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Managing Slash to Minimize Colonization of Residual Trees by *Ips* and Other Bark Beetle Species Following Thinning in Southwestern Ponderosa Pine

Tom DeGomez, Christopher J. Fettig, Joel D. McMillin, John A. Anhold and Christopher Hayes

Introduction

Due to high fire hazard and perceived reductions in forest health, thinning of small diameter trees has become a prevalent management activity particularly in dense stands. Creation of large amounts of logging slash, however, has created large quantities of habitat for bark beetles primarily in the *Ips* genus (Coleoptera: Curculionidae, Scolytinae). Evidence indicates that prior to Euro-American settlement fire played a major role in maintaining ponderosa pine stands in a condition that was much more open in structure than today (Cooper 1960, Covington and Moore 1994, Kolb et al. 1994). In general, lower tree densities led to increased tree growth (Ronco and Edminster 1985) and trees that were more vigorous and presumably less susceptible to insect attack (Kolb et al. 1998, Fettig et al. 2007). Bark beetles are a large and diverse subfamily of insects commonly recognized as the most important biotic mortality agent in western coniferous forests. Most bark beetles feed in the cambium and phloem and some species directly kill the host. These insects influence forest ecosystem structure and function by regulating certain aspects of primary production, nutrient cycling, ecological succession and the size, distribution and abundance of forest trees (Fettig et al. 2007). Attacks reduce tree growth and hasten decline, mortality and subsequent replacement by other tree species.

In the southwestern U.S., thinning is advocated by land managers as a means of reducing fuel loads, improving residual tree growth, and as a preventive measure for reducing subsequent amounts of bark beetle-caused tree mortality (DeGomez 2006a). The thinning prescriptions are quite diverse, and their application can result in significantly different stand structures. In most cases large amounts of downed material (i.e., slash) are created and left in the field, due to lack of developed markets for small diameter trees. This material, if left on the ground, has inherent value and ecological functions (e.g., nutrient cycling and wildlife habitat), while at the same time creates host material for many bark beetle species, specifically those in the genus *Ips* (hereafter referred to as ips). Forest managers and forest health specialists tend to agree that fresh slash left untreated on the forest floor increases risks from bark beetle infestations and eventually wildfire, but those who are managing for other forest attributes are prone to recommend leaving some of the slash untreated to serve as habitat for a variety of fauna that contribute to a healthy forest condition (Brown et al. 2003).

This publication presents treatment options and guidelines for managing slash that minimize bark beetle activity in response to thinning treatments. We focus on southwestern ponderosa pine, but borrow knowledge gained from other geographic locations. In addition, while the primary focus is on ips response to thinning and slash management treatments, we also include information on other bark beetle species associated with slash (e.g., *Dendroctonus* species such as western pine beetle and red turpentine beetle).

David T. Almquist, University of Florida, Bugwood.org

Figure 1. Ips bark beetle. The number and shape of the spines on the posterior portion of the hardened forewings (elytra) aid in identification. Adults are 3-6.5 mm (0.1-0.25 in.) in length.

Ips Bark Beetles

Among the western bark beetles, *Ips* species are second in their tree killing ability to *Dendroctonus* species. Twenty-five ips are currently recognized in the western U.S. Adults are typically reddish-brown to black in color, cylindrical, and range from about 3.0 mm (0.1 in.) to 6.5 mm (0.25 in.) in length. A distinguishing characteristic of this genus is the pronounced declivity of the adult's elytra, which is margined with three to six tooth-like spines, the arrangement of which is distinct to individual species (Fig. 1).

Ips threaten live trees in the Southwest when stand and weather conditions come together to stress trees beyond their ability to resist attack from these bark beetles (USDA Forest Service 2003) or when a large volume of suitable host material is present for brood production and subsequent populations increase (Parker 1991). *Ips lecontei* (first) and *I. pini* (second) have historically been the most important ips in Arizona in past outbreaks (Parker 1991). Current stand conditions and weather patterns have created ideal circumstances for ips to attack and kill large numbers of trees (USDA Forest Service


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Figure 2. Ips gallery pattern etched on outer surface of ponderosa pine sapwood. Three or more egg galleries radiate away from a central chamber.

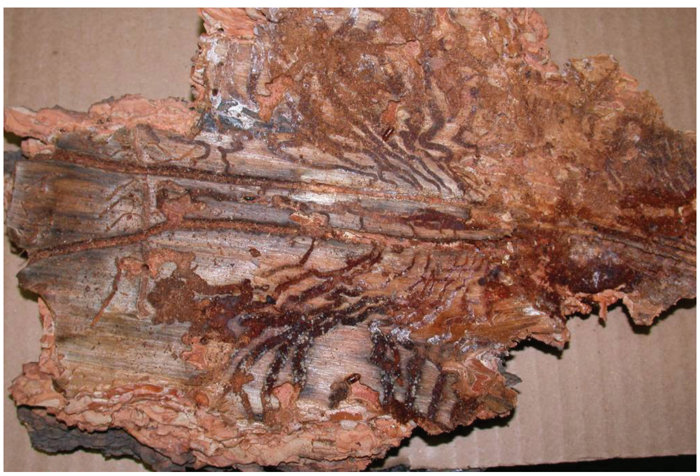
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Figure 3. Ips gallery pattern in ponderosa pine inner bark.

2003). Most ips beetles have multiple generations per year. Additional generations can occur in years when conditions for growth and development are favorable. Recently, Williams et al. (2008) reported collecting five different ips species during a trapping study in ponderosa pine forests of north-central Arizona. Flight in both spring and fall was one month longer at low elevations [<1,736 m (5,695 ft.)] compared with higher elevation sites [<2,505 m (8,218 ft.). DeGomez et al. (2006) found three species that colonized logs in Flagstaff, Arizona.

When stands are logged or thinned ips beetles are attracted to and reproduce in the slash generated by these treatments (Sartwell 1970, Livingston 1979, Parker 1991, Gara et al. 1999, Figs. 2-4). The level of slash colonization by bark beetles is also influenced by background population levels, which may be estimated by recent amounts of bark beetle-caused tree mortality in adjacent areas (i.e., fading trees [lime or yellow crowns] with evidence of bark beetle attack). Steed and Wagner (2004) reported that when ips densities are high, increased colonization of slash is likely to occur.

Stand Density. The effect of stand density on bark beetle responses to slash and other logging residues is mediated through several pathways. Pre-treatment stand density, and method and intensity of thinning are important because they


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Figure 4. Sawdust from bark beetle entrance holes in ponderosa pine slash.

influence the amount of slash produced. Treatment of dense stands typically results in the creation of greater amounts of slash than treatment of less dense stands. Generally, the greater the amount of slash the greater the number of ips beetles emerging in a given area (Reid 1957). Once beetles emerge from slash, factors affecting the susceptibility of residual trees to bark beetle attack are of primary importance. Over stocked conditions, often defined as high stand density, basal area or stand density index; tree diameter and host density are consistently identified as primary attributes associated with bark beetle infestations (Fettig et al. 2007).

Stand density can also influence utilization of slash by certain bark beetle species (Figs. 5-6). Villa-Castillo and Wagner (1996) evaluated the effects of light intensity on the behavior and performance of ips adults and brood in ponderosa pine stands of Arizona. The authors reported that logs exposed to high natural light intensity (i.e., low density stands) were attacked less frequently and had lower ips brood production than logs exposed to low or moderate light intensity. The researchers explained these effects as potentially due to reduced phloem quality and host finding ability due to changes in microclimate (e.g., increased wind speed). However, phloem moisture content of downed logs, a common measure of host suitability, was similar among three stand densities [12.2 m^2/ha, 26.4 m^2/ha, and 29.6 m^2/ha (53 ft^2/ac, 115 ft^2/ac, and 129 ft^2/ac)]. In a study conducted in Alberta, Canada, Hindmarch and Reid (2001a) reported male ips within felled trees attracted more females in thinned than unthinned lodgepole pine stands, and that females in thinned stands extended their egg galleries farther, laid more eggs, and had higher egg densities than in unthinned stands. Differences in the results of these two studies may be attributed to abiotic conditions. Specifically, the Alberta study was conducted in a northern location where higher temperatures resulting from increased solarization following thinning may have been advantageous to beetle mating and brood production. Other factors that may help explain these different results are that the two groups of researchers worked in different forest types. Furthermore, the size of the logs tested were dissimilar and one group baited with pheromones (Hindmarch and Reid 2001a).

Scattering slash in sunny areas is recommended to encourage desiccation of host material and influence brood production (Livingston 1979). While evidence exists for fewer beetle

Figure 5. Ponderosa pine stand with a basal area of 27.5 m^2/ha (120 ft^2/ac).

Figure 6. Ponderosa pine stand with a basal area of 13.8 m^2/ha (60 ft^2/ac).

attacks in logs exposed to high sunlight levels in Arizona (Villa-Castillo and Wagner 1996, Hayes et al. 2008), evidence of the effects of sunlight level on reproductive performance is mixed. For example, Villa-Castillo and Wagner (1996) found poor reproductive performance of ips in logs exposed to high sunlight levels, while Hayes et al. (2008) found no consistent negative effect caused by high sunlight on ips reproductive performance.

In summary, initial stand density affects the amount of slash produced, with higher quantities of slash providing a better opportunity for buildups of large ips populations. Residual stand density can influence the abundance and distribution of flying beetles (Zausen et al. 2005, Hindmarch and Reid 2001a & b), beetle colonization and brood production in slash, and the ability of residual trees to repel attacks, by both beetles emerging from slash or those immediately colonizing residual trees following harvest (e.g., coincident with slash colonization phase). However, results vary among individual studies. In southwestern ponderosa pine, the body of evidence suggests that low density stands will result in lower brood production in slash and residual trees that are less susceptible to bark beetle attack overall (Fettig et al. 2007).

Slash Availability and Climate. The time of year slash is created can have a significant impact on subsequent ips brood production, and top-kill of big trees and tree mortality rates (Hall 1947, Buckhorn 1957, Steed and Wagner 2004, Fettig et al. 2006a, Hayes et al. 2008, Fig. 7). For example, studies by Buckhorn (1957) demonstrated that ponderosa pine mortality caused by ips in Oregon was greatest when slash was generated between the period of February and July, as compared to August through January. Slash material produced from January through June is generally most optimal for ips colonization and brood production, and is considered the "hazardous period" for creating slash (Sartwell 1970). Conversely the "safe period" for producing slash is generally from July through December (Parker 1991). During this period, host material declines in suitability over time as phloem moisture is reduced. The drying of the phloem within the slash is thought to be a major factor in reducing the opportunity of attacking ips to successfully complete their lifecycle (Redmer et al. 2001).

Climate variability can alter the time frame of the hazardous and safe periods for slash production, as well as the susceptibility of adjacent standing green host trees to bark beetle attack. For example, slash subjected to warmer and dryer conditions will desiccate faster and may allow more flexibility in generating slash material, especially at low-elevation ponderosa pine stands. In contrast, cooler/wetter climates, such as those found in high-elevation ponderosa pine stands, might preserve the quality of slash phloem, making it more suitable for brood production for a longer period. However, land managers should keep in mind that increased brood production in slash at high elevation/high quality sites may not pose as great of risk as increased brood production at low elevation/low site quality sites where host trees may be more stressed and there are more generations per year of beetles (Williams et al. 2008).

During periods of drought, live trees also become more prone to beetle attacks as their capacity to produce pitch is diminished (Cates and Alexander 1982, Lieutier 2002). Pines have a well-defined resin duct system, which is capable of mobilizing large amounts of oleoresin following wounding (Christiansen et al. 1987). This has traditionally been considered the primary defense against bark beetle attack. Beetles that initiate host selection are often killed by drowning or immobilization in resin especially when adequate moisture, oleoresin flow, and exudation pressure exist. Successful beetle colonization requires overcoming tree defenses, which can only be accomplished by recruitment of a critical minimum number of beetles, which may vary with changes in host vigor. Several bark beetle species (e.g., some ips spp.) preferentially attack green logs, slash or recently dead and dying trees. In these cases, little host resistance may be encountered. When suitable slash is available during drought periods emerging beetles may encounter stressed trees, with insufficient resin production to protect against beetle attacks (Struble and Hall 1955). Conversely, when there are wet periods during the growing season, residual trees are more likely to be able to defend against beetle attacks, shortening the hazardous period for slash production. In much of the Southwest, this wet period typically occurs during the mid to late summer.

Spatial Considerations. There are spatial considerations that need to be considered as well. Slash should generally not be created for more than one year at the same location (*see* Green Chaining). If green slash is present for a second year, there is a greater likelihood that the second year's ips population could


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Figure 7. Top kill on ponderosa pine from ips bark beetle attack.

be larger and may then overcome the defenses of adjacent live host trees. It is also recommended that a buffer, of more than 3 km (2 miles) between subsequent treatment sites, be used to minimize the opportunity for ips populations to reach outbreak levels in a localized area (Parker 1991).

Site Quality. Site quality factors that might influence ips beetle attacks are difficult to measure because of the many interacting forces at any given site. However, anecdotal evidence suggests ips damage is greater on lower-quality than on higher-quality ponderosa pine sites. In the Southwest, poor sites are usually found along the transitional zones at the lower pine elevations adjacent to pinyon/juniper woodlands, on rocky ridges and outcroppings and south facing slopes (Parker 1991). Parker (1991) recommends not creating slash for more than one year at sites in lower elevation forests in Arizona and New Mexico, especially where *I. lecontei* is present and trees are infected with dwarf mistletoe. Sites where trees are growing vigorously and have not had ips activity in the recent past may not require extra preventative measures (Parker 1991).

Slash Management Techniques

Green Chaining. "Green chaining" is a strategy developed primarily in the northern Rocky Mountains and is designed to keep a fresh supply of host material available for emerging adult ips throughout the flight season (Kegley et al. 1997). Because ips have preference for fresh slash compared to standing trees, a continuous supply of new slash can keep emerging adults from attacking standing trees. This technique has been suggested for implementation when ips populations are building in slash and therefore poses a threat to surrounding pine stands (Wiggins and Foss 2005). Green slash is either generated continuously or at two week intervals beginning in early summer through August, and later in forests at lower latitudes (Overhulser 1999) or just at the beginning of the pupal stage for each generation (Kegley et al. 1997, Wiggins and Foss 2005). In Idaho, it is recommended to have fresh slash distributed throughout the treatment area since ips generally fly less than 400 m (¼ mile) (Wiggins and Foss 2005). If green chaining is combined with commercial logging operations, logs can be left on site for a period of 2 – 4 weeks to absorb flying beetles and then removed from the site and processed at the mill. When logs are used to trap colonizing bark beetles, the wood will typically become stained by symbiotic fungi (e.g., blue stain fungi) carried by colonizing beetles. While this process does not affect wood quality or structural integrity, the value of such logs is often slightly reduced.

To our knowledge the green chaining approach has not been used intentionally in the Southwest. Potential problems associated with this strategy include guaranteeing that slash will be continuously created throughout the flight season of beetles. Temporary closures of forests have occurred during May through early July in recent drought years. In addition, chainsaw restrictions occur on a regular basis during May through early July. If closures or activity restrictions were to occur during a green chaining approach, the slash food supply would be cut-off, and beetles may move into standing green trees. Therefore, we caution against use of this approach as numerous factors may result in "breaking of the chain" with potential attacks to residual trees by resulting populations.

Piling. Putting slash into piles with either mechanized equipment (Fig. 8) or by hand is a convenient way to handle slash and it does not contribute to long term surface fuel levels. However, it may not be the best approach for preventing bark beetle build-up.

When piles are created with bulldozer-type equipment the piles tend to be bigger, and large and small material is intermixed. When large material is deep in the pile it may not dry out for an extended period of time, potentially resulting in higher bark beetle brood production. When slash piles are built by hand, smaller material is generally placed in the middle with the larger logs piled on the outside. This method will promote a more uniform drying of all sized material. Another word of caution is to make sure fresh slash and logs are not stacked or piled against residual standing host trees (Livingston 1979). Ips frequently attack standing trees at the same time they are infesting slash or beetles that develop in the slash may emerge to infest adjacent trees.

Related to the green chaining strategy is the approach of creating large slash piles (>3-6 meter (10-20 foot) width, length and height). These large piles may function as multi-generational food resource traps that prevent beetles from attacking standing trees (Kegley et al. 1997). Emerging beetles re-infest slash deeper in the pile and then at the end of the summer brood can be reduced by burning the piles (Overhulser 1999), or through the lack of a fresh supply of slash the following spring (Wiggins and Foss 2005). Six et al. (2002) found no difference in *I. pini* colonization in large [4 m diameter x 2-2.5 m height (13 ft. x 6.5-8.2 ft.)] versus small slash piles [1.5 m x 1.5 m (5 ft. x 5 ft.)]. However, the larger piles may not have had enough volume to create a multi-generational food source. Again, it is recommended in the northern Rockies to distribute piles throughout the treatment area, because of the limited flight capacity of ips (Wiggins and Foss 2005).

Slash piles created in the fall have the potential to dry out sufficiently by spring and can be burned prior to brood emergence. Terra torches (flame thrower) have been used to kill developing ips brood in slash piles by significantly scorching the bark and cambium of slash that was too green to completely burn.

Direct removal. Removing slash immediately after thinning to a central disposal site will mitigate the buildup of ips and other bark beetles in slash. To that end, fuels reduction projects in Arizona have included language in service contracts that operators must remove all slash greater than 10 cm (4 in.) in diameter within 30 days of cutting. This cut, wait and remove approach appears to be successful in managing slash by allowing beetles to infest fresh slash and then removing the material before brood development is completed. In this context, timing is critical. Infested slash should be moved more than 3 kilometers (2 miles) away from ponderosa pine stands to prevent attacks of standing trees from emerging beetles (Parker 1991). Some fuel reduction projects in the Southwest have chipped the slash after cutting and then chips are hauled to biomass energy plants. Fuel reduction projects in Arizona that include immediate hauling of chips to biomass energy plants have not experienced tree mortality within treated stands.

Solarization. Developing brood within slash can be killed by covering slash piles with clear plastic and securely anchoring the plastic to the ground (Parker 1991), a process called solarization (Fig. 9). This recommendation is based on the work in Arizona by Buffam and Lucht (1968) who experimentally demonstrated that covering infested slash with 4-mil clear plastic sheeting resulted in approximately 89 percent beetle mortality. Beetle mortality was only 11 percent when slash was covered with black plastic sheeting and 5 percent for uncovered control piles. The greater mortality in the clear plastic treatment was attributed to higher temperatures reached under the plastic 74.4 °C (165.9 °F); thus, the clear plastic acts like a greenhouse where temperatures underneath reach lethal levels.

Use of solarization treatments has been recommended for a variety of bark beetle-host systems (Craighead 1920, Graham 1924, Patterson 1930, Massey and Wygant 1954, Negrón et al. 2001). However not all studies corroborate the findings of Buffam and Lucht (1968) on ips. For example, Holsten and Werner (1993) reported similar treatments were ineffective for spruce beetle-infested Lutz spruce bolts in Alaska. Although ethylene dibromide fumigation treatments combined with plastic sheeting were successful in killing mountain pine beetle in ponderosa pine infested bolts, the plastic-only treatment resulted in small population reductions and effects were generally limited to bolts on the top of stacks (McCambridge et al. 1975).

To be effective at reducing beetle brood production, solarization treatments must reach lethal temperatures >45 °C (>113°F). Therefore, it is recommended that clear plastic be used and solarization treatments should be established in areas and conditions that promote the highest temperatures possible, such as in forest openings and at southern exposures (Negrón et al. 2001). Additionally, temperatures may not reach


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Figure 8. Large slash pile of ponderosa pine created with heavy equipment. Note the large logs suitable for bark beetle colonization.

lethal thresholds in the middle and bottom of deeply stacked piles (e.g., > three or more layers deep) or if piles are shaded for much of the day (Negrón et al. 2001). Using thick plastic (>6 mil) will help to prevent rips and punctures in plastic which can result in decreased maximum temperatures through venting of heat.

Another factor that should be considered is the timing of the solarization treatments. Careful monitoring is needed to ensure beetles have not emerged from the slash prior to treatment implementation. To increase the efficacy of treatments, solarization treatments should be in place as soon as boring dust is observed on the bark surface. Also, care must be taken to minimize holes in the plastic created by branch stubs or other debris.

Negrón et al. (2001) also noted that ant nests were common inside many of the stacks treated with plastic sheeting, perhaps due to increased humidity and protection from predators. The ants became a problem in the process of removing and disposing of the plastic sheeting. The authors emphasize that there is the need to responsibly dispose of the plastic sheeting when treatments are complete.

Burying. Researchers have not conducted studies to specifically examine the effectiveness of this treatment. However, intuitively it would be effective in limiting beetle access to host material by providing a physical barrier. If burying of slash is implemented caution should be used to not cause detrimental soil disturbance or encourage the introduction or spread of exotic organisms (e.g., plants, fungi, and microbes) to the site.

Bucking (cutting into short lengths). Slash size may be important in regulating ips reproductive performance (Anderson 1948, Haack et al. 1984, 1987). Studies have investigated the effects of slash diameter and length on beetle reproductive success and attack preference (Wesley et al. 1995, Steed and Wagner 2004, Hayes et al. 2008).

Slash management guidelines recommend removal or treatment of all slash >10 cm (4 in.) diameter (Wilkinson and Foltz 1982, Parker 1991), but ips reproductive rates have been shown to be high in 10 cm (>4 in.) diameter slash in Arizona (Hayes et al. 2008). Ips will attack slash with diameters ≤5 cm (≤ 2 in.) (Steed and Wagner 2004), but reproductive performance

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Figure 9. Stack of logs covered with clear plastic to solar sterilize the logs by high temperature to reduce bark beetle brood production.

in logs of this diameter is generally poor (Wesley et al. 1995). Small diameter logs may be more vulnerable to desiccation because of their thin bark, with rapid drying occurring under certain conditions (Schenk and Benjamin 1969, Hayes et al. 2008), and have greater inter- and intra-species competition for limited host resources.

Steed and Wagner (2004) suggested that short logs could impact phloem desiccation rate and in turn reduce beetle reproductive performance. There is some evidence that very short logs rapidly desiccate. Wesley (1995) found that intermediate lengths [122 cm (48 in.)] were preferred by ips over shorter [61 cm (24 in.)] and longer [144 cm (96 in.)] lengths, but Hayes et al. (2008) found a significant positive relationship between log length and phloem moisture in ponderosa logs ≤61 cm (≤24 in.) long. Specifically, logs ≤30.5 cm (≤12 in.) dried rapidly enough to render the phloem unsuitable for ips brood production under most climatic conditions. Logs cut during the summer rainy season, however, experienced beetle reproduction in all log lengths, including 15 cm (6 in.).

It is also thought that large diameter logs are poor habitat for ips. Hypotheses explaining the lack of utilization of large diameter trees and logs by ips include evolutionary factors (i.e., niche partitioning) (Amezaga and Rodriguez 1998), phloem thickness as a limiting factor (Haack et al. 1984, Reid and Robb 1999), and avoidance of thick bark due to higher energy expenditures required for burrowing to the phloem (Kolb et al. 2006). Struble and Hall (1955) state that *I. paraconfusus* in California has preference for and produces the largest brood in slash that has bark thickness of 0.6 cm (0.25 in.) and 1.3 cm (0.5 in.), and that bark more than 2.5 cm (1 inch) is seldom attacked. In a study conducted on pheromone-baited live trees, Kolb et al. (2006) found that more ips attacked thin-barked, small diameter trees than thick-barked, large diameter trees. Hayes et al. (2008) reported similar attack densities on large [25 cm (10 in.)] and smaller [10 cm (4 in.)] diameter logs, but reproductive performance decreased in large diameter logs. Steed and Wagner (2004) reported that diameter had no effect on performance in logs 5, 10 and 20 cm (2, 4, and 8 in.) in diameter. It may be that in live trees, where competition with other bark beetles species (e.g., those in the genus *Dendroctonus* species) is an additional factor, ips avoid attacking areas with thick bark in order to avoid encounters with competing species, but when attacking downed logs exhibit different attack behavior, showing little preference based on bark thickness. In other words, ips may attack small diameter standing trees or the tops of big trees as a way to avoid direct competition with *Dendroctonus* species, but show no inherent reproductive benefit when attacking thin-barked small diameter slash material.

Phloem thickness is positively correlated with reproductive success in *I. calligraphus* (Haack et al. 1987), but has not been shown to affect other ips species. Neither phloem thickness nor stem diameter was correlated with *I. pini* attack on live ponderosa pine (Kolb et al. 2006). As reported above, Hayes et al. (2008) found that larger diameter logs [25 cm (10 in.)] had lower brood reproductive success than smaller diameter logs and as stated above *I. paraconfusus* preferred thinner bark.

Overall, log size does have notable effects on ips reproduction and the management of their populations. Extremely short logs [30.5 cm (≤ 12 in.)] and very small diameter logs [5 cm (≤2 in.)] serve as poor habitat (Steed and Wagner 2004, Hayes et al. 2008). Logs with lengths ≥61 cm (≥ 24 in.) and diameters of ≥12.5 cm (≥5 in.) are generally suitable habitat (Steed and Wagner 2004, Hayes et al. 2008). There remains a question, however, as to the utility of ≥25 cm (≥10 in.) diameter logs for ips reproduction. It may be that a large ips species (e.g., *I. calligraphus*) can benefit from availability of very large diameter material, while smaller species (e.g., *I. pini*) may be limited by large log diameter.

Lop-and-Scattering. One of the most convenient methods of managing slash is to scatter it around the area where it was cut. The material left behind can be a benefit to wildlife by creating desirable habitat, and will eventually decompose contributing to nutrient cycling. Generally, this technique is most appropriate for use in non wildland/urban interface areas when <27.2 metric tons (30 tons) of 0 to 25 cm (0 to 10 in.) diameter material is created/0.4 ha (1.0 acre) and when no more than 4.5 metric tons (5 tons) are from 0 to 8 cm (0 to 3 inch) diameter material (Brown et al. 2003).

To reduce the utilization of slash by beetles when conducting lop-and-scatter treatments it has been recommended that slash be cut as small as practical and placed in non-shaded locations where it will receive the greatest possible solar energy to promote drying (Villa-Castillo and Wagner 1996). However, a recent study (Hayes et al. 2008) has shown that high sunlight levels did not consistently reduce ips brood production in slash. This was true for slash created during any season of the year. There was evidence, however, that beetle performance was low in thin barked [10 cm diameter (4 in.)] and short [30.5 cm (< 12 in.)] logs (*see* Bucking section). Lop-and-scatter treatments may result in fewer attacks on and less mortality of residual trees compared with other treatments such as chipping (*see* next section).

Chipping. In recent years, chipping small diameter logs and slash into very small pieces (Fig. 10) has commonly been used for slash management (Fig. 11), particularly in areas of the Southwest where markets for small dimensional material are lacking. Some land managers consider chipping an ideal treatment as woody biomass is retained on site for nutrient cycling, and fire hazard and soil impacts are reduced, and host material is eliminated in comparison to piled-and-burned and lopped-and-scattered treatments.

Forest health specialists have expressed concerns about bark beetles being attracted to newly chipped areas especially when chips are broadcasted and retained on site (Fig. 12).

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Figure. 10. Chipping in ponderosa pine stands, Arizona.

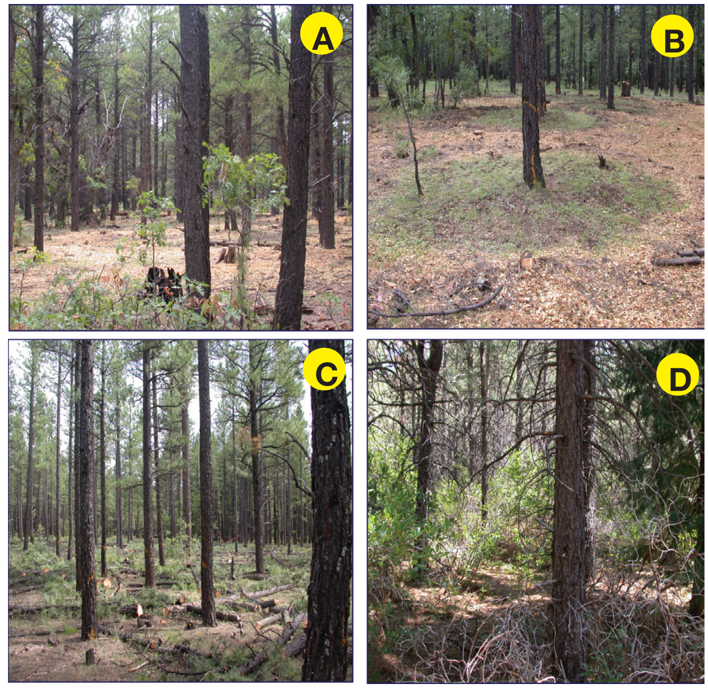

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Figure 11. Slash management treatments in ponderosa pine stands (A) chipped, (B) chipped-and-raked, (C) lopped-and-scattered, and (D) untreated control, California and Arizona.

Although bark beetles do not colonize chips, and could not complete their lifecycle within chips (Six et al. 2002), they may be attracted to treated areas by host volatiles emanating from fresh chips. Fettig et al. (2006a) conducted a study to determine the effects of chipping and other slash management treatments on subsequent amounts of bark beetle activity in ponderosa pine. Treatments included: (1) an untreated control, (2) thinned biomass chipped and randomly dispersed within each plot in spring (CS) and late summer (CF), (3) thinned biomass chipped, randomly dispersed within each plot, but raked 2 m (6.5 feet) from the base of residual trees in spring (CRS) and late summer (CRF), and (4) thinned biomass lopped-and-scattered within each plot in spring (LS) and late summer (LF) (Fig. 11). This study demonstrated that bark beetle activity is exacerbated by chipping of sub- and unmerchantable trees in ponderosa pine stands. A three-fold increase in the proportion of residual trees attacked by bark beetles (all species) was observed in chipped versus lopped-and-scattered treatments and the untreated control (Fig. 13). Higher levels of bark beetle activity occurred when chipping was conducted in spring (CS; Fig. 13), which in general corresponded with peak periods of adult flight activity for several bark beetle species. Raking chips away from the base of residual trees did not significantly affect attack rates, although a 20% reduction occurred when raking was conducted.

Despite higher levels of bark beetle attack in chipped plots (Fig. 13), no significant differences in tree mortality were observed among treatments during the first two years of this study (Fig. 14) (Fettig et al. 2006a). However, the authors commented that negative effects of prolonged and large numbers of red turpentine beetle attacks, among others, on individual tree health may not be realized for some time (Fettig et al. 2006a), and to continue monitoring these plots for bark beetle-caused tree mortality should be conducted on an annual basis. Cumulatively (2003-2006), a significant treatment effect was also observed (Fig. 14), with significantly higher levels of bark beetle-caused tree mortality occurring in CS than LF treatments. Slash management treatments that were implemented in spring versus late summer resulted in significantly higher levels of tree mortality during the four year period.

Based on these and other results, guidelines have been developed for minimizing tree losses due to bark beetle infestation following chipping in southwestern ponderosa pine:

(1) chipping should be conducted during periods of adult bark beetle inactivity—in the Southwest, late summer through early winter is optimal;

(2) efforts should be made to limit the piling of large quantities of chips against residual trees—raking or use of tarps to prevent chips from accumulating around tree bases may help to reduce bark beetle attacks;

(3) treatments that promote desiccation of slash and/or other host material and slow release of monoterpenes (i.e., tree volatiles that attract certain bark beetle species) prior to chipping could be considered;

(4) treatment units should be designed to minimize the amount of edge per unit area as chipping may influence bark beetle attacks beyond the spatial scale of treatments. This may be of particular importance in the wildland urban interface where large amounts of boundary exist per unit area, and where bark beetle-caused tree mortality may increase fire risks in areas likely not to be re-treated for many years; and where residual trees are of generally higher value;

(5) increased monitoring of chipping sites is needed since the percentage of red turpentine beetle attacked trees was positively correlated with the number of trees chipped (Fettig et al. 2006a), the response of this species, and perhaps others, will likely increase with thinning (and chipping) intensity. The more biomass chipped, the higher probability of bark beetle attack and tree loss will occur; and

(6) hauling of fresh chips away from the host type will

significantly reduce bark beetle activity within treated stands. Currently, no data are available on bark beetle responses to mastication treatments (e.g., excavator-mounted rotary heads which shred plant material into large chips or chunks) in the Southwest. Anecdotal evidence from California suggests responses similar to those observed for chipping may be common.

Chemical Treatment of Slash

Semiochemicals. Semiochemicals are chemicals produced by an organism that incite a behavioral response in another organism. Bark beetles typically utilize pheromones, which cause a specific behavioral or physiological reaction in a receiving individual of the same species. Other types of semiochemicals that have been discovered include kairomones, allomones and synomones. Researchers have attempted to use bark beetle semiochemicals to manipulate beetle behavior with the goal of reducing ips attacks in logging slash (Bedard et al. 1979, Wood 1980, DeMars et al. 1980, Gibson and Weber 2004, DeGomez et al. 2008).

The use of pheromone baited traps to reduce populations has been tested against several bark beetle species (Bedard et al. 1979, Wood 1980, DeMars et al. 1980). In Montana workers have had success by placing three to four pheromone baited Lindgren funnel traps around piled slash to prevent emerging ips beetles from attacking standing live trees (Gibson and Weber 2004). Their project showed that baited traps could catch over 50,000 beetles from the slash piles on 161 ha (400 acres) of thinned forest.

Attempts to mass-trap bark beetles have found that beneficial predators (*Temnochila* spp., *Enoclerus* spp. and others) have inadvertently been caught in the traps, thus reducing the number of natural enemies of the target pest (Dahlsten et al. 2003). Research has shown (Dahlsten et al. 2003, Ross and Daterman 1995) that modifying the pheromone blend used to attract the target species can reduce the number of predators captured. Aukema and Raffa (2002), working in the Great Lakes region, have identified pheromones which attract ips predators but not pine engravers. The ability to selectively attract predators provides opportunities for augmentative biological control.

An additional hurdle to overcome with mass trapping (killing) of bark beetles with pheromones is the need for approval by the EPA to use semiochemicals as pesticides. Thus, additional work is needed to develop recommendations for mass trapping in the Southwest.

Considerable work has been conducted on the use of the antiaggregation pheromone verbenone. Verbenone is produced from verbenols by microorganisms (Hunt and Borden 1989) and directly through autoxidation of the host monoterpene, a-pinene, and subsequently *cis*- and *trans*-verbenol to verbenone (Hunt et al. 1989). The process is mediated by several tree-killing bark beetles species (e.g., *D. brevicomis*) and through degradation of host material by natural processes (Lindgren and Miller 2002).

Researchers have shown that pine engravers are repelled by high concentrations of verbenone (Borden et al. 1992, Miller et al. 1994, Lindgren and Miller 2002, Salle and Raffa 2007). Verbenone has also been combined with non-host volatiles in an attempt to reduce ips attraction to logging slash. Green leaf volatiles plus verbenone has been found to significantly reduce *I. typographus* attraction to host trees and logs (Zhang 2003, Zhang and Schlyter 2004). Huber et al. (2001) found a combination of repellent synomones, verbenone plus ipsenol,

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Figure. 12. Bark beetle-caused tree mortality following chipping treatments in ponderosa pine stands, Arizona.

combined with a conophthorin, a non-host volatile, to be effective in disruption of *I. pini* attraction to traps and may provide protection to trees, logs or stands.

DeGomez et al. (2008) tested verbenone in the form of Disrupt® (Hercon Environmental, Emigsville, PA), a controlled release laminated polymeric dispenser [flakes 3mm x 3mm (0.1 in. x 0.1 in.)] alone and in conjunction with freshly chipped limbs of non-host species. In 2005, the label rate of 100 g (3.5 oz) of flakes/slash pile was applied with and without 3.5 kg (7.7 lb) of non-host chips per pile, the chips were reapplied weekly. A small though statistically significant effect was detected, with a decrease in beetle success in the slash piles treated with verbenone. The non-host chips had no observable effect on bark beetle behavior. In 2006, verbenone was applied at treatment rates equal to and two, four and eight times higher than labeled rates [100, 200, 400 and 800 g (3.5, 7.0, 14.0, and 28.0 oz) of flakes per slash pile]. No significant difference between the treatments and the control was found.

Despite some initial successes by the research community, there are still no commercially-available semiochemical-based tools that are effective for protecting logging slash from ips attack in the Southwest.

Insecticides—Prevention. Preventing bark beetle attack with insecticides is only effective when applying chemicals to the bark of individual trees and is impractical for use at the stand level. Candidate trees are those that are of high value on private property, developed recreational areas, and forest administrative sites. Insecticides have been shown to be effective in preventing bark beetles from successfully colonizing live standing trees (Hastings et al. 2001 and references cited therein, Fettig et al. 2006b). Additional studies have shown that bark beetles can be prevented from colonizing downed

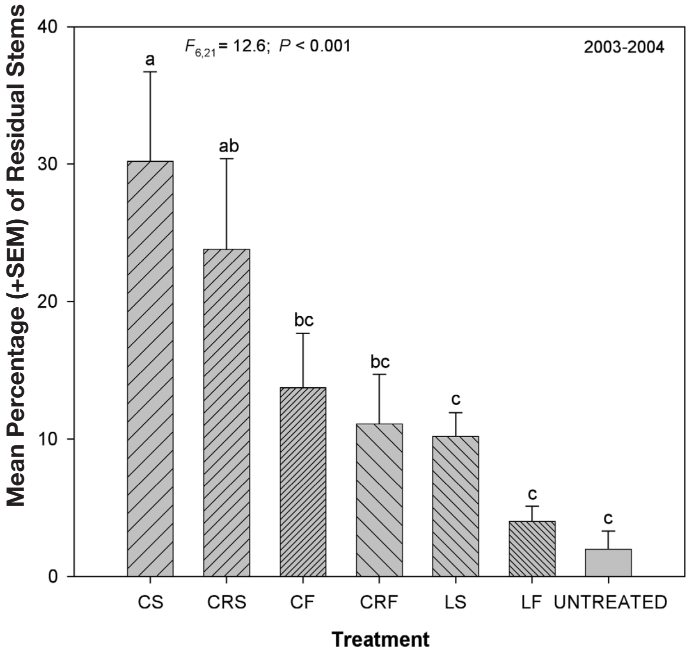

Figure. 13. Mean percentage (+ SEM) of residual trees attacked by bark beetles following hazardous fuel reduction treatments in Arizona and California, 2003-2004. Treatments were applied in late spring (S) and late summer (F) and included: (C) thinned biomass chipped and randomly dispersed within each plot, (CR) thinned biomass chipped, randomly dispersed, and raked 2 m (6.5 feet) from the root collar of residual trees, (L) thinned biomass lopped-and-scattered within each plot, and (Untreated) control. Means followed by the same letter are not statistically different (*P*>0.05; Tukey's HSD).

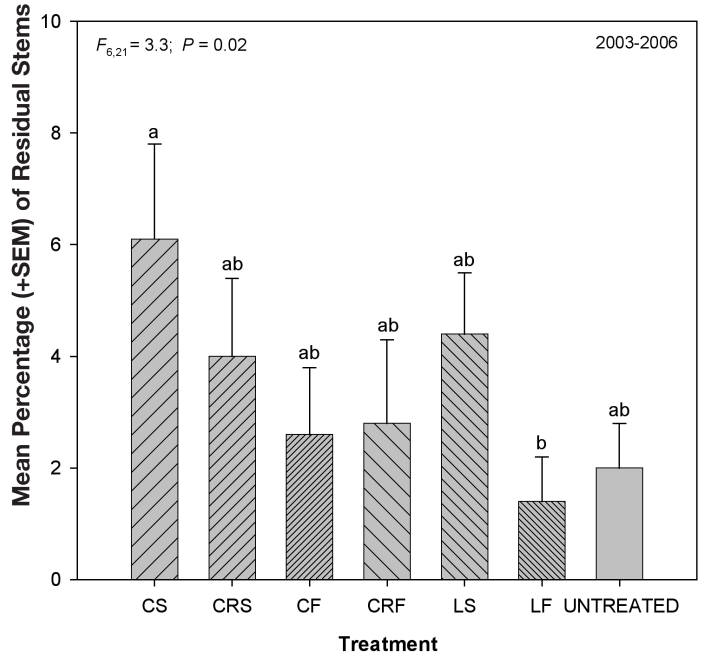

Figure. 14. Mean percentage (+ SEM) of residual trees killed by bark beetles following hazardous fuel reduction treatments in Arizona and California, 2003-2006. Treatments were applied in late spring (S) and late summer (F) and included: (C) thinned biomass chipped and randomly dispersed within each plot, (CR) thinned biomass chipped, randomly dispersed, and raked 2 m (6.5 feet) from the root collar of residual trees, (L) thinned biomass lopped-and-scattered within each plot, and (Untreated) control. Means followed by the same letter are not statistically different (*P*>0.05; Tukey's HSD).

material when insecticides are applied to the bark of the tree prior to felling (DeGomez et al. 2006). Insecticides may also be applied immediately after felling and subsequent slash production. Currently, registered insecticides that are most commonly used for prevention purposes include carbaryl, permethrin, and bifenthrin (DeGomez 2006b). To determine which insecticides are currently registered in the Southwest or other areas refer to the Kellysolutions Service Site at http://www.kellysolutions.com/.

Insecticides—Suppression. Valcarce and Hay (1973) conducted trials using lindane to prevent emergence of brood from slash that had been attacked by *I. pini.* They found that treating slash while broods of bark beetles were still immature protected the residual trees within stands that had been thinned. Ostmark (1969) found similar results with the fumigant EDB (ethyl dibromide) when ponderosa pine are infested with *I. lecontei.* However, lindane and EDB are no longer registered and no other insecticide is currently recommended for suppression treatments on infested slash.

Conclusions

In this publication we have outlined the many ways that managers can reduce the buildup of ips beetles in slash and limit attacks on residual trees. Our goal was to present a broad array of techniques so that methods can be selected that best suit the specific management needs of any given site. The need for, and success of most management treatments hinge on current ips population levels. For example, if ips populations are endemic and historically have not been an issue there may be more flexibility in what treatment to consider if any. Within the wildland-urban interface it may be justified to treat most of the slash with chipping (using the guidelines suggested in chipping section), or hauling to reduce fire danger and bark beetle susceptibility. However, in rural areas more slash may be tolerated in order to meet other resource needs, such as maintenance of wildlife habitat.

Critical Management Factors

1. **Timing —** The most important factors in deciding when to create slash are the seasonality of beetle activity and tree susceptibility. Since ips beetles become active in the early spring, prior winter moisture levels are important. If winter moisture has been normal potential host trees will be more resistant to bark beetle attack than if moisture is below normal. Climate patterns in the Southwest dictate very dry weather in May, June, and often into early July; these months are critical for the success of first generation ips beetles seeking a suitable host tree. Another related factor is whether there have been successive dry years. Drought reduces tree resistance to bark beetle attack.
2. **Site factors —** For many of the same reasons that slash should not be created during a drought, slash management is critical in poor site quality areas or stress prone sites. Poor sites often have less water available for plant use and trees become stressed more quickly when drought conditions occur.
3. **Act early —** No matter what time of year slash is produced, removal and utilization of slash is the most effective method to reduce bark beetle risks associated with slash. Treatment activities should be conducted within the first 30 days after slash creation to reduce brood production. Treatment

activities such as taking the slash offsite or manufacturing it into other products such as chips or lumber will eliminate the production of brood that can attack standing live trees in the area harvested. Cutting the material into firewood lengths will not render the bark unsuitable for brood production. However, if slash is to be left on the ground for several months without treatment, slash production should be avoided from January to June.

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Cooperative Extension

The University of Arizona
College of Agriculture and Life Sciences
Tucson, Arizona 85721

Tom DeGomez
Regional Specialist and Area Agent, Agriculture and Natural Resources, University of Arizona

Christopher J. Fettig
Principal Research Entomologist, Pacific Southwest Research Station, USDA Forest Service

Joel D. McMillin
Entomologist, Forest Health Protection, USDA Forest Service

John A. Anhold
Entomologist, Forest Health Protection, USDA Forest Service

Christopher Hayes
Research Specialist, Natural Resources

Contact:
Tom DeGomez
degomez@ag.arizona.edu

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