Comparison of Naturally and Synthetically Baited Spruce Beetle Trapping Systems in the Central Rocky Mountains

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ABSTRACT We compared naturally baited trapping systems to synthetically baited funnel traps and fallen trap trees for suppressing preoutbreak spruce beetle, *Dendroctonus rufipennis* Kirby, populations. Lures for the traps were fresh spruce (*Picea* spp.) bolts or bark sections, augmented by adding female spruce beetles to create secondary attraction. In 2003, we compared a naturally baited system ("bolt trap") with fallen trap trees and with synthetically baited funnel traps. Trap performance was evaluated by comparing total beetle captures and spillover of attacks into nearby host trees. Overall, the trap systems did not significantly differ in spruce beetle captures, although bolt traps caught 6 to 7 times more beetles than funnel traps during the first 4 wk of testing. Funnel traps with synthetic lures had significantly more spillover than either trap trees or bolt traps. The study was repeated in 2004 with modifications including an enhanced blend synthetic lure. Again, trap captures were generally similar among naturally and synthetically baited traps, but naturally baited traps had significantly less spillover. Although relatively labor-intensive, the bolt trap could be used to suppress preoutbreak beetle populations, especially when spillover is undesirable. Our work provides additional avenues for management of spruce beetles and suggests that currently used synthetic lures can be improved.

KEY WORDS pheromones, bark beetle management, funnel traps, semiochemicals

The spruce beetle, *Dendroctonus rufipennis* Kirby is the most important mortality agent of mature spruce (*Picea* spp.) (Holsten et al. 1999). Periodic outbreaks of this insect have killed millions of host trees throughout western North America, and epidemics have resulted in the loss of up to 99% of overstory spruce across thousands of acres (Schmid and Frye 1977, Holsten et al. 1999). Although such outbreaks are difficult, if not impossible, to control, there are several methodologies that can successfully suppress incipient or relatively small outbreaks (Schmid and Frye 1977, Holsten et al. 1999).

Among the methods are trapping variants. Because of the spruce beetle's preference for downed material, fallen trees can trap thousands of beetles (Schmid and Frye 1977). Deployment of trap trees has disadvantages and some limitations, however, including the requirement to mill, burn, or peel the infested log to destroy parent beetles and their brood. Also, a trap tree becomes unattractive when it is fully colonized because antiaggregation pheromones repel late-arriving beetles (Dodds et al. 2000, Laidlaw et al. 2003). This fixed capacity to absorb beetles may further be compromised if spruce beetle competitors, e.g., *Ips pilifrons* Swaine and *Dryocoetes affaber* (Mannerheim), colonize the host. To address this issue, previous deployments of fallen trap trees have consisted of one trap tree for every two to 10 standing infested trees (Holsten et al. 1999). Finally, even treatment of a trap tree does not necessarily result in the death of all beetles that enter, depending on timing of treating the infested log. This is because most parent spruce beetles reemerge from their initial galleries and can successfully initiate a second brood in another host (Massey and Wygant 1954, Hansen and Bentz 2003).

Lethal trap trees, either fallen or standing and baited with synthetic pheromones, do not have the limitations of fallen trap trees in that arriving beetles are killed and the trees remain attractive throughout the flight period (Dyer et al. 1975, Schmid and Frye 1977). As originally devised, lethal trap trees were injected with arsenical silvicides, resulting in the mortality of most brood (Chansler and Pierce 1966, Buffam 1971). No silvicides, however, are currently registered in the United States (Schaupp and Frank 2000). A variation of the lethal trap tree is to spray insecticide on the bole of a felled or baited tree (Gray et al. 1990), and there are several suitable pesticides for this application. Most of these pesticides, however, are not labeled for application over snow or near water. Also, transportation of spray equipment generally restricts use of lethal trap trees to areas with road access.

Multiple-unit funnel traps baited with synthetic pheromones (Lindgren 1983), routinely used to detect and monitor trends in bark beetle populations,

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also have been used to help control spruce beetles in combination with other suppression measures (Bentz and Munson 2000). Dyer and Chapman (1971), however, found that synthetic baits composed of frontalin and α-pinene were less attractive than female beetle-infested billets. Moreover, deployment of synthetically baited traps often results in spillover or infestation of live hosts near the trap, resulting in the need to remove infested hosts or otherwise destroy the brood (Borden 1989, Thier and Patterson 1997, Laidlaw et al. 2003). Although funnel traps are highly portable to remote areas, they are not recommended as a suppression tool largely because of the likelihood of spillover.

We devised naturally baited trapping systems that integrate the advantages of trap trees and funnel traps while eliminating many of their disadvantages. These systems combine 1) the attractiveness of recent blowdown, 2) season-long attraction, 3) mortality of trapped beetles without the use of sprayed pesticides, 4) the ability to be deployed away from roads, and 5) little or no spillover into live host trees. Our objective was to test the suppression potential of naturally baited traps against fallen trap trees and synthetically baited funnel traps by comparing total beetles captured and amounts of spillover near each trap type. As testing progressed, we also examined an enhanced synthetic lure formulation.

Materials and Methods

Trap Design. The lures for the naturally baited traps were fresh Engelmann spruce, *Picea engelmannii* Parry ex. Engelm., bolt or bark sections suspended in a vented, beetle-proof enclosure that allowed volatile semiochemicals to escape. Secondary attraction was created by augmenting host material with female spruce beetles (Dyer and Taylor 1968). Beetles attracted to the lure collide with the enclosure and fall into a collecting cup. The apparent contradiction, i.e., infesting a bolt with females and then protecting the bolt from additional infestation, is a strategy to elicit the release of beetle-produced aggregation pheromones but not antiaggregation pheromones (Rudinsky et al. 1974).

Our initial design, the "bolt trap," used a fresh spruce bolt for the lure. Bolts, ≈40 cm in length by 25 cm in diameter, were suspended with an eye-bolt in a vented, acrylic box measuring 50 by 28 by 28 cm (Fig. 1). A polycarbonate funnel, 80 cm in diameter, was hung below the enclosure. Beetles were collected in a cup containing dichlorovinyl dimethyl phosphate-impregnated plastic to reduce losses to predators. To obtain female beetles for infesting the bolts, we felled trees infested with adult brood several weeks before beetle flight. Bolts were placed in rearing cans at room temperature, and emerging beetles were collected and sexed using characters of the seventh tergite (Lyon 1958). Each bolt was infested with 10 female beetles, established in holes predrilled into the phloem, and the holes were then sealed with screen to prevent emergence. This basic design was used during three seasons of testing (2002–2004).

Fig. 1. View of the bolt trap. Box material is black acrylic; funnel material is polycarbonate, Lexan. Additional vents are on the top surface of the box, and the bottom is enclosed with removable window screening.

In an effort to reduce the size and weight of the trap, two additional designs were added during the third season. The lures for these new designs were fresh bark sections measuring ≈10 by 15 cm, extending ≈3 cm into the xylem. Each bark piece was infested with four female spruce beetles, approximating the density of natural infestation. Exposed xylem edges were sealed with paraffin wax to reduce desiccation. In the first of these designs, the "bark-baited pipe trap," we suspended six infested bark sections within a perforated, black ABS pipe section measuring 20 cm in diameter by 120 cm (Fig. 2). The profile of this design is similar to the "sticky stovepipe" trap of Chénier and Philogéne (1989); the silhouette of the latter is thought to impart superior attraction to approaching beetles compared with funnel traps. The collecting funnel and cup were identical to that for the bolt trap except with a smaller diameter, 60 cm. The second design, the "bark-baited funnel trap," used three infested bark sections, each contained in a vented poly-

Fig. 2. View of the bark-baited pipe trap. Piping is 20-cm-diameter ABS, topped with a PVC cap with two 5-cm attic vents. Additional ventilation is provided by hundreds of 2-mm holes drilled into the pipe surface and by window screening held onto the pipe bottom with a hose clamp. The lure for the trap is composed of six female-infested bark sections suspended within the pipe.

Fig. 3. View of the bark-baited funnel trap. Trap is a commercially available 16-unit funnel trap (ChemTica International). Female-infested bark sections are held individually in each of three vented PVC sections.

vinyl chloride (PVC) pipe section measuring 10 cm in diameter by 18 cm (Fig. 3). The three PVC sections were then attached to a 16-unit Lindgren funnel trap (ChemTica International, San Jose, Costa Rica).

Prototype Test: 2002. Two prototype bolt traps, with enclosures made of clear acrylic, were installed in areas of severe spruce beetle outbreak on the Dixie National Forest, UT, 23 May 2002. The bolt traps were paired with 12-unit funnel traps baited with commercially available two-component lure (Table 1). The trap types were spaced at 100 m, and the two plots were ≈2 km apart. To increase visual cues, each bolt trap also had an unbaited 16-unit funnel trap installed 1 m distant. All traps were checked weekly through late July 2002.

Field Study: 2003. Sixteen test plots were established in Colorado, Utah, and Wyoming (Table 2). Each plot contained three treatments: 1) a cluster of three 16-unit funnel traps baited with two-component lure, the three traps spaced equilaterally at ≈10 m; 2) a bolt trap with 10 initial females; and 3) a fallen trap tree, 38–50-cm diameter at breast height (dbh). Because prototype bolt trap testing indicated diminishing captures with time, 10 additional female beetles were placed on top of the logs every 2 wk after installation in an effort to maintain secondary attraction. Also, log enclosures for the bolt traps were changed from clear to black, to maximize visual cues, and adjacent unbaited funnel traps were omitted.

At each plot, an apparent center of current spruce beetle activity was identified, and treatments were randomly assigned in either an equilateral or linear design, depending on stand constraints; treatments spaced at 100 m. Because spruce beetles avoid sun-exposed trap trees, generally attacking only shaded bole portions (Holsten et al. 1999), trees were felled in the shade to the maximum extent possible. Also, pruned branches were placed on any sun-exposed bole sections where full shade was not available. Bolt and funnel traps also were placed in the shade as far from hosts as possible but within stand boundaries. Minimum spacing between plots was 200 m. Collections were done weekly, starting at the time of installation and continuing through mid-August 2003. Plots in Colorado and Wyoming were established 20–22 May 2003, and Utah plots were established 3–5 June 2003.

To inventory spillover and assess stand differences, a 100% postflight survey of all trees >8 cm dbh was

Table 1. Semiochemicals, with release rates, in synthetic lures used to trap spruce beetles in funnel traps

Lure type	Semiochemical	Release rate (mg/d @ 20°C)	Device
Two-component lure[a]			
	Frontalin	2.5	Centifuge tube
	α-Pinene	1.5	Centifuge tube
Three-component lure[b]			
	Frontalin	2.5	Centifuge tube
	α-Pinene	1.5	Centifuge tube
	1-Methyl-2-cyclohexenol	2.0	Bubblecap
Enhanced blend lure[b]			
	Frontalin	2.5	Centifuge tube
	Host terpene blend	125	Poly bottle
	1-Methyl-2-cyclohexenol	2.0	Bubblecap

[a] PheroTech, Inc., Delta, British Columbia, Canada.
[b] Synergy Semiochemical, Inc., Burnaby, British Columba, Canada.

conducted within a 50- by 50-m block centered on each trap, August and September 2003. Infested spruce were classified by year of attack (i.e., current, previous year, 2 yr prior, or older; Hansen and Bentz 2003) and type of attack (i.e., mass, strip, or pitch-out). Also, the trap trees were sampled to estimate the numbers of beetles absorbed therein (Schmid 1981).

Field Study: 2004. Because of inconclusive results from 2003 testing, we repeated the study with the following modifications: 1) the female beetle-infested bolt in the bolt trap was replaced 4 wk after trap installation and no additional female beetles were added thereafter; and 2) we switched to a commercially available three-component lure (Table 1), as the baseline synthetic device. The latter change was because of findings by Ross et al. (2005) who showed superior performance of the three-component lure compared with the two-component device. Motivated by 2003 results, we also tested an enhanced blend synthetic lure that adds additional host monoterpenes to the three-component device (Table 1). This resulted in five treatments: 1) bolt trap, 2) bark-baited pipe trap, 3) bark-baited funnel trap, 4) three-component-baited funnel trap (this treatment used a single trap rather than the three as deployed in 2003), and 5) enhanced blend-baited funnel trap. Infested bark sections in the two bark-baited traps were replaced semiweekly. Because of the high number of treatments, trap trees were not tested in 2004. At each plot, treatments were spaced at 100 m in a pentagonal pattern and randomly allocated. As in 2003, plots were established at locations in Colorado, Utah, and Wyoming (Table 2). Spillover and stand characteristics were measured as in 2003. Additionally, because anecdotal observations in 2003 suggested the natural trap system caught fewer clerid beetles (an important bark beetle predator) than the synthetic system, we counted all clerids caught in traps at the nine Utah plots. Also, spruce beetle sex ratios were determined for each treatment by plot by date combination, Fishlake plots only, by sexing all collected beetles up to a maximum of 200 per semiweekly sample. All traps were collected on a semiweekly schedule.

Analyses. Mixed models (PROC MIXED, SAS Institute, Cary, NC) were used to detect differences in stand variables among the treatments (Littell et al. 1996). Forest, area within forest, and the forest by treatment interaction were included as random variables. When the response variable was count or proportional data, we used GLIMMIX (a SAS macro for fitting generalized linear mixed models; 20 September 2000 release; SAS Institute) that allows for Poisson or binomial error distribution. Also, stand variables were tested as covariates where appropriate. In cases where a trap had fallen to the ground, beetle counts were omitted from all treatments within the same plot for that interval (i.e., weekly or semiweekly trap catches). For some analyses, these methods did not result in normally distributed residual errors. Specifically, problems were detected when analyzing spillover data, which included multiple zero counts. To analyze 2003 spillover, which was measured as currently infested stem counts, we used ranks within each plot. To analyze 2004 spillover, we used Box–Cox transformations to identify the most appropriate transformation. To avoid zero counts for observations without spill-

Table 2. Locations of areas used to compare spruce beetle traps, and the number of plots within each area, in 2003 and 2004

State	Forest	Area	Lat/long	Elevation (m)	2003 Plots	2004 Plots
Colorado	Routt	Coulton	40° 47′ N, 106° 51′ W	2,550	3	
Colorado	Routt	Bear's Ears	40° 47′ N, 107° 20′ W	2,960	4	3
Utah	Cache	School Forest	41° 50′ N, 111° 31′ W	2,600	3	3
Utah	Fishlake	LeBaron	38° 12′ N, 112° 24′ W	2,950	3	3
Utah	Manti	Rolfson	39° 35′ N, 111° 16′ W	2,740		3
Wyoming	Medicine-Bow	Silver Lake	41° 18′ N, 106° 22′ W	3,040	3	3

Silver Lake was selectively harvested during the 1970s; portions of School Forest were selectively harvested during the late 1990s (Bentz and Munson 2000); and Rolfson was sanitation/salvage harvested during the 1960s after a spruce beetle outbreak. To our knowledge, these and the other areas are otherwise unmanaged.

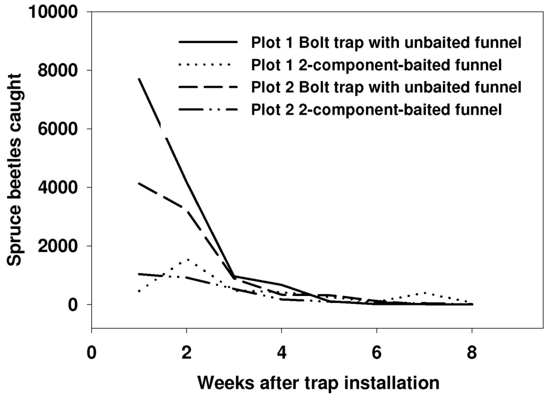

Fig. 4. Spruce beetles caught per week after trap installations during 2002 prototype testing at two plots ≈2 km apart in an area of severe spruce beetle outbreak on the Dixie National Forest, Utah. The trap systems tested were 1) naturally baited bolt trap with an adjoining, unbaited funnel trap; and 2) a two-component-baited 12-unit funnel trap.

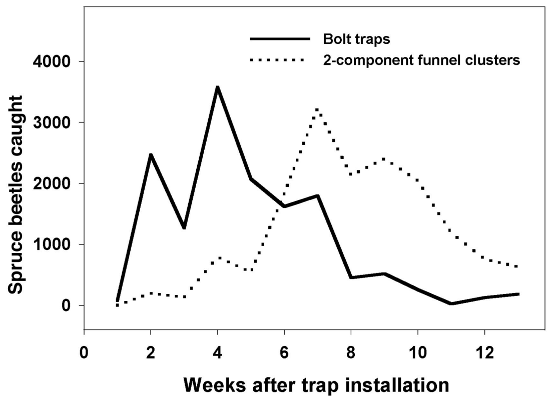

Fig. 5. Spruce beetles caught per week after trap installations of bolt traps and clusters of three 16-unit funnel traps (2003 testing). Data shown are pooled trap catches from 16 plots at five areas (see Table 2).

over, we added 0.01 to currently infested stem counts for all observations. Finally, our analyses include cost estimates for each treatment.

Results

Prototype Test: 2002. At one plot, the two-component-baited funnel trap caught 2,870 spruce beetles, whereas the bolt–funnel combination caught 9,018 spruce beetles, with 3,725 of those beetles in the unbaited funnel trap. At the other plot, the two-component-baited funnel trap caught 3,719 spruce beetles, whereas the bolt–funnel trap combination caught 13,659 spruce beetles, with 8,590 of those beetles in the unbaited funnel trap. Superior performance of the bolt–funnel combination occurred only during the first 4 wk of the study (Fig. 4), thus the decision to add fresh female beetles semiweekly for the 2003 study.

Field Study: 2003. Overall, beetle captures did not significantly differ among the treatments ($F_{2,\ 9.56} = 2.03$; $P = 0.1837$); however, analyses of plots on individual forests revealed significant differences among the treatments on two forests (Table 3). On the Cache National Forest, trap trees and bolt traps did not differ, but both caught more beetles than two-component-baited funnel trap clusters ($F_{2,\ 9} = 10.97$; $P = 0.0039$). On the Fishlake National Forest, bolt traps did not differ from either trap trees or funnel trap clusters, but trap trees outperformed funnel traps ($F_{2,\ 9} = 8.27$; $P = 0.0092$).

A likely source of inconsistent performance, when comparing the bolt trap and two-component-baited funnel trap clusters, is illustrated by examining the weekly trap captures. Although there was no overall difference in total seasonal captures among the two trap systems, early season results greatly favored the bolt traps. This was especially true at plots where beetles began flight within a week of plot establishment (i.e., Cache, Fishlake, and lower elevation Routt plots). Bolt traps at these plots caught 6 to 7 times more beetles than funnel trap clusters during the first 4 wk. This advantage was reversed, however, as the flight season progressed (Fig. 5). At the higher elevation Routt and Medicine-Bow plots, beetle flight did not commence until July, some 4–6 wk after the traps were deployed. Bolt traps performed relatively poorly at these sites. Analysis confirmed a significant interaction between time after installation and treatment (treatment by week interaction: $F_{12,\ 390} = 7.22$; $P < 0.0001$). Inspection of bolt trap bolts showed poor establishment rates, 3–35%, for female beetles that

Table 3. Log-scale mean numbers of spruce beetles captured by various trapping treatments during 2003 testing; Cache and Fishlake plots only (three each)

Trap type	Cache		Fishlake	
	Log-scale (ln) beetle captures (mean ± SE)	Backtransformed (mean)	Log-scale (ln) beetle captures (mean ± SE)	Backtransformed (mean)
Trap tree	6.85 ± 0.17a	946	8.30 ± 0.18a	4,027
Bolt trap	7.31 ± 0.14a	1,496	7.37 ± 0.29ab	1,587
Funnel trap cluster	3.74 ± 0.81b	42	6.75 ± 0.40b	855

Backtransformations of means are included to aid interpretation. Within the same column means followed by the same letter are not significantly different at $P > 0.05$ by using tests of pairwise differences (Tukey–Kramer).

Trap trees and bolt traps are considered naturally baited traps, whereas the funnel trap clusters were baited with two-component synthetic lures.

Table 4. Spruce beetle spillover, expressed as ranks per plot of infested stem counts within a 50- by 50-m block centered on each trap, associated with various trapping treatments during 2003 testing

Trap type	Mean ranks, per plot, of infested stem counts (mean ± SE)	Original scale means (no. of infested stems within 50- by 50-m blocks)
Funnel trap cluster	7.57 ± 0.67a	5.8
Trap tree	4.68 ± 0.67b	2.5
Bolt trap	3.77 ± 0.67b	1.3

Original scale means are included to aid interpretation. Within the same column means followed by the same letter are not significantly different at $P > 0.05$ by using tests of pairwise differences (Tukey–Kramer).

were added to log tops after the initial infestation. Because of these results, we decided to replace the entire bolt at 4-wk intervals for the 2004 study.

Ranks of spillover were significantly related to treatment type ($F_{2, 10.6} = 10.75$; $P = 0.0028$). Funnel trap clusters had more spillover than either bolt traps or trap trees, whereas trap trees and bolt traps did not significantly differ (Table 4). Stand variables did not explain the amount of spillover (e.g., live spruce basal area: $F_{1, 43} = 0.07$; $P = 0.7998$).

Filed Study: 2004. Analyses were confounded by results from the Manti National Forest where a significant outbreak, beginning in 2002, infested most mature stems. For example, normality assumptions were not met for residuals when analyzing all data pooled; thus, we analyzed the Manti data separately. Excluding the Manti data, total spruce beetle captures were significantly related to treatment ($F_{4, 18.7} = 8.63$; $P = 0.0004$). Multiple comparisons indicated that the bolt, enhanced blend-baited funnel, and three-component-baited funnel traps were equivalent, each outperforming the bark-baited funnel trap; the enhanced blend-baited funnel trap also caught more beetles than the bark-baited pipe trap (Table 5). For the Manti data alone, captures also were significantly related to treatment ($F_{4, 12} = 8.14$; $P = 0.0021$). Multiple comparison results were similar to those for the other forests; the enhanced blend-baited funnel trap was equivalent to the bolt trap and three-component-baited funnel trap while outperforming the bark-baited pipe and bark-baited funnel traps (Table 5). Unlike 2003 results, no week by treatment interaction was detected ($F_{16, 322} = 0.96$; $P = 0.4966$), suggesting that bolt and bark replacements in the naturally baited traps were successful at extending trap performance.

Clerid captures also were significantly related to treatment type ($F_{4,5.33} = 13.61$; $P = 0.0054$). The synthetically based systems generally caught more clerids than the naturally based systems (Table 6). Sex ratios of captured beetles were significantly related to treatment ($F_{4, 40} = 23.17$; $P < 0.0001$) and collection date ($F_{1, 40} = 18.17$; $P = 0.0001$). The synthetically baited traps caught more females than males, whereas the reverse was true of naturally baited traps (Table 7). The proportion of female beetles captured increased during the late summer, regardless of trap system.

Spillover, expressed as currently infested stem counts within a 50 by 50-m block centered on each trap, was significantly related to treatment ($F_{4, 16} = 4.34$; $P = 0.0144$). The enhanced blend-baited trap had more spillover than the bolt trap, whereas the other treatments did not differ from each other. Repeating the analysis without the Manti data, both the enhanced blend-baited funnel and three-component-baited funnel traps had more spillover than the bolt trap ($F_{4, 12} = 5.87$; $P = 0.0074$; Fig. 6). Analyzing the Manti data alone revealed no treatment effect ($F_{4, 8} = 0.82$; $P = 0.5494$); most Manti plots had substantial infested stem counts, which probably reflects more on the large local beetle population rather than the trap systems. In summary, the naturally baited trap systems had less spillover than the synthetically baited systems, although the difference was significant only when comparing the synthetic systems to the bolt traps.

Treatment Costs. The naturally based trap systems are more expensive to build than funnel traps with synthetic lures, whereas trap trees have no material costs and labor costs are relatively minimal. Additionally, there are extra labor costs involved with rearing beetles and replacing lures used in the naturally baited systems (Table 8). The synthetically based traps, however, will be less cost-effective overall if spillover disposal is included. Our calculations are for peeling infested logs and do not consider differences if salvage logging is used to treat infested logs (i.e., salvage log-

Table 5. Mean numbers (log scale) of spruce beetles captured by various trapping treatments during 2004 testing

Trap type	Manti excluded		Manti only	
	Log-scale (ln) beetle captures (mean ± SE)	Backtransformed (mean)	Log-scale (ln) beetle captures (mean ± SE)	Backtransformed (mean)
Enhanced blend-baited funnel	6.69 ± 0.28a	802	9.90 ± 0.26a	20,020
Bolt	6.67 ± 0.28ab	789	9.47 ± 0.27ab	13,016
Three-component-baited funnel	6.18 ± 0.29ab	483	9.34 ± 0.28ab	11,363
Bark-baited pipe	5.91 ± 0.30bc	370	8.95 ± 0.30b	7,744
Naturally baited funnel	5.21 ± 0.34c	184	8.81 ± 0.31b	6,714

Backtransformations of means are included to aid interpretation. Within the same column means followed by the same letter are not significantly different at $P > 0.05$ by using tests of pairwise differences (Tukey–Kramer).

Raw capture data were square root-transformed before GLIMMIX runs to achieve normal distribution of residuals; backtransformed means were calculated using the inverse log of means and squaring the result.

Table 6. Mean numbers of clerids captured by various trapping treatments during 2004 testing (Utah plots only)

Trap type	Total clerids captured (natural log scale) (mean ± SE)	Backtransformed (mean captures)
Enhance blend-baited funnel	3.25 ± 1.10a	25.8
Three-component-baited funnel	2.85 ± 1.11a	17.3
Bolt	1.71 ± 1.13ab	5.5
Bark-baited pipe	0.33 ± 1.17b	1.4
Bark-baited funnel	−1.53 ± 1.42b	0.2

Backtransformations of means are included to aid interpretation. Within the same column means followed by the same letter are not significantly different at $P > 0.05$ by using tests of pairwise differences (Tukey–Kramer).

ging could be less expensive than peeling, especially if the material is merchantable). Another confounding factor in this evaluation is that all traps in the naturally and synthetically based systems can be used multiple years. After the initial investment, therefore, subsequent treatment costs will largely consist only of labor.

Discussion

There is a broad diversity of literature, particularly from North America and Europe, describing attempts to trap bark beetles for purposes of suppression, population monitoring, life history studies, and determination of semiochemical attraction. The trapping systems used in previous studies range from trap trees to a variety of artificial traps by using synthetic or natural lures. Beetle response to these traps is species dependent and can vary for conspecifics in differing geographies. For example, Aukema et al. (2000) determined that certain synthetic lures with funnel traps caught more *Ips pini* (Say) than traps baited with infested red pine, *Pinus resinosa* Soland, bolts in Wisconsin, whereas an otherwise similar study found equivalent trapping performance among the two trapping systems for *I. pini* in California (Dahlsten et al. 2004). *Ips typographus* (L.), much like the spruce beetle, prefers recently downed host material and

Table 7. Logit scale proportions of female beetles captured by various trapping treatments during 2004 testing (Fishlake plots only)

Trap type	Females captured (logit scale proportions) (mean ± SE)	Backtransformed proportions (%)
Enhanced blend-baited	0.223 ± 0.068a	55.5
Three-component-baited funnel	0.157 ± 0.078ab	53.9
Bark-baited funnel	−0.335 ± 0.174bc	41.7
Bolt	−0.348 ± 0.047c	41.4
Bark-baited pipe	−0.547 ± 0.075c	36.7

Backtransformations of means are included to aid interpretation. Within the same column means followed by the same letter are not significantly different at $P > 0.05$ by using tests of pairwise differences (Tukey–Kramer).

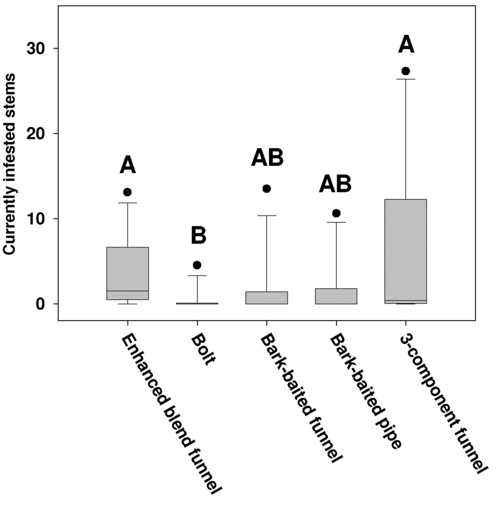

Fig. 6. Spillover, expressed as the number of infested stems within a 50- by 50-m block centered on each trap, among various trap types tested in 2004. Plots from the Manti National Forest, where an ongoing epidemic resulted in numerous infested stems regardless of trap type, are not included here. Means of boxplots with the same letter are not significantly different at $P > 0.05$ by using tests of pairwise differences (Tukey–Kramer).

trap trees substantially outperformed synthetically baited traps in at least two studies (Drumont et al. 1992, Raty et al. 1995). *Dendroctonus ponderosae* (Hopkins), however, rarely attacks freshly felled lodgepole pine despite the observation that conspecifics infest freshly felled ponderosa pine (Amman 1983). Similarly, spruce beetles were not attracted to uninfested spruce bolts in an Alaskan study (Gara and Holsten 1975), whereas conspecifics in British Columbia were trapped using similar lures (Moeck 1978). Furthermore, spruce beetles in Alaska and British Columbia and Alberta, Canada, differentially respond to synthetic lure combinations (Borden et al. 1996). These results imply that lure attraction is not only species dependent but also can vary within species, depending on the system or location.

Trap trees have been used to trap and destroy spruce beetle broods since at least the 1940s (Massey and Wygant 1954). Several reports have shown consistent, if anecdotal, evidence for successful suppression of spruce beetles by using trap trees (Nagel et al. 1957, Gibson 1984, Hodgkinson 1985, Burnside 1991, Bentz and Munson 2000), and trap trees are currently recommended for managing beetle populations, depending on stand conditions and population levels (Holsten et al. 1999). Bolts also have been used as lures by other investigators to trap spruce beetles, although not for the purpose of suppressing beetle populations. Moeck (1978) used uninfested bolts to determine primary attraction, and Furniss et al. (1976) used infested logs to assess the efficacy of methylcyclohexanone as an antiaggregant. Dyer and Chapman (1971) reported that α-pinene and frontalin will induce attacks on spruce although at a reduced rate compared with

Table 8. Estimated treatment costs for single deployments of the spruce beetle trapping systems tested in 2003 and 2004

	Materials ($)[a]	Labor ($)[b]	Subtotal ($)	Spillover disposal ($)[c]	Grand total ($)
Trap tree	0	90	90	216	306
Bolt trap	208	226	434	48	482
Bark-baited pipe trap	133	239	372	204	576
Bark-baited funnel trap	58	183	241	192	433
Enhanced blend-baited funnel	47	150	197	408	605
Three-component-baited funnel	45	150	195	732	927

Estimates are for a single season only, thus costs decline as traps are redeployed over multiple seasons. All labor costs calculated at $15/h.
[a] Materials include funnel traps or trap parts, lures, and rearing cans.
[b] Labor costs include trap construction, tree felling, rearing and sexing beetles, infesting natural lures, field installation of traps, and trap checking. Tree felling and rearing costs for naturally baited traps are spread over 15 deployments. Trap checking cost based on two people, one day per week for 8 wk, cost dispersed over 15 deployments.
[c] Spillover disposal costs are based on peeling, and numbers of stems needing treatment are based on 2004 results by using the mean number of currently infested stems over all plots, excepting for Manti plots. Trap tree spillover, which was measured only during 2003 testing, is prorated according to 2004 bolt trap results, bolt traps being a common treatment for both study years, and includes the trap tree itself.

female-infested spruce bolts. These two semiochemicals are now used in the commercially available two-component lure, although other semiochemicals have greater attraction in Alaska and Canada (Furniss et al. 1976, Borden et al. 1996). Synthetically baited traps have since been used to monitor spruce beetle populations, particularly after the introduction of the funnel trap (Lindgren 1983). Bentz and Munson (2000) included two-component-baited funnel traps as part of a multitreatment strategy to suppress a small spruce beetle population in northern Utah. Although the combination of funnel traps, trap trees, and harvesting of infested trees seemed to be successful, the contribution of the funnel traps to this outcome was not determined, and the authors noted that the funnel traps caused unwanted spillover despite deployment in clusters of previously killed trees.

We view the naturally based trapping systems presented here as potential alternatives for suppressing preoutbreak spruce beetle populations. Although we made no effort to test the suppression efficacy of any trapping systems examined herein, we feel that these traps can be used in situations where trap trees might otherwise be prescribed. These systems have advantages over existing trapping methods, combining high catch potential, on-site beetle mortality, benign environmental effects, and little risk of spillover. However, these systems are more labor-intensive than synthetically based trap systems. In fact, each trap system we evaluated has advantages and disadvantages.

Naturally Baited Traps. The bolt trap significantly outperformed clusters of three two-component-baited funnel traps when the female-infested bolt was fresh, and results from 2004 testing indicate that bolt replacement at 4-wk intervals should maintain this performance advantage. Dyer and Chapman (1971) found similar results in that female infested billets attracted almost 9 times more spruce beetles than barrier traps baited with frontalin and α-pinene. Dyer and Chapman (1971) indicated that additional, undiscovered chemical cues are involved in secondary attraction. Our results support this supposition. The bolt trap, however, was only roughly equivalent to the enhanced blend-baited funnel trap, which contains a more complete suite of primary attractants. Additional research into spruce beetle chemical ecology may uncover additional semiochemicals to yield an even more effective synthetic lure.

Comparison of the bolt trap with trap trees is more enigmatic. Although trap trees, overall, caught more beetles than bolt traps in 2003 testing, this difference was not significant and could have been offset by replacing the bolt in the bolt trap. Regardless, we suspect the bolt trap is comparable with a trap tree provided the infested bolt lure is replaced after 4 wk. Because the bolt trap performs similarly to trap trees, we propose that operational deployments of bolt traps should follow guidelines developed for trap trees regarding the density of traps needed (Holsten et al. 1999). Deployment of unbaited funnel traps immediately adjacent to a bolt trap may further increase total captures.

The near lack of spillover associated with bolt traps is, perhaps, the greatest advantage this system has over synthetically based systems. This benefit alters cost-effectiveness comparisons among the trapping options if spillover must be treated with labor-intensive methods such as peeling or burning. Trap trees also have relatively low spillover, but the trap tree itself must be treated or removed from the site to prevent additional infestations. In situations where spillover and pesticide use are undesirable, such as in recreational areas or riparian zones, the bolt trap may be preferable to trap trees. Finally, the naturally baited traps caught fewer beneficial clerids than synthetically based systems.

The bark-baited pipe and bark-baited funnel trap systems were designed to provide less expensive and lighter, more transportable options to the bolt trap. The bark-baited funnel trap is particularly simple to construct, because it is based on a commercially available trap, and is easily deployed well away from road access. The trapping performance of this option, however, is significantly below that of the bolt trap. A cluster of three bark-baited funnel traps may result in performance equivalent to that of a single bolt trap, but such a strategy would cancel cost and transportability advantages. The bark-baited pipe trap, however, was not significantly different than the bolt trap in any measured parameter. This trapping system is slightly less expensive and easier to construct than the bolt trap. Furthermore, the pipe trap is far lighter than the bolt trap, albeit similarly bulky, making it easier to deploy away from road access.

Synthetically Baited Traps. Although we did not directly compare the two- and three-component lures, our results implicitly support the finding of Ross et al. (2005) that three-component lures are significantly more attractive to spruce beetles in the central and southern Rocky Mountain area. That is, the bolt trap outperformed two-component-baited funnel traps but was only equivalent to a single three-component-baited funnel trap. The enhanced blend-baited funnel trap is potentially even more attractive, having trapped the most beetles, although not by significant margins. Deployment of all synthetically baited traps we tested, however, resulted in varying amounts of spillover, which is undesirable in many management situations. One metric that favored the synthetically baited traps was the sex ratio of captured beetles; our results are consistent with those of Dyer and Taylor (1968) that female infested spruce bolts attract a predominance of males. If we had measured and compared only the numbers of female beetles captured, relative performance of the synthetically baited traps would have improved, possibly enough to outperform the bolt trap in terms of total females captured. However, Dodds et al. (2000) argued that trapping a single Douglas-fir beetle, *Dendroctonus psedotsugae* Hopkins, male or female, could effectively remove a mated pair because that species is predominantly monogamous and has an even sex ratio. Because spruce beetle has similar characteristics (Schmid and Frye 1977), this argument can be extended to interpretation of our results. Regardless, the observation that female beetles, which pioneer attacks on new hosts, are proportionately more attracted to the synthetic lures may explain why spillover is more of a problem near synthetically baited traps.

Altering the release rate of the blend device or adding other, possibly yet unknown, semiochemicals may result in a lure that matches the characteristics of the naturally baited systems: high trap catch combined with little spillover. Such a device would be cost-effective, highly portable, and easy to deploy. In situations where spillover can be salvaged, the enhanced blend device as formulated represents an advance in trapping methodology. If spillover is undesirable, however, we do not recommend any of the synthetic baits for use in funnel traps as stand alone suppression treatments. This is because of the high cost of treating spillover and the risk of intensifying incipient populations if infested stems are left untreated.

Trap Trees. Trap trees remain a good suppression option. They are the most cost-effective of the trapping systems we tested, an advantage that is increased when the trap tree and any spillover can be salvaged. If a trap tree and associated spillover are not salvaged, however, they *must* be treated because trapped beetles are not killed by the trap. In comparison, the naturally and synthetically based traps can kill beetles on site, with no further treatment required (excepting spillover). Also, lethal trap trees are a good suppression option if environmental concerns or road access are not constraints.

Conclusions. The naturally baited trapping systems described herein are novel options for suppressing preoutbreak spruce beetle populations in situations where spillover, road access, logging restrictions, and pesticide application are issues of concern. Other bark beetles with strong attraction to downed host material, e.g., Douglas-fir beetle, also may be targeted by this technology, although our results might not apply to other areas such as Alaska (Gara and Holsten 1975). Our testing also has illustrated the limitations of currently available synthetic lures and points to new directions for bark beetle pheromone research. For example, there likely is a suite of pheromones and kairomones that act synergistically in attracting specific bark beetle species to suitable host materials. Consequently, trap lures can be improved if the natural system is more closely mimicked, as demonstrated by the enhanced blend lure. Understanding the broader chemical ecology of these systems will increase our understanding of bark beetle disturbances as well as provide novel management tools.

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