Effectiveness of Carbaryl and Pyrethroid Insecticides for Protection of Engelmann Spruce from Attack by Spruce Beetle (Coleoptera: Scolytidae)

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EFFECTIVENESS OF CARBARYL AND PYRETHROID INSECTICIDES FOR PROTECTION OF ENGELMANN SPRUCE FROM ATTACK BY SPRUCE BEETLE (COLEOPTERA: SCOLYTIDAE)

by

Karen J. Johnson

A thesis submitted in partial fulfillment of the requirements for the degree of

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in

Forestry

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1996
ABSTRACT

Effectiveness of Carbaryl and Pyrethroid Insecticides for Protection of Engelmann Spruce from Attack by Spruce Beetle (Coleoptera: Scolytidae)

by

Karen J. Johnson, Master of Science
Utah State University, 1996

Major Professor: Dr. Michael J. Jenkins
Department: Forest Resources

A field experiment tested the effectiveness of carbaryl and two pyrethroid insecticides, cyfluthrin and esfenvalerate, in protecting high-value Engelmann spruce trees from attack by Dendroctonus rufipennis Kirby. Carbaryl suspension at the 2% registered rate and a reduced rate of 1% were both effective in protecting Engelmann spruce from attack by D. rufipennis through two pheromone baiting periods and 24 months following insecticide application. Cyfluthrin at 0.025% rate and esfenvalerate at 0.025 and 0.05% rates provided effective protection through one pheromone baiting and 12 months following insecticide application. Only cyfluthrin at 0.008% rate was judged ineffective protection 12 months following insecticide application.

A laboratory evaluation utilizing a 32-h bioassay on D. rufipennis adults determined all three insecticides were toxic by contact. Carbaryl and piperonyl butoxide bioassays testing synergism were inconclusive. The methodology presented provides a means for forest land managers to quantify insecticide toxicity and monitor for resistance development.
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Spruce Beetle and Engelmann Spruce Ecology

The spruce beetle, *Dendroctonus rufipennis* Kirby (Coleoptera: Scolytidae), is a native bark beetle species occurring throughout the range of spruce in North America and is a significant mortality agent of mature spruce (Holsten et al. 1991). Engelmann spruce, *Picea engelmannii* Parry, is the principal host in the southern and central Rockies, while blue spruce, *P. pungens* Engelm., is an infrequent host (Schmid and Frye 1977). The principal hosts in Canada and Alaska are white spruce, *P. glauca* (Moench) Voss, and Sitka spruce, *P. sitchensis* (Bong.) Carr. (Schmid and Frye 1977). Massey and Wygant (1954) reported mortality caused by the spruce beetle to lodgepole pine, *Pinus contorta* Dougl., during outbreak conditions at White River National Forest in Colorado in the 1940’s. This atypical host can be attacked when mixed with Engelmann spruce.

Engelmann spruce is widely distributed throughout western North America, ranging north from just inside Mexico to British Columbia, and is one of the most characteristic trees of the Rocky Mountains (Lanner 1984, 91). It is a high elevation tree found typically from 457-1,524 meters (m) in the northern Rockies to 3,049-3,659 m in the southern Rockies (Preston 1989, 59). It grows in the highest and coldest forest environment in the Rockies in the United States. Like most spruces, this species has a relatively shallow root system which, combined with the frequent moist soil conditions contributes to its susceptibility to blowdown following windstorms. The thin bark, resinous wood and foliage of Engelmann spruce, along with its high elevation site where lightening storms are common, result in a tree that is often killed by fire. If located in a ravine or alongside a creek bottom where fire seldom burns, this tree can live up to 500 years.
Engelmann spruce can form pure stands, but is frequently associated with subalpine fir, *Abies lasiocarpa* (Hook.) Nutt., quaking aspen, *Populus tremuloides* Michx., Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, lodgepole pine, and several other subalpine conifers. Subalpine fir is the most common associate of Engelmann spruce at all elevations in the central Rockies (Schmid and Frye 1977). Together these two species form the spruce-fir forests that are characterized as long-living, tolerant to extremely shade tolerant (Baker 1949), and expected to dominate late successional stages (Odum 1969). Research by Aplet et al. (1988) on the patterns of community dynamics in Colorado Engelmann spruce-subalpine fir forests explained stand development involving processes operating from both equilibrium and nonequilibrium models. Previously, spruce and fir were thought to coexist in equilibrium as a stable, climax community through the balancing effect of two complementary life histories (Shea 1985, Veblen 1986). Research supporting the nonequilibrium coexistence (Bloomberg 1950, Day 1972, Romme and Knight 1981) required a forest disturbance followed by recolonization of a site by both species, preventing competitive exclusion of one species by the other. Aplet et al. (1988) provided a comprehensive view of stand development in spruce-fir forests depending on a broad range of disturbance intensities interacting with the life histories of the two species.

The resulting disturbance created by a 1940’s spruce beetle outbreak in Colorado was studied by Veblen et al. (1991). In 1939 following a large blowdown event in a subalpine forest in western Colorado, growth of endemic spruce beetle populations resulted in the largest recorded epidemic of this century. When the epidemic subsided in 1952, $4.3 \times 10^9$ board feet (bf) of timber were killed (Massey and Wygant 1954). An estimated 290,000 hectares (ha), or approximately three-quarters of the total mortality, was in the White River National Forest, and the remainder in the Grand Mesa, Routt, and Arapaho National Forests (Hinds et al. 1965, Cahill 1977). Veblen et al. (1991) found the predominant response to the outbreak was the release of previously suppressed small-
diameter spruce (not attacked) and subalpine fir (a non-host species). Accelerated growth of released trees following a spruce beetle outbreak, instead of new seedling establishment, was a major contrast to the response of stand development following fire. It was concluded the effects of disturbance by spruce beetle outbreaks in some Colorado subalpine forests appeared to be as great as those due to fire.

Other outbreaks documented the widespread activity of the spruce beetle. According to Holsten et al. (1991), in the past 25 years outbreaks resulted in estimated losses of more than 25 million bf in Montana, 31 million in Idaho, over 100 million in Arizona, 2 billion in Alaska, and 3 billion in British Columbia. The last decade saw a marked increase in spruce beetle infestations in the Intermountain Region 4, which includes southern Idaho, Nevada, Utah, and western Wyoming. In 1993, records indicated 18,980 ha infested by the spruce beetle on National Forests in Region 4 (U.S. Department of Agriculture 1994). Tree mortality attributed to the spruce beetle remained static from 1992 to 1993, 56,100 trees killed in 1992 compared to 58,200 killed in 1993. The largest infestation in 1993 occurred in Idaho on the Payette National Forest, where 35,200 trees were killed. In Utah, 21,800 trees were killed on the Manti-La Sal and Dixie National Forests, while a smaller outbreak, located on the Fishlake National Forest, killed 700 trees.

Werner et al. (1977) and Holsten et al. (1991) provided thorough documentation on spruce beetle biology. The adult spruce beetle is blackish-brown to black with reddish-brown or black wing covers. Adults are cylindrical, approximately 6 millimeters (mm) long and 3 mm wide. The eggs of the spruce beetle are oblong, pearly white, and 1.5 mm long. Larvae are stout, cylindrical, legless grubs that pass through four larval stages (instars) and at maturity reach a length of 6 mm. Pupae are opaque white, inactive, and have legs, wings, and antennae fully visible.

Spruce beetle development depends on climatic conditions, geographic area, and elevation. The life cycle is completed in 1 year on warm sites at lower elevations or up to
3 years on cool, shady locations on north slopes, with a 2-year life cycle common in the Rocky Mountains. Werner and Holsten (1985) found that direct solar radiation to the bark surface of white spruce was the primary environmental factor influencing the developmental rate of spruce beetles in Alaska. A phloem threshold temperature of 16.5°C was required to initiate the development of 1-year life cycle beetles. The south sides of standing trees and the south and top sides of felled trees were characterized by an average phloem temperature of 16.5°C and supported 1-year life cycles. North and west sides of standing trees and the north and bottom sides of felled trees were characterized by an average phloem temperature of 10.6°C and supported 2-year life cycles.

In the 2-year life cycle adults may emerge to attack green host material any time from May to October, depending on temperature. A pioneering female spruce beetle locates a suitable host, bores through the outer bark of the host tree, and begins gallery construction in the underlying phloem tissue. The female produces a pheromone that is released and attractive to both sexes, resulting in mass attack and colonization of the host tree. The male spruce beetles produce a closely related pheromone, which, together with the volatile myrcene from the tree itself, further aids in mass attack. Eventually, through male stridulation and other factors not fully understood, the females are stimulated to release pheromones that reduce the attractant response. Mating takes place in the nuptial chamber and gallery construction proceeds parallel to the wood grain and upward from the entrance hole in standing trees, all but the terminal portion of the gallery packed with frass and boring dust. Length of the egg gallery ranges from about 6 to 30 cm and is wider than the beetle. Eggs are deposited in short rows along alternate sides of the gallery and when hatched, the first instar larvae bore horizontally from the egg gallery. The larvae feed as a group for the first and second instars and subsequently construct individual feeding galleries as third and fourth instars. The larval stage predominates during the first winter, although all life stages may be present. Larval feeding kills the tree by destroying the
phloem and girdling the tree. Additionally, the spruce beetle transports several species of fungi which are inoculated into the tree with a successful spruce beetle attack. The fungi, commonly called blue stain, can completely penetrate the sapwood, occluding the outer conducting tissues in the xylem and interfering with translocation within the tree (Schmid and Frye 1977). Most larvae pupate 1 year after the initial attack in pupal chambers at the end of the larval galleries. Following a pupation period of 10 to 15 days, adults may overwinter in their pupal sites for the second winter or may emerge and bore into the base of the tree to hibernate near the litter line. Adults appearing in August to October may represent this movement of maturing brood adults to hibernation sites. Adults emerge from overwintering sites and attack fresh host material approximately 2 years following the initial attack.

Evidence of spruce beetle infestation is first indicated by the accumulation of reddish-brown boring dust at the beetle entrance holes, in bark crevices, and on the ground around the trunk of the infested tree. Masses of pitch may accumulate around the entrance sites. Trees that repel beetles produce pitch tubes that are usually whitish in color, but beetles that continue to bore successfully produce pitch tubes from the tree, containing frass and boring dust that are reddish-brown in color. If these signs are questionable or are less noticeable months later, a positive identification for spruce beetle infestation is made by taking a bark sample and observing for presence of gallery construction and brood development. Some standing trees may receive a "strip attack," or attacks on only one side of the bole. The tree usually survives, but is frequently infested by subsequent spruce beetle generations and may host two or more generations simultaneously. The first fall and winter following spruce beetle infestation, debarking of trees from woodpecker feeding on beetle larvae is often noticeable. Typically during the second summer following infestation, the tree foliage begins to discolor. The green needles turn yellowish and give the tree a faded appearance. By the third summer dead needles are removed from the trees
by wind or thunderstorms, leaving sparse foliage and exposed branches that give the tree a yellowish-orange to reddish hue.

Endemic spruce beetle populations usually live in windthrown trees. The beetle prefers downed spruce to standing trees due to the advantages of snow cover on the downed spruce. Snow cover provides insulation from cold, winter temperatures and protection from predation on the beetle larvae by woodpeckers (Knight 1958). Most outbreaks have originated from windthrown trees although beetle populations have also increased in logging residuals. If beetle populations develop to high levels in downed material, they may enter susceptible, adjacent standing trees (Schmid 1981). In mature spruce stands, large-diameter trees (≥46 cm) are usually attacked first, a characteristic indicating increased susceptibility to spruce beetle attack (Schmid and Frye 1977, Werner et al. 1977). If an infestation persists in the stand, smaller diameter trees are attacked. Hard (1985) determined that radial growth, an indicator of host vigor, was an important characteristic in evaluating susceptibility to spruce beetle attack. Sampling of 25 plots in 1982 showed mean recent radial growth of unattacked trees was higher than radial growth of unsuccessfully attacked or beetle-killed trees. Additionally, trees killed in 1982 had significantly higher density of completed egg galleries than trees unsuccessfully attacked in 1982, but did not differ in diameter. Hard’s research raised doubts on the hypothesis that spruce beetles selected hosts solely according to diameter.

Rating unmanaged stands for their susceptibility to potential outbreaks is based on average diameter of the spruce, basal area, species composition and physiographic location (Schmid and Frye 1976). In the Rocky Mountain area, spruce stands are highly susceptible if they grow on well-drained sites in creek bottoms, have an average diameter at breast height (dbh) of 41 cm or more, have a basal area greater than 34 square meters per ha (m²/ha), and have more than 65% spruce in the canopy (Holsten et al. 1991).
In a natural forest supporting Engelmann spruce, the spruce beetle performs an important role maintaining vigorous growth and recycling of host material. Not only does the spruce beetle breed and consume the phloem tissues of their host, but they introduce or provide accessibility for other disease agents that contribute to tree mortality and nutrient breakdown. Ultimately more vigorous growth of the surviving plants occurs following the removal of these trees. However, this activity often comes in conflict with management objectives man has established for the forest and its products, resulting in the need to reduce or eliminate losses to the spruce beetle.

Management of the Spruce Beetle Using Protective Chemical Sprays

Strategies to prevent or reduce resource losses to spruce beetles were reviewed by Holsten et al. (1991) and summarized in the subsequent paragraphs. The authors emphasized consideration of the beetle population level and evaluation of resource values and economics of management actions for each stand prior to strategy development.

If beetle populations are not immediately threatening resource values, the primary strategy should employ silvicultural treatments to potentially susceptible stands with the goal of maintaining health through stand modification. Silvicultural treatments applied prior to a spruce beetle outbreak results in long-term effectiveness and therefore is the strategy of choice. However, converting susceptible spruce stands to a low potential outbreak status by this method can take years, and if beetle populations are threatening, then a method of suppression is more appropriate (Schmid and Frye 1977).

Silvicultural, physical, and chemical treatments are available to effectively control existing beetle populations. Sanitation cuts and trap trees provide examples of silvicultural treatments used on infested standing trees and felled green trees. Sanitation cuts remove all infested and susceptible spruce to improve the health and vigor of the remaining stand. Trap trees are green trees with a diameter greater than 46 cm (dbh) that are felled before
beetle flight to provide an attractive site for infestation. Once infested, the trap trees are removed from the forest and destroyed. Lethal trap trees are green trees injected with a silvicide and felled prior to beetle flight. The subsequent brood fails to survive, making it unnecessary to remove the trap trees from the site. A report by Lister et al. (1976) supported the effectiveness of lethal trap trees as a treatment for spruce beetle control. Exposing infested logging residuals and windthrow to direct sunlight or fire are examples of physical treatments used to kill inhabiting brood. The synthetic reproduction and testing of the chemical substances that influence insect behavior, the aggregating and anti-aggregating pheromones, shows promise in attracting spruce beetles to trees to be removed, or discouraging attack and providing protection to high-value trees. Another protective chemical treatment for high-value trees are sprays applied to the boles of uninfested trees that can provide short-term protection by killing attacking adults. The use of chemical sprays to protect individual, high-value Engelmann spruce against the spruce beetle was the management tool of interest in this report.

Several insecticides were reported effective in providing protection to high-value spruce trees from attack by spruce beetles. Werner et al. (1984) determined chlorpyrifos (1%) provided 100% protection to individual, high-value white spruce 16 months after application. Additionally, permethrin (0.25%) and fenitrothion (2%) provided 98% protection 16 months after application. These insecticides were selected for field testing based on results of laboratory toxicity tests and remedial bioassays of efficiency of several insecticides against the spruce beetle reported by Werner et al. (1983). In another study by Werner et al. (1986), white spruce were provided total protection 16 months after application of carbaryl (1 and 2%) and lindane (0.05%). Additionally, these insecticides were 89, 96, and 94% effective, respectively, at the end of the third growing season.

Remedial control of the spruce beetle was achieved with different insecticides as well as with diesel oil alone or with insecticides. Werner and Holsten (1992) believed the
remedial treatment of individual spruce trees infested with spruce beetles significantly reduced the number of beetles that would normally emerge and attack adjacent standing green trees. They tested several formulations of carbaryl, one carbaryl formulation in diesel oil, and diesel oil alone, for remedial control of the spruce beetle in Lutz spruce, *P. x lutzii* Little. Findings identified carbaryl formulations and combinations with diesel oil effective on different life stages of the spruce beetle. In the 1983 investigation by Werner et al., fenitrothion provided remedial control of emerged and nonemerged spruce beetles in spruce bolts by 91 and 64%, respectively, but had a high effect on parasites and predators. Permethrin (2%) was almost equally effective, but had less effect on parasites and predators. Holsten (1989) obtained 65% mortality of spruce beetle brood when diesel oil was used as a remedial treatment of infested trap trees.

Carbaryl has had widespread success as a protective spray for individual, high-value trees against several *Dendroctonus* species. Preliminary field tests with 2% carbaryl prevented attacks by the western pine beetle, *D. brevicomis* Le Conte, mountain pine beetle, *D. ponderosae* Hopkins, and roundheaded pine beetle, *D. adjunctus* Blandford, on ponderosa pine, *P. ponderosa* Laws., and mountain pine beetle on lodgepole pine from 3-36 months (Smith et al. 1977). The scope of this test was large as the result of selecting four widely separated locations in California, Colorado, Idaho, and Nevada, by using two species of pine, and by using three species of beetles. Hall et al. (1982) also found that 1, 2, and 4% carbaryl protected ponderosa pine from western pine beetle attack for 1 year. Further support for the use of carbaryl for protecting ponderosa pine was provided by another field test in California indicating 2% carbaryl prevented attacks by western pine beetle and mountain pine beetle for 10 months or longer (Smith 1982), and a field test in Colorado, which showed 2% carbaryl protected ponderosa pine from mountain pine beetle attack for 13 months (McCambidge 1982). Field tests in Idaho showed that 2% carbaryl was totally effective in protecting lodgepole pine, *P. contorta* var. *latifolia* Engelmann,
from mountain pine beetle attacks for 1 year and was 66.6% effective the third season after treatment (Gibson and Bennett 1985). Werner et al. (1986) found 1 and 2% carbaryl provided 100% protection to white spruce from attack by spruce beetle 16 months following application, and were 89 and 96% effective, respectively, at the end of the third growing season after treatment. Carbaryl at 2% protected ponderosa pine from attack by western pine beetle for only one flight season (Haverty et al. 1985). Carbaryl did not protect southern pines, *Pinus* spp., from attacks by the southern pine beetle, *D. frontalis* Zimmermann (Hastings and Jones 1976). Field testing of the effectiveness of carbaryl in protecting individual Engelmann spruce from attack by spruce beetle was not found documented in current literature. The research to date led to and has maintained current approval by the Environmental Protection Agency (EPA) for the use of carbaryl at a 2% rate in protecting forest trees from attack by several bark beetle species.

Carbaryl is an organic insecticide, belonging to the class of carbamate insecticides, which are derived from carbamic acid (Coulson and Witter 1984, 200). The mode of action against insects and other animals involves the inhibition of acetylcholinesterase, the enzyme which hydrolyzes acetylcholine. The increase in acetylcholine at its sites of action in the nervous system interferes with transmission of nerve signals and induces rapid twitching of voluntary muscles and finally paralysis in insects (Coulson and Witter 1984, 199). Acetylcholinesterase inhibition is the same mechanism by which this insecticide can cause toxicity in mammals (U.S. Department Of Health, Education, and Welfare (DHEW) 1976). According to the report by DHEW, which compiled human and animal research on exposure and effects of carbaryl, common signs and symptoms of carbaryl toxicity in humans included, but were not limited to, salivation, watery eyes, blurred vision, muscle tremors, difficulty breathing, excessive sweating, abdominal cramps, nausea, vomiting, diarrhea, weakness, and headache. This same report provided documentation of human overexposure to carbaryl in the workplace environment resulting in rapid onset of
symptoms followed by a full recovery soon after the individual was removed from the exposure.

Due to the potential of this insecticide to stimulate the cholinergic nervous system, the possible harmful effects on nontarget organisms should be evaluated prior to use for control of the desired forest pest. However, a ground application project to individual, high-value trees is by nature target specific in contrast to aerial-dispersed insecticide applications. Exposure to carbaryl by humans in the forestry setting is most likely to occur to the applicators during treatment to the individual tree bole. Risks to carbaryl exposure are virtually eliminated by compliance with protective clothing and mixing and spraying requirements provided by the manufacturer. Carbaryl applied directly to the bark of the trees releases very little into the nontarget environment. Most of the insecticide is bound by and absorbed in the tree’s bark. Haverty et al. (1983), in experiments conducted to quantify the amount of drift and worker exposure resulting from ground application of individual trees, found that carbaryl could not be detected at distances greater than 12.2 m from an individually treated tree. The report indicated that greater than 80% of the material applied stayed on the tree. Furthermore, about 45% of the material that fell to the ground was deposited within 2 m of the base of the tree. The amount of material decreased rapidly as distance from the treated tree increased; 50.2 µg/cm² at 1 m; 14.2 µg/cm² at 3 m; 2.3 µg/cm² at 8 m; 0.0 µg/cm² at 12 m.

Exposure to carbaryl by forest vertebrates is minimal and localized as the result of ground application and minimal drift of carbaryl to individual trees. Research indicated that carbaryl had no major effects on forest birds (Richmond et al. 1979). Following aerial spraying of carbaryl (Sevin-4-oil), DeWeese et al. (1979) detected no significant decrease in bird numbers from breeding-pair estimates or live bird counts. Of the breeding pairs present before the spraying, 92% percent remained on the carbaryl plots following the spraying, the same percentage as on the control plots. Counts of live birds before and after
the spraying supported the results of the breeding-pair estimates. Additionally, 74% of 242 birds monitored had tracer dye from insecticide contact on their feet and feathers and targeted insects were found in their stomachs, but no sick or dead birds were found.

A different class of organic insecticides currently under research for chemical control in forestry are the synthetic pyrethroids. These insecticides are synthesized from petroleum-based chemicals and are related to the potent insecticidal properties of flowering plants in the genus *Chrysanthemum*, which have long been known. As early as 1800, powders made from these plants were used for insect control (Pajares and Lanier 1989). The structure of the natural pyrethrins was clarified by 1924, opening the way for research on synthetic analogues (Anonymous 1988). Culmination of research in 1949 produced the first synthetic compound allethrin, which was soon marketed. Allethrin has similar insecticidal properties to the natural pyrethins, including its tendency to decompose on exposure to sunlight, but continues to find much use in the public health market (Anonymous 1988). Subsequent research focused on increasing the toxic activity and improving the stability of synthetic pyrethroids. By the mid 1970's the first of the light stable "second-generation" pyrethroids, such as permethrin, was commercialized. In the current phase, new "third-generation" pyrethroids provide the most active and stable compounds, examples of which include cyfluthrin and esfenvalerate (Anonymous 1988).

The natural pyrethrins and the newer synthetic pyrethroids have many desirable qualities as insecticides. They demonstrate toxicity that is very high to insects and yet is low to mammals. However, the natural pyrethrins are expensive to produce and unstable under exposure to air and sunlight, limiting their application in agriculture and forestry. The "second-" and "third-generation" pyrethroids are more stable under a variety of environmental conditions and therefore have greater residual activity. They are highly toxic, generally requiring small amounts to control the desired insect. Another advantage
over natural pyrethrins includes more rapid intoxication and knockdown with negligible recovery that eliminates the need for addition of synergists to increase their effectiveness. These attributes plus cheaper production than the natural pyrethrins make the synthetic pyrethroids more cost-effective.

Pyrethroids are neurotoxic to insects. They act at the nerve membrane to modify the sodium channels that result in neurophysiological changes including repetitive firing, blocking of impulse conduction or of neuromuscular transmission, and spontaneous depolarization of the resting potential. Most sensitive to these effects are the sensory neurons, neurosecretory cells, and nerve endings (Zerba 1988). Symptoms of exposure and toxicity include hyperexcitation, tremors, convulsions, lethargy, and paralysis.

Passive penetration of liposoluble insecticides such as pyrethroids through the insect cuticle is the primary means of entrance into the insect. However, ingestion of treated material adds to the intoxication process, serving as another means of exposure. Having passed the integument barrier, the insecticide can enter the insect haemolymph to be carried to all parts of the body to exert its toxic influence (Zerba 1988). While the lipophilic characteristics of these compounds enhance rapid penetration to the arthropod’s nervous system, the low inherent toxicity seen with mammals may be attributed to rapid metabolic degradation, together with incomplete absorption from the gastrointestinal tract that collectively prevents direct contact with the nervous system (Flannigan et al. 1985). The most common symptom associated with topical contact of pyrethroids by humans is a cutaneous sensation, paresthesia (Knox et al. 1984, Flannigan et al. 1985). Cases of acute pyrethroid poisoning have not been reported, but studies on laboratory mammals suggested that a very large dose may induce tremors, ataxia, and other neurological symptoms (Anonymous 1988). Most pyrethroid insecticides are highly toxic to fish and other aquatic organisms. However, they are rather insoluble in water and become less available to aquatic and soil organisms due to their high affinity to soil and suspended organic matter (Anonymous
Werner et al. (1984), in a ground application field study of chemical sprays including the pyrethroid permethrin, reported the residues from insecticides in a stream adjacent to the treatment site were insignificant from 0 days to 15 weeks after application. Movement of residues from the treated trees into the soil from rain runoff was minimal.

Studies documenting the effectiveness and suitability of pyrethroid insecticides for forest and shade tree pests were all relatively recent. Nine insecticides tested by topical application on mixed sexes of adult spruce beetles included permethrin, a pyrethroid insecticide, which was found to have the highest level of toxicity of the nine tested (Werner et al. 1983). Additionally, this same study showed permethrin at a 2% rate second in effectiveness only to the insecticide fenitrothion in providing best remedial control of emerged and nonemerged spruce beetles, and had the least impact on parasites and predators. Werner et al. (1984) found a concentration of 0.25% permethrin provided acceptable protection 16 months after application to white spruce from attack by spruce beetle. On another bark beetle species, a large-scale study by Shea et al. (1984) tested three concentrations of fenitrothion and 0.1, 0.2, and 0.4% permethrin for protecting high-value ponderosa pine trees from attack by the western pine beetle. All treatments except the 0.1% permethrin treatment were determined effective 1 month after application, but by 13 months after application only the highest two concentrations of fenitrothion were still considered effective in providing protection.

Four pyrethroid insecticides were tested on the European elm bark beetle, *Scolytus multistriatus* Marsham, and compared with the insecticide methoxychlor (Pajares and Lanier 1989). Laboratory toxicity bioassays determined all four of the pyrethroid insecticides 222 to 548 times more toxic than methoxychlor. All the pyrethroids provided superior protection from twig feeding. Two of the pyrethroids, cypermethrin and esfenvalerate, killed all beetles contacting sample twigs that were sprayed and prevented twig feeding through an 18-week period of bioassays. The same two pyrethroids applied
to infested Siberian elm wood, *Ulmus pumila* L., killed all beetles before or shortly after they emerged. Conclusions indicated these four pyrethroids may increase the effectiveness of spraying elm crowns to prevent Dutch elm disease or could find use in eliminating elm bark beetles as they emerge from pyrethroid-treated brood wood.

No documentation of research related to the pyrethroids cyfluthrin and esfenvalerate in providing protection to Engelmann spruce trees from attack by the spruce beetle was found in the literature. These two pyrethroids are registered by the EPA as broad spectrum insecticides for use against a variety of insects, but not specifically any of the bark beetles. Recent studies completed tested the efficacy of these two pyrethroids and carbaryl on individual, high-value lodgepole pine versus the mountain pine beetle in Montana, and ponderosa pine versus the western pine beetle in two different studies in Idaho and California (P.J.S., unpublished data). The results indicated that carbaryl at a rate lower than the currently registered 2%, specifically 0.5%, protected ponderosa pine from attack by the western pine beetle for one flight season, and was efficacious against the mountain pine beetle on lodgepole pine up to 15 months following application. Additionally, the pyrethroids cyfluthrin and esfenvalerate provided effective protection in all three studies at low concentrations. Published results of these studies and further research on the efficacy of these pyrethroids may provide future registered alternatives for chemical control of bark beetles on individual, high-value trees.

Laboratory Testing of Chemicals Using Bioassays

Insecticide bioassays are experiments done with an insecticide on a living organism to estimate the probability that a pest population will respond in the desired manner (Robertson and Preisler 1992, 1). Many decisions about pest management begin with laboratory bioassays. They are a valuable tool for pursuing studies with insecticides, including research on structure activity relationships, resistance mechanisms and genetic
modes of inheritance, comparative toxicities, and metabolism (Robertson and Worner 1990). Laboratory bioassays are often precursors to actual field use of insecticides to determine the suitability and potential effectiveness of the insecticide against the pest of interest. They may also provide confirmation of results already determined in the field setting. The mechanical processes and equipment used to do insecticide bioassays are documented in detail by Busvine (1971) and have changed little. More recent research documented classical bioassay technique in the forestry setting (Robertson and Haverty 1981, Haverty and Robertson 1982, Pajares and Lanier 1989).

The terminology used to express toxicity of insecticides to an organism was reviewed by Matsumura (1975, 17-18). The most common expression of insecticide toxicity is in terms of the LD$_{50}$ (lethal dose). This value represents the amount of poison per unit weight that will kill 50% of the particular population of the animal species tested. In some cases, the exact dose initially given to the insect cannot be determined but the concentration of insecticide in the surrounding external media can, resulting in a value expressed as an LC$_{50}$. Other frequent toxicity terms include LT$_{50}$, representing the time required to attain 50% mortality of the population at a certain dose or concentration, the median knockdown dose and knockdown time, expressed as KD$_{50}$ and KT$_{50}$, and the reproductive terms ED$_{50}$ and EC$_{50}$ (effective dose and effective concentration), which measures the effects of the insecticide on fertility and fecundity. Toxicity data on an insecticide is supplied by the manufacturer in the Material Safety Data Sheet (MSDS) (Table 1).

Just as there are several terms to express the toxicity of insecticides, there are also several techniques for administering insecticides to the test subjects (Matsumura 1975, 18-19). The most common method of administration is topical application, where the insecticide is dissolved in a nontoxic and volatile solvent, such as acetone, and applied with a special applicator to a particular location on the body surface of the test subject. The
Table 1. Acute animal toxicity data on three insecticides

<table>
<thead>
<tr>
<th>Insecticide Chemical Name</th>
<th>Insecticide Brand Name</th>
<th>Oral LD$_{50}$</th>
<th>Dermal LD$_{50}$</th>
<th>Inhalation LC$_{50}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbaryl</td>
<td>Sevimol</td>
<td>354 mg/kg</td>
<td>&gt; 2000 mg/kg</td>
<td>Not available</td>
</tr>
<tr>
<td></td>
<td></td>
<td>body weight</td>
<td>body weight</td>
<td></td>
</tr>
<tr>
<td>Cyfluthrin</td>
<td>Tempo 2 EC</td>
<td>647 mg/kg</td>
<td>&gt; 2000 mg/kg</td>
<td>&gt; 1.6 mg/L $\sigma$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>body weight $\sigma$</td>
<td>body weight</td>
<td>4-hr exposure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>695 mg/kg</td>
<td>&gt; 2000 mg/kg</td>
<td>&gt; 2.0 mg/L $\varphi$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>body weight $\varphi$</td>
<td>4-hr exposure</td>
<td></td>
</tr>
<tr>
<td>Esfenvalerate</td>
<td>Asana XL</td>
<td>458 mg/kg</td>
<td>&gt; 2000 mg/kg</td>
<td>&gt; 2.93 mg/L</td>
</tr>
<tr>
<td></td>
<td></td>
<td>body weight</td>
<td>body weight</td>
<td>4-hr exposure</td>
</tr>
</tbody>
</table>

Compiled from Material Safety Data Sheets provided by Rhone-Poulenc Ag Company (1993), Miles Inc. (1991), and Du Pont Co. (1992).

Contact method utilizes insecticide in a solvent, which is applied to the internal surface of a container where insects are confined. The solvent is evaporated by rotating the container until the insecticide is spread evenly over the entire container. When knowledge of the exact amount of insecticide delivered to the body is required, the injection method is used. The dipping method is used for dipterous larvae. The feeding method delivers the insecticide orally on a food source; fumigation evaluates the toxicity of inhaling the insecticide.

Related in importance to technique is the need to avoid untested assumptions that could invalidate a bioassay that is otherwise well designed and performed. For example, Robertson et al. (1981) and Savin et al. (1982) challenged the assumption that insects responded to toxicants in direct proportion to their body weight. Proportional adjustment of topical doses to compensate for weight was not always appropriate. As a more prudent practice, the authors suggested a uniform volume application that included body weight as an additional variable in statistical analysis.

Insecticide bioassays are often elaborate, expensive, and rigorously controlled in the laboratory environment, and large differences between toxicity data and preventive field...
tests have occurred. For example, the topical application of nine different insecticides on mixed sexes of adult spruce beetles resulted in an LD$_{50}$ for carbaryl that indicated the lowest toxicity level of all nine insecticides (Werner et al. 1983). In fact, the LD$_{50}$ for carbaryl was not obtained because it was too large. Carbaryl, at the registered rate of 2%, prevented attack on trees by the western pine beetle, mountain pine beetle, the roundheaded pine beetle, and the spruce beetle (Smith et al. 1977, Hall et al. 1982, Werner et al. 1986).

However, in this study carbaryl appeared ineffective by topical application to spruce beetle adults. In another test with carbaryl, large differences were also found between laboratory toxicity and preventive field tests for the western pine beetle (Hall et al. 1982).

Recent improvements in insecticide bioassays predicting arthropod population response in the field have been made. Haverty and Robertson (1982) derived conversion factors relating laboratory application rates to field use. Multiple bioassays are another approach to more realistic prediction. Robertson and Haverty (1981) used multiple bioassays to define separate aspects of pesticide effectiveness (e.g. defined effects by ingestion and contact, residual toxicities, and rainfastness in experiments with western spruce budworm) and synthesized them to estimate effectiveness on a population. Ultimately, Robertson and Worner (1990) suggested that a population response, opposed to response of individuals selected for uniformity, will improve the application of insecticide bioassays performed in the laboratory.

As an alternative to elaborate and highly controlled bioassays previously described, Brindley (1974) developed a simplified contact bioassay for testing alfalfa weevils. The procedure did not carefully control for such variables as photoperiod, temperature, humidity, micrograms of insecticide per insect, or population structure, but results were consistently quantitative and reliable. Contact bioassays were convenient for laboratory and field testing and have had especially good success in the agricultural setting. The research led to the development of simplified bioassay kits prepared in advance for use by
land managers to monitor the development of insecticide resistance in a population in the field.

In the forestry field, the documentation of insecticide bioassays on the spruce beetle appeared limited. Research on this subject published by Werner et al. (1983) reported the toxicity of carbaryl and the pyrethroid permethrin on the spruce beetle, determining carbaryl the least effective of nine insecticides tested in the laboratory setting. No published papers reporting laboratory toxicity data on the pyrethroids cyfluthrin and esfenvalerate versus the spruce beetle were found.
FIELD EXPERIMENT TESTING CARBARYL AND PYRETHROID INSECTICIDES IN PREVENTING SPRUCE BEETLE ATTACK ON ENGELMAN SPRUCE

Introduction

The destructive activity of the spruce beetle, *Dendroctonus rufipennis* Kirby (Coleoptera: Scolytidae), is documented across its range in western North America, from just inside Mexico north to Alaska (Massey and Wygant 1954, Hinds et al. 1965, Cahill 1977, Werner et al. 1984, Werner et al. 1986, Holsten et al. 1991, Werner and Holsten 1992). In the United States, Intermountain Region 4 has documented an overall increase in infestation and mortality attributed to the spruce beetle in the last decade (U.S. Department of Agriculture 1994, 23). In 1993, 19,385 hectares (ha) on National Forests and state and private lands in Idaho and Utah were infested by the spruce beetle, resulting in the mortality of 59,200 trees (U.S. Department of Agriculture 1994).

Engelmann spruce, *Picea engelmannii* Parry, is the principal host of the spruce beetle in the Intermountain Region, where the beetle normally maintains endemic populations in windthrown trees or logging slash. If beetle populations develop to high levels in down material, they may become a serious problem in adjacent standing trees (Schmid 1981). All known major outbreaks have originated from stand disturbances (Schmid and Frye 1977). In mature stands, large-diameter trees (≥46 cm diameter at breast height [dbh]) usually are attacked first. If an infestation persists in a stand, smaller diameter trees are attacked.

According to Schmid and Frye (1977), if spruce beetle populations are not immediately threatening resource values, the primary management strategy should employ silvicultural treatments to potentially susceptible stands with the goal of maintaining health through stand modification. However, in the face of an outbreak, a method of suppression is more appropriate for protection of high-value trees located in residential areas and
recreation or administrative sites. The value of these individual trees and the cost of removing and replacing them may justify their protection through the duration of the outbreak, emphasizing the need for available, effective insecticides to use in protecting individual, high-value trees.

The efficacy of carbaryl as a protective spray for individual, high-value trees is well documented versus several *Dendroctonus* species. Studies have shown carbaryl effective in preventing attacks by the western pine beetle, *D. brevicomis* Le Conte, the mountain pine beetle, *D. ponderosae* Hopkins, and the roundheaded pine beetle, *D. adjunctus* Blandford, on their respective hosts for varying lengths of time (Smith et al. 1977, Hall et al. 1982, McCambridge 1982, Smith 1982, Gibson and Bennett 1985, Haverty et al. 1985). Werner et al. (1986) found 1 and 2% carbaryl provided 100% protection to white spruce, *P. glauca* (Moench) Voss, from attack by spruce beetle 16 months following application, and were 89 and 96% effective, respectively, at the end of the third growing season after treatment. Carbaryl did not protect southern pines, *Pinus* spp., from attacks by the southern pine beetle, *D. frontalis* Zimmermann (Hastings and Jones 1976).

Carbaryl is currently approved and registered at a 2% rate by the Environmental Protection Agency (EPA) for use against several bark beetle species.

The synthetic pyrethroids offer a potential alternative as protective sprays for individual, high-value trees. Synthesized from petroleum-based chemicals and related to the potent insecticidal properties of flowering plants in the genus *Chrysanthemum*, they demonstrate toxicity that is very high to insects and relatively low to mammals (Pajares and Lanier 1989). The synthetic pyrethroids are highly toxic, generally requiring small amounts to control the desired insect, and have good residual activity as a result of their stability under a variety of environmental conditions.

Recently completed field studies tested the efficacy of two pyrethroids, cyfluthrin and esfenvalerate, along with carbaryl on individual, high-value lodgepole pine, *Pinus*
contorta Dougl., versus the mountain pine beetle in Montana, and ponderosa pine, *P. ponderosa* Laws., versus the western pine beetle in two different studies in Idaho and California (P.J.S., unpublished data). The results of all three studies indicated the pyrethroids provided effective protection at low concentrations. Cyfluthrin and esfenvalerate are registered by the EPA as broad spectrum insecticides for use against a variety of insects, but not specifically any of the bark beetles. Published results of these three studies, along with additional research, may lead to the registration of additional or safer alternative chemical sprays for use in protecting individual, high-value trees versus bark beetles.

The efficacy of carbaryl and pyrethroids in protecting Engelmann spruce from attack by the spruce beetle needed evaluation. The objectives of this field experiment included the following: (1) assess the current registered rate and a lower concentration of the insecticide carbaryl versus the spruce beetle on Engelmann spruce; and (2) evaluate two concentrations each of the pyrethroids cyfluthrin and esfenvalerate versus the spruce beetle on Engelmann spruce.

Materials and Methods

The experimental field study was conducted on the Manti-La Sal National Forest on the Ferron Ranger District and the Sanpete Ranger District. Evaluation of these districts indicated multiple outbreak areas in host type material, many in visually sensitive locations. In 1993, a total of 3,076 ha was infested and 15,600 trees were killed by the spruce beetle on the Manti-La Sal National Forest (U.S. Department of Agriculture 1994).

Due to the sensitivity of a proposed chemical spray project and in compliance with the National Environmental Policy Act (NEPA), appropriate action and documentation were completed in the summer of 1993 prior to application of insecticides to the study trees (Appendices A to E). This was initiated with the preparation of a Scoping Document for public review and comment, which described the Proposed Action and the purpose and
need for the experimental study, as well as presented the No Action alternative. The Environmental Assessment provided a more complete assessment of the effects of the Proposed Action and the No Action alternative for public record. The Decision Notice and Finding of No Significant Impact announced the decision by the forest supervisor of the Manti-La Sal National Forest to implement the Proposed Action, and the resulting Legal Notice completed the necessary documentation for the implementation of the experimental study.

All sample trees selected in July and August of 1993 were living Engelmann spruce, 25 to 94 cm dbh, located in areas with heavy spruce beetle activity and isolated from other sample trees by at least 150 m so a sufficient beetle population in the vicinity of each tree would rigorously test the effectiveness of the treatments. Sample trees were within 75 m of an access road to facilitate treatment application and were at least 100 m away from an aboveground water source.

A total of 256 trees was used in this experiment. Each insecticide treatment was randomly assigned to 32 trees; untreated controls were randomly assigned to 64 trees. One set of 32 untreated control trees was used for each of two baiting periods. No study trees were lost to road building, wood cutting or logging. Sample trees that did not have a bait at the time of either data collection were removed from the analysis, but treated trees unbaited and eliminated from the first analysis that were baited for the second evaluation period were included in the 1995 analysis, resulting in unequal sample sizes between treatments and years. Six untreated control trees for 1995 were baited in March 1994 and one tree that did not have a bait was removed from the analysis, resulting in total sample size of 37 trees in the untreated controls for 1994. In 1995, one untreated control tree was attacked prior to baiting and two trees that did not have a bait at the time of data collection were all removed from the analysis, resulting in a total sample size of 29 trees in the untreated controls for 1995. All trees appeared healthy and uninfested at the beginning of the experiment.
Insecticide application was completed September 7-10, 1993. Carbaryl (Sevimol), cyfluthrin (Tempo 2), and esfenvalerate (Asana XL) were formulated in water and applied at rates of 1 and 2% (AI), 0.008 and 0.025% (AI), and 0.025 and 0.05% (AI), respectively. Using a truck-mounted or trailer-mounted FMC Bean hydraulic sprayer, insecticides were applied to the circumference of the bole of each treated tree until runoff to a height of at least 10 m. This treatment required approximately (ca.) 15.0 liters of formulated spray material per tree or ca. 0.82 liter/m$^2$ of bark surface. Each insecticide was applied to all 32 trees at the lowest rate first, followed by line purging and cleansing of equipment prior to formulation of the higher rate. Special care was taken to thoroughly clean the equipment between the different insecticides.

In order to ensure adequate attack densities of spruce beetles, every tree in the study received a bait with spruce beetle aggregating pheromones, attached on the north side of the tree bole 2 m above the ground. All treated trees and the first year untreated control trees were baited in March 1994. The surviving treated trees and the second set of control trees were baited over the course of spring 1995. The accessibility to the experimental site and history of the spruce beetle flight in this area determined the baiting schedule.

Data collection to evaluate insecticide effectiveness was completed August 29-31 and September 1-2, 1994 following the first pheromone baiting period and September 25-28, 1995 following the second pheromone baiting period. Insecticide effectiveness was determined by the single criterion of whether or not the individual tree succumbed to spruce beetle attack (Hall et al. 1982). Each sample tree was evaluated for spruce beetle activity indicative of successful attack and pending mortality, including pitch tubes containing the reddish-colored frass of the spruce beetle, boring dust in bark crevices or at the base of the tree, presence of spruce beetle egg galleries, and debarking by woodpeckers.
Data were analyzed using a $(2 \times 3) + 1 \chi^2$ contingency table to determine the main effect of insecticides and rates ($\alpha = 0.05$). Planned comparisons to determine the simple effects among the insecticides and between the rates of each insecticide were analyzed using $2 \times 2 \chi^2$ contingency tables ($\alpha = 0.05$). Data were analyzed by year and accumulated across both years. Criteria for determining insecticide efficacy were taken from Shea et al. (1984). Insecticide treatments were considered efficacious if less than seven of the treated trees died as a result of spruce beetle attack. This criterion was based on a sample size of 30-35 trees/treatment and the test of the null hypothesis, $H_0: S$ (survival) $\geq 90\%$. These parameters provided a conservative binominal test ($\alpha = 0.05$) to reject $H_0$ when more than six trees die. The power of this test was .84 when the true protection rate was 70\%.

Additionally, treatments were considered to have had sufficient attack pressure by spruce beetle if at least 19 of 32 (60\%) of the remaining untreated control trees died following pheromone baiting. If the criterion of 60\% mortality of untreated checks was not met, inferences about the efficacy of the insecticide treatments accounted for less than sufficient beetle pressure for that baiting period.

Results

The histogram of dead versus alive trees within each treatment and the untreated controls evaluated in 1994 is presented in Fig. 1. According to the experimental design, five of the six insecticide treatments were considered efficacious in protecting individual Engelmann spruce trees 12 months following treatment application and through one pheromone baiting period. The lowest rate of cyfluthrin, 0.008\% (AI), which lost 12 trees to spruce beetle mortality and therefore did not meet the criterion of less than seven dead trees within a treatment, was judged ineffective (Table 2). Additionally, a rigorous test of the treatments occurred; 32 of 37 untreated control trees were killed (86.5\% mortality), more than meeting the criterion of 60\% mortality necessary to document adequate spruce
Fig. 1. Frequency distribution of dead and alive Engelmann spruce trees within each treatment and the untreated controls in 1994.
Table 2. August 1994 and September 1995 evaluation of Engelmann spruce mortality following two baiting periods with *Dendroctonus rufipennis* pheromone.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>1994 Dead</th>
<th>1994 Total</th>
<th>1994 % survival</th>
<th>1994 95% C.I.</th>
<th>1995 Dead</th>
<th>1995 Total</th>
<th>1995 % survival</th>
<th>1995 95% C.I.</th>
<th>Cumulative Dead</th>
<th>Cumulative Total</th>
<th>Cumulative % survival</th>
<th>Cumulative 95% C.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbaryl 1.0%</td>
<td>0</td>
<td>30</td>
<td>100</td>
<td>±0</td>
<td>5</td>
<td>31</td>
<td>83.9</td>
<td>±12.9</td>
<td>5</td>
<td>31</td>
<td>83.9</td>
<td>±12.9</td>
</tr>
<tr>
<td>Carbaryl 2.0%</td>
<td>1</td>
<td>31</td>
<td>96.8</td>
<td>±6.2</td>
<td>0</td>
<td>30</td>
<td>100</td>
<td>±0</td>
<td>1</td>
<td>31</td>
<td>96.8</td>
<td>±6.2</td>
</tr>
<tr>
<td>Cyfluthrin 0.008%</td>
<td>12</td>
<td>32</td>
<td>62.5</td>
<td>±16.8</td>
<td>10</td>
<td>19</td>
<td>47.4</td>
<td>±22.5</td>
<td>22</td>
<td>31</td>
<td>29.0</td>
<td>±16.0</td>
</tr>
<tr>
<td>Cyfluthrin 0.025%</td>
<td>1</td>
<td>31</td>
<td>96.8</td>
<td>±6.2</td>
<td>8</td>
<td>30</td>
<td>73.3</td>
<td>±15.8</td>
<td>9</td>
<td>31</td>
<td>71.0</td>
<td>±16.0</td>
</tr>
<tr>
<td>Esfenvalerate 0.025%</td>
<td>5</td>
<td>30</td>
<td>83.3</td>
<td>±13.3</td>
<td>7</td>
<td>26</td>
<td>73.1</td>
<td>±17.0</td>
<td>12</td>
<td>31</td>
<td>61.3</td>
<td>±17.1</td>
</tr>
<tr>
<td>Esfenvalerate 0.05%</td>
<td>6</td>
<td>30</td>
<td>80.0</td>
<td>±14.3</td>
<td>10</td>
<td>26</td>
<td>61.5</td>
<td>±18.7</td>
<td>16</td>
<td>32</td>
<td>50.0</td>
<td>±17.3</td>
</tr>
<tr>
<td>Controls 1994</td>
<td>32</td>
<td>37</td>
<td>13.5</td>
<td>±11.0</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Controls 1995</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>29</td>
<td>29</td>
<td>0</td>
<td>±0</td>
<td>61</td>
<td>66</td>
<td>7.6</td>
<td>±6.4</td>
</tr>
</tbody>
</table>

*Trees without a pheromone bait at the time of data collection were removed from the analysis, resulting in uneven sample sizes between treatments from year to year.*
beetle population pressure and support inferences made about the efficacy of the insecticides.

The histogram of dead versus remaining alive trees within each treatment and the 29 untreated controls evaluated in 1995 is presented in Fig. 2. According to the experimental design, two of the remaining five insecticide treatments, 1.0 and 2.0% (AI) carbaryl, were considered efficacious in protecting individual Engelmann spruce trees 24 months following treatment application and through two pheromone baitings. Carbaryl 1.0% (AI) lost no trees in 1994 and five trees in 1995 to spruce beetle mortality (Table 2). Carbaryl 2.0% (AI) lost one tree in 1994 and suffered no further mortality in 1995. Both treatments met the effective criterion of less than seven dead trees within a treatment. The higher rate of cyfluthrin, 0.025% (AI), lost eight trees in 1995 and had a cumulative mortality of nine trees. Both rates of esfenvalerate, 0.025 and 0.05% (AI), lost 7 and 10 trees in 1995 with cumulative mortalities of 12 and 16 trees, respectively. All three treatments were judged ineffective in protecting individual Engelmann spruce trees 24 months following treatment application and through two pheromone baitings. Fig. 3 presents the cumulative histogram of dead versus alive trees within each treatment and the untreated controls for 1994 and 1995. As in 1994, a rigorous test of the treatments occurred, indicated by 100% mortality in the untreated control trees and more than meeting the criterion of 60% mortality necessary to document adequate spruce beetle population pressure and support inferences made about the efficacy of the insecticides.

The results of the $(3 \times 2) + 1 \chi^2$ analysis indicated a significant difference between the untreated control trees versus the treated trees, producing a large $\chi^2$ value and accounting for a large portion of the variation in both years and in the cumulative analysis (Table 3). The variation among the treated trees indicated a significant difference across all three insecticides in both years and the cumulative analysis. Differences in the rates across all three insecticides accumulated to a significant level in the analysis combining both years.
Fig. 2. Frequency distribution of dead and alive Engelmann spruce trees within each treatment and the untreated controls in 1995.
Fig. 3. Frequency distribution of dead and alive Engelmann spruce trees within each treatment and the untreated controls accumulated in 1994 and 1995.
### Table 3. Results of $(2 \times 3) + 1 \chi^2$ analysis evaluating main effect of insecticides and rates

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls vs Rest</td>
<td>1</td>
<td>85.53</td>
<td>$=0^*$</td>
<td>60.45</td>
<td>$=0^*$</td>
<td>64.89</td>
<td>$=0^*$</td>
</tr>
<tr>
<td>Among Rest</td>
<td>5</td>
<td>16.73</td>
<td>$0.01 &gt; p &gt; 0.005^*$</td>
<td>17.58</td>
<td>$0.005 &gt; p &gt; 0.0025^*$</td>
<td>36.46</td>
<td>$=0^*$</td>
</tr>
<tr>
<td>Insecticides</td>
<td>2</td>
<td>11.23</td>
<td>$0.005 &gt; p &gt; 0.0025^*$</td>
<td>14.54</td>
<td>$0.001 &gt; p &gt; 0.0005^*$</td>
<td>26.16</td>
<td>$p &lt; 0.0005^*$</td>
</tr>
<tr>
<td>Rates</td>
<td>1</td>
<td>3.75</td>
<td>$0.10 &gt; p &gt; 0.05$</td>
<td>1.39</td>
<td>$0.25 &gt; p &gt; 0.20$</td>
<td>4.20</td>
<td>$0.05 &gt; p &gt; 0.025^*$</td>
</tr>
<tr>
<td>Interaction</td>
<td>2</td>
<td>1.75</td>
<td>$p &gt; 0.25$</td>
<td>1.65</td>
<td>$p &gt; 0.25$</td>
<td>6.10</td>
<td>$0.05 &gt; p &gt; 0.025^*$</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>102.26</td>
<td>$=0^*$</td>
<td>78.03</td>
<td>$=0^*$</td>
<td>101.35</td>
<td>$=0^*$</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 level.
Likewise, interaction between all insecticides accumulated to a significant level in the analysis combining both years. Planned comparisons using $2 \times 2 \chi^2$ analysis in both years and the cumulative analysis indicated a significant difference in tree mortality between carbaryl and cyfluthrin, and carbaryl and esfenvalerate, but not between cyfluthrin and esfenvalerate (Table 4). The $2 \times 2 \chi^2$ analysis comparing the two rates of each insecticide indicated a significant difference among the two rates of cyfluthrin in 1994, a significant difference among the two rates of carbaryl in 1995, but not among the two rates of esfenvalerate in 1994 or 1995 (Table 5). The cumulative data analysis indicated a significant difference among the two rates of cyfluthrin only.

Discussion

The results of this and similar experiments (Smith et al. 1977, Hall et al. 1982, McCambridge 1982, Smith 1982, Gibson and Bennett 1985, Werner et al. 1986) found carbaryl effective in protecting individual, high-value trees against several *Dendroctonus* species for varying time periods. The results of this experiment were also in agreement with similar experiments (P.J.S., unpublished data) supporting the efficacy of low concentrations of the pyrethroids cyfluthrin and esfenvalerate as protective chemical sprays versus various *Dendroctonus* species. Specifically, the data from this experiment suggested that carbaryl at 1% and the registered rate of 2% (AI), cyfluthrin at 0.025% (AI), and esfenvalerate at 0.025 and 0.05% (AI) all provided protection to individual Engelmann spruce trees from attack by spruce beetle through one pheromone baiting and at least 12 months following insecticide application. Only the lower rate of cyfluthrin, 0.008% (AI), was judged ineffective after the 12-month duration. Furthermore, carbaryl at 1% and the registered rate of 2% (AI) provided protection to individual Engelmann spruce trees from attack by spruce beetle through two pheromone baetings and at least 24 months following insecticide application. Cyfluthrin at 0.025% (AI) and esfenvalerate at 0.025 and 0.05% (AI) were judged ineffective after the 24-month duration.
Table 4. Results of $2 \times 2 \chi^2$ analysis evaluating planned comparisons between insecticides

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>df</th>
<th>$\chi^2$</th>
<th>p-value</th>
<th>$\chi^2$</th>
<th>p-value</th>
<th>$\chi^2$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbaryl and Cyfluthrin</td>
<td>1</td>
<td>11.17</td>
<td>$p &lt; 0.001^*$</td>
<td>13.38</td>
<td>$p &lt; 0.0005^*$</td>
<td>24.08</td>
<td>$p &lt; 0.0005^*$</td>
</tr>
<tr>
<td>Carbaryl and Esfenvalerate</td>
<td>1</td>
<td>9.44</td>
<td>$p &lt; 0.0025^*$</td>
<td>10.74</td>
<td>$p &lt; 0.0025^*$</td>
<td>19.07</td>
<td>$p &lt; 0.0005^*$</td>
</tr>
<tr>
<td>Cyfluthrin and Esfenvalerate</td>
<td>1</td>
<td>0.10</td>
<td>$p &gt; 0.25$</td>
<td>0.18</td>
<td>$p &gt; 0.25$</td>
<td>0.39</td>
<td>$p &gt; 0.25$</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 level.

Table 5. Results of $2 \times 2 \chi^2$ analysis evaluating simple effect between rates of each insecticide

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>df</th>
<th>$\chi^2$</th>
<th>p-value</th>
<th>$\chi^2$</th>
<th>p-value</th>
<th>$\chi^2$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbaryl</td>
<td>1</td>
<td>0.98</td>
<td>$p &gt; 0.25$</td>
<td>5.27</td>
<td>$p &lt; 0.025^*$</td>
<td>2.95</td>
<td>$0.10 &gt; p &gt; 0.05$</td>
</tr>
<tr>
<td>Cyfluthrin</td>
<td>1</td>
<td>11.29</td>
<td>$p &lt; 0.001^*$</td>
<td>3.37</td>
<td>$0.10 &gt; p &gt; 0.05$</td>
<td>10.90</td>
<td>$p &lt; 0.001^*$</td>
</tr>
<tr>
<td>Esfenvalerate</td>
<td>1</td>
<td>0.11</td>
<td>$p &gt; 0.25$</td>
<td>0.79</td>
<td>$p &gt; 0.25$</td>
<td>0.81</td>
<td>$p &gt; 0.25$</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 level.
All of the treatments were rigorously tested. A mortality of 86.5% occurred in the untreated control trees in 1994, and three of the five remaining untreated control trees counted as alive showed evidence of spruce beetle attack. Strip attacks accounted for two of the attacked trees, and the third had 20 successful attacks scattered over the lower third of the tree bole. A rigorous test of the treatments continued into 1995 as indicated by 100% mortality in the untreated control trees. During the 1995 data collection period it was documented on nine trees and observed on others that the upper bole above the spray point had received successful spruce beetle attacks not detected in 1994, indicated in 1995 by discoloration of the upper crown and debarking by woodpeckers above the spray point. However, this additional observation did not change the status of the tree as recorded in 1994.

Other indicators of high spruce beetle activity were observed and noted. The trees selected for the study varied widely in dbh, ranging from 25 to 94 cm. In mature spruce stands, large-diameter trees (≥46 cm) are usually attacked first, but a persistent infestation produces attacks in smaller diameter trees (Schmid and Frye 1977, Werner et al. 1977). Of the 256 trees selected for the study, at least 49 trees had a dbh less than 46 cm. These smaller diameter, green trees were located in areas where the infestation had already resulted in mass attack of the large-diameter spruce trees within the previous year or two, indicating an active spruce beetle population. Subsequently, the remaining smaller diameter, green trees selected and baited with an aggregating pheromone were subjected to high spruce beetle population pressure.

The trees treated with 1 or 2% (Al) carbaryl lost one tree to spruce beetle mortality between the two treatments after 12 months and a total of six trees to mortality after 24 months, five trees from the lower rate and one tree from the higher rate. Statistical analysis indicated no significant difference between the two rates in the cumulative analysis. Excluding the six trees lost to mortality, the trees receiving these treatments were free of
signs of attack, except for an occasional single successful attack or some pitchouts on the tree bole indicating an unsuccessful attack. However, trees of varying diameters observed within a 9-m radius of the treated tree were found mass attacked during the current year.

Trees receiving any one of the pyrethroid treatments showed more visible signs of spruce beetle activity. These trees frequently had noticeable streaking of the bole with resin. A tree sustaining a light attack had 10 or less successful spruce beetle attacks counted on the bole; a moderate attack counted >10 and up to 40 successful attacks; a tree with >40 successful attacks was categorized as a heavy attack. The removal of a bark sample showed an absence of egg galleries established at the attack sites, or egg gallery development was stunted in length. Occasional eggs were noted in the trees that had egg galleries, but no further development of brood was noted. No boring dust was found in the bark crevices or at the bases of these trees. Although unsightly, the trees treated with the pyrethroids and demonstrating this wide variation in symptoms were judged effectively protected from mortality by the spruce beetle. In contrast, trees treated with the pyrethroids counted as dead showed >50 successful attacks on the tree bole, establishment and development of egg galleries and brood, boring dust in the bark crevices and at the tree base, and frequently had signs of debarking by woodpeckers. The trees treated with 0.008 or 0.025% (AI) cyfluthrin lost 13 trees to spruce beetle mortality between the two treatments after 12 months and a total of 31 trees after 24 months. The large difference in mortality between the two rates of cyfluthrin in 1994 resulted in a significant difference in 1994 and the cumulative analysis, but similar losses to mortality in 1995 resulted in no significance between the two rates in 1995. Trees treated with 0.025 or 0.05% (AI) esfenvalerate experienced mortality in 11 trees after 12 months and a total of 28 dead trees after 24 months. The mortality was distributed more evenly among the two rates of esfenvalerate, resulting in no significance between the two rates. As noted with carbaryl treatments, trees of varying diameters within 9 m of the trees treated with the pyrethroids
were found mass attacked during the current year. Frequently the treated tree was the only live tree remaining within a stand of trees at distances even greater than the 9-m radius.

Similar experiments (Shea et al. 1984, Werner et al. 1986), applied the insecticide treatments just prior to the bark beetle flight and challenged the experimental trees with pheromone baits immediately. In this experiment, insecticide treatments were applied in September 1993 following the completion of the previous spruce beetle flight season. This was necessary due to the elevation and inaccessibility of the research site during the spring prior to snow melt. Therefore, the treated trees were subjected to 9 months or more of seasonal weather prior to challenge with pheromone baits and pressure from the subsequent spruce beetle flight. The results indicated that this spraying regime was effective in protecting individual Engelmann spruce for varying time periods.

All of the objectives of this study were met. Carbaryl at the current registered rate of 2% (AI) effectively prevented spruce beetle attacks on individual Engelmann spruce trees for at least 24 months. The reduced rate of carbaryl, 1% (AI), was also effective for the same duration and may reduce the concern and potential side effects to nontarget organisms in the surrounding environment. Statistical analysis indicated a significant difference between the mortality in the carbaryl treatments versus the pyrethroid treatments. Although the trees treated with the pyrethroids experienced greater mortality and had more visible signs of spruce beetle activity on the surviving trees, cyfluthrin at 0.025% (AI), and esfenvalerate at 0.025 and 0.05% (AI) all met the effective criterion for protection of individual Engelmann spruce from attack by spruce beetle for 12 months.

The low rates, low toxicity to mammals, and stability in the natural environment make the pyrethroids a favorable chemical protective spray. Yearly application may be necessary to maintain an effective level of protection when high spruce beetle populations are present. However, the residual activity of these chemicals may be enhanced for a greater time period where pressure from spruce beetle populations are less intense. If
registered for use versus bark beetles, the pyrethroids could provide forest pest control specialists, land managers, and private citizens with additional or alternative protective chemical sprays for protecting individual trees of high-value through the duration of a bark beetle infestation.
LABORATORY EVALUATION OF CARBARYL AND PYRETHROID INSECTICIDE TOXICITY TO THE SPRUCE BEETLE

Introduction

The insecticide carbaryl has proved effective in protecting individual, high-value trees versus several bark beetle species, including the spruce beetle, *Dendroctonus rufipennis* Kirby (Coleoptera: Scolytidae), and is currently registered at a 2% rate (Smith et al. 1977, Hall et al. 1982, McCambridge 1982, Smith 1982, Gibson and Bennett 1985, Haverty et al. 1985, Werner et al. 1986). As alternatives to carbaryl are evaluated for possible future registration, laboratory bioassays may help determine suitable insecticides for field testing against the spruce beetle, or provide confirmation of results already determined in field studies.

Insecticide bioassays are experiments done with an insecticide on a living organism to estimate the probability that a pest population will respond in the desired manner (Robertson and Preisler 1992, 1). Many decisions about pest management begin with laboratory bioassays. They are a valuable tool for pursuing studies with insecticides, including research on structure activity relationships, resistance mechanisms and genetic modes of inheritance, comparative toxicities, and metabolism (Robertson and Worner 1990). The mechanical processes and equipment used to do insecticide bioassays are documented in detail by Busvine (1971) and have changed little. More recent research documented classical bioassay technique in the forestry setting (Robertson and Haverty 1981, Haverty and Robertson 1982, Pajares and Lanier 1989).

A common expression of insecticide toxicity to an organism is in terms of the LD₅₀ (lethal dose). This value represents the amount of poison per unit weight that will kill 50% of the particular population of the animal species tested (Matsumura 1975, 17-18). In some cases, the exact dose initially given to the insect cannot be determined but the concentration of insecticide in the surrounding external media can, resulting in a value expressed as an
Other toxicity terms include LT_{50}, representing the time required to attain 50% mortality of the population at a certain dose or concentration, the median knockdown dose and knockdown time, expressed as KD_{50} and KT_{50}, and the reproductive terms ED_{50} and EC_{50} (effective dose and effective concentration), which measures the effects of the insecticide on fertility and fecundity.

Common methods of insecticide administration include, but are not limited to, topical and contact bioassays. A topical bioassay dissolves the insecticide in a nontoxic and volatile solvent, such as acetone, and applies it with a special applicator to a particular location on the body surface of the test subject. The contact method utilizes insecticide in a solvent that is applied to the internal surface of a container where insects are confined. The solvent is evaporated by rotating the container until the insecticide is spread evenly over the entire container (Matsumura 1975, 18-19).

Insecticide bioassays are often elaborate, expensive, and rigorously controlled in the laboratory environment, and large differences between toxicity data and preventive field tests have occurred (Hall et al. 1982, Werner et al. 1983). As an alternative to elaborate and highly controlled bioassays, Brindley (1974) developed a simplified contact bioassay for testing alfalfa weevils. The procedure did not carefully control for such variables as photoperiod, temperature, humidity, micrograms of insecticide per insect, or population structure, but results were consistently quantitative and reliable. Contact bioassays were convenient for laboratory and field testing and have had widespread success in the agricultural setting.

Brindley’s simplified contact bioassay procedure warrants evaluation in the forestry setting. In developing protective sprays for use versus bark beetles, quantifying the toxicity and metabolism of the registered insecticide carbaryl in a spruce beetle population provides a baseline for comparison with other potential insecticide treatments. Additionally, the development of a standardized contact bioassay for testing bark beetles...
could provide the means for forest land managers to compare insecticide toxicities among the same bark beetle species in different locales and monitor for resistance development.

The objectives of this laboratory evaluation included the following: (1) quantify the toxicity of carbaryl, cyfluthrin, and esfenvalerate to the spruce beetle; (2) explore the use of monooxygenase (mixed-function oxidase) system by the spruce beetle to inhibit carbaryl toxicity; and (3) establish a basis for practical resistance surveillance by forest managers in the field.

Materials and Methods

Laboratory experiments utilized a 32-hour (h) contact insecticide bioassay to evaluate the insecticides carbaryl, cyfluthrin, and esfenvalerate against the target population of adult spruce beetles of both sexes. The experiments were based on the results of preliminary studies conducted March-May 1994 that defined the research design for toxicity testing on the spruce beetle using contact bioassays. All spruce beetles tested in the preliminary studies and for the duration of the experiment were collected on site or reared from infested Engelmann spruce, *Picea engelmannii* Parry, removed from the Manti-La Sal National Forest on the Sanpete Ranger District and the Ferron Ranger District. Evaluation of these districts demonstrated multiple outbreak areas in host-type material, many in visually sensitive locations. In 1993, a total of 3,076 hectares (ha) was infested and 15,600 trees killed by the spruce beetle on the Manti-La Sal National Forest (U.S. Department of Agriculture 1994). A concurrent field experiment was conducted on this site testing the efficacy of the three insecticides versus the spruce beetle on individual Engelmann spruce sprayed with two rates of each insecticide.

Laboratory experiments were performed on the same spruce beetle population at two different dates. Adult spruce beetles were collected from the bases of Engelmann spruce trees in September 1994 at the Deep Lake area on the Manti-La Sal National Forest and tested on site with contact bioassay kits prepared in advance in the laboratory.
Additionally, an Engelmann spruce infested with all life stages of the spruce beetle was felled, sectioned into 0.3-meter (m) bolts and removed from the Manti-La Sal National Forest. The bolt ends were sealed with paraffin and placed in cold storage through mid-May 1995 to simulate overwintering conditions. The bolts were removed from cold storage in May 1995 and placed in a screened porch at room temperature to rear out the spruce beetles. As emergence increased, spruce beetles were collected from bark samples peeled from the bolts and immediately tested with contact bioassay kits prepared in advance in the laboratory.

Technical grade carbaryl, cyfluthrin, and esfenvalerate (99.8% Sevimol® supplied by Rhone-Poulenc Ag Company, Research Triangle Park, N.C.; Tempo 2 95.9% supplied by Miles Inc., Kansas City, Mo.; and Asana XL® supplied by E.I. Du Pont De Nemours and Company, Wilmington, Del., corrected to 100% active ingredient with weighings) were used to prepare broad concentrations of stock solutions. For each insecticide, solid was weighed using an analytical balance and dissolved in 10 milliliters (ml) of acetone. Dilutions in tenfold increments were made from the original stock solution for a total of four stock solutions for each insecticide. Preliminary studies determined the same four stock solution concentrations, 0.1, 0.5, 2.0, and 10 micrograms (µg) appropriate for each of the three insecticides. Dilutions were prepared such that residue for each 5-dram treated glass vial was contained in 0.5 ml of acetone. The acetone was pipetted, in 0.5 ml aliquots, into uncapped glass vials and rolled on a rack until the acetone solution evaporated, leaving a residue on the walls of the vial. Control vials were prepared using 0.5 ml of acetone without any insecticide. Following acetone evaporation vials were capped with plastic caps containing a 7-millimeter (mm) drill hole covered with a plastic screen. A single bioassay included 4 vials each of the four concentrations and acetone-treated controls, for a total of 20 vials. One spruce beetle was randomly assigned to each vial. More beetles in the vial resulted in cannibalism. The bioassay was replicated five
times for each insecticide in September 1994 and again in May 1995. One bioassay from both carbaryl and esfenvalerate got wet during the September 1994 experiments and the data were removed from the analysis. The vials were placed in a portable incubator (Brindley et al. 1982) held constant at 20°C. The spruce beetles were evaluated at 8-h intervals through 32 h and recorded as dead or alive at each interval.

A 200-µg stock solution of piperonyl butoxide (90% technical grade from Aldrich Chemical Company Inc., Milwaukee, Wis.) was prepared using the same methods to test for synergism with carbaryl that was suggested in the preliminary studies. Each spruce beetle was randomly placed for 1 h in a vial treated with 200-µg piperonyl butoxide and transferred to one of 20 vials contained in a carbaryl bioassay. Two replicates were completed for each set of adult spruce beetles tested in September 1994 and May 1995. The vials were stored and results evaluated and recorded as previously described.

Results of preliminary studies indicated predictable behavior in the spruce beetle prior to absolute death, or no movement, when exposed to the insecticide treated vials. In contrast to surviving 10 days in an untreated vial, spruce beetles in treated vials showed symptoms indicative of toxicity within hours after exposure. Continued exposure resulted in incapacitation to the point that only a rare twitch of a tarsus or antenna was noted. Persistence of this end stage behavior beyond the 32-h evaluation period resulted in the establishment of a behavioral criterion for mortality.

In preliminary studies, spruce beetles demonstrating the end stage symptoms of poisoning were removed from the insecticide treated vial and put in an untreated vial for continued evaluation at 8-h intervals. None of the spruce beetles demonstrated increased activity or signs of recovery from the insecticide 3 days following removal from the insecticide treated vials. Additionally, spruce beetles demonstrating these same advanced symptoms of poisoning were removed from the insecticide treated vial and placed in groups in cages. The cages were constructed of 5-centimeter (cm) long pieces of PVC pipe with a
wire screen sealing one end and the open end attached firmly to the outside of a green Engelmann spruce bolt, the bolt baited with an aggregating pheromone. The bolt was left at room temperature and the caged spruce beetles observed for signs of recovery. There were no signs of boring activity, such as boring dust, resin streaking, or the establishment of an egg gallery. All the beetles showed no movement 7 days after introduction to the cages. Therefore, spruce beetles that demonstrated the occasional twitch of a tarsus or antenna were tallied as dead in subsequent bioassays.

The bioassay data were analyzed using regression. Correction for mortality in the controls used Abbott’s Formula (Abbott 1925). The percent mortalities were regressed against the log_{10} of the concentrations (micrograms/vial). The percent mortalities were also transformed to the arcsine of the square root of the proportion killed, and these values were regressed against the log_{10} (micrograms/vial). Slopes, intercepts, their variances, the correlation coefficient $R^2$ were calculated, as well as concentrations expected to give 1, 10, 20, 30, 40, 50, 60, 70, 80, 90, or 99% mortality based on the concentration/mortality relationship discovered. A third method transformed percent mortalities to probits and these values were regressed against the natural log (ln) (micrograms/vial), estimating slopes, intercepts, their variances, $\chi^2$ goodness-of-fit tests, and concentrations expected to give mortality as described above (SAS/STAT User’s Guide, Probit Procedure, 1325-1350). A Type III (Wald) $\chi^2$ test was conducted on data combined from the carbaryl, cyfluthrin and esfenvalerate trials at 32 h to test for main effects of date (September 1994 versus May 1995), insecticide treatment, interaction of date and insecticide treatment, and concentration. Within each insecticide treatment the slopes of the regression lines from the two different dates were tested for parallelism using a two-sample t-statistic.

Results

Table 6 shows the LC_{10}, LC_{50}, and LC_{90} for each insecticide. These results combined bioassays at 32 h for each insecticide regressing percent mortality against
Table 6. Contact bioassay toxicity at 32 h of three insecticides applied to the spruce beetle

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Date</th>
<th>LC(_{10})</th>
<th>LC(_{50})</th>
<th>LC(_{90})</th>
<th>LC(_{10})</th>
<th>LC(_{50})</th>
<th>LC(_{90})</th>
<th>LC(_{10})</th>
<th>LC(_{50})</th>
<th>LC(_{90})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbaryl</td>
<td>9-94</td>
<td>0.21</td>
<td>1.29</td>
<td>7.75</td>
<td>0.33</td>
<td>1.32</td>
<td>5.23</td>
<td>0.39</td>
<td>1.43</td>
<td>5.19</td>
</tr>
<tr>
<td></td>
<td>5-95</td>
<td>0.19</td>
<td>1.01</td>
<td>5.38</td>
<td>0.28</td>
<td>1.01</td>
<td>3.56</td>
<td>0.20</td>
<td>0.76</td>
<td>2.87</td>
</tr>
<tr>
<td>Cyfluthrin</td>
<td>9-94</td>
<td>0.16</td>
<td>0.90</td>
<td>4.97</td>
<td>0.24</td>
<td>0.87</td>
<td>3.13</td>
<td>0.47</td>
<td>0.99</td>
<td>2.06</td>
</tr>
<tr>
<td></td>
<td>5-95</td>
<td>0.22</td>
<td>1.16</td>
<td>6.00</td>
<td>0.34</td>
<td>1.18</td>
<td>4.04</td>
<td>0.37</td>
<td>0.90</td>
<td>2.18</td>
</tr>
<tr>
<td>Esfenvalerate</td>
<td>9-94</td>
<td>0.16</td>
<td>0.86</td>
<td>4.67</td>
<td>0.21</td>
<td>0.80</td>
<td>2.92</td>
<td>0.41</td>
<td>0.86</td>
<td>1.78</td>
</tr>
<tr>
<td></td>
<td>5-95</td>
<td>0.28</td>
<td>1.62</td>
<td>9.10</td>
<td>0.46</td>
<td>1.65</td>
<td>5.94</td>
<td>0.48</td>
<td>1.48</td>
<td>4.51</td>
</tr>
</tbody>
</table>

\(^{a}\)Values represent µg/vial.
concentration, the arcsine-transformed percent mortality against the log_{10} of the concentration, and the probit-transformed percent mortality against the ln of the concentration. Mortality occurred with all insecticides at low concentrations within 32 h.

Results of the synergism experiments using piperonyl butoxide did not document use of the mixed-function oxidase system by the spruce beetle. The toxicity pattern of carbaryl to the spruce beetle appeared to change with the addition of piperonyl butoxide in the September 1994 experiments, as the LC_{50} of the synergized population fell below the LC_{50} of the nonsynergized population at 24 h (2.59 and 17.69 µg/vial, respectively). However, this difference was not documented in May 1995 at 24 or 32 h, making the overall results of the synergism experiments inconclusive (Table 7).

Results of the Type III (Wald) χ^2 test indicated the main effect of concentration across all three insecticides significant, but insecticide, date, and interaction of date and insecticide were not significant (Table 8). In other words, mortality was significantly different among the four different concentrations in all three insecticides combined. However, the combined data showed no significant differences between the two different test dates nor indicated that one insecticide was significantly more toxic than the others. Further confirmation of the nonsignificance of date was obtained with the two-sample t-statistic. The hypothesis that the slopes were equal was accepted for each insecticide (Table 9). The carbaryl and piperonyl butoxide bioassays that explored synergism were not considered in the Type III (Wald) χ^2 test.

Discussion

Discussion of the insecticide bioassay results used the results of the probit analysis (Table 9). The three models used to evaluate the data estimated similar lethal concentration values, closest in the center of the range at the LC_{50}. Probit analysis was chosen as the best fitting model overall for reporting the results of these experiments. This decision was based on the s-shaped curves produced on plots of the observed percent mortality versus
Table 7. Comparison of carbaryl toxicity at 24 and 32 h with and without addition of synergist piperonyl butoxide

<table>
<thead>
<tr>
<th>Insecticide Treatment</th>
<th>24 h LC$_{50}$</th>
<th>32 h LC$_{50}$</th>
<th>24 h LC$_{50}$</th>
<th>32 h LC$_{50}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbaryl</td>
<td>17.69</td>
<td>1.43</td>
<td>2.06</td>
<td>0.76</td>
</tr>
<tr>
<td>Carbaryl + PB</td>
<td>2.59</td>
<td>0.99</td>
<td>2.05</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Values represent µg/vial.

Table 8. Type III (Wald) $\chi^2$ results evaluating main effects

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>$\chi^2$</th>
<th>Pr &gt; $\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>1</td>
<td>1.14</td>
<td>0.2847</td>
</tr>
<tr>
<td>Insecticide</td>
<td>2</td>
<td>0.03</td>
<td>0.9851</td>
</tr>
<tr>
<td>Date * Insecticide</td>
<td>2</td>
<td>1.38</td>
<td>0.4997</td>
</tr>
<tr>
<td>Concentration</td>
<td>4</td>
<td>103.82</td>
<td>0.0001*</td>
</tr>
</tbody>
</table>

*Significant at the 0.05 level.
Table 9. Parameters associated with results of probit analysis for insecticide treatments applied to the spruce beetle

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Bioassay Date</th>
<th>Insects treated</th>
<th>Insects control</th>
<th>Slope + SE(^a)</th>
<th>LC(_{50})(^b)</th>
<th>95% Fiducial limits</th>
<th>2-sample t-statistic(^{c,*})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbaryl</td>
<td>9-94</td>
<td>64</td>
<td>16</td>
<td>0.99 ± 0.21</td>
<td>1.43</td>
<td>0.83 - 2.38</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>5-95</td>
<td>80</td>
<td>20</td>
<td>0.96 ± 0.19</td>
<td>0.76</td>
<td>0.45 - 1.28</td>
<td></td>
</tr>
<tr>
<td>Carbaryl + PB</td>
<td>9-94</td>
<td>32</td>
<td>7</td>
<td>10.15 ± 51584</td>
<td>0.99</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>5-95</td>
<td>32</td>
<td>8</td>
<td>0.88 ± 0.27</td>
<td>0.92</td>
<td>0.33 - 2.53</td>
<td></td>
</tr>
<tr>
<td>Cyfluthrin</td>
<td>9-94</td>
<td>78</td>
<td>20</td>
<td>1.75 ± 0.44</td>
<td>0.99</td>
<td>0.62 - 1.42</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>5-95</td>
<td>80</td>
<td>20</td>
<td>1.46 ± 0.33</td>
<td>0.90</td>
<td>0.59 - 1.31</td>
<td></td>
</tr>
<tr>
<td>Esfenvalerate</td>
<td>9-94</td>
<td>64</td>
<td>15</td>
<td>1.75 ± 0.51</td>
<td>0.86</td>
<td>0.47 - 1.32</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td>5-95</td>
<td>80</td>
<td>20</td>
<td>1.15 ± 0.25</td>
<td>1.48</td>
<td>0.96 - 2.35</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Slope of the bioassay line from probit-transformed percent mortalities regressed against the natural log (ln) of the concentration (micrograms/vial).

\(^b\)Values represent µg/vial.

\(^c\)Ho: slopes equal  *None significant at the 0.05 level
the ln of the concentration, and the results of goodness-of-fit tests. Additionally, results of insecticide bioassays in the forestry field have commonly been reported using probit analysis (Werner et al. 1983, Robertson and Smith 1984, Robertson and McLean 1985, Pajares and Lanier 1989). In one case the probit model resulted in a questionable fit for the data. This occurred in the September 1994 32-h carbaryl and piperonyl bioassays, a small set of data points with either 100 or 0% mortality in all concentrations. Fig. 4 presents a graph of the concentration/mortality relationship estimated from the observed values of this data set using probit analysis. The results of the relationships estimated from the percent and arsine-transformed data were included for comparison. Probit analysis produced a line with a steep slope and huge standard error (Table 9) that would have skewed the results of the Type III (Wald) \( \chi^2 \) test, so the data from all the carbaryl and piperonyl butoxide trials were not included. The carbaryl and piperonyl butoxide bioassays were completed to explore the metabolism of carbaryl in the spruce beetle, but were not necessary to establish a baseline LC\(_{50}\) for carbaryl. The questionable fit of this September 1994 data to the probit model did not change the overall outcome of the results of the laboratory evaluation. Therefore, the results of probit analysis were chosen to report for consistency and ease of discussion.

The LC\(_{50}\) values at 32 h for the insecticides carbaryl (0.76-1.43 \( \mu \)g/vial), cyfluthrin (0.90-0.99 \( \mu \)g/vial), and esfenvalerate (0.86-1.48 \( \mu \)g/vial) indicated toxicity to the spruce beetle (Fig. 5). Results did not indicate that one insecticide was more toxic than the others. The hypothesis testing parallel slopes of the regression lines for each insecticide was not rejected, indicating difference in test date was not significant. Early speculation hypothesized that the spruce beetle population would show a difference in toxicity between the two test dates. This was based on the biology of the spruce beetle (Werner et al. 1977, Holsten et al. 1991). Collections of spruce beetles from the bases of Engelmann spruce in September 1994 for insecticide bioassays probably represented adults completing the most
Fig. 4. Regression lines fit to the 32-h carbaryl + piperonyl butoxide data using three methods of analysis.
Fig. 5. Comparison of LC50 values at 32 h among three insecticides.
recent flight season and their life cycle, or callow adults migrating to the base of the tree to overwinter prior to emergence the following spring, the conclusion of an active phase of the life cycle. This was in contrast to the insecticide bioassays completed May 1995 on spruce beetles reared from Engelmann spruce bolts maintained in cold storage to simulate overwintering conditions, a phase of the life cycle characterized by cold temperatures and hibernation. The spruce beetles tested in May 1995 were in cold storage for 7 months, but no differences in susceptibility to the insecticides between the two dates were found.

The time in which the insecticides produced toxic symptomology in the spruce beetle differed between carbaryl and the pyrethroids. The data at 8 and 16 h were inconclusive in the carbaryl trials. Insufficient mortality had occurred to establish a concentration/mortality relationship until 24 h (Fig. 6). In contrast, a concentration/mortality relationship was established by 8 h in all of the pyrethroid trials (Fig. 7). Carbaryl inhibits acetylcholinesterase and interferes with conduction of nerve impulses between nerve cells (Coulson and Witter 1984, 199), while the pyrethroids exert their toxic influence within the nerves cells modifying sodium channels (Zerba 1988). The different modes of action may have affected the rate of insecticide penetration through the insect cuticle and metabolism of the insecticide, producing the differences seen in the toxicity patterns between the two classes of insecticides.

Within the pyrethroid trials, the LC$_{50}$ at 16 h was higher than the value at 8 h and subsequently decreased again at 24 h. The pyrethroids are characterized by an initial rapid knockdown effect that renders the insect motionless, followed by a subsequent lethal effect (Miller 1988). The relatively low LC$_{50}$ at 8 h followed by an increase in the LC$_{50}$ at 16 h may have represented a slight recovery from this initial knockdown effect, but a decreasing LC$_{50}$ at 24 h indicated eventual mortality. Fig. 7 illustrates this pattern of toxicity for esfenvalerate in the May 1995 bioassays, LC$_{50}$'s of 2.87, 4.97, 1.60, and 1.48 µg/vial for 8, 16, 24, and 32 h, respectively.
Fig. 6. Comparison of LC$_{50}$ values at 24 and 32 h for carbaryl.
Fig. 7. Comparison of LC$_{50}$ values at 8, 16, 24, and 32 h for esfenvalerate.
Data from experiments testing the presence of a monooxygenase (mixed-function oxidase) system by the spruce beetle to inhibit the toxicity of carbaryl were inconclusive. Carbaryl and other carbamate insecticides are generally detoxified by monooxygenases, enzymes widely distributed among insects that play an important role in insecticide detoxification and resistance (Osman and Brindley 1981). Brattsten and Metcalf (1970) reported lower carbaryl LD$_{50}$ values among a large number of insect species when treated with piperonyl butoxide, a synergist that compromises the mixed-function oxidase system. Other studies supported the success of the mixed-function oxidase system inhibiting this class of insecticides (Guirguis and Brindley 1975, Rose and Brindley 1984). In this laboratory evaluation the bioassays conducted in September 1994 resulted in a 24-h LC$_{50}$ = 2.59 µg/vial for the spruce beetle population synergized with piperonyl butoxide versus 17.69 µg/vial for the nonsynergized population, the shift to a lower LC$_{50}$ being suggestive of mixed-function oxidase activity. However, a difference was not documented in the bioassays in May 1995, the LC$_{50}$ values equivalent at 2.0 µg/vial for the synergized and nonsynergized populations at 24 h (Table 7). The data for all the insecticide bioassays showed big differences in mortality among the trials through 24 h. The LC$_{50}$ differences seen at 24 h in September 1994 comparing synergized and nonsynergized populations may have represented unsettled mortality only and did not provide conclusive evidence of spruce beetle mixed-function oxidases. However, the results suggested that further research is warranted. Preliminary studies produced results similar to those in September 1994. Additionally, development of a meaningful concentration/mortality relationship was delayed until 24 h in the carbaryl bioassays versus 8 h in all the pyrethroid trials, suggesting the presence of mixed-function oxidase activity. Documentation of carbaryl detoxification using the mixed-function oxidase system by numerous insect species supports further research of this mechanism in the spruce beetle.
A 32-h contact bioassay was determined appropriate for evaluating the toxicity of these three insecticides to the spruce beetle. This was based on the results of preliminary studies that carried out bioassays to 72 h. These data indicated big differences in LC$_{50}$ values among trials within each insecticide through 24 h, which were attributed to unsettled mortality. Mortality was often difficult to assess due to the persistence of symptoms found indicative of advanced poisoning. The spruce beetle demonstrated predictable behavior prior to absolute death, or no movement, when exposed to the insecticide treated vials. The toxic symptoms were characterized by agitation and decreasing coordination that progressed to lethargy and an inability to maintain an upright position. The end stage symptoms included a rare twitch of a tarsus or antennae that often persisted to 72 h. This persistent moribund stage resulted in the establishment of a behavioral criterion to establish an endpoint that made the bioassay more practical. Once the behavioral criterion was applied, the mortality recorded at 32 h remained virtually unchanged through 72 h, supporting a 32-h contact bioassay.

The methodology and results achieved with these experiments provide baseline estimations of a range of lethal concentrations for three insecticides for the spruce beetle. The experiments are easily duplicated and are a practical means for forest land managers to quantify insecticide toxicity and monitor resistance development in the forestry setting. The LC$_{50}$ results from these experiments established a baseline for comparison with other spruce beetle populations, as previous resistance development to these three insecticides by the spruce beetle population tested here was unlikely. The LC$_{50}$'s for all three insecticides were small values that indicated toxicity to the spruce beetle. Additionally, the use of carbaryl at the field site where these beetles were collected for experiments has been limited to application to individual Engelmann spruce boles in areas where the trees have high aesthetic value, such as a developed campground. Until the main thrust of the spruce beetle infestation subsides in this area, these relatively small groups of trees have been sprayed.
yearly at most to protect them from spruce beetle attack. This is in contrast to insecticide use in the agricultural setting, where often numerous and widespread applications occur in a single growing season. The magnitude of this spruce beetle outbreak on the Manti-La Sal National Forest, the beetles’ exposure to small groups of trees sprayed infrequently with carbaryl, and the low $L_C_{50}$ value obtained with laboratory bioassays suggested previous development of resistance to carbaryl unlikely. The pyrethroids currently are not registered for use versus bark beetles but were tested as alternatives to carbaryl in a field experiment conducted on the Manti-La Sal National Forest over the same time period as the laboratory bioassays. Out of the 256 Engelmann spruce comprising the field study, separated by a minimum distance of 150 m from each other, 128 trees received a pyrethroid treatment in September 1993. The spruce beetle exposure to 128 individual Engelmann spruce with a one-time pyrethroid insecticide application since September 1993 made resistance development unlikely.

Forest land managers faced with bark beetle infestations have the methodology for a 32-h contact bioassay to quantify the toxicity of any insecticide used to protect forest trees from attack by bark beetles. Additionally, contact bioassays repeated over time can detect increases in the estimates of lethal concentrations that may indicate the development of resistance to the insecticide. The 32-h timeframe needed to complete the bioassay is practical and the results are easily communicated among forest land managers. Preparation of the vials in the laboratory makes it convenient to conduct the experiments in either the field or laboratory setting. The contact bioassay also provides a means to validate findings of insecticides tested in field experiments. Results of contact bioassays performed in this laboratory evaluation supported the findings of the field evaluation conducted over the same time period testing the effectiveness of carbaryl, cyfluthrin, and esfenvalerate sprayed on individual Engelmann spruce boles for protection from attack by spruce beetle. The $L_C_{50}$ estimates obtained in laboratory bioassays confirmed the toxicity of pyrethroid insecticides
to the spruce beetle and indicated the pyrethroids potentially effective insecticides for the protection of high-value Engelmann spruce. The results may encourage further research that could ultimately lead to the registration of these insecticides as additional treatments or potential alternatives to carbaryl.
The substantial tree mortality lost to spruce beetle epidemics necessitated research on protective chemical sprays that effectively protect trees of high value. Carbaryl is currently the registered insecticide of choice for protecting individual trees of high value from attack by spruce beetle. The pyrethroids are a different class of insecticides characterized by high toxicity to insects using low concentrations and relatively low toxicity to mammals. The purpose of this research was to test the effectiveness of carbaryl and two different pyrethroids, cyfluthrin and esfenvalerate, in protecting Engelmann spruce from attack by the spruce beetle.

The research consisted of both field and laboratory experiments. The field experiment was conducted on the Manti-La Sal National Forest, which was experiencing a spruce beetle epidemic. A total of 256 green, uninfested Engelmann spruce trees was selected for the study. Two rates of carbaryl, cyfluthrin, and esfenvalerate were applied to the boles of 32 trees each in September 1993; 64 trees served as controls. All trees in the study were challenged with pheromone baits, and the effectiveness of the insecticides in protecting the trees from spruce beetle attack was evaluated 1 and 2 years following insecticide application. Carbaryl at the 2% registered rate and a reduced rate of 1% were both effective in protecting Engelmann spruce from attack by spruce beetle through two pheromone baiting periods and 24 months following insecticide application. Cyfluthrin at a 0.025% rate and esfenvalerate at 0.025 and 0.05% rates provided effective protection through one pheromone baiting and 12 months following insecticide application. Only cyfluthrin at the lowest rate, 0.008%, was judged ineffective protection 12 months following insecticide application.

The laboratory experiment utilized a 32-h contact bioassay to quantify the toxicity of carbaryl, cyfluthrin, and esfenvalerate to the spruce beetle. The bioassays were performed on spruce beetles collected from the field experiment site on the Manti-La Sal National
The LC$_{50}$ values at 32 h for carbaryl (0.76-1.43 µg/vial), cyfluthrin (0.90-0.99 µg/vial), and esfenvalerate (0.86-1.48 µg/vial) indicated toxicity to the spruce beetle. Results of the contact bioassays supported the findings of the field evaluation, which found all three insecticides effective in preventing spruce beetle attack on Engelmann spruce for varying time periods. The laboratory experiments developed a simple methodology for toxicity tests on the spruce beetle. Additionally, an established baseline of toxicity data for three insecticides versus the spruce beetle facilitates comparisons among different spruce beetle populations and provides forest land managers the means to monitor for the development of insecticide resistance. Bioassays are useful for screening the potential success of insecticides to be tested in subsequent field experiments. In this case, the laboratory experiment was conducted concurrently with the field experiment and the results of each study provided support for the other.

The results of this research may stimulate further study of pyrethroids and lower rates of carbaryl as protective chemical sprays. If registered, the pyrethroids could provide forest land managers and private citizens additional or alternatives to carbaryl that give reasonably safe bark beetle control.
LITERATURE CITED


Robertson, J. L., and J. A. McLean. 1985. Correspondence of the LC50 for arsenic trioxide in a diet-incorporation experiment with the quantity of arsenic ingested as measured by x-ray, energy-dispersive spectrometry. J. Econ. Entomol. 78: 1035-1036.


APPENDICES
Appendix A

Letter to General Public

Reply to: 1950
Date: July 1993

Dear Interested Citizen:

The USDA Forest Service with Utah State University as a cooperator proposes to conduct a field experiment comparing the effectiveness of two synthetic pyrethroid insecticides, cyfluthrin and esfenvalerate, and carbaryl insecticide in preventing spruce beetle attacks on live, individual Engelmann spruce trees. The study will be conducted on the Manti-La Sal National Forest on the Sanpete Ranger District and the Ferron Ranger District. The study site will be accessible from Skyline Drive running from the Sanpete/Sevier County Line to South Twin Creek east of Spring City.

Enclosed is a Scoping Document and a Preliminary Environmental Assessment based on known and anticipated issues identified so far. We welcome and encourage your comments and suggestions on the proposed experimental study. The districts will accept public comments until August 24, 1993. Due to scheduling of insecticide application for this Fall, this 30 day comment period will also serve as the 30 day Pre-Decision Review. Please phone or mail your comments to: District Ranger, Sanpete Ranger District, 150 S. Main Street, Ephraim, UT 84627, phone (801)283-4151 or District Ranger, Ferron Ranger District, 98 S. State, P.O. Box 310, Ferron, UT 84523, phone (801)384-2372.

Thank you for your participation. Please share this document with others who might have an interest, or contact either of the above addresses for additional copies.

Sincerely,

Karen Johnson
Utah State University
Department of Forest Resources

Enclosure
Appendix B

Scoping Document

Spruce Beetle Management Experimental Project
Sanpete and Ferron Ranger Districts
Manti-La Sal National Forest

This Scoping Document for the Spruce Beetle Management Experimental Project is available for public review and comment until August 24, 1993. This 30 day comment period will also serve as the 30 day Pre-Decision Notice period. Please direct your comments to:

District Ranger
Sanpete Ranger District
150 S. Main Street
Ephraim, UT 84627
(801)283-4151

or

District Ranger
Ferron Ranger District
98 S. State
P.O. Box 310
Ferron, UT 84523
(801)384-2372
I. Proposed Action

The USDA Forest Service with Utah State University as cooperator are proposing to conduct a field experiment comparing the effectiveness of two synthetic pyrethroid insecticides, cyfluthrin and esfenvalerate, and carbaryl insecticide in preventing spruce beetle attacks on individual Engelmann spruce trees. Application and evaluation of insecticide efficacy against the spruce beetle on individual trees, not a forest wide setting, is the scope of this proposed experiment. The study will be conducted on the Sanpete and Ferron Ranger Districts of the Manti-La Sal National Forest.

The experiment will consist of six treatments and a control. The treatments will be two concentrations each of the three insecticides. Each treatment will be applied to 32 Engelmann spruce trees. Another 64 trees will be identified as unsprayed controls, 32 for each yearly evaluation period. Treatments and controls will be assigned at random to the selected 256 trees comprising the study. All study trees will be located in areas with heavy spruce beetle activity and isolated from other sample trees by at least 150 m so there will be a sufficient beetle population in the vicinity of each tree to rigorously test the effectiveness of treatments. In order to ensure adequate attack densities of spruce beetle, every tree in the study will be baited with spruce beetle aggregating pheromones, attached on the trunk 2 m above the ground. Insecticide application will be in September 1993. Treatment effectiveness will be evaluated following the 1994 and 1995 spruce beetle flight periods.

The assessment of alternatives, issues, and concerns to date is documented in the Environmental Assessment

II. Purpose and Need

Insecticides with proven efficacy and safety are warranted and must be readily available to protect individual trees of high-value, such as around homesites, campgrounds, administrative areas or other visually sensitive areas. The aesthetic value of these trees, the cost of removal if killed, the replanting costs, and the expense associated with maintenance of these areas may justify the need to protect individual, live trees from spruce beetle attack until the main thrust of an infestation subsides.

Currently, carbaryl at a 2% rate is the most widely used chemical protective spray registered by the Environmental Protection Agency for bark beetle control. There is some concern whether the manufacture will continue to maintain the registration of this chemical versus bark beetles. Clearly, alternatives to carbaryl need evaluation to provide greater flexibility to resource managers and homeowners for preventing individual tree mortality from bark beetles.

Pyrethroid insecticides offer an excellent alternative to carbaryl. They cause few environmental disruptions, except for their high toxicity to cold-blooded vertebrates and aquatic invertebrates. Generally, pyrethroids have low toxicity to mammals, require very small quantities to control insects, and are registered for control of pests of ornamentals and use in forest tree nurseries.
The purpose of the Proposed Action is to identify additional effective insecticidal treatments for protecting individual Engelmann spruce from attack by spruce beetle. If registered, these additional treatments may provide forest pest control specialists, resource managers, and private citizens with cost-effective and reasonably safe bark beetle control.

III. Area Description

The study site for the proposed experiment is located on the Manti-La Sal National Forest on the Sanpete and Ferron Ranger Districts. The study site will be accessible from Skyline Drive running from the Sanpete/Sevier County Line to South Twin Creek east of Spring City.

Recent evaluation of the Sanpete and Ferron Ranger Districts indicated multiple spruce beetle outbreak areas in host type material, many in visually sensitive locations. A buildup of spruce beetle populations occurred in an unusually large number of downed spruce in the early 1980’s, leading to the current outbreak conditions.

IV. Proposed Activities

The Proposed Action presents a field experiment to test the effectiveness of three insecticides in preventing spruce beetle attack on live, individual Engelmann spruce trees. Sample trees will be selected in August after the 1993 flight period. No sprayed trees will be located within 46 m of campgrounds or other human habitation. No trees within 150 m of streams, ponds or lakes will be used in this study. Following insecticide application in September 1993, treatment effectiveness will be evaluated following the 1994 and 1995 flight periods and will be based on whether or not treated trees are successfully attacked and killed by the spruce beetle.

V. Preliminary Issues

Preliminary issues have already been identified by the Forest Service. Public involvement may surface others. The following list summarizes issues identified thus far:

1. Potential Effects on Preventive Treatment Opportunities

   a. No Action - Alternatives to the 2% registered rate of carbaryl as an insecticidal preventive treatment would not be evaluated. Carbaryl would be used as long as it is available, determining the need for development and testing of other preventive treatments if formulations of carbaryl are removed from the market. In that developmental period, no treatments may be available for dealing with spruce beetle in recreational and other high-use sites.

   b. Conduct a Field Experiment with Two Concentrations Each of Carbaryl, Cyfluthrin, and Esfenvalerate - This alternative would result in valuable information regarding carbaryl efficacy at reduced rates and the performance of two different pyrethroid insecticides as preventive treatments against spruce beetle on Engelmann spruce
trees. Data could lead to additional testing and ultimately registration of these pyrethroids as preventive treatment alternatives to carbaryl.

2. Potential Effects on Terrestrial Wildlife - Insecticides will be applied directly to the bark of the trees, releasing very little into the nontarget environment. A recent study showed 80% of the sprayed insecticide was bound and absorbed in the tree’s bark. Additionally, almost half of the material that fell to the ground was deposited within 2 m of the base of the tree. There will be no significant effects from the proposed treatment on terrestrial wildlife because of the size of the treatment areas.

3. Potential Effects on Nontarget Arthropods - Carbaryl and the two pyrethroids are broad spectrum insecticides, toxic to most groups of insects and spiders. Even though most insects that contact sprayed surfaces prior to deactivation will be killed, the overall impact is slight, due to the size of the treatment areas and the fact that only the boles or trunks of the trees and the forest floor immediately under these trees are impacted by the spray.

4. Human Health and Safety - The greatest risk to human health and safety associated with spruce beetle activity is the safety hazard created by an increased number of dead trees. The greatest risk for insecticide exposure to humans for this project is to the applicators. Only 192 trees will be sprayed, separated from one another by a minimum of 150 m, making this a small-scale spraying project and exposure to insecticides minimal. Additionally, a project safety plan will provide further instruction and protection to insecticide applicators. The public will be notified in advance of insecticide application and appropriate postings on site and enforcement of closed areas will be carried out.

VI. Preliminary Alternatives

Due to the experimental nature of the proposed study, the No Action and the Proposed Action are the alternatives identified to date.
Appendix C

Environmental Assessment

Effectiveness Of Carbaryl And Pyrethroid Insecticides For Protection Of Engelmann Spruce From Attack By Spruce Beetle (Coleoptera: Scolytidae)

Sanpete and Ferron Ranger Districts

Manti-La Sal National Forest

USDA Forest Service

August 1993
I. Purpose and Need for Action

A. Introduction

The spruce beetle, *Dendroctonus rufipennis* Kirby (Coleoptera: Scolytidae), is the most significant natural mortality agent of mature spruce (Holsten et al. 1991). In the southern and central Rockies, Engelmann spruce, *Picea engelmannii* Parry, is the principal host (Schmid and Frye 1977). Evaluations throughout the state of Utah have revealed high spruce beetle populations and subsequent tree mortality in many areas. If initiated prior to beetle outbreak, silvicultural programs designed to reduce the susceptibility of high risk stands to bark beetle attack are the treatment strategy of choice. However, during outbreak conditions direct chemical control tactics may be advisable to protect individual trees of high value, such as around residences, campgrounds, administrative areas or other visually sensitive locations. For such applications insecticides with proven efficacy and safety are warranted and must be readily available.

The USDA Forest Service with Utah State University as cooperator are proposing to conduct a field experiment comparing the effectiveness of two synthetic pyrethroid insecticides, cyfluthrin and esfenvalerate, and a reduced rate of carbaryl insecticide against the 2% registered rate of carbaryl in preventing spruce beetle attacks on Engelmann spruce. Application and evaluation of insecticide efficacy on individual trees, not a forest wide setting, is the scope of this proposed experiment. The study will be conducted on the Manti-La Sal National Forest in designated areas of the Sanpete Ranger District and the Ferron Ranger District. The proposed treatments will be applied in September 1993 and evaluated following the 1994 and 1995 spruce beetle flight seasons.

This Environmental Assessment (EA) describes alternatives considered for protection of individual Engelmann spruce trees from attack by spruce beetle and their effects. The alternatives are evaluated and the preferred alternative identified. Impacts associated with the proposed field experiment are evaluated.

B. Background

1. The Site

The spruce beetle prefers downed spruce to standing trees. If beetle populations develop to high levels in downed material, they may become a serious problem in adjacent standing trees (Schmid 1981). All known major outbreaks have originated from stand disturbances (Schmid and Frye 1977). An unusually large number of downed Engelmann spruce on the Sanpete and Ferron Ranger Districts in the early 1980's supported a buildup of spruce beetle populations. Recent evaluation of these districts indicates multiple outbreak areas in host type material, many in visually sensitive locations. Salvage operations have occurred on both districts.

Infestations severely affect such resource values as timber, watershed, wildlife, range and recreation (Loomis et al. 1985). In addition to extensive stand mortality, the spruce beetle can have devastating effects on other forest amenities such as campgrounds, picnic areas, visitor centers and permanent and summer residences. Although little can be done to significantly sway the course of an infestation, the value of individual trees, the cost of removal, the cost of replanting, and the expense associated with maintenance of these areas
may justify protecting highly valued, individual trees until the main thrust of an infestation subsides.

The study site for the proposed experiment is on the Manti-La Sal National Forest on the Sanpete Ranger District and the Ferron Ranger District. Two general areas accessible from Skyline Drive have been identified for the selection of trees to comprise the experiment. Twelvemile Flat running north to Duck Fork Reservoir and south to the Forest Boundary comprises the largest area. Additionally, trees will be selected from an area encompassing Bacon Rind Canyon to the north and Reeder Canyon to the south (Fig. 8).

2. Treatment Descriptions

Recent research indicated that land managers have few options for direct interventions to manage spruce beetle infestations on large or small tracts of land. New and better tools are needed by managers to reduce the threat of spruce beetle mortality to individual, high-value Engelmann spruce.

Research has demonstrated the effectiveness of several formulations of carbaryl for protecting individual trees from attack by bark beetles. A 2% formulation of carbaryl (Sevimol) provided excellent protection from attack by western pine beetle, *D. brevicomis* Le Conte, on ponderosa pine, *Pinus ponderosa* Laws. (Hall et al. 1982, Haverty et al. 1985), and mountain pine beetle, *D. ponderosae* Hopkins, on lodgepole pine, *P. contorta* Dougl. ex Loud (Gibson and Bennett 1985). Additionally, another formulation of carbaryl (Sevin SL) at a 1 and 2% rate provided 100% protection to white spruce, *P. glauca* (Moench) Voss, for 16 months from spruce beetle attack (Werner et al. 1986). These and other studies (Smith et al. 1977, McCambridge 1982) led to registration of 2% carbaryl as a preventive spray. Further research needs to be conducted to determine the efficacy of carbaryl against the spruce beetle on Engelmann spruce. Additionally, alternatives to carbaryl that provide more flexibility for integrated pest management in the forestry setting and for homeowners needs evaluation.

Pyrethroid insecticides offer an excellent alternative to carbaryl. They cause few environmental disruptions, except for their high toxicity to fish and aquatic invertebrates, and bees. Generally, pyrethroids have low toxicity to mammals and birds, require very small quantities to control insects, and are registered for use against pests of ornamental trees and in forest nurseries. Cyfluthrin and esfenvalerate are the two pyrethroids that have been selected for this study.

3. Spruce Beetle Life Cycle and Behavior

The life stages of the spruce beetle are the egg, larva, pupa, and adult. The life cycle may be completed in 1 year on warm sites at lower elevations or take up to 3 years on cool, shady locations on north slopes. Generally, the 2-year life cycle is the most common (Schmid and Frye 1977, Holsten et al. 1991). In the 2-year cycle, adults typically attack green trees in June and July. By mid-October, eggs have hatched and the larvae have developed to the second, possibly fourth, instar. The larval stage predominates during the first winter. About 1 year after attack the larvae pupate, transforming into adults. The second winter is passed in the adult stage followed by summer emergence to attack new host material (Schmid and Frye 1977). Insecticides must have effective residual lives or repeated applications to protect trees from the potential variation in life cycle length.
Fig. 8. Boundary areas containing test trees on field experiment study site, Manti-La Sal National Forest.
Endemic spruce beetle populations are usually maintained in windthrown trees. When beetle populations increase to high levels in downed trees, beetles may enter susceptible, large-diameter, standing timber. In mature stands, large-diameter trees (≥46 cm diameter breast height (dbh)) usually are attacked first. If an infestation persists in a stand, smaller diameter trees are attacked. A host may not by selected for its large diameter, but instead for its pattern of slow radial growth (Hard 1985). The proximity of uninfested standing spruce trees to infested hosts also denotes vulnerability to attack. In the Rocky Mountain area, susceptibility of a stand to spruce beetle attack is based on the physiographic location, tree diameter, basal area, and percentage of spruce in the canopy. Spruce stands growing on well drained sites in creek bottoms, having an average dbh >41 cm, a basal area of 34 square meters per hectare (m²/ha), and more than 65% spruce in the canopy are at highest risk (Schmid and Frye 1976).

C. Scoping

In accordance with the National Environmental Policy Act (NEPA) process, this project was internally scoped with Forest Pest Management, the Manti-La Sal National Forest and selected additional contacts to identify issues and potential impacts related to the study. A proposed Finding of No Significant Impact incorporates these issues.

D. Issues

The following list of issues have been identified in analyzing alternatives to deal with the impacts of spruce beetle activity on the study site:

1. Potential effects on preventive treatment opportunities.
2. Potential effects on terrestrial wildlife and sensitive birds.
3. Potential effects on nontarget arthropods.
4. Human health and safety.
5. Consistency with the Forest Plan.

II. Alternatives, Including the
   Proposed Action

A. Introduction

Threats to individual trees in recreation and other high value sites exist on the Sanpete and Ferron Ranger Districts. While carbaryl insecticide at a 2% rate is registered as a preventive spray for use against bark beetle attacks, it is desirable to obtain efficacy data for reduced rates of carbaryl and alternative insecticides that would provide greater flexibility for integrated pest management for the land manager.
B. Alternatives

1. No Action - This alternative would not test and perhaps eventually register additional insecticides or reduced rates of carbaryl as preventive treatments to spruce beetle attacks. Treatments would be limited to carbaryl at currently registered formulations and rates, based on appropriate site specific analyses, as long as it is available.

2. Single Application with Two Concentrations Each of Carbaryl, Cyfluthrin, and Esfenvalerate - In this alternative, the Proposed Action, all three insecticides would be tested in a field experiment. Carbaryl at 2%, the current registered rate, would be the standard against which the two pyrethroid insecticides, at two different rates each, and a reduced rate of carbaryl would be compared.

C. Comparison of Alternatives

1. No Action - The No Action alternative means that no effort in time or dollars would be expended to evaluate alternatives to carbaryl or reduced rates of carbaryl as protective sprays against the spruce beetle on Engelmann spruce. While we realize there is no guarantee carbaryl will be available or registered for use versus bark beetles indefinitely, we would continue to rely on its use as long as possible.

2. Conduct a Field Experiment with Single Application of Two Concentrations Each of Carbaryl, Cyfluthrin, and Esfenvalerate - In this, the Proposed Action, the experiment will consist of six treatments and a control. The treatments will be carbaryl (Sevimol) at 1 and 2%, cyfluthrin (Tempo 2) at 0.008 and 0.025%, and esfenvalerate (Asana XL) at 0.025 and 0.05% each applied to 32 trees for a total of 192 treated individual Engelmann spruce. An additional 64 trees will be identified as untreated controls, 32 to be used in 1994 and the remaining 32 used in 1995. Treatments and controls will be assigned at random. The entire study will require at least 256 trees. The live and unattacked trees will be located in areas with heavy spruce beetle activity and isolated from other sample trees by at least 150 m so there will be a sufficient beetle population in the vicinity of each tree to rigorously test the effectiveness of treatments. In order to ensure adequate attack densities of spruce beetles, every tree in the study will be challenged with spruce beetle aggregating pheromones, attached on the trunk 2 m above the ground.

Sample trees will be selected in August after the 1993 spruce beetle flight period. No trees will be located within 46 m of campgrounds or other human habitation. Furthermore, no trees within a 100 m of an above-ground water source will be selected. The study will comply with the restrictions outlined in the Forest Travel Plan, with the exception of a one time exemption during insecticide application to spray trees located off normal travel routes. Insecticides will be applied with a FMC Bean hydraulic sprayer mounted on a truck or trailer, and the entire circumference of each tree will be treated until runoff to a height of at least 10 m. Treatment effectiveness will be based on whether or not treated and pheromone challenged trees are successfully attacked and killed by the spruce beetle 1 and 2 years following treatment application. The untreated controls will serve as indicators of adequate spruce beetle population pressure.
III. Environmental Consequences

A. Introduction

This section describes the environmental effects of the proposed alternatives. An understanding of these expected effects provides the responsible official with the information necessary to select the preferred alternative.

B. Consequences of Alternatives

1. Potential Effects on Preventive Treatment Opportunities
   
   a. No Action - Under the No Action alternative we would not evaluate alternatives to carbaryl insecticide as a preventive treatment. We would continue to use carbaryl, testing other preventive treatments at a time when conditions warranted it. In that developmental period, chemical control of the spruce beetle in recreational and other high use sites would be severely limited.
   
   b. Conduct a Field Experiment with Single Application of Two Concentrations Each of Carbaryl, Cyfluthrin, and Esfenvalerate - Selecting this alternative would result in valuable information regarding carbaryl insecticide at a reduced rate and the performance of two different pyrethroid insecticides as preventive treatments against the spruce beetle in Engelmann spruce. Data could ultimately lead to further testing or registration of the pyrethroids for use against bark beetles. Either would greatly enhance our preventive treatment alternatives for chemical control of bark beetles.

2. Potential Effects on Terrestrial Wildlife and Sensitive Birds

   No adverse effects of insecticides to animals is expected. The insecticides will be applied directly to the bark of the trees, releasing very little into the nontarget environment. Most will be bound by and absorbed in the tree’s bark. Haverty et al. (1983) in experiments conducted to quantify the amount of drift and worker exposure resulting from ground application of insecticides to individual trees, found that greater than 80% of the material applied stayed on the tree. Furthermore, about 45% of the material that fell to the ground was deposited within 2 m of the base of the tree. The amount of material decreased rapidly as distance from the treated tree increases; 50.2 µg/cm² at 1 m; 14.2 µg/cm² at 3 m; 2.3 µg/cm² at 8 m; 0.0 µg/cm² at 12 m.

   The northern three-toed woodpecker and goshawks have been identified as sensitive species living within or adjacent to the proposed experiment site. Synthetic pyrethroids, based on the insecticidal ingredients known as pyrethrins extracted from the oleoresin of dried chrysanthemum flowers, are relatively non-toxic to birds (Anonymous 1988). The two pyrethroid insecticides used in this study are characterized by rapid knockdown of insects, good residual activity, and low dosage rates, reducing the overall pesticide load in the environment. Research on the interactions between pyrethroids, the sensitive birds identified, and spruce beetle do not exist.
Research indicated that carbaryl, a carbamate insecticide, had no major effects to forest birds (Richmond et al. 1979). DeWeese et al. (1979) detected no significant decrease in bird numbers from breeding-pair estimates or live bird counts after aerial spraying of carbaryl. Of the breeding pairs present before the spraying, 92% remained on the carbaryl plots following the spraying, the same percentage as on the control plots. Counts of live birds before and after the spraying supported the breeding-pair estimates. Additionally, 74% of 242 birds monitored had tracer dye from insecticide contact on their feet and feathers and targeted insects were found in their stomachs, but no sick or dead birds were found.

It is emphasized that ground application of insecticides to the boles of 192 trees spaced a minimum distance of 150 m apart will comprise this study. Due to the small scope of the study and the dispersed pattern of the treated trees, no potential effects to the northern three-toed woodpecker or the goshawk are anticipated. As a raptor, goshawks will have negligible contact with the sprayed trunk of the treated trees. The northern three-toed woodpecker is an important predator of the spruce beetle, particularly on beetle larvae in winter (Schmid and Frye 1977). If protection is maintained following insecticide application to live, unattacked trees, no food source in the treated tree will be available for the woodpecker. Hence, chances for contact between sprayed tree bark and woodpecker is minimal.

3. Potential Effects on Nontarget Arthropods

The normal complement of forest arthropods can be found at the experiment site. No threatened or endangered species are known to occur in the immediate area. Carbaryl, cyfluthrin, and esfenvalerate are broad spectrum insecticides, toxic to most groups of insects and spiders. Even though most insects that contact sprayed surfaces prior to deactivation will be killed, the overall impact is slight. Only the boles of 192 Engelmann spruce and the forest floor immediately under these trees are impacted by the spray. Few species of insects and spiders permanently reside or frequently visit these individual locations; hence, few will be affected.

4. Human Health and Safety

The greatest potential risk to humans for exposure to carbaryl, cyfluthrin, and esfenvalerate is to the applicators. These risks will be virtually eliminated by compliance with the Project Safety Plan, which describes protective clothing and mixing and spraying requirements. Spraying will be conducted under the direction of a certified pesticide applicator.

5. Consistency with the Forest Plan

This project is consistent with the Forest Plan direction for providing Integrated Pest Management (IPM) to prevent or suppress epidemic insect populations. The study will help to identify additional tools which could be used in IPM activities.

IV. Mitigating Measures

Procedures, guidelines, and other measures can be implemented to mitigate nontarget effects in suppression/protection projects that include the use of insecticides. During application, insecticide droplets that can settle on nontarget organisms, including humans,
can be minimized by using the proper type of application equipment, adherence to strict standards for a site, and by following the operation plan for the project.

The public will be notified of the dates the insecticides will be applied by telephone, local newspaper, local radio, individual letter, and/or personal contact. The public will be notified in advance of insecticide application and appropriate postings on site and enforcement of closed areas will be carried out.

Potential exposure to insecticides is greatest for individuals involved in the actual mixing and application. Protective clothing, such as coveralls, rubber gloves, and a respirator will be provided and minimize any risk to individuals involved in these tasks. A Safety Plan will provide for contingencies such as pesticide spills and worker exposure.

No applications will be made within 100 m of an above-ground water source to minimize insecticide dispersal and exposure to aquatic organisms.

Insecticides will be applied only when weather conditions favor effective insecticide deposition. Most insecticide treatments will be applied in the early morning (up to 1000) and late afternoon to early evening hours (1600 to 2100), as this is when atmospheric conditions generally are the most favorable for maximizing insecticide deposition in treatment areas. Occasionally, insecticide application may continue throughout the day so long as conditions are favorable. To minimize spray drift, application of insecticides will be made only when wind speed does not exceed 7 km/hr. Insecticide application will be suspended when rain is imminent. After rain, insecticide will be applied only when the tree trunk is dry. Travel off roads will not occur when area is wet.

V. Document Preparation

Karen J. Johnson
M.S. Candidate, Department of Forest Resources, College of Natural Resources, Utah State University, Logan, UT 84322

VI. Agencies and Persons Consulted

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<thead>
<tr>
<th>Name</th>
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<tr>
<td>Reed Irwin</td>
<td>Forest Planner</td>
<td>Manti-La Sal National Forest</td>
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<tr>
<td>Rodney L. Player</td>
<td>Wildlife Biologist</td>
<td>Manti-La Sal National Forest</td>
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<tr>
<td>A. John Vasten</td>
<td>Forester</td>
<td>Manti-La Sal National Forest</td>
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<tr>
<td>Billy J. Dye</td>
<td>Forester</td>
<td>Ferron Ranger District</td>
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<td>Don L. Okerlund</td>
<td>Forester</td>
<td>Sanpete Ranger District</td>
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VII. Project Safety Plan

1. Transport of insecticides to specific field sites will be in the outside bed of a pickup truck and secured in spill proof containers with absorbent material.

2. Spraying will be discontinued when substantial drift is observed by increased winds.

3. Clean protective clothing, including hard hats with face plates or goggles, spray suits, rubber gloves and respirators, will be worn by operators while spraying.

4. All used and empty formulation containers will be disposed of according to the instructions on the labels.

5. All sprayed trees will be posted with appropriate warning signs.

6. No sprayed trees will be located within 46 m of campgrounds or other human habitation.

7. No trees within 100 m of streams, ponds or lakes will be used in this study.

8. Spray crews will carry radios and be within communication distance to the District Ranger Stations in the event of an accident or vehicle failure.

9. Operators will wash thoroughly before eating. No eating or drinking will be permitted at the test sites while spraying.

10. Unused insecticides will be stored in original containers only in the FPM warehouse in Ogden. Unused, unopened insecticide containers will be returned to the supplier.

11. Spray application will be under the supervision of a licensed operator.
VIII. Accident Spill Plan

Prevention, rather than provision for remedy, will be the goal.

1. The spray crew will carry an adequate supply of paper towels, soap, and an emergency eye wash bottle and water.

2. Any small spill on the exposed portion of a worker will be immediately washed off with excessive amounts of soap and clear water.

3. Each spray crew member will have a complete change of clothing in the truck. Any large spill on the clothing and exposed part of a worker will require immediate and thorough washing of exposed portions and a change of clothing.

4. Any spill on the ground in excess of 0.5 liter of concentrate or the equivalent will be covered with soil, marked and reported to the appropriate personnel and agencies. If decontamination is recommended by the District Ranger, the specific instructions outlined on the label will be followed.

5. Spillage in open water is not expected, even by accident, since one provision of the plot location is the avoidance of live streams, lakes and potable water. However, should such occur, the spray pump intake will be used to remove as much contaminated water as possible. The water carboys will be used to contain the contaminated water. If the volume of water exceeds the capacity of the carboys, water will be sprayed over a wide area of nearby land and marked. Local authorities will be notified of this action.

6. Should an accident occur on the main road, the requirement appropriate to item 4 and 5 will be used.


Appendix D

Decision Notice
and
Finding of No Significant Impact

Spruce Beetle Management Experimental Project
Sanpete and Ferron Ranger Districts
Manti-La Sal National Forest
USDA Forest Service

I. Proposed Action

The USDA Forest Service with Utah State University as a cooperator are proposing to conduct a field experiment comparing the effectiveness of two synthetic pyrethroid insecticides, cyfluthrin and esfenvalerate, and a reduced rate of carbaryl insecticide, against the 2% registered rate of carbaryl in preventing spruce beetle attacks on live, individual Engelmann spruce trees. Application and evaluation of insecticide efficacy on individual trees, not a forest wide setting, is the scope of the proposed experiment. The experiment will be conducted on the Sanpete and Ferron Ranger Districts of the Manti-La Sal National Forest. Trees will be selected from two areas accessible from Skyline Drive. Twelvenmile Flat running north to Duck Fork Reservoir and south to the Forest Boundary comprises the largest area. Additionally, trees will be selected from an area encompassing Bacon Rind Canyon to the north and Reeder Canyon to the south.

The experiment will consist of six treatments and a control. The treatments will be carbaryl (Sevimol) at 1.0 and 2.0%, cyfluthrin (Tempo 2) at 0.008 and 0.025%, and esfenvalerate (Asana XL) at 0.025 and 0.05% each applied to 32 trees for a total of 192 treated individual Engelmann spruce. An additional 64 trees will be identified as untreated controls, 32 to be used in 1994 and the remaining 32 used in 1995. The entire study will require at least 256 unattacked trees. No sprayed trees will be located within 46 m of campgrounds or other human habitation. No trees within 100 m of streams, ponds or lakes will be used in this study. The trees will be in areas with heavy spruce beetle activity and isolated from other sample trees by a minimum of 150 m. In order to ensure adequate attack densities of spruce beetles, every tree in the study will be baited with spruce beetle aggregating pheromones, attached on the tree bole 2 m above the ground. Treatment effectiveness will be based on whether or not treated and pheromone challenged trees are successfully attacked and killed by the spruce beetle 1 and 2 years following treatment application. The untreated controls will serve as indicators of adequate spruce beetle population pressure.

The assessment of alternatives, issues, and concerns to date is documented in the Environmental Assessment.
II. Finding of No Significant Impact

It is my decision to implement the Proposed Action which provides for a single application with two concentrations each of carbaryl, cyfluthrin, and esfenvalerate as described above. I have reviewed the Council on Environmental Quality Regulations for significance (40 CFR 1509.27) and have determined this is not a major Federal action that would significantly affect the quality of the human environment. Therefore, an Environmental Impact Statement will not be prepared. This determination was made considering the following factors of context and intensity:

1. The experimental treatment area is small in overall size and effects of treatment are short-term and local.

2. There are no known threatened or endangered species which will be disturbed or affected. The two sensitive species of birds identified will not be disturbed due to the small treatment size.

3. Public health and safety will not be affected since insecticide applications will comply with EPA label directions and State and Federal laws.

4. The treatment area is not unique or ecologically critical and not in wetlands or floodplains.

5. The project effects are not controversial.

6. Effects on the human environment are not highly uncertain nor involve unique or unknown risks.

7. The action does not establish a precedent for future actions nor has cumulative effect.

8. Water quality within the area will not be affected and will be maintained.

9. The action does not threaten to violate Federal, State or local requirements imposed for the protection of the environment.

10. In some areas an adequate number of trees may not be available adjacent to roads which are open to vehicle travel. In those cases it will be acceptable to drive the spray unit off road only during the initial application, where no resource damage will occur.

George A. Morris
Forest Supervisor
Manti-La Sal National Forest
On August 27, 1993, George A. Moffis, Manti-La Sal National Forest Supervisor, made the decision to approve a field experiment comparing the effectiveness of two synthetic pyrethroid insecticides, cyfluthrin and esfenvalerate, against the current standard insecticide, carbaryl. The test involves spraying trees with one of the insecticides and comparing the results against trees that were not sprayed. A total of 192 Engelmann spruce trees on the Ferron and Sanpete Ranger Districts will be sprayed using a truck or trailer mounted sprayer.

No significant issues were identified during the scoping process.

This decision may be implemented seven days after publication of this Legal Notice in the Sun Advocate.

This decision is subject to appeal under 36 CFR 217. Specific procedures for filing an appeal are located in 36 CFR 217.8. Copies of the appeal regulation are available at local Forest Service offices.

To be considered a valid appeal:

1. The appeal must be filed within 45 days of publication of this notification of decision in the Price Sun Advocate newspaper. This time period starts the day after publication and includes all calendar days.

2. The appellant must file two (2) copies of the Notice of Appeal in accordance with regulations contained in 36 CFR 217.9, with the Regional Forester, Intermountain Region, 324 25th Street, Ogden, UT 84401. The Regional Forester is the Reviewing Officer.

It is the responsibility of those who appeal a decision to provide the Reviewing Officer sufficient narrative evidence and argument to show why the decision should be changed or reversed. The appellant must identify the specific change(s) in the decision which is being sought. Minimum requirements for the written notice of appeal are identified in 36 CFR 217.9 (b).

The Reviewing Officer shall render his/her appeal decision not more than 100 days from the date the appeal was filed. This review period may be extended to allow for conduct of meaningful negotiations (36 CFR 217.12 (a)). If the project or activity would be implemented before an appeal decision could be issued, the Reviewing Officer will consider written requests to stay implementation of the decision, pending completion of the review. To request a stay of implementation, a written request must be filed with the Reviewing Officer as prescribed in the 36 CFR 217.10.
For additional information concerning this decision of the Forest Supervisor, please contact A.J. Frandsen, Resource Specialist, Manti-La Sal National Forest, 599 West Price River Drive, Price, UT 84501, (801)637-2817.