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THE RELATIONSHIP BETWEEN FIRE AND BARK BEETLE ATTACK IN WESTERN NORTH AMERICAN FORESTS

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SUMMARY

The nature of western North American forests is the result of the interactions between fire, insects and logging. The interrelationships between forest fires and phytophagous insects is of considerable importance in determining the composition and structure of stands of forest trees. This paper examines the interactions between bark beetles and forest tree species by presenting three specific case studies. The case studies are the red turpentine beetle and ponderosa pine, the Douglas-fir beetle and Douglas-fir and the mountain pine beetle and lodgepole pine in northeastern Wyoming, western Wyoming and northern Utah respectively.

A brief review of some of the literature examining the mechanisms of host selection by bark beetles is presented.

INTRODUCTION

The specificity of many forest insects affects forests through direct tree mortality, and alteration of stand structure and composition. Insects are capable of influencing the amount and type of vegetation and can directly determine the probability of ignition and fire behavior.

Fire can also have important effects on forest insect population dynamics. Fire-caused mortality creates habitat for many coleopterous and hymenopterous borers and tree wounding by fire stresses trees decreasing their resistance to insects. Fire induced cambial damage has been shown to result in increased incidence of bark beetle attacks in many North American forest tree species (Furniss 1965, Geiszler et al 1980). Ultimately, by creating vegetative diversity, fires affect the distribution of all organisms in an ecosystem.

In western North America and elsewhere forest management has influenced fire/insect interactions. In the early 1900's selective logging commonly meant removal of high value pine species which led to a general increase in shade tolerant conifers and subsequent expansion of western spruce budworm (Choristoneura occidentalis Freeman, Lepidoptera: Tortricidae) populations (Anderson et al. 1987). Increased top kill and outright budworm mortality has fueled many large catastrophic fires typifying the later decades of the twentieth century. Very few forested ecosystems have not been influenced by regular patterns of fires for thousands of years. The successful suppression of wildfires since about 1900 had significant impact on fuels accumulation and tree overmaturity resulting in bark beetle epidemics and eventually large catastrophic fires as, for example, in Yellowstone National Park in 1988 (Arno and Brown 1989).

To illustrate the above relationships I will develop three examples of the interaction between fire and bark beetle populations using data collected in different ecosystems in western North America. The three examples will be 1) red turpentine beetle (D. valens LeConte Coleoptera: Scolytidae) in ponderosa pine (P. ponderosa) forests; 2) the Douglas-fir beetle (D. pseudotsugae Hopkins) in Douglas-fir (Pseudotsuga menziesii) forests and 3) mountain pine beetle (Dendroctonus ponderosae Hopkins) in lodgepole pine (Pinus contorta) forests.

RED TURPENTINE BEETLE/PONDEROSA PINE

The U.S. Department of the Interior, National Park Service (NPS) has used prescribed fire for vegetation and wildlife management since 1968 in a number of national parks and monuments (Kilgore 1984). Devils Tower National Monument in Wyoming, however, experienced little fire use with only three ignitions on 51 acres reported (Fischer 1984). NPS records dating back to 1951 record only 18 wildfires, all but two of which were small fires burning less than 0.1 hectare. The frequency and size of these fires differed greatly from historical fire frequency as documented by Fisher et al.

(1986). The primary consequence of reduced fire frequency has been an accumulation of large fuel loads. This condition has been recognized by personnel at Devils Tower and their fire management plan lists fuels reduction as an important objective in addition to the primary objective of simulating the historical occurrence of ground fires and increasing shrubs, grasses and forbs to improve wildlife habitat. Research conducted at the monument evaluated the extent of direct tree mortality and bark beetle attacks resulting from a prescribed fire conducted to meet the above objectives.

The fire was conducted in an old growth ponderosa pine stand possessing many old, large fire resistant pines and numerous seedlings, saplings and fuel jackpots (accumulations) appearing since the alteration of the historical fire regime (Fisher et al. 1986). The fuel load in this type averaged 2.6 kg/m^2 with a large proportion (86%) of the total in the 1000 hour time lag class.

In the prescribed fire a total of 2372 trees with an average mean diameter of 22.86 cm were killed directly by the fire (Table 1). Direct fire mortality was common in areas where fuel jackpots and fuel ladders existed at the base of old trees and on slopes and in gullies. Another 76 trees were wounded to an extent that they became susceptible to bark beetle attack. The species responsible was the red turpentine beetle which has a wide distribution in North America and is known to attack weakened trees or those injured by fire, logging, etc. Populations of this species rarely reach outbreak proportions, but it is capable of causing considerable mortality in areas where large numbers of trees have been weakened (Furniss and Carolin 1977). The average diameter of trees killed by the bark beetle was 35.9 cm which is as would be expected since D. valens prefers larger diameter trees, generally greater than 20 cm (Wood 1982).

The activity of D. valens at Devils Tower was a relatively minor problem, but it points out the potential for bark beetle outbreaks when large diameter trees are wounded. Other scolytid beetles such as D. ponderosae can cause considerable damage when populations are allowed to increase at times of tree stress. Ips beetles can also cause high levels of mortality, especially in combination with Dendroctonus beetles. Ips beetles were also collected from a large diameter pine in the burn area. Ips beetles are polygamous and breed in slash and can at times make primary attacks on healthy trees. In stands like those at Devils Tower where many large over mature trees exist and where there is an abundance of large diameter branch wood for breeding, Ips can present a real problem. In situations such as this Ips and Dendroctonus beetles can kill those trees most valued by NPS managers and their visitors.

DOUGLAS-FIR BEETLE/DOUGLAS-FIR

The character of Rocky Mt. Douglas-fir forests has been shaped by fire, insects, disease and timber harvesting leaving typical multistoried stands with a preponderance of shade tolerant species. Douglas-fir commonly occupies dry and rocky, mid elevation slopes between ponderosa pine and Engelmann spruce and on such sites is susceptible to drought. Fire suppression, site and stand structure have combined to produce conditions favorable for persistent western spruce budworm infestations during the past half century. Drought and budworm defoliation are two common factors predisposing Douglas-fir to bark beetle attack.

The Douglas-fir beetle attacks Douglas-fir trees throughout its range in western North America. The beetle is normally considered secondary attacking wind thrown, defoliated, diseased or otherwise environmentally stressed trees. Damage from logging drought, wildfire and snow breakage have also been associated with Douglas-fir beetle outbreaks (Bedard 1950, Fredericks and Jenkins 1988).

In 1988 the Hunter Fire burned as part of the Greater Yellowstone fire complex east of Grand Teton National Park in Wyoming . The fire burned through an old growth stand of Douglas-fir killing many smaller diameter trees and scorching numerous thick-barked older individuals. In the two years since the fire many of these old trees have been attacked by bark beetles and flatheaded borers (Coleoptera; Buprestidae). The likelihood of an individual tree being attacked is related to tree diameter and scorch height and circumference. The incidence of bark beetle attack is much greater than in a similar unburned adjacent stand.

MOUNTAIN PINE BEETLE/LODGEPOLE PINE

Lodgepole pine grows on a wide variety of soils from sea level to 3500 meters throughout western North America. It is often seral to other conifers including spruce, fir, Douglas-fir, cedar or hemlock, but can form edaphic, topographic or fire climax stands. It can often persist on sites too harsh for other conifers.

Lodgepole pine systems are fire dependant and require periodic fires for proper functioning and species existence. The role of fire is to renew or perpetuate lodgepole pine. Cone serotiny is a fire adaptive trait that is variable in lodgepole pine depending on genotype, age, dominance and stand. The level of serotiny and fire intensity interact to determine fire effects on regeneration. Low intensity fires do not produce conditions favorable for regeneration of pines. Moderate intensity fires are most favorable for pine regeneration and high intensity fires can kill seeds.

The mountain pine beetle is the most serious pest in western North America attacking numerous pine species. Endemic populations function to remove over mature trees, maintain stand productivity and a constant food supply. Outbreaks generally occur when there are an abundance of trees greater than 20 cm in diameter, over 80 years old and growing at elevations below 3000 meters (Amman et al. 1977). Short term stress by agents including drought, wounding, defoliation, air pollution and root rots can favor the development of epidemics. Fire suppression has generally resulted in the production of stands with these characteristics. Presently in the United States over two million acres of lodgepole pine are infested by mountain pine beetle (USDA 1989).

Brown (1975) proposed the general scheme for forest succession in lodgepole pine forests incorporating the effects of bark beetles and fire return intervals. Over time, bark beetles function to produce enough fuel for large stand replacing fires. Post mountain pine beetle epidemics produce 60-100 tons/ha and contributed to the high intensity fires observed in Yellowstone National Park in 1988.

Of more interest is the effect of low intensity surface fires on bark beetle populations. Surface fires result in root and or cambium damage leading to fungal invasion and a general lowering of tree resistance. This makes trees susceptible to bark beetle attack and eventual mortality (Gara et al. 1984).

In order to test these relationships, trees in a lodgepole pine stand in northern Utah were stressed by girdling and data on beetle attack rate were collected. Three plots were established in nearly pure stands of lodgepole pine which had a mean basal area of 50.5 m^2/ha. Plot centers were established at random provided there were no group infestations within 500 m. Diameter at breast height was recorded for all trees within the immediate vicinity of the plot center and pairs were formed on the basis of diameter, crown class as well as presence or absence of scars on the bole. A girdling treatment was then randomly applied to one member of each pair. The treatment trees were girdled at breast height, removing the bark and phloem from a band approximately 10 cm. wide. Following treatment all of the study trees were fitted with 'sticky traps' which consisted of a 1.3 m band of white nylon cloth gauze and then coated with a layer of 'Tanglefoot'. The traps were inspected on a daily basis during the beetle flight period. The number of trapped mountain pine beetles was noted and the insects were removed from the trap. Once a tree was actually attacked by the beetles (determined by the presence of frass and/or pitch tubes) the phenomena of secondary attraction was considered to have begun, and the pair was removed from the study population.

At the end of the experiment total numbers of trapped beetles on the treated and untreated trees were summarized (Table 2). A significant difference was found in the landing rate between treated and untreated trees (Fig. 1).

The results of the study demonstrate that the mountain pine beetle is able to locate wounded and stressed trees while in flight.

DISCUSSION

The case studies presented here and decades of empirical evidence support the hypothesis that bark beetles are preferentially attracted to stressed or trees injured by agents such as fire. There has, however, been a considerable controversy among entomologists as to the exact mechanisms of host attraction.

Gara et al.. (1984) found greater mountain pine beetle landing rates on trees under natural stress (fire scars and fungal decay). They concluded that the beetles were landing more frequently on the stressed trees than those with no signs of scarring or decay. They hypothesized that the cues used by the beetle resulted form the interaction between the host and the fungal decay. Heikkenen and Hrutfiord (1965) established that the Douglas-fir beetle can distinguish between several of the important compounds found in the host (primarily alpha and beta pinene). They hypothesized that the attractancy effect of the alpha pinene served to aid the beetle in locating water stressed trees which release proportionally more alpha pinene from their stomata. Heikkenen (1977) also studied the effect of tree wounding on the response of the southern pine beetle (D. frontalis). He compared the landing rates of southern pine beetles on loblolly pines which had been girdled versus untreated controls. The results showed that landing rates were greater on the treated trees indicating that the southern pine beetle was attracted to the wounded trees while on their dispersal flight.

In contrast to these studies, work done by Hynum and Berryman (1980) suggested that the mountain pine beetle is unable to distinguish susceptible from nonsusceptible hosts by olfactory cues. They found that landing rates on dead and living lodgepole pine and non-host Douglas-fir were not significantly different. Their data suggested that the mountain pine beetle lands on objects at random, and only after sampling the substrate and feeding are they able to determine the suitability of the object. They contended that the presence of chemical feeding stimulants in the bark causes the beetle to begin construction of the gallery (Raffa and Berryman 1982a).

A model explaining the epidemiology of the southern pine beetle proposed by Coulson et al. (1985) was based on the incidence of lightning struck trees as providing a highly susceptible host tree. Once located, these trees were colonized and were able to sustain large numbers of brood, sometimes establishing large infestation centers around the lightning struck tree. Lightning struck trees are similar to fire damaged trees in that large amounts of resin are released into the air which may be attractive to in flight beetles. In addition the disruption of the phloem causes a rapid decrease in the amount of carbohydrates supplied to the tree's root system resulting in a decline in the root's ability to supply water and nutrients to the crown. Trees of this type provide more suitable habitat especially for endemic populations of less aggressive bark beetle species. More information is needed regarding the interplay of host stress and beetle response, especially mechanisms by which beetles locate weakened trees. Future work will examine varying degrees of host stress induced by nonphysical methods and how the beetles react to these levels.

Forest managers must understand the interrelationships between fire, bark beetles and host trees in implementing harvesting schemes. The use of clearcutting and burning for site preparation in suitable tree species is often a method compatible with the relationships developed above. The primary consideration of fire managers is protection from the large unwanted catastrophic fire. The most common method to accomplish this objective is the use of prescribed fire for hazardous fuel reduction. This is often difficult because the type of fire necessary is the same as that from which the system is being protected. And it is often difficult to sustain a fire of sufficient intensity during "safe" fire weather conditions. Of primary importance is the recognition that well planned harvesting schedules can be the best method of minimizing fire and bark beetle hazards.

Table 1. Dimensional statistics for trees greater than 10cm affected by prescribed fire at Devils Tower National Monument.

Number of trees	Mean diameter (cm)	Mean height (m)	Mean scorch height (m)
	All Trees		
20,768	32.0	18.7	5.2
	Trees Killed by Fire		
2,373	22.9	16.7	8.2
	Trees Killed by Bark Beetles		
76	35.9	20.7	8.2

Table 2. Statistical analysis of landing rates on treated and untreated lodgepole pines.

	N	Tested N	W	P Value
Treatment vs. Non treatment	16	7	28	99.2
DBH >20cm vs. <20cm		a	16.2	82.7
Plot Basis	32	b	0.91	40.0

a Wilcoxon test for unequal treatments

b Kruskal-Wallis test for one-way layout

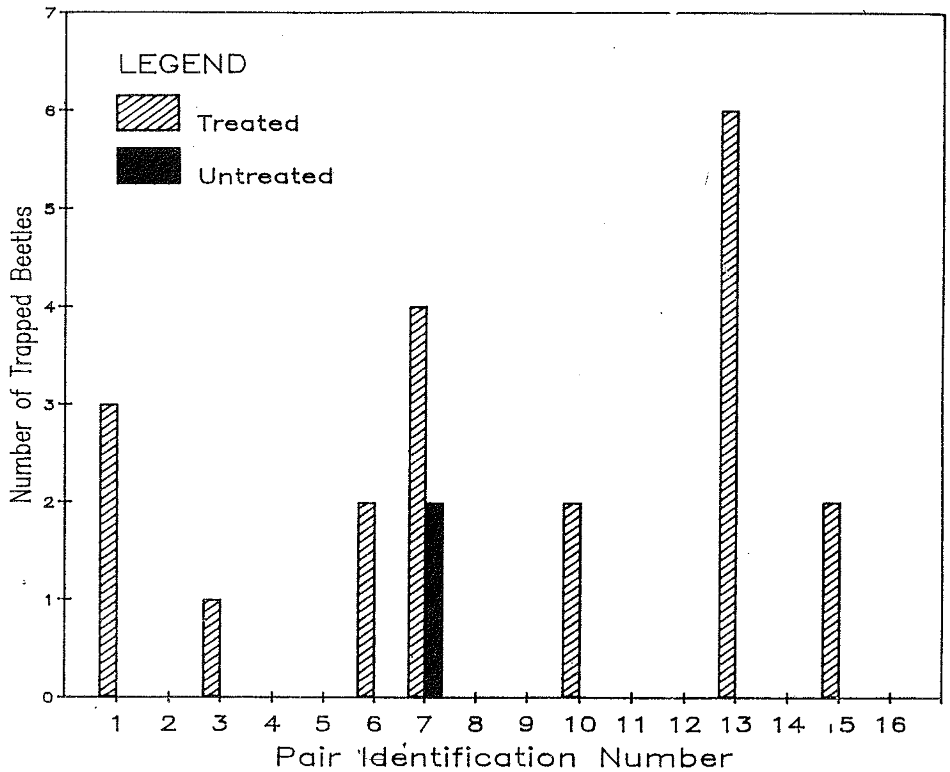

Fig. 1. Landing rates of mountain pine beetle on treated and untreated lodgepole pines.

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