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Forest Insect Hazard Rating

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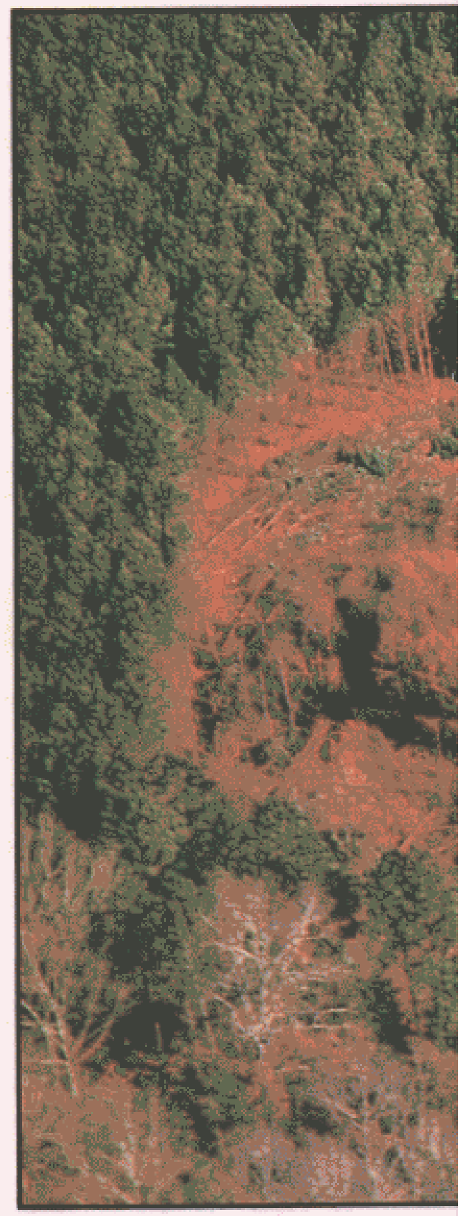
FOREST INSECT H

Applying a little-understood management tool using the southern pine beetle and the gypsy moth.

By R.R. Hicks, Jr., J.E. Coster, and G.N. Mason



Hazard rating is considered by many to be a cornerstone of integrated forest pest management. The subject of a symposium held in Athens, GA, from July 31 to August 1, 1980, hazard rating is taken by some to be a panacea; others consider it to be little more than an academic pursuit. Certainly hazard rating can be a powerful tool when used properly, albeit not a cure-all. Forest managers, even those who embrace hazard rating, are often not fully aware of its benefits or of some limitations that should be considered in its application and interpretation. This article purports to foster a better understanding of hazard rating and its application for two forest insects—the southern pine beetle *(fig. 1)* and the gypsy moth *(fig. 2)*.

The Concept

Since the earliest reported forest insect outbreaks in the United States, foresters, entomologists, and others have recognized and reported conditions associated with varying levels of insect activity and forest damage. More recently, these observations have become more quantitative, and the terms "hazard" or "risk" rating have been used to describe broad relationships between pest activity and forest conditions. Several systems have been developed for a number of forest pests—for example, the spruce beetle, gypsy moth, southern pine beetle, and western pine beetle. As with forest-fire hazard rating, insect hazard rating recognizes conditions under which a damaging event is most likely to occur and where highest levels of damage might be expected. Also, because many other factors come into play besides the presence of a hazardous situation, insect hazard rating does not predict when, or even if, an event will occur, nor does it guarantee that insects will not cause damage in locations classed as low hazard. Ratings simply provide additional information that managers should find useful in identifying and ranking locations or stands that warrant consideration for increased surveillance, preventive treatment, accelerated suppression action, or post-damage appraisal.

In contrast to hazard, risk is the probability that an event will occur. High-hazard stands can exist with little or no risk of attack when insect populations are low. The converse is true during epidemic periods.

Insect hazard ratings relate categories of site, stand, and tree conditions to general patterns of damage for stand types within the designated hazard classes. These ratings are based on existing factors that predispose stands to attack and that cause infestations. In many instances, true causal factors may not be known or may be of a qualitative or subjective nature and, as such, may be impossible to measure. Stress factors that may result in increased host susceptibility are long or short term in nature and may be caused by a number of uncontrollable

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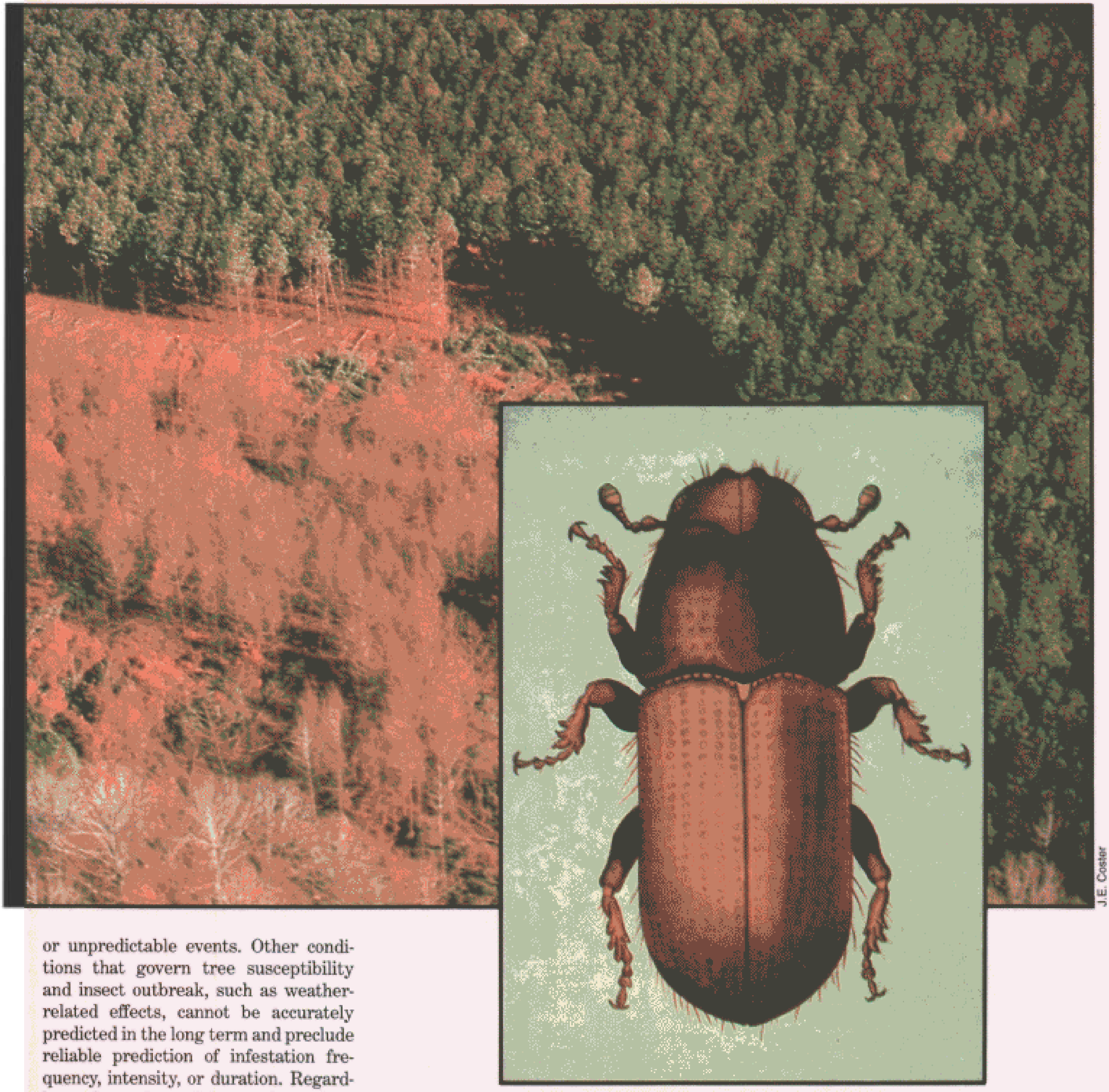
AZARD RATING



or unpredictable events. Other conditions that govern tree susceptibility and insect outbreak, such as weather-related effects, cannot be accurately predicted in the long term and preclude reliable prediction of infestation frequency, intensity, or duration. Regardless of stand condition or immediate susceptibility, infestation occurrence and damage levels are dependent upon pest population presence, distribution and intensity, and environmental conditions suitable for population survival or expansion. These are but some of the

Figure 1. (Foreground) Southern pine beetles (SPB), such as this artist's rendering, generally infest trees of low vigor. Hazard rating systems can help managers determine forest stands predisposed to infestation. (Background) SPB attack forests in spots, such as this one in Arkansas. Foresters cut and will burn uninfested trees surrounding the spot to prevent the insects from spreading.

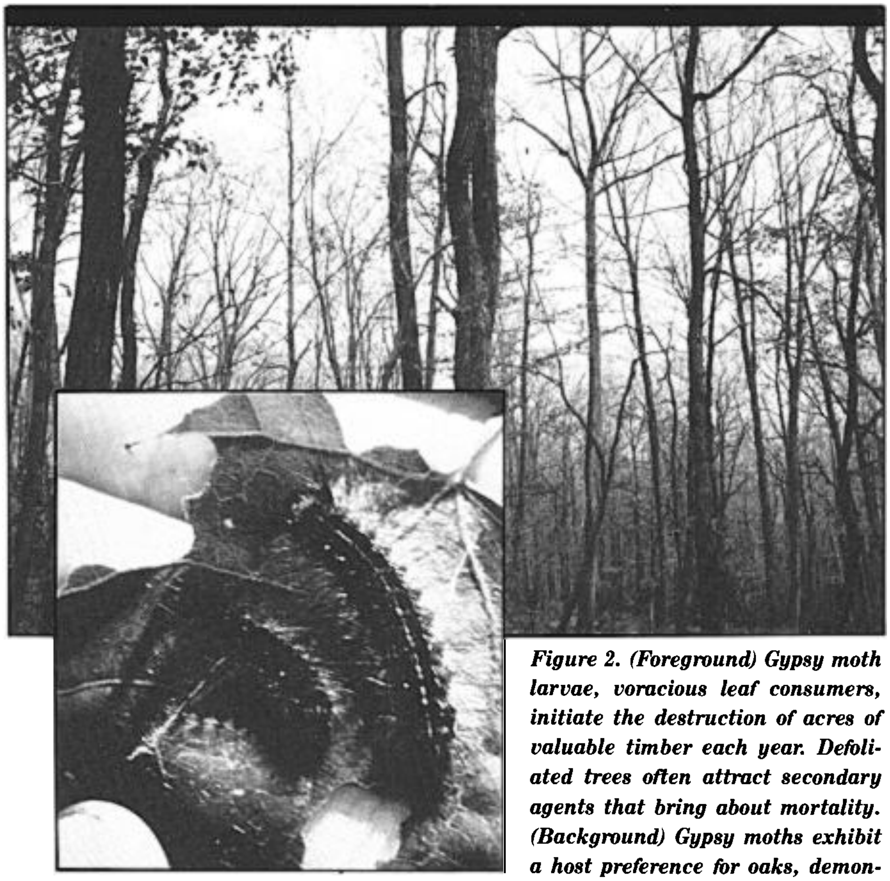


Figure 2. (Foreground) Gypsy moth larvae, voracious leaf consumers, initiate the destruction of acres of valuable timber each year. Defoliated trees often attract secondary agents that bring about mortality. (Background) Gypsy moths exhibit a host preference for oaks, demonstrated by this defoliated forest. Although hazard rating cannot predict insect infestation, it provides vital decision-making information.

factors that preclude forecasting site-specific or even areawide outbreak or infestation levels.

Problems aside, it is well documented that for a number of forest insects, certain conditions do predispose trees to attack. These include species, age, site, drought, and canopy position.

Benefits from Rating

Hazard ratings for forest stands require little or no data beyond what is currently available through routine forest inventory activities. They provide an added dimension for making informed management decisions. Many forest managers find hazard ratings also useful in developing justifications regarding the need, scheduling, and timing of management operations such as intermediate cuttings, harvest, and regeneration. Stand hazard rating offers an opportunity to examine overall resource conditions and to weigh needs and priorities for stand-management actions against the likelihood of outbreaks, expected losses, and the cost of direct control actions.

Hazard rating can be useful in identifying areas that serve as reservoirs for insect populations during endemic periods. For instance, overstocked pine stands on poorly drained sites often serve as locations of the first southern pine beetle (SPB) spots *(fig. 1, background)* following periods of low activity. For the gypsy moth (GM), these focal stands are characterized as upper-elevation sites supporting high proportions of white or chestnut oak and with an abundance of tree and site structural features where GM life stages are sheltered from predation. Adequate identification of probable reservoirs and timely treatment during periods of low insect activity may serve to prevent or slow the development of outbreaks.

Forest managers are gaining a better understanding of the effects of insects under specific site and stand conditions, and they are becoming increasingly aware of alternative pest-management approaches. They are also more aware of the importance of integrated pest management and of considering pest impact throughout the life of a stand. These priorities have caused managers to recognize the need, under certain conditions, to evaluate insect infestation on a stand-by-stand basis, and to weigh stand condition and present and future values against current and projected insect-caused loss. Stand hazard rating, as it describes the nature and condition of the forest, can greatly improve the manager's ability to make pest-management decisions that are biologically and economically sound. Better understanding of forest and stand conditions through hazard rating can enhance the effectiveness of ground and aerial surveys by focusing on areas where activity is most likely. During endemic periods, aerial detection surveys may be focused on "indicator" areas where detectable levels are most likely to be found. If warranted, the survey may then be expanded to areas of less likely occurrence. In the case of the GM, the manager can also consider stand condition and value (as indicated by the stand rating) along with the previous year's defoliation *(fig. 2)* and insect population in determining or justifying the need for more intensive ground monitoring.

Predisposition

Intuitively, one would hypothesize that tree stress is somehow the basic issue in predisposing trees to insects, but such a simplistic theory is far easier to state than to prove. A major weakness with this stress theory is that researchers have not clearly differentiated between stress and vigor.

Stress and low vigor may have somewhat similar effects on the physiological state of a tree, but they differ in the time scale over which they operate. Declining vigor, due to factors such as shading, root competition, or poor site, generally takes place over a relatively long period of time. Stress, on the other hand, may occur rapidly and is much more readily reversible. One of the best examples is moisture stress resulting from summer drought. Stress will persist until adequate rainfall occurs to break the drought. Then trees respond rapidly, unless the drought was so severe as to cause mortality or dieback.

Physical damage, such as that resulting from lightning, logging, or fire, can also cause a kind of stress, but the recovery may be slower than from drought stress. Lorio and Hodges (1977) demonstrated that drought-stressed pines had lower oleoresin exudation pressure and were more susceptible to induced SPB attack.

With GM defoliation, low-vigor trees seem to be generally more vulnerable to mortality. However, Hicks (1985) found that pockets of high mortality occurred in defoliated forests where trees were otherwise apparently healthy and that mortality was slightly greater for trees growing on better sites. These seemingly conflicting results probably relate to the different secondary agents responsible for mortality.

Gaining an understanding of the nature of stress and vigor relationships requires that some index to the vigor or stress state of the tree be found. A number of indexes have been studied that presumably reflect vigor, such as radial growth, root-starch content, and crown condition. Measures used as indicators of short-term stress include electrical resistance and internal water balance. Measuring short-term stresses may be practical only through indirect indicators such as soil moisture, precipitation, temperature, and relative humidity, which cannot, in themselves, be used to indicate tree stress but which might forecast when stress is likely to occur. Perhaps one reason that stand basal area has been a consistently useful variable for SPB hazard rating is that it relates to several causal factors that operate at different levels. Overstocked stands may be of low vigor and are also perhaps more susceptible to stress. But using basal area stocking as an empirical measure of hazard probably does not explain all the causal relationships, which is why using several variables in a hazard-rating model is advisable.

Insect Population Levels

Site, stand, and tree factors may account for susceptibility to insect invasion, but insect population level is the final determining element. The actual risk of an occurrence is determined by the dynamic relationship between changing forest conditions and fluctuating insect populations. When insect populations are sparse, even the most susceptible stand is in little danger of attack. As populations increase, risk increases rapidly in high-hazard stands, with a simultaneous and proportional increase for other stands in low-hazard categories. This balance between host condition and insect population was proposed by Nebeker and Hodges (1983) and further described and illustrated by Paine, Stephen, and Mason (1983) *(fig 3)*.

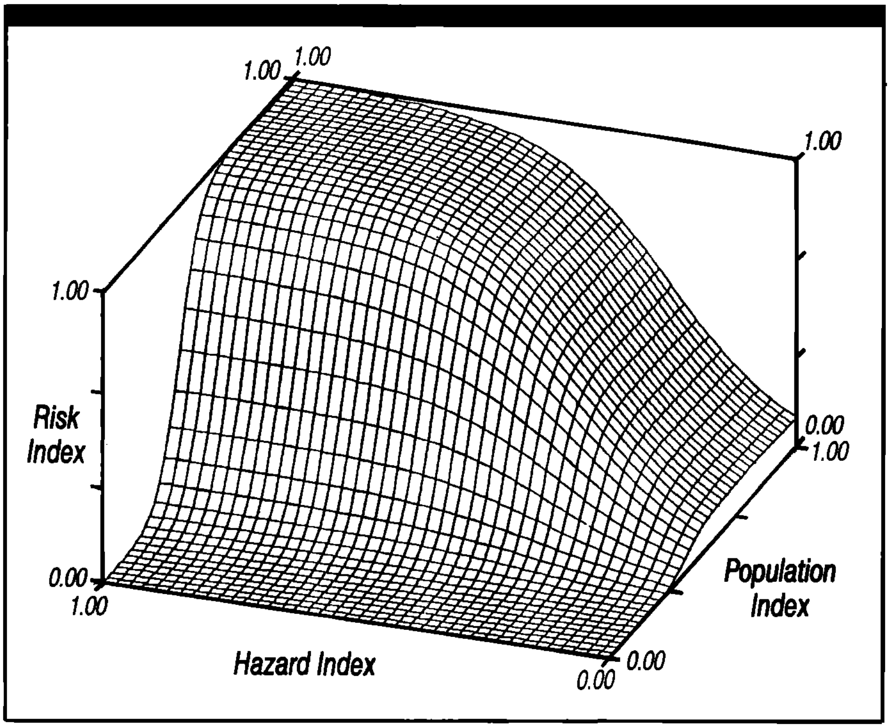


Figure 3. Response surface relating risk of insect attack to the combined effects of hazard and insect population levels (from Paine, Stephen, and Mason 1983). Risk is defined as the probability of occurrence of an infestation, whereas hazard is a relative measure of the presence of conditions predisposing forests to attack.

During endemic periods, insect population would be expected only in the most susceptible, most suitable, high-hazard stands. However, as populations and population pressures increase, a proportionate increase in infestation numbers would be expected in low- and moderate-hazard stands. Stand condition is less of a determining factor during epidemics. The distribution of SPB spots among hazard classes during epidemics was demonstrated to be proportional to the land area in each class (Hicks and Mason 1982). That is, if the greatest land area is in the moderate class, by simple availability, most of the infestations will occur in that class; fewer will develop in the less abundant high- and low-hazard areas. However, as populations again subside, the greater proportion of infestations will again be found in the less abundant but more suitable habitats represented by conditions in stands classed as high-hazard.

However, during stable low-level populations, or during periods of population increase and decline, other forms of tree stress (disease, infestation by other pest organisms, damage by logging, drought, lightning, and other such events) play an important role in infestation initiation and spread. Upon close examination of a stand or infestation, such disturbances can often explain the occurrence of an infestation in what would otherwise be considered a low-hazard area.

Patchiness of Habitat

The SPB occurs in forests with a high degree of spatial heterogeneity. Host pines occur on a wide range of soils and as a component of several forest communities. Site, tree, and stand factors associated with SPB infestations include tree growth rate and age; soil drainage, texture, and moisture retention properties; chemical properties of soils; and landform. Combinations of these conditions produce patches of the forest that are more susceptible to attack and provide focuses to initiate infestations. Recognition of these more susceptible patches would be of value to forestland managers so that silvicultural measures could be initiated to reduce their susceptibility.

With GM, environmental patchiness has been addressed by scientists studying the occurrence of focal stands, or forests that harbor resident populations, even during endemic phases of population cycles. Such focuses are thought to serve as reservoirs of insects that spread to surrounding forests during epidemic outbreaks.

"Hazard rating can be useful in identifying areas that serve as reservoirs for insect populations during endemic periods."

Patchiness has been defined as a "bounded, connected discontinuity in a homogenous reference background" (Levin and Paine 1974). Weins (1976) and Pickett (1983) emphasize that the discontinuities in environmental character states are of biological significance to organisms since these states are the stimuli to which they respond. They stress that environmental patchiness is meaningful only in terms of how the organism responds to it; therefore, it should be organism-defined.

Response to the components of a susceptible patch of forest would occur via the central nervous system of the insect. However, there are no results from behavioral research to indicate how insects respond to susceptible patches in the forest. Southern pine beetles either distribute their activity nonrandomly among subunits of the forest, or they employ a shotgun strategy whereby insects are randomly distributed but only initiate successful attacks where site and stand conditions are favorable. The so-called primary attractants, such as oleoresins exuded by tree wounds, suggest that, at least in some instances, SPB distribution is nonrandom. By contrast, distribution of GM is almost certainly of the latter type. Ballooning larvae randomly disperse, initiating successful attacks where conditions are favorable.

Distribution of an animal's activity among environmental units has been expressed in the concept of "grain response." Both "coarse-grained" and "fine-grained" responses have been suggested (MacArthur and Wilson 1967). These responses are explained by Weins (1976): "Given a certain environmental mosaic of resources, we may consider a fine-grained response one in which units of the mosaic (the 'grains') are utilized in direct proportion to their frequency of occurrence (i.e., in a random fashion)." An individual or population exhibiting a coarse-grained response, on the other hand, distributes its utilization nonrandomly among the elements of the same mosaic; i.e., it exhibits patch preference. Both SPB and GM appear to be associated most often with patches in the forest exhibiting certain site, tree, and stand characteristics and are, therefore, coarse-grained in their response, and SPB may exhibit patch selection.

A frequency distribution of suitable patches exists at any given time, and the distribution of patches may be predicted for subsequent time intervals, given knowledge about the factors that cause patches to occur. Disturbance factors, such as logging, lightning strikes, and construction, are associated with about 65 percent of the incipient SPB outbreaks in eastern Texas. These factors appear either to increase the probability of perception of a patch by the beetle or perhaps to create patches that are successionally different from their surroundings.

Although heterogeneity in host suitability can be induced by disturbances, it may also result from variations in certain host conditions due to edaphic or stand variations.

Two 1-acre loblolly pine stands in eastern Texas provide an example of the degree of heterogeneity in forests and the effect that frame of reference has on the perception of uniformity. These predominantly loblolly pine stands were selected for a thinning experiment because they had similar numbers of trees and basal area stocking levels (approximately 200 trees and 105 square feet per acre). However, when divided into 0.2-acre subplots and resampled, the range in basal area stocking for the subplots was 0 to 258 square feet per acre. An organism that responds to forests at the 1-acre level would see these stands as uniform, whereas one that responds to forests at the 0.2-acre level would see them as heterogeneous.

Precautions

Development of hazard-rating systems is an important step toward integrated pest management. However, precautions should be considered when developing, interpreting, or applying insect hazard-rating systems.

The ultimate goal of hazard rating is to identify and utilize factors that predispose trees to attack. Empirical variables may be useful as an interim step, but they should not be considered the final answer.

It is important to separate factors that affect tree vigor from those that cause stress, since those two conditions have different characteristics and require different management strategies.

Changes in patch selection behavior by insects may occur with changes in population density. Most forest-insect research is carried out when insect population levels are high; thus results are biased toward whatever behavior is typical of epidemic populations.

Rating susceptibility of large stands based on combinations of variables obtained from small susceptible patches may not reflect the true stand hazard. Susceptibility may be more accurately reflected by the frequency distribution of susceptible patches rather than the stand average for the variables.

Hazard- or risk-rating systems will require periodic updating, even when stands are undisturbed. The rate of change of key stand factors must be understood.

Finally, it must be stressed that hazard ratings based strictly on host conditions can, at best, provide only a probability of infestation given some arbitrary insect population density. In addition to host conditions, insect populations respond to a variety of factors such as weather, parasites, predators, and genetic changes. ■

"The actual risk of an occurrence is determined by the dynamic relationship between changing forest conditions and fluctuating insect populations."

Specific Limitations and Complications

In a conceptual sense, insect hazard-rating systems should be based on existing factors that predispose a forest to infestations. In reality, causal factors may not be known or may be of a qualitative or subjective nature and, as such, impossible to measure. Attempts to develop hazard-rating systems for southern pine beetle and gypsy moth illustrate these and other problems of insect hazard rating.

Southern pine beetle—For years, it has been postulated that the southern pine beetle (SPB) is more likely to infest trees of low vigor. Since vigor cannot be measured directly, some index of vigor must be used. Hicks et al. (1978) examined the relationship of radial growth (adjusted for tree age) to SPB attack as a surrogate measure of tree vigor. Although a relationship was found, the measure was not as useful as had been hoped. Firstly, perhaps the index, adjusted radial growth, is not an accurate measure of vigor. Secondly, host vigor may be one of several things related to infestation. Finally, under the most ideal conditions, errors in measurement or sampling of the index can occur. The difficulty in measuring tree vigor does not mean that vigor is not involved in predisposition to attack or that hazard rating is not possible.

In practice, investigators studying SPB have measured an array of site and stand variables and, without trying to identify causal relationships, looked for empirical associations of these variables with SPB attack. Usually a complement of noninfested, or baseline, plots was measured to establish the normal conditions for comparison with the infested plots. Stepwise discriminant analysis, a statistical procedure used to assign subjects to categories, has been used to select the variables for inclusion in a model, or discriminant scores have been used directly for predicting whether stands were infested.

A limitation specific to the empirical hazard-rating approach outlined above is that it is based upon a linear association of independent variables with the dependent variable (infestation state). One cannot, in such models, account for variables that have nonlinear effects. A good case in point is soil moisture regime and its effect on SPB susceptibility. In eastern Texas, susceptibility to SPB is associated with wet sites, but infestations are also known to be associated with dry conditions and droughty sites. Thus, very wet and very dry sites promote susceptibility, whereas intermediate (mesic) sites are the least prone to damage. When considering the potential for interaction among factors, the situation becomes even more complex. For example, consider the fact that on moist bottomland sites the root-to-shoot ratio for loblolly pine is generally lower than on drier sites, and the basal area is frequently higher. During a dry season, these overstocked bottomland stands may become more stressed than stands growing on normally droughtier sites.

Gypsy moth—The situation with gypsy moth (GM) is complicated by the fact that trees defoliated by the insect do not necessarily die, thus there is the question of susceptibility (likelihood of defoliation) versus vulnerability (likelihood of damage after defoliation). It has been found that GM expresses a definite preference for oaks (particularly white oak) as its host and avoids yellow-poplar. Furthermore, mortality is frequently brought about by so-called secondary agents, such as twolined chestnut borer and *Armillaria* root rot. Thus, tree mortality becomes a function of defoliation plus biological factors that predispose trees to secondary agents. Since several species of secondary agents are involved, the causal factors are extremely complex, and investigating them is a mammoth undertaking, but one which should be pursued.

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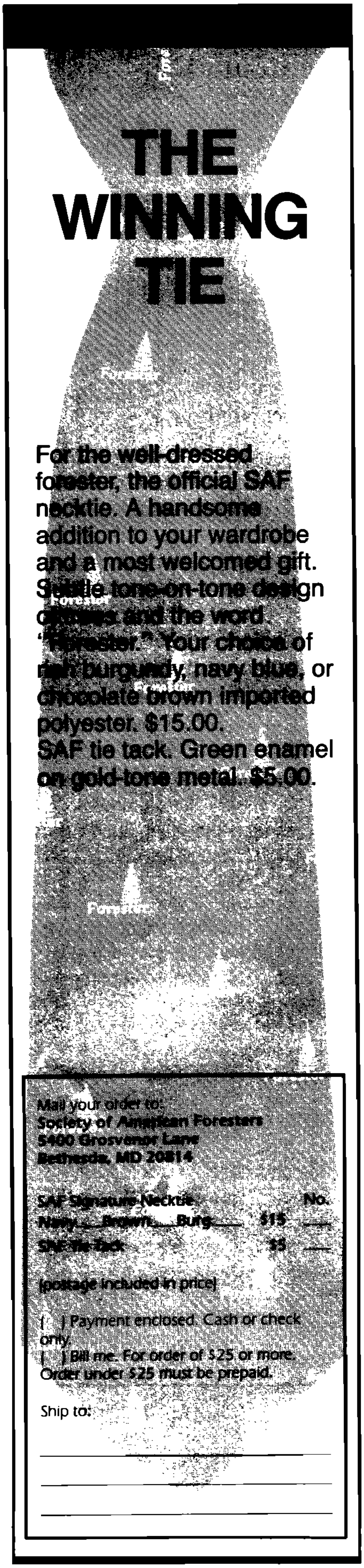

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