Effects of Prescribed Fire and Fire Surrogates on Saproxylic Coleoptera in the Southern Appalachians of North Carolina[1]

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Abstract We examined the effects of forest management practices (prescribed burning, mechanical, and prescribed burn plus mechanical) on saproxylic forest Coleoptera in the southern Appalachian Mountains of North Carolina. During the 2-yr study, we captured 37,191 Coleoptera with baited multiple-funnel traps and pipe traps, comprising 20 families and 122 species that were used for our analysis. Saproxylic beetle numbers increased greatly from the first year to the second year on all treatments. Species richness and total abundance of Coleoptera were not significantly affected by the treatments, but several families (e.g., Elateridae, Cleridae, Trogositidae, Scolytidae) were significantly more abundant on treated plots. Abundances of many species, including various species of Scolytidae were significantly affected by the treatments. However, these scolytids (*Hylastes salebrosus* Eichoff, *Ips grandicollis* Eichoff, *Xyloborinus saxeseni* Ratzburg, *Xyleborus* sp., *Xyleborus atratus* Eichoff) did not respond in the same way to the treatments. Likewise, other Coleoptera such as *Pityophagus* sp. (Nitidulidae), *Hylobius pales* Herbst (Curculionidae), and *Xylotrechus sagittatus* Germar (Cerambycidae) also varied in their responses to the treatments. Species richness was not significantly different for the spring 2003 trapping seasons, but the fall 2003 sample had a higher number of species on mechanical shrub removal only and mechanical shrub removal plus prescribed burning plots compared with controls. Linear regression analysis suggests that increased dead wood caused by hot fires on mechanical plus burn and burn only treatments resulted in increases among various Coleoptera families and species. We saw no evidence that the treatments negatively impacted saproylic species and in most cases they benefited from the disturbances.

Key Words prescribed burn, forest management, Scolytidae, saproxylic insects, multiple funnel trap, coarse woody debris

Saproxylic beetles are a diverse insect group that is dependent on dead wood for food and habitat. They are the most abundant of all saproxylic invertebrates (Berg et al. 1994) and comprise more than 30% of the beetle fauna found within a forest (Speight 1989). Saproxylic beetles are an important component of a forest ecosystem because they contribute to wood decomposition and nutrient cycling and add organic matter into the soil (Grove 2002). Woody material is broken down by the beetles through tunneling and feeding action, and indirectly by facilitating bacterial and fungal growth that cause wood decay (Speight 1989). In addition, saproxylic insects are

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important components of the food web supporting a variety of invertebrate and vertebrate fauna (Tanner 1941, Harmon et al. 1986, Speight 1989, Hanula and Horn 2004).

Some saproxylic beetles (e.g., Scolytidae) are considered pests because they cause economic damage by killing trees or degrading wood quality. However, the few pest species readily recognized by landowners and researchers are greatly outnumbered by lesser known beetles that are valuable forest ecosystem components with little or no known negative economic impacts. Therefore, understanding how these unique Coleoptera respond to various forest management practices is important for conserving them. In many areas, forest management is the main influence affecting forest dynamics (Kuuluvainen 2002). The majority of saproxylic species are specialists and not very mobile, which makes them susceptible to habitat isolation resulting from large distances between pieces of dead wood (Nilsson and Baranowski 1997, Schiegg 2000). Forestry management practices often negatively impact many saproxylic beetle species (Niemela et al. 1996, Kuuluvainen 2002) because most of these practices decrease dead wood within forests (Ranius et al. 2005, Wikars et al. 2005) contributing to a loss of biodiversity (Fridman and Walheim 2000). Areas unaffected by such forestry practices have higher diversities of saproxylic organisms (Trave 2003). Thinning forests and removing dead and dying trees reduce needed resources for saproxylic species. However, species are not equally affected by reductions in dead wood so some species decline whereas others are unaffected (Kaila et al. 1994).

Due to long-term intensive forestry, many saproxylic beetles are endangered or extinct in parts of Europe (Kaila et al. 1994, Hammond et al. 2004, Wikars et al. 2005). Other areas of the world may begin to see decreases in saproxylic beetle diversity if intensive forest management is practiced over extensive areas. Most saproxylic invertebrate fauna are poorly known and potential impacts of various forestry practices are currently not well understood for many areas (Hammond et al. 2004), including the southeastern U.S. Therefore, we measured relative abundances and species richness of saproxylic beetle families and species after various forest management practices were applied in the southern Appalachian Mountains to determine how these practices might affect some early successional species.

Materials and Methods

This study was part of the National Fire and Fire Surrogate Study which is designed to examine the impacts of fuel reduction treatments on multiple components of forested ecosystems across the U.S. (Youngblood et al. 2005). We collected Coleoptera on the Green River Game Management Area, near Hendersonville, NC (Polk and Henderson counties) in the southern Appalachian Mountains. This forest is managed by the North Carolina Wildlife Resources Commission and encompasses 5,841 ha managed for game habitat and ecosystem restoration.

Twelve study sites were selected on the basis of size, stand age, cover type and management history. Each site was 14 ha in size to allow for a 10 ha measurement area and a buffer of at least 1 tree length (20 m) around the measurement area. All selected sites were judged to be in danger of uncharacteristically severe wildfire due to heavy fuel loads. None had been thinned during the past 10 yrs nor had any sites been burned (wild or prescribed) in at least 5 yrs. Stand ages varied from 80-120 yrs. Oaks dominated all sites including northern red oak (*Quercus rubra* L.), chestnut oak

(*Q. prinus* L.), white oak (*Q. alba* L.), and black oak (*Q. velutina* Lamarck). Other common species included pignut hickory (*Carya glabra* P.Mill.), mockernut hickory (*C. tomentosa* Poiret) and shortleaf pine (*Pinus echinata* P.Mill.). A thick shrub layer composed primarily of mountain laurel (*Kalmia latifolia* L.) and rhododendron (*Rhododendron maximum* L.), occurred on approx. one-half of the study area.

The study was a randomized complete block design consisting of 3 blocks of 4 treatments each. Treatments were applied to 10-ha plots and consisted of: (1) untreated, (2) dormant season burn, (3) mechanical, and (4) mechanical plus dormant season prescribed burn. The mechanical treatments consisted of chainsaw felling and bucking of the shrub understory, which was primarily composed of rhododendron, mountain laurel and small diameter trees (<7.5 cm). The felled material was left in place after cutting. The mechanical plus burn plots were treated the same way and later burned. One block was burned by hand ignition using spot fire and strip-headfire techniques. The other blocks were ignited by helicopter using a spot fire technique. Fire intensity was moderate to high with flame lengths of 1-2 m throughout the burn unit, but flames reached as high as 5 m in localized spots where topography or intersecting flame fronts contributed to erratic fire behavior. Shrubs were cut during the winter of 2001-2002, and plots that were burned were treated on 12 or 13 March 2002. Each plot was marked by grid points with 50 m between points to facilitate pre and posttreatment sampling.

Trap design has been shown to affect the number and species of beetles captured. We used 8-unit and 12-unit multiple funnel traps (PheroTech, Delta, BC), as well as modified pipe traps (D. Miller, unpubl. data) to capture flying saproxylic Coleoptera. Multiple funnel traps are effective for assessing abundance and diversity of Coleoptera (Chenier and Philogene 1989). Pipe traps work well for certain weevils and wood borers (Cerambycidae) and capture a variety of other beetles as well (D. Miller, pers. comm.). One of each trap type was used on each plot. The traps were suspended on a nylon string stretched between 2 trees. An ultra-high release α-pinene packet (PheroTech) and a 95% ethanol packet were placed within the 12-unit funnel trap and the pipe trap; whereas, only a 95% ethanol packet was placed in the 8-unit funnel trap. Collecting cups at the bottom of each trap were partially filled with propylene glycol to preserve captured insects. The pipe trap consisted of a solid, black, 1-m long, 15.2-cm diam. PVC pipe in place of the funnels and a large diameter collecting funnel (Miller, unpubl. data). Alpha-pinene is one of the common monoterpenes found in the resin of most pine species (Mirov 1961), whereas ethanol is a by-product of decomposition and a general attractant for a variety of bark and wood boring beetles (Fatzinger 1985, Fatzinger et al. 1987). Traps were placed 50 m apart near the center of each plot. In 2003, we trapped during the spring and fall for 10 wks each time, and in 2004 we trapped during the spring for 12 wks. A 2004 fall sample was not obtained because traps were damaged by Hurricane Ivan. During each trapping period, trap samples were gathered and the collecting cups were refilled with propylene glycol every 3-4 wks. Samples were stored in 70% ethyl alcohol until they were identified.

The density of trees remaining on the plots was estimated by measuring tree basal area (Avery 1975) on ten 0.2-ha subplots within each 10-ha treatment plot. Basal area was measured in 2001 (pretreatment) and in 2004-2005 (posttreatment). Because basal area should increase with time in undisturbed stands, we used change in basal area (posttreatment minus pretreatment basal area) as an indicator of treatment effects on dominant trees. Decreases in basal area were the result of treatment-related tree mortality.

Data were analyzed using PROC GLM (SAS 1985) to conduct two-way ANOVAs with replications and treatments as dependent variables, and the various families, genera or species of Coleoptera as independent variables. The Ryan-Einot-Gabriel-Welsch multiple range test was used to determine differences in relative abundances and diversities of Coleoptera between treatments. Square-root transformation was used to assure normality and homogeneity of variance. For statistical analysis we compared the numbers caught and species richness of spring 2003, fall 2003, spring 2004 separately, and all data together. We used the GLM procedure to calculate simple linear regressions of families and species versus change in basal area.

Results

During the 2 yrs of sampling, we captured 37,191 saproxylic Coleoptera and associated predators comprising 20 families and 122 species (Table 1). Overall, species richness (Fig. 1) and total numbers of saproxylic Coleoptera (Fig. 2) were not significantly different among treatments, but differences in abundance were observed at the family and species level (Table 2). For example, Elateridae were significantly higher in samples from mechanical shrub control plus burn treatments than controls in spring 2003 and in spring 2004 the mechanical shrub control plus burn and mechanical shrub control only plots had more elaterids than burn only and control plots (Table 2). Trogositidae were captured in higher numbers on mechanical shrub control only treatment plots compared with burn only plots in spring 2003 but not in other trapping periods. Cleridae abundance in spring 2004 was significantly higher on mechanical shrub control plus burn treatments compared with all other treatments. Overall, Scolytidae numbers increased greatly from the first year to the second in all treatments (Fig. 3). In fall 2003, Scolytidae were captured in higher numbers on mechanical shrub control plus burn treatment plots compared with other treatments, but they did not differ significantly during other sample periods (Fig. 3, Table 2).

In 2003, 4 species of Scolytidae were significantly different in abundance among treatments (Table 1). *Hylastes salebrosus* Eichoff ($P = 0.06$) were caught in higher numbers on the burn-only plots compared with control plots in spring 2003, but in fall 2003 they were captured in higher numbers ($P = 0.07$) on mechanical shrub control only treatment plots compared with the other 3 treatments. *Ips grandicollis* Eichoff were caught in higher numbers on mechanical shrub control only treatment plots in spring 2003 but in fall 2003 more were caught on the mechanical shrub control plus burn treatment. In spring 2004, *I. grandicollis* numbers were higher on the mechanical shrub control plus burn and mechanical shrub control only treatment plots than on the burn-only plots and the mechanical shrub control plus burn plots had more than the controls. In spring 2003, *Xyloborinus saxeseni* Ratzburg and *Dryoxylon onoharaensum* Murayama were more abundant on mechanical shrub control treatments compared with burn only and mechanical shrub control plus burn. In the spring 2004, *Dryoxylon onoharaensum* followed the same pattern but *X. saxeseni* were more abundant on the mechanical shrub control plus burn treatment compared with the control.

Species richness was not significantly different for either spring trapping season (Fig. 4). The fall 2003 sample had the lowest species richness of the 3 trapping periods, but the number of species was significantly higher on mechanical shrub control only and mechanical shrub control plus burn plots compared with controls

Table 1. Coleoptera genera and species and total numbers captured with multiple funnel traps on fire and fire surrogate treatments on the Green River Game Management Area near Hendersonville, NC

Family	Genus/Species	Total Number Captured
Anobiidae	*Hadrobregmus* sp.	58
	Hemicoelus sp.	68
	Trichodesma sp.	2
Anthribidae	sp. 1	38
	sp. 2	80
	Eurymycter fasciatus	7
	Toxonotus sp.	2
Bostrichidae	*Amphicerus bicaudatus*	1
	sp. 1	8
	Xylobiops sp. 1	8
Brentidae	*Arrhenodes minutus*	5
Buprestidae	*Acmaeodera* sp.	1
	Agrilis *sp. 1*	2
	Agrilis sp. 2	1
	Buprestis salisburyensis	1
	Buprestis sp. 1	9
Cerambycidae	*Acanthocinus obseletus*	11
	Acanthocinus pusillus	3
	Acanthocinus sp.	1
	Aneflomorpha sp.	19
	Arhopalus rusticus	3
	Brachysomida bivittata	5
	Clytus marginicollis	4
	Clytus ruricola	351
	Cyrtophorus verrurosus	90
	Gaurotes cyanipennis	17
	Judolia cordifera	6
	Knulliana cincta	3
	Leptostylus sp.	7
	Leptura plebeja	1
	Leptura sp. 1	1
	Megacyllene caryae	3

Table 1. Continued.

Family	Genus/Species	Total Number Captured
	Microclytus sp.	1
	Microgoes oculatus	9
	Monochamus titillator	15
	Neoalosterna capitata	1
	Neoclytus acuminatus	10
	Neoclytus mucronatus	1
	Neoclytus sp.	2
	Phymatodes sp.	22
	Phymatodes varius	1
	Pidonia aurata	4
	Purpuricenus humeralis	1
	Rhagium inquisitor	14
	Saperda lateralis	1
	Sarosethus fulminans	1
	Spondylis sp. 1	145
	Spondylis sp. 2	37
	Stenosphenus notatus	1
	Stenosphenus sp.	2
	Strangalepta abbreviata	6
	Stranglia sp.	1
	Strophiona nitens	3
	Tilloclytus geminatus	2
	Tylonotus sp.	4
	Typocerus sp.	1
	Xylotrechus sagittatus	417
	Xylotrechus sp.	40
Cleridae	*Cymatoderma* sp.	99
	Enoclerus ichneumoneus	10
	Thanasimus dubius	89
	Zenodosus sp.	25
Colydidae	*Namunaria guttulatus*	1
	Pycnomerus sp.	25

Table 1. Continued.

Family	Genus/Species	Total Number Captured
Cucujidae	*Catogenus* sp. 1	15
	Catogenus sp. 2	4
	Cucujus clavipes	6
	Laemophloeus sp.	21
	Silvanus bidentatus	4
Curculionidae	*Cossonus corticola*	29
	Cryptorhynchus sp. 1	60
	Cryptorhynchus sp. 2	1
	Curculio sp.	4
	Cyrtepistomus sp.	23
	Dryophthorus sp.	27
	Hylobius pales	1538
	Pachylobius picivorus	18
	Pissodes sp.	180
Elateridae	*Alaus myops*	27
	Alaus oculatus	25
	Ampedus sp.	17
	Ctenicera trivittatus	18
	sp. 1	1696
	sp. 2	4
	Hemirhipus sp.	8
	Lacon sp.	128
Histeridae	*Euspilotus* sp.	9
	Hippocaccus sp.	6
	Hister sp.	4
	sp. 1	44
	sp. 2	14
	Hololepta sp.	53
	Platysoma sp.	7
Lagriidae	*Anthromacra aenoe*	4
Lucanidae	*Platycerus virescens*	137

Table 1. Continued.

Family	Genus/Species	Total Number Captured
Nitidulidae	*Amphotis* sp. 1	7
	Amphotis sp. 2	1
	sp. 1	150
	Pityophagus sp.	310
Platypodidae	*Platypus flavicornis*	4
	Platypus sp.	5
Pyrochroidae	*Neopyrochroa* sp.	1
Scolytidae	*Dendroctonus terebrans*	153
	Dryoxylon onoharaensum	5795
	Hylastes salebrosus	1488
	Hylastes tenuis	1577
	Hylurgops rugipennis	853
	Ips grandicollis	154
	Ips pini	4
	sp. 1	24
	sp. 2	24
	Xyleborinus saxeseni	10561
	Xyleborus affinis	30
	Xyleborus atratus	745
	Xyleborus sp. 2	251
	Xyleborus sp. 3	850
	Xylosandrus crassiusculus	7925
Tenebrionidae	*Bolitotherus* sp.	16
	Corticeus sp.	16
	Tarpela sp.	19
Trogositidae	*Temnochila virescens*	46
	Tenebroides sp.	244

during this trapping period. The burn-only plots were not significantly different from other treatments.

Linear regression analysis showed that the number of Scolytidae captured was correlated with change in basal area (r^2=0.47, $P \leq .01$), but the relationship was

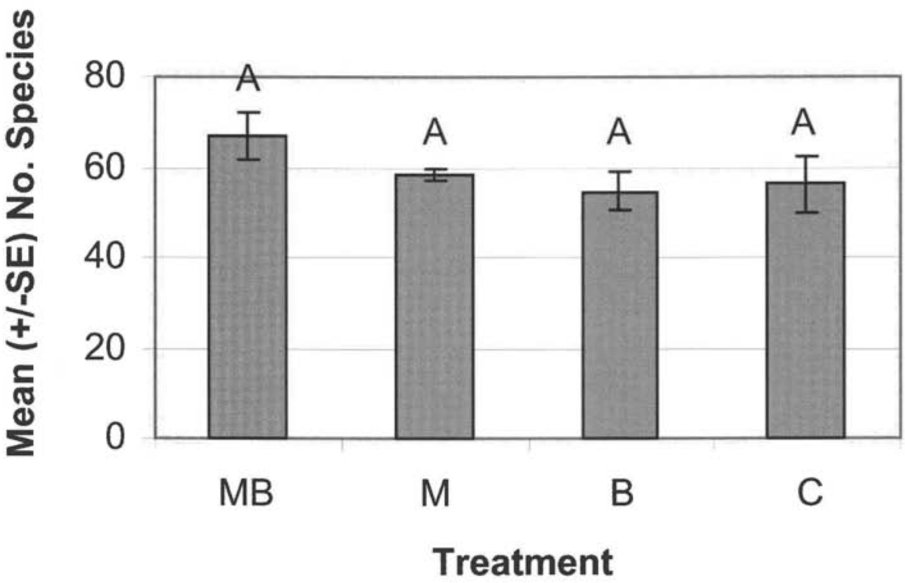

Fig. 1. Mean number of species (+/–SE) of Coleoptera captured per plot with multiple funnel and pipe traps in 2003 and 2004 on 10 ha forest plots near Hendersonville, NC, that received fire or fire surrogate treatments. Columns with the same letter are not significantly different ($P \leq 0.05$; REGWQ, SAS 1985). Treatments were; MB = mechanical shrub removal plus burn, M = mechanical shrub removal, B = burn, C = control.

primarily the result of a single beetle, *X. saxeseni* (Fig. 5). When *X. saxeseni* were removed, Scolytidae were no longer correlated with change in basal area (Fig. 5). In addition to *X. saxeseni*, *Dendroctonus terebrans* Olivier was another scolytid correlated with change in basal area ($r^2 = 0.61$, $P \leq .002$). Likewise, Cleridae ($r^2 = 0.40$, $P \leq .05$) and Elateridae ($r^2 = 0.45$, $P \leq .01$) were correlated with change in basal area; whereas, Cerambycidae ($r^2 = 0.23$, $P \leq .10$) was only weakly correlated (Fig. 5).

Discussion

Overall, saproxylic beetle abundance and species richness were not affected by our treatments, but some individual families or species were. However, they responded differently to the various treatments and in some cases species abundance varied with sampling period. For example, *Hylastes salebrosus* was captured in higher numbers in burn-only plots than in control plots in spring 2003, but higher numbers were caught in the mechanical only treated plots in fall 2003. Bark beetles and other wood-dwelling Coleoptera comprise a wide range of niches in woody material within forests, so differential response to the treatments was not unexpected.

Mechanical plus burn treatments resulted in higher captures of several wood dwelling beetle species in the fall 2003 and spring 2004. In all cases, the beetles affected by our treatments were species that use weakened, dying, or recently dead

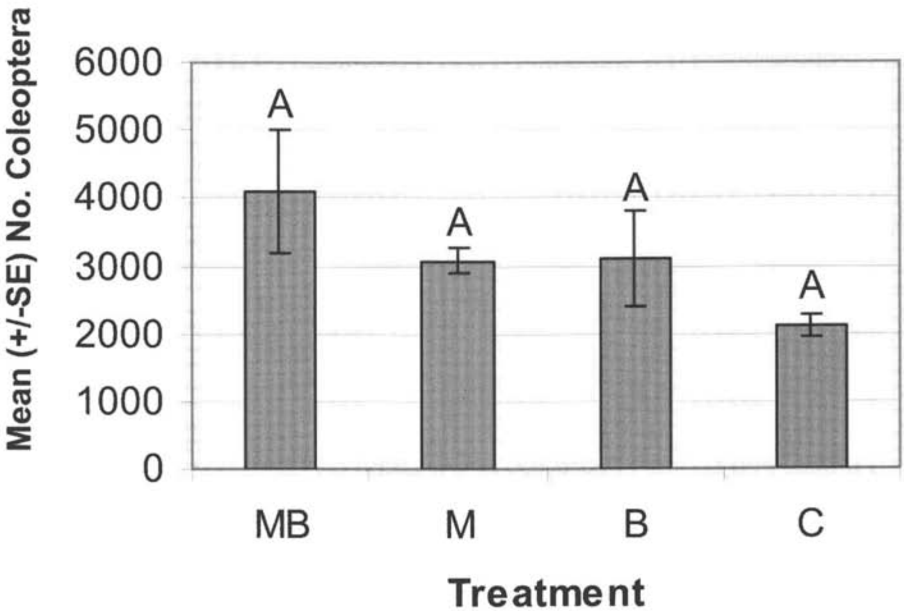

Fig. 2. Mean number (+/−SE) of Coleoptera captured per plot with multiple funnel and pipe traps during 2003 and 2004 on plots receiving fire or fire surrogate treatments on the Green River Game Management Area in the southern Appalachian Mountains near Hendersonville, NC. Columns with the same letter are not significantly different at $P \leq 0.05$ (REGWQ, SAS 1985). Treatments were: MB = mechanical shrub removal plus burn, M = mechanical shrub removal, B = burn, C = control.

trees or prey upon species in these habitats. All of the mechanical plus burn treatment plots and one of the burn-only plots had a reduction in overstory tree basal area (Fig. 5) following treatment because hot fires on those plots caused significant tree mortality. One of the most abundant scolytids, *X. saxeseni*, was strongly correlated with change in basal area but so was *D. terebrans* which occurred in much lower numbers. *Xyloborinus saxeseni* is an ambrosia beetle that utilizes a wide variety of host tree species that includes both hardwoods and conifers (USDA Forest Service 1985) whereas *D. terebrans* only utilizes pines. Likewise, Cleridae, Elateridae, and Cerambycidae were correlated with change in basal area and were more abundant on plots with reduced basal area and more dead trees. Those groups included species that used dead pine or hardwood trees as habitat or preyed upon species in those habitats.

For most species we sampled, little is known about their response to the treatments we tested, but in some cases published information exists. For example, *H. salebrosus* and *H. tenuis* Eichoff were more abundant on the mechanical-only treatment in the fall of 2003. Both species use pines (USDA Forest Service 1985) and can be found in stumps and roots. In a previous study (Hanula et al. 2002), *H. salebrosus* was caught in much higher numbers on unburned control areas compared with ex-

Table 2. Mean number (SE) of saproxylic beetles captured per plot for families and common species on plots receiving prescribed burns or other restoration treatments on the Green River Game Management Area in the southern Appalachian Mountains near Hendersonville, NC

Family*	Genera/Species*	Treaments**			
		MB	M	B	C
2003 Spring					
Anobiidae		6.0 (6.0)[a]	7.0 (4.4)[a]	1.7 (1.2)[a]	0.7 (1.2)[a]
Anthribidae		3.0 (1.7)[a]	1.7 (0.9)[a]	2.7 (1.5)[a]	6.3 (3.2)[a]
Bostrichidae		0.3 (0.3)[a]	1.3 (0.9)[a]	2.0 (1.5)[a]	0.3 (0.3)[a]
Cerambycidae		23.0 (7.0)[a]	16.3 (4.3)[a]	15.0 (1.5)[a]	14.3 (0.3)[a]
	Cyrtophorus verrurosus	6.7 (3.8)[a]	5.0 (1.5)[a]	2.7 (0.7)[a]	2.7 (2.2)[a]
	Xylotrechus sagittatus	3.7 (1.5)[a]	2.7 (1.8)[a]	2.3 (0.3)[a]	2.7 (1.3)[a]
Cleridae		5.3 (1.8)[a]	4.0 (2.1)[a]	2.0 (0.6)[a]	5.0 (1.2)[a]
Cucujidae		3.7 (0.9)[a]	3.3 (1.8)[a]	2.3 (0.9)[a]	3.3 (1.5)[a]
Curculionidae		52.7 (4.5)[a]	61.3 (13.1)[a]	86.3 (22.0)[a]	52.0 (25.1)[a]
	Hylobius pales	44.3 (3.8)[a]	53.3 (14.7)[a]	79.7 (21.2)[a]	46.0 (25.0)[a]
Elateridae**		149.7 (54.0)[a]	52.7 (14.9)[ab]	74.0 (3.2)[ab]	41.3 (2.7)[b]
Histeridae		3.3 (0.9)[a]	4.3 (1.9)[a]	5.7 (2.4)[a]	3.7 (2.7)[a]
Lucanidae	*Platycerus virescens*	3.7 (2.3)[a]	6.7 (2.7)[a]	3.0 (2.0)[a]	10.3 (4.4)[a]
Nitidulidae		9.3 (6.4)[a]	15.0 (3.1)[a]	20.7 (5.8)[a]	23.3 (11.6)[a]
	*Pityophagus sp.**	9.0 (6.0)[b]	15.0 (3.1)[ab]	20.7 (5.8)[a]	23.3 (11.6)[a]

Table 2. Continued.

Family*	Genera/Species*	Treaments**			
		MB	M	B	C
Scolytidae		153.0 (58.5)[a]	241.3 (59.0)[a]	168.7 (44.3)[a]	192.0 (12.8)[a]
	Dendroctonus terebrans	7.0 (2.5)[a]	5.7 (2.3)[a]	4.0 (0.6)[a]	4.3 (2.4)[a]
	*Dryoxylon onoharaensum***	8.3 (2.3)[b]	41.7 (12.3)[a]	12.3 (5.5)[b]	32.7 (4.9)[ab]
	*Hylastes salebrosus**	50.3 (17.3)[ab]	45.7 (12.2)[ab]	80.7 (34.5)[a]	37.7 (16.9)[b]
	Hylastes tenuis	54.7 (34.7)[a]	50.3 (7.6)[a]	39.3 (9.8)[a]	53.3 (34.7)[a]
	*Ips grandicollis***	1.7 (1.2)[ab]	3.0 (1.0)[a]	1.7 (0.9)[ab]	0.7 (0.3)[b]
	Xyleborus atvatus	7.3 (2.9)[a]	13.0 (1.5)[a]	9.3 (2.2)[a]	11.7 (2.4)[a]
	*Xyleborinus saxeseni**	6.7 (1.8)[b]	25.7 (7.3)[a]	8.3 (3.5)[b]	17.3 (4.5)[ab]
	Xylosandrus crassiusculus	0[a]	0[a]	3.0 (3.0)[a]	3.3 (2.0)[a]
Tenebrionidae		2.0 (1.5)[a]	1.0 (1.0)[a]	1.0 (1.0)[a]	1.7 (1.7)[a]
Trogositidae**		13.0 (5.5)[ab]	20.7 (4.2)[a]	4.7 (1.5)[b]	11.7 (2.3)[ab]
2003 Fall					
Cerambycidae		26.3 (6.3)[a]	20.0 (7.8)[a]	15.7 (5.0)[a]	11.7 (4.1)[a]
	Xylotrechus sagittatus	26.0 (6.2)[a]	18.7 (7.3)[a]	14.3 (4.4)[a]	10.7 (3.4)[a]
Cleridae		10.7 (8.2)[a]	6.7 (0.9)[a]	3.3 (1.8)[a]	1.7 (0.9)[a]
Curculionidae		4.0 (0.6)[a]	8.0 (3.8)[a]	4.0 (0.6)[a]	4.3 (0.9)[a]
	Hylobius pales	3.3 (0.9)[a]	4.0 (2.0)[a]	2.0 (0.6)[a]	3.7 (1.2)[a]
Elateridae		2.0 (1.5)[a]	4.3 (0.3)[a]	1.3 (0.7)[a]	2.3 (0.3)[a]

Table 2. Continued.

Family*	Genera/Species*	Treaments**			
		MB	M	B	C
Scolytidae**		304.3 (45.0)^{a}	130.7 (13.5)^{b}	114.0 (29.8)^{b}	93.0 (19.3)^{b}
	*Hylastes salebrosus**	18.0 (3.5)^{b}	41.7 (8.0)^{a}	22.7 (7.3)^{b}	18.0 (3.8)^{b}
	*Hylastes tenuis***	4.3 (0.9)^{b}	14.0 (3.5)^{a}	4.0 (1.5)^{b}	3.3 (1.9)^{b}
	*Ips grandicollis***	2.6 (0.9)^{a}	0.3 (0.3)^{b}	0^{b}	0^{b}
	Xyleborinus saxeseni	75.3 (33.4)^{a}	20.7 (9.6)^{a}	34.7 (14.4)^{a}	45.7 (29.8)^{a}
	Xylosandrus crassiusculus	74.3 (46.5)^{a}	12.7 (7.8)^{a}	26.7 (10.8)^{a}	12.7 (3.9)^{a}
2004 Spring					
Anobiidae		6.7 (3.7)^{a}	12.7 (5.0)^{a}	3.7 (2.0)^{a}	4.0 (1.2)^{a}
Anthribidae		0.0 (0.0)^{a}	8.0 (8.0)^{a}	4.7 (1.5)^{a}	16.0 (6.9)^{a}
Cerambycidae		79.7 (12.4)^{a}	65.0 (7.2)^{a}	70.3 (13.9)^{a}	65.0 (20.6)^{a}
	Clytus ruricola	14.7 (2.6)^{a}	20.7 (6.4)^{a}	41.3 (12.2)^{a}	35.7 (14.5)^{a}
	Cyrtophorus verrurosus	3.3 (1.5)^{a}	2.7 (0.9)^{a}	3.3 (0.9)^{a}	3.7 (3.2)^{a}
	*Xylotrechus sagittatus**	19.3 (2.3)^{a}	15.3 (0.9)^{ab}	11.3 (1.5)^{b}	12.0 (2.6)^{b}
Cleridae**		19.7 (5.0)^{a}	6.0 (1.5)^{b}	5.3 (1.9)^{b}	4.7 (0.3)^{b}
Cucujidae		0.0 (0.0)^{a}	1.7 (1.2)^{a}	2.0 (1.5)^{a}	0.3 (0.3)^{a}
Curculionidae		83.7 (19.9)^{a}	75.3 (18.3)^{a}	115.7 (22.5)^{a}	79.3 (8.9)^{a}
	*Hylobius pales**	62.7 (17.6)^{ab}	47.7 (8.2)^{b}	100.7 (19.1)^{a}	65.3 (8.4)^{ab}

Table 2. Continued.

Family*	Genera/Species*	Treaments** MB	M	B	C
Elateridae**		112.0 (2.5)[a]	115.0 (5.1)[a]	49.3 (1.5)[b]	37.0 (8.9)[b]
Histeridae		4.7 (2.3)[a]	7.7 (1.2)[a]	7.3 (1.9)[a]	8.3 (5.8)[a]
Lucanidae	*Platycerus virescens*	4.3 (1.7)[a]	5.3 (1.9)[a]	5.3 (2.8)[a]	7.0 (2.3)[a]
Nitidulidae		17.3 (2.8)[a]	29.0 (3.0)[a]	27.3 (9.9)[a]	11.3 (5.6)[a]
	Pityophagus sp.	5.3 (0.9)[a]	10.0 (4.7)[a]	10.0 (3.6)[a]	8.7 (3.2)[a]
Scolytidae		2984.0 (756.8)[a]	2125.0 (123.3)[a]	2270.7 (664.9)[a]	1368.0 (164.4)[a]
	Dendroctonus terebrans	10.7 (1.7)[a]	6.3 (2.9)[a]	5.7 (2.0)[a]	2.7 (1.2)[a]
	*Dryoxylon onoharaensum**	350.0 (158.1)[b]	645.3 (129.3)[a]	513.7 (116.4)[ab]	327.7 (99.4)[b]
	Hylastes salebrosus	53.0 (18.4)[a]	43.0 (14.0)[a]	44.7 (17.4)[a]	40.7 (24.3)[a]
	Hylastes tenuis	110.3 (38.7)[a]	93.0 (0.0)[a]	68.0 (21.6)[a]	31.0 (10.8)[a]
	*Ips grandicollis***	19.7 (2.9)[a]	12.7 (3.8)[ab]	3.0 (1.2)[c]	6.0 (2.0)[bc]
	*Xyleborus atvatus***	48.7 (3.7)[ab]	48.0 (2.5)[ab]	72.0 (10.0)[a]	36.0 (3.1)[b]
	*Xyleborinus saxeseni***	1506.3 (740.5)[a]	675.0 (272.9)[ab]	733.3 (156.3)[ab]	371.3 (186.3)[b]
	Xylosandrus crassiusculus	815.3 (563.8)[a]	512.0 (247.3)[a]	756.0 (550.2)[a]	432.0 (205.1)[a]
Tenebrionidae		0.7 (0.3)[a]	3.0 (2.0)[a]	2.0 (2.0)[a]	2.3 (1.9)[a]
Trogositidae		9.3 (0.9)[a]	13.3 (0.9)[a]	8.0 (1.5)[a]	14.3 (4.9)[a]

* Within each family or genus/species, means followed by the same letter(s) are not significantly different ($P \leq 0.05$) according to the Ryan-Enoit-Gabriel-Welsch multiple comparison test (SAS 1985). A family, genus, or species followed with an ** indicates a significant difference at $P \leq 0.05$ and * indicates $P \leq 0.10$.

** MB=mechanical shrub removal plus burn, B=burn, M=mechanical shrub removal, C=control

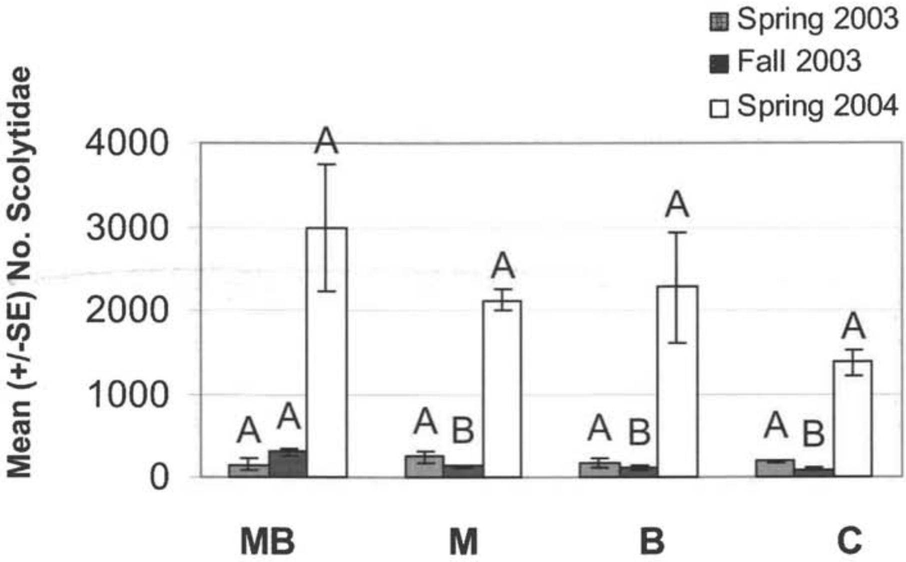

Fig. 3. Mean number (+/–SE) of Scolytidae captured per plot for each trapping period with multiple funnel and pipe traps during the three trapping periods among the plots that received fire or fire surrogate treatments. Columns of the same trapping period with the same letter are not significantly different ($P = \leq 0.05$; REGWQ, SAS 1985). Treatments were: MB = mechanical shrub removal plus burn, M = mechanical shrub removal, B = burn, C = control.

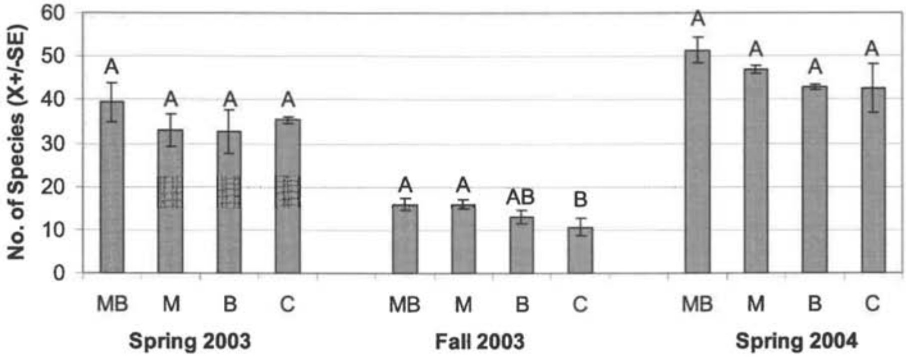

Fig. 4. Mean number (+/–SE) of Coleoptera species captured per plot with multiple funnel and pipe traps in 2003 and 2004 on 10 ha forest plots near Hendersonville, NC, that received fire or fire surrogate treatments. Columns of the same date with the same letter are not significantly different ($P = \leq 0.05$; REGWQ, SAS 1985). Treatments were: MB = mechanical shrub removal plus burn, M = mechanical shrub removal, B = burn, and C = control.

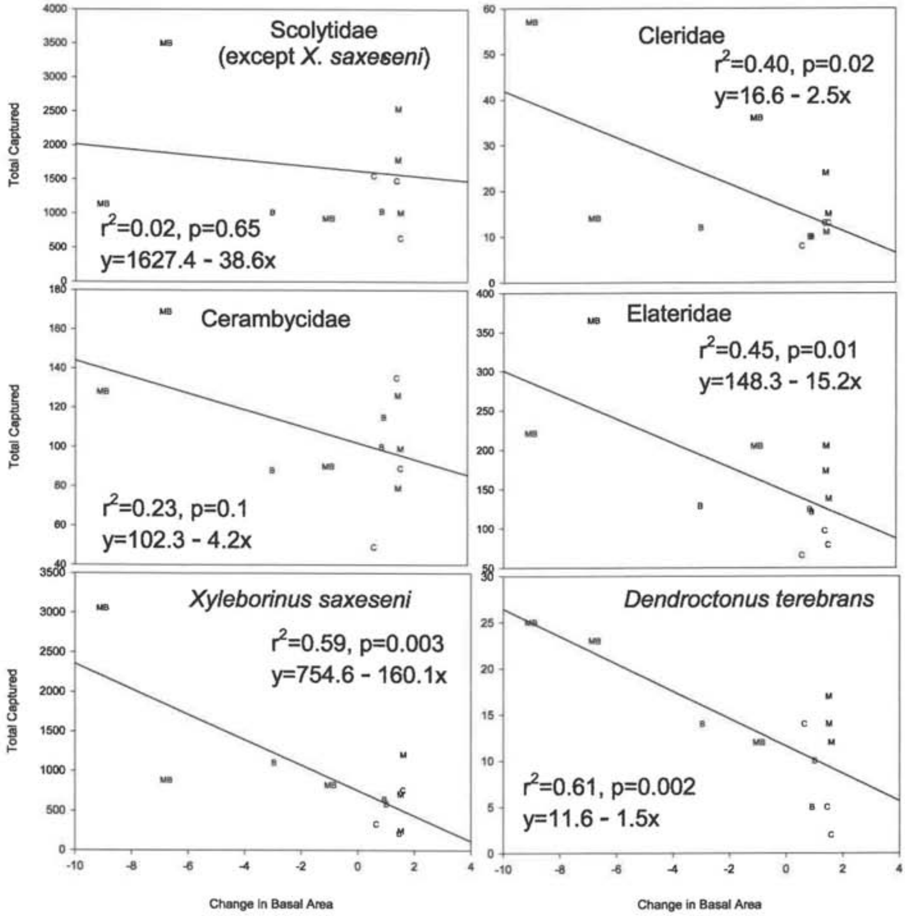

Fig. 5. Linear regressions of various saproxylic Coleoptera captured in funnel traps and change in basal area of 10 ha plots treated with various combinations of prescribed fire and mechanical brush removal. Negative numbers indicate a post treatment decrease in basal area (more dead wood on plots). MB = mechanical plus burn, M = mechanical, B = burn, C = control

tensive areas that experienced low to high wildfire severity, so these results might indicate that this beetle is less likely to occur in burned areas. However, in spring 2003 it was more abundant on burned areas than on the controls, and Sullivan et al. (2003) found *H. salebrosus* was attracted to small burned plots, so factors other than fire alone likely affected *H. salebrosus* populations in this study. Likewise, *D. terebrans* abundance increased as basal area decreased. In all plots with high *D. terebrans* populations, fire was the cause of the tree mortality in this study, but the beetles were either attracted to the areas by the dead trees or used them for brood production. In comparison, Hanula et al. (2002) caught fewer *D. terebrans* in recently burned areas that were part of a 15,000 ha wildfire. Our lack of capture success for *Ips* species could be a bias in the funnel traps because Smith et al. (1993) showed that some species of *Ips*, such as *I. avulsus* Eichoff and *I. calligraphus* Germar were not highly attracted to ethanol or turpentine.

Increased abundance of *X. saxeseni* in spring 2003 may have been a result of fire reducing the available habitat. This species was probably able to use the cut rhododendron and mountain laurel because it has been found feeding on nearly all genera of deciduous trees (Furniss and Johnson 2002). The mechanical shrub control only treatment plots had an abundance of freshly cut wood in 2003, and the controls had normal background levels of newly dead material. On the other hand, prescribed burns were applied just before our spring 2003 trapping period and reduced the amount of wood from the cut shrubs and small trees or may have rendered it unacceptable as host material. By 2004 beetles were likely emerging from the fire-killed trees on the mechanical plus burn plots. Also, our traps may have competed with the scents released by the freshly cut wood and recently fire-killed trees in 2003, but by 2004 this competition should have ceased. Thus, newly-emerged brood and reduced competition between traps and freshly cut wood might explain the large numbers of *X. saxeseni* captured in 2004 compared with 2003. Because we do not know host plants of *Dryoxylon onoharaensum*, increased abundance also could be due to increased amounts of dead rhododendron and mountain laurel. The higher elaterid abundance in 2004 probably resulted from the increased dead wood availability or emergence of brood from the previous year.

An introduced species that has a wide host range, *X. crassiusculus* Motschulsky was captured in large numbers during this study. First discovered in South Carolina in 1974, it is considered a major pest in nurseries (Oliver and Mannion 2001) and a potential problem in forests because they can attack healthy trees (Atkinson et al. 1988). The spring 2003 sample contained few *X. crassiusculus* but captures increased in the fall 2003 and by spring 2004 our samples contained large numbers. Due to the likely increase in scents from cut and burned wood, our traps may have competed with these odors in 2003; whereas, in 2004 the scents had dissipated and our traps were much more effective. The increase in cut wood in 2003 would have allowed for more beetles to breed and possibly resulted in a large emergence by 2004, which could also explain the rise in numbers of *X. crassiusculus* and other beetles in 2004. However, captures of this species were not correlated with decreasing basal area resulting from fire-caused tree mortality, nor did any of the treatments result in higher numbers, so the reasons for the population increase are unclear. Like *X. crassiusculus, X. saxeseni, X. atratus*, and *Dryoxylon onoharaensum* are nonnative species. Because *X. crassiusculus, X. saxeseni,* and *D. onoharaensum* comprised the large majority (~80%) of our captures of Scolytidae, it raises the question of whether these species are displacing native insects.

Pityophagus sp. (Nitidulidae) was captured on burn-only and controls in significantly higher numbers compared with mechanical shrub control plus burn plots in spring 2003. It is unknown why its abundances would be affected by these treatments. This genus is predatory on bark beetles and has only rarely been found in the southeastern United States.

Because we used 3 traps per plot and our plots were relatively close to each other, the proximity of the plots and large amount of α-pinene and ethanol released from our traps may have attracted beetles from outside the treatment plots or they may have been able to move from one treatment plot to the next. Future studies may want to consider using only 1 funnel trap per plot, using larger plots, or passive traps like flight intercept traps.

Beetles varied in their responses to the treatments but, in general, treatments that created the most tree mortality resulted in greater numbers of saproxylic species. The reintroduction of fire into forests where it has been excluded may initially benefit saproxylic organisms. Our samples included primarily early successional species and dead wood created by these treatments should be an important resource for later successional species for some time. However, because the stands were "thinned" by fire it is unlikely that much additional tree mortality will occur in the near future because the fire reduced competition and tree vigor should improve. Future research should focus on long-term changes among Coleoptera assemblages, the effects of intermittent versus continuous inputs of dead wood on saproxylic species, and the impacts of nonnative species on native saproxylic fauna.

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References

Atkinson, T. H., R. J. Rabaglia and D. E. Bright. 1988. *Xylosandrus crassiusculus* (Motschulsky), an Asian ambrosia beetle recently introduced into Florida (Coleoptera: Scolytidae). Florida Dept. Agric. Consum. Serv. Entomol. Circ. 310.

Avery, T. E. 1975. Natural resources measurements. McGraw-Hill. New York.

Berg, A., B. Ehnstrom, L. Gustafsson, T. Hallingback, M. Jonsell and J. Weslien. 1994. Threatened plant, animal and fungus species in Swedish forests: distribution and habitat associations. Conserv. Biol. 8: 718-731.

Chenier, J. V. R. and B. J. R. Philogene. 1989. Field responses of certain forest Coleoptera to conifer monoterpenes and ethanol. J. Chem. Ecol. 15: 1729-1745.

Fatzinger, C. W. 1985. Attraction of the black turpentine beetle (Coleoptera: Scolytidae) and other forest Coleoptera to turpentine-baited traps. Environ. Entomol. 14: 768-775.

Fatzinger, C. W., B. D. Siegfried, R. C. Wilkinson and J. L. Nation. 1987. *trans*-Verbenol, turpentine and ethanol as trap baits for the black turpentine beetle *Dendroctonus terebrans*, and other forest Coleoptera in Florida. J. Entomol. Sci. 22: 201-209.

Fridman, J. and M. Walheim. 2000. Amount, structure, and dynamics of dead wood on managed forestland in Sweden. For. Ecol. Manage. 131: 23-36.

Furniss, M. M. and J. B. Johnson. 2002. Field Guide to the Bark Beetles of Idaho and Adjacent Regions. Agricultural Publications, Moscow, ID.

Grove, S. J. 2002. Saproxylic insect ecology and the sustainable management of forests. Ann. Rev. Ecol. Syst. 33: 1-23.

Hammond, H. E. J., D. W. Langor and J. R. Spence. 2004. Saproxylic beetles (Coleoptera) using *Populus* in boreal aspen stands of western Canada: spatiotemporal variation and conservation of assemblages. Can. J. For. Res. 34: 1-19.

Hanula, J. L. and S. Horn. 2004. Source, distribution and abundance of macroarthropods on the bark of longleaf pine: potential prey of the red-cockaded woodpecker. For. Ecol. Manage. 102: 89-102.

Hanula, J. L., J. R. Meeker, D. R. Miller and E. L. Barnard. 2002. Association of wildfire with tree health and numbers of pine bark beetles, reproduction weevils and their associates in Florida. For. Ecol. Manage. 170: 233-247.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins and S. V. Gregory. 1986. Ecology of coarse woody debris in temperate ecosystems. Adv. Ecol. Res. 15: 133-302.

Kaila, L., P. Martikainen, P. Punttila and E. Yakolevv. 1994. Saproxylic beetles (Coleoptera) on dead birch trunks decayed by different polypore species. Ann. Zool. Fennici. 31: 97-107.

Kuuluvainen, T. 2002. Disturbance dynamics in boreal forests: defining the ecological basis of restoration and management of biodiversity. Silva Fennica. 36: 5-12.

Mirov, N. 1961. Composition of gum turpentines of pines. USDA Forest Service Tech. Bull. No. 1239.

Niemela, J., Y. Haila and P. Punttila. 1996. The importance of small-scale heterogeneity in boreal forests: variation in diversity in forest-floor invertebrates across the succession gradient. Ecography 19: 352-368.

Nilsson, S. G. and R. Baranowski. 1997. Habitat predictability and occurrence of wood beetles in old-growth beech forests. Ecography 20: 491-498.

Oliver, J. B. and C. M. Mannion. 2001. Ambrosia beetle (Coleoptera: Scolytidae) species attacking chestnut and captured in ethanol-baited traps in middle Tennessee. Pop. Ecol. 30: 909-918.

SAS. 1985. SAS Procedures Guide for Personal Computers, Version 6 Edition. SAS Institute, Inc., Cary, NC.

Schiegg, K. 2000. Are there saproxylic beetle species characteristic of high dead wood connectivity? Ecography 23: 579-587.

Smith, M. T., S. M. Salom and T. L. Payne. 1993. The southern pine beetle guild: and historical review of the complex olfactory communication system of the five principal species. VPI & SU, Agric. Exp. Stn. Bull. 93-4. 106 pp.

Speight, M. C. D. 1989. Saproxylic invertebrates and their conservation. Strasbourg, Fr: Counc. Eur. Pgs. 79.

Ranius, T., H. Ekvall, M. Jonsson and G. Bostedt. 2005. Cost-efficiency of measures to increase the amount of coarse woody debris in managed Norway spruce forests. For. Ecol. Manage. 206: 119-133.

Sullivan, B. T., C. J. Fettig, W. J. Otrosina, M. J. Dalusky and C. W. Berisford. 2003. Association of severity of prescribed burns and subsequent activity of conifer-infesting beetles in stands of longleaf pine. For. Ecol. Manage. 185: 327-340.

Tanner, J. T. 1941. Three years with the Ivory-billed Woodpecker, America's rarest bird. Audubon Mag. 43: 5-14.

Trave, J. 2003. Dead wood and saproxylic complex in the Massane forest. Role in the conservation of invertebrates. Proc. Second pan-European conf. on Saproxylic Beetles. People's Trust for Endangered Species. Pgs., 1-4.

USDA Forest Service. 1985. Insects of eastern forests. USDA Forest Service Misc. Publ. No. 1426, Washington, DC, 608 pp.

Wikars, L., E. Sahlin and T. Ranius. 2005. A composition of three methods to estimate species richness of saproxylic beetles (Coleoptera) in logs and high stumps of Norway spruce. Can. Entomol. 137: 304-324.

Youngblood, A., K. Metlen, E. E. Knapp, K. W. Outcalt, S. L. Stephens, T. A. Waldrop and D. Yaussy. 2005. Implementation of the fire and fire surrogate study—a national research effort to evaluate the consequences of fuel reduction treatments, Pp. 315-321. *In* Peterson, C. E. and D. A. Maguire (eds.). Balancing ecosystem values: innovative experiments for sustainable forestry. Proc. Gen. Tech. Rep. PNW-GTR-635. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.