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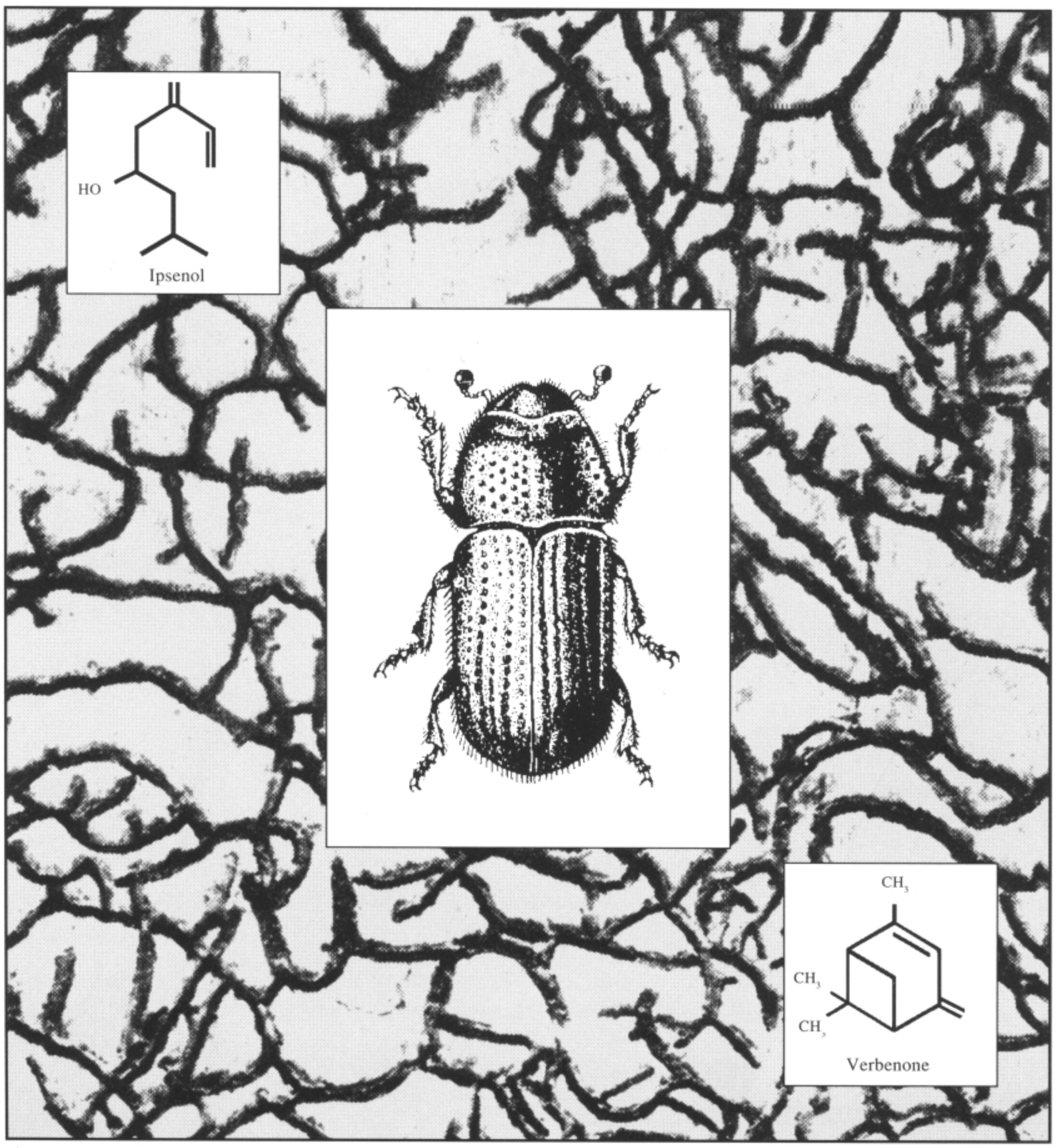
June 22-25, 1992 Kailua-Kona, Hawaii



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Despite the fact that some semiochemicals are being used in various bark beetle management scenarios in western North America there is considerable need for additional research. Various semiochemical-based bark beetle management tactics such as spot baiting, trap-out, concentration and containment, anti aggregation, and use of competing species are all under rigorous field testing. The successful development of these tactics, integrated with other forest management strategies will provide land managers with effective alternatives for reducing the impacts of western bark beetles.

Retrieval Terms: semiochemicals, pheromones, *Dendroctonus, Ips,* antiaggregation management

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Patrick J. Shea, *Technical Coordinator*

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In Brief...

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Retrieval Terms: semiochemicals, pheromones, anti-aggregation management, *Dendroctonus, Ips*

This volume presents the proceedings of the Symposium, Management of Western Bark Beetles with Pheromones: Recent Research and Development, held in conjunction with the 76th Annual Meeting of the Pacific Branch, Entomological Society of America, June 22-25, 1992, Kailua-Kona, Hawaii. The primary objective of the meeting was to set in the record the status of research and development of semiochemicals for management of bark beetle-caused mortality in western North America.

Although our understanding of the role semiochemicals play in bark beetle ecology is quite extensive, their use in integrated pest management strategies is fairly limited. During the late 1980's and to the present western North America has been experiencing unprecedented levels of tree mortality caused by bark beetles. This has spurred renewed interest in attempting to develop semiochemical-based management strategies aimed at mitigating the impacts of bark beetles. In the western United States the USDA Forest Service formed a Western Bark Beetle Working Group (later to become a National Steering Committee) to assist in the planning, coordination, and facilitation of bark beetle research, development, and application in the west. Importantly, membership of the committee is composed of both Forest Pest Management and Forest Insect and Disease Research personnel. A major contribution of this committee was the development of a comprehensive 5-year Research and Development plan for all the important western bark beetles. This plan was used to generate new funding through the congressional appropriation process.

Spruce beetle is the most important forest insect in Alaska where it currently infests over 300,000 acres of white, Lutz, and Sitka spruce. Management of this mortality by various semiochemical-based strategies has been the subject of intensive research for the last several years. In particular MCH (methylcyclohexione), the antiaggregation pheromone of spruce beetle, offers great promise. Other strategies such as trap-out and dispersion baiting with use of competing species is also being investigated.

MCH is also of interest in the Pacific Northwest and Northern Rocky Mountains Region where past research and development activities has demonstrated its effectiveness in preventing build-up of Douglas-fir beetle in blowdown. Additional research is underway to test the efficacy of MCH in preventing or reducing the impact of Douglas-fir beetle in standing timber. Another antiaggregation pheromone, verbenone, has been extensively tested for its efficacy in preventing or reducing mortality in lodgepole and ponderosa pine stands caused by mountain pine beetle. Both ground applications using bubble caps and aerial applications using verbenone-impregnated beads have been tested.

Pine engravers (*Ips* sp.) are of concern to land managers throughout western North America. Their ability to build up in logging debris and attack standing trees, causing either top kills or tree mortality, especially in plantations, is well documented. Researchers and pest management specialists have been investigating the use of antiaggregation pheromones to prevent this build-up. Novel approaches such as the addition of pheromones from potential competitors to enhance the efficacy of the species-specific antiaggregation pheromone are being tested.

Ponderosa pine mortality caused by western pine beetle in California has been at extremely high levels during the ongoing drought. Western pine beetle produces several generations per year in California. Before effective semiochemical-based management strategies can be developed, flight periodicity (when do beetles fly) must be well known. Research on management of western pine beetle in California with semiochemicals has concentrated on development of antiaggregation tactics through the use of verbenone. This research has demonstrated the importance of enantiomerism.

Finally, if semiochemicals are going to be developed for use in managing the impacts of western bark beetles, compounds must be synthesized and formulated in appropriate, effective, and efficient dispensers. Private industry must be encouraged to produce these novel compounds and offer them in the marketplace. These specialty compounds and their low financial return, coupled with stringent use regulations in pest management programs, create barriers to development by private industry.

Management of Western Bark Beetles with Pheromones: Recent Research and Development[1]

Patrick J. Shea[2]

Abstract: The existence of bark beetle pheromones was suggested some 70 years ago. Twenty-six years ago the first bark beetle pheromone was identified, described, and synthesized. Since then, a tremendous amount of research, both basic and applied, has been conducted on bark beetle pheromones. The present-day research emphasis centers on attempting to develop semiochemical-based bark beetle management systems that will reduce tree mortality.

There is a long and fascinating history to forest entomology research leading to the discovery and description of the first scolytid pheromones. Some 86 years ago, in 1916, Keen wrote a report (later included in Miller and Keen 1960) summarizing his summer's research on western pine beetle, *Dendroctonus brevicomis* LeConte and *Ips,* around Ashland, Oregon. In this report he suggests that large numbers of western pine beetles were attracted to specific trees. During the next 10-15 years, numerous forest entomologists and plant chemists, including H.L. Person, N.T. Mirov, H. Dubraw, A. Gordon and others, continued to pursue this attraction phenomenon (Miller and Keen 1960). Then in 1931, H. L. Person published a paper in the *Journal of Forestry* that attempted to provide a theory to explain the selection of particular trees by western pine beetles. Although Person's primary objective in this paper was to discuss the process we now know as primary attraction, he also hints that the individual beetles may somehow be involved in the mass attack process. To quote, "...these (beetles) in turn introduce a yeast into the inner bark which produces a fermentation strong enough to attract other beetles from a wider radius." Well, he was almost right. In 1948, Rodger F. Anderson published a paper in the *Journal of Economic Entomology* describing his research on host selection by *Ips pini* (Say) in north-central Minnesota. In this paper he attempts to expand on Person's theory regarding the attractiveness of yeast. Through a series of deductive experiments he failed to confirm Person's conclusions but states, "The pleasant odor which could be detected close to freshly made entrance holes suggests that attraction may be due to an odoriferous substance emitted by males." Finally, in 1966 Milt Silverstein, Otto Rodin, and Dave Wood published a paper in *Science* magazine that described the isolation, identification, and synthesis of the primary pheromone components of *Ips paraconfusus* Lanier (*I. confusus* at that time). This was the first complete description of a scolytid pheromone and its behavioral effects.

Present-Day Compounds

Since Silverstein and others' 1966 paper, numerous other scolytid aggregation and antiaggregation pheromones as well as host plant kairomones have been isolated, identified and, in many cases, synthesized. Borden (1985) lists the pheromonal and kairomonal components of some 42 species of scolytids whose pheromones and kairomones have been characterized. Further, most of the semiochemicals of these species are available from commercial sources or, when not available, the synthesis process has been published. However, there are some notable gaps in our knowledge concerning the pheromones of several important western bark beetles. Although Renwick and Pitman (1979) identified 1-heptanol and 2-heptanol from the hindgut of Jeffrey pine beetle, recent field bioassays have been unable to verify their attractiveness. *Scolytus ventralis* LeConte is another important western bark beetle whose pheromone remains to be described. The same is true for *Ips lecontei* Swaine. However, there are active research programs aimed at closing the knowledge gap for all three species.

Despite the multitude of research papers (Borden 1982 lists 704 references to scolytid pheromone research) over the past 26 years on bark beetle pheromones, there are few clear examples where they have been successfully used to manage tree mortality caused by bark beetles. In 1979 D.L. Wood reported in a review paper that few large-scale field experiments using bark beetle pheromones aimed at crop protection had been conducted. In the four identified programs which involved mountain pine beetle (*Dendroctonus ponderosa,* Hopkins), western pine beetle, ambrosia beetles (*Trypodendron lineatum* [Oliver]), and the larger European elm beetle (*Scolytus multistriatus* [Marsham]), only one program (ambrosia beetle) has demonstrated a clear, unequivocal positive effect. It is appropriate here also to include the MCH (methylcyclohexenone)/Douglas-fir beetle (*D. pseudotsugae* Hopkins), in the list of successful semiochemical-based bark beetle management programs. The operational feasibility and efficacy of MCH for preventing Douglas-fir beetle build-up in downed material has been fully demonstrated on several occasions (Furniss and others 1974). Only registration by the Environmental Protection Agency stands in the way of this strategy to be fully operational (Furniss and others 1977).

[1]An abbreviated version of this paper was presented at the Symposium on Management of Western Bark Beetles with Pheromones: Recent Research and Development, June 22-25, 1992, Kailua-Kona, Hawaii.

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Progress in Research and Development

Some would argue that we still do not know enough about the semiochemical ecology of most bark beetles to develop management strategies. Others would argue that experiments with pheromones are impossible to conduct or too expensive. I disagree. I am not suggesting that the entire semiochemical complex is completely known for any one bark beetle. Considerable research remains to be conducted on the effect of enantiomeric qualities of specific compounds, dose, elution rates, interspecific and intraspecific responses (especially responses by sex and geographic populations), and purity, to name only a few. Research in recent years has discovered new pheromone components for both the spruce beetle (Weisner and others 1991) and *Ips pini* in New York (Teal and others 1991). I am suggesting, however, that we possess enough knowledge and understanding of the semiochemical ecology of the more important western bark beetles that management strategies which utilize this knowledge and understanding need to be devised and tested. Later on, there will be considerable opportunity to incorporate significant additional compounds into research, development, or operational programs. I am also suggesting that we cannot wait until every last compound in the pheromonal bouquet is known. The necessary research and development leading to the establishment of usable strategies and tactics is going to be a long and protracted process. It is also going to be an expensive process. Lastly, I think it is imperative that we get on with the research and development process to, if for no other reason, provide answers to the lingering questions about the utility of semiochemicals in bark beetle pest management.

How then do we get on with the job of formulating and testing semiochemical-based bark beetle management strategies? First, we must realize that testing and development of these strategies is based on several important necessary conditions: (1) adequate (but perhaps not complete) knowledge and understanding of the pheromone system, (2) synthesis pathways to provide adequate quantities in the appropriate formulation (purity and enantiomeric composition) for testing, (3) reliable elution devices (Coulson and Witter 1984). Second, it is important that we follow a specific research protocol that allows for and encourages a stepwise progresssion of events. Rigorous new experimental designs and approaches must be devised and used to test for effects and produce data that are statistically reliable. We must identify straightforward parameters of interest, such as reduction in tree mortality, and sample with the necessary precision instead of trying to sample everything and ending up with nothing of statistical or interpretive value. Thirdly, close coordination and cooperation, such as that fostered by the Western Bark Beetle Pheromone Steering Committee, must be continued. This forum has provided the platform for significant advances in bark beetle management. The committee has brought together researchers and forest pest management specialists from all sectors throughout the western United States to jointly conduct field studies aimed at development of bark beetle management strategies. The amount of cooperative studies and mutual efforts between research and forest pest management specialists is unprecedented.

Symposium

Finally, one of the primary objectives of this symposium, and of the Proceedings, is to record where we are at this date in the development of semiochemicals for management of bark beetle-caused mortality. Representatives from throughout the western United States will discuss their programs. These programs range from basic laboratory research whose objectives are the isolation and identification of aggregation and antiaggregation pheromones to field bioassays of enantiomeric blends. We will also hear about relatively large-scale tests being conducted for management of tree mortality. Importantly, we will also hear from research managers in both the public and private sector.

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Western Bark Beetle Pheromones Research, Development, and Application Program[1]

David G. Holland[2]

Abstract: During the 1980's and up until the present, the western United States, including Alaska, has been experiencing unprecedented levels of tree mortality caused by bark beetles. Land managers have few options for mitigating the effects of bark beetle-caused tree mortality. In response to these infestations, the USDA Forest Service formed a Western Bark Beetle Working Group to assist in coordinating bark beetle research and application in the West. A large percentage of the research and application emphasized development of bark beetle pheromones to reduce bark beetle-caused of tree mortality. Since 1988, this group has been responsible for developing a bark beetle research and development program, as well as, providing guidance for funding Forest Pest Management (FPM) Technology Development proposals.

I appreciate the opportunity to present a very successful and unique research, development, and application program on bark beetles in the western United States. To do this, however, I must first address the "evolution" of the Western Bark Beetle Working Group and our current operating procedures for the application portion of the program.

During the 1980's, western North America experienced unprecedented levels of tree mortality from bark beetles. Large outbreaks of mountain pine beetles occurred throughout the West in the late 1970's and early 1980's, followed by epidemics of Ips, Douglas-fir beetle, spruce beetle, western pine beetle, Jeffrey pine beetle, and fir engraver beetle. Many of the past "control" strategies were not effective, and the outbreaks were simply too massive to manage through silvicultural practices. A decade of research on lepidoptera and beetle pheromones was beginning to show some success for manipulative strategies to mitigate the impacts of bark beetles. The lack of effective "control" strategies created a very aggressive environment for "case history" type experimentation with pheromones, often on an operational basis.

This experimentation expanded and accelerated rapidly during the mid-1980's throughout the western United States and Canada. As the "word got out" about the usefulness of pheromone baiting and trapping, the use proliferated with very little coordination among scientists and users. Success with pheromone baits or lures was inconsistent at best; however, determining why the results might differ from project to project was very difficult. To gain a better understanding of the status of bark beetle pheromone research and application in North America, a workshop was held January 26-29, 1988, in Denver, Colorado. The purpose of the meeting was to have the Western Regions of the USDA Forest Service develop a Westwide Plan to standardize pheromone use and provide direction toward project funding from the Washington Office.

The meeting was a good forum for discussion of the "state-of-the-art" on pheromones. Participants included a mix of federal, state, industry, and academic scientists from the United States and Canada. The end products of the meeting were a set of recommendations including guidelines for standardizing use and funding; packet summarizing current scientific literature; summary of anticipated uses for 1988; and a list of support needs for the future. The meeting provided the first forum for everyone to see what was happening in the pheromone research, development, and application (RD&A) area. It was readily apparent that the lack of information sharing and coordination was resulting in duplication of effort, poorly based research projects, and unsuccessful operational projects. However, by early summer 1988, nothing more had happened regarding the need for a more scientific, systematic, and coordinated approach to the development of pheromone-based strategies to mitigate the impact of bark beetle epidemics.

The need for coordination among users and scientists had come to a "head" because of inconsistent results, reduced funding available to adequately assess and develop new pheromone strategies, and difficulties with the Environmental Protection Agency to register these new insecticides. As a result of the need for pooling our resources and developing some strategy for pheromone research and application, a meeting of scientists and users was held in Boise, Idaho, in October 1988. The purpose of the Boise meeting was to develop a workplan for pheromone research, development, and application. The group entitled themselves the "Western Bark Beetle Working Group" and served as an ad-hoc team for coordinating RD&A activities related to pheromones. The uniqueness of this initial effort in 1988 was a sharing of funds and scientist time between research, industry, and users during a period when there was little support for pheromone development.

As the Work Group secured its place as the clearinghouse in the western United States for bark beetle pheromone RD&A activities, the group functioned as a team in ranking projects by priority for funding, clearing work plans, reviewing results, and recommending future research. For the next several years, the Work Group met semi-annually in developing annual work plans and funding needs to submit for funding through the FPM Technology Development Process. In 1991, the Forest Service's Washington Office of Forest Pest Management formalized the Work Group by making it the "official" National Bark Beetle Steering Com-

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mittee responsible for all applied bark beetle projects in the United States. Although the group has been expanded geographically, the purpose of the Steering Committee remains the same, to coordinate the development of projects and funds toward the best scientific buys.

Several activities have resulted from the cooperative efforts of this ad-hoc group such as a strong team effort among a diverse array of users; guidelines for developing and funding pheromone projects; and increased funding for pheromone research and development leading toward a formal RD&A program.

The teamwork cannot be overstated as the single most important factor for success during this process. All participants, whether scientists, users, or industry folks, have taken responsibility for each other's success in implementing pheromone-based strategies. This approach has included sharing project designs, pooling available funding for priority projects, and providing field and office support for each other's projects. This type of cooperation requires a shared vision of the need and future for pheromone research, development, and application. We all know this is very rare.

Early in the process, the Work Group established annual priority lists for proposed projects. However, to better compete for national funds, it was necessary to develop a list of criteria for ranking projects at the national level. The list includes criteria that rank projects based on:

- Importance-i.e., extent that the project addresses a high-priority pest, crisis situation, and national goal
- Results-i.e., assess project ability to produce implementable results
- Technical Merit-i.e., technically sound methodology
- Cost and Economic Efficiency-i.e., benefits out weigh costs
- Work Group Plan-i.e., project meets working group plan

Funding for bark beetle pheromone projects has improved significantly over the past 5 years from $300,000 per year to more than $1,500,000 in Fiscal Year 1992 (FY 92) in the Forest Service. In addition, state, university and industry funding has increased in support of the development of these alternatives to chemical insecticides. This increased support for pheromone-based strategies has increased the user's awareness of pheromone use, success in application of strategies, and a stronger expression of need for the future.

In 1991, the increased levels of spruce beetle, ips, western pine beetle, and fir engraver beetle in the West caused concern in Congress for the health of western forests. Congress requested a formal bark beetle RD&A plan to mitigate the tree mortality from western bark beetles. The timely development of a full RD&A plan was simply an extension of the Working Group's plan and has served as the basis for a $1.5 million budget in FY 92. That budget included $1 million in new research funding. The complete RD&A effort includes a 5-year RD&A proposal for $5.7 million/year to develop and bring on line new environmentally acceptable technology to control western bark beetles. This budget figure includes $3.7 million for research and development and $2 million for applications for pilot testing and technology transfer. Currently, we await funding in FY 1993 to initiate the RD&A. However, if the RD&A does not get fully funded, priority projects will continue to be selected as funding exists according to the Working Group's priorities.

The approach I have described for cooperative research, development, and application is very successful and is now being expanded to include all of western North America. Most of the research and development studies you will read about in these Proceedings are a part of western bark beetle RD&A.

Future of Semiochemicals for the Management of Bark Beetle Populations[1]

John H. Borden[2]

Abstract: Semiochemicals are now used operationally against bark beetles in western North America for monitoring, mass trapping, containment and concentration, and post-treatment mop-up of infestations. However, in relation to the number of target species and the multitude of potential single and integrated applications, current operational uses represent only a promising beginning. One requirement for continued success is that the quest for new semiochemicals not be abandoned. No semiochemical-based communication system is fully understood, and for many species of bark beetles nothing is known. Yet sophisticated knowledge will be required if semiochemicals are to be used optimally in complex integrated pest management (IPM) programs. All of the above tactics will be developed, refined, and implemented extensively in the future. In addition, semiochemicals will be used increasingly to prevent or control infestations by disrupting attack. These applications will involve such advances as the employment of antiaggregation pheromones from the target species combined with those of one or more competing species to discourage attack, and the use of "push-pull" tactics in which disruptants in one area will be combined with attractants in another. Although semiochemical-based tactics may represent a minority of the total available tactics to be integrated in IPM strategies in the future, without them entire programs may fail. Thus the era of applied use of bark beetle semiochemicals is just dawning.

In the past two decades, outbreaks of bark beetles in western North America have focused renewed attention on these devastating forest pests. The impact of present outbreaks and the anticipated impact of future outbreaks have been strong stimuli for the continuation of basic research on semiochemical-based communication systems, and for the development of semiochemicals for the monitoring and management of western bark beetles.

Although applications are still limited, semiochemicals are now used operationally in western North America primarily for monitoring, mass-trapping (ambrosia beetles), containment and concentration, and post-treatment mop-up of infestations (Billings 1988, Borden 1990, Borden and Lindgren 1988, McLean and Stokkink 1988). An example of the extent of this use can be found in a survey done by the British Columbia (B.C.) Forest Service (Hall 1992). This survey found that in 1991, there were 46,186, 6,735, and 1,562 attractive semiochemical baits used by both industry and government in B.C. against the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, the spruce beetle, *D. rufipennis* (Kirby), and the Douglas-fir beetle, *D. pseudotsugae* Hopkins, respectively. The principal use of these baits was to contain and concentrate infestations prior to harvest. However, some baits were used to monitor populations, and others were used to induce attack on trees that were later disposed of by either falling and burning or by application of the systemic herbicide monosodium methane arsonate (MSMA). An additional 8,991 baits were used in mass-trapping of ambrosia beetles. All of the baits were manufactured and sold by Phero Tech Inc., Delta, B.C. This company also sells numerous trap-lures and tree-baits for use in research and development of bark beetle management in the western United States, and also provides substantial amounts of antiaggregative semiochemicals for operational trials of population disruption.

The operational implementation of semiochemicals has occurred rapidly. For example, in 1984, the year after tree-baits were shown to be effective for the mountain pine beetle, 20,681 baits were used operationally in B.C. (Borden and Lacey 1985). Their use increased substantially thereafter, because forest managers were desperate for an effective tool to use in managing beetle populations.

This promising beginning bodes well for the future of this exciting field of forest pest management. My objective is to describe my vision of the future for semiochemical-based management of western bark beetles, keeping in mind the progress and constraints of the past and present.

The Quest for New Semiochemicals

Semiochemicals are known for a number of economically important western bark beetles and for a few species of minor importance as forest pests. However, it is uncertain for any of these species whether the complete blend of semiochemicals used to mediate host selection and reproduction in nature is known. For example, for several species new pheromones or kairomones have been discovered recently that augment other semiochemicals that have been known for some time. These include 2-hydroxy-4,4, 6-trimethyl-2,5-cyclohexadien-1-one (Lanierone) (Teale and others 1991) and b-phellandrene (Miller and Borden 1990) for the pine engraver, *Ips pini* (Say), as well as 4-methylene-6, 6-dimethylbicyclo[3. 1 1] hept-2-ene (verbenene) (Gries and others 1992) and 1-methylcyclohex-2-en-1-ol (MCOL) for the spruce beetle (Wieser and others 1991) and the Douglas-fir beetle (Lindgren and others 1992). Other research continues to disclose additional information, such as the combined role of both structural and optical isomerism of *exo*- and *endo*-brevicomin in maintaining species integrity and level of response in *Dryocoetes confusus* Swaine and *D. affaber* (Mannerheim) (Camacho and others 1993).

A critical examination of the state-of-the-art in bark beetle semiochemistry discloses that we do not know nearly enough (Vite and Francke 1992). Strategic subjects that

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demand the attention of researchers include elucidation of the complete blends of host- and beetle-produced semio-chemicals that mediate host selection in aggressive bark beetles; the identity and function of antiaggregation pheromones; the existence and basis for interspecific communication; and the nature of semiochemicals that mediate host selection by members of secondary species. The latter subject may be of particular importance, because recent studies suggest that semiochemicals of secondary species could be used to induce biological control of primary species by competitive displacement. Moreover, potential climatic change could thrust secondary species into primary pest status.

Thus research on the isolation, identification, and synthesis of bark beetle semiochemicals should continue at full pace. Because some research administrators tend to hold the opinion that enough is known, and because successful practical applications with existing semiochemicals tend to reinforce that opinion, it is not easy to gain sufficient funding to conduct such research. The quest is not made easier by the fact that this research has historically followed a well-established protocol (Silverstein and others 1967) and is often viewed (erroneously) as "crank turning."

The above opinions and conclusions are belied by the fact that emerging technologies have revolutionized the isolation, identification, and synthesis business. Recent technological innovations include the development of techniques for the micro-capture and analysis of volatiles emanating from individual bark beetle galleries (Gries and others 1988); the analysis of candidate semiochemicals by coupled gas chromatography-single cell receptor detection (Wadhams 1982); techniques for derivatization and gas chromatographic analysis of minute amounts of enantiomers of terpene alcohols (Slessor and others 1985); the separation of pheromone enantiomers by chiral gas chromatographic columns (Schurig and others 1982, 1983); and the use of enzymes (Stokes and Oehlschlager 1987) and yeast (Ramaswamy and Oehlschlager 1989) to synthesize chiral pheromones of absolute purity.

It is hard to predict what ingenious technology will contribute to this research in the future. One might guess that there will be major advances in the use of biotechnology, e.g., in the identification of trace semiochemicals biomagnified through tissue culture of relevant insect or plant cells, and in the use of engineered microorganisms in the synthesis of semiochemicals that are beyond the practical or financial limitations of conventional organic chemistry. Before the advent of these technologies, it is almost certain that re-examination of many species by coupled gas chromatographic-electroantennographic analysis at the micro level will disclose a host of previously unknown, bioactive compounds.

Tree Baiting, Silviculture, and Harvesting

Applications of semiochemicals that induce natural responses are those that are most likely to work. Tree baiting tactics, which induce attack on baited trees and those around them (Borden 1992), alter nature only to the extent that mankind directs where the attack will occur. For the mountain pine beetle (Borden and Lacey 1985, Borden 1990) and for the spruce beetle (Holland 1992), tree baiting prior to logging has become routine in some areas. It is cheap (Borden and others 1986) and effective (Gray and Borden 1989, Shore and others 1990) and has allowed a transition to occur from "beetle chasing" to "beetle management."

Some forest managers have ignored this tactic, choosing to chase beetles until there was no more timber in their operating areas. In some cases this has apparently been due to greed, as industry set aside long-term goals in favor of exploiting cheap, beetle-killed timber in the short run. In other cases it may have been due to ignorance. I have heard of one manager who did not use tree baits because he was afraid that they would attract beetles!

The future will dispose of such managers. The demands for timber not in reserves and the fear of potential impact of bark beetle infestations will make pre-logging, containment and concentration baiting a requirement in many instances. There is a possibility that because losses of beetles through dispersal may be reduced, more trees will be attacked in a baited stand than might occur in nature. However, this possibility will be offset by the knowledge of where the attacked trees and the beetles are and by the ease of managing these modified infestations.

Direct management of bark beetles by clearcutting, selection cutting, or by single tree treatments (Amman and others 1977, McMullen and others 1986) may leave residual, undetected infestations in the forest. Once other treatments have been applied, it is a simple matter to bait a few trees, to allow them to be attacked, and if any residual beetles are left, to dispose of them through single tree treatments or small-scale logging (Borden and others 1986, Borden 1990). I predict that such semiochemical-based, mop-up tactics will become common in a future that will demand integrated pest management (IPM) practices.

Monitoring

There have been very few applications of semiochemicals for detection and monitoring of bark beetle populations. Semiochemicals are used successfully to detect insipient outbreaks of the southern pine beetle, based on changing ratios of bark beetles to predators (Billings 1988). This tactic has not been tried for other species. Other potential or little-used applications include the use of semiochemical-baited traps to signal when hauling of infested logs should be restricted (Stock 1984) and to time the commencement of single tree treatments, such as arsenical injections (Hall 1989). As forest management efforts intensify, such semiochemical-based monitoring efforts should also intensify.

The future may also see increased demand for importations of timber from Siberia, or other locations, to make up for timber lost in creating reserves for spotted owls or other endangered species. There is a significant risk that such timber could harbor exotic bark beetle pests (USDA 1991). Therefore, if proposed importations become a reality, each port and mill site processing the timber should be ringed with traps baited with attractive semiochemicals for Siberian larch, pine, and spruce bark beetles. The alarming detection of the southern pine beetle in semiochemical-baited traps in Israel (Mendel and Argman 1986) suggests that this tactic could well be applied to detect unwanted intruders in the ports of western North America.

Mass Trapping

I contend that mass trapping has acquired an unjustifiably bad reputation. It is more difficult than tree-baiting because of the need to replicate or outperform Nature. Yet when it was tried on one generation of the western pine beetle in southern California, there were encouraging signs of success (Bedard and Wood 1974; DeMars and others 1980). It certainly does work in IPM programs against ambrosia beetles in limited areas (Borden and McLean 1981, Lindgren 1990, Lindgren and Fraser 1993), and it should work against small populations of bark beetles (Payne and others 1985). The ultimate development of mass trapping is dependent on three factors.

Firstly, basic research directed at identifying all of the semiochemicals used by the target species must precede serious efforts to make the tactic work. Without the potential capacity to outcompete Nature, mass trapping will probably fail.

Secondly, there must be a commitment to apply the tactic intensively for as long as is necessary. Had the pilot study on an isolated infestation of the western pine beetle in southern California (Bedard and Wood 1974) been continued beyond a single generation of beetles, the outbreak might possibly have been terminated. This could have occurred even if the trapping program had inevitably left some residual beetles in the forest.

Lastly, spillover attacks on standing timber must be viewed as an opportunity for integrating single tree or group silvicultural treatments with mass trapping, rather than as a negative side effect that makes mass trapping undesirable. Infestations that develop in the vicinity of a trap could be used to modify stand management by the application of group selection or mini clearcuts, in a transition to an uneven-aged silvicultural system. A misdirected mass trapping program could create such a large number of spillover attacks that the majority of trees within the trapout area become infested. In such instances the program might have the same effect as a well applied tree baiting procedure for containment and concentration and could be followed by a sanitation-salvage clearcut. Although most of the trees would be lost over a wide area, the effect would probably not be as devastating as if the infestation were allowed to run its natural course.

Disruption of Attack

Numerous researchers have attempted to use antiaggregation pheromones to prevent or disperse infestations, particularly for the Douglas-fir beetle (Furniss and others 1972, 1981, 1982) and the mountain pine beetle (Amman 1993). Widespread, broadcast use of these agents might never occur, operationally. However, they will be useful in addressing small, isolated infestations, a few hectares in size, or in deterring attack in limited areas where control by harvesting or where use of conventional chemical pesticides is inappropriate or prohibited. Such areas include riparian zones, game corridors, commercial recreational facilities, parks and wilderness areas, and rural residential zones.

While results with the Douglas-fir beetle have been encouraging (Furniss and others 1981), results with the mountain pine beetle have been discouraging (Amman 1993). Tactics using the antiaggregation pheromone, verbenone, against *D. ponderosae* have been inconsistently effective between doses (Borden and Lindgren 1988, Gibson and others 1991), years (Shea and others 1992, Amman 1993), host trees (Gibson and others 1991, Amman 1993), and geographic locations (Amman 1993).

Applications of verbenone may fail because of technological and environmental factors that reduce the dose of verbenone in the forest to ineffective levels (Amman 1993). In addition, under ultraviolet radiation verbenone in the vapor phase photoisomerizes to chrysanthenone, an inactive material (Kostyk and others 1993). This mechanism makes verbenone unique among the known natural antiaggregants. Its photoisomerization to chrysanthenone quite probably prevents widespread disruption of attack in nature and may also explain its inconsistent ability to prevent or disrupt infestations in operational trials.

Recently, there have been some exciting results. Research in the south has shown that green leaf volatiles, characteristic of hardwood forests, are natural deterrents for southern pine beetles and two associated *Ips* spp. (Dickens and others 1992).

Projects in California and British Columbia have shown that binary combinations of disruptant semiochemicals can be much more effective than a single disruptant. A combination of verbenone, an antiaggregation pheromone of the western pine beetle, and ipsdienol, an aggregation pheromone of the California fivespined ips, *Ips paraconfusus* Lanier, was very effective at disrupting the response of western pine beetles to traps baited with attractive semiochemicals (Paine and Hanlon 1991). Similarly, Borden and others (1992) found that attacks by pine engravers, *Ips pini* Say, were almost completely deterred in the presence of verbenone and ipsenol, antiaggregation and aggregation pheromones, respectively, of the competing species *D. ponderosae* and *Ips latidens* (LeConte). Applications of these semio-chemicals in impregnated plastic beads were effective in deterring attack for up to six weeks (Devlin 1992; Miller and others 1993).

The success of the multiple disruptant treatment apparently lies in creating a bogus message that a habitat is already occupied by the target species and one or more competing species, or that more than one competing species are present in a habitat. It now seems probable that in the future, these "supernatural" blends will become the operationally effective disruptants that we have long sought.

Integrated tactics using disruptants also show great promise. In controlling spot infestations of the southern pine beetle, Payne and others (1992) found that felling infested trees combined with applying verbenone to trees at the advancing head of an infestation was more effective than verbenone treatment alone. Felling of infested trees apparently disrupted both visual and olfactory orientation by the beetles. In another integrated approach, Lindgren and Borden (1993) used a "push-pull" tactic against the mountain pine beetle. Verbenone-treated blocks combined with flanking blocks in which trees were baited with attractive semiochemicals were more effective in shifting the distribution of subsequent attacks than either treatment alone.

In a particularly integrated approach, P.J. Shea has used an antiaggregant blend combined with mass trapping in a "push-pull" program that has apparently saved the last remaining natural stand of Torrey pines, *Pinus torreyana* Parry ex Carr., from devastation by *I. paraconfusus* (Berson 1992). The antiaggregant blend was composed of verbenone and ipsdienol, apparently creating the semiochemical message that the treated stand was a "slum," already infested by the competitors *D. brevicomis* and *I. pini.* On the other hand, the baited traps would have conveyed the message that the adjacent stand was an attractive "new subdivision" under initial attack by *I. paraconfusus.* It is certain that the future will see innovative programs like this applied to a much greater extent on a much broader scale.

Induction of Competitive Displacement

One precept of intelligent pest management is that it is often based on exploiting vulnerable points in the natural biology of the target species (Borden 1989). Some time ago, researchers in Texas found that a pheromone treatment designed to deter attack instead induced competitive displacement of the southern pine beetle by the small southern pine engraver, *Ips avulsus* (Eichoff) (Watterson and others 1982, Payne and Richerson 1985). In British Columbia, Rankin and Borden (1991) found that if trees attacked by the mountain pine beetle are baited soon after attack with ipsdienol, an aggregation pheromone of the pine engraver, the latter species will outcompete the former. When the weakly aggressive ips emerge from a tree in place of southern pine beetles or mountain pine beetles, they will pose relatively little threat to the remaining standing trees. These studies suggest that semiochemical-induced competitive displacement can be developed on an operational basis as a new form of biological control.

The potential for success of competitive displacement will be limited by the population sizes of secondary species. Therefore this tactic will probably be integrated with others. For example, for light, but threatening, populations of the mountain pine beetle, an arsenical herbicide might be the desired single tree treatment, but within 10 m of fish-bearing streams, where conventional pesticides cannot be used, competitive displacement might be applied.

There are legions of secondary bark beetles in the forest. Many of them are known to be effective on occasion in nature at displacing members of aggressive species (Rankin and Borden 1991). By virtue of their rapid life cycles they are able to pre-empt the phloem resource, displacing the aggressive species that initially kill the host trees. But in order to test these species as biocontrol agents through induced competitive displacement, it is essential that their semiochemical systems be understood. This is one reason why the quest for new semiochemicals must continue.

The Future

Semiochemicals will never be the "magic bullet" that some simplistic forest managers seek. For example, a task force in British Columbia identified six broad strategies and 25 tactics that could be used in IPM of mountain pine beetles. Only three of these tactics involved the use of semiochemicals (Safranyik and Hall 1990), but without them IPM programs might fail. Thus I believe that the era of applied use of bark beetle semiochemicals is just dawning.

It is up to researchers, pest management specialists, and administrators to meet the challenge. If they do, one can expect semiochemical-based tactics to be integrated, both with themselves and with other pest management tactics. These in turn will be integrated more closely than ever before with forest management practices applied to an ever shrinking working forest. Some semiochemical-based tactics will be used to protect endangered species of trees or threatened ecosystems. We will be so good at using semiochemicals in IPM programs to prevent or manage infestations that healthy outbreaks should occur only in reserves, where they will be treasured as natural phenomena.

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The Role of Spruce Beetle Pheromones as Management Strategies in Alaska[1]

Edward H. Holsten[2]

Abstract: The most promising tools for reducing losses to natural resource productivity from spruce beetles in Alaska appear to involve the use of pheromones. Results of past research and development activities on spruce beetle pheromones suggest a high probability that successful management systems can be developed through an aggressive research, development, and application effort. From 1988 to 1991, a cooperative project was started between entomologists from Forest Health Management, Alaska Region and of Pacific Northwest Research Station of the USDA Forest Service in Alaska to develop operational use strategies employing semiochemicals to manage spruce beetle populations. These management strategies were divided into two main groups: those utilizing aggregation pheromones for trap-out and diversion trapping of beetles, and those using the antiaggregation pheromones such as MCH beads and bubblecaps to prevent or reduce infestation of stands and logging slash.

Alaska is the largest state in the Union, encompassing more than 420 million acres, and is 2 1/2 times the size of Texas! Alaska is a state extremely rich in renewable and non-renewable natural resources. Petroleum exploration and extraction are big business, followed closely by tourism, fisheries, and forestry. Alaska's forested land encompasses more than 129.1 million acres statewide with 21 million acres classified as timberland (commercial forest land, >20 ft^3/acre/year). Approximately 23 million acres of forest land occur in southeast Alaska, the remainder in interior Alaska.

Alaska's interior represents a gross area approximately one-fifth the size of the continuous 48 states; with only about 3,000 miles of roads. Access is limited. For example, the southwest portion of Alaska, the Bristol Bay area, is approximately 93,750 sq. miles (Oregon is 96,980 sq. miles) but has less than 30 miles of road! Most travel is accomplished by river boat or small plane. About 32 percent of interior Alaska, or 106 million acres, is forested, and of this amount approximately 21 percent is classified as timberland. The better forest stands are confined mostly to the lower slopes and valleys of the larger rivers and their main tributaries, such as the Susitna, Copper, Tanana, Yukon, and Kuskokwim Rivers, and the west half of the Kenai Peninsula-areas that historically have been prone to spruce bark beetle outbreaks. Interior Alaska forests are generally mixtures of white (*Picea glauca* (Moench) Voss) and Lutz (*P.* x *lutzii* Little) spruce, paper birch (*Betula papyrifera* Marsh.), aspen (*Populus tremuloides* Michx.), and balsam poplar (*P. balsamifera* L.), although nearly pure stands of each species are found (Hutchinson and Schumann 1976).

[1]An abbreviated version of this paper was presented at the Symposium on Management of Western Bark Beetles with Pheromones: Recent Research and Development, June 22-25, 1992, Kailua-Kona, Hawaii.

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As with other areas of the United States, there are a variety of pests in Alaska that affect forest health. In view of the extent of damage, economic considerations, and "regularity" of damage, the spruce beetle (*Dendroctonus rufipennis* Kirby) is the primary tree-killing insect in Alaska and is prevalent south of the Alaska range. In fact, the spruce beetle is the most significant mortality agent of mature spruce in the United States and Canada. Outbreaks of this beetle have caused extensive mortality from Alaska to Arizona and have occurred in every forest with substantial spruce stands. Damage by spruce beetles results in the loss of 500 million board feet annually. In the past 25 years, outbreaks have resulted in estimated losses of more than 25 million board feet in Montana, 31 million in Idaho, over 100 million in Arizona, 2 billion in Alaska, and 3 billion in British Columbia (Holsten and others 1991).

Ongoing and new (as of 1991) infestations now cover approximately 373,000 acres throughout Alaska (USDA For. Serv. 1992). Spruce beetle activity increased throughout Alaska during 1991. Substantial spruce beetle mortality is occurring north of the Alaska Range along the Yukon River south of Galena. This infestation now encompasses close to 100,000 acres but has been declining the past few years. Infestations of approximately 160,000 acres occur on the Kenai Peninsula. The majority of these infestations, which occur in white and Lutz spruce types, are recent and are increasing. In 1990, approximately 11,000 acres of spruce beetle activity were noted south of the confluence of the Chitina and Copper Rivers in interior Alaska. This activity expanded in 1991 as more than 45,000 acres of spruce beetle activity were aerially detected. The first spruce beetle outbreak (200,000 acres) recorded in Alaska in 1922 was located near this area. It appears that after 70 years, the live residual stand has become susceptible to spruce beetle activity. In southeast Alaska, active spruce beetle infestations totalled almost 16,000 acres in 1991. Approximately 9,200 acres of Sitka spruce (*P. sitchensis*) are infested within Glacier Bay National Park. Approximately 27,000 acres have been affected since spruce beetle was first detected there in the late 1970's.

In 1987, USDA Forest Service conducted an inventory of the forest resources on the Kenai Peninsula--historically, the area most heavily impacted by the spruce bark beetle. The objective of the inventory was to assess the impact of the spruce beetle on the timberland component of the forest resource (Van Hees and Larson 1991). Total timberland area of the Kenai was estimated at 482,000 acres. Cubic volume on this timberland was estimated at 1,211,577,000 ft^3. Timber growth and mortality were estimated at 9,245,000 and 7,958,000 ft^3, respectively. Estimates of mortality are averages over the 5 years before the inventory was undertaken. Apparently the spruce beetle has had a significant impact on overall mortality. On all timberlands, insect damage is responsible for 52 percent (4,157,000 ft^3) of the total mortality. It appears that the infestation over the whole Kenai Peninsula has increased substantially in recent years and will likely maintain its magnitude. Another recent study conducted on the Kenai Peninsula (Van Hees 1992) estimated the area of land affected by ongoing infestations (infested less than 5 years) to be 120,983 acres, almost the same as the estimated area where infestations have run their course (142,619 acres). Also, the estimated area of potential infestation is 80,759 acres.

In addition to extensive tree mortality, spruce beetle outbreaks modify stand structure by reducing the average tree diameter, height, and stand density, leaving small, slow-growing trees and intermediate-sized trees to become dominant. As mature spruce are killed, forage species may increase, benefiting some wildlife species. But species that depend on the mature spruce for habitat may be adversely affected.

Indirectly, extensive spruce mortality can also affect water yields and result in water gains in rivers, lakes, and streams because of reduced transpiration from dead and dying trees (Holsten and others 1991). Likewise, the risk of catastrophic wildfire increases as the amount of dead and dying timber increases. With respect to spruce beetle-caused impact on other non-timber resources of the Chugach National Forest and elsewhere on the Kenai Peninsula, results of a recent cooperative study revealed several consistent patterns of perceptual and attitudinal responses by forest visitors to an ongoing spruce bark beetle outbreak. Residents and visitors consistently and significantly rated bark beetle-damaged forest vistas lower in scenic beauty, and the more tree mortality present, the lower the perceived scenic beauty (Orland and others 1992).

Preferred hosts for the spruce beetle are large diameter (> 8 inches dbh), slowly growing white spruce, Lutz spruce, and Sitka spruce. Black spruce (*P. mariana* [Mill.] B.S.P.) is rarely attacked. The commercial hemlock (*Tsuga heterophylla* [Raf.] Sarg.)-Sitka spruce type occupies 5,506,000 acres mainly in southeast Alaska's coastal forests. Historically, Sitka spruce is less susceptible to spruce beetle outbreaks than either white or Lutz spruce. Cool, wet spring conditions, so prevalent in southeast Alaska, are not conducive to spring beetle dispersal and brood development. However, as of 1991 there are approximately 23,000 acres of Sitka spruce infested by spruce beetle. As previously mentioned, it is the white-Lutz spruce type that has supported the majority of spruce beetle outbreaks. Climate is more continental and thus, more conducive to rapid population buildup as generation times are lessened from as slow as one generation every three years to one generation per year in interior Alaska.

Spruce beetles generally prefer downed trees. Endemic populations are usually maintained in windthrown trees. When populations increase to high levels in downed trees, beetles may enter susceptible, large-diameter standing timber if adequate amounts of downed trees are not available. Many outbreaks in standing timber originate in windthrown trees, although logging residuals--especially cull logs from logging areas, right-of-way lines, or seismic operations are contributing factors. In logging areas, beetles may be found in cull logs, tops, and stumps. Adults prefer the sides and lower surface of logs and tree tops. The same is true for Ips beetle outbreaks. Of those engraver outbreaks that have been documented, the majority have originated from flood damaged (stressed) spruce and stands that have suffered broken tops or blowdown. Likewise, *Ips* outbreaks normally develop only when the residual standing trees have poor vigor. Spruce beetle outbreaks, once started, are aggressive and can remain active in a stand for as long as 10 years although rarely last more than 3 years. In mature stands, larger diameter trees are usually attacked first, but trees in all diameter classes may be killed. If an infestation persists in a stand, beetles will infest smaller-diameter trees after large trees are killed. Spruce beetles can destroy up to 90 percent of the commercial spruce basal area (Werner and Holsten 1983).

Forest managers can develop various strategies to mitigate resource losses to spruce beetles. The development of any strategy presumes that resource values, accessibility, and operability of each stand, as well as the beetle population level, have been evaluated. Beetle population level is important because it dictates whether a preventive or suppression strategy will be used.

The primary strategy should be silvicultural treatment of potentially hazardous stands to maintain a healthy stand with moderate to good growth rates (Holsten and others 1991). Preventive strategies can also be used in high-value areas, such as in campgrounds where cutting large spruce may be undesirable. Protective sprays can be used to protect the standing spruce from emerging beetles in adjacent stands. Suppressive strategies are usually employed against infestations in standing trees or in logging residuals that threaten residual stands. Suppressive methods can be used singly or in combination against infestations in standing trees. If a small number of infested trees occur in an accessible area, then trap trees or sanitation thinning are effective. In larger infestations, sanitation clearcutting may be the best alternative. For infestations in inaccessible locations, trap trees are a viable option if the trees can be treated and removed before beetle flight; otherwise, lethal traps are the only suppressive option if removal of trap trees is impracticable. For infested logging residuals and windthrown trees in cutting areas, solar heat, fire, or chemicals can be used. Infested logging residuals need never become a significant contributor to spruce beetle populations if stump height is kept below 18 inches, and if cull logs and tree tops are limbed and cut into short lengths and left unshaded, unpiled, and exposed to sunlight.

As previously mentioned, most Alaska spruce beetle outbreaks originate from breeding material such as large diameter woody debris from blowdown or seismic or powerline right-of-way clearing activities (Werner 1978). For example, a large spruce beetle outbreak was detected in 1972 on the westside of Cook Inlet and by 1973 covered more than 200,000 acres (Holsten 1990). The cause of the outbreak was not definitely known but was believed to be associated with seismic line clearing debris from the late 1960's and a severe drought in 1968-70. Likewise, increased spruce mortality was detected on the Chugach National Forest on the Kenai Peninsula. This mortality was a result of beetle populations breeding and increasing in extensive blowdown occurring in 1974 and 1975 (Werner and Holsten 1983). In both cases, large woody debris from seismic line clearing and blowdown occurred in inaccessible areas. Because of the control techniques available then and the lack of accessibility, treatment of the downed, potential spruce beetle breeding material was not undertaken.

Several control techniques are presently recommended for manipulation of spruce beetle populations. Among the recommended techniques is the immediate salvage of infested trees prior to emergence of the new population, burning of infested trees, and treating trees with insecticides as a means of remedial or preventive control (Werner and others 1983, 1984). However, these techniques are adequate only where infestations are accessible, an uncommon occurrence in Alaska with little more than 3,000 miles of road. Another technique is the potential use of synthetic spruce bark beetle pheromones to prevent attack or reduce the attack density of the spruce beetle to a level below the threshold density required for the development of brood trees. Pheromones are chemical substances that influence insect behavior and include aggregants and antiaggregants.

The use of pheromones has several advantages. First, ready access to treatment areas may not be necessary since aerial application of a treatment formulation might be possible. Secondly, beetle resistance to some groups (antiaggregants) of pheromones might be impossible since successful brood development would be prevented. Also, there would be no direct mortality to parasites and predators as occurs with conventional insecticide treatments. Lastly, pheromone usage is more favorably received by the general public than traditional insecticide use.

The spruce bark beetle, similar to other *Dendroctonus* species, produces two types of pheromones: aggregant and an antiaggregant. When spruce beetles attack live standing trees, they attack quickly and in force in order to overcome the tree's defenses. If the beetles fail to successfully attack a host tree, the host successfully repels and kills attacking beetles through the production of resin and other toxic secondary compounds. Spruce beetles, upon encountering a suitable host for colonization, produce and release a powerful attractant which signals other dispersing beetles of both sexes of the availability of the suitable host. Mass attack and colonization quickly follow. Current research in Alaska has demonstrated that the spruce beetle aggregant pheromone is a ternary formulation which includes alpha-pinene, frontalin, and 1-methylcyclohex-2-enol (MCOL). This powerful lure is currently available from Phero Tech Inc., Vancouver, British Columbia.

When population densities of spruce beetles reach a critical level within a colonized host tree, spruce beetles produce an antiaggregant, 3-methyl-2-cyclohexen-1-one (MCH). The release of MCH into the air apparently signals incoming spruce beetles to locate another host. The production and release of MCH thus serves to reduce intraspecific competition. MCH likewise is available in a variety of formulations from Phero Tech, Inc. However, MCH has not yet been registered by the U.S. Environmental Protection Agency.

The most promising tools for reducing beetle losses in the short term appear to involve the use of pheromones. Results of past research and development activities on bark beetle pheromones suggest that there is a high probability that successful management systems can be developed through an aggressive research, development, and application effort (Werner and others 1988). From 1988 to 1991 a cooperative project was started between entomologists from USDA Forest Service, Forest Health Management and the Pacific Northwest Research Station in Alaska on the development of strategies for spruce beetle management in Alaska using pheromones.

These management strategies are divided into two main groups: those using the aggregation pheromone and those using the antiaggregation pheromone.

Aggregation Pheromones:

1. The use of attractant pheromones to lure beetles to baited trees. In essence, a bait-and-cut strategy which concentrates spruce beetle populations in a stand that has been designated for harvest. The beetles are removed during logging and are destroyed in the milling process. However, this tactic assumes that logging is an economically viable option, logs are processed in a timely fashion, and road access exists.

2. The use of attractant pheromones placed in funnel traps to monitor buildup of beetle populations. An attempt should be made to correlate general insect and disease conditions with spruce beetle trap catches and risk and hazard rating systems currently used in Alaska.

3. The use of attractant pheromones in funnel traps to "trap-out" spruce beetles from an isolated stand. Pheromone-baited traps would encircle an infested stand. Traps would be placed in open areas or non-host types such as birch or aspen stands. Dispersing beetles would be lured to the funnel traps, reducing the attack level within the spruce stand.

4. Most wildfires in Alaska cause some damage to adjacent spruce stands in the fringe area of the fire. These stands are often placed in a stressed condition from smoke and lightly burned root and bark surfaces and are highly susceptible to attack by spruce beetles. The use of a trapping strategy to divert spruce beetles from these susceptible stands is desirable.

Antiaggregation Pheromone:

The use of antiaggregation pheromones has the largest potential "pay-off' of all spruce beetle pheromone tactics in Alaska. As previously mentioned, almost all spruce beetle outbreaks originate from some type of stand disturbance such as blowdown. In Alaska, blowdown is common and usually occurs in inaccessible areas. Accordingly, the blowdown is "left" for the beetles.

1. Aerial applications of formulated MCH in a slow release system may prevent the buildup of spruce beetle populations in the downed material. Spruce beetles would be "tricked into believing" that the blowdown is already occupied. Population buildup would be prevented. Downed spruce is attractive to dispersing spruce beetles for 2 years. Thus, only two applications of MCH would be needed. MCH could also be used to treat seismic line and powerline right-of-way clearing debris which, in Alaska, generally occurs in inaccessible areas.

2. Currently, formulations of carbaryl and lindane are registered for prevention of spruce beetle attacks. One application results in 2 years of protection. However, Alaska "publics" are becoming increasingly concerned over the use of traditional chemical controls. MCH has the potential as a preventive treatment for high-value standing trees located around homes, administrative sites, and campgrounds.

3. Recent Alaskan studies have shown that the addition of *exo*-brevicomin to funnel traps baited with spruce beetle aggregation pheromone reduced spruce beetle catches by as much as 86 percent. *Exo*-brevicomin has been identified as the pheromone for *Dryocoetes affaber* which is the primary scolytid competitor to the spruce beetle (Whitmore 1983). It appears that dispersing spruce beetles, upon detection of a competitor species pheromone, are repelled. The competitor species pheromone possibly serves as a messenger to spruce beetles, signalling an already occupied host. It is anticipated that the addition of *exo*-brevicomin will greatly enhance the efficacy of MCH in preventing spruce beetle attacks.

Most Alaskan forests are inaccessible. Because spruce has shallow roots, blowdown is widespread in Alaska. The use of spruce beetle pheromones, especially the antiaggregation pheromone MCH, shows much promise as a management strategy for preventing and controlling buildup of spruce beetle populations.

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Research on the Use of Semiochemicals to Manage Spruce Beetles in Alaska[1]

Richard A. Werner[2]

Abstract: Field tests on the efficacy of various scolytid bark beetle pheromones to attract *Dendroctonus rufipennis* (Kirby) were conducted from 1977 through 1991 in stands of white spruce (*Picea glauca* [Moench] Voss) and Lutz spruce (*P. lutzii* Little) in interior and south-central Alaska. The use of semiochemicals to manipulate populations of spruce beetles is under way, and current studies examine several operational use strategies such as beetle trap-out, spot baiting, and diversion trapping using baited traps and trap trees; antiaggregation semiochemicals such as MCH; and inducing interspecific competition with spruce beetles in pheromone-baited trap trees.

The spruce beetle (*Dendroctonus rufipennis* [Kirby] infests most species of *Picea* in North America. White spruce (*Picea glauca* [Moench] Voss), Sitka spruce (*P. sitchensis* [Bong.] Carr.), and the hybrid Lutz spruce (*Picea* x *lutzii* Little) are the major hosts in Alaska (Werner and others 1977). Past outbreaks in south-central Alaska have been associated with warm, dry summers and an accumulation of spruce debris from windthrown and felled trees from right-of-way construction which are highly productive breeding sites for spruce beetles (Werner 1978). When beetle populations increase and a sufficient supply of breeding material is no longer available for colonization, beetles can infest nearby living trees, particularly in mature stands (Werner and others 1977, Werner and Holsten 1983).

Presently, the strategies developed to mitigate the effects of spruce beetles on spruce stands in Alaska involve some form of stand manipulation or the use of chemical insecticides (Werner and others 1977, Werner 1978). Among the recommended techniques for treatment of logging slash, felled, or windthrown green trees is the immediate salvage of the trees; or disposing by burning, chipping, or burying; or treating with insecticides approved by the Environmental Protection Agency (EPA)(Werner and others 1983, 1984, 1986). The use of semiochemicals to manage populations of spruce beetles is under way, and current studies examine several operational use strategies such as interspecific competition in pheromone-baited trap trees, and trap-out, spot baiting, and diversion trapping using baited traps and trap trees.

Initial Pheromone Studies

Field bioassays using various known pheromones of scolytid species were first conducted in Alaska from 1977 to 1979 in south-central and interior Alaska (Werner and Holsten 1984). During this time, several scolytid pheromones and host terpenes such as seudenol, frontalin, ipsenol, ipsdienol, and alpha-pinene were identified as aggregants for *D. rufipennis, D. simplex* LeConte, *Dryocoetes affaber* (Mannerheim), *Polygraphus rufipennis* (Kirby), and *Ips perturbatus* (Eichhoff) (*table 1*). In these field tests, frontalin and seudenol when tested alone caught significantly more beetles than when alpha-pinene was added to either pheromone; however, trees baited with frontalin alone and in combination with alpha pinene caught more spruce beetles than seudenol alone and in combination with alpha pinene (Werner and Holsten 1984, Werner and others 1981, unpublished data[3]). These early studies, currently being repeated, did not compare release rates or enantiomers.

Seudenol plus alpha-pinene caught more eastern larch beetles (*Dendroctonus simplex*) than seudenol alone. Frontalin plus alpha-pinene caught more *Polygraphus rufipennis* than frontalin alone. The other semiochemicals tested were not attractive to any of the scolytids mentioned. Ipsdienol plus ipsenol caught the most *Dryocoetes affaber,* but subsequent field tests indicated *exo*-brevicomin was more attractive to *Dryocoetes.* Ipsdienol plus alpha-pinene caught more *Ips perturbatus* than ipsdienol alone, ipsenol alone, ipsenol plus alpha-pinene, and ipsdienol plus ipsenol. Some of the other semiochemicals also caught large numbers of *I. perturbatus.* The other host terpenes were also tested in combination with frontalin, seudenol, ipsdienol, and ipsenol, and none caught as many scolytids as alpha-pinene plus the pheromones.

Research Strategies

From 1988 to 1991, a cooperative project between Forest Pest Management, USDA Forest Service, Alaska Region, Anchorage, Alaska, and the Institute of Northern Forestry, Pacific Northwest Research Station, USDA Forest Service, Fairbanks, Alaska, was initiated on "The Development of Strategies for Spruce Beetle Management in Alaska Using Semiochemicals." This project was part of a larger international project in which the Institute of Northern Forestry and Forest Pest Management cooperated with Forestry Canada, the University of Calgary, Simon Fraser University, and Phero Tech Incorporated of Canada. This project had two phases:

[1]An abbreviated version of this paper was presented at the Symposium on Management of Western Bark Beetles with Pheromones: Recent Research and Development, June 22-25, 1992, Kailua-Kona, Hawaii.

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[3]Werner, Richard A. 1991. Unpublished data on the role of scolytid pheromones in inducing interspecific competition. On file with: Institute of Northern Forestry, Fairbanks, AK.

Table 1-*Summary of field tests comparing response of various scolytids to different semiochemicals in Alaska, 1977-1979*[1]

	Mean number of beetles caught per week[2]				
Semiochemical	*Dendroctons rufipennis*	*Dendroctonus simplex*	*Polygraphus rufipennis*	*Dryocoetes affaber*	*Ips* spp.
Alpha-pinene(AP)	0d	18c	0d	1d	0e
Frontalin	144b	5c	176b	12c	135d
AP + frontal in	306a	12c	306a	39b	234c
Seudenol(S)	375a	131b	33c	9d	98d
AP + seudenol	31c	265a	52c	13d	166d
Ipsenol	20c	4c	19c	21c	126d
AP +ipsenol	14c	7c	41c	36b	384b
Ipsdienol	1d	2c	34c	29c	457b
AP + ipsdienol	21c	3c	44c	45b	618a
Ipsdienol/ipsenol	15c	0c	47c	65a	266c
Beta-pinene	0d	3c	0d	0d	0e
Camphene	0d	5c	0d	0d	0e
Carene	0d	1c	0d	0d	0e
Limonene	0d	7c	0d	0d	0e
Myrcene	0d	3c	0d	1d	0e
Beta-phellandrene	0d	3c	0d	0d	0e

[1]Five cylindrical sticky traps were used for each treatment; trapping lasted 6 weeks starting June 1 of each year.

[2]Means within columns followed by the same letter are not significantly different ($P < 0.5$, Tukey's [1953] Studentized Range [HSD] test).

Phase I: Development of new semiochemicals

(a) To develop and optimize pheromone blends for attracting spruce beetles to traps and baited trees.

(b) To determine the semiochemicals which deter spruce beetles from entering into traps or from attacking baited trees.

(c) To determine the best release rates of the pheromone blends that are attractive to the spruce beetle.

Phase II: Operational use of semiochemicals

(a) To develop strategies for monitoring endemic spruce beetle populations using semiochemicals in traps and on baited trees.

(b) To develop strategies for effective beetle management using aggregation and antiaggregation semiochemicals.

Phase I from 1988 to 1991 included the development of an improved pheromone blend for attracting spruce beetles. This new blend was a ternary formulation which included alpha-pinene, frontalin, and 1-methylcyclohex-2-enol (MCOL). This phase also included field tests on the efficacy of the new blend in northern and southern Alberta, British Columbia, and south-central and interior Alaska using similar testing methodologies. Phase II in 1992-1993 is proposed to demonstrate the efficacy of using improved formulations of semiochemicals for manipulating spruce beetle populations in various management strategies.

Field Testing Semiochemicals

New Spruce Beetle Pheromone Blend

Efficacy field trials were conducted on the new ternary blend of spruce beetle lure in stands of white spruce in interior Alaska and Lutz spruce in south-central Alaska from 1988 to 1991. The efficacy of the ternary blend was tested simultaneously against that of the binary blend of alpha pinene and frontalin and proved superior by a wide margin as spruce beetles were attracted in greater numbers in all areas of the field test *(table 2).* The ternary blend worked extremely well in areas with both endemic and epidemic beetle populations. Trap captures as high as 1737 per trap during one week were observed during peak flight in interior Alaska during 1988 *(table 3).* Trap catches in south-central Alaska for 1988 were not as high because the mean daily temperature seldom reached 15°C, the minimum mean daily

Table 2-*Summary of field tests comparing response of spruce beetles to a ternary blend of pheromone in Alaska, 1988-1989*[1]

Treatment	Mean number of beetles caught per week[2]	
	1988	1989
South-central Alaska		
Control	2 ± 7b	1 ± <1c
SBB (AP=1.3, FN=1.7 mg/d)	12 ± 5b	34 ± 10b
SBB (AP=45, FN=0.45 mg/d) + (+) MCOL (1.3 mg/d)	201 ± 51a	147 ± 32a
SBB + VE		83 ± 22b
SBB + MCOL + VE		141 ± 57a
SBB (AP=2, FN=1.7 mg/d) + (+) MCOL (1.3 mg/d)		90± 10b
SBB (AP=50, FN=1.7 mg/d) + (+) MCOL (1.3 mg/d)		98 ± 12b
Interior Alaska		
Control	67 ± 16c	<1 ± 1c
SBB (AP=1.3, FN=1.7 mg/d)	254 ± 60b	4 ± <1c
SBB (AP=45, FN=0.45 mg/d) + (+) MCOL (1.3 mg/d)	1737 ± 409a	10 ± 2c
SBB + VE		7 ± 11c
SBB + MCOL + VE		31 ± 22b
SBB (AP=2, FN=1.7 mg/d) + (+) MCOL (1.3 mg/d)		62 ± 32a
SBB (AP=50, FN=1.7 mg/d) + (+) MCOL (1.3 mg/d)		32 ± 20b

[1]Five Lindgren 12-funnel traps used per treatment; trapping lasted for 6 weeks starting June 1 of each year.

[2]Means within columns followed by the same letter are not significantly different (P < 0.5, Tukey's [1953] Studentized Range [HSD] test).

SBB = spruce beetle pheromone which contains alpha-pinene (AP) and frontalin (FN); MCOL = methylcyclohexenol, VE = verbenene.

Table 3-*Summary of field tests comparing response of spruce beetles to MCOL and verbenene in interior and south-central Alaska, 1991*[1]

Treatment	Mean number of beetles caught per week[2]	
	Interior	South-central
Control	0 ± 0a	5 ± 1c
SBB (AP=0.7, FN=0.1 mg/d)	0 ± 0a	69 ± 17b
SBB + (+)MCOL (0.5 mg/d)	1 ± 1a	94 ± 23a
SBB + (R/S)VE (1.2 mg/d)	0 ± 0a	75 ± 21b
SBB + (+)MCOL + (R/S)VE	1 ± 1a	100 ± 20a

[1]Five Lindgren 12-funnel traps used per treatment; trapping lasted for 6 weeks starting June 1 of each year.

[2]Means within columns followed by the same letter are not significantly different (P < 0.5, Tukey's [1953] Studentized Range [HSD] test).

SBB = spruce beetle pheromone which contains alpha-pinene (AP) and frontalin (FN); MCOL = methylcyclohexenol, VE = verbenene.

temperature at which spruce beetles fly. The addition of MCOL to the binary blend, however, resulted in increased trap catches in both areas for 1988 and 1989.

Traces of verbenene had been detected in spruce beetle hindguts by chemists at Simon Fraser University. In 1989, verbenene was added to both the binary and ternary blends to determine its effect on these blends. In south-central Alaska, the binary blend plus verbenene caught significantly fewer beetles than the ternary blend plus verbenene or the ternary blend alone. The addition of verbenene to the ternary blend increased trap catch by more than 30 percent over the ternary blend alone *(table 2)*. In interior Alaska, the addition of verbenene to the binary and ternary blends did not affect trap catches. This study was repeated in 1991. Contrary to the 1989 study in south-central Alaska, the addition of verbenene to either the binary or ternary blends did not increase trap catches *(table 3)*. The ternary blend, however, proved more attractive than the binary blend; a 26 percent increase in trap catches in south-central Alaska. A tree baiting study conducted in 1991 resulted in significantly higher attack densities when trees were baited with the binary blend compared to the ternary blend.

Alpha-pinene was also tested at three different release rates in both the binary and ternary blends. Alpha-pinene at 1.3 mg/day caught more spruce beetles than release rates of 0.7, 2.0, 20, 45, and 50 mg/day *(table 4)*.

The number of beetles caught with varying release rates of frontalin from 0.1 to 5.0 mg/day appeared to diminish with increased release rates of frontalin, which suggests that frontalin is required at a fairly low rate *(table 4)*.

The (+) and (-) enantiomers of MCOL were also compared. The highest number of beetles were caught in traps baited with the (+) enantiomer in interior Alaska *(table 5)*. Another test compared the (R) and (S) enantiomers of verbenene; however, there was no significant difference in the number of beetles caught in interior Alaska between individual treatments of the enantiomers or combination treatments *(table 6)*.

A comparison of dosage levels of (+) MCOL in the ternary blend was done to obtain a more precise release rate for (+) enantiomer. The field test compared the binary blend at release rates for alpha-pinene at 0.7 mg/day and frontalin at 0.1 mg/day, with different release rates of (+) MCOL at 0.6, 1.2, 1.5, 3.0, and 4.5 mg/day. In south-central Alaska, MCOL at 4.5 mg/day caught significantly more beetles than the other blends tested. MCOL at 0.6 and 3.0 mg/day also caught more beetles than the other blends except the 4.5 mg/day *(table 7)*. The 4.5 mg/day release rate created spillover of beetles in trees up to 61 m from the baited trap. In interior Alaska, where spruce beetle populations were extremely low, the ternary blend with a MCOL release rate of 0.6 and 3.0 mg/day caught significantly more spruce beetles than the binary blend and the ternary blend with MCOL at 1.2 mg/day (Wieser and others 1989). There were few differences, however, between release rates of MCOL and trap catches in interior Alaska *(table 7)*.

Antiaggregation Pheromones

3-Methylcyclohex-2-enone (MCH) is the primary antiaggregation pheromone used by spruce beetles and is naturally derived from female spruce beetles (Rudinsky and others 1974). Field tests on the efficacy of slow-release formulations of liquid and granular MCH were initiated in stands of Lutz spruce in south-central Alaska in 1983. Liquid and granular formulations (2 percent MCH) were applied around felled trees at three dosages: 4.6, 9.2, and

Table 4-*Summary of field tests comparing response of spruce beetles to alpha-pinene and frontalin in Alaska, 1989*[1]

Treatment	Release rate	Mean number of beetles caught per week[2]
Alpha-pinene	(0.7 mg/d)	1 ± 1c
Alpha-pinene	(1.3 mg/d)	250 ± 34a
Alpha-pinene	(2.0 mg/d)	50 ± 14b
Alpha-pinene	(20.0 mg/d)	15 ± 6b
Alpha-pinene	(45.0 mg/d)	5 ± 2c
Alpha-pinene	(50.0 mg/d)	2 ± 1c
Frontalin	(0.1 mg/d)	100 ± 22a
Frontalin	(0.5 mg/d)	85 ± 13b
Frontalin	(0.7 mg/d)	76 ± 15b
Frontalin	(1.7 mg/d)	24 ± 6c
Frontalin	(5.0 mg/d)	8 ± 1d

[1]Five Lindgren 12-funnel traps used per treatment; trapping lasted or 6 weeks starting June 1 of each year.

[2]Means within columns followed by the same letter are not significantly different ($P < 0.5$, Tukey's [1953] Studentized Range [HSD] test).

Table 5-*Summary of field tests comparing response of spruce beetles to enantiomers of MCOL in interior Alaska, 1990*[1]

Treatment	Mean number of beetles caught per week[2]
Control	0 ± 0c
SBB (AP=0.7, FN=0.1 mg/d)	0 ± 0c
SBB + (+) MCOL (0.6 mg/d)	28 ± 19a
SBB + (-) MCOL (0.6 mg/d)	5 ± 3b
SBB + (+,-) MCOL (0.6 mg/d)	13 ± 8b

[1]Five Lindgren 12-funnel traps used per treatment; trapping lasted for 6 weeks starting June 1 of each year.

[2]Means within columns followed by the same letter are not significantly different (P < 0.5, Tukey's [1953] Studentized Range [HSD] test).

SBB = spruce beetle pheromone which contains alpha-pinene (AP) and frontalin (FN); MCOL = methylcyclohexenol.

Table 6-*Summary of field tests comparing response of spruce beetles to enantiomers of verbenene in interior Alaska, 1990*[1]

Treatment	Mean number of beetles caught per week[2]
Control	0 ± 0a
SBB (AP=0.7, FN=0.1 mg/d)	0 ± 0a
SBB + (S) VE (2.0 mg/d)	0 ± 0a
SBB + (R) VE (2.0 mg/d)	0 ± 0a
SBB + (R/S) VE (2.0 mg/d)	2 ± 1a

[1]Five Lindgren 12-funnel traps used per treatment; trapping lasted for 6 weeks starting June 1 of each year.

[2]Means within columns followed by the same letter are not significantly different (P < 0.5, Tukey's [1953] Studentized Range [HSD] test).

SBB = spruce beetle pheromone which contains alpha-pinene (AP) and frontalin (FN); V = verbene.

Table 7-*Summary of field tests comparing response of spruce beetles to dosage levels of MCOL, Alaska 1990*[1]

Treatment	Mean number of beetles caught per week[2]	
	Interior	South-central
Control	0 ± 0c	1 ± 2c
SBB (AP=0.7, FN=0.1 mg/d)	1 ± 1c	20 ± 7c
SBB + MCOL (0.6 mg/d)	12 ± 4b	45 ± 14b
SBB + MCOL (1.2 mg/d)	2 ± 1c	12 ± 6c
SBB + MCOL (1.5 mg/d)	8 ± 3b	13 ± 5c
SBB + MCOL (3.0 mg/d)	14 ± 5b	46 ± 15b
SBB + MCOL (4.5 mg/d)	6 ± 2b	66 ± 12a

[1]Five Lindgren 12-funnel traps used per treatment; trapping lasted for 6 weeks starting June 1 of each year.

[2]Means within columns followed by the same letter are not significantly different (P < 0.5, Tukey's [1953] Studentized Range [HSD] test).

SBB = spruce beetle pheromone which contains alpha-pinene (AP) and frontalin (FN); MCOL = methylcyclohexenol.

13.8 kg/ha. The 9.2 kg/ha dosage reduced beetle attacks and beetle brood by 70 and 61 percent, respectively, when compared to the untreated controls (Holsten and Werner 1984). Further studies indicated that the cool microenvironment of the forest floor and the underside of felled trees were major factors in preventing complete elution of the MCH from granules formulated to elute at 20°C.

In 1984, further field studies were conducted to bracket the dosage rates tested in 1983 (Holsten and Werner 1985). A slow-release granular formulation (2 percent MCH) was applied at 6.9, 9.2, and 11.5 kg/ha along the top side of felled Lutz spruce using a hand-held fertilizer spreader. The elution rate of MCH was 0.38, 0.50, and 0.63 g/ha/day, effective for a 30 to 60 day period. The results showed no significant differences between treated and untreated controls. This lack of efficacy was attributed to the lower-than-expected release rates of the MCH formulation. Elution rates were determined in the laboratory at 21°C at 50 percent relative humidity for 32 days. Mean laboratory elution rates for MCH granules were 3.7 + 5.3 g/ha/day which falls within the optimal rate (0.5-5.0 g/ha/day) determined in the 1983 field test (Holsten and Werner 1984). The high variation demonstrated that the elution rate was not constant. The elution rate of MCH granules tested in the field was 1.8 g/ha/day for 32 days; 51 percent less than the laboratory elution rate. Again, it was concluded that the cold microenvironment of the forest floor retarded elution of MCH granules (Holsten and Werner 1986).

A field test to determine efficacy of MCH to protect Lutz spruce using MCH-impregnated bubblecaps was conducted in south-central Alaska in 1987 (Holsten and Werner 1987). Bubblecaps were formulated to release MCH at 16°C with elution rates of 1, 3, and 5 mg/day. Treatments reduced the number of attacks from 43 to 54 percent, but differences between treatments were not significant. Treatments had no effect on number of egg galleries and progeny but did cause a reduction in length of egg galleries.

In 1991, a field test using aerial and ground applications of MCH beads was done to determine the effectiveness of MCH in protecting decks of Lutz spruce mixed with birch along a 16-mile gasline right-of-way (Holsten 1992, Holsten and others 1992). The aerial test consisted of three treatments replicated seven times: MCH applied at a rate of 4.6 and 9.2 kg/ha as well as untreated control plots. The ground test consisted of three treatments replicated three times: MCH applied at rates of 9.2 and 13.8 kg/ha as well as untreated control plots. MCH applications were undertaken during mid-May 1991, prior to the spruce beetle dispersal flight.

Overall, very low numbers of beetle attacks and progeny were observed in the plots treated by aerial application *(table 8)* and those treated by ground application *(table 9)*.

Table 8-*Mean number of spruce beetle attacks, number of galleries, number of brood, and number of Ips adults in bark samples following aerial application of MCH beads*[1]

Treatment	Mean number of attacks	Mean number of galleries	Mean number of SB[2] brood	Mean number of Ips adults
Control	0.08 ± 0.00	0.42 ± 0.00	2.79 ± 0.05	0.63 ± 0.02
4.6 kg/ha	0.13 ± 0.00	0.57 ± 0.01	3.53 ± 0.05	0.64 ± 0.02
9.2 kg/ha	0.09 ± 0.00	0.66 ± 0.01	3.26 ± 0.04	0.45 ± 0.01

[1]Means based on 30 bark samples (81 cm^2 each) per replication
[2]SB = spruce beetle.

Table 9-*Mean number of spruce beetle attacks, number of galleries, number of brood, and number of Ips adults following ground application of MCH beads*[1]

Treatment	Mean number of attacks	Mean number of galleries	Mean number of SB[2] brood	Mean number of Ips adults
Control	0.08 ± 0.01	0.47 ± 0.04	2.42 ± 0.18	0.39 ± 0.08
9.2 kg/ha	0.01 ± 0.00	0.45 ± 0.04	1.39 ± 0.17	0.00 ± 0.00
13.8 kg/ha	0.00 ± 0.00	0.22 ± 0.02	0.56 ± 0.04	0.22 ± 0.03

[1]Means based on 12 samples (81 cm^2 each) per replication.
[2]SB = spruce beetle.

Approximately 61 percent of all bark samples (81 cm^2 per sample from treatment and control trees) were unattacked with no brood present, which indicated an endemic spruce beetle population *(table 9),* in contrast to a 1991 trap tree study on the Kenai Peninsula where 25 percent of the bark samples had no brood or adults (Burnside 1991).

In 1992, a field test was established to determine the efficacy of MCH bubblecaps to protect high-value spruce trees in a campground from infestation by spruce beetles. MCH was formulated into a controlled-release bubblecap consisting, by weight, of 400 mg of MCH and formulated to elute at 15°C.

Interspecific Competition

A study was initiated in 1991 to test the feasibility of using scolytid pheromones to increase interspecific competition with spruce beetles in order to reduce spruce beetle brood production and survival in felled trap trees. The study was done in stands of white and Lutz spruce and initially used baited Lindgren funnel traps in a completely randomized block design to determine if any of the pheromones tested repelled each other. The following pheromones were tested alone and in various combinations: the ternary blend from spruce beetles, *exo*-brevicomin from *Dryocoetes affaber,* 2-methyl-3-buten-2-ol from *Polygraphus rufipennis,* and racemic ipsdienol from *Ips perturbatus.* The combinations of *exo*-brevicomin and ipsdienol and *exo*-brevicomin and methyl butenol added to spruce beetle pheromone-baited traps caused the greatest reduction (86 percent) in spruce beetle catch. The study will continue in 1992 and will compare brood development and survival between felled green trees baited with pheromones from spruce beetles, *Dryocoetes affaber,* and *Ips perturbatus.*

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Development and Operational Use of the Antiaggregative Pheromone MCH to Prevent Attack of the Douglas-Fir Beetle in Windthrow[1]

R. Ladd Livingston[2] Mark D. McGregor[3]

Abstract: Research application of the Douglas-fir beetle antiaggregative pheromone, 3-methyl-2-cyclohexen-1-one (MCH), evaporated from glass vials and polyamide beads has reduced the number of successful beetle attacks in trees cut to simulate windthrown timber by 92 to 97 percent. Operational use of this technique on natural windthrow in northern Idaho to prevent buildup of beetle populations, using aerial application of MCH loaded beads, proved to be equally as successful, reducing attacks by 95.6 percent.

The Douglas-fir beetle *(Dendroctonus pseudotsugae)* Hopkins, is the most important bark beetle infesting Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco) throughout the range of this tree in western North America (Furniss and Carolin 1977). In Idaho it is of special importance because it has killed hundreds of thousands of trees *(table 1)* containing enough volume to construct more than 18,200 homes during the past 14 years.

Low beetle populations are maintained in trees weakened by root diseases or in windthrown or damaged trees. Outbreaks are initiated by catastrophic events, usually as widespread windthrow or breakage. The Douglas-fir beetle readily attacks the down material and produces new, large, vigorous generations, which then attack and kill standing, healthy Douglas-fir trees. These attacks generally take place in stands characterized by trees that average 80-90 years of age or older, are 18 inches in diameter at breast height (dbh) or larger and are dense and pure to Douglas-fir. Outbreaks usually persist for 2-3 years in the general vicinity. Techniques to reduce the potential for beetle attack in susceptible stands include prompt salvage of the down or damaged trees and reducing Douglas-fir basal area to 80 percent of normal for the site (Furniss and others 1982). Since salvage is not always possible, other tools are needed to prevent development of beetle outbreaks.

One natural mechanism of beetle regulation is through the production of an antiaggregative pheromone, 3-methyl-2-cyclohexen-1-one (MCH) (Kinzer and others 1971). When an attack sufficient to overcome a tree's defenses has been achieved, the beetles produce MCH which deters further attacks and reduces intraspecific competition (Rudinsky and Ryker 1976).

Emulation of this natural process for beetle control has been successful. The evaporation of MCH from glass vials (Furniss and others 1974) and from a hand broadcast, controlled-release formulation of polyamide beads containing 2 percent MCH (Furniss and others 1977) applied around trees freshly felled to simulate windthrow has reduced subsequent attack densities up to 96 percent compared to untreated trees. MCH-loaded beads, applied by helicopter with a modified aerial spreader at 1.41-9.80 kg/ha and 2.04-2.69 kg/ha (measured at ground level), reduced attacks by 92-97 percent and 96.4 percent, respectively (Furniss and others 1971, McGregor and others 1984).

The need for operational use of these techniques presented itself in fall 1973 when tornado force winds touched down in the North Fork of the Clearwater River, Clearwater County, Idaho, uprooting and breaking an estimated 100 million board feet of timber along the sides of Dworshak Reservoir (Livingston 1973). Of this volume, approximately 10 percent was Douglas-fir, much of which was on the steep

Table 1-*Douglas fir trees killed with associated volume, in Idaho, 1978 to 1991*[1]

Year	Number of Trees killed	Volume MBM[2]
1978	3,392	1,280
1979	16,255	6,502
1980	8,339	3,247
1981	6,925	2,424
1982	3,034	1,062
1983	4,668	1,770
1984	28,534	9.702
1985	5,611	1,908
1986	9,382	2,220
1987	55,821	17,324
1988	155,676	37,408
1989	233,966	46,425
1990	198,690	35,281
1991	92,722	15,720
Totals	823,015	182,273

[1]Summarized from Idaho Department of Lands Forest Insect and Disease Conditions Reports, 1978-199 1.

[2]Thousands of board feet

[1]An abbreviated version of this paper was presented at the Symposium on Management of Western Bark Beetles with Pheromones: Recent Research and Development, June 22-25, 1992, Kailua-Kona, Hawaii.

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[3]Deceased; with Northern Region, USDA Forest Service, Missoula, MT, at the time of the project.

slopes of the river canyon. The decision was made to attempt to prevent the buildup of Douglas-fir beetle populations through an aerial application of MCH in areas that were inaccessible to conventional salvage operations. A 24(c) special-local-needs registration was obtained from the Idaho Department of Agriculture (SLN #ID-84005), allowing for use of MCH. An environmental assessment was prepared, and decision notices with finding of no significant impact were signed by officials of the Idaho Department of Lands, the USDA Forest Service, and the U.S. Army Corps of Engineers. A projected treatment cost of $54.44/acre gave a benefit/cost ratio of 20.59:1 for the majority of the state ownership, and 6.48:1 for the remainder.

Treatment Area

The treatment was applied to scattered blocks totaling approximately 2400 acres along the Dworshak Reservoir *(fig. 1)* in areas where salvage could not be completed by fall 1984 or by beetle flight in 1985. The treatment area was owned by the State of Idaho (1555 acres) and by the Corps of Engineers (861 acres) who administer the land close to the reservoir as winter range for big game.

Application of MCH

A controlled-release formulation of macromelt plastic pellets containing 2 percent MCH was applied at the rate of approximately 36 grams Al in 4 lb of pellets per acre. The MCH was eluted as a vapor at the rate of about 1 gram per acre per day. The application equipment consisted of a Bell 206-B helicopter and a modified Simplex model 6400 aerial spreader (Furniss and others 1982). Treatments were conducted during early April before beetle flight. The granules were applied at an airspeed of 45 mph with the bucket 50 feet above the tree tops. Swaths were 50 feet wide, more or less on contour. Treatment extended at least 50 feet beyond any windthrown Douglas-fir and to the edge of the Douglas-fir stands along the reservoir. No applications were made to the water. Large blocks were divided into smaller units for ease of treatment. The acreage was calculated for each subunit and loads prepared to assure a 4 lb/acre coverage.

Determining Effectiveness of Treatment

Effectiveness was determined during June 4-8, 1984, by counting Douglas-fir beetle attacks as shown by piles of frass on the bark (Furniss and others 1982) in 5 plots in the treated area and 5 plots in the untreated area. The diameter at breast height (dbh) and a visual rating of shade (light shade = 1, medium shade = 2, heavy shade = 3) for the sample trees was recorded and compared between treated and untreated trees because the size and shading of the bole can influence the number of attacks on down trees (Furniss and Schmitz 1970). Differences in the mean number of attacks, mean tree diameters, and the relative degree of shading as indicated by the mean shade index, between treated and untreated plots, were tested for significance using a one-way analysis of variance and the Duncan's Multiple Range test, p = 0.05.

Results and Discussion

The number of attacks in the sample trees is summarized in *table 2.* MCH significantly reduced the number of attacks (95.4 percent), comparing favorably to the results of smaller research plots and field tests (Furniss and others 1977, 1981, McGregor and others 1984).

The reduction in attacks appears to be primarily due to the application of the MCH because the average dbh of the treated and untreated blocks was basically identical, 18.5 and 18.2 inches, respectively. Also, analysis of the shade indexes indicated that there was significantly more shade in the treated plots (mean 1.9) than in the untreated blocks (mean 1.5). Therefore, based on shade, attacks should have been higher in the treated blocks.

The use of MCH was successful in preventing attacks of the Douglas-fir beetle in windthrown Douglas-fir and, coupled with salvage, in protecting adjacent stands. Douglas-fir beetle populations did not build up in the project area during the following 2 years while there were increases in other parts of the state (Schwandt and others 1986). Final project costs totaled $75,925 or $31.43 per acre, significantly less than the $54.44 per acre estimated cost.

Table 2-*Douglas-fir beetle attacks in treated and untreated trees, June 1984*[1]

Plot	Trees	Attacks
	Treated	
Silver Creek	20	18
Smith Ridge #1	20	15
Smith Ridge #2	20	7
Long Creek Point	12	7
Little Silver Sddl	26	161
Totals	98	208
Mean no. attacks		2.10*
	Untreated	
Smith Ridge	7	1,869
Grandad Bridge #1	20	251
Grandad Bridge #2	20	1,290
Camp F	20	848
Elk Berry	21	252
Totals	88	4,510
Mean no. attacks		51.08*

*Means significantly different.
ANOVA p = 0.05 Duncan's Multiple Range Test
[1]There was a 95.4 percent reduction in Douglas-fir beetle attacks in the MCH-treated plots compared to untreated plots.

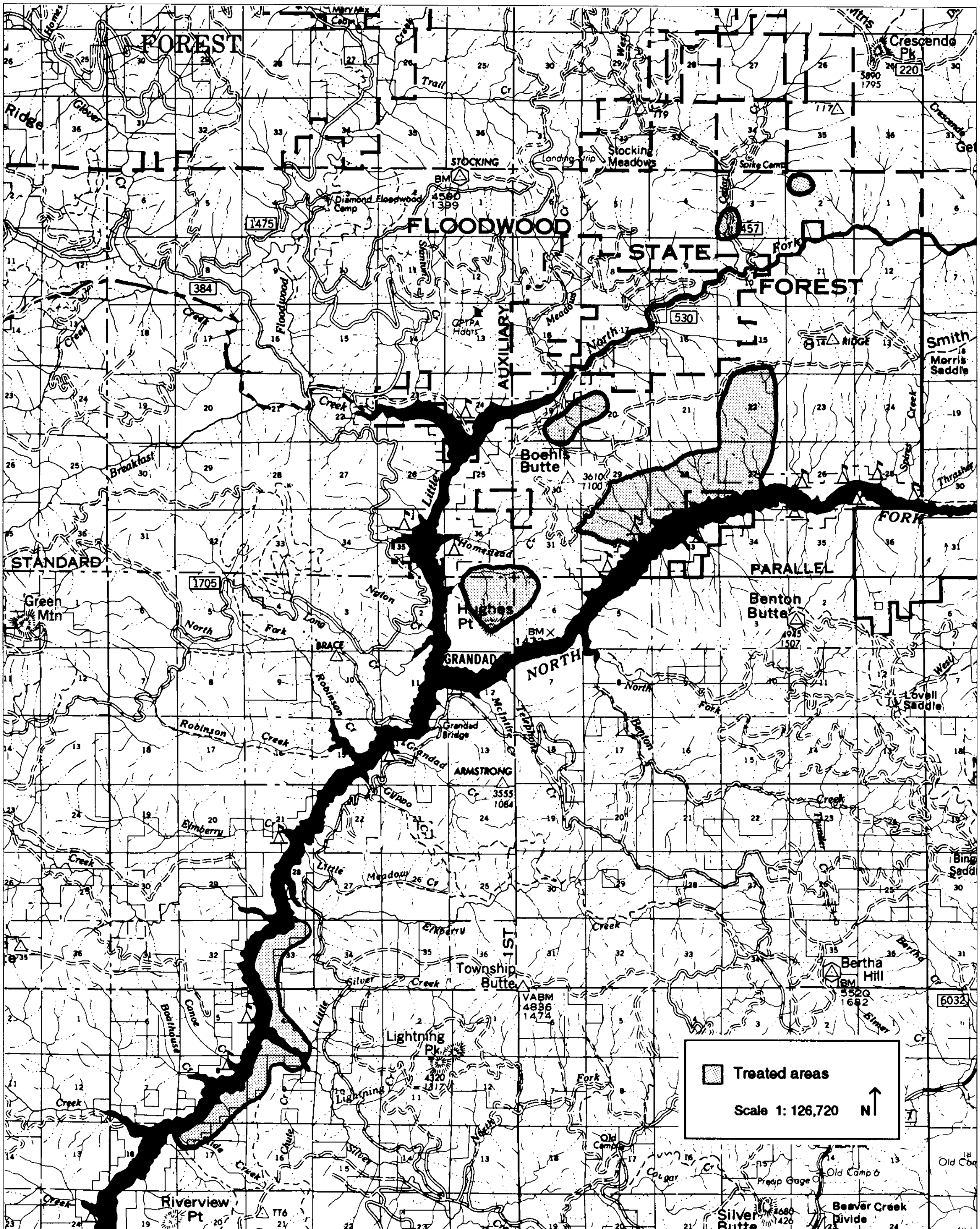

Figure 1-Sites treated with 3-methyl-2-cyclohexen-1-one (MCH) in 1984 to prevent attack of Douglas-fir beetle in windthrown Douglas-fir, North Fork Clearwater River, Idaho.

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Distribution of MCH and Similar Behavioral Chemicals in the Field after Release from Artificial Sources[1]

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Abstract: MCH (3,2-methylcyclohexen-1-one) and verbenone are behavioral chemicals which repel several species of bark beetles. We plan to determine the release patterns of MCH, verbenone, and similar materials and determine how they are transported and dispersed in air in the forest. The purpose is to determine whether currently used formulations are efficient. Preliminary results indicate that vertical dispersion, to 50 percent of the concentration on level with the release, is fairly rapid in moderate wind. A vertical movement of 1 unit occurs with 3 to 5 units of drift downwind of the release point. This estimate is consistent with previous behavioral data obtained with moths in a forested area.

Technologies advance in surges. Insect behavioral chemical technology surged in the 1960's as micro-analysis techniques improved sufficiently to give behaviorists materials to work with. Progress was rapid, but high expectations for immediate practical application, often driven by overly zealous promotion, were not always realized. Synthetic dispensers used to effect control were not always efficient, or even adequate, in the face of high expectations. Chemical blends meaningful to the insects, particularly the complex blends of bark beetles, were only partially resolved. Although not pesticides, behavioral chemicals were evaluated as though they were, and their anticipated use was assumed similar. Alternative approaches were required, and their development takes time. Inevitably, interest, progress, and expectations slowed.

Considerable development of pheromone technology continued through the 1980's. For example, dispensers such as bubble caps can now usually be expected to last through a season; chemical blends are better elucidated, and hence more effective; we have a better grasp of what works and what does not; and at least one commercial venture specializes in materials targeted at bark beetles. This progress provides the base for a new surge in development. We also have a renewed constituency wanting bark beetles controlled, and some new researchers, with new perspectives, have entered the field. I expect substantial progress over the next decade.

MCH (3,2-methylcyclohexen-1-one) and verbenone are examples of behavioral chemicals that repel certain species of bark beetles important in Pacific Northwest forests. Simi-lar compounds attract beetles into traps. The Forest Service has plans to test MCH against Douglas-fir beetle, *Dendroctonus pseudotsugae*, while it is attacking live trees. Similar tests in the past demonstrated such treatment can be effective in preventing Douglas-fir beetle from infesting recently downed trees (McGregor and others 1984, Furniss and others 1974, 1977). Recently, a series of toxicity tests have been conducted for MCH and verbenone by the Forest Service. Registration is a distinct possibility. These materials are applied in the field in either bubble caps, usually stapled on trees at head height, or in plastic beads, scattered on the ground via helicopter-transported fertilizer spreaders.

Getting enough behavioral chemical in the proper location, and at the right time, to gain optimum efficiency is still something of a problem. Formulations must be economical, distribute material into the forest with minimum waste, remain in place for the required interval, and resist weathering. Such problems have been overcome, at least with certain materials such as verbenone or MCH released from bubble caps. Still, how the active material is distributed in the field is uncertain, and questions remain as to optimum placement strategies. If insects are active high up a tree, is it sufficient to spread behavioral chemicals at ground level and let material just drift up to the needed level? Or must we place dispensers at the higher level, at higher cost? To be assured of optimum formulations and cost effectiveness, we need to know much more about dispersal of behavioral chemicals in a forest.

We plan to determine the release patterns of MCH, verbenone, and similar materials, and determine how they are transported and dispersed in the air in the forest. We will also determine the effective dosages, that is, the dosages actually evaporated into the air space used by the beetles, from materials applied at the ground or at head height on trees. Our primary purpose is to determine whether currently used formulations are efficient in delivering effective doses of behavioral chemicals. If not, an informed discussion is needed regarding development of new formulations and application methods.

Methods

We have three basic approaches to the problem: 1) Measure release rates from substrates in the laboratory. 2) Characterize movement of material in the forest using model compounds (and visible smoke). 3) Confirm release and dispersion of actual behavioral chemicals in the forest.

Variable effects of temperature, air speed, and field seasoning will be determined in the laboratory. Field seasonings will be under actual use conditions including those appropriate for MCH beads used in Douglas-fir, MCH beads applied to sitka spruce, MCH used in bubble caps in Douglas-fir, and

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verbenone used in bubble caps in pine. We have existing laboratory technology to do this part of the project.

Model compounds will be released into the forest and recaptured from air to determine their vertical and horizontal dispersion within field plots. Concentrations will be determined at several levels above ground and during diverse weather conditions and temperatures favorable to beetle activity. Methods for measuring materials in air in the field have been developed after those of Birgersson and Bergstrom 1989, Chang and others 1988, and Petersson 1988. Basically, air is drawn through a small Porapack Q [TM] trap held in a glass tube. Trapped volatiles are then rinsed out of the Porapack with solvent and analyzed with a gas chromatograph/mass spectrometer. Resolution (nanograms) with such methods should be barely sufficient to determine MCH content in air in field plots where dosages of 30 g/acre or more are applied. It is easier to determine content in air of the more volatile MCH analogue cyclohexanone which will be used as a model compound. Specific objectives are to determine how material released at the ground, or from head height and higher on trees, disperses horizontally and vertically in the field. Temperature, wind, and forest type (i.e., open vs. dense stands) are important variables. Information derived will allow development of a model to describe field dispersal of materials. Photographs and video-recordings of smoke plumes will be made to allow visualization of dispersal patterns. Model compounds can confirm that the same dispersal patterns occur with volatile chemicals as with smoke particles. We recognize that smoke is particulate, whereas the behavioral chemicals will be in a gas phase and thus may behave somewhat differently.

Equipment designed to pull a sufficient, and known, volume of air through Porapack [TM] traps in the field has been constructed. A generator-powered vacuum pump takes air samples up to 24 m above ground at 3-m intervals along a hose hoisted up into a tree. A string line is shot over a high limb, and then a rope is pulled up to hoist the apparatus. Cyclohexanone is released from glass wool placed either on trees at head height or on the ground to simulate typical release locations.

Since field conditions are variable, we believe the proper approach is to do numerous (20-40) release and recapture tests at diverse locations with the model compound. During each test, temperature, humidity, wind speed, stocking, and crown characteristics will be recorded. Also, we plan to put collection apparatus in existing experimental plots, treated with MCH and verbenone, for longer periods of time (48 h) at least three times each to determine dispersal of actual materials.

Preliminary Results and Discussion

Preliminary results, conducted on a grass field, suggest that vertical dispersion, to concentrations of at least 50 percent of that found at dispenser height, is fairly rapid in moderate wind. Here, about 1 m of vertical movement occurs for each 3 to 5 m of downwind movement. This preliminary indication is consistent with previous behavioral results obtained with the Douglas-fir tussock moth, *Orgyia pseudotsugata,* in 1-ha mating disruption plots located in habitat similar to that used by bark beetles. For that test, traps baited with synthetic pheromone were placed at several heights on trees located near the plot centers. The objective was to determine how high disruption effect extended upwards from the dispensers placed at 1.5 m above ground. The following data, reconstructed from a figure reported by Sower and Daterman (1977), indicate the approximate proportionate distribution of males captured per trap at indicated distances above ground:

	1.5m	6m	12m	18m
Untreated Plots	0.23	0.20	0.27	0.29
Treated Plots	0.03	0.06	0.14	0.77

At 18 m the trap catches were about the same in both untreated and treated plots. These data indicate that the disruption effect extended up to about 12 m at a location about 50 m inside the treated plot boundaries.

We plan to develop a basic model describing field dispersal of bark beetle behavioral chemicals, in typical western forest habitats, and in diverse temperature and wind conditions. A recommendation regarding the need to pursue development of improved dispensers and application methods will be provided to the Forest Service.

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Bark Beetle Pheromone Use in the USDA Forest Service's Northern Region[1]

Kenneth E. Gibson[2]

Abstract: Several species of bark beetles are causing unacceptable levels of mortality in the Forest Service's Northern Region. Over the past several years research related to bark beetle pheromones in this area has concentrated on mountain pine beetle, *Dendroctonus ponderosae,* and Douglas-fir beetle, *D. pseudotsugae,* which are by far the most serious bark beetle pests in the intermountain West. Most recently, research on managing *Ips pini,* with pheromones, has gained heightened interest. Much of the research on mountain pine beetle and Douglas-fir beetle has attempted to take advantage of an antiaggregation strategy-using the naturally-occurring compounds MCH for Douglas-fir beetle and verbenone for mountain pine beetle. Whereas the efficacy of MCH for preventing buildup of Douglas-fir in blowdown is well documented, that of verbenone in reducing lodgepole pine mortality has been inconsistent. Research is in progress on the use of combinations of antiaggregation pheromones for preventing buildup of *Ips pini* in ponderosa pine slash. Lastly, aggregation pheromones have been used in an almost routine manner in baiting lodgepole pine stands scheduled for harvest.

Testing of bark beetle pheromones, both attractants and anti-attractants, dates to approximately the mid-1960's. By the early seventies, works of Vile, Rudinsky, Pitman, Furniss and others began in earnest as important semiochemicals of major bark beetles, particularly mountain pine beetle *(Dendroctonus ponderosae* Hopkins) and Douglas-fir beetle *(Dendroctonus pseudotsugae* Hopkins), were identified. The identification of these chemical messengers and how they affect bark beetle population dynamics eventually led to the development of synthetic substitutes which have had, and will continue to have, a profound effect on our ability to manipulate bark beetle populations to our advantage.

Much of the pheromone-related work in the Forest Service's Northern Region has concentrated on mountain pine beetle and Douglas-fir beetle-and with good reason. They are by far the two most important and devastating bark beetles in our Region-not only because of the extensive damage caused by the beetles, but also because of the extent of their hosts. We have nearly 7 million acres of lodgepole pine in the Region, so mountain pine beetle is by far our most important insect pest. Within the past 25 years, an estimated 3 million acres have been infested to some extent. During that time, we estimate that approximately 250 million trees have been killed-enough lumber to build more than 1 million homes! Now, though mountain pine beetle is on the decline Region-wide, more than 160,000 acres are still infested (Oakes and Gibson 1992). And with the amount of soon-to-be-susceptible lodgepole pine, the mountain pine beetle will always be a management concern.

Douglas-fir beetle presents a similar problem, fortunately on a smaller scale. Though its host is extensive in the Region--as many as 6 million acres of Douglas-fir exist, much of which is susceptible to the beetle-Douglas-fir beetle outbreaks are neither as expansive nor long-lasting as mountain pine beetle epidemics. Within the past decade, our most widespread outbreak occurred in 1988 when 27,000 acres were infested. An estimated 120 million board feet of timber have been killed in the Region in the past 10 years. An additional 100 million board feet were killed in the early 1970's.

Other bark beetles are of occasional concern. In the past decade, we have had smaller outbreaks of spruce beetle (*Dendroctonus rufipennis* [Kirby]), western pine beetle (*Dendroctonus brevicomis* LeConte), fir engraver (*Scolytus ventralis* LeConte), and western balsam bark beetle (*Dryocetes confusus* Swaine). Though some have from time to time and from place to place, caused significant amounts of mortality, none are of the long-term concern in our Region they are in other parts of the country. Neither do they present significant management concerns as do the mountain pine beetle and Douglas-fir beetle.

Unlike the previously mentioned beetles, which have the potential to develop into full-scale outbreaks-and do at various times-the pine engraver (*Ips pini* [Say]) is more a chronic problem that comes and goes with weather and the creation (usually through management activities) of brood sites. In any given year, a few thousand acres of ponderosa pine type may harbor some level of mortality caused by pine engraver. In 1991, that infested area totaled more than 3,000 acres. Not usually a serious problem in lodgepole pine, pine engraver has recently created a unique situation in and around Yellowstone National Park. Because of the extensive area of fire-injured lodgepole pine, which resulted from wildfires in 1988 and ensuing near-drought conditions, nearly 5,000 acres of small-diameter lodgepole pine are currently experiencing mortality caused by the pine engraver (Oakes and Gibson 1992).

In describing the development of pheromones and their use, I have chosen to concentrate on the currently most important beetles in our Region-mountain pine beetle, Douglas-fir beetle and pine engraver. Others are either of less importance in our area, or less work has been done in identifying the pheromone complexes important to them.

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Bark Beetle Pheromone Development

Reviewing the literature reveals that most bark beetle-pheromone testing began in the mid- to late-1960's. As early as 1963, Rudinsky (1963) explored the attraction of flying Douglas-fir beetles to feeding, virgin female beetles. Over the next several years, he identified key attractant chemicals-produced either by beetles themselves (pheromones) or by the host (kairomones) (Rudinsky 1966, 1968, 1969). The first extensive field test of a bark beetle pheromone was conducted in 1968 by Silverstein and coworkers when they attempted to suppress infestations of western pine beetle by mass trapping beetles using the attractant pheromone exo-brevicomin (Silverstein and others 1968).

In 1976, Lanier and others (1976) conducted similar studies in an effort to reduce populations of the smaller European elm bark beetle (*Scolytus multistriatus* [Marsham]). By 1977, McLean and Borden (1977) were obtaining a measure of success in trapping ambrosia beetles using sticky traps baited with pheromone attractants. Throughout the mid to late 1970's, testing progressed on several bark beetle species throughout the United States and Canada. Both attractant and anti-attractant pheromones were evaluated with varying levels of success: frontalin for spruce beetle (Dyer 1975); methylcyclohexenone (MCH) for both spruce beetle (Rudinsky and others 1974) and Douglas-fir beetle (Furniss and others 1972); aggregants for southern pine beetle (*Dendroctonus frontalis* Zimmerman) (Vite 1970; Copony and Morris 1972; Coulson and others 1973 a, b; Coulson and others 1975); and the Douglas-fir beetle attractant "douglure" tested in southern Idaho (Knopf and Pitman 1972). No doubt there were others.

During that time, efforts to identify and synthesize pheromone complexes of mountain pine beetle were also being conducted. In 1968, Pitman and others (1968) described the aggregative pheromone, *trans*-verbenol, produced by female beetles; then in 1969 they defined the male-produced aggregant, *exo*-brevicomin. Pitmans's later tests, conducted in 1976-1977, showed an inhibitory effect of *exo*-brevicomin at high concentrations when used in western white pine stands (Pitman and others 1978). Subsequent tests have shown no inhibitory effects when used in lodepole pine stands, however. Earlier studies had shown the effectiveness of "pondelure" (*trans*-verbenol and *alpha*-pinene) as an aggregant of mountain pine beetle.

In a paper presented at the Mountain Pine Beetle Symposium in Kalispell, Montana, in 1988, Lindgren and Borden (1988) described additional research conducted on important pheromones of mountain pine beetle. Their conclusions described uses for the most important pheromone and kairomone semiochemicals of mountain pine beetle-the female-produced *trans*-verbenol, the male-produced *exo*-brevicomin, and the host-produced myrcene. Those have been shown to be important aggregative semiochemicals. A final one, verbenone--produced primarily by female beetles and other organisms in infested trees--appears to be a significant antiaggregant of the beetle. Borden and others (1983) and Conn and others (1983) described the development of useful semiochemical tools and strategies for mountain pine beetle in the early 1980's. The subsequent synthesizing and packaging of these tools by Phero Tech, Inc. led to our entering the age of mountain pine beetle-pheromone technology in 1984.

Use of Bark Beetle Pheromones in the Northern Region

Beginning in 1984, we were anxious to try new techniques which might help offset some of the enormous beetle-caused losses then being experienced in many lodgepole pine stands in our Region. Relatively new on the market at that time were controlled-release containers of aggregative bark beetle pheromones called "tree baits" and monitoring/ control devices called "Lindgren Funnel Traps." With an exuberance that, in hindsight, was probably excessive, we began using both tree baits and funnel traps in a nearly operational mode in 1984. Baits were used in the manner described by PMG/Stratford (1983) and Borden and others (1983)--ringing of small spot infestations (3-20 trees) at 50-meter intervals and gridding of larger ones (5-50 acres) on 50-meter spacing. Traps were used in a similar fashion for areas in which we had planned not to cut trees.

For the most part, only "observations" resulted following the 1984 field season: Baits worked well--best where populations were not excessively high. In all, they seemed to contain better than attract. Where populations were high, attractant distance may have been 50 yards or less. Where populations were low, attractant distance was much greater--perhaps approaching one-half mile (Gibson, unpublished data). Most work that year was with mountain pine beetle traps and baits. A few traps and baits for Douglas-fir beetle and spruce beetle were used in more isolated situations. Initial results with traps, for all beetle species, were disappointing.

Some of the data collected during 1984 enabled us to compare mortality caused by mountain pine beetle, from both baited and unbaited lodgepole pine stands. Survey techniques provided mortality data for the preceding year (1983, in which no baits were used) as well as the current year (1984). *Table 1* shows the effect of baiting as expressed in

Table 1-*Average basal area mountain pine beetle-caused mortality before and after use of tree baits, lodgepole pine, Kootenai National Forest, Montana. Baited in 1984.*

Year	Baited	Unbaited
	square feet/acre	
1983	14.64	11.40
1984	67.7	35.41

"average basal area killed" in baited and unbaited plots (32 paired plots, ranging in size from 5 to 20 acres each).

As noted, whereas mortality had been similar in the two areas in 1983 (unbaited), basal area mortality nearly doubled in baited stands (1984), when compared to unbaited stands. Not all areas baited since that time have been analyzed, but we have been consistently pleased with baiting results. Baiting of lodgepole pine stands scheduled for removal has become nearly "standard operating procedure."

In 1985, we continued at about the same level of use with mountain pine beetle traps and baits. In retrospect, I question our continued use of funnel traps. The trap lures were so effective, their use invariably resulted in trees near the traps being killed. To this day, we do not recommend their use for anything other than monitoring or occasional testing.

Early in 1986, the Environmental Protection Agency (EPA) ruled that pheromone tree baits then being used, required registration. As a result, a moratorium was placed on their use. The ruling did not affect the use of funnel traps, but because of disappointing effects, their use was virtually suspended as well. So, for 1986 and 1987 almost no bark beetle-related pheromone work was done in our Region. In September 1987, EPA made another fairly arbitrary ruling--stating that aggregative pheromones would not require registration while antiaggregative pheromones would! After that edict, we began using tree baits in earnest in 1988. Most subsequent use has been with mountain pine beetle baits, but some Douglas-fir beetle and spruce beetle tree baits have been used as well.

Our early efforts with antiaggregant pheromones followed the MCH work done primarily by Furniss in northern Idaho. In cooperation with Furniss and others, we conducted a large-scale pilot project in 1982 on the Nez Perce and Payette National Forests (NF). In that test MCH was aerially applied as small polymer beads into which the pheromone had been impregnated. It effectively prohibited infestation of downed Douglas-fir and some Engelmann spruce *(table 2).*

An operational project in northern Idaho followed in 1984-a treatment equally effective. On more than 2,400 acres treated, post-treatment evaluation showed a 95.4 percent reduction in number of attacks when compared to adjacent untreated areas.

Since that time, MCH has not been used in our Region, neither operationally nor experimentally. We still are awaiting its registration. Any current use is done under the auspices of an experimental use permit, which expires in May 1993. We have been attempting to conduct a pilot test to measure its effectiveness in protecting standing green trees. We are yet hopeful of conducting that test in spring 1993.

In the meantime, field testing continued with verbenone, the antiaggregative pheromone for mountain pine beetle. We were part of a multi-Region effort, coordinated through Intermountain Experiment Station in 1988 and 1989, to test the efficacy of verbenone bubble caps in protecting both lodgepole pine and ponderosa pine. Results in other Regions, as well as ours, showed some measurable effect in lodgepole pine-less so in ponderosa pine (Gibson and others 1991). Still, results were variable enough that we are not yet prepared to recommend the operational use of verbenone. That it is not yet registered, renders the point meaningless anyway.

Also in 1988 and 1989, a cooperative project between the Forest Service's Pacific Southwest Research Station and Phero Tech-and to a lesser extent, the Northern Region-evaluated the effectiveness of verbenone, applied aerially, in protecting lodgepole pine from attack by mountain pine beetle. Verbenone was impregnated in small polymer beads, as had been done with MCH, and applied at a rate of 4 pounds per acre. The 1988 test showed promise-statistically demonstrating verbenone's potential effectiveness *(table 3,* Shea and others 1992). A followup test, conducted in 1989, was inconclusive because of low beetle populations.

In 1990, a similar pilot project was conducted on the Lolo National Forest, in Montana. In that test, we attempted to evaluate the effectiveness of a range of aerially applied verbenone treatments in lodgepole pine against mountain pine beetle. Unfortunately, beetle populations were so high that treatments were ineffective. In 1990, we learned under what conditions verbenone probably *will not* work.

Table 2 -*Effectiveness of MCH in preventing Douglas-fir beetle attacks on downed Douglas-fir in central Idaho, 1982 (McGregor and others 1984*)

Site	Treated		Untreated		
	Trees	Attacks / tree	Trees	Attacks / tree	Percent reduction
1	50	8.9	52	186.0	95.2
2	52	1.1	37	104.8	98.8
3	32	6.3	9	93.2	93.3
Total	134	98	5.3	147.0	96.4
Aveage	134	155.6	98	629	383.7

Table 3-*Effectiveness of aerially applied verbenone in preventing mountain pine beetle attacks in lodgepole pine stands in northwestern Montana, 1988.*

	Treated	Untreated
1987 Attacks/acre	21.1	21.2
1988 Attacks/acre	4.0	16.3
1988 Unsuccessful attacks/acre	7.6	2.5
Total	32.7	40

In 1992, we had planned to conduct an aerial verbenone test on the Flathead National Forest, in northwest Montana, reproducing as closely as we could the conditions of the 1988 test. Test conditions would have duplicated those of 1988--beads with 1.2 percent loading (by weight) of verbenone, applied at 4 pounds per acre, and strict selection criteria regarding stand conditions and mountain pine beetle populations. We were unable to locate sufficient plots meeting test criteria, so the project has been postponed until 1993.

We are conducting instead a smaller, modified program which will test the effectiveness of verbenone and ipsdienol as mountain pine beetle antiaggregants in lodgepole pine and western white pine stands. Rather than an aerial application, baited funnel traps will be used to measure treatment effects.

Finally, an ongoing project is being conducted cooperatively by Idaho Department of Lands, the Northern Region, and Phero Tech. Begun in 1991, the project is testing the effectiveness of a combination of verbenone and ipsenol as antiaggregants of pine engraver. In 1991, we applied the chemicals, impregnated in polymer beads at the rate of 0.85 and 0.05 grams, respectively, per square meter, on ponderosa pine slash. The results, not as pronounced as we had hoped, but statistically significant, provided the impetus for a more "basic" project this year. In 1992, we tested the effect of a combination of the same two antiaggregants in masking the attractant properties of ipsdienol and lanierone. We used bubble cap formulations of all chemicals in Lindgren funnel traps. Preliminary results, based on early trap catches, suggest a measurable inhibitory effect of the two antiaggregants when used in concert.

Conclusion

In conclusion, as this symposium has suggested, research and development efforts during the past 20 years have provided a better understanding of conditions affecting successful use of synthetic pheromones for bark beetle management. Much remains to be learned. Still, we are hopeful--perhaps even confident--that pheromone tools will become valuable to the land manager as a means of making silvicultural manipulations more effective. Although not a panacea to the myriads of problems presented by bark beetles, the use of pheromones should enable us to influence their behavior to their distinct disadvantage.

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Potential of Verbenone for Reducing Lodgepole and Ponderosa Pine Mortality Caused by Mountain Pine Beetle in High-Value Situations[1]

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Abstract: Antiaggregative pheromones of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins, Coleoptera: Scolytidae) have been known for a number of years, but only recently have they been used in efforts to minimize infestation in stands of trees. Early tests in lodgepole pine (*Pinus contorta* Douglas) significantly reduced infestation in verbenone-treated stands. However, subsequent tests gave nonsignificant results. In ponderosa pine (*Pinus ponderosa* Lawson), significant reductions in beetle infestation were never attained with verbenone. Some possible reasons for the variable results are offered, with some suggestions for future research in reducing tree losses with antiaggregative pheromones.

Environmentally acceptable strategies are needed to protect high-value trees and stands (such as those along roads, campgrounds, riparian areas, and lakeshores) from infestation by the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), of the family Scolytidae (Schmitz 1989). Chemical insecticides are currently available to prevent attacks on high-value trees. Insecticides sprayed on the bole from ground level to the lower crown just before beetle emergence will prevent attacks for up to 2 years (Gibson and Bennett 1985; McCambridge 1982; Page and others 1985; Shea and McGregor 1987; Smith and others 1977). However, these preventive sprays also may affect nontarget insects, other invertebrates, and humans. Recent developments in the commercial production of mountain pine beetle (MPB) pheromones have led pest managers to consider antiaggregating pheromones as a substitute for preventive sprays for high-value trees.

Verbenone (4,6,6-trimethylbicyclo[3.1.1]-hept-3-en-2-one) was first isolated and identified from the mountain pine beetle pheromone complex by Pitman and others (1969), using the hindguts of newly emerged and feeding female mountain pine beetle. It was also identified from air passed over emergent male/female pairs (Rudinsky and others 1974). The first evidence of the antiaggregative properties of verbenone against the mountain pine beetle resulted when laboratory and field bioassays of (-)-verbenone inhibited mountain pine beetle response to selected host- and beetle-produced volatiles (Ryker and Yandell 1983).

[1]An abbreviated version of this paper was presented at the Symposium on Management of Western Bark Beetles with Pheromones: Recent Research and Development, June 22-25, 1992, Kailua-Kona, Hawaii.

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Verbenone previously exhibited antiaggregative properties against southern pine beetle (*Dendroctonus frontalis* Zimmerman) when used in traps (Renwick and Vite 1970), and also reduced landing on trees (Richerson and Payne 1979). The addition of verbenone to attractive lures also reduced the catch of western pine beetle (*D. brevicomis* LeConte) (Bedard and others 1980) response of *D. adjunctus* (Blandford) to attractive baits (Livingston and others 1983) and inhibits the response of *Ips paraconfusus* (Lanier) (Byers and Wood 1981) and *I. typographus (L.)* (Bakke 1981; Schlyter and others 1988).

Role of Verbenone in Host Colonization

The principal antiaggregative semiochemical regulating mountain pine beetle response to its host is (-)-verbenone (Borden and others 1987; Libbey and others 1985; Ryker and Yandell 1983). Verbenone originates from three sources: (1) female beetles (Pitman and others 1969); (2) auto-oxidation of alpha pinene to *cis-* and *trans*-verbenol, then to verbenone (Hunt and Borden 1989; Lindgren and Borden 1989); and (3) oxidation of *cis-* and *trans*-verbenol by microorganisms (primarily yeasts) associated with the beetle (Hunt and Borden 1989; Lindgren and Borden 1989). The following conceptual model proposed by Borden and others (1987) summarizes what is known about the sources of verbenone, the onset of production in relation to the sequence of attack, and its probable role in regulating the duration and density of attack.

At the onset of attack by female mountain pine beetle, volatiles (including the host monoterpenes alpha-pinene and myrcene, together with female-produced *trans*-verbenol) attract additional beetles to the tree. As males reach the tree, they release *exo*-brevicomin, which initially attracts primarily females, thereby enhancing the level of attraction. As additional males colonize the tree, concentrations of *exo*-brevicomin increase and are augmented by the male-produced antiaggregant, frontalin. Simultaneously, concentrations of the aggregative components, *trans*-verbenol, and the host monoterpenes begin to decline. At this stage in colonization, the concentration of verbenone produced (1) by auto-oxidation of the host monoterpene, alpha-pinene, to *cis-* and *trans*-verbenol and then to verbenone and (2) by conversion of *cis-* and *trans*-verbenol to verbenone by microorganisms deter additional beetles from attacking the focus tree. The effect of these antiaggregants limits attacks to a density that ensures survival of the ensuing brood.

Verbenone Field Tests

Reducing Response to Attractive Traps

During summer 1986, Schmitz and McGregor (1990) conducted tests in the Wasatch National Forest in Utah to compare the number of mountain pine beetle attracted to the standard mountain pine beetle lure consisting of *trans*-verbenol, *exo*-brevicomin, and myrcene, with and without verbenone. The test was conducted in a mature lodgepole pine stand surrounded by stands in which mountain pine beetle populations were building to outbreak levels. The eight test blocks were 30 meters square and were separated from one another by 30-meter intervals. Funnel traps were hung at each of the four corners of a block. The four treatments-MPB lure, MPB lure with verbenone, verbenone alone, and empty trap-were randomly assigned to each of four positions. Effectiveness of verbenone as an antiaggregant was assessed by the number of mountain pine beetle caught, by treatment.

They caught a total of 1,130 mountain pine beetle, distributed among the four treatments as follows:

	Number	Percent
MPB lure alone	1,082	95.8
MPB lure with verbenone	19	1.7
Verbenone alone	7	0.6
Unbaited trap	22	.9
Total	1,130	100.0

Overall, the addition of verbenone to the synthetic MPB lure reduced the catch by 98 percent.

A similar test in British Columbia by Borden and others (1987) showed that when verbenone was released in funnel traps in the presence of the attractive synthetic mountain pine beetle lure, the response of males was reduced approximately 75 percent. Female response was reduced, but not significantly.

The encouraging results from these studies to suppress catch of mountain pine beetle in traps prompted tests to determine the efficacy of verbenone for reducing mountain pine beetle infestation in Rocky Mountain lodgepole and ponderosa pine stands.

Tests in Lodgepole Pine Stands

Field studies[3] to test the efficacy of verbenone in reducing mountain pine beetle infestation were conducted in Idaho, Montana, and British Columbia, starting in 1987. In Idaho, a 2 x 2 factorial design, replicated four times, was used to test verbenone in the presence of the mountain pine beetle tree bait (Amman and others 1989). Treatments consisted of (1) MPB tree bait, (2) verbenone, (3) MPB tree bait and verbenone, and (4) check. Verbenone was eluted from the standard plastic bubble cap at 5 mg/24 h/capsule at 25°C. Each treatment was applied individually to 1-ha plots. Five mountain pine beetle tree baits were used in each baited plot.

The three-part tree bait was stapled 2 m above ground level on the north side of a lodgepole pine 20 cm or larger d.b.h. Mountain pine beetle tree baits were placed at the center of the plot and at each cardinal direction from the center, approximately 20 m from the outside boundary of the plot.

Verbenone-treated plots had 100 verbenone bubble capsules per hectare, spaced in a grid pattern approximately 10 m apart. Each capsule contained 0.5 g of verbenone having a chemical purity of 98.6 percent and optical purity ee = (-)72 percent. In the plots treated with mountain pine beetle tree bait plus verbenone, baits and verbenone bubble capsules were distributed as described for each alone. Check plots were untreated.

Treatment effects were assessed by comparing the percentage of 1987 mountain pine beetle-infested lodgepole pine 15.2 cm d.b.h. and larger in each plot. Highly significant differences were found in percentages of infested trees among treatments. Plots having only mountain pine beetle tree baits had significantly more mass-attacked trees than other treatments. There was no significant difference among the other three treatments. Average numbers of lodgepole pine infested by mountain pine beetle were:

	Trees infested	
	MPB tree bait present	MPB tree bait absent
	pct	
Verbenone present	7.425	0.875
Verbenone absent	24.425	3.275

Verbenone in the presence of mountain pine beetle tree bait resulted in a 2.3-fold reduction in infested trees and a 2.7-fold reduction where tree baits were not used.

An examination of the percentage change in numbers of MPB-infested trees for the four treatments between 1986 and 1987 shows that only in verbenone-treated plots did an average reduction occur (-48.6 percent). In contrast, check plots showed an average increase of 64.7 percent. Changes in infestation in verbenone-treated and check plots were small when compared to baited plots, which showed an average 25-fold increase in infestation. Plots containing mountain pine beetle baits and verbenone had an average 4-fold increase in infestation. A test conducted in British Columbia also in 1987 gave similar results (Lindgren and others 1989). However, in a second test that used verbenone but no attracttive baits, mountain pine beetle infestation was reduced but not significantly (Lindgren and others 1989). Shore and others (1992) showed that verbenone reduced the response of mountain pine beetle to trees baited with exo-brevicomin, one component of the mountain pine beetle tree bait.

Two questions arose from these tests: (1) Would a different dosage of verbenone be more effective than 100 capsules

[3]Pheromone products were obtained from Phero Tech Inc., Delta, BC, Canada. The use of trade or company names in this paper is for information only and does not imply endorsement by the USDA Forest Service.

per hectare, and (2) would mountain pine beetle be attracted into areas adjacent to verbenone-treated stands, resulting in increased numbers of infested trees in adjacent stands. These questions formed the basis for additional tests in Idaho and Montana in 1988 and 1989.

In 1988, a randomized complete block design, replicated seven times, was used to test densities of verbenone capsules of 0, 25, 49, 100, and 169 per hectare, spaced in a grid pattern within the treated plots. Plots were 1 ha in size and were located 100 m apart. Treatments within a block were randomly assigned. In 1988, the verbenone capsules were of the same design as those used in 1987.

To assess the possible attractiveness of mountain pine beetle to verbenone in stands adjacent to 1988 treatments, two 20-m-wide strips were established around each plot, and all trees infested in 1987 and 1988 were counted and tallied separately for each strip.

The 1989 test differed from the 1988 test as follows:

1. Only the dosage-response portion of the study was repeated.
2. Treatments were replicated eight times instead of seven.
3. A newly designed capsule was used, consisting of an opaque bubble with clear plastic membrane. Each capsule contained 0.8 g of verbenone.

The percentage of newly infested trees varied significantly among treatments in 1988. The four verbenone capsule treatments-25 ($\bar{x}$ = 1.80 percent), 49 ($\bar{x}$ = 0.21 percent), 100 ($\bar{x}$ = 0.51 percent), and 169 ($\bar{x}$ = 1.71 percent)-all had lower percentages of infested trees than the check ($\bar{x}$ = 5.39 percent) (Amman and others 1991).

In 1989, treatments also exhibited significant differences. The percentages of newly infested trees by treatment were: 25 (x = 3.89 percent), 49 (x = 2.52 percent), 100 (x = 0.72 percent), 169 (x = 1.58 percent), check (x = 4.93 percent). Although 49 capsules per hectare appeared to do as well as 100 capsules per hectare in 1988, mountain pine beetle infestation increased in the 49 capsules per hectare treatment in 1989 (Amman and others 1991).

Greater infestation rates in the 169 capsules per hectare treatment than in the 100 capsules per hectare treatment were observed in both 1988 and 1989 and in a similar test in Montana (Gibson and others 1991). Borden and Lindgren (1988) also noted more trees were attacked and at higher attack densities when high dosages of verbenone were used. A high concentration of verbenone may cause beetle confusion.

Studies similar to those in Idaho were conducted in Montana lodgepole pine stands in 1988 and 1989. In 1988, treatments were not significantly different. In 1989, however, treatments were significantly different and were very similar to Idaho results (Gibson and others 1991). As in the Idaho test, the 100 capsules per hectare treatment showed the greatest reduction in percent of infested trees ($\bar{x}$ =0.3 percent), when compared to the check plots ($\bar{x}$ = 5.2 percent). The lack of significance in 1988 was attributed to the low number and poor distribution of infested trees because the average percentage of infested trees ranged between 0.2 and 2.5 when the study was installed.

Although significant results were shown in Idaho and Montana, no differences in numbers of infested trees were shown among application rates of verbenone in British Columbia (Borden and Lindgren 1988). Shore and others (1992) concluded from their study that verbenone is not repellent, because it neither significantly reduced the number of trees infested by mountain pine beetle nor lowered beetle attack densities. They stated that treating trees with verbenone does not appear to make them less attractive to mountain pine beetle than unbaited trees. However, differences in infestation among treated stands in the Idaho and Montana tests suggest a repellent action on an area basis.

In the two 20-meter-wide strips surrounding verbenone-treated blocks, the number of infested trees per hectare did not differ significantly among treatments. Beetles were expected to disperse from the plots to infest trees somewhere outside the plots, but most likely within 2 chains of the treated plot. Although none of the capsule treatments differed significantly, the trend was for fewer beetle-infested trees in strips surrounding blocks treated with verbenone than in check blocks. These data, although not significant, suggest the suppressing effect of verbenone could be extending beyond the treated plots, particularly in the 169 capsules per hectare treatment.

Tests were continued in Idaho in 1990 and 1991 to resolve the question of whether 49 capsules per hectare (the best treatment in 1988) or 100 capsules per hectare (the best treatment in 1989) would give consistent results (Rasmussen, unpublished data, Intermountain Research Station, Ogden, Utah). Surprisingly, treatments were not significantly different from check plots in either year. These results were totally unexpected, especially after previous tests demonstrated statistically significant reductions in mountain pine beetle infestation for three consecutive years.

Tests in Ponderosa Pine Stands

Although the use of verbenone to minimize infestation in the early lodgepole pine tests appeared quite promising, tests in ponderosa pine were judged not successful from the beginning. Bentz and others (1989), Gibson and others (1991), and Lister and others (1990) used methods similar to those I described for lodgepole studies in 1988 to test the effect of verbenone in ponderosa pine stands in southwestern Colorado, in western South Dakota, and in western Montana.

Mountain pine beetle infestations in these areas were in outbreak status, but the intensity of the infestations was much higher in southwestern Colorado, where over 150 trees per hectare were killed in 1988 (Bentz and others 1989). In the outbreak cycle, the Colorado area was considered at its peak. In contrast, the South Dakota area was in the early stages of an outbreak, with tree mortality averaging about 22 trees per hectare. The Montana area was intermediate, with an average of 32 infested trees per hectare.

In each area, as in the lodgepole pine tests, four replicates were used to test the five treatments: 0, 25, 49, 100, and 169 verbenone capsules per hectare. In 1988, no significant differences occurred among treatments in any of the areas. The number of mass-attacked trees in the strips surrounding each plot also were not significantly different among treatments.

In 1989, eight replicates were used to again test different densities of verbenone capsules in South Dakota and Montana. Mountain pine beetle populations had reached outbreak status, but the population trend was static in South Dakota (11.6 infested trees per hectare) and in Montana (11.0 infested trees per hectare).

In the 1988 South Dakota test, the mean numbers of infested trees were 35 per hectare for check, and 10, 14, 8, and 4, respectively, for the 25 to 169 capsule treatments (Bentz and others 1989), compared to 1989 means of 29.1 for the check and 14.4, 11.8, 7.5, and 5.6, respectively, for the verbenone treatments (Lister and others 1990). In the Montana test, mean numbers of infested trees in 1988 were 30.5 per hectare for the checks, compared to 6.0, 20.8, 11.3, and 2.3, respectively, and the 1989 results were 11.0 per hectare for the checks, and 9.5, 6.3, 7.5, and 2.5, respectively, for the 25 to 169 verbenone capsule treatments (Gibson and others 1991).

The South Dakota and Montana tests showed a downward trend in infestation rate with increased number of verbenone capsules, but the variance within treatments was so great that significant treatment effects could not be demonstrated.

Conclusions

The inconsistent results from year to year and between tree hosts of mountain pine beetle point to the need for much additional research before antiaggregative pheromones can be used effectively to reduce mountain pine beetle infestation of high-value trees. There are several possible explanations for the inconsistent results, ranging from a faulty verbenone product to genetic changes in the beetle population:

1. In the Idaho tests, the bubble capsule was judged adequate. The enantiomeric ratio of capsule contents was analyzed and found to be -80 percent.[4] Therefore, the ratio should not be a problem. Also, verbenone eluted at a rate consistent with previous tests (Rasmussen, unpublished data). However, observations in ponderosa pine suggest that some capsules do not elute at specified rates (Bentz and others 1989).

2. Stand microclimate may have changed from earlier tests because of trees killed by mountain pine beetle, particularly those of larger diameter. Dead trees may become warmer because of solar insolation and serve as chimneys that cause vertical movement of verbenone out of the stand.

3. Weather factors (particularly temperature) were considered a problem in the ponderosa pine tests (Bentz and others 1989). High temperatures may have caused above-average elution of verbenone.

4. Genetic change of mountain pine beetle (Stock and Amman 1985) related to smaller trees (in which phloem is usually thin) being infested after larger trees (in which phloem is usually thick) have been killed in prior years may have contributed to the selection of beetles that tend to ignore the verbenone signal.

Whether these or other unidentified factors are responsible, the promise of verbenone to protect high-value trees does not look as bright as we thought after the earlier tests. At best, verbenone was not completely effective in preventing mountain pine beetle infestation. Strategies that may improve verbenone effectiveness are (1) use mountain pine beetle baits in conjunction with verbenone treatments to attract beetles from stands where verbenone is deployed to stands scheduled for harvest (Borden and Lindgren 1988; Schmitz and McGregor 1990); (2) use verbenone in conjunction with other pheromones that have an aggregative effect on mountain pine beetle (Hunt and Borden 1988); and (3) use pheromones at low mountain pine beetle population levels rather than high population levels. These are the subject of current research.

[4]Chemical analysis was done by Dr. Lonne L. Sower, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR.

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The Use of Antiaggregation Semiochemicals in Controlling Pine Engravers in Stands of Lodgepole Pine[1]

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Abstract: Antiaggregation semiochemicals, such as antiaggregation pheromones and pheromones of other species, may serve a role in reducing the threats from bark beetles such as the pine engraver, *Ips pini.* In British Columbia, the combination of verbenone and ipsenol reduced the attack densities of pine engravers on lodgepole pine slash, as well as delaying the onset of mass attack. Verbenone and ipsenol are pheromones for the mountain pine beetle, *Dendroctonus ponderosae,* and another pine engraver, *I. latidens,* respectively. However, not all antiaggregation semiochemicals are necessarily effective in mitigating impacts by bark beetles. The antiaggregation pheromone, myrcenol, failed to protect felled lodgepole pines from attack by the pine engraver. In the future, successful use of antiaggregation semiochemicals will probably require judicious use of several compounds in complex pest management programs. Moreover, cost/benefit analyses are still required before such tactics can be employed.

The pine engraver, *Ips pini* (Say) (Coleoptera: Scolytidae), is a common, transcontinental bark beetle species in pine stands throughout Canada and the northern United States (Bright 1976, Chamberlin 1958, Hopping 1964, Lanier 1972, S.L. Wood 1982). It characteristically breeds in the phloem tissue of slash or moribund trees created by wind, fire, logging activities or *Dendroctonus* species of bark beetles (Furniss and Carolin 1980, Geiszler and others 1984, Livingston 1979, Sartwell and others 1971).

Pine engravers can sometimes kill significant numbers of standing trees if conditions provide the opportunity for rapid buildup of population numbers. In 1966, almost 10,000 red pines, *Pinus resinosa* Ait., across 37 plantations in Michigan, were killed by pine engravers as a consequence of buildup in slash and thinning material (Kennedy 1969). In 1971, 16 percent of the ponderosa pines, *P. ponderosa* Dougl. ex Laws., in a 12,431-acre forest in the Northern Cheyenne Indian Reservation were killed by the combination of the pine engraver and another engraver, *I. calligraphus* (Germar) (Dewey and others 1974). Presumably, beetles were able to build up in trees defoliated by the pine looper, *Phaeoura mexicanaria* (Grote). Two years after the 1988 fire in the greater Yellowstone area, 44 percent of a sample of 147 lodgepole pine, *Pinus contorta* var. *latifolia* Engelm., were infested by pine engravers (Amman and Ryan 1991).

The risk of tree mortality by pine engravers is high whenever large quantities of slash are available (Livingston 1979, Thomas 1961). Pine engravers have a high reproductive potential. The beetles have a relatively high fecundity, with the opportunity for multiple broods per female (Livingston 1979, Miller and Borden 1985, Rankin and Borden 1991, Schenk and Benjamin 1969, Thomas 1961). In addition, they can breed quickly because of relatively short generation times (1-2 months), often resulting in multiple generations per year (Livingston 1979, Miller and Borden 1985, Prebble 1933, Reid 1955, Schenk and Benjamin 1969, Thomas 1961).

Various tactics for controlling pine engravers are available. The most common tactic is sanitation through the timely disposal of slash (Eiber and others 1989, Furniss and Carolin 1980, Livingston 1979). Beetles cannot breed in material that is no longer suitable for brood production. Another successful tactic is the use of the "green chain," first proposed for controlling pine engravers in thinned stands of ponderosa pine (Livingston 1979). Beetles are diverted from standing trees to fresh, unattacked slash. Slash is created throughout the summer and early fall to ensure containment of the population. During the winter, natural mortality factors reduce the threat from the beetles to negligible levels by the following spring. Finally an effective third option is the use of conventional chemical pesticides, primarily carbaryl or pyrethroid derivatives.

However, all tactics have limitations. Pesticides are not generally viewed with much favor by the public, particularly in areas with high recreational or wildlife values. Weather may preclude the burning of slash as a sanitation measure. Contractors involved in "green chain" activities may fail to put down slash in advance of emerging brood.

The need for alternate tactics is apparent not only for pine engravers but for bark beetles in general. Research into the use of semiochemicals for controlling scolytid beetles is gaining acceptance as efficacy is demonstrated for various species. Mass-trapping programs for ambrosia beetles are operational tools in the Pacific Northwest (Borden and McLean 1981, McLean and Borden 1979). Pheromones of the mountain pine beetle, *Dendroctonus ponderosae* Hopk., are used operationally to contain populations in stands of lodgepole pine (Borden and Lacey 1985).

In contrast to aggregation pheromones which attract beetles, antiaggregative semiochemicals inhibit attraction of or attack by bark beetles and might be useful in reducing the threat from pine engravers by preventing brood production. In Idaho, Ralph Thier, Ladd Livingston, and Ken Gibson

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are investigating the use of two pheromones, ipsenol (2-methy-6-methylene-7-octen-4-ol) and verbenone (4,6, 6-trimethylbicyclo[3.1.1]hept-3-en-2-one), used by two sympatric species of bark beetles, in protecting thinning slash in stands of ponderosa pine from attack by pine engravers (Thier and Livingston 1992). We discuss a similar approach in protecting slash material in stands of lodgepole pine through the use of myrcenol (2-methyl-6-methylene-2,7-octadien-3-ol) or the combination of ipsenol and verbenone.

Myrcenol

Like many other scolytids, pine engravers aggregate rapidly and in large numbers to a suitable host (Anderson 1948). Both sexes are attracted to the male-produced aggregation pheromone, ipsdienol (2-methyl-6-methylene-2, 7-octadien-4-ol) (Birch and others 1980, Lanier and others 1980, Plummer and others 1976, Stewart 1975, Vité and others 1972). Recently, lanierone (2-hydroxy-4,4, 6-trimethyl-2,5-cyclohexadien-l-one) was identified as a synergistic pheromone in the attraction of pine engravers to ipsdienol (Teale and others 1991). No other compound appears to act as an aggregation pheromone for pine engravers.

However, pine engravers also produce myrcenol (Gries and others 1988), which may serve as an antiaggregation or spacing pheromone (Miller and others 1990). Catches of pine engravers in ipsdienol-baited multiple-funnel traps were significantly lowered by myrcenol released at medium and high rates (3.0 and 6.0 mg per day at 24 °C) *(fig. 1)* (Miller and others 1990). The release rate was 0.6 mg per day at 24 °C for ipsdienol. The effect was the same for both sexes *(fig. 2).*

Various species of bark beetles use antiaggregation pheromones to terminate attacks on hosts that have been fully colonized, facilitating a switch to adjacent hosts (Borden 1982, D.L. Wood 1982). If myrcenol is an antiaggregation pheromone for pine engravers, then it is possible that it could be used to protect slash from attack by pine engravers. Therefore, in 1988, we felled 20 mature lodgepole pines in south-central British Columbia to test this hypothesis (Miller and others 1990). Sixteen of these downed trees were treated with various numbers of devices, each releasing myrcenol at a rate of 0.6 mg per day at 24 °C.

Myrcenol did not protect the treated pines from attack by pine engravers *(fig. 3).* In fact, it seemed to have facilitated attacks. Downed pines with nine devices had significantly more attacks than the control logs. The attacks seemed to be clustered around the myrcenol devices.

One possible explanation for these results is that myrcenol may have facilitated the landing of beetles on treated downed pines but deterred the beetles from landing initially close to the devices. Subsequent to landing, the beetles may have tracked back to the source of myrcenol in search of the edge of the aggregation of pine engravers. Finding no such aggregation, the beetles proceeded to the devices themselves and began boring, resulting in additional attacks. An alternate explanation is that myrcenol may be attractive when present

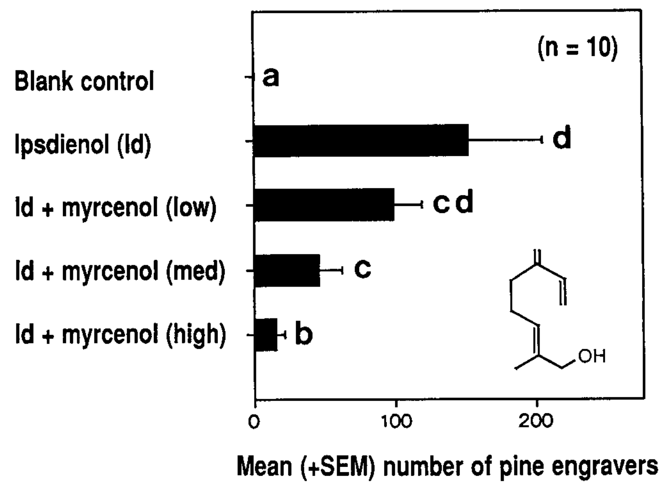

Figure 1-Effect of myrcenol (inset) on catches of pine engravers in ipsdienol-baited multiple-funnel traps in stands of lodgepole pine in British Columbia (modified from Miller and others 1990). Means followed by the same letter are not significantly different at P=0.05 [Scheffe's multiple comparison test on data transformed by log(Y+1)].

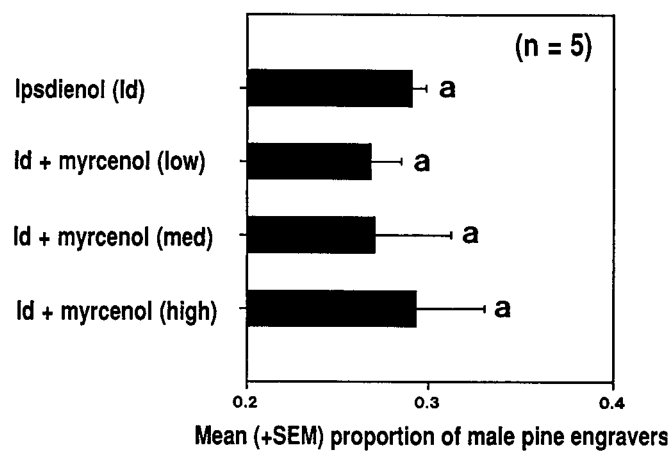

Figure 2-Effect of myrcenol on the sex ratio of pine engravers caught in ipsdienol-baited multiple-funnel traps in stands of lodgepole pine in British Columbia (modified from Miller and others 1990). Means followed by the same letter are not significantly different at P=0.05 (Scheffe's multiple comparison test on data transformed by arcsin).

with host compounds. Such compounds were absent in the trapping experiment.

Whatever the explanation, one conclusion is clear. Results from trapping experiments are not necessarily valid for field situations. Our use of traps did not measure the effecttive range of myrcenol nor did it account for the possibility of subsequent responses by walking beetles on the host. We clearly cannot recommend the use of myrcenol to protect either slash or logs from pine engravers.

Ipsenol and Verbenone

Pheromones used by one species of bark beetle can affect the behavior of individuals of other sympatric species of bark beetles (Borden 1982, Byers 1989). Mutual inhibittion of response to pheromones occurs among various pairs of bark beetles in sympatry in western North America such as between the western pine beetle, *Dendroctonus brevicomis* LeC., and the California fivespined ips, *Ips paraconfusus* Lanier. The attraction of western pine beetles to its pheromones is inhibited by all three pheromones of the California fivespined ips (Byers and Wood 1981). The antiaggregation pheromone, verbenone, produced by western pine beetles, inhibits the response of the California fivespined ips to its pheromones (Byers and Wood 1980).

Similar interactions occur between pine engravers and two sympatric species in British Columbia: the mountain pine beetle and another engraver, *I. latidens* LeC. The latter species uses ipsenol as an aggregation pheromone (Miller and Borden 1990, Miller and others 1991, Seybold 1992). Ipsenol inhibits the attraction of pine engravers to ipsdienol-baited multiple-funnel traps *(fig. 4)* (Borden and others 1992).

Verbenone is an antiaggregation pheromone for the mountain pine beetle, inhibiting the response of mountain pine beetles to their pheromones and thereby regulating attack densities on suitable hosts (Borden and others 1987, Ryker and Yandell 1983). Similarly, catches of pine engravers to ipsdienol-baited multiple-funnel traps are significantly reduced by the presence of verbenone *(fig. 5)* (Borden and others 1992).

In 1989, we proceeded to determine the efficacy of both ipsenol and verbenone in protecting downed lodgepole pines in south-central British Columbia. Two sets of bubblecaps releasing ipsenol and verbenone separately at 0.3 and 10 mg/day at 24 °C, respectively, were attached to treated downed trees. Control trees did not receive any bubblecaps. The lowest attack density occurred on downed trees treated with ipsenol and verbenone, even when the antiaggregants were challenged with the aggregation pheromone, ipsdienol *(fig. 6)* (Borden and others 1992). The reproductive successes of beetles were similar in all treatments. Therefore we can relate the lower attack densities directly to lower numbers of emerging offspring and a lower risk to standing trees.

We next attempted to protect slash over a larger area. In 1989, thinning was simulated by felling six trees in plots

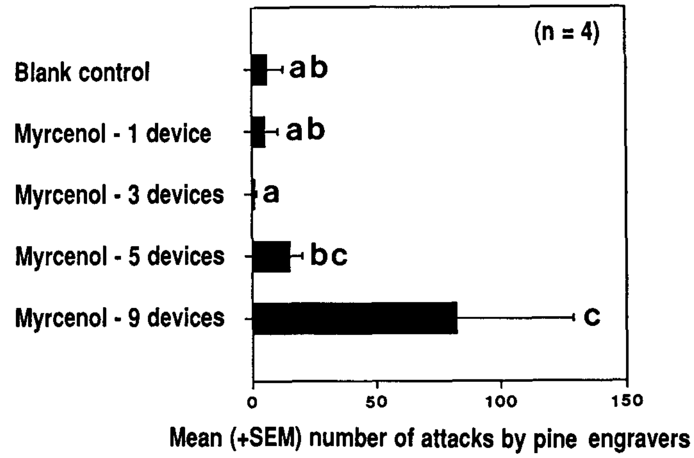

Figure 3-Effect of myrcenol on attack densities of pine engravers on felled lodgepole pines in British Columbia (modified from Miller and others 1990). Means followed by the same letter are not significantly different at P=0.05 [Scheffe's multiple comparison test on data transformed by log(Y+1)].

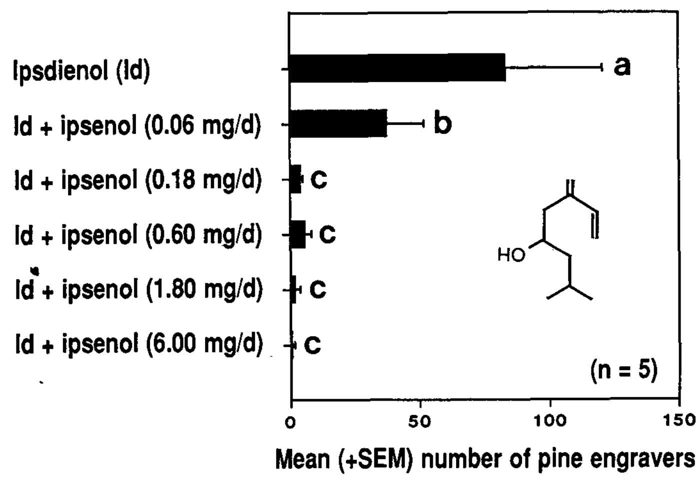

Figure 4-Effect of ipsenol (inset) on catches of pine engravers in ipsdienol-baited multiple-funnel traps in stands of lodgepole pine in British Columbia (modified from Borden and others 1992). Means followed by the same letter are not significantly different at P=0.05 [Duncan's multiple range test on data transformed by log(Y+1)].

measuring 15 m x 15 m in mature stands of lodgepole pine in south-central British Columbia. The slash in the experimenttal plots was treated with polypropylene and polyethylene beads, releasing ipsenol and verbenone, respectively (Devlin 1992). The beads were dispersed by a hand-held fertilizer spreader. Different plots were treated at different times prior to first attack as determined by weekly observations of the control plots. Two doses of ipsenol and verbenone were used in the experiment. The results reported herein are for the high dose which initially released ipsenol and verbenone at rates of 0.05 and 2.5 mg/m^2 at 24 °C, respectively. Bubblecaps releasing the aggregation pheromone, ipsdienol, at a rate of 0.3 mg/day at 24 °C, were placed at the center of each plot to ensure adequate beetle pressure.

Ten weeks after the first attacks by pine engravers occurred on material in the control plots, the attack densities were significantly lower on slash material in all treated plots than those on material in the control plots *(fig. 7)* (Devlin 1992). Moreover, the attacks on slash in the treated plots began 4-5 weeks later than the attacks on material in the control plots *(fig. 8).* We conclude that the combination of ipsenol and verbenone can effectively minimize the increases in population levels of pine engravers.

Cost/benefit analyses will be required before this tactic can become operational. As well, some improvements in the technology are also required with respect to release devices. Attacks on slash in the plots treated 4 weeks prior to first attack were significantly higher than those on material in plots treated 2 weeks prior to first attack *(fig. 7).* This is probably a function of the high initial release rates of ipsenol and verbenone, and the substantial decline within the first 2 weeks *(fig. 9)* (Devlin 1992). Successful use of ipsenol and verbenone to protect slash from pine engravers will require devices that release large amounts of both semiochemicals for a longer period of time.

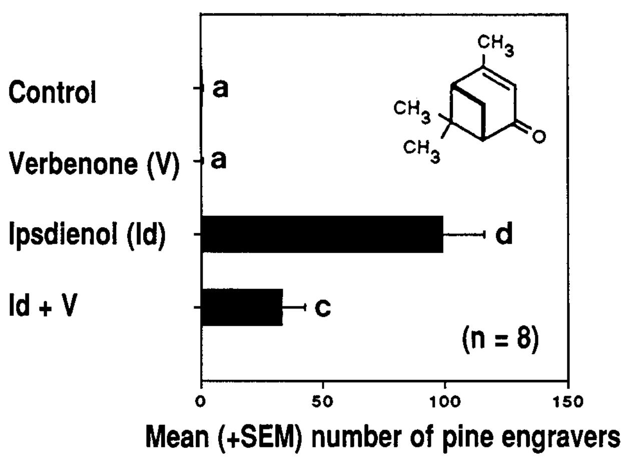

Figure 5-Effect of verbenone (inset) on catches of pine engravers in ipsdienol-baited multiple-funnel traps in stands of lodgepole pine in British Columbia (modified from Borden and others 1992). Means followed by the same letter are not significantly different at P=0.05 [Duncan's multiple range test on data transformed by log(Y+1)].

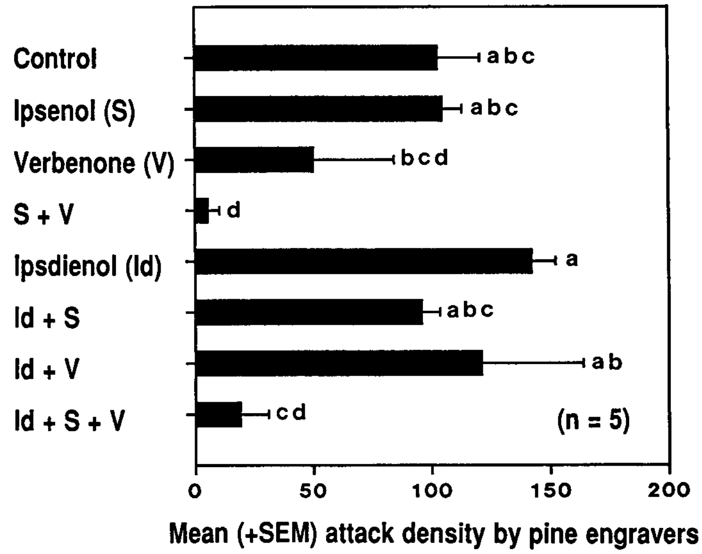

Figure 6-Effects of verbenone, ipsenol and ipsdienol on attack densities (counted after debarking) of pine engravers on felled lodgepole pines in British Columbia (modified from Borden and others 1992). Means followed by the same letter are not significantly different at P=0.05 [Newman-Keul's multiple comparison test on data transformed by log(Y+1)].

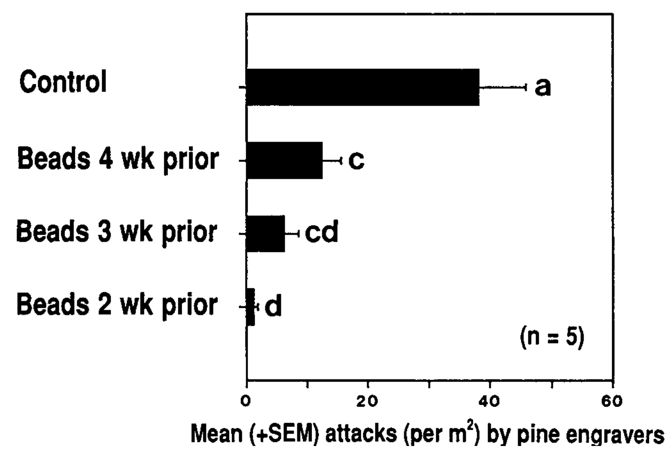

Figure 7-Effect of ipsenol and verbenone (released from polypropylene and polyethylene beads, respectively) on attack densities of pine engravers on simulated thinning slash in stands of lodgepole pine in British Columbia (modified from Devlin 1992). Beads were applied 2, 3 and 4 weeks (H2, H3 and H4, respectively) prior to first attacks on thinning slash in control plots. Means followed by the same letter are not significantly different at P=0.05 (nonparametric multiple comparison test).

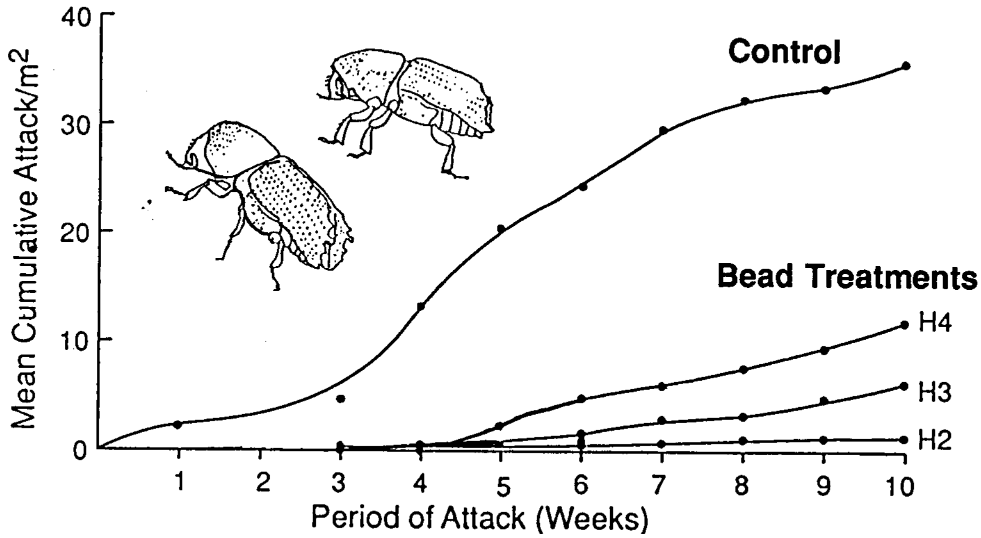

Figure 8-Effect of ipsenol and verbenone (released from polypropylene and polyethylene beads, respectively) on attack periods of pine engravers (inset) on thinning slash in stands of lodgepole pine in British Columbia (modified from Devlin 1992). Beads were applied 2, 3 and 4 weeks (H2, H3 and H4, respectively) prior to first attacks on thinning slash in control plots.

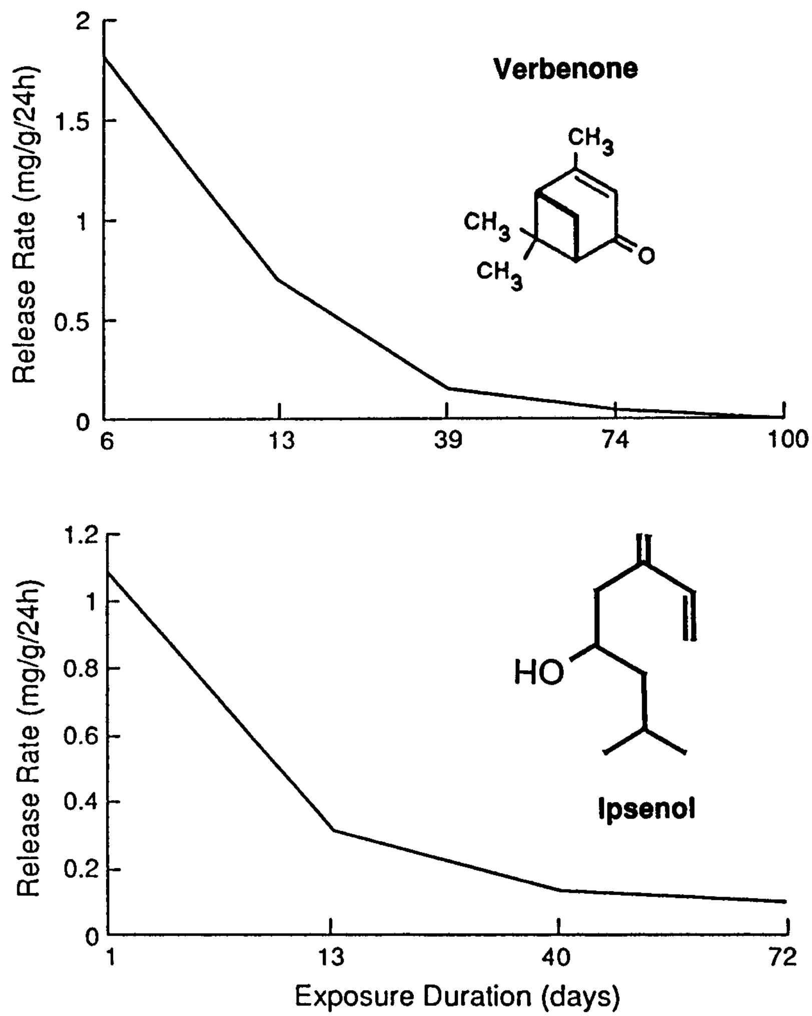

Figure 9-Release rates of verbenone and ipsenol (insets) from polyethylene and polypropylene beads, respectively, at 24 °C (modified from Devlin 1992).

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Bark Beetle Pheromone Research in Southern California[1]

Timothy D. Paine[2]

Abstract: Southern California forests, adjacent to one of the largest population centers in North America, are examples of heavily urbanized forest communities. High public access and high visibility of the forests, combined with very limited timber value, result in unique pest management problems. Tree mortality must be minimized because of the recreational and aesthetic value of the trees, but use of pesticides is limited because of cost, safety, and exposure (public and environmental). However, this also provides an opportunity to use pheromones for individual tree protection. Research is being directed toward using the inhibitors verbenone and racemic ipsdienol to interrupt the response of *Dendroctonus brevicomis* and *Ips paraconfusus* to their aggregation pheromones.

Forests in southern California are subject to different use patterns than most other forests in western North America. The only timber use for the stands has been in firewood sales rather than sawlogs. Urban centers with more than 16 million residents lie within 2-hour drives of the forested areas. There are many public parks, private summer camps, and winter ski resorts scattered throughout the mountains of the region that are destinations for visitors from the cities. In addition, the urbanization of the mountains has been extensive over the past 90 years. Thus, the forests are heavily used and valued for their recreational and aesthetic qualities.

One of the consequences of having highly visible and heavily utilized forested areas is the importance placed on individual trees. The value of the trees must be determined in a non-traditional way. Value specifically relates to the type of interventive or direct control practices that are economically and environmentally acceptable for tree protection. Because the trees are more valuable, more options at higher cost may be considered. However, because of the general urban public resistance to insecticide use and the high degree of public access or exposure in these southern California forests, control options using pesticides may be restricted. There is a need for non-pesticide based management. As in other urban or highly public forests of the West, the value of the trees may encourage development of pheromone-based management at potentially higher costs for individual tree protection.

Dendroctonus brevicomis, Ips paraconfusus, I. confusus, D. ponderosae, D. valens, and *Scolytus ventralis* are among the most common primary and secondary bark beetles colonizing trees in the mountains of southern California. The tree species composition in the forest communities is different than in many of the other forest communities of the West which may alter the interactions among beetle species utilizing the same hosts. In addition, the trees are subject to stresses, particularly from air pollutants (Cobb and others 1968), that potentially increase their susceptibility to bark beetle infestation. Although there is a considerable amount of information available about the pheromone systems of the two *Ips* species and the two tree-killing *Dendroctonus* species, the research addressed in the recent management studies has focused on *I. paraconfusus* and *D. brevicomis.*

There are several strategies for using pheromones to protect individual trees. One of the most promising may be the use of inhibitor pheromones or interruptants. Light and Birch (1979) demonstrated that arrival of *I. paraconfusus* to its own pheromone of (-)-ipsenol, (+)-cis-verbenol, and (+)-ipsdienol (Silverstein and others 1966) was interrupted by (-)-ipsdienol, the single component pheromone of *Ips pini* in California (Birch and others 1980a, b). Mutual pheromone inhibition within a genus, between *I. pini* and *I. paraconfusus,* was also demonstrated (Birch and Light 1977, Birch and others 1980a, b). Bedard and others (1980) determined that the response of *D. brevicomis* to its pheromone (+)-exo-brevicomin and (-)-frontalin plus the host monoterpene myrcene was interrupted by verbenone, an auto-oxidation product of alpha-pinene also produced by male *D. brevicomis* (Byers and Wood 1980). Studies by Byers and Wood (1980, 1981) illustrated mutual inhibition between genera by showing that verbenone interrupts the response of *I. paraconfusus* and that components of the pheromone of *I. paraconfusus* interrupt the response of *D. brevicomis.*

Paine and Hanlon (1991) tested these inhibitors to block attraction of beetles to pheromones in Lindgren funnel traps. The inhibitors verbenone and racemic ipsdienol were individually able to significantly reduce arrival of *I. paraconfusus* and *D. brevicomis* to their pheromones. Release of 1.8 mg/day of either 69 percent (+)/ 31 percent (-) or 16 percent (+)/ 84 percent (-) verbenone appeared to be the most effective and economical rate. The combination of both ipsdienol and verbenone released together significantly reduced the attraction of *D. brevicomis* over the observed reduction resulting from release of either compound alone. The results of these studies suggest that there may be potential to apply the inhibitors to individual trees for protection against arriving beetles. However, the technical problems of release devices, longevity, and cost must be resolved before commercial applications can be developed.

Technical and biological problems associated with tree protection remain the focus of continuing research projects. It will be important to know the quantity or relative ratio of inhibitor compound required to override the effects of any given amount of the aggregation chemical signal. This information is necessary to optimize the release rate of the inhibitors. How the inhibitors are released on the stem of the tree

[1]An abbreviated version of this paper was presented at the Symposium on Management of Western Bark Beetles with Pheromones: Recent Research and Development, June 22-25, 1992, Kailua-Kona, Hawaii.

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to provide protection over the entire bark surface may be of equal importance as release rate. If this problem cannot be resolved, there may be protected and unprotected bands on the trunk. Beetle colonization of the unprotected areas could result in the death of the tree. If a commercial application is to be developed, the material must be easily applied, relatively long lasting, and effective.

An alternative approach to tree protection with inhibit-tors is to reduce beetle populations using attractants to either mass trap or concentrate beetles into trees that can be removed. There are indications that the technique may work under specific conditions (Bedard and Wood 1974, Borden and others 1983), but may not be appropriate for others. An alternative approach may be a combination of mass attract-tion and inhibition. That is, using attractants to concentrate beetles in traps or trees that can be removed and placing inhibitors in adjacent stands of trees that must be protected to interrupt the landing response. This approach may be particularly useful in areas where public lands are adjacent to private properties. Trees on private land at the urban forest interface have a higher value than trees on public lands because of their contribution to the property value. Thus, if cooperative programs can be developed to concentrate beetles in trees on public forests before moving into private urban forests, then the most valuable trees may be protected. Alternatively, where there are isolated highly valued public (e.g., parks or campgrounds) or private stands of trees at risk of beetle mortality, beetles may be moved out of the stands into traps baited with attractants. The process may be enhanced when interruptants are placed within the stand to inhibit the beetles from landing on trees as they fly through the area. The inhibit-attract or push-pull approach may be very effective in these urban or recreational forest stands.

The use of pheromones may not be appropriate for large scale forest protection, in part because there is limited information available concerning the fate of the population of beetles. Disruption of the colonization process in one area without removal of beetles could result in increased tree mortality elsewhere. The possibility of shifting beetle problems around forests remains an uncertainty because it has never been rigorously tested. However, pheromone-based management has great potential for individual tree or focused, limited-scale stand protection. There are technical problems of application technology and associated costs that must be resolved. Currently, there is a growing interest in using the technology, but appropriate caution must be observed to prevent unrealistic expectations from developing and dissatisfaction with the technology resulting as a conessquence. Research must continue to provide information that can solve some of the technical problems and take advantage of the current level of public support.

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Bark Beetle Research in California[1]

Patrick J. Shea **John M. Wenz**[2]

Abstract: The western pine beetle, *Dendroctonus brevicomis,* is the most important insect pest of ponderosa pine, *Pinus ponderosa,* in California, and the level of tree mortality has been exacerbated by the current drought conditions. *Ips* spp are a chronic problem in downed ponderosa pine and, if allowed to build up, populations can be a threat to standing trees. Before effective semiochemical-based management strategies can be tested, the flight periodicity (i.e., when are beetles flying) of the target species must be well known. Two years of flight periodicity data on western pine beetle and one year of flight periodicity data on *Ips paraconfusus* and *Ips pini* data are presented. The response of western pine beetle to various enantiomers of verbenone and verbenone combined with ipsdienol are described.

The western pine beetle (WPB), *Dendroctonus brevicomis* Leconte, (Coleoptera:Scolytidae) has historically been considered the most destructive bark beetle in California (Keen 1966) and is currently causing above-normal levels of ponderosa pine (*Pinus ponderosa* Lawson) mortality throughout most of the State. Extended drought conditions in much of the Sierra Nevada and Southern California have contributed to the high level of western pine beetle activity. Pest management alternatives currently available to resource managers to prevent or reduce unacceptable western pine beetle-related mortality are limited to maintaining stands at appropriate stocking levels, preventive treatment of individual trees with insecticides, and direct control.

Individual tree treatment can be effective but is not feasible over large areas. Currently available direct control methods for western pine beetle have not been shown to be consistently efficacious on an area-wide basis. Through time, getting stands to, and maintaining them at, appropriate stocking levels reduces tree susceptibility to western pine beetle through increased host tree growth and vigor. However, the current trend in management direction recognizes the importance of wildlife habitat and other nontimber resources which has resulted in a desire to have more multi-storied, uneven-aged stands with greater crown closure. Such complex resource management objectives increase the need for effective strategies to reduce impacts caused by western pine beetle. Development of effective techniques to control western pine beetle that result in prevention/reduction of unacceptable resource impacts would benefit resource managers throughout the range of western pine beetle in the western United States.

Large populations of *Ips* beetles sometimes build up in logging slash or blowdown caused by severe winter storms. During these events *Ips* switch their attack behavior to standing trees and cause top-kill or whole tree mortality. These situations become even worse during periods of drought. Currently, under the concept of ecosystem management large amounts of coarse-woody debris (CWD) will be left on the ground during commercial logging operations or timber stand thinning projects. This CWD is meant to improve wildlife habitat (small mammals) and improve soil nutrient cycling. Unfortunately this CWD may also be utilized by populations of *Ips* beetles. As with the western pine beetle, effective strategies to manage *Ips* are needed to prevent unacceptable losses of valuable forest resources.

In 1990 and 1991, cooperative experimental work was conducted by the Forest Service Pacific Southwest Research Station and State and Private Forestry, Forest Pest Management, Pacific Southwest Region (Region 5) as part of a continuing, west-wide, effort to develop and implement environmentally sensitive, biologically effective, and economically feasible methods to reduce and/or prevent impacts on forest resources by the western pine beetle.

Objectives

The basic objectives of the experiments discussed here were to (1) determine the effectiveness of several enantiomeric blends of verbenone to interrupt the response of western pine beetle to Lindgren funnel traps baited with the western pine beetle lure and (2) determine the flight periodicity of western pine beetle, *Ips paraconfusus* Lanier(IPA) and *I. pini* (Say) (IPI), in selected locations throughout California.

Objective 1.

Recent developments make the use of verbenone potentially effective as a protectant for individual trees and high-value stands. Verbenone has been shown to reduce the catch of western pine beetle at sources of synthetic and natural attractant (Bedard and others 1980). It has also been shown that the higher the release rate of verbenone, the greater the reduction in trap catch. Verbenone has two chiral forms (plus and minus) called enantiomers. In addition, chirality has been shown to be an important factor in determining the responsiveness of several bark beetles (Birch and others 1977, Shea and Wenz unpublished data). The experiments discussed here were a necessary step in the process leading to the development of an individual tree or/and stand protection technology.

In 1990, the tests were conducted at the following four locations to determine the effectiveness of several enantiomeric blends of verbenone in interrupting the response of

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western pine beetle to Lindgren funnel traps baited with the WPB lure: Shasta-Trinity National Forest, Eldorado National Forest, Sierra National Forest, and Sequoia National Forest. Sixty (60) Lindgren funnel traps were established at each location at least 0.2 miles from each other. The following treatments were randomly assigned, 10 traps/treatment, at each location:

1. WPB bait alone.
2. WPB bait + (-)97 pct,(+)3 pct verbenone
3. WPB bait + (+)97 pct,(-)3 pct verbenone
4. WPB bait + (+)50 pct,(-)50 pct verbenone
5. WPB bait + (+)75 pct,(-)25 pct verbenone
6. WPB bait + (-)75 pct,(+)25 pct verbenone

All traps were placed along roads in second-growth ponderosa pine stands. Traps were hung in non-host trees at least 90 ft from the road. Traps were emptied weekly from 4/27/90 on the Sequoia site and 5/21/90 on the remaining sites to 10/16/90. All western pine beetles from each trap were counted, and the mean number of western pine beetles/trap was calculated for each week at all locations.

Complete statistical analysis of all individual data sets has not been completed, but ANOVA of the combined data from all four locations indicated that there was a significant difference between two of the treatments when compared to the baited traps alone. The mean number of western pine beetles/trap/week of the (-)97 pct/(+)3 pct and (+)50 pct/(-)50 pct verbenone treatments (191.3±28.0, 217.1±30.6, respectively) was significantly lower (F=6.44,df=5,96, alpha=.05) than the mean number of western pine beetles/trap/week (377.3±30.3) of the western pine beetle baits alone. This amounted to a 50.6 and 47.3 percent reduction respecttively, in trap catch compared to the WPB bait alone traps.

Based on these 1990 results and research by Paine and Hanlon (1991) that indicated the addition of (+)50 pct/(-)50 pct ipsdienol further decreased trap catches over verbenone alone, the enantiomeric blend studies were continued at two locations (Eldorado National Forest and the Stanislaus National Forest) in 1991. The following treatments were assigned to 60 Lindgren funnel traps, 10 traps/treatment, at each location:

1. WPB bait alone.
2. WPB bait + (+)50 pct, (-)50 pct verbenone.
3. WPB bait + (-)97 pct,(+)3 pct verbenone.
4. WPB bait + (+)50 pct,(-)50 pct verbenone + (+)50 pct,(-)50 pct ipsdienol
5. WPB bait + (-)97 pct,(+)3 pct verbenone + (+)50 pct,(-)50 pct ipsdienol
6. WPB bait + (+)50 pct,(-)50 pct verbenone (low release rate)

The results of 1991 data were consistent with the 1990 data for the two comparable enantiomeric treatments. The two verbenone treatments (treatments 2 and 3) reduced trap catch about 42 pct compared to the WPB baited traps alone. Based on the mean number of western pine beetles/trap/week for all time periods, both the (+)50 pct,(-)50 pct and the (-)97 pct,(+)3 pct verbenone + ipsdienol treatments (127+15.5, 115+12.2 respectively) were statistically different (F=15.04, df=5,102, alpha=.05) than the western pine beetle bait alone (485.5+47.0), resulting in about 78 pct reduction in western pine beetle catch.

Objective 2.

In 1990, the western pine beetle bait-alone traps used in the verbenone enantiomeric blend experiments were also used to determine the flight periodicity in the same four geographic locations. Therefore, there were 10 western pine beetle bait-alone traps in each location. Western pine beetles were removed and counted weekly to determine the mean number of beetles per trap per location.

The results have not been statistically analyzed, but some preliminary observations can be made. Throughout the 1990 trapping period it appears that western pine beetles were flying in all four geographical areas consistently between late May/early June through early October *(figs. 1-4)*. During this period weekly mean catches varied from less than 100 to about 1300 western pine beetles/trap for each location. The highest trap catch was in the Shasta location during 1991 when the weekly average per trap was about 2600 beetles *(fig. 1)*. This site also exhibited the largest difference between years in beetles trapped per week. Without additional analysis such as time series analysis the variability associated with the weekly trap catches makes it difficult to distinguish between flight peaks and/or determine causes of the fluctuations.

The flight periodicity work was continued in 1991 in the same locations as in 1990 except that the Sierra National Forest location (Oakhurst) was replaced by an area on the Stanislaus National Forest (Sonora). As in 1990, 10 traps were baited with the western pine beetle lure at each location. All traps were checked weekly, beginning in May 1991. In addition, at these same locations, five traps each were baited with the appropriate attractant for the pine engravers, *Ips paraconfusus* (IPA) and *I. pini* (IPI). The pine engraver traps were checked weekly beginning the first week in June.

In 1991, western pine beetle were caught at each location around the middle of May except on the Sequoia National Forest where beetles were not trapped until the first week of June *(fig. 4)*. The flight of western pine beetle continued at all locations through the first week of October. As in 1990, there was considerable variation between weekly means of western pine beetles/trap within the same locality. Means ranged from less than 100 to 2600/trap. Seasonal means for number of beetles trapped for all areas were two to four times greater in 1991 than in 1990. The Shasta location had the lowest mean catch in 1990 but the highest in 1991; the Eldorado location had the highest in 1990 and the lowest in 1991.

No comparable periodicity data on ips flight were collected in 1990. Both IPA and IPI were caught at all four geographical locations in 1991 *(figs. 5-8)*. The Eldorado site

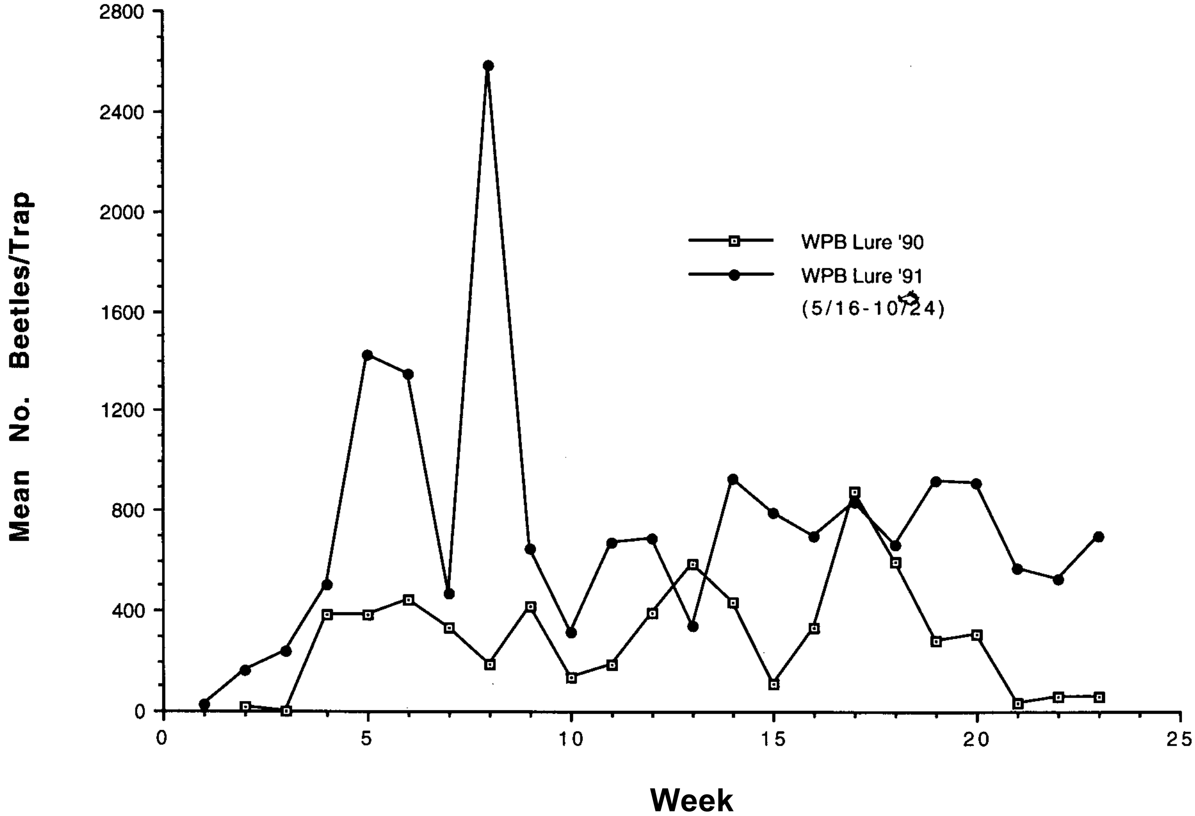

Figure 1-Flight periodicity of western pine beetle at the Shasta site, 1990-1991.

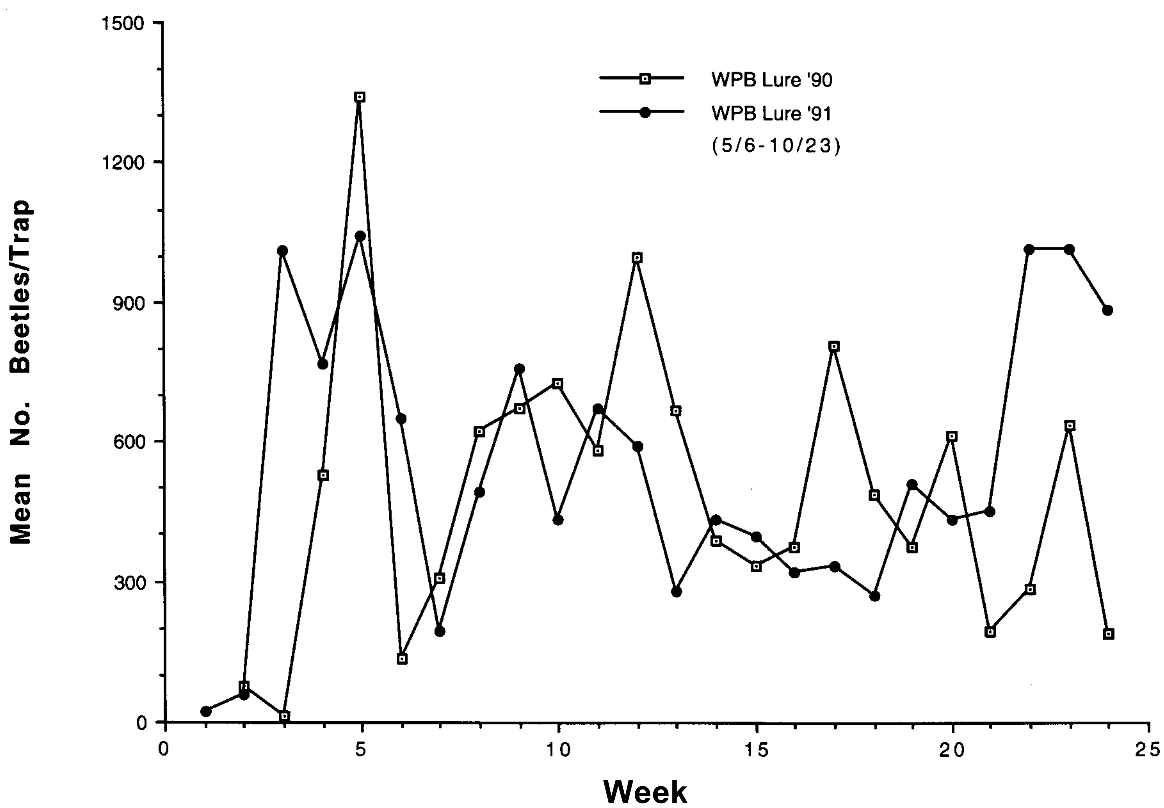

Figure 2-Flight periodicity of western pine beetle at the Georgetown site, 1990-1991.

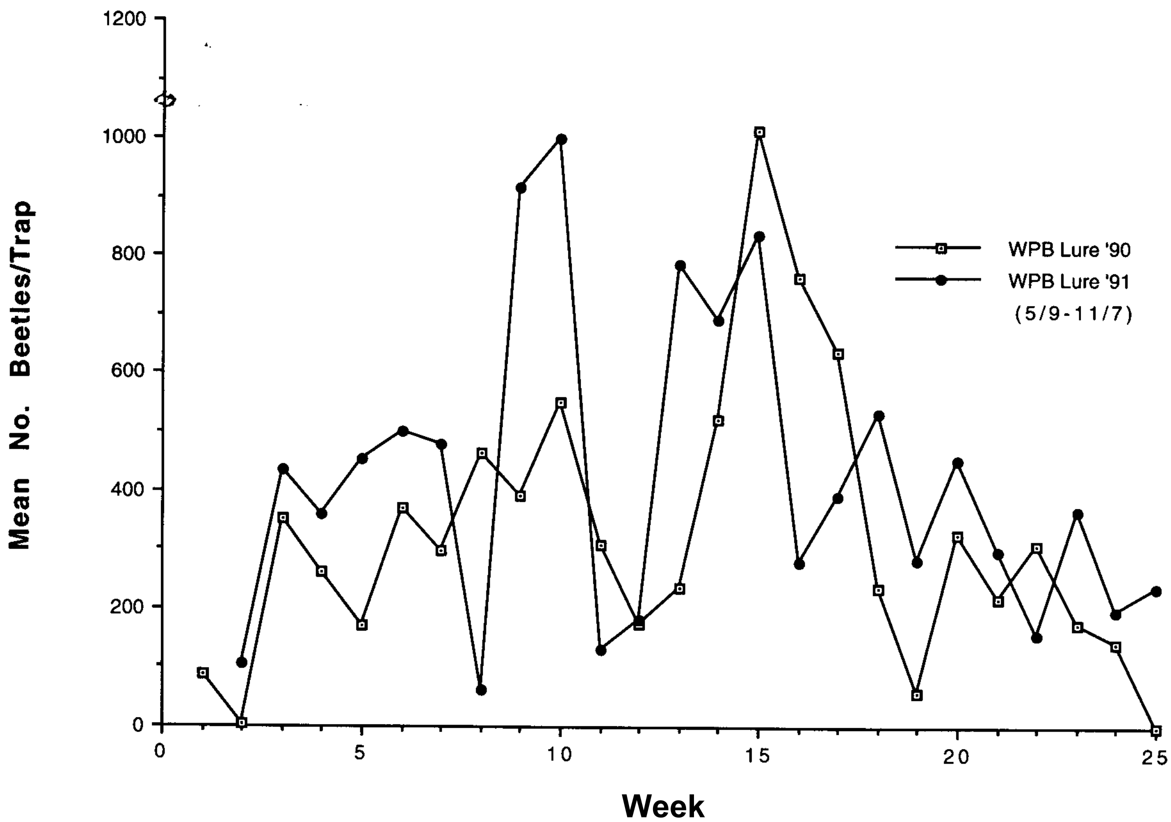

Figure 3-Flight periodicity of western pine beetle at the Sonora/Oakhurst site, 1990-1991.

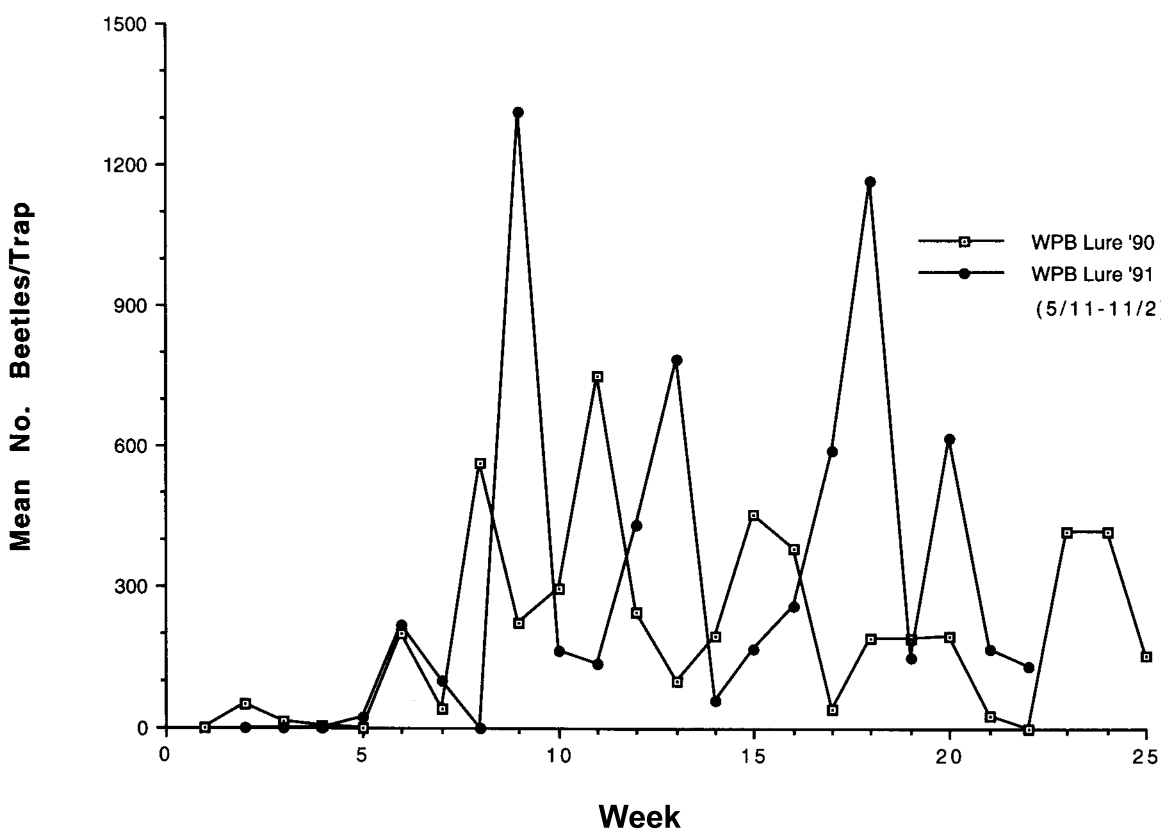

Figure 4-Flight periodicity of western pine beetle at the Sequoia site, 1990-1991.

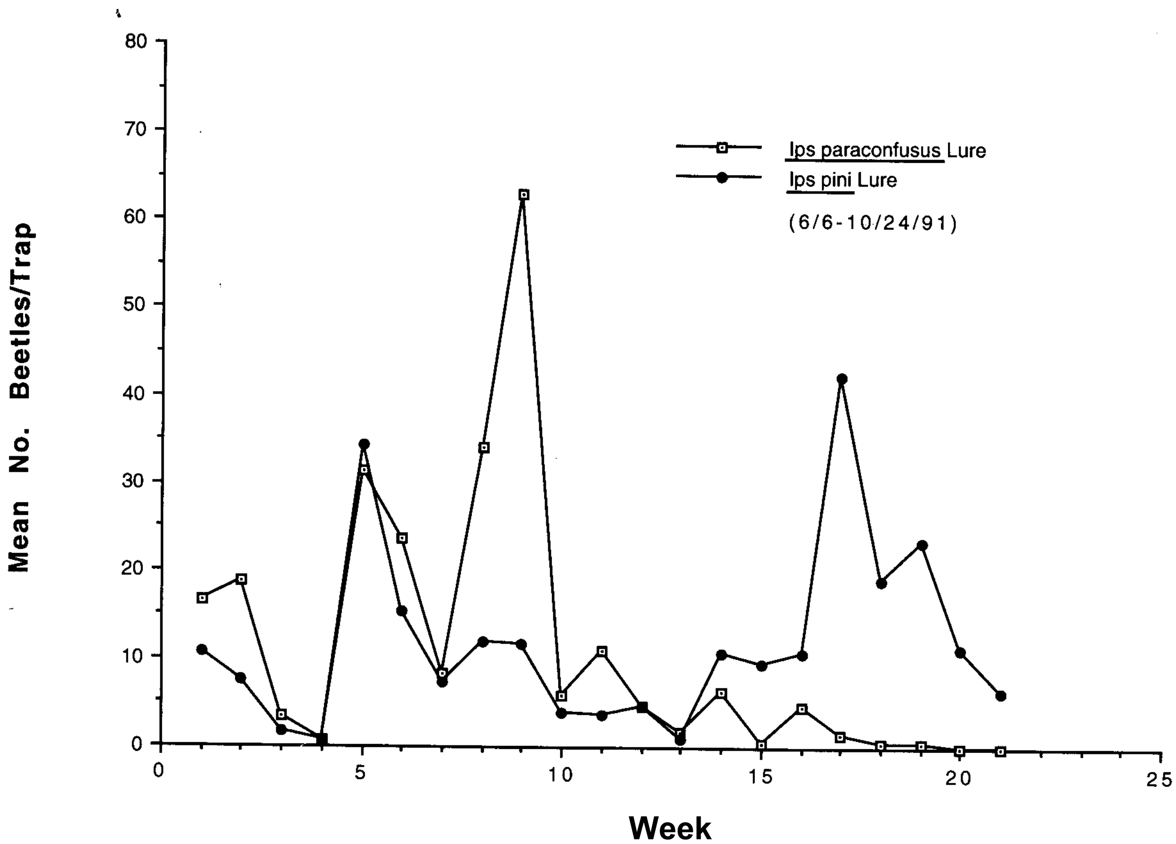

Figure 5-Flight periodicity of *Ips paraconfusus* and *I. pini* at the Shasta site, 1991.

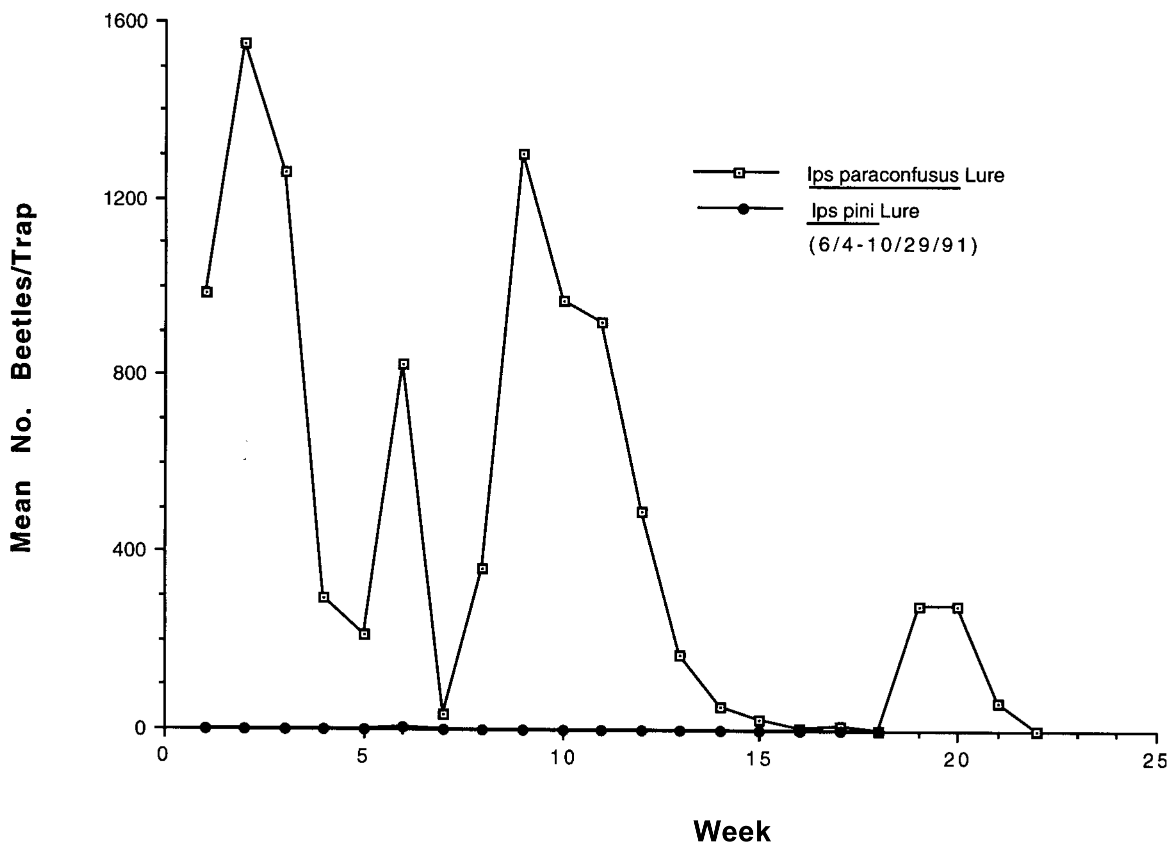

Figure 6-Flight periodicity of *Ips paraconfusus* and *I. pini* at the Georgetown site, 1991.

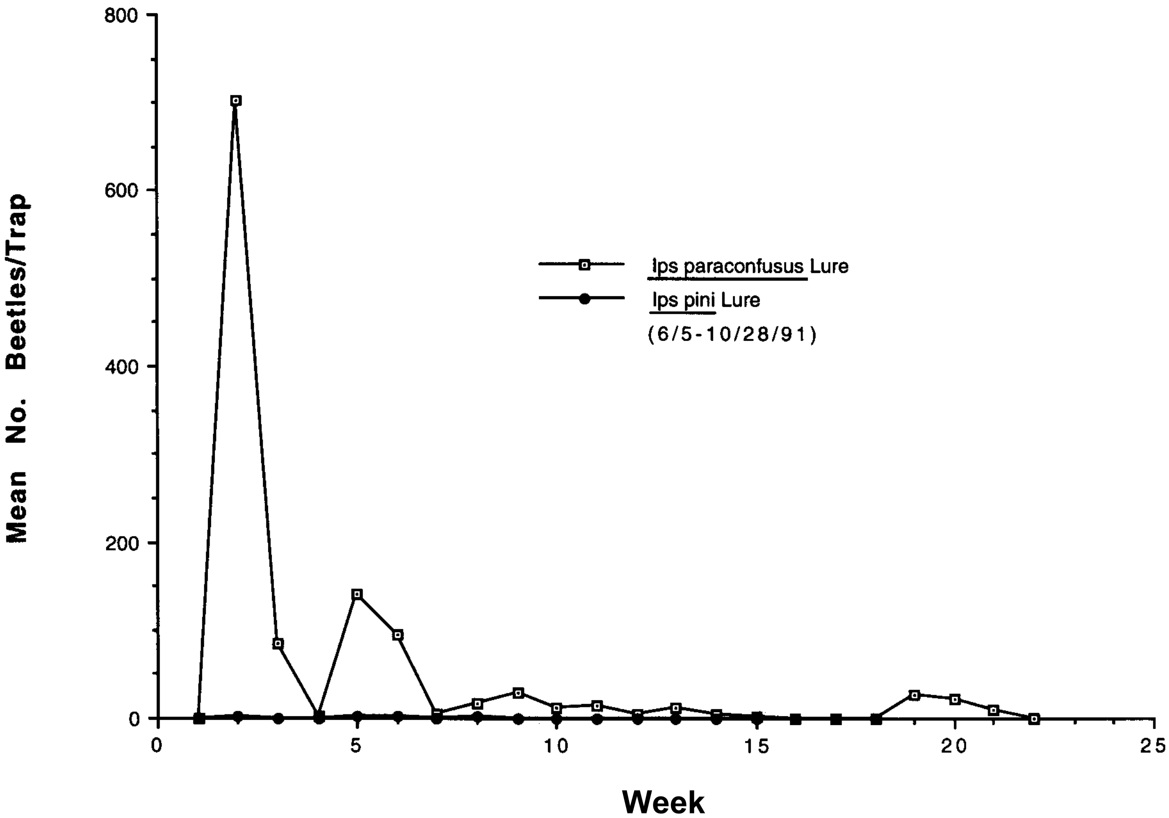

Figure 7-Flight periodicity of *Ips paraconfusus* and *I. pini* at the Sonora site, 1991.

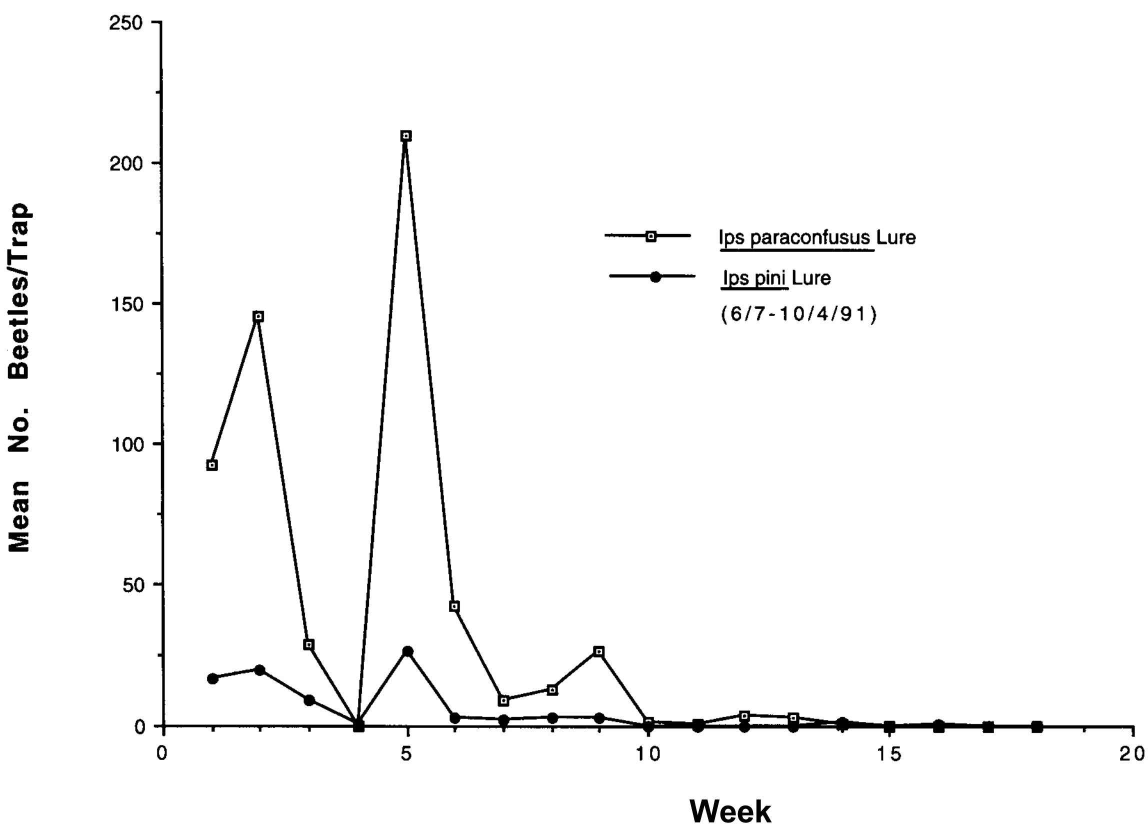

Figure 8-Flight periodicity of *Ips paraconfusus* and *I. pini* at the Sequoia site, 1991.

caught the most IPA *(fig. 6)* and the Shasta site the fewest *(fig. 5)*. IPA were caught from early June, when the traps were first established, through early October *(figs. 5-8)*. However, except for the Eldorado site, weekly mean trap catches declined to less than 10 IPA/trap after the first week in August. At the Eldorado site *(fig. 6),* IPA were caught consistently in relatively high numbers (average of about 750 IPA/trap) through early September and continued to be trapped at low numbers into early October. For IPI, the Shasta *(fig. 5)* and the Sequoia *(fig. 8)* sites caught far more pine engraver beetles than the Eldorado and the Stanislaus locations. Inadequate numbers (less than a mean of 4 IPI/trap/week) of beetles were caught at the Eldorado and Stanislaus locations, making it difficult to draw conclusions about flight periodicity at those sites. On the Sequoia, IPI were trapped from the first week in June through early September *(fig. 8);* however, mean weekly trap catches averaged less than 10 IPI/trap after mid-July. At the Shasta location, IPI were caught from the first week in June through the early October with mean weekly trap catches ranging from 1 to about 40 IPI/trap *(fig. 6)*.

Current (1992) and Future Cooperative Research on Bark Beetle Pheromones

Based on the results with verbenone summarized above, additional cooperative work is being conducted to assess the efficacy of (+)50 pct/(-)50 pct verbenone in combination with (+)50 pct/(-)50 pct ipsdienol for preventing/reducing western pine beetle-related mortality in ponderosa pine stands in California. Work will also be initiated to evaluate the efficacy of verbenone to protect individual ponderosa pine from attack from western pine beetle. In addition, field tests are being conducted to determine the efficacy of several rates of (-)50 pct/(+)50 pct ipsdienol and (-)86 pct/(+)14 pct verbenone in combination for inhibiting colonization and population buildup of IPA in piled and dispersed ponderosa pine slash. The flight periodicity studies will continue with WPB, IPA, and IPI and be expanded to include the mountain pine beetle, *Dendroctonus ponderosae* Hopkins. Further, flight periodicity for these four species will be evaluated along elevational gradients in selected locations along the west side of the Sierra Nevada.

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Bark Beetle Pheromones: A Current Industry Assessment[1]

Peter J. Putland[2]

The history of the pheromone business is liberally sprinkled with failures and very sparsely dotted with successes. Only a cursory look at the business is needed to tell the interested observer why the failure rate has been so high. I would like to discuss this feature with respect to a segment of the pheromone business I know fairly well--bark beetle pheromones.

The North American market for bark beetle pheromone products is small, and it is not developing very quickly. The market that does exist is subject to the vagaries of weather and beetle biology. When one considers the cost of doing the research and development of just a single product, patenting that product where necessary, obtaining product registration where necessary, and then taking the product to market, you can see that a great deal of care must be exercised if a company is to remain solvent.

In addition this business incurs all the normal overhead expenses that most businesses have such as building rent, utilities, insurance, employee salaries and benefits, and so on. Let me give an example of the order of magnitude of the cost of taking just one product from the basic research stage to market.

I will use the example where patenting and registration are required. Patents and/or registration are not required in all cases:

Typical patent costs	$20,000
Company labor costs	200,000
Research and development (R & D)	500,000
Registration	50,000 (minimum)
	$770,000

These figures do not include the additional R&D costs that are covered by noncompany personnel. Researchers from federal and state agencies help provide the linkage from conception to market. In our business we rely heavily on the field work that these people perform just as we rely heavily on some basic researchers from the university sector. Finally, there are the costs associated with field trials that must be conducted to finalize formulation and generate efficacy data. By the time a product moves through this phase of its development, the equivalent of at least another 2 person-years of labor and related expense has been incurred.

None of the items mentioned above are extraordinary or unusual to a business that is bringing new products to the marketplace. The one thing that makes this particular kind of business different is that the market for products produced is fickle and very slow to develop.

A number of factors can be identified that contribute to this condition. Some of these factors are:

- the need to conduct extensive field trials in varying geographic areas,
- a slow-to-develop public insistence that new bio-compatible technology be put into use at a faster pace, and
- the time and resources required to satisfy all regulatory agency requirements.

I think it is clear that in order to support the development of a new product, there must be revenue flowing in from the sale of previously developed products. If revenue from product sales is insufficient, this directly affects the continuing development of new products and could, in the extreme, affect on the financial health of the company.

These are some of the considerations that will undoubtedly have a bearing on the future of the bark beetle pheromone business. We feel very strongly that the bark beetle pheromone business has a good future. This future is based upon the infrastructure that has taken years to achieve. As public pressure grows to force more rapid implementation of environmentally sound forest pest management alternatives, the infrastructure will react in a positive manner. We see this beginning to happen with the U.S. Government initiative currently getting under way to find alternatives to insecticides for the management of bark beetles in the western United States.

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