PEST MANAGEMENT SERIES

INTEGRATED PEST MANAGEMENT ON CALIFORNIA PARKLANDS

Number 4

CONTROL OF BARK BEETLES

Pest Management Analysis and Planning Program

STATE OF CALIFORNIA
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Branch of Environmental Monitoring and Pest Management
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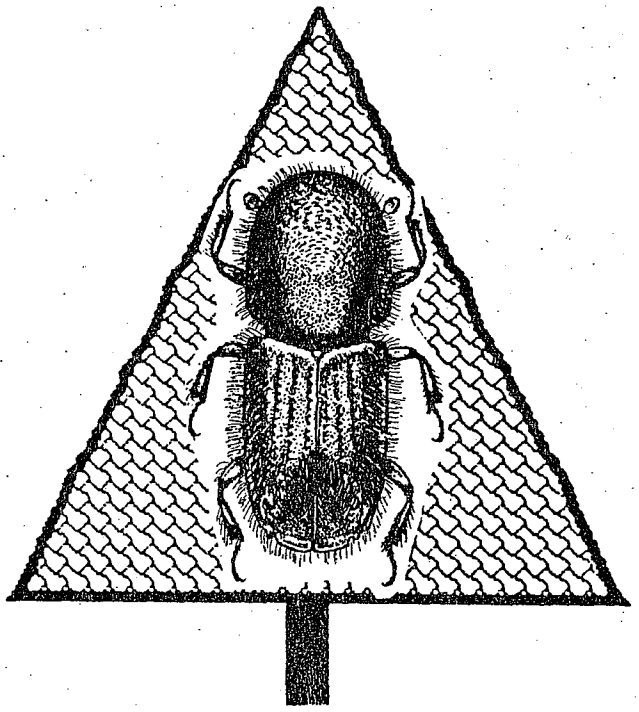
CONTROL OF BARK BEETLES



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Pest Management Analysis and Planning

Pest Management Series

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Report to California Department of Parks and Recreation

January, 1987

TABLE OF CONTENTS

	PAGE
Table of Contents	i
List of Figures and Tables	ii
Acknowledgements	iii
Disclaimer	iii
Introduction	1
Pest Management Need	1
Pest Identification	4
Biology by Species	7
Mountain Pine Beetle	7
Damage	7
Description	7
Development and Range	7
Western Pine Beetle	8
Damage	8
Description	9
Development and Range	9
Red Turpentine Beetle	9
Damage	9
Description	10
Development and Range	10
California Fivespined Engraver Beetle	10
Damage	10
Description	11
Development and Range	11
Detection and Monitoring	11
Control Thresholds	16
Control Measures	17
Biological	18
Cultural	19
Tree Resistance	20
Sanitation/salvage	23
Thinning	24
Physical Destruction of Infested Trees	26
Chemical	27
Pheromones	28
Lindane	29
Chlorpyrifos	29
Oxydemeton-methyl	30
Carbaryl	30
Summary	31
Bibliography	40
Methods	44

Figures

PAGE

1. Beetle host interactions..... 32
2. General life cycle..... 33
3. Beetle sketches..... 34
4. Preferential distribution..... 35
5. General examples of bark beetle sign..... 36

Tables

1. Pinus species in California..... 5
2. Preferred hosts of bark beetles..... 5
3. USDAFS guide for use when considering pesticides..... 37
4. Recommendations for chlorpyrifos use..... 39

ACKNOWLEDGEMENTS

A special thanks is due the following:

Mark Pepple for extensive review and valuable suggestions.

Linda Heath for contributions concerning artwork, layout and style.

C.S. Koehler and D.R. Dahlston (University of California); B. Barrette, D. Burns, N. Cook, and B. Hagen (California Department of Forestry); S. Harrison (California Department of Parks and Recreation); S. Marshall and D. Owen (USDA Forest Service) for technical review.

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CONTROL OF BARK BEETLES

INTRODUCTION

There are a multitude of insects that inhabit the pine forest community. The most destructive group of insects belong to the family Scolytidae, known as bark beetles. The family is represented by 44 different genera and 170 species in California. This group includes beetles that feed not only in the bark, but in the xylem, and other plant parts of trees. Many bark beetles are native to California, but others have been introduced, such as Scolytus multistriatus. The genera Dendroctonus and Ips contain species that mine the phloem-cambium region and are some of the most destructive. Because of the diversity of California forests, and the complexity involved in studying each species of bark beetle in a particular ecosystem, this report should be used as a general introduction to the four species of bark beetles that are reported. Three species of Dendroctonus and one species of Ips are discussed in this report. Though there are other bark beetles that are serious pests in California forests, such as Scolytus ventralis which attacks mature true firs, these are four bark beetles that specifically attack pines.

PEST MANAGEMENT NEED

Bark beetles cause damage to pines by mining in the phloem-cambium region, where they spend the majority of their lifecycle. The feeding and tunneling effectively girdles the pine tree, cutting off the flow of

nutrients within the tree. The beetles also introduce fungi into the tree. Blue stain fungi have been associated with Dendroctonus brevicomis and Dendroctonus ponderosae (Safranyik et al., 1974). The fungi invade the sapwood, disrupting the vascular system, and thus hastening the death of the tree. Blue stain fungi also lower the market quality of the wood by staining it, though in some cases, the stained wood is desired as a building material.

Bark beetles typically attack trees that are predisposed by some factor such as environmental stress, damage from other insects and pathogens, or mechanical injury. Water stress brought on by drought, or nutrient stress caused by competition for nutrients and sunlight can predispose the pine tree to attack (Figure 1). Air pollution can contribute to pine stress and increase the possibility of bark beetle damage. Studies have shown that ponderosa pines in the San Bernadino mountains with advanced symptoms of oxidant injury were most frequently infested and killed by the mountain pine beetle and the western pine beetle (Stark et al., 1968). A later study in the same area, showed that ponderosa stands with a higher proportion of oxidant damaged trees had greater losses and allowed the western pine beetle to increase at a greater rate than in stands that had a lower proportion of damaged trees (Dahlsten and Rowney 1980).

In the westside Sierra Nevada mixed conifer forest, mountain pine beetle and western pine beetle kill some ponderosa pine that has been predisposed by the black stain root disease, Verticicladiella wageneri (Goheen and Cobb 1980).

For some Dendroctonus species, older, overmature trees are frequently attacked. But younger trees are also attacked if they are under stress. The mountain pine beetle will frequently attack dense stands of second growth ponderosas (greater than 150 square feet basal area). Some bark beetles need a minimum amount of phloem to complete their development, but the exact relationship between tree size/age and susceptibility is still unclear (Mitchell et al., 1983). It has also been suggested that the larger trees present a larger silhouette and landing surface for the bark beetles (Shepherd 1966). Ips species prefer smaller diameter pine (5 to 9 inches), and the tops of larger pines (Marshall personal communication 1987).

Species that attack and kill healthy trees are said to be primary killers (Rudinsky 1979). Usually, primary species attack trees that are of a reduced growth rate. Outbreaks occur when conditions are adverse to the host trees, such as during periods of environmental stress. During outbreaks, bark beetles are less selective and will attack both stressed and healthy trees. Secondary species attack dead or dying trees, often those attacked previously by primary species.

The bark beetles release aggregation pheromones during an attack, attracting other bark beetles to the target tree. The beetles and fungi in combination cause the death of the tree.

Native bark beetles are part of the natural environment of the coniferous forest. The bark beetles play an important part in the productivity and natural cycling of the forest ecosystem. Older, overmature trees, weakened trees, or trees that are in dense stands may be killed by bark beetles and other organisms. These dead trees create a large fuel load that leads to forest fires, followed by a period of growth and regeneration.

Trees that have been killed by bark beetles and other organisms have an increased potential to fall. This can pose a serious problem in campgrounds, where people can be killed or injured, or facilities damaged by falling trees or limbs. Even in remote areas, large numbers of dead trees may not be compatible with recreational uses of the land. Increased fire hazard, loss of aesthetic value, and significant wildlife habitat change may be serious concerns. Therefore, a management program is needed to promote stability of bark beetle populations and reduce the incidences of major outbreaks.

PEST IDENTIFICATION

Although there are a large number of bark beetle species in California, this report focuses on the four major species that attack pines in

California. The major species of pines in California are listed below in Table 1. The four species of bark beetles and their preferred hosts are listed in Table 2.

Table 1. Pinus Species in California

P. contorta	Lodgepole pine	*P.attenuata*	Knobcone pine
P.ponderosa	Ponderosa pine	*P.coulteri*	Coulter pine
P.lambertiana	Sugar pine	*P.albicaulis*	Whitebark pine
P.sabiniana	Digger pine	*P.jeffreyi*	Jeffrey pine
P.monticola	Western white pine	*P.radiata*	Monterey pine

D. R. Hamel, 1983
Courtesy of USDA Forest Service

Table 2. Preferred Hosts of Bark Beetles

Dendroctonus ponderosae	Sugar pine
Mountain pine beetle	Lodgepole pine
	Western white pine
	Whitebark pine
	Poderosa pine

Table 2 (cont.)

Dendroctonus brevicomis	Ponderosa pine
Western pine beetle	Coulter pine
Dendroctonus valens	Ponderosa pine
Red turpentine beetle	Lodgepole pine
	Jeffrey pine
	Sugar pine
	Monterey pine
	Western white pine
Ips paraconfusus	Ponderosa pine
California fivespined	Sugar pine
engraver beetle	Coulter pine
	Monterey pine
	Digger pine
	Lodgepole pine
	Western white pine

D. R. Hamel, 1983
Courtesy of USDA Forest Service

BIOLOGY BY SPECIES

MOUNTAIN PINE BEETLE

Damage

The mountain pine beetle is considered the most damaging of all the bark beetles in the western United States. Millions of lodgepole pines, one of the hardest hit species, are killed each year (USDA 1985). The mountain pine beetle is a primary killer of pine trees, but it can be secondary to other bark beetles or to pathogens. For example, the mountain pine beetle can be secondary to attacks by the western pine beetle. The mountain pine beetle attacks older lodgepole pine, and old growth ponderosa, dense stands of second growth ponderosa, and younger trees of other species.

Description

The adult mountain pine beetle is 3.7-7.5 mm in length. It is a stout, black, cylindrically shaped beetle.

Development And Range

There is usually one generation per year (Figure 2) in most of the range of the mountain pine beetle (Furniss and Carolin 1977). Below 6,600 feet, south of latitude 40 degrees north (Marysville), 2-3 generations

per year can develop (Bright and Stark 1973). The beetles overwinter as larvae or adults. They are found in California mostly on the western slopes of the Sierras, and occasionally in the coastal mountains from Oregon to Mexico.

WESTERN PINE BEETLE

Damage

Where many experts consider the mountain pine beetle the most destructive, others believe the western pine beetle to be the most serious pest in the pines of California (Bright and Stark 1973). The western pine beetle does not have as wide of a host range as the mountain pine beetle, yet it is a strong primary killer of pines during an outbreak. It is the bark beetle most frequently associated with the death of larger ponderosa pines. It has a greater ability to overcome trees with a strong oleoresin flow (see Tree Resistance) than the mountain pine beetle.

Besides the mechanical damage of larval feeding, the western pine beetle, like the mountain pine beetle, aids in the destruction of pine trees by introducing blue stain fungi into the sapwood. The western pine beetle rarely attacks trees less than 6-12" in diameter, or 30 centimeters DBH (diameter breast height) (Stark and Dahlsten 1970). Like the mountain pine beetle, once the beetle has successfully invaded a tree, aggregation phermones are released.

Description

The western pine beetle is the smallest of the four bark beetles. The adult is 3.2-5 mm long. It is dark brown in color (Figure 3).

Development And Range

One to three overlapping generations a year are produced, depending upon environmental conditions (Miller and Keen 1960). The beetle overwinters as adults, larvae, or pupae. Flights and attacks start in late spring and continue until the onset of cold weather. The western pine beetle has a similar range as the mountain pine beetle: from Oregon to Mexico, scattered in the coastal mountains, and also in the Sierra Nevadas.

RED TURPENTINE BEETLE

Damage

The red turpentine beetle is different from the western and mountain pine beetles because it is considered a secondary invader. It may attack apparently healthy trees, but is usually unsuccessful at killing them. It attacks pines at the base of the tree, up to 20 feet from the ground. It is strongly attracted to fresh oleoresins (natural tree exudates) from freshly cut stumps, limbs, fire-scorched, or injured trees.

Description

The red turpentine beetle is shiny, reddish brown in color. It is the largest of the bark beetles. The average length of an adult is 8 mm.

Development And Range

The beetle has one generation per year in Northern California. At higher elevations and colder temperatures, it may take up to two years to complete one generation. There are 2-3 generations per year in warm areas at lower elevations in Southern California (Bright and Stark 1973). Flights and attacks occur throughout the the warm season. The red turpentine beetle is found in the Sierras, and more extensively in the coastal mountain ranges than either the mountain or the western pine beetle.

CALIFORNIA FIVESPINED ENGRAVER BEETLE

Damage

The California fivespined engraver is the most damaging of the 9 Ips species found in California (Bright and Stark 1973). The fivespined engraver will attack standing trees, as well as fresh slash (freshly cut or fallen trees and branches). In the central Sierra Nevada mountains, ponderosa pine is especially at risk to attack (USDA 1985). The beetle will kill saplings and young trees up to 26 inches in diameter. Ips

will often move into the crowns of larger trees, causing top kill. Ips also produces aggregation phermones during an attack.

Description

The California fivespined engraver beetle is named for the five spines located on each half of the elytra (wing covering) declivity (Hopping 1963). The adults are reddish brown to black, ranging from 3.0-6.5 mm in length.

Development And Range

There are 2-5 generations per year in California. The beetles overwinter as larvae, pupae, or callow adults. Males attack trees first, and attract females to nuptial chambers beneath the bark. They are found in the Sierras and throughout the coastal mountains, including the San Francisco Bay area. Populations may build up in the spring in fresh slash, and then move into living trees. The flights begin in late February in the coast range, and mid-April at higher elevations. The flights continue through the warm season.

DETECTION AND MONITORING

Bark beetle infestations and damage can be identified in three ways:

1) By capturing a specimen, and using a key.

2) By visually appraising the symptoms on the tree.

3) By examining the galleries beneath the bark.

In order to determine the increase of infested trees in a forest, monitoring programs are needed. Most of the monitoring for bark beetle attacks is based on signs of attack (actual presence of beetles), and host symptoms (responses of the tree to attack).

Entrance and exit holes are signs of bark beetle activity. Pitch tubes and boring dust are also signs of attack. Pitch tubes are often a combination of resin and boring dust, and are exuded from entrance holes (Rudinsky et al. 1979). Pitch tubes plus dry boring dust are usually a sign of Dendroctonus species activity, but not Ips species. If the sap flow is poor, as is often the case with stressed trees, pitch tubes may not be formed following a beetle attack. Red boring dust at the base of the tree, or in the bark crevasses, is a sign of either Dendroctonus species or Ips invasion. Ips will create either yellow or red boring dust (Furniss and Carolin 1977). White boring dust is a sign of Ambrosia beetles, which are secondary invaders.

Woodpeckers and their damage can also indicate a bark beetle infestation. Of the four beetles mentioned, woodpecker presence is mostly associated with the western pine beetle. The woodpeckers feed in two ways. In some cases, as with the western pine beetle, they will flake the bark off to get at the larvae. In trees with smooth bark,

they will often make a hole through the bark to get at the adult stage underneath (Dahlsten personal communication 1987).

The bark beetles of various species maximize the use of the tree by distributing themselves at preferred locations (Figure 4). Therefore, all monitoring for signs should not be down at ground level.

Certain bark beetles require a minimum thickness of phloem in which to complete their development. The mountain pine beetle requires a minimum of 1.5 cm (1/16") of phloem to survive in lodgepole pine (Safranyik et al. 1974). Therefore, lodgepole pines that have a small diameter with thin bark are not good subjects for mountain pine beetle monitoring programs.

Foliage symptoms begin to appear as the vascular system is destroyed. The importance of monitoring foliage symptoms is to track outbreaks and possible epidemics of bark beetle populations in large forested areas. Foliage symptoms can also be used on single trees that have been attacked. This is important in campgrounds, where concern over tree failure dictates a precise evaluation of individual trees.

Foliage symptoms show a chronological progression from one color to another. Color changes occur rapidly in warm weather, and slower in cool weather. Foliage symptoms usually appear the following spring after a mid-summer attack (Safranyik et al. 1974). Below is the color

progression for a beetle-killed ponderosa and Monterey pine (Rudinsky et al. 1979). Other pines may show a similar progression.

GREEN

FADED GREEN

YELLOW

RED,SORREL

BROWN

Aerial surveys with regular and infrared film can be used in conjunction with ground surveys to evaluate bark beetle outbreaks based on foliage symptoms (Dillman and White 1984). Aerial surveys provides aid to long term control strategies by following population increases and movement of bark beetles by identifying those trees showing foliar symptoms. Aerial survey has been used effectively in the Blodgett forest on the west side of the Sierra Nevadas to map insect-caused stand mortality (Stark and Dahlsten 1970). In Canada, annual aerial detection and

ground inspections are done in June and July for the mountain pine beetle in lodgepole pine (Safranyik et al 1974). Two surveys in Colorado using this combination method produced accurate results, with standard errors of 4.7 and 15.7%. The comprehensive aerial survey using a U-2 plane covered 12 million acres and cost $51,000. Combined with the cost for field collection of information, the total cost was 1-2 cents per acre (Dillman and White 1984).

Individual bark beetle species can be identified by keying out the specimens, or by having the University, the Department of Forestry, or the Forest Service identify them. Beetles can also be identified by studying the galleries beneath the bark, which are species specific for a given tree species (see Figure 5). Western pine beetle galleries are long and winding, criss-crossing many times. The mountain pine beetle creates long, straight galleries that run longitudinally along the trunk with a characteristic hook at the bottom, forming a "J". The red turpentine beetle excavates short, irregular, longitudinal to cavelike galleries between the bark and the wood on the lower portion of the trunk and root crown (Furniss and Carolin 1977). California fivespined engraver galleries resemble an inverted tuning fork, or trident pattern (Rudinsky et al. 1979). Tree species, location on the tree, size and color of the beetle, and gallery pattern are all clues to identify the species present.

CONTROL THRESHOLDS

Because of the complexity and diversity of the pine forest ecosystem, development of economic thresholds for control of bark beetles is difficult. Each parcel, or unit of private or public forest land should be evaluated and specific goals and guidelines determined, in order to create an effective control program. Relative changes in bark beetle populations can be monitored through the use of visual detection programs (outlined above), and environmentally favorable periods of buildup can be identified, based on weather data. The question is whether monitoring of bark beetle population increases should lead to a direct control program. Most evidence in the literature supports reduction of tree loss to bark beetles through cultural management programs, and not direct control of bark beetles through chemical and physical control methods. This includes those trees that are in campgrounds and home sites, as well as in large timber areas.

Therefore, stand management is the recognized tool for reducing tree loss from bark beetle attack. Assessing the risk of a particular host tree, stand, or forest unit is used in preparing a cultural management program, instead of using bark beetle population numbers compared to a control threshold value.

There has been much work done on risk analysis of various pines to bark beetle attack (Safranyik et al. 1974). Overmature,and underthinned stands, stands that have been defoliated by other insects, as well as

stands decadent from disease, are the most susceptible to attack. Lodgepole pine stands that are 80 years old or older, with an average diameter of 8 inches or greater, are very susceptible (Safranyik et al. 1974). In ponderosa and Jefferey pines for the western pine beetle, a risk rating system has been developed and refined over the last 40 years (Smith et al., 1981). The California System (as it is called), is primarily applicable to the sierra eastside old growth ponderosa and Jefferey pines. The trees are visually appraised according to their crown characteristics and placed in one of four susceptibility classes. When the system is utilized as a management practice, it is called sanitation/salvage logging. The removal of as little as 10 to 15% of the stand volume as high risk trees, reduced losses as much as 80% for more than 20 years (Safranyik et al., 1974).

The recreational forests of California are located in a variety of geographical areas, and consist of a diverse mix of tree species of various ages. Therefore, an all encompassing risk rating system is not available for the recreational forests of California. Existing systems might be used and modified, with the help of foresters, to develop applicable risk rating systems for each forest unit.

CONTROL MEASURES

There are four types of control for bark beetles: biological, cultural, physical, and chemical. The biological control factor is part of the forest environment and, at this time, the importance is not fully known

(Dahlsten 1987). Since bark beetles generally prefer to initially attack overmature and low vigor trees, the most effective control method is proper cultural management of the forest. Physical control of bark beetles in infested trees is used in combination with other management programs. High value trees within campgrounds might be protected using chemical methods. However, this is only a short term solution, since chemical treatments are needed each year, and probably have little overall effect on the bark beetle population within the surrounding forest.

BIOLOGICAL

There are over 100 species of organisms that are associated with a ponderosa pine under attack by the western pine beetle (Stephen and Dahlsten 1976). Seventy species of insect associates have been identified for the western pine beetle, and 60 have been identified for the mountain pine beetle (Dahlsten 1982). For the western pine beetle, 18 natural enemy species are known, of which four are abundant (Stark and Dahlsten 1970). In actual population numbers, 2 Coleoptera species (Enoclerus lecontei and Temnochila chloridia) make up 80 to 90% of the predators that attack bark beetles (Swezey and Dahlsten 1983). There are a number of hymenopterous parasitoids that reduce bark beetle populations. Coeloides dendroctoni is a major parasitoid of the mountain pine beetle (Safanyik et al.1974). Other natural enemies include woodpeckers, spiders, nematodes, and mites. Nematodes affect

the vigor of the bark beetles, and reduce viability and fecundity (Coulson and Stark 1982).

Some natural enemies of bark beetles respond to aggregation pheromones and migrate to trees under attack, while others respond to signals from the host tree. Under normal conditions these various insects are an important factor in bark beetle population regulation. But when environmental and host conditions favor bark beetle buildup, there is no evidence that the predator/parasite populations respond to prevent bark beetles from reaching epidemic levels.

Therefore, the biological control factor exists and influences the population dynamics of bark beetles, but it is not known just how important this factor is in managing populations.

CULTURAL

Cultural control is by far the most important method for preventing large fluctuations in damage to pine forests by bark beetles (Mitchell et al.1983). Silviculture, or management of the timber resource, is practiced on many commercial, private and public timber producing lands. Maintaining high tree vigor through proper management reduces host susceptibility, and limits the incidence and severity of bark beetle outbreaks. Weather is an uncontrollable factor, but proper silvicultural management will aid trees in handling environmental stress. Silvicultural management practices may also influence natural

enemies, which in turn may positively or negatively affect bark beetle populations (Dahlsten personal communication 1987).

Public acceptance of cultural control programs within the recreational forests is important. Cutting timber as part of a cultural management program can bring adverse reaction from the public. Hall (1958) found good public acceptance of cutting timber in the Barton Flats recreational area when the the public was informed of the goals of the management program.

Tree Resistance

The importance of cultural control is strongly related to the mechanisms of host resistance in pine trees. Pine trees respond to the invasion of fungi and beetles in two ways. 1) When injured, the tree produces resin to trap, kill, or flush the organism from the tree. Resin has toxic, viscous, and crystalline properties that are strong deterrents to bark beetle invasion (Smith 1972). A pine tree can repel bark beetle attacks if there is sufficient resin flow. This process is known as 'pitching out'. The resin also blocks entrance holes, preventing the entrance of other organisms. Sufficient resin flow depends on a variety of factors, including genetic make-up, age, environmental conditions, and intensity of bark beetle attack. 2) With fungi, some trees exhibit a hypersensitive response to pathogen entry into the bark. The cells surrounding the fungi die, and compartmentalize, but do not kill the fungi within (Berryman 1972).

In both cases, the integrity of the bark is important to maintaining a viable barrier against invasion. Physical damage to the tree allows an opening in the defenses for attack. Wounded trees send out an olfactory signal to the bark beetles. The same resin which can capture and kill a bark beetle, can release volatile terpenes that act as an attractant to invading bark beetles.

The goal of cultural management can be achieved in 3 ways.

1. Avoid tree and soil damage. Since bark beetles respond to trees that have been damaged or wounded, care should be taken to avoid injuring trees. Heavy equipment should be moved carefully through the forest to avoid limb breakage and bark damage. Soil compaction should be avoided to allow for proper water infiltration and oxygen supply to the roots. This will help to avoid water stress, as well as destructive erosion. It should be noted that sanitation/salvage and slash clean-up programs can contribute to the above problem because of increased traffic of equipment in the forest. Therefore, cultural programs should include emphasis on traffic reduction while still meeting the goals of sanitation.

2. Avoid excess slash during Ips species flight periods to eliminate breeding sites. Slash creates an attractive site for bark beetle development, and sanitation will help to eliminate an early build-up of bark beetles, especially the fivespined engraver. Slash present in early spring should be removed, burned, or chipped and scattered in a sunny opening to eliminate a moist environment for brood

development. Weak trees that have been cut down during flight periods should be removed or debarked. Infested trees can be harvested and used in the lumber industry, since damage to the phloem does little to lower the lumber quality (unfortunately, blue stain fungus and other wood borers often associated with bark beetles do act to lower the lumber quality). Unseasoned, freshly cut firewood should not be stacked near healthy trees. Stumps should be removed, or treated with a fungicide (such as Borax) to prevent introduction of pathogens to the root systems. In areas where the red turpentine beetle is a problem, stumps should be removed, stump-ground, or debarked to eliminate a breeding site for bark beetle buildup.

3. Maintain high tree vigor through stand management. Since bark beetles prefer trees of lower vigor, predisposition of trees to invasion can be prevented by monitoring and maintaining healthy stands. Where applicable, sanitation/salvage can be used to economically remove trees that are of high risk. Stand thrift can be accomplished by thinning, and logging of overmature pines, and should be done consistently as part of the general management plan of the unit. Drought conditions can seriously stress trees, rendering them susceptible to attack. Proper stand management reduces competition for light, water, and nutrients, encouraging optimum growth and vigor. In some cases, fertilizer can be used to increase the vigor of trees in nutrient deficient areas.

Sanitation/Salvage

Results from a study in the Barton Flats recreational area in California, support the conclusion that insect depradation can be effectively suppressed through sanitation/salvage logging without damaging an area for recreational use (Hall 1958). The study took place on 5,500 acres which had a timber type similar to northeastern California where sanitation/salvage has been effectively used. The forest is principally mixed Jefferey and ponderosa pine, with some sugar pine, white fir, and incense cedar. The principal bark beetles are the western pine beetle in ponderosa pine, the Jefferey pine beetle in Jefferey pine, and the flatheaded borer in both pine species.

The management plan called for cutting all high risk trees (risk III and IV) in the majority of the forest, while cutting all risk IV and some risk III trees in recreational areas. The trees were cut and sold. The sanitation/salvage program was followed up by a program of year-round maintenance control, the main objective being to log all trees infested with bark beetles.

Losses two years before the sanitation/salvage treatment exceeded 200 board feet per acre. Losses were reduced 92 percent the first year after treatment, and 90 percent the second year (Hall 1958). The success of sanitation/salvage depends on the ability of the program participants to rate the trees accurately, and to develop an economically feasible way to harvest the trees.

Thinning

Thinning has been shown to reduce losses to bark beetles by reducing competition, and removing older trees that are most susceptible to bark beetle attack. Light thinning can contribute to future bark beetle attacks by allowing trees to grow vigorously initially after light thinning, then become stressed by competition. Studies have shown that maintaining proper vigor in lodgepole pine stands reduces the susceptibility to attack (Mitchell et al., 1983).

Vigor is influenced by four measurable environmental parameters: 1) basal area of trees (meter sq./hectare); 2) crown competition factor; 3) density (trees/hectare); 4) leaf area index (LAI). It is necessary to measure and calculate each factor at each particular site in question to determine stand vigor.

Blodgett forest, which is on the westside of the central Sierra Nevada mountains, is a mixed coniferous forest containing five different conifers and one hardwood species. Ponderosa pine occurs in single species groups or aggregations. One thinning study showed that the bark beetles took the same proportion of trees in the control as in the thinned block. In this case, thinning did not reduce the proportion of trees taken to the total number of trees in the stand. However, it is anticipated that eventually, because of less tree competition and

improved tree vigor, a significantly higher number of trees will be taken in the control plots as compared to the thinned plots (Lang et al., 1978).

A study in Oregon showed that pure lodgepole pine stands should be thinned to achieve vigor values on either side of 100 grams/M sq. This corresponds to a basal area value of 10-20 meter sq./ha., and a density of around 200 trees/acre (500 trees per hectare) (Mitchell et al., 1983). A study in Wyoming that evaluated several cutting/harvesting methods for Lodgepole pine determined the leave-tree method to be the best for resistance to bark beetles. The leave-tree method involves leaving a total of 100 trees per acre (250/ha) of all tree species. The trees that are of the best growing stock in terms of age and vigor are selected (Cole et al., 1983). For ponderosa pine in Oregon, damage occurs when the basal area exceeds 28-34 meter sq./ha (Larsson et al., 1983).

There are no absolute rules for thinning to promote maximum vigor for bark beetle resistance. Managers, working with foresters, should evaluate each site for type of trees, elevation, and general weather conditions to establish management guidelines. Several degrees of thinning should be used to create different stand densities in an area. Observation of each stand will help determine optimum densities for that particular site.

PHYSICAL DESTRUCTION OF INFESTED TREES

Preventative removal of slash and trees has been discussed previously. Destruction of bark beetles within slash or dead trees alone is not an effective method for controlling populations of bark beetles in forests, but can be done to eliminate beetles and infested trees as part of a sanitation program. Trees and limbs that have been weakened from bark beetles and other organisms may fall, injuring people or damaging property.

Heat from the sun or from burning can be used as tools to kill Dendroctonus and Ips species in these particular trees. Burning must be used with care to prevent scorching and damaging of live trees in the area, which could predispose them to attack. Where fire hazard is a problem, solar heat can be used. Four methods for using heat are the following (Rudinsky et al., 1979):

1. Fell, peel, and burn - Dead or infested trees are cut down. The bark is peeled off and piled against tree and burned.

2. Fell, pile, and burn - Slash and trees are piled together, sprayed with oil, and burned.

3. Oil burning - Standing dead trees are sprayed with oil, and burned.

4. Solar heat - Trees are felled, limbed, the bark peeled off and spread out flat. When air temperatures reach 85 degrees, internal bark temperatures can reach 115-120 degrees, which is sufficient to kill bark beetles. Small diameter trees can be felled in a north/south direction and left unpeeled. After several days of high temperatures the tree is rolled 180 degrees. This method is only effective when temperatures are high enough. This method may also encourage predation by birds, rodents, and insects, since the bark is peeled off, exposing the beetles (Rudinsky et al., 1979). Bark beetle losses to natural enemies might also be reduced, due to mortality of natural enemies from the heat beneath the bark (Dahlsten personal communication 1987).

CHEMICAL

Chemical control, like physical control, fits into a bark beetle management program as a method of killing bark beetles on a short term basis in one area. It can also be used to protect small stands of high value trees, such as in a campground or in a scenic spot, but there is no evidence that these chemical treatments have any major effect on bark beetle populations within the forest unit. Chemical control should not substitute for good cultural management. Insecticides sprayed on living trees kill the beetles boring in or out, but their efficacy is limited on beetles underneath the bark. Therefore, a chemical treatment applied once a tree is heavily infested will not drastically reduce the

population underneath the bark, until the beetle stage leaves the phloem-cambium region and comes into contact with the treated surface.

SEE TABLES 3 AND 4 FOR INSECTICIDE GUIDELINES

Pheromones

There has been much conjecture on the possible use of the aggregation pheromones as a means to control bark beetles. Unfortunately, because of the complexity of the forest ecosystem, methods such as mass trapping and mating disruption have not been developed so that they are operational on large scale practical to use. There are many factors involved in the release and reception of the pheromones by bark beetles. Experiments with Dendroctonus species have shown that traps may attract beetles to trees nearby, instead of to the trap. The three attractants, Exo-brevicomin, Frontalin, and Myrcene have different effects at various rates and combinations. Therefore, additional work has to be done before mass trapping or disuption becomes part of a management program for bark beetles (Bedard and Wood 1981).

Another method that has been investigated is the use of 'trap-trees' sprayed with a combination of pheromone and insecticide (Chatelain and Schenlk 1984). Combinations of pheromones and insecticides can be used to attract bark beetles to sprayed trap-trees. High-value trees should not be sprayed with a pheromone/insecticide mix. The problem with this

method is similar to that of mass-trapping. The pheromone-baited trap-trees may attract beetles to attack other trees nearby (Pitmann 1971).

Lindane

Lindane is a long-residual insecticide. Water, not oil, should be used as a spray carrier, because oil may cause phytotoxicity. Lindane should be applied in 0.5-1.5% solutions. The tree should be sprayed from the ground up to where the tree is 4 inches in diameter for most species except the red turpentine beetle, which is only found on the lower portion of the bole (Koehler 1978). It should be applied once a year in early to mid February in the San Francisco Bay area, earlier in warmer regions, and later in the spring at colder locations.

Lindane remains effective into the second year (Koerber et al.1976). The problem with lindane is that it is more toxic to bark beetle predators, especially E. lecontei and T. chlorodia, than to bark beetles. In field tests, a 2 percent remedial application of lindane on ponderosa pine for western pine beetle reduced the overall emergence of natural enemies by 89 percent (Swezey and Dahlsten 1983).

Chlorpyrifos

Labeled for preventive as well as remedial treatments, chlorpyrifos has been shown to be effective as a protectant for living trees. A 4% solution was shown to be effective for protecting pines against the red

turpentine beetle, but did not reduce the damage from the western pine beetle on ponderosa pine (Hall 1984). As a contact spray, chlorpyrifos is 4 times more toxic than lindane to the western pine beetle (Sweezy et al. 1982).

Oxydemeton-methyl

Oxydemeton-methyl is currently under review by CDFA for possible cancellation. Currently there are only three products remaining that are still registered. The only product still registered for pines is Injecticide, which consists of pre-measured injection units. Oxydemeton-methyl provides systemic action against bark beetles, and will kill them beneath the bark. The cost per tree is very expensive, and the treatment is used mainly for high value trees.

Carbaryl

In recent years, carbaryl has emerged as an effective chemical for protection of ponderosa pine. A 4% spray solution of carbaryl showed a significant reduction in red turpentine beetle attacks when used as a protectant. A 2% formulation of carbaryl also provided good protection (Hall 1984).

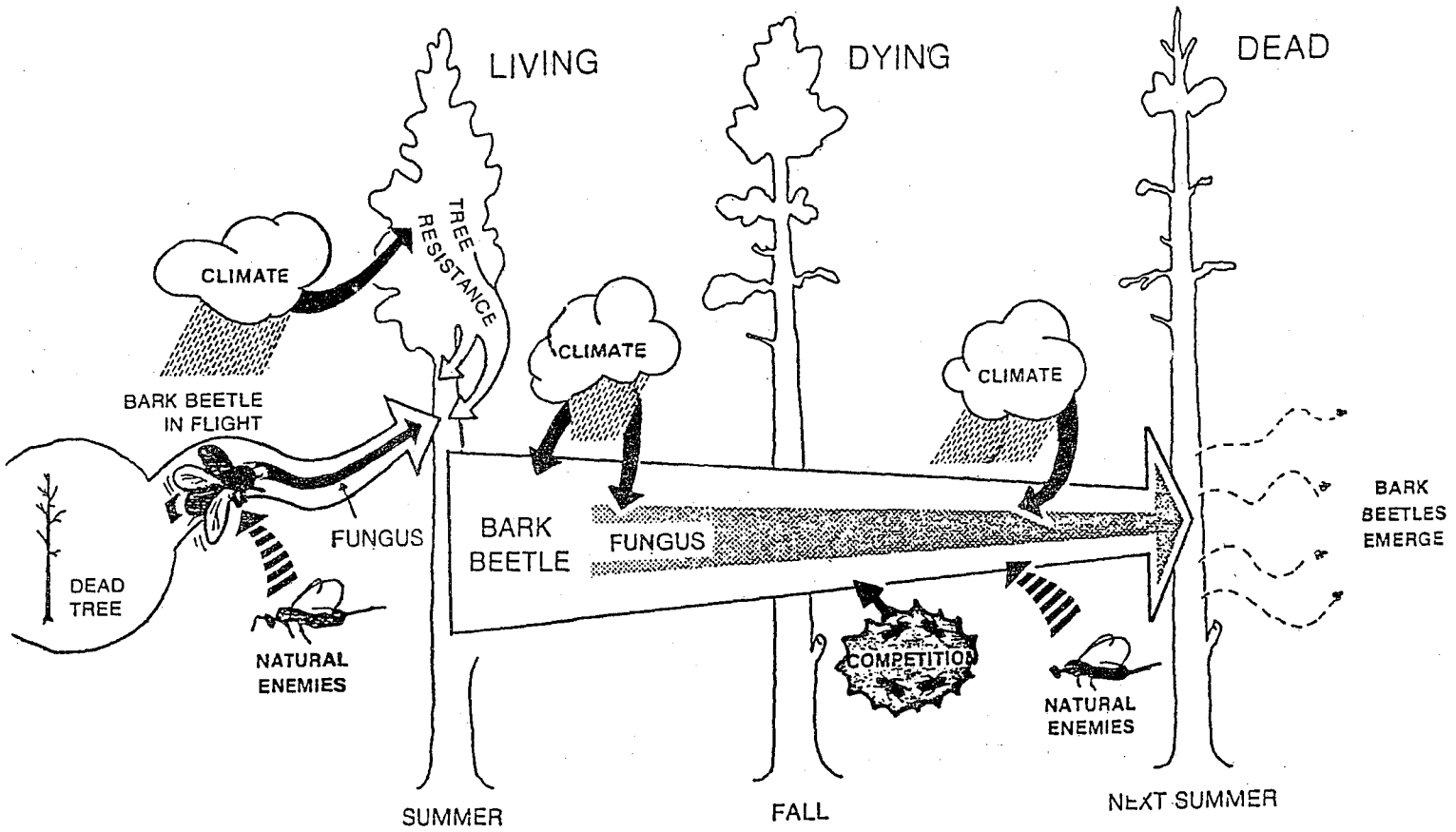
One of the benefits of carbaryl is low-mortality to beneficials. Both E. lecontei and T.chlorodia, major predators of the western and mountain pine beetles, show more tolerance to topical doses of carbaryl compared

to the western pine beetle (Swezey et al.1982). Unfortunately, carbaryl is highly toxic to the parasitoids of the bark beetles, and to bees.

SUMMARY

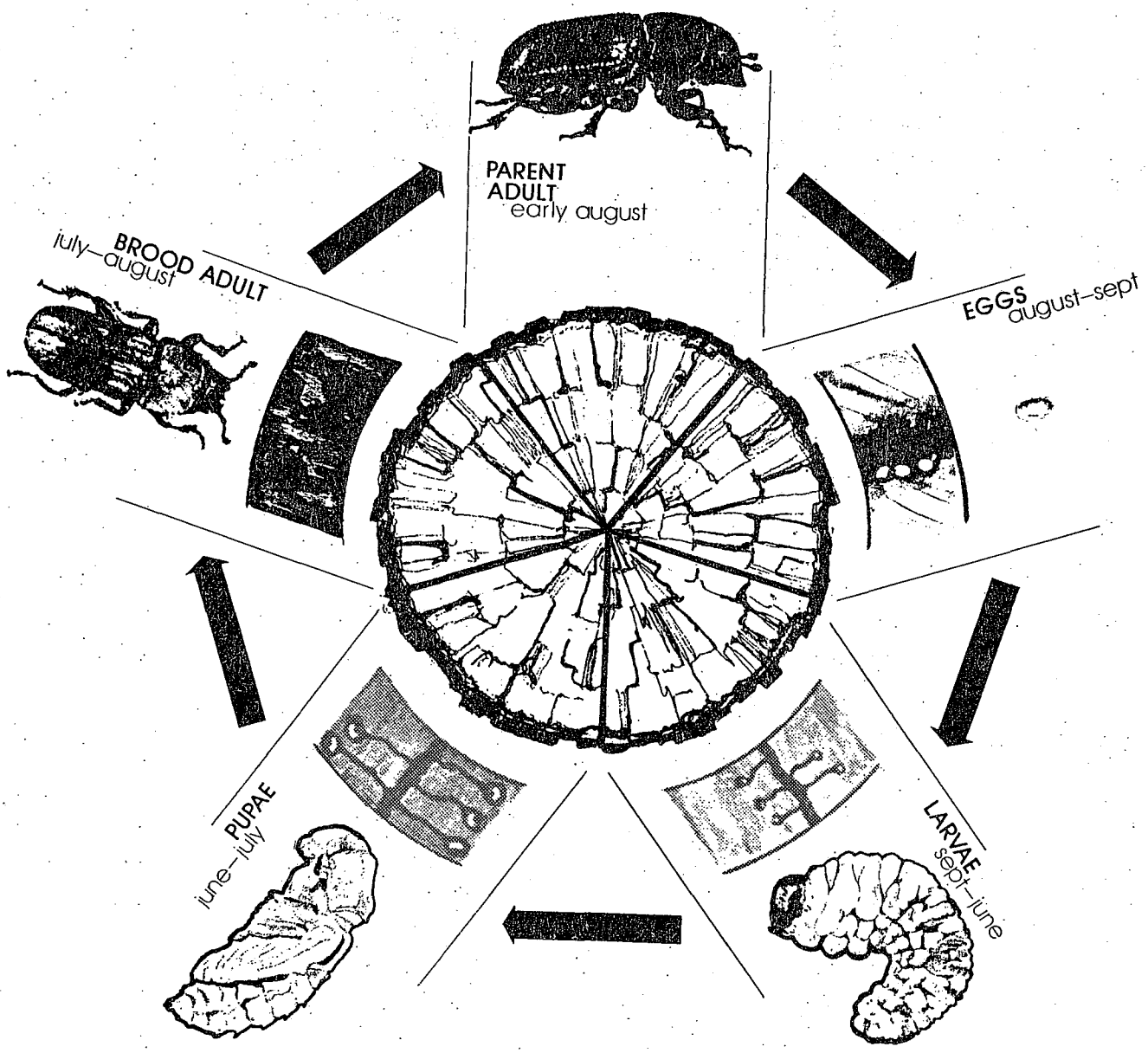
Silviculture and cultural management are the major tools for reducing the amount of losses from bark beetle populations. Programs focus on increasing the vigor of the host, and removing those trees that are most susceptible. Risk analysis, sanitation/salvage logging, thinning, soil compaction reduction, and tree injury avoidance are all important aspects of cultural management. Biological control is an important natural factor influencing populations. How important this factor is to managing populations is still not completely known. Physical and chemical control can be used effectively in a sanitation program in conjunction with sound cultural programs. Chemicals as protectants have been shown to be effective on a short term basis, but not proven to have any lasting effect on populations in the forest unit. Manipulation of bark beetle populations using phermones has shown some promise, but there is currently no effective large scale program for use in recreational forests.

Figure 1. Beetle host interactions



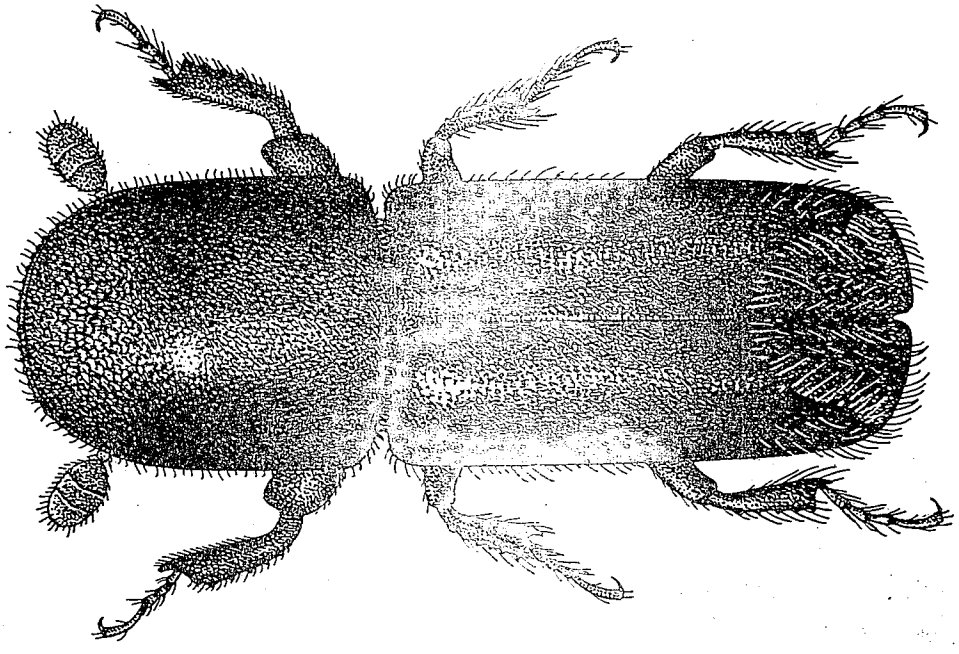
L. Safranyik, 1974
Courtesy of Canadian Forestry Service

Figure 2. General life cycle



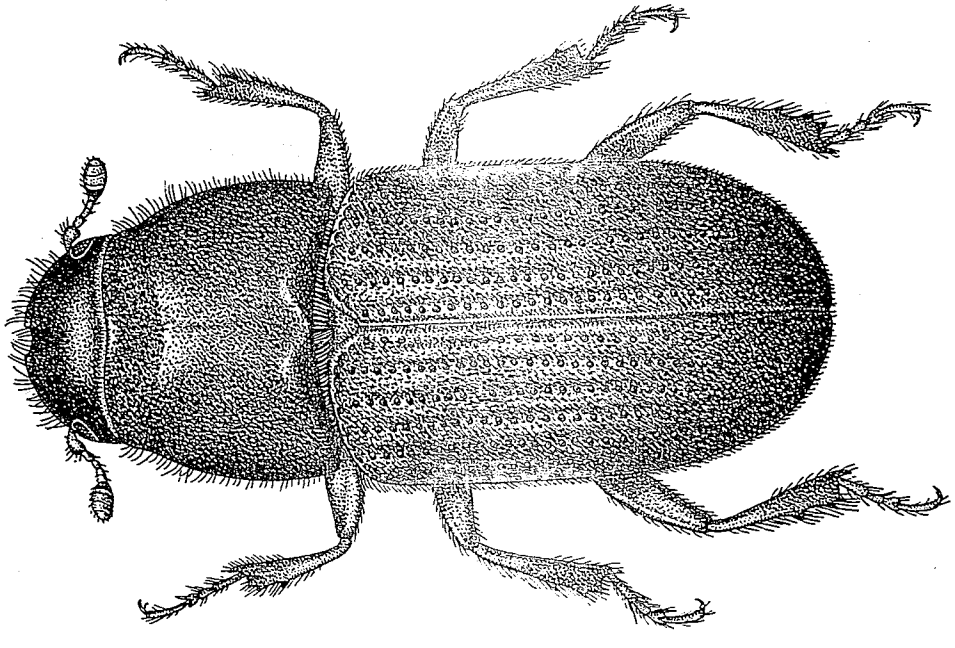
Courtesy of USDA Forest Service, 1985

Figure 3. Beetle sketches



IPS PARACONFUSUS

LENGTH: 3-6.5 mm



DENDROCTONUS BREVICOMIS

LENGTH: 3.2-5 mm

C. Green, 1973
Courtesy of University of California

Figure 4. Preferential distribution

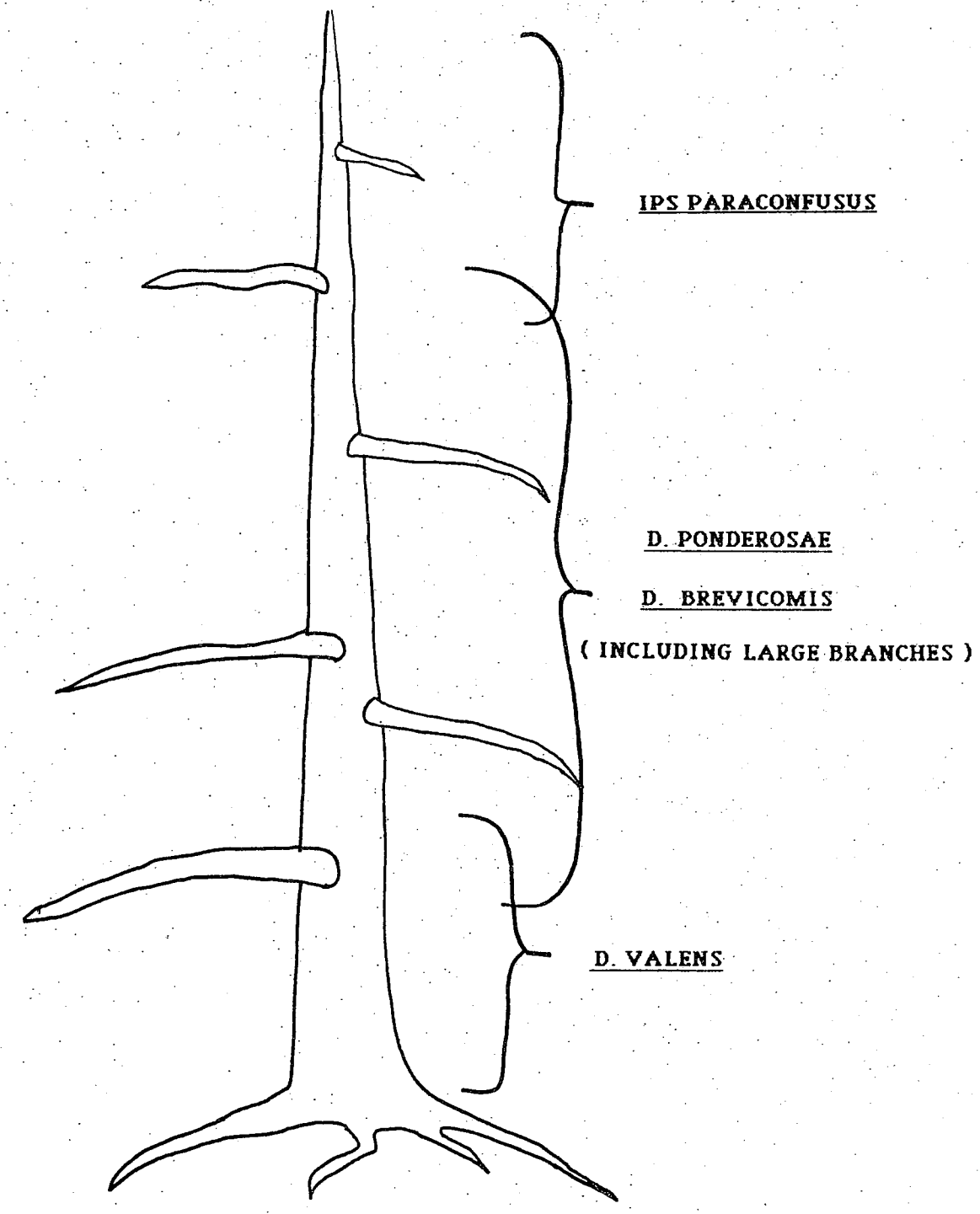
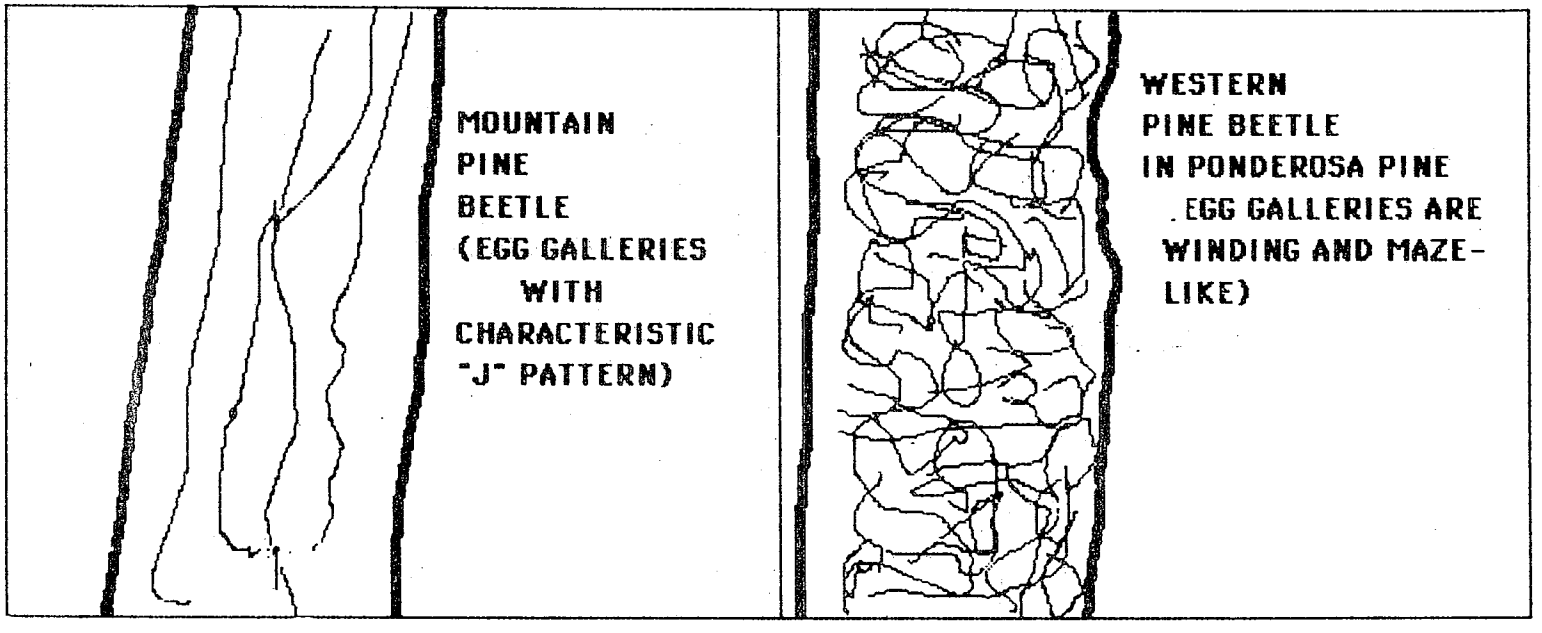


Figure 5. General examples of bark beetle sign



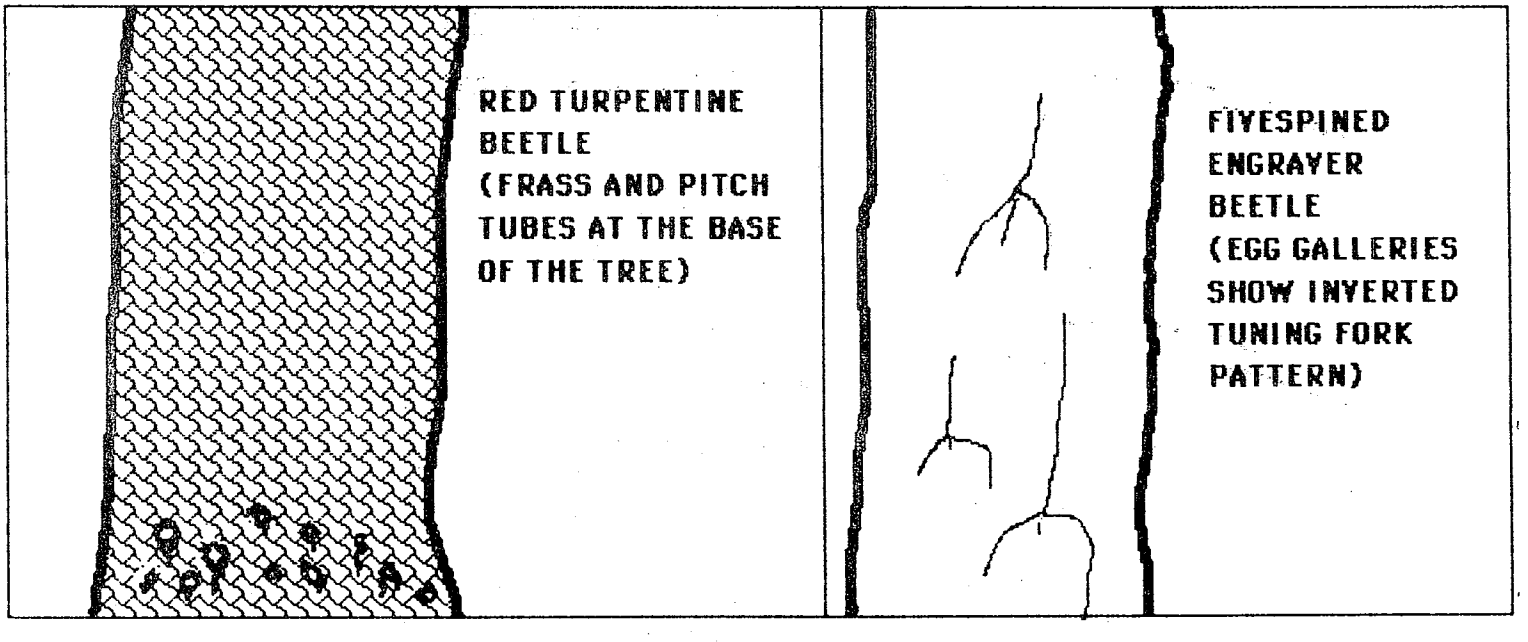


Table 3. USDAFS Guide for use when considering pesticides

California five-spined ips
(Ips paraconfusus)

INSECTICIDE OR ACARICIDE	FORMULATION	DILUTION	APPLICATION	REMARKS
Carbaryl	80% WP	25 lb+100 gals water	Appl 1 gal spry per 50 sq ft of bark in May to early June. Repeat annually. Preventative only.	Avoid direct appl to water. Toxic to bees.
Lindane	1 lb ai/gal	1 pt+4-5 gal water	Thoroughly wet for prevention and control.	Avoid direct appl to water. Do not apply to wet bark.
Oxydemeton-methyl	Injection units	Undiluted 3 ml/unit	Inject trees greater than 2"dbh at 5-6" intervals in spring.	Avoid skin or eye contact. Wear protective clothing.

Mountain pine beetle
(Dendroctonus ponderosae)

INSECTICIDE or ACARICIDE	FORMULATION	DILUTION	APPLICATION	REMARKS
Carbaryl	4 lb ai/gal	20 qt+100 gal water	Grnd spray 1gal sol to 50 sq ft of bark as prev.	Avoid direct appl to water. Toxic to bees.
Lindane	1 lb ai/gal	1 pt+4-5 gal water	Thoroughly wet bark for prev and control.	Avoid direct Appl to water. Do not apply to wet bark.

TABLE 3. Continued

Red turpentine beetle
(Dendroctonus valens)

INSECTICIDE OR ACARICIDE	FORMULATION	DILUTION	APPLICATION	REMARKS
Lindane	1 lb ai/gal	1 pt+4-5 gal water	Thoroughly wet bark of infest portion of trees as indicated by pitch tubes.	Avoid direct appl to H2O. Do not apply to wet bark.
Oxydemeton-methyl	Injection units	Undiluted, 3 mls/unit	Inject trees greater than 2 dbh at 5-6" intervals in spring.	Avoid skin or eye contact. Wear protect. clothing.

Western pine beetle
(Dendroctonus brevicomis)

INSECTICIDE OR ACARICIDE	FORMULATION	DILUTION	APPLICATION	REMARKS
Oxydemeton-methyl	Injection units	Undilut-3 ml/unit	Inject trees greater than 2"dbh at 5"-6" intervals in spring.	Avoid skin or eye cont. Wear protect clothing.
Carbaryl	4 lb ai/gal	20 qt+100 gal water	Grnd spray-1gal to 50 sq ft of bark as prevent.	Avoid direct appl to water. Toxic to bees.
	80% WP	25 lb+100 gal water	Apply 1gal spray to 50 sq ft bark May to early Jun. Prev. only/repeat annually.	
Lindane	1 lb ai/gal	1 pt+4-5 gal water	Thoroughly wet bark for prevention and control.	Avoid direct appl to water. Do not apply to wet bark.

D. R. Hamel, 1983
Courtesy of USDA Forest Service

Table 4. Recommendations for chlorpyrifos use for pine beetle control. (source: product labels)

FORMULATION	AMOUNT OF PRODUCT IN 100 GALLONS	DIRECTIONS
50 Wettable	16.66 lbs	**PREVENTATIVE:** Apply spray to the main trunk in early spring or when threat exists from nearby infested trees. **REMEDIAL:** Apply spray to main trunk of infested trees or logs when damage occurs or before adult beetles begin to emerge.
4 E (4 lbs ai/g)	2 gallons	**PREVENTATIVE:** Apply spray to the main trunk in early spring or when threat exists from nearby infested trees. **REMEDIAL:** Apply spray to main trunk of infested trees or logs when damage occurs or before adult beetles begin to emerge.

D. R. Hamel, 1983
Courtesy of USDA Forest Service

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METHODS

This report is based upon information gathered from literature searches, personal observations, and oral interviews. Initially a Dialog computer search was done to identify key references. Additional references were identified from the reference sections of the Dialog references. Using the CDPR outline to determine format, a rough draft was created on the AT&T computer using Wordmarc word processing software. The first draft was then evaluated within CDFA. Corrections were made, and the second draft was written. The report was then sent to outside reviewers. Corrections and additions were then made based on input from the outside reviewers.

Figures and tables were taken from the sources cited. Some tables and figures were created, using the Wordmarc software, or on the MacIntosh computer using MacPaint software.