennoscandia are considered negatively affected by forestry and 8 of the 21 *Aradidae* species including the only *Aneurus* species found in Sweden are nationally red listed (Gärdenfors 2005). Four of these red-listed species have been found in the three northern Swedish counties where our study areas are situated.

Statistical analyses

The flat bugs caught in the three traps at each sampling site were pooled and used as one observation. Hence, the number of replicates was nine for each stand-age and six for the burned and the unburned forest, respectively. We performed separate analyses of the stand-age and the fire data because they were collected during different years using different designs. Neither original nor transformed data fulfilled the requirements of normality and homoscedasticity for parametric tests and therefore we used the non-parametric Quade test for the stand-age data, with study area as the block factor and the Mann–Whitney U test to compare the burned and unburned forest. We used the tests to compare total flat bug abundance, species richness and the abundances of individual species. Because of the low statistical power no analyses were performed for species that occurred in less than five individuals or caught in less than four sampling sites. We used SYSTAT 12 (Systat Software Inc. 2007) for all analyses.

Results

In total we caught 119 flat bug individuals belonging to eight species of the genus *Aradus*. About 89 individuals of five species were caught in the 135 traps of the stand-age study and 30 individuals of five species in the 36 traps of the fire study (Tables 1, 2). Of the eight species, only *Aradus betulae* (L.) and *Aradus cinnamomeus* Panzer were present in both studies in low abundance. The two most abundant species in the stand-age study (*Aradus depressus* (Fabricius) and *Aradus betulinus* Fallén), together representing 87% of the individuals, were not caught in the fire study. The most common species in the fire study (*Aradus brevicollis* Fallén, 47% of the individuals) was not detected in the stand-age study.

Stand-age

The highest number of flat bugs was caught in old-growth stands (30 individuals) while the lowest number (9 individuals) was found in young unthinned spruce stands developed after clear-cutting (Table 1). Neither the differences in abundance nor the differences in species richness were, however, statistically significant in the Quade test (Table 1). *A. depressus* was significantly more abundant in the old-growth, mature, and thinned stand categories than on the clear-cuts, whereas, *A. betulinus* appeared to be indifferent to stand-age (Table 1). *A. betulae* was only caught in clear-cuts (4 individuals), *A. corticalis* (L.) appeared in clear-cuts (3) and thinned forests (1), and the 4 individuals of *A. cinnamomeus* were distributed among clear-cut, thinned and mature stands.

Forest fire

Both species richness and total abundance was significantly higher in the burned pine forest than in the unburned control (Table 2), where no flat bug was caught. For *A. brevicollis* and *Aradus lugubris* Fallén the difference was statistically significant (Table 2).

Discussion

Our results show that both forest fire and clear-cutting forestry/stand-age have pronounced effects on the abundance of individual flat bug species in Swedish boreal

Table 1 Accumulated number of species and individuals of flat bugs caught in the stand-age study

Variable	Clear-cut	Unthinned	Thinned	Mature	Old	Total	Quade test statistic	P	Paired post hoc tests
Species richness	4	2	4	2	2	5	0.637	0.640	
Abundance									
Aradus betulae	4	0	0	0	0	4			
Aradus betulinus	8	2	3	0	3	16	2.081	0.106	
Aradus cinnamomeus	1	0	2	1	0	4			
Aradus corticalis	3	0	1	0	0	4			
Aradus depressus	0	7	10	17	27	61	3.148	0.027	CC < T, M, O
Total	16	9	16	18	30	89	0.756	0.561	

Clear-cuts, un-thinned stands and thinned stands are the result of modern clear-cutting forestry, whereas the mature and old stands are two age classes of naturally regenerated forests that have been subjected to different degrees of historic selective cutting. The results of Quade tests on species richness, total abundance and abundance of the two most abundant species are presented in the three last columns. $N = 9$, i.e., the 9 stands sampled in each category were used as replicates

CC clear-cut, *T* thinned, *M* Mature, *O* old

Table 2 Accumulated number of species and individuals of flat bugs caught in the fire study and results from Mann–Whitney *U* tests on species richness, total abundance and abundance of the two most abundant and frequent species

Variable	Burned	Unburned	Mann–Whitney *U* test statistic	Kruskal–Wallis *P*
Species richness	5	0	36.00	0.002
Abundance				
Aradus betulae[a]	6	0		
Aradus brevicollis	14	0	36.00	0.002
Aradus cinnamomeus	1	0		
Aradus crenaticollis	3	0		
Aradus lugubris	6	0	30.00	0.021
Total	30	0	36.00	0.002

$N = 6$, i.e., the 6 sampling sites in each category were used as replicates

[a] This species was only found in two sampling sites and therefore no test was performed

forest. The effect of fire has previously been demonstrated (e.g., Hjältén et al. 2006), but the influence of clear-cutting and stand-age is less well known.

The fact that only two of the eight species were found in both studies could potentially be attributed to geographical distance, difference in dominating tree species (spruce vs. pine), differences between the 2 years, or to the effect of fire disturbance. All *Aradus* species occurring in the region of the study are good flyers (CC Coulianos, personal communication) suggesting that the catches can be attributed to the habitat association of the species. None of the two species appearing in both studies are specifically associated with fire or undisturbed spruce forests, which may explain their broad occurrence. *A. cinnamomeus* is a potential pest species living under the bark of living young pine trees (<30 years old) sucking the cambium and deeper tissues. The species thrives in exposed warm conditions and prefers sparse stands on dry, nutrient poor sites (Heliövaara and Väisänen 1988; Eidmann and Klingström 1990). We caught the species in low numbers in both young and older spruce-dominated forests and one individual was caught in the burned area. The other species present in both studies (*A. betulae*) was found only in the burned area and in the clear-cuts. In earlier studies it was also recorded from burned areas (Lappalainen and Simola 1998), which together with our results suggests that *A. betulae* is favored by disturbance both by fire and clear-cutting. *A. betulae* has been found on polypores on birch, particularly *Piptoporus betulinus*, but also on *Fomitopsis pinicola* and *Fomes fomentarius* on Scots pine, Norway spruce and deciduous trees (Heliövaara and Väisänen 1983; Coulianos 1989). In Germany the species has been found in relatively sunny habitats and strongly associated with the polypore *F. fomentarius* commonly found on dead or dying birches and other broadleaves (Gossner et al. 2007).

Stand-age

The assemblage composition of saproxylic beetles and parasitoid wasps has been shown to differ between old forests and clear-cuts (Hilszczański et al. 2005; Gibb et al. 2006; Johansson et al. 2007) and mature managed stands often support beetle (Martikainen et al. 2000) and wood fungi assemblages (Penttilä et al. 2004) different from those of natural old-growth forests. With respect to flat bugs, little evidence of such relationships exists. Our results show, however, that clear-cuts differ from spruce stands in that the most frequently caught species, *A. depressus*, could not be detected. In addition, this species seems to increase in abundance with stand-age, implying that it is a late-successional species. The lack of observations from the burned forest also suggests that in contrast to several other boreal species, it is not a disturbance-adapted species attracted by forest fires. In earlier studies *A. depressus* was recorded from polypores on deciduous trees particularly aspen and birch but also on pine (Heliövaara and Väisänen 1983; Coulianos 1989). It is likely that the older stands support larger populations as a result of the greater quantities of suitable habitats and substrates, such as dead stems and polypores. The old-growth stands in this study contain approximately three times more deciduous dead wood than the thinned and unthinned stands and almost twice as much as the clear-cuts (Gibb et al. 2005; Stenbacka unpublished data). The possibility that *A. depressus* could be intolerant to fully sun- and wind-exposed conditions must also be considered, athough the species can tolerate relatively open forests in Germany (Gossner et al. 2007).

Aradus betulinus seems to be a stand-age generalist that not only tolerates clear-cuts, but also tends to be more abundant on them (although differences were not statistically significant). The species lives on polypores, e.g., the common *F. pinicola*, on dead standing or lying Norway spruce and Scots pine and sometimes also on polypores on birch. It thrives in old shady forests and the species is reported as declining in Finland (Heliövaara and Väisänen 1983; Coulianos 1989). However, the broad habitat presence in this study suggests that *A. betulinus* may survive in the managed landscape. The lack of observations in the burned forest also suggests that the species is not pyrophilous (attracted to forest fires), making it even less vulnerable to current forest management.

Three of the four individuals of *A. corticalis* were caught on clear-cuts and the fourth in a thinned stand. Both these stand types have abundant supplies of recently killed tree parts such as stumps and tops. In contrast to *A. betulae* it was not caught in the fire study. Despite its low abundance in our data, *A. corticalis* is one of the most common flat bugs in Sweden and occurs on spruce stumps and polypores on spruce and pine especially on the common *F. pinicola* (Heliövaara and Väisänen 1983; Coulianos 1989). It has also earlier been recorded from clear-cuts (Pettersson and Nilsson 1986; Jonsell et al. 2005). This together with our record from a recently thinned stand and the lack of records from the burned area suggest that *A. corticalis* is attracted to relatively fresh dead wood not killed by fire. This may also explain the commonness of the species in the managed forest landscape.

Forest fire

The much higher total abundance and species richness in the burned area the first summer after the fire indicates that forest fire attracts flat bugs from relatively great distances. In addition, the lack of observations of three of the five species caught in the burned forest (representing almost 80% of the individuals) in the much larger stand-age study further strengthens this conclusion. For *A. lugubris* and *Aradus crenaticollis* Sahlberg, our results (Table 2) confirm earlier studies reporting that these species are more abundant in burned areas (Heliövaara and Väisänen 1983; Coulianos 1989; Wikars 1997; Lappalainen and Simola 1998; Bess et al. 2002; Wyniger et al. 2002; Hjältén et al. 2006). *A. lugubris* occurs mostly in burned pine forests while *A. crenaticollis* is also found in deciduous forest (Matsuda 1977; Heliövaara and Väisänen 1983). *A. crenaticollis* has been shown to quickly establish populations on new burned areas (Coulianos 1989). *A. lugubris* is known to disperse over great distances, which is characteristic of many pyrophilous species, as it has been found far from their present distribution area (Coulianos 1989). It has been repeatedly found in burned areas in northern Sweden (Pettersson 1994) suggesting that it can locate patches of suitable habitat over a large area. Furthermore, *A. lugubris* is known to utilize the fire dependent, wood living ascomycete *Daldinia loculata* (Wikars 2001), further supporting fire dependence.

Interestingly, *A. brevicollis* was by far the most abundantly caught species in the burned area while it was not found in the relatively large stand-age study, which contradicts earlier knowledge on the biology of this species. In previous studies *A. brevicollis* has been found on stumps and logs of Scots pine and Norway spruce in unburned forest (Heliövaara and Väisänen 1983; Coulianos 1989). It was not recorded from any of the investigated burned areas in northern Sweden in a study by Pettersson (1994) but recorded on burned clear-cuts by Bohman (2004). Further studies are thus required to establish the relationship of *A. brevicollis* abundance and fire.

We did not catch any of the four nationally red-listed flat bug species occurring in the region although three of them are considered pyrophilous (SLU 2005). This result suggests that they are rare and strengthens their red-list status. The strong attraction of fire for *A. lugribis* and *A. crenaticollis* (and perhaps also *A. brevicollis*) suggests that they, although still being relatively frequent, should be considered for the red-list as species that have declined considerably.

Conclusions

To conserve the flat bug fauna in Fennoscandian boreal forest, suitable habitats for all species must be maintained not only in reserves but also in the managed forest. Our results, in combination with previous studies, show that there is a group of pyrophilic flat bugs that most likely are totally dependent on the regular presence of forest fires in an area. In addition to this there seems to be at least one species (*A. depressus*) associated with relatively old stands. Still other species are present on clear-cuts and in young stands developed after clear-cutting suggesting that they are tolerant to modern forestry. In some cases clear-cutting may partly substitute forest fire, provided that tree stumps and tops are not harvested, because the post-clear-cutting landscape resembles the open and sun exposed habitats created by fire. The pyrophilic species could be favored by prescribed burnings where substantial volumes of trees are burned. *A. depressus* could likely be favored by the creation of dead aspen and birch wood in forest stands. Similar recommendations are given to promote many other organisms negatively affected by forestry and it should therefore be possible to conserve flat bugs within more general conservation and mitigation programs.

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References

Ahti T, Hämet-Ahti L, Jalas J (1968) Vegetation zones and their sections in northwestern Europe. Ann Bot Fenn 5:169–211

Anonymous (1994) Skogsvardslagen 1993:553. Handbok. in Swedish. Skogsstyrelsen, Jönköping

Anonymous (2000) Svensk FSC-standard för certifiering av skogsbruk (in Swedish). Forest Stewardship Council AC, Upsala

Anonymous (2006) Sveriges miljömål, officiell portal för våra miljömål. http://miljomal.nu/om_miljomalen/miljomalen/mal12.php#skog_2. Accessed 11 May 2006

Anonymous (2008) Encyclopædia Britannica.http://search.eb.com/eb/article-9034500. Accessed Sept 11

Aune K, Jonsson BG, Moen J (2005) Isolation and edge effects among woodland key habitats in Sweden: is forest policy promoting fragmentation? Biol Conserv 124:89–95. doi:10.1016/j.biocon.2005.01.015

Bengtsson J, Angelstam P, Elmqvist T, Emanuelsson U, Folke C, Ihse M, Moberg F, Nystrom M (2003) Reserves, resilience and dynamic landscapes. Ambio 32:389–396. doi:10.1639/0044-7447(2003)032[0389:RRADL]2.0.CO;2

Berg A, Ehnström B, Gustafsson L, Hallingbäck T, Jonsell M, Weslien J (1994) Threatened plant, animal, and fungus species in Swedish forests—distribution and habitat associations. Conserv Biol 8:718–731. doi:10.1046/j.1523-1739.1994.08030718.x

Bess EC, Parmenter RR, McCoy S, Molles MCMJ (2002) Responces of riparian forest-floor arthropod community to wildfire in the middle Rio Grande Valley, New Mexico. Environ Entomol 31:774–784

Bohman P (2004) Saproxylic and pyrophilous beetles on prescribed burned clear-cuts in northern Sweden. Exam work. Swedish University of Agricultural Sciences, Umeå

Caruso A, Rudolphi J, Thor G (2008) Lichen species diversity and substrate amounts in young planted boreal forests: a comparison between slash and stumps of *Picea abies*. Biol Conserv 141:47–55. doi:10.1016/j.biocon.2007.08.021

Coulianos C-C (1989) Nya landskapsfynd av barkstinkflyn (Hem.-Het., Aradidae) jämte *Aradus truncatus*, ny för Sverige. Entomol Tidskr 110:53–57 in Swedish

Deyrup M, Mosley JG (2004) Natural history of the flat bug *Aradus gracilicornis* in fire killed pines (Heteroptera: Aradidae). Fla Entomol 87:79–81. doi:10.1653/0015-4040(2004)087[0079:NHOTFB]2.0.CO;2

Dynesius M, Hylander K, Nilsson C (2009) High resilience of bryophyte assemblages in stream-side compared to upland forests. Ecology (in press)

Eidmann HH, Klingström A (1990) Skadegörare i skogen (in Swedish). LTs förlag, Stockholm

Engelmark O (1999) Boreal forest disturbances. In: Walker LR (ed) Ecosystems of disturbed ground. Elsevier, Amsterdam, pp 161–186

Esseen P-A, Ehnström B, Ericson L, Sjöberg K (1992) Boreal forests—the focal habitats of Fennoscandia. In: Hansson L (ed) Ecological principles of nature conservation. Elsevier Applied Science, London, pp 252–325

Fridman J (1999) Skog i reservat—beräkningar från riksskogstaxeringen (in Swedish). Fakta Skog 12:1–4

Froeschner RC (1988) Family Aradidae Spinola, 1837, the flat bugs. In: Henry TJ, Froeschner RC (eds) Catalogue of the Heteroptera, or true bugs, of Canada and the continental US. E J Brill, USA

Gärdenfors U (2005) The 2005 red list of Swedish species. Artdatabanken, Uppsala

Gibb H, Ball JP, Johansson T, Atlegrim O, Hjältén J, Danell K (2005) The effects of management on coarse woody debris volume and quality in boreal forests in northern Sweden. Scand J For Res 20:213–222. doi:10.1080/02827580510008392

Gibb H, Pettersson RB, Hjältén J, Hilszczański J, Ball JP, Johansson T, Atlegrim O, Danell K (2006) Conservation-oriented forestry and early successional saproxylic beetles: responses of functional groups to manipulated dead wood substrates. Biol Conserv 129:437–450. doi:10.1016/j.biocon.2005.11.010

Gossner M, Engel H, Blaschke M (2007) Factors determining the occurrence of flat bugs (Aradidae) in beech dominated forests. Waldoekologie online 4:59–89

Grove SJ (2002) Saproxylic insect ecology and the sustainable management of forests. Annu Rev Ecol Syst 33:1–23. doi:10.1146/annurev.ecolsys.33.010802.150507

Gu W, Heikkilä R, Hanski I (2002) Estimating the consequences of habitat fragmentation on extinction risk in dynamic landscapes. Landscape Ecol 17:699–710. doi:10.1023/A:1022993317717

Harrison S, Bruna E (1999) Habitat fragmentation and large-scale conservation: what do we know for sure? Ecography 22:225–232. doi:10.1111/j.1600-0587.1999.tb00496.x

Heiss E, Péricart J (2007) Hemiptères Aradidae, Piesmatidae et Dipsocoromorphes Euro-Méditerranéens.-Faune de France 91, Paris, 509 p

Heliövaara K, Väisänen R (1983) Environmental changes and the flat bugs (Heteroptera, Aradidae and Aneuridae). Ann Entomol Fenn 49:103–109

Heliövaara K, Väisänen R (1988) Periodicity of *Aradus cinnamomeus* (Heteroptera, Aradidae) in northern Europe. Entomol Tidskr 109:53–58

Hilszczański J, Gibb H, Hjältén J, Atlegrim O, Johansson T, Pettersson RB, Ball JP, Danell K (2005) Parasitoids (Hymenoptera, Ichneumonoidea) of Saproxylic beetles are affected by forest successional stage and dead wood characteristics in boreal spruce forest. Biol Conserv 126:456–464. doi:10.1016/j.biocon.2005.06.026

Hjältén J, Atlegrim O, Sandström F, Pettersson R, Rexstad EA (2006) Occurence of flat bugs (Heteroptera: Aradidae) in burned and unburned forests. Entomol Fenn 17:130–135

Johansson T, Hjältén J, Gibb H, Hilszczański J, Stenlid J, Ball JP, Alinvi O, Danell K (2007) Variable response of different functional groups of saproxylic beetles to substrate manipulation and forest management: implications for conservation strategies. For Ecol Manag 242:496–510. doi:10.1016/j.foreco.2007.01.062

Jonsell M, Schroeder LM, Weslien J (2005) Saproxylic beetles in high stumps of spruce: Fungal flora important for determining the species composition. Scand J For Res 20:54–62. doi:10.1080/02827580510008211

Kuuluvainen T, Aapala K, Ahlroth P, Kuusinen M, Lindholm T, Sallantaus T, Siitonen J, Tukia H (2002) Principles of ecological restoration of boreal forested ecosystems: Finland as an example. Silv Fenn 26:409–422

Lappalainen H, Simola H (1998) The fire-adapted flat bug Aradus laeviusculus Reuter (Heteroptera: Aradidae) rediscovered in Finland (North Karelia, Koli National Park. Entomol Fenn 9:3–4

Linder P, Östlund L (1998) Structural changes in three mid-boreal Swedish forest landscapes, 1885–1996. Biol Conserv 85:9–19. doi:10.1016/S0006-3207(97)00168-7

Martikainen P, Siitonen J, Punttila P, Kaila L, Rauh J (2000) Species richness of Coleoptera in mature managed and old-growth boreal forests in southern Finland. Biol Conserv 94:199–209. doi:10.1016/S0006-3207(99)00175-5

Matsuda R (1977) The insects and Aracnids of Canada. Part 3. The Aradidae of Canada. Hemiptera: Aradidae. Department of Agriculture. Biosystematics Research Institute, Ottawa, Ontario, Canada

Östlund L, Zackrisson O, Axelsson A-L (1997) The history and transformation of a Scandinavian boreal forest landscape since the 19th century. Can J For Res 27:1198–1206

Penttilä R, Siitonen J, Kuusinen M (2004) Polypore diversity in managed and old-growth boreal *Picea abies* forests in southern Finland. Biol Conserv 117:271–283. doi:10.1016/j.biocon.2003.12.007

Pettersson R (1994) Brandfält och brandanpassade insekter i Norrland (in Swedish). Natur i norr 13:63–67

Pettersson RB, Nilsson AN (1986) Några nordsvenska fynd av barkstinkflyn med *Aradus angularis* J. Sahlberg ny för landet. Entomol Tidskr 107:112–114 in swedish

Pettersson RB, Stenbacka F, Hjältén J, Hilszczanski J (2007) Återfynd av rödhalsad brunbagge (*Phryganophilus ruficollis* Fabr.) och Huggerts plattbrackstekel (*Chartobracon hugerti* C. van Achterberg). Entomol Tidskr 128:101–105

Siitonen J (2001) Forest management, coarse woody debris and saproxylic organisms: Fennoscandian boreal forest as an example. Ecol Bull 49:11–41

SLU (2005) Artdatabanken, http://www.artdata.slu.se. Accessed 14 May 2005

Systat Software Inc. (2007) SYSTAT 12. Chicago, USA

Taylor SJ (1988) Observations on parental care in the family Aradidae (Heteroptera). Great Lakes Entomol 21:159–161

Usinger RL (1936) Studies in the American Aradidae with descriptions of new species (Hemiptera). Ann Entomol Soc Am 29:490–516

Weber D, Stocks BJ (1998) Forest fire and sustainability in the boreal forest of Canada. Ambio 27:545–550

Wikars L-O (1992) Skogsbränder och insekter. Entomol Tidskr 113:1–11 In Swedish

Wikars L-O (1997) Effects of forest fire and the ecology of fire adapted insects. Ph.D. thesis. University of Uppsala, Uppsala

Wikars L-O (2001) The wood-decaying fungus *Daldinia loculata* (Xylariaceae) as an indicator of the fire-dependent insects. Ecol Bull 49:263–268

Wyniger D, Moretti M, Duelli P (2002) *Aradus lugibris* Fallén, 1807 (Hemiptera, Heteroptera, Aradidae) in a chestnut forest of Southern Swizerland after a fire experiment. Mitt Schweiz Entomol Ges 75:61–64

Zackrisson O (1977) Influence of forest fires on the North Swedish boreal forest. Oikos 29:22–32. doi:10.2307/3543289

Zackrisson O, Östlund L (1991) Branden formade skogslandskapets mosaik (in Swedish). Skog & Forskning 4:13–21