Response of Bark and Woodboring Beetles to Host Volatiles and Wounding on Western Juniper

Jane L. Hayes, Patricia L. Johnson, Andris Eglitis, Donald W. Scott, Lia Spiegel, Craig L. Schmitt, and Steven E. Smith

ABSTRACT: In central Oregon, management of western juniper (*Juniperus occidentalis* var. *occidentalis* Hook.) has included use of prescribed fire and mechanical removal. After these treatments, several species of bark and woodboring beetles have been observed on treated trees and also occasionally on trees outside management areas, suggesting that these insects might contribute to juniper mortality. In this 2-year (2002–2003) study, we identified bark and woodboring beetles that attack western juniper along with associated beetle predators and examined whether these insects can be manipulated for use in juniper management. Using funnel traps and sticky traps on trees wounded by pruning or treated with host volatiles (juniper berry oil, cade oil, and ethanol) that may attract insects, we captured beetles in the families Buprestidae, Cerambycidae, and Scolytidae (20 species in 17 genera) and known predators in the families Cleridae and Trogositidae (8 species in 7 genera). Cedar bark beetles (*Phloeosinus* spp.) were the most prevalent insects captured on trees treated with host volatiles and/or wounded. Treatments that included ethanol plus wounding were most attractive to these beetles. However, there was no obvious insect-caused damage or mortality of treated trees in either year of this study.

Keywords: *Phloeosinus*, beetle predators, ethanol, juniper berry oil, cade oil

Western juniper (*Juniperus occidentalis* var. *occidentalis* Hook.) is found in high desert environments in northern California, central and eastern Oregon, southwest Idaho, and less commonly in northwestern Nevada and southeastern Washington (Sowder and Mowat 1965, Dealy 1990). Although its rate of expansion has declined in some areas, the range of this medium-sized native conifer has increased as much as 10-fold since the late 1800s (Miller and Wigand 1994). The density of juniper stands has also generally increased over this period. In eastern Oregon, the estimated area of juniper forest increased fivefold between 1936 and 1988 (Gedney et al. 1999, Azuma et al. 2005). Over 890,000 ha are classified as juniper forest (>10% crown cover), and with the inclusion of juniper savanna and seedling-sapling stands, the total area with juniper is estimated to be 2.4 million ha in Oregon (Gedney et al. 1999, Azuma et al. 2005). Compared with prehistoric times, expansion has occurred with increasing aridity, decreasing fire-return intervals and grass density, increasing livestock grazing, decreasing sagebrush (*Artemesia* spp.) density, and introduction of non-native plant species (Eddleman et al. 1994; Miller and Rose 1995, 1999; Karl and Leonard 1996; Hann et al. 1997). The continued expansion of western juniper, particularly in productive rangelands, has raised concerns about potentially harmful effects on wildlife habitat, biodiversity, and hydrologic conditions (e.g., Eddleman et al. 1994, Belski 1996, Karl and Leonard 1996, Hann et al. 1997, Miller 2001).

Although additional research is needed to assess the long-term impacts of western juniper expansion (see Belski 1996, Hann et al. 1997), efforts to manage juniper continue throughout much of its range (e.g., Martin et al. 1978, Leavengood and Swan 1998; summarized in Miller et al. 2005). The most common control practices include use of prescribed fire and mechanical treatments (e.g., cut, masticated, or shred). The use of prescribed fire is both site- and condition-dependent, can contribute to increased non-native plant invasion and decreased air quality (Eddleman et al. 1994, Karl and Leonard 1996, Hann et al. 1997), and may adversely affect sage-grouse (*Centrocercus urophasianus*) habitat, and perhaps other sagebrush-dependent species (United States Department of the Interior 2004). Although most frequently used, mechanical treatments, particularly chainsaw cutting, can be labor-intensive and costly (e.g., Young et al. 1982), and the commercial use of juniper wood is limited.

Other causes of juniper mortality, including mortality caused by insects and diseases, are not well understood. It has been observed that there is little juniper mortality caused by either insects or diseases (Karl and Leonard 1996). However, at least one historical (1700s) instance of widespread decline due to heartrot fungus

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(probably caused by *Antrodia juniperina* [Murrill] Niemelae & Ryvarden) has been described (Knapp and Soule 1999). Annosus root disease (*Heterobasidion annosum* [Fr.] Bref.) occasionally causes localized mortality in juniper-ponderosa pine (*Pinus ponderosa* P&C Lawson) communities. These disease centers are usually associated with large ponderosa pine stumps that became colonized by airborne spores immediately after cutting. Mortality may occur years later as the causal pathogen spreads across root contacts to adjacent juniper and pine trees (Schmitt et al. 2000). Several authors describe extensive mortality of apparently healthy juniper under drought conditions in the 1920s and 1930s in central Oregon caused by bark beetles in the genus *Phloeosinus* (Sowder and Mowat 1965, Furniss and Carolin 1977, Dealy 1990). In addition, Furniss and Carolin (1977) list at least 10 insect species that feed on some portion of the tree.

Near Burns, OR, the Bureau of Land Management (BLM) has been attempting to control western juniper using prescribed fire since 1991 and mechanical means since 1984 (Jon Reponen, BLM, personal communication, Apr. 2002). In connection with some of these treatments, a number of insects, particularly bark and woodboring species, were observed, and at times they appeared to be present in relatively high numbers (Jon Reponen, BLM, personal communication, Apr. 2002). These insects were found on trees wounded by fire or that had recently been felled, and they also appeared to be affecting trees outside treated areas. The insects observed include cedar bark beetles *Phloeosinus* spp. (Scolytinae) and longhorned (Cerambycidae) and flatheaded (Buprestidae) woodborers. Others have observed insects associated with the burning of juniper (e.g., Westcott, 2007). These observations give rise to questions about possible attraction to host volatiles and whether insects could play a role as mortality agents in juniper management programs. A corollary question is whether increased populations of these insects present a threat to other vegetation adjacent to juniper management sites.

No comprehensive study has been published of bark and woodboring insects associated with western juniper. Feeding and colonization by insects may play a significant role in juniper community ecology in general and more specifically in the decomposition of dead juniper, and in some cases they could damage living trees. Insects that attack conifers are often attracted to host-produced volatiles (D.L. Wood 1982) and especially those produced by weakened or wounded hosts, such as ethanol, which tends to attract a broad array of insects (e.g., Kelsey and Joseph 2001, 2003). Volatile compounds produced by western juniper have been described by several authors (e.g., Kurth and Lackey 1948, Fahey and Kurth 1955, von Rudloff et al. 1980). However, it is apparently not known whether any specific compounds produced by juniper serve as semiochemical attractants of the insects that are found in association with this host.

The objectives of this study were to identify insects that feed on or colonize western juniper, with emphasis on the bark beetles and woodborers, and determine whether these insects can be predictably manipulated with semiochemicals for use in management of this tree. In 2002, we initiated a 2-year study near Burns, OR, to address three questions: (1) What are the predominant bark or woodboring beetles associated with western juniper? (2) Can these insects be attracted to host trees by baiting with host volatiles and by host wounding? and (3) Is any damage caused by these insects sufficient to contribute to juniper mortality or damage to adjacent vegetation?

Materials and Methods

Bark and Woodboring Insect Survey

To obtain a baseline inventory of insects associated with juniper, specifically focusing on bark and woodboring beetles and their beetle predators, baited Lindgren funnel traps (12-funnel design) were installed in early May 2002 at two sites, one managed (cut; site 1) and one unmanaged (uncut; site 2), approximately 100 km apart. An array of traps (total of 12) was placed adjacent to an area along Skull Creek Road (43°39.21′N, 119°11.15′W; elevation 1,625 m; site 1), where juniper had been mechanically treated (felled and left on site) in 2001. Also, traps (total of 16) were located within a proposed management demonstration area, the Western Juniper Management Area (42°46.18′N, 118°44.55′W; elevation 1,880 m; site 2), along the North Loop Road of Steens Mountain, which has not been subject to previous juniper management. The two study sites are both considered mountain big sage-bunch grass plant community types with mid-stage transition juniper. At site 1, which is slightly lower in elevation and drier, the dominant grass is Thurber needlegrass (*Achnatherum speciosum* [Trin. & Rupr.] Barkworth), with juniper in the 80–110-year-old age class and adjacent vegetation including bitterbrush (*Purshia tridentata* [Pursh] DC), curlleaf mountain mahogany (*Cercocarpus ledifolius* Nutt), and ponderosa pine. At site 2, the dominant grass was Idaho fescue (*Festuca idahoensis* Elmer), the juniper were more variable in density and age (from less than 50 to more than 200 years old), and adjacent vegetation included mountain mahogany but also aspen (*Populus tremuloides* Michx.) and snowberry (*Symphoricarpos albus* [L.] S.F. Blake), reflecting the higher moisture at this site.

At each site, funnel traps were suspended from metal poles such that the collection cup was approximately 1 m above the ground. To prevent escapes and predation, a small piece (approximately 2 × 2 cm) of dichlorovos-impregnated plastic was placed in the collection cup of each trap.

Semiochemical treatments included the following: (a) juniper berry oil (distilled from berries, needles, and wood of *J. communis* L.), (b) cade oil (destructively distilled from branches and heartwood of *J. oxycedrus* L.), (c) ethanol, or (d) acetone (see Table 1 for details). Oils from other juniper species were used because commercial release devices were available. Ethanol and acetone are found in the inner bark of live trees and frequently used in wood boring beetle attractants, especially ethanol, which is produced by stressed trees. Estimated elution rates were determined gravimetrically (devices were weighed daily for a month) under laboratory conditions and approximately constant temperatures (25°C) (Table 1). Over the course of the insect collection period each year, the average high and low temperatures at the study sites were 25.7°C (range, 8.3 to 41.1°C) and 5.7°C (range, −5.5 to 16.1°C) in 2002 and 27.4°C (range, 7.8 to 40°C) and 7.1 (range, 5 to 18.3°C) in 2003, respectively. Weather data were obtained from a nearby remote area weather station (42°97.36′N, 199°24.61′W; elevation 1,524 m).

At site 1, traps were placed in two lines (traps 1–4 and 5–9) with a minimum of 80.5 m (2 chains) between traps and trap lines. Ethanol, cade, and berry treatments were assigned in sequence (e.g., traps 1, 4, and 7 ethanol, traps 2, 5, and 8 cade, etc.). At a distance of 80.5 m from traps 1–4, an additional three traps (traps 10–12) were set up with a distance of 80.5 m between traps. These traps were baited with acetone, such that there were three traps per treatment (treatments a–d). At site 2, four sets of four traps were distributed along a road; trap sets were separated by approximately 400 m.

Table 1. Semiochemicals used in funnel traps and on western juniper trees with wounding.

Compound	Device	Volume	Release rate	Product no.
2002				
Acetone	Plastic container	5 ml	1.24 g/day	—
Ethanol	White pouch	15 ml	35 mg/day at 20°C[a]	L2-2041/000
Cade oil	Bubble cap	400 μl	1.87 mg/day	RD-0623/000
Juniper berry oil	Microcentrifuge tube	300 μl	1.63 mg/day	RD-0622/000
2003				
Ethanol	Black UHR pouch	150 ml	280 mg/day at 20°C[a]	L2–2041/500
Ethanol	White 40-cm pouch	15 ml	35 mg/day at 20°C[a]	L2–2041/000
Cade oil	Bubble cap	400 μl	1.87 mg/day	RD-0623/000
Juniper berry oil	Microcentrifuge tube	300 μl	1.63 mg/day	RD-0622/000

[a] UHR, ultra high release. Value provided by Phero Tec Inc. (Delta, B.C., Canada).

At this site, trap sets were arranged in a square pattern with 80.5 m between traps; traps in each set were randomly assigned one of the four semiochemical baits (totaling four per treatment). At both sites, trapping was initiated on May 7, 2002, and terminated on Sept. 23, 2002. Traps were checked approximately biweekly from May through July and monthly in August and September. The contents from collection cups were placed in paper envelopes and stored at 4°C until they could be transported to the Forestry and Range Sciences Laboratory at La Grande, OR, for identification.

Attraction of Bark and Woodboring Insects to Simulated Wounding and Semiochemical Attractants

The effect of treatment with semiochemicals and/or simulated wounding on insects associated with juniper trees was assessed. This portion of the study was conducted around the perimeter of a juniper control area at site 1 and more than 2 km south of the funnel traps located at the site described above. At the same time that funnel traps were installed, a total of 60 apparently healthy, mature juniper trees were selected that were located along a north-south transect and separated from one another by a distance of 40–120 m. All trees were at least 25 cm diameter at the base, ranging from 27.5 to 79.0 cm, with a mean of 44.5 cm. Using a chainsaw, wounding was accomplished by removing several (4–13; mean, 7) midbole branches (2.5–14.25 cm diameter; mean, 6.5 cm) on the north side of the tree. Cut branches were left at the base of the tree. These trees (15/treatment) were randomly assigned to undergo one of the following treatments, wounded and: (1) not baited (control); (2) baited with ethanol; (3) baited with juniper berry oil; or (4) baited with cade oil (see Table 1). Baits and passive barrier traps (15.24 × 30.48 cm Sticky Strips, BioQuip, Rancho Dominguez, CA) to capture attracted insects were stapled to the bole within the area where branches had been removed at a height of approximately 1.4 m. Treatments were installed on the same day and collected following the same schedule as the funnel traps described above. Insects adhering to the sticky traps were removed, placed in paper envelopes, and handled as described above.

In 2003, old sticky traps were removed and replaced on Apr. 5. Given preliminary evidence of a significant response by *Phloeosinus* spp. to ethanol (see below), 20 trees (5 from each 2002 treatment group) were randomly selected to be retreated with a new, larger ethanol release device (Table 1). The remainder received no new semiochemical treatment ($n = 40$; control). To determine how insects respond to a combination of semiochemicals, 15 additional trees were selected and wounded, and sticky traps were placed on their boles as described above. Each tree was then baited with all three semiochemicals (berry oil, cade oil, and ethanol [BCE]; Table 1). Sticky traps were also placed on another 15 trees (located approximately 20–80 m apart), which received no wounding or baiting, to measure insect activity on untreated trees. Collections were made on a biweekly basis through Sept. 3, 2003, and samples were collected and processed as described above.

Tree Damage

Treated and nearby untreated trees were visually examined for evidence of attack or resulting damage (presence of boring or boring dust around the bole and lower large limbs or dead or dying limbs over the entire crown) in late summer 2002, the following spring, and again in late summer 2003. In the spring of 2004, samples (approximately 25-cm sections) of limbs and boles were removed and returned to the La Grande Forestry and Range Sciences Laboratory for insect rearing. Three sections were removed from the cut limbs left around each of 8 trees treated with ethanol in 2003 (2 each with the same treatment history in 2002), 12 trees untreated in 2003 (3 each with the same treatment history in 2002), and 5 trees treated with all baits in 2003. A 25-cm section of bole was removed from four trees selected at random (one each of cade-ethanol, berry-control, berry-ethanol, and BCE).

Insect Processing and Identification

Insects were identified using established keys (Fisher 1942; Linsey 1962, 1964; Hatch 1962, 1971; Barron 1971; Bright 1976; Furniss and Carolin 1977; S.L. Wood 1982; Arnett and Thomas 2001) and verified by experts (see Acknowledgments). Voucher specimens were provided to experts, and a reference collection is maintained at the La Grande Forestry and Range Sciences Laboratory. The number of each selected species was recorded by treatment and date. Initially, three species (*Phloeosinus scopulorum* Swaine, *P. serratus* [LeConte], and *Chaetophloeus heterodoxus* [Casey]) were grouped in samples identified as *Phloeosinus* spp., given their similarity and small size. All funnel trap samples were re-examined to determine the approximate proportion of each species. For sticky traps, subsamples of up to 40–50 insects from selected collections were cleaned with petroleum ether. All ethanol-baited trap collections on May 17 and 28, 2002, and five trap collections each of the other treatments from May 28, 2002, were subsampled. All BCE-baited trap collections on June 6, 2003 and five trap collections each of the other treatments from this date were subsampled. These collection dates were chosen because they represented large collections.

Data Analysis

General Approach

For both types of traps, variances were not homogeneous for the number of each target insect species captured across all experimental units of each treatment based on an F_{max} test (Sokal and Rohlf 1995). Distributions of the number of insects captured were also highly non-normal. Transformation did not suitably rectify heterogeneous variances or non-normality; therefore, all analyses were done using the nonparametric Kruskal-Wallis test (Zar 1999).

Funnel Trap Data

The number of target insects collected in funnels traps from each location was small (156 at site 1 and 57 at site 2). Analyses of treatment differences were only performed for those species where a total of >5 individuals were collected. Data were combined over five consecutive collection dates (May through early July) for site 1 and six consecutive collection dates (May through July) for site 2. Later collection dates yielded too few insects for analysis by treatment.

Sticky Trap Data

For each of 10 species of bark and woodboring beetles or their predators found most often on sticky traps and also found in funnel traps (with the exception of the predator *Enoclerus sphegeus* [F.] [Coleoptera: Cleridae], which was found only on sticky traps), the number of insects collected per collection date was analyzed using Kruskall-Wallis tests (SAS Institute Inc. 2000) to evaluate treatment effects in 2002 and in 2003. To determine whether treatment response in 2003 was influenced by 2002 treatment, each combination of 2002 and 2003 treatments (e.g., ethanol-ethanol, ethanol-control, berry-ethanol, berry-control, etc.) was likewise analyzed using the Kruskall-Wallis test assuming a completely randomized design with eight treatments (see Table 4). For those species showing significant treatment effects, multiple comparisons of treatments were carried out using Dunn's test (Zar 1999). Statistical significance was assigned at $P \leq 0.05$ in all experiments.

Flight Phenology

The number of target insects collected from sticky traps on each collection date over each year of the study was used to infer the phenology of adult flight. To determine the beginning of the flight period, trapping was initiated earlier in 2003.

Table 2. Number of insects by taxa captured in funnel traps (sites 1 and 2 combined) and sticky traps and reared from western juniper limb sections.

Family, Genus, & Species	Traps: Funnel 2002	Traps: Sticky 2002	Traps: Sticky 2003	Reared 2004
Buprestidae				
Chrysobothris				
lilaceous Chamb.	7	19	19	1
viridicyanea Horn	4	18	9	9
Anthaxia				
prasina Horn	2	925	1,442	0
simiola Csy.	32	192	361	0
Acmaeodera idahoensis Barr	6	8	16	0
Buprestis subornata LeC.	1	0	0	0
Chalcophora angulicollis LeC.	15	0	0	0
Dicerca callosa frosti Nelson	1	0	0	0
Cerambycidae				
Semanotus ligneus (Fabricius)	2	18	13	0
Callidium texanum Schaeffer	6	184	18	8
Centrodera spurca (LeConte)	9	0	0	0
Cortodera bari Linsley and Chemsak	2	0	0	0
Phymatodes nitidus (LeConte)	1	0	0	0
Stenocorus vestitus (Haldeman)	2	0	0	0
Ergates spiculatus (LeConte)	2	0	0	0
Curculionidae Scolytinae				
Phloeosinus spp.	80	8,663	6,620	18
s. scopulorum Swaine	24	187[a]	70[a]	0
serratus LeConte	32	1,004[a]	582[a]	15
Unknown	12			3
Chaetophloeus heterodoxus (Casey)	12	0	0	0
Pityogenes sp.	2	0	0	0
Pityophthorus sp.	1	0	0	0
Cleridae				
Enoclerus sphegeus (F.)	0	201	47	0
Thanasimus undatulus (Say)	1	0	0	0
Cymatodera				
decipiens (Fall)	2	0	0	1
sodalist (Barr)	1	0	0	0
Phyllobaenus lautus (Barr)	1	0	0	0
Trichodes ornatus Say	1	0	0	0
Trogositidae				
Nemosoma fissiceps (Fall)	29	296	31	1
Temnochila chlorodia (Mannerheim)	13	0	0	0
Melyridae				
Malachius horni Fall	4	0	0	12

[a] Determined from cleaned subsamples; see text for details.

Results and Discussion

Bark and Woodboring Insects Associated with Western Juniper

Various members of Hymenoptera, Lepidoptera, Hemiptera, and Coleoptera were found in the funnel traps; however, we focused on the bark and woodboring beetles in the Buprestidae and Cerambycidae families, and Scolytinae subfamilies and their associated predators (Cleridae and Trogositidae) (Table 2). The general predator *Malachius horni* Fall (Coleoptera: Melyridae) is also included, because it was not only collected in funnel traps but also reared from removed limbs. A total of 20 species in 17 genera of bark and woodboring beetle families, and 7 species in 6 genera of associated predators, were captured in funnel and sticky traps. Although there were more funnel traps at site 2, half as many insects were captured ($n = 57$, $\bar{x} =$ approximately 4 per trap at site 2; $n = 156$, $\bar{x} =$ approximately 14 per trap at site 1). The difference may be attributable to management activities in the juniper control area (site 1), which resulted in more dead and dying trees on site than occurred at site 2. In addition, the differences in plant communities in the two sites may account for some of the differences observed, particularly the presence of ponderosa pine at site 1; at least four species collected at site 1 are common to pine, such as *Chalcophora angulicollis* (LeConte) (western pine borer).

A number of the species captured are known to use twigs or dead and dying host tree boles or limbs, such as *Phloeosinus* spp. (Furniss and Carolin 1977), which were the most prevalent beetles (*P. scopulorum* and *P. serratus*) in both funnel and sticky traps. Juniper is known to be the host of two species of buprestids in the genus *Chrysobothris*, *C. viridicyanea* (Horn) and *C. lilaceous* (Chamberlin), and two species of cerambycids, *Callidium texanum* Schaeffer and *Semanotus ligneus* Fabricius (Hatch 1971). The hosts of *S. ligneus* also include *Libocedrus decurrans*, *Cupressus* spp., and *Sequoia gigantea* (Linsey 1964).

Several of the woodborers in the family Buprestidae, including *Anthaxia* spp., are cone or flower feeders as adults and had the highest number captured during May and June, when the western juniper is releasing pollen (Figures 1 and 2). Although larval hosts are unknown, adult *Anthaxia prasina* (Horn) have been observed feeding on *Taraxacum* sp. (dandelion), *Rosa* sp. (rose), and *Balsamorhiza sagittata* (Pursh) Nutt (arrowleaf balsamroot) (Hatch 1971).

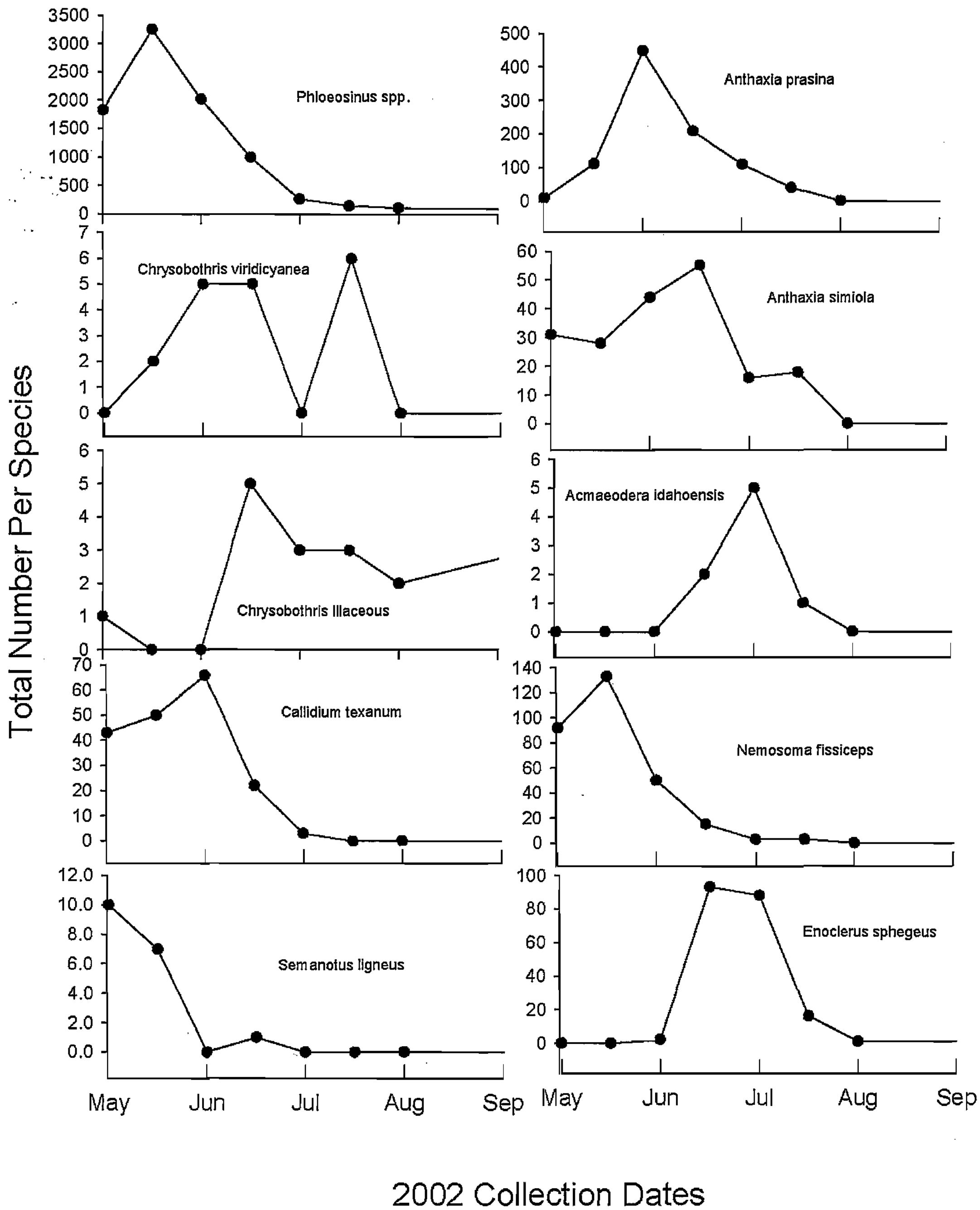

Figure 1. Phenology (total per collection date) of target species from sticky traps, 2002.

Adult *Anthaxia simiola* (Casey) feeds on various flowers, and immatures are associated with mountain mahogany (Hatch 1971). Another species of buprestid or flathead woodborer, *Acmaeodera idahoensis* Barr, feeds as an adult on various flowering plants: *Balsamorhiza* sp., *Ercophyllum* sp., *Achillea millefolium* L., *Erysimum* sp., and *Taraxacum* sp. The larvae of this species feed on the wood of mountain mahogany and *Celtis occidentalis* L. The mountain mahogany bark beetle, *Chaetophloeus heterodoxus* (Casey), a scolytine that feeds on weakened, injured, and recently dead branches of mountain mahogany, as well as *Prunus, Amelanchier*, and various desert shrubs (Furniss and Carolin 1977), was captured only in funnel traps (Table 2).

Because of its close resemblance to *Phloeosinus* spp., mountain mahogany bark beetle was initially combined in this group, but when re-examined, it was found to represent only approximately 15% of the insects in funnel trap samples collectively labeled *Phloeosinus* spp.; some specimens could not be identified because of their poor condition (Table 2). *Phloeosinus* spp. were also grouped in sticky trap collections because of their similarity and the difficulty of identifying insects coated in "stickem." Although the two are approximately the same size (2.4–4.0 and 2.2–3.7 mm, respectively), *P. scopulorum* is generally associated with twigs and small branches (<4 cm diameter), whereas *P. serratus* (juniper bark beetle) attacks the bole as well as branches of western juniper (S.L. Wood 1982). Based on cleaned subsamples, no *C. heterodoxus* were found, and it appears that *P. serratus* was the dominant of the two *Phloeosinus* spp. in this species grouping, making up approximately 85% and 89% of the samples examined in 2002 and 2003, respectively (Table 2).

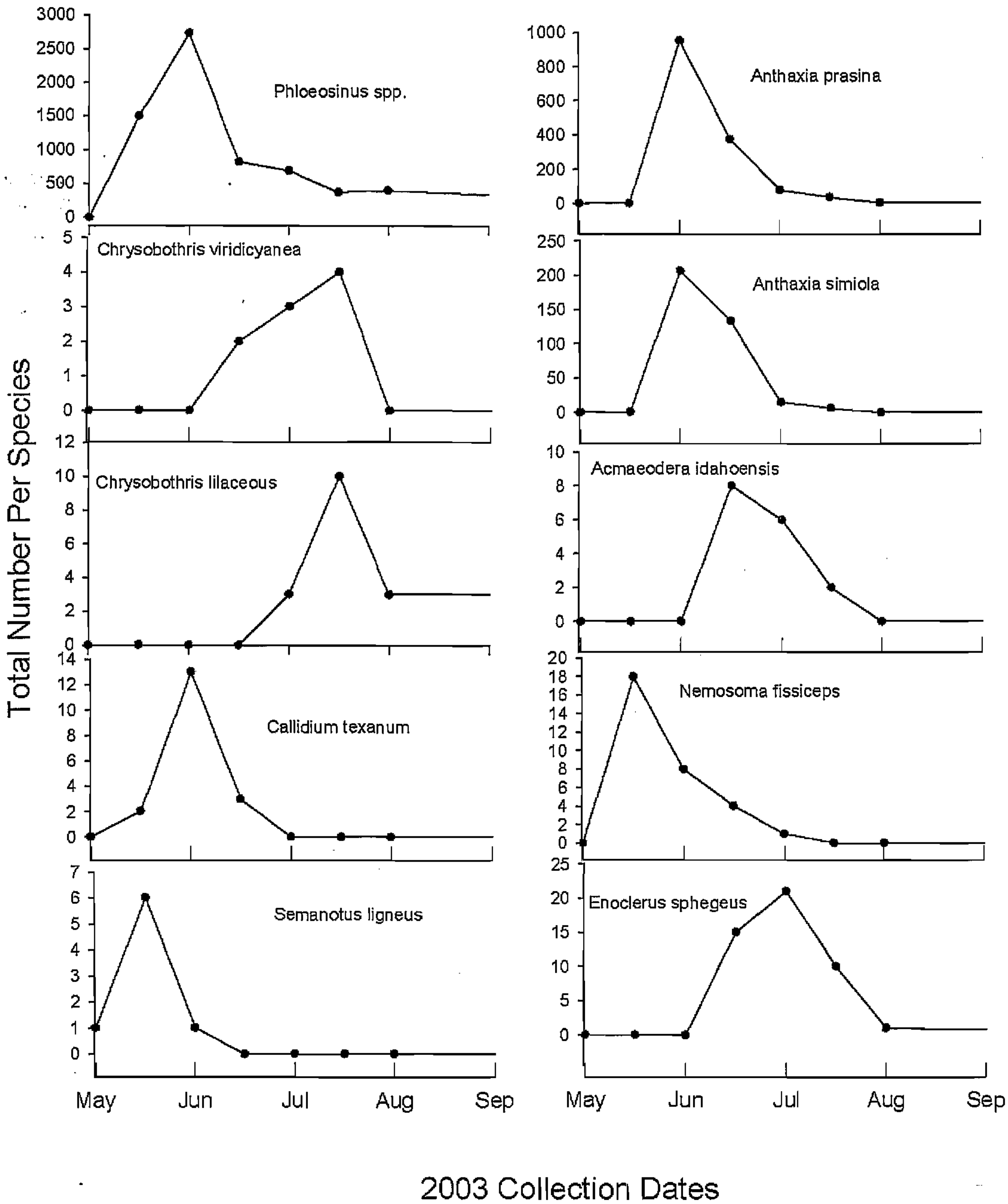

Figure 2. Phenology (total per collection date) of target species from sticky traps, 2003.

Again, because of poor condition, not all cleaned specimens could be identified.

Four of the species captured in funnel and/or sticky traps (the clerids *E. sphegeus* and *Thanasimus undatulus* [Say] and the trogositids *Temnochila chlorodia* [Mannerheim] and *Nemosoma fissiceps* [Fall]) are known predators of adult and immature stages of bark and woodboring insects (Furniss and Carolin 1977). We did not directly observe predation by any of these common scolytine predators of beetles associated with juniper; however, we did rear *Malachias horni* from juniper limbs, and this generalist predator may exert considerable pressure on juniper borers.

Of the species included in treatment analysis of funnel trap collections, only the predators *N. fissiceps* ($P < 0.014$) and *T. chlorodia* ($P < 0.003$) at site 1 and the cerambycid *Centrodera spurca* (LeConte) ($P < 0.028$) at site 2 showed significant treatment effects based on Kruskall-Wallis tests. The sample sizes were small, and multiple comparison tests showed no significant differences among treatments. However, more of all three species were collected in ethanol- and cade-baited traps than acetone or berry-baited traps. Neither *T. chlorodia* nor *C. spurca* was collected on sticky traps, and therefore they were not included in further analysis.

Baiting with Host Volatiles and Host Wounding

Although the trapping methods are not directly comparable, there were nearly 20 times more insects captured per sticky trap than per funnel trap in 2002 (Table 2; Figures 1 and 2). Although there is overlap in the species captured by the two collection methods (Table 2), both methods have their drawbacks. It is not surprising that species were collected in funnel traps that were not found on the sticky traps. Funnel traps are more likely to attract or incidentally trap insects that are not specifically associated with juniper but that may be attracted to one of the baits or the dark silhouette of the trap. Funnel trap collections, in number of both individuals and representative species, are likely low for a number of reasons, including the fact that we used dry collection cups, which can permit escape and predation until the insecticide takes effect. On the other hand, it is not surprising that a larger number of insects were collected on sticky traps, given the presence of the combination of host volatiles released through wounding and specific semiochemical volatiles and the pruned limbs available at the base of each tree as potential host material. Also, sticky traps are likely to capture insects that are locally abundant and/or that alight on any available surface. In addition, in previous studies, we have observed strong, typically large, beetles to escape from sticky traps (J.L. Hayes, personal observation).

Beetles from all five targeted families were captured in both funnel and sticky traps. Of the insects captured in funnel traps, nine species of beetles (two *Phloeosinus* spp. were combined for the purpose of analysis) in seven genera were also captured in sticky traps at site 1 and used in subsequent analyses. The exception was the predatory clerid, *E. sphegeus*, which was not found in funnel traps but was found in relatively high numbers on sticky traps and included in analyses. For the purposes of our analyses, we considered those species known to use juniper as a larval host as being directly associated with juniper (*Phloeosinus* spp., *C. viridicyanea*, *C. lilaceous*, *C. texanum*, and *S. ligneus*), whereas the other species were considered nonassociated, although they may visit juniper cones as adults. In 2002, the analysis of treatment differences by species revealed that only *Phloeosinus* spp. showed a significant treatment effect ($P < 0.001$), and the number of *Phloeosinus* spp. was significantly higher in ethanol-baited traps than other treatments (Figure 3; Table 3). Ethanol is produced by trees under stress (e.g., Kelsey and Joseph 2001, 2003). The number of *Phloeosinus* spp. captured was also significantly higher in cade-baited traps than the control (Figure 3; Table 3). The apparent lack of significant treatment effects among the other species may be largely attributable to small sample sizes. It is also important to note that neither of the juniper oils (cade and juniper berry) was derived from *J. occidentalis*, and even subtle differences in the constituent compounds among host species may yield substantial differences among coevolved insects.

Although not significantly different, three of the other associated species were trapped most frequently on cade oil-treated trees (*C. texanum*, *C. lilaceous*, *C. viridicyanea*) along with one of the nonassociated species, *A. prasina*, and the predator *N. fissiceps*. Interestingly, more than twice as many *N. fissiceps* were collected in ethanol-baited ($n = 19$) than cade-baited ($n = 8$) funnel traps. The other associated species, *S. ligneus*, and a nonassociated species, *A. simiola*, were trapped most frequently on ethanol-treated trees, whereas the nonassociate *A. idahoensis* responded equally to cade and ethanol, and the predator *E. sphegeus* occurred slightly more frequently on traps on unbaited (control) trees (Figure 3).

To determine whether there was any influence from the previous year's treatment, all combinations of treatments in 2002 and 2003 (e.g., year 1, berry; year 2, ethanol, etc.) were analyzed for treatment effects. Significant differences were found among treatment combinations for *Phloeosinus* spp. ($P < 0.001$), *C. lilaceous* ($P < 0.004$), and *E. sphegeus* ($P < 0.01$) (Table 4). However, the results of the multiple comparison tests for *Phloeosinus* spp. suggest that ethanol treatment in 2003, regardless of previous year treatment, in most cases significantly influenced capture numbers. For *C. lilaceous*, treatment with ethanol in both years significantly influenced captures over most treatments.

Not surprisingly, a comparison between trees wounded in 2003 and baited with all three semiochemicals (BCE), and no treatment (semiochemical or wounding), revealed significant treatment effects for 7 of the 10 species (Figure 3; Table 5). Only the associated species *C. texanum* and the nonassociated species *A. simiola* showed no treatment effect; no *A. idahoensa* were collected in these treatments.

Flight Phenology

We examined flight phenologies among species by comparing insects captured in sticky traps over all treatments in each year (Figures 1 and 2). Only *Phloeosinus* spp. were captured throughout the period from May through September, although most were captured in late May. The cerambycid *S. ligneus* was found only during the first two collection periods in May. The cerambycid *C. texanum* and the buprestids *A. simiola* and *A. prasina* were found in traps from May into July, and each reached peak numbers by early June. The buprestid *C. viridicyanea* was captured from late May through July, and *C. lilaceous*, was trapped from the end of June until trapping ceased in September. The buprestid *A. idahoensis* was trapped in June and July. The two predators *Enoclerus sphegeus* and *Nemosoma fissiceps* overlapped but showed distinctly different peak flight periods. The clerid *E. sphegeus* did not appear until early June and reached peak numbers in late June/mid-July, whereas the trogositid *N. fissiceps* reached peak numbers in May.

Damage Caused by These Insects

No obvious signs of insect attack or damage were observed at the end of the first or second year of this experiment. A small number of insects were successfully reared from pruned limbs (Table 2), confirming their colonization of juniper. There was no obvious relationship between numbers of reared insects and the treatment history of the tree, and a surprising number were reared from limbs cut in 2002 (on the ground for 2 years). The generalist predator *Malachius horni* was one of the most abundantly reared insects and may have contributed to the low number of emerging insects. A few of these predators were found in funnel trap collections (Table 2) but were not tracked on sticky traps. No insects were reared from bole samples.

Phloeosinus spp. were the most abundant insect reared from limbs. Of the specimens that could be identified, all were *P. serratus*. In general, *Phloeosinus* spp. are associated with feeding under the bark of weakened, dead, or dying bole and tops or branches of their host. However, under certain conditions, *Phloeosinus* spp., particularly *P. serratus*, have been described as primary mortality agents of western juniper (Sowder and Mowat 1965, Furniss and Carolin 1977, Dealy 1990). Several firsthand accounts exist of juniper mortality in central Oregon caused by *P. punctatus* (possibly *serratus*) (Chamberlin 1917) and *P. juniperi* (= *serratus*) (Chamberlin 1939, 1958).

Phloeosinus spp. are widely recognized as pests of juniper and other members of the family *Cupressaceae*. Drought in the southwestern United States is apparently creating sufficient stress for *Phloeosinus cristatus* to be a contributing factor in mortality of native and ornamental cypress and juniper in this region (e.g., Schalau 2003, US Forest Service 2003). In the Mediterranean region and elsewhere, *Phloeosinus* spp. cause minor damage to *Cypress* spp., but

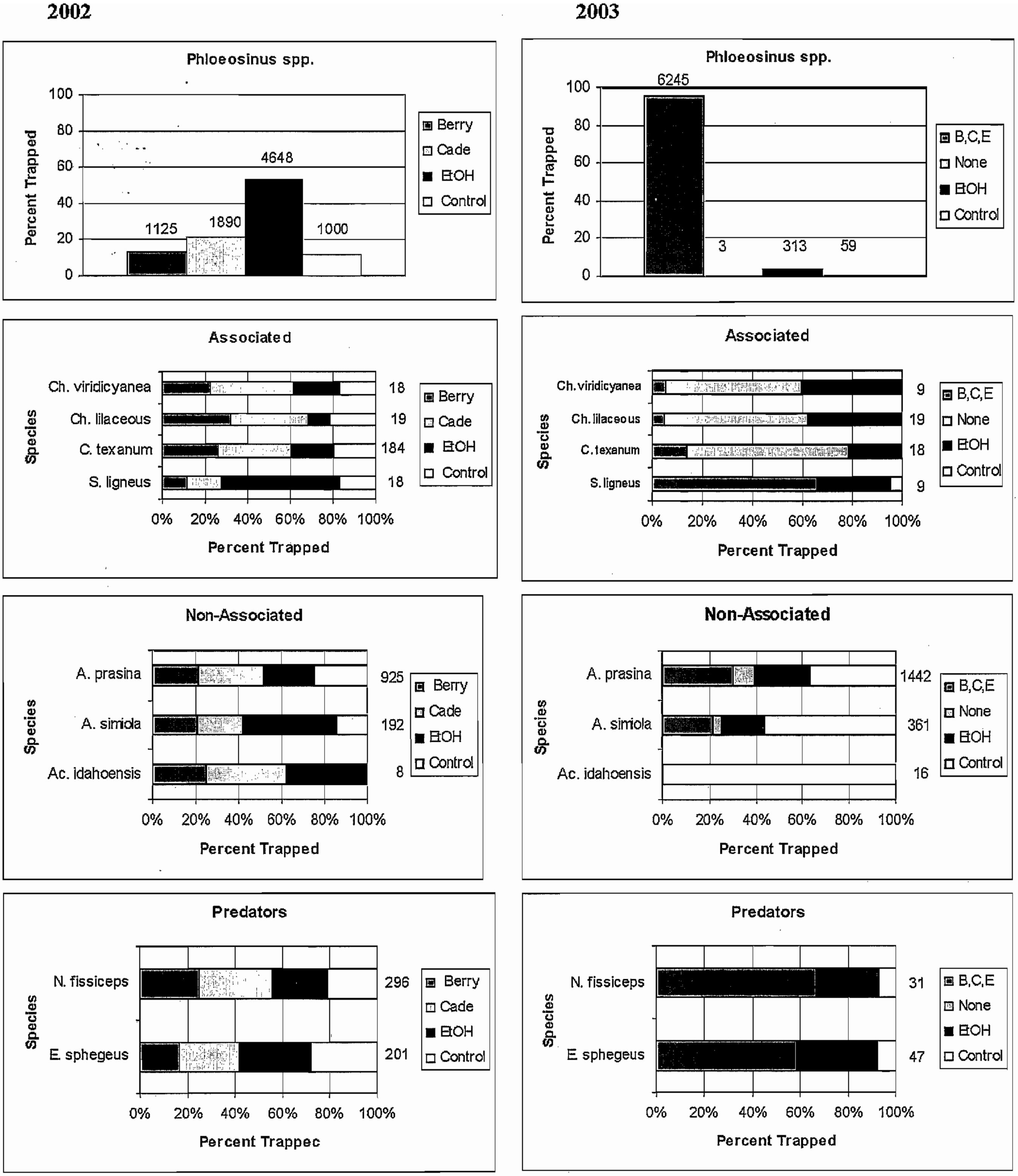

Figure 3. Proportions of *Phloeosinus* spp., other associated species, nonassociated species, and predators collected by 2002 treatments (left column) and by 2003 treatments (right column). See Tables 4 and 5 for results of Kruskal-Wallis analyses and multiple comparisons. B.C.E., berry oil, cade oil, and ethanol; EtOH, ethanol.

Table 3. Effects of semiochemical treatment on the total number of *Phloeosinus* spp. captured on sticky traps in 2002.

	P	Berry	Cade	Control	Ethanol
Phloeosinus spp.	<0.001	9.38, A	15.75, BD	8.33, CD	38.73, AC

Treatment means with the same letter differed significantly based on Dunn's test ($P < 0.05$; Zar 1999).

they are a serious concern as vectors of plant pathogens (e.g., Mendel 1983, Moricca et al. 2000).

Despite the seemingly high numbers of *Phloeosinus* spp. attracted to our traps, we did not observe damage attributable to these bark beetles in our treated trees. Although the historical record suggests it is possible for *Phloeosinus* spp. to cause significant damage, it appears

Table 4. Results of Kruskal-Wallis test and multiple comparisons of sticky traps from 2002–2003.

Species	P	2002 = / 2003 =	Berry / EtOH	EtOH / EtOH	Control / EtOH	Control / Control	EtOH / Control	Cade / EtOH	Cade / Control	Berry / Control
Phloeosinus spp.	<0.001		ABDE	ABDE	ABDE	AC	B	C	D	E
C. lilaceous	0.004		A	ABCDE	B	C	D	E		
E. sphegeus	0.01									

Within species (rows), the treatments with the same letter differed significantly by Dunn's test ($P < 0.05$; Zar 1999). EtOH, ethanol.

Table 5. Results of Kruskal-Wallis test for sticky trap data shown in Fig. 3 from 2003 treatments: Mean number of insects responding to all three semiochemicals (berry oil, cade oil, and ethanol [BCE]) plus wounding or no treatment; $n = 15$.

Species	P	BCE + wounding	No treatment
Phloeosinus spp.	<0.001	52.042	0.03
C. lilaceous	0.004	0.075	0
C. viridicyanea	0.82	0.033	0
S. ligneus	0.024	0.042	0
C. texanum	0.007	0.075	0
A. simiola	0.053	0.317	0.05
A. prasina	0.041	2.15	0.617
A. idahoensis			
N. fissiceps	0.001	0.142	0
E. sphegeus	<0.001	0.183	0

there was sufficient susceptible material to colonize in the limbs left at the base of treated trees and that the simulated wounding was not sufficiently severe to make the trees vulnerable to attack. It is possible that if trees were more severely wounded or weakened and baited with ethanol, *Phloeosinus* spp. might be induced to attack standing trees and ultimately cause mortality. With sufficient population size, there may also be spillover effect to other untreated trees nearby. However, it seems unlikely under current conditions that this insect or others can be induced to help in juniper management. The host specificity of these insects suggests that they would not threaten the adjacent plant community. Of some concern would be an increased population of insects that attack mountain mahogany; however, with possible exception of *C. heterodoxus*, the numbers of these insects were low, and their presence was likely due to adults visiting juniper cones. *C. heterodoxus* was found in very small numbers and only in funnel traps.

Although attraction of insects to apparently healthy trees did not result in tree mortality, there may be a benefit to enhanced attraction of insects to juniper management areas. Juniper trees store significant quantities of aboveground nutrients in the typically nutrient-poor sites they inhabit (Eddleman et al. 1994, Belski 1996, Karl and Leonard 1996). Increased insect activity may accelerate degradation and decomposition of dead junipers and the recycling of nutrients. Other ecological relationships may benefit as well. For example, insectivorous predation by foraging avian and mammalian guilds may be enhanced by increased insect abundance and activity in juniper woodlands. Preliminary investigations on avian abundance and diversity in Oregon juniper communities during the breeding season have found more than 60 species of birds nesting in juniper woodlands (Miller et al. 1999, Miller and Willis 2005).

Conclusion

In this study, we examined the potential for manipulating insects associated with juniper for use in management programs and evaluated the nontarget potential of the insects associated with these management activities. We found a large number of different bark and woodboring beetle species associated with western juniper. The numbers of individuals and species should be considered conservative given the drawbacks of the trapping methods used; in particular, rare or large species may have eluded capture. By far the most prevalent associated beetles captured were members of the genus *Phloeosinus*. These insects were attracted in the largest numbers to wounded trees baited with ethanol, but they were also found to be the most abundant species associated with wounding and terpenoid baits. In general, other associated species appeared to be more influenced by the presence of cade oil; however, these were collected in relatively low numbers compared with members of the *Phloeosinus*. Nevertheless, we did not find that this insect or others caused damage to treated trees. Because of the host specificity of the *Phloeosinus* spp. and other insects collected, it is unlikely that adjacent vegetation would be affected by increased numbers of these insects.

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