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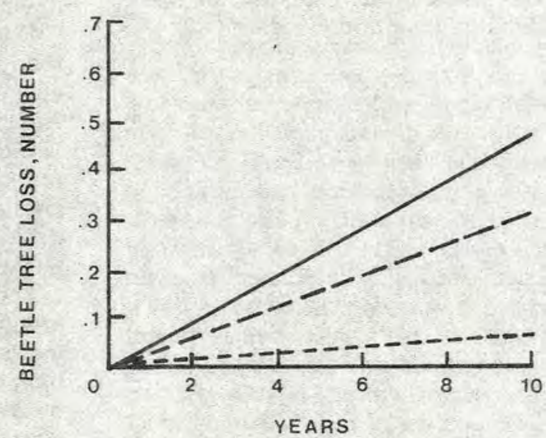
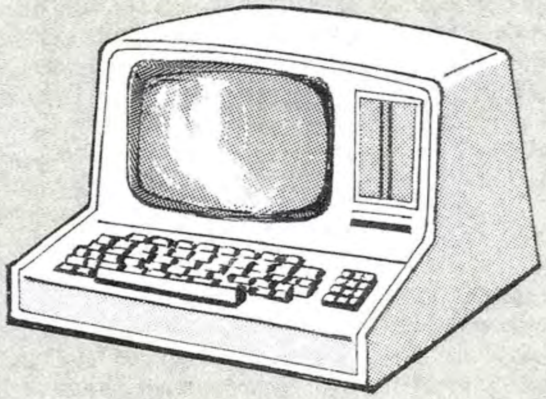
Estimating the Rate and Amount of Tree Loss from Mountain Pine Beetle Infestations

**Walter E. Cole
Mark D. McGregor**

Outbreak-When?



Amount of Loss



Hazard Rating

Strategy or Prescription

THE AUTHORS

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RESEARCH SUMMARY

Because of recurrent depredations by the mountain pine beetle in lodgepole pine, managers have less than a 50 percent chance of growing lodgepole pine to 16-inch diameters in most stands. This paper describes a Rate of Loss Model that estimates the amount of tree and volume loss per year and the longevity of the infestation, and shows how the model can be incorporated into forest planning. The model assumes optimum conditions for the life of an epidemic. However, actual field conditions can cause beetle populations to deviate from predictions causing a bit of overestimation, which is not considered serious in most infestation cases.

The model predictions, based on 2-inch diameter classes as populations, are further modified by habitat type. The classification provides the framework essential for organizing information to select alternative management activities for habitat types. The Rate of Loss Model has been integrated with the Insect and Disease Damage Survey (INDIDS) models to estimate mortality trends for stands with ongoing mortality or to obtain loss estimates by diameter class over infestation time for green stands, should they become infested.

One approach to modeling tree mortality caused by the mountain pine beetle uses FORPLAN to predict susceptible areas within analysis areas, which one would be affected, and the expected mortality over two decades. Or, when stands within analysis areas are identified through timber or stand exam surveys, beetle attack may then be simulated by a "prescription" that shows the effects of an epidemic in the absence of timber management.

The model has been verified using some 2,500 stands in the Forest Service's Northern Region. By using assessments from FORPLAN and harvesting in high-hazard, susceptible stands before an epidemic develops, land managers should be able to minimize tree mortality caused by the beetle.

Estimating the Rate and Amount of Tree Loss from Mountain Pine Beetle Infestations

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INTRODUCTION

Because of recurrent depredations by the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) in the Intermountain West, managers have less than a 50 percent chance of growing lodgepole pine to 16-inch (40.6-cm) diameters in most stands and, in some cases, less than 25 percent chance (Roe and Amman 1970). Consequently, forest managers commonly ask two questions: "Which of the lodgepole pine stands are most susceptible to the mountain pine beetle?" and "How many trees will I lose if the stand becomes infested with the beetle?" The first question is addressed in previously published management guidelines (Amman and others 1977; Cole and Cahill 1976). Answers to the second question depend on the rate of loss from an infestation. This paper describes a model that estimates the amount of tree and volume loss per year and the longevity of the infestation, and shows how the model can be incorporated into forest planning.

BACKGROUND

Most models for epidemic processes are based on continuous-infection assumption and treat epidemics in a fully probabilistic manner, and most of the processes considered are diseases. The continuous-infection concept assumes that an individual (the host tree) can be infectious from the moment it receives the infection (the beetle) until it dies, recovers, or is removed. This clearly is not the case with the mountain pine beetle. The mountain pine beetle has a discrete generation and discrete stages of growth, and its epidemic behavior does not fit the continuous-infection assumptions.

An alternative to the continuous-infection assumption was established by Reed and Frost in 1928 (Abbey 1952) and by Greenwood (1931). They postulated that the period of infectiousness is comparatively short, and the latent and incubation periods are constant (Bailey 1957). This alternative assumption appears to fit the epidemic behavior of the mountain pine beetle and amount of tree loss. In lodgepole pine stands in the Intermountain West, the period of infesting a tree (beetle attack) is fairly short (approximately 1 day for one tree and up to 4 to 6 weeks within a stand), the latent period is the time beetle development takes place without the emission of any infectious material (brood development), and the incubation period is the elapsed time between the receipt of the infection and the appearance of symptoms (time between attack and foliage discoloration). Both the latent and incubation periods can be considered constant in relation to the life cycle of the beetle and tree fade.

A first approximation model considers the latent and incubation periods as constant, the period of infectiousness as reduced to a single point, and a single attack as conferring immunity. At each stage in the epidemic, there are specific numbers of infectives and susceptibles. It is reasonable to assume that the susceptibles will yield a fresh crop of cases distributed in a binomial series at the next stage. This then creates a chain of binomial distributions; the actual probability of a new infection at any state depends on the numbers of infectives and susceptibles at the previous stage.

If we begin with one infested tree within a stand, or possibly several simultaneously infested trees, the infestation will spread in a series of stages, as each new generation of adult beetles attacks living green trees. If the stand of trees is suitable for successful infestation, we expect the number of trees killed at any stage to have a binomial distribution based upon numbers of susceptible and infested trees. Therefore, throughout the course of a mountain pine beetle epidemic, we have a chain of binomial distributions. The probability of a tree becoming infested at any generation depends upon the numbers of infested trees and susceptible green trees during the preceding generation of beetles.

Therefore, an epidemic started in a lodgepole pine stand by a single infested tree, or by several trees becoming infested simultaneously, will continue in a series of stages (generations of beetles) until either no more beetles are left to attack green, large diameter trees or no more green trees are left to be attacked. In each stage of the epidemic (each generation of beetles), there will be a specific number of infested trees and a specific number of susceptibles. The susceptibles can be attacked by a new generation of beetles, and the newly infested trees will be distributed in a binomial series. Thus, the chain of binomial distributions begins.

The assumptions underlying models based on discrete time usually consider all susceptible and infested individuals to be mixed together homogeneously. This situation is most nearly represented by small groups of trees but does not hold for large stands. However, incubation and latent periods are not variable, and the infesting of a tree can be considered as a relatively short period of time. As this model was refined, habitat type and volume yield factors were included. These factors govern tree and stand susceptibility and affect the life processes of beetle populations.

One important problem with the chain binomial model is that substantial departures from the assumptions of constant incubation and latent periods and a very short infectious period would invalidate the model. Another problem is failure to properly identify the links of the chain. However, if a highly variable incubation period occurs, or the symptoms cannot be identified correctly, there is still an alternative—to base our analysis on the total number of cases occurring during the course of the epidemic. Some precision is lost when the parameters are estimated. However, if the number infested is large, frequencies based on this number can be calculated directly and will probably be more accurate than those derived from the probabilities of the individual chains.

THE RATE OF LOSS MODEL

If p is the probability of a tree becoming infested in a given time interval, then $q = 1 - p$ is the probability of a tree not becoming infested. The probability of a tree becoming infested depends on the susceptibility or resistance of the tree, the infestivity of the beetle, the length of attack period, and the size of the attacking beetle population, as well as the environmental conditions of the stand.

If D_t is the number of trees infested at time t, then q^{D_t} is the probability that a specified tree will not be infested, and $1 - q^{D_t}$ is the probability that the tree will be infested. If there are G_t green trees capable of being infested in the population at time t, the expected number of infested trees produced at the time $t + 1$ is G_t times the probability of at least one tree being infested. Or:

$$D_{t+1} = G_t\ (1 - q^{D_t}) \text{ and } G_{t+1} = G_t q^{D_t}.$$

This equation provides a method of stepwise calculation of trees infested at successive time periods as shown in table 1.

If $G_t = 0$, all the trees are dead—no more susceptible trees are left—and the epidemic subsides due to food depletion. If $D_t = 0$, there are no more trees successfully producing beetles—and the epidemic subsides.

The Greenwood model postulates that the probability of a susceptible tree being infested is a constant and is not related to the number of infested trees. In other words, a susceptible tree in a stand with one infested tree is as likely to be attacked as the same tree surrounded by many infested trees. This is obviously not the case. Thus, we adopted the Reed-Frost model for susceptibility because it accounts for the increase in infestation pressure due to the number of infested trees. In the Reed-Frost model, the probability of a tree not being infested from only one source is taken to be a constant, q. The probability of not being infested from two sources is thus (q) (q), and consequently from n sources it is q^n.

The value of q, the probability of a tree not being infested from one source, can be calculated by solving the equation of G_{t+1} for q. This yields:

$$q = (G_{t+1}/G_t)^{(1/D_t)}$$

Theoretically, q will be a constant, but the real world is never constant. Thus the q for time t (q_t) varies slightly with t, and may be determined for each time interval. However, we found a closer prediction of D_{t+1} was obtained if several values for q_t were calculated, and q was estimated by q_t for several stands. We also found that precision of prediction increased with decreasing size of diameter classes. Estimates of tree mortality over time approximated true losses more closely when predicted by 2-inch (5.1-cm) diameter classes than by larger diameter classes.

Table 1.—*Calculation of a theoretical epidemic from the Reed-Frost model ($p = 0.5$)*

Time period	Number of dead trees	Number of susceptible trees	Calculation of D_{t+1} and G_{t+1}
0	1	100	$D_1 = 100\ (1 - 0.95) = 5.00 = 5$ $G_1 = 100 - 5 = 95$
1	5	95	$D_2 = 95\ (1 - 0.95^5) = 21.49 = 21$ $G_2 = 95 - 21 = 74$
2	21	74	$D_3 = 74\ (1 - 0.95^{21}) = 48.80 = 29$ $G_3 = 74 - 49 = 25$
3	49	25	$D_4 = 25\ (1 - 0.95^{49}) = 22.97 = 23$ $G_4 = 25 - 23 = 2$
4	23	2	$D_5 = 2\ (1 - 0.95^{23}) = 1.39 = 1$ $G_5 = 2 - 1 = 1$
5	1	1	$D_6 = 1\ (1 - 0.95^1) = 0.05 = 0$ $G_6 = 1 - 0 = 1$
6	0	1	

For high q values, peak mortality tended to be overestimated. By the third year, q usually becomes small due to the "high-grading" action of the beetle in thinning a stand, resulting in greater overestimation of tree mortality. However, the critical time during an infestation by the mountain pine beetle is at the point of change from endemic to epidemic. The value q applied to the larger diameter trees forecasts the pending infestation adequately in spite of the tendency toward overestimation.

The model assumes optimum conditions for the life of the epidemic. However, actual field conditions can cause beetle populations to deviate from predictions. Overestimation of tree mortality is not considered serious in most cases, particularly in the larger diameter classes. Epidemics usually begin in larger diameter trees preferred by the mountain pine beetle, and the rate of tree loss within these classes is critical. Thus, any factor that affects brood survival (such as thick phloem [food supply], which is correlated with larger diameters) will affect the rate of tree loss and, in turn, successive generations.

Dispersion of the beetle is also affected by stand characteristics such as species, age, stocking levels, growth rates, and diameter class distribution; and by site characteristics, including habitat type, soils, elevation, slope, and aspect. During the past decade the system of environmental classification by habitat type developed by Daubenmire for the Northern Rocky Mountain Forest Ecosystem has gained increasing acceptance in other areas of the West. This concept stresses use of the entire climax plant community as an environmental indicator that permits identification of environments (habitats) with similar biotic potentials. All environments (habitats) with the potential to support approximately the same mix of stable (climax) plant species are considered to be within the same habitat type regardless of successional status of the vegetation.

Recent data from the Forest Service Northern Region show that the extent of lodgepole pine mortality caused by the mountain pine beetle varies by habitat type group, and by habitat type within groups. This type of classification provides the framework essential for organizing information to select alternative management activities for habitat types.

MODEL TESTS AND REFINEMENT

Data from a mountain pine beetle infestation in the Bechler River Drainage of Yellowstone National Park (Klein and others 1978) were used to predict tree loss by 2-inch (5.1-cm) diameter classes (situation A, table 2; fig. 1). Trees were also grouped by 6- to 12-inch (15.2- to 30.5-cm), 14- to 16-inch (35.6- to 40.6-cm), greater than 16-inch (40.6-cm) diameters, and total stand (table 3; fig. 2 and 3).

Table 2.—*Predicted versus observed tree loss by year based on $\bar{q}_t$, the average probability of tree loss by 2-inch (5.1-cm) tree diameter class (Situation A, Klein and others 1978)*

Diameter class	Year of infestation	Number of trees per acre		$1/D_t$	q_t	Predicted tree loss
		Green	Dead			
6-inch (15.2-cm)	0	79.8	0.3	3.333	0.9875	0.14
	1	79.5	0	0	1.0000	0
	2	79.5	.3	3.333	.9857	.14
	3	79.2	2.1	.476	.9873	.99
	4	77.1	0	0	1.0000	0
	5	77.1	0	0	1.0000	0
	6	77.1	0	0		0
		Total loss:	2.7 (6.75/ha)	Average:	.9937	1.27 (3.175/ha)
8-inch (20.3-cm)	0	62.7	.8	1.250	0.984	0.90
	1	61.9	.8	1.250	.984	.89
	2	61.1	2.7	.370	.983	2.92
	3	58.4	8.1	.120	.982	7.99
	4	50.3	.7	1.430	.980	.63
	5	49.6	.5	2.000	.980	.63
	6	49.1	0	0		0
		Total loss:	13.6 (34.0/ha)	Average:	.982	13.96 (34.9/ha)
10-inch (25.4-cm)	0	38.8	0.8	1.250	0.974	1.09
	1	38.0	1.1	.909	.974	1.46
	2	36.9	3.9	.256	.972	4.79
	3	33.0	10.6	.0943	.964	10.38
	4	22.4	1.4	.714	.955	1.09
	5	21.0	.6	1.667	.953	.44
	6	20.4	.2	5.000		.14
	7	20.2	0	0		0
		Total loss:	18.6 (46.5/ha)	Average:	.965	19.39 (48.475/ha)
12-inch (30.5-cm)	0	17.0	0.6	1.667	0.942	0.95
	1	16.4	1.3	.769	.938	1.91
	2	15.1	2.8	.357	.932	3.54
	3	12.3	4.2	.238	.902	4.06
	4	8.1	1.2	.833	.875	.88
	5	6.9	.2	5.000	.863	.13
	6	6.7	.1	10.000		.64
	7	6.6	0	0		0
		Total loss:	10.4 (26.0/ha)	Average:	.909	11.87 (29.675/ha)

Table 2.—*con.*

Diameter class	Year of infestation	Number of trees per acre		$1/D_t$	q_t	Predicted tree loss
		Green	Dead			
14-inch (35.6-cm)	0	8.0	0.4	2.500	0.880	0.89
	1	7.6	1.2	.833	.867	2.28
	2	6.4	2.2	.454	.826	3.07
	3	4.2	2.0	.500	.724	1.88
	4	2.2	.4	2.500	.606	.25
	5	1.8	.2	5.000	.55	.10
	6	1.6	0	0		0
		Total loss:	6.4 (16.0/ha)	Average:	.743	8.47 (21.175/ha)
16-inch (40.6-cm)	0	2.1	0.3	3.333	0.598	0.624
	1	1.8	.3	3.333	5.45	.534
	2	1.5	.7	1.429	.407	.841
	3	.8	.3	3.333	.209	.238
	4	.5	.2	5.000	.078	.105
	5	.3	.1	10.000	.017	.033
	6	.2	0	0		0
		Total loss:	1.9 (4.75/ha)	Average:	.309	2.375 (5.925/ha)
>16-inch (>40.6-cm)	0	2.0	0.3	3.333	0.582	0.63
	1	1.7	.4	2.500	.511	.67
	2	1.3	.9	1.111	.270	.88
	3	.4	.1	10.000	.056	.05
	4	.3	.2	5.000	.004	.06
	5	.1	0	0	0	0
	6	.1	0			0
		Total loss:	1.9 (4.75/ha)	Average:	.285	2.29 (5.725/ha)
Total	0	211.0	3.0			5.2
	1	208.0	5.0			7.7
	2	203.0	14.0			16.2
	3	189.0	27.0			15.6
	4	162.0	4.0			3.0
	5	158.0	2.0			1.3
	6	156.0	1.0			.2
	7	155.0	0			0
		Total loss:	56.0 (140.0/ha)	Average:	.753	59.2 (148.0/ha)

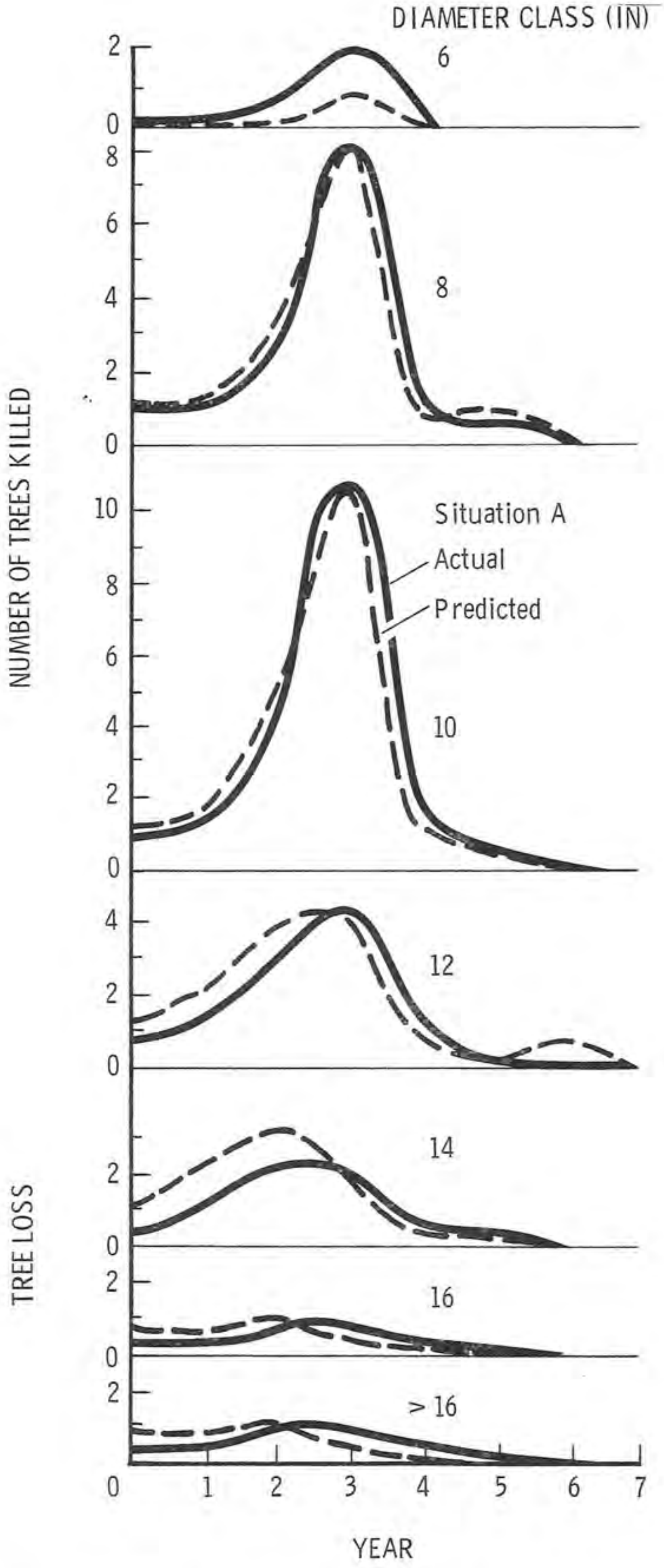

Figure 1.—Predicted versus observed tree loss by year based on q_t by 2-inch tree diameter class (Situation A, Klein and others 1978).

Table 3.—*Predicted versus observed tree loss by year based on $\bar{q}_t$, the average probability of tree loss, by tree diameter class and stand (Situation A, Klein and others 1978, grouped by greater diameter spread)*

Diameter class	Year of infestation	Number of trees per acre		$1/D_t$	q_t	Predicted tree loss
		Green	Dead			
6-12 inch (15.2-30.5-cm)	0	198.3	2.5	0.4000	0.997	2.5
	1	196.8	3.2	.3125	.995	3.1
	2	193.6	9.7	.103	.995	9.2
	3	183.9	25.0	.040	.994	21.7
	4	158.9	3.3	.303	.994	2.6
	5	155.6	1.3	.769	.994	1.0
	6	154.3	.3	3.333	0	.2
	7	154.0	0	0		
		Total loss:	44.3 (110.75/ha)	Average:	.995	40.3 (100.75/ha)
14-16 inch (35.6-40.6-cm)	0	12.1	1.0	1.000	0.917	2.5
	1	11.1	1.9	.526	.906	3.9
	2	9.2	3.8	.263	.869	5.4
	3	5.4	2.4	.416	.783	2.3
	4	3.0	.8	1.250	.679	.5
	5	2.2	.3	3.333	.613	.15
	6	1.9	0	0	0	0
		Total loss:	10.2 (25.5/ha)	Average:	.794	14.8 (37.0/ha)
>16-inch (>40.6-cm)	0	4.1	0.6	1.667	0.768	1.6
	1	3.5	.7	1.429	.727	1.7
	2	2.8	1.6	.625	.589	2.0
	3	1.2	.4	2.500	.363	.3
	4	.8	.4	2.500	.177	.2
	5	.4	.4	10.000	.056	.03
	6	.3	0	0	0	0
		Total loss:	3.8 (9.5/ha)	Average:	.447	5.9 (14.75/ha)

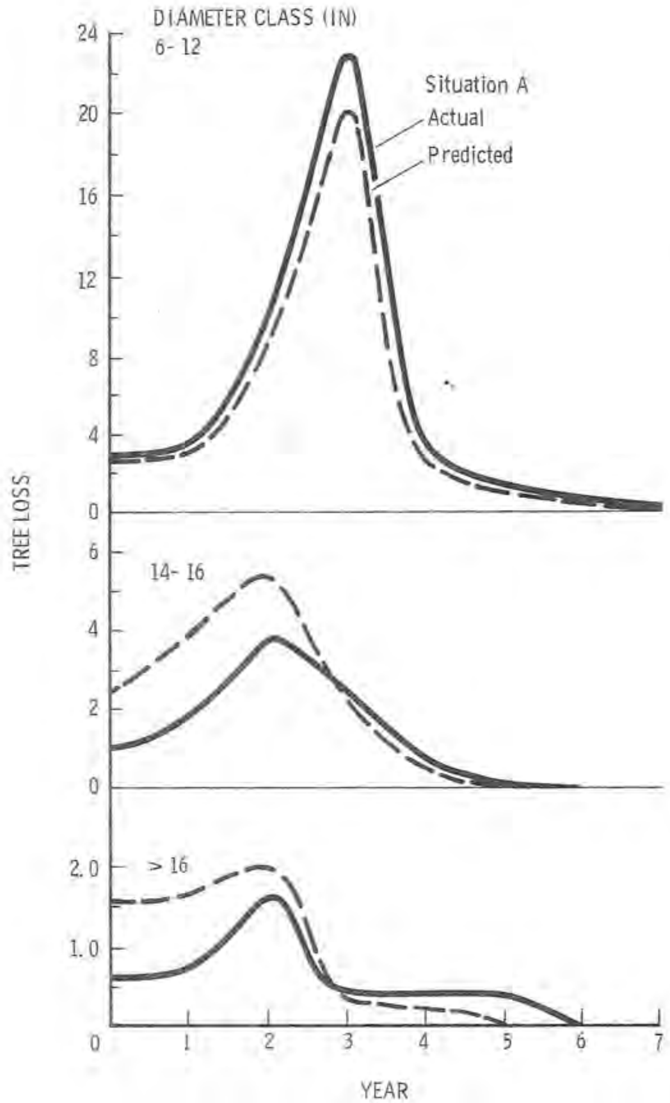

Figure 2.—Predicted versus ob-served tree loss by year based on q_t, by grouped tree diameter classes and total stand (Situation A, Klein and others 1978).

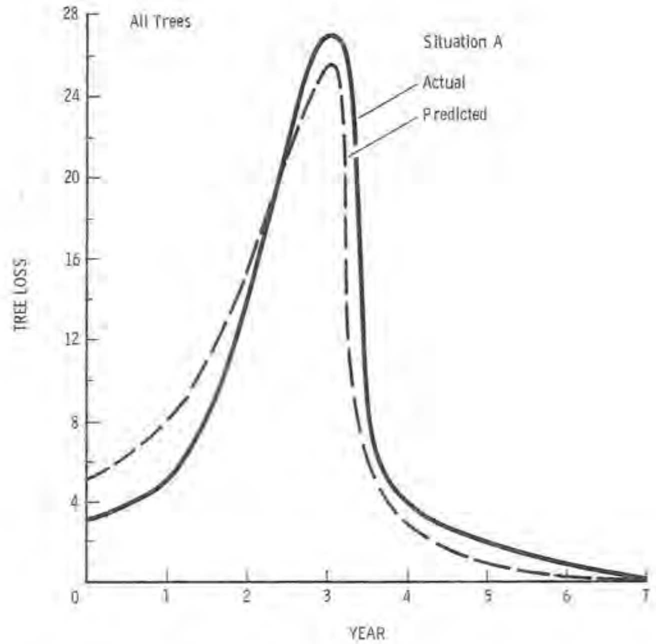

Figure 3.—Predicted versus ob-served tree loss by year for total stand based on q_t (Situation A, Klein and others 1978).

The second data set came from a mountain pine beetle infestation in the Gallatin River Drainage, and was used only for total tree loss, because the data were not originally taken by diameter classes (situation B). Tree loss over time did not fall into the usual bell-shaped pattern, yet the predicted tree loss approximated the actual double-peaked curve (table 4; fig. 4) (Burnell 1977).

Answers to the questions, "Which of the lodgepole pine stands are the most susceptible to mountain pine beetle outbreak development?" and "How many trees will the manager lose if the stand becomes infested?" depend upon risk. A definition of risk has two parts: (1) probability of an outbreak within a set time period, and (2) expected loss in the advent of an outbreak (Safranyik 1982). Reliable methods are not available to predict when an outbreak will develop, but we can predict the most susceptible stands and also forecast stand depletion in terms of stand structure should an epidemic occur. To date, six risk-rating systems have been developed that are based on climatic and tree/stand variables having a major effect on beetle survival and distribution. Rate of spread could be considered using historical maps (fig. 5) or mathematical models based on habitat type.

Table 4.—*Predicted versus observed tree loss by year based on $\overline{q}_t$, the average probability of tree loss by tree diameter class and stand (Situation B, Burnell 1977, grouped by total stand)*

Year of infestation	Number of trees per acre		$1/D_t$	q_t	Predicted tree loss
	Green	Dead			
0	370.2	3.6	0.278	0.997	6.6
1	366.6	.8	1.250	.997	1.5
2	365.8	19.5	.0513	.997	34.1
3	346.3	16.4	.0609	.997	27.3
4	329.9	77.8	.0128	.999	106.5
5	252.1	31.8	.0315	.992	37.1
6	220.3	10.3	.0971	.987	11.1
7	210.0	0	0	0	0
	Total loss:	160.2 (400.5/ha)	Average:	.995	224.2 (560.5/ha)

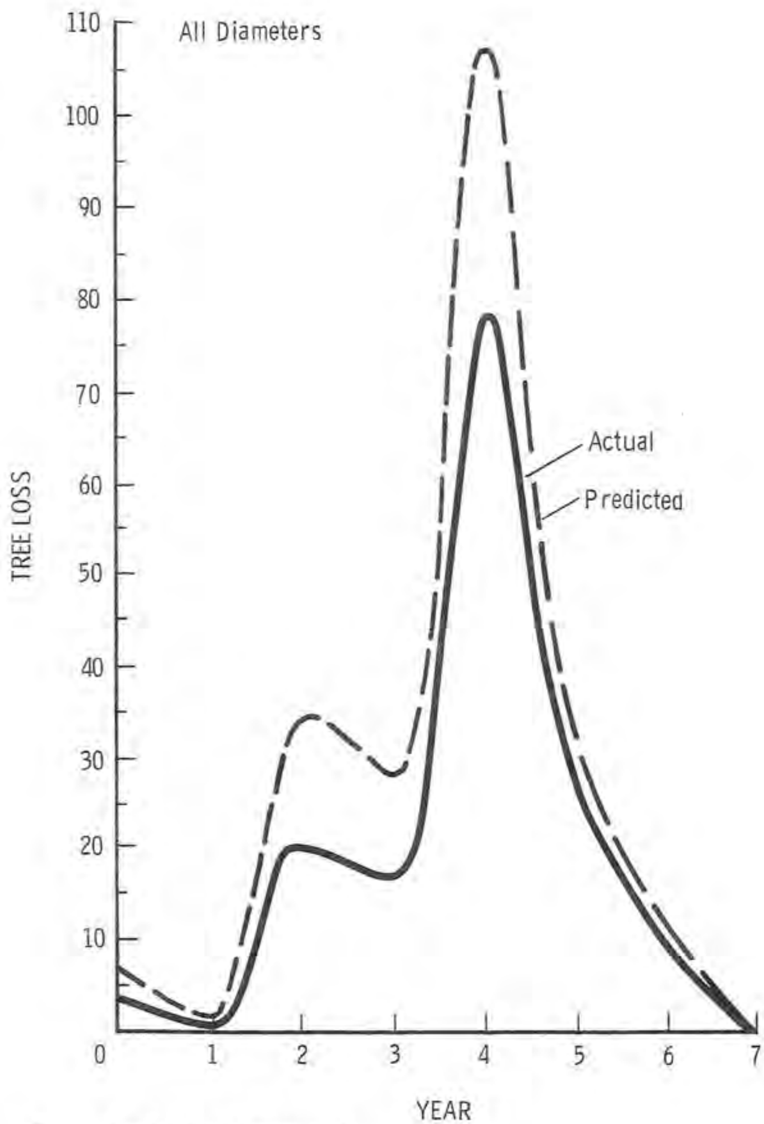

Figure 4.—Predicted versus observed tree loss by year based on q_t, by tree diameter class, grouped and total stand (Situation B, Burnell 1977).

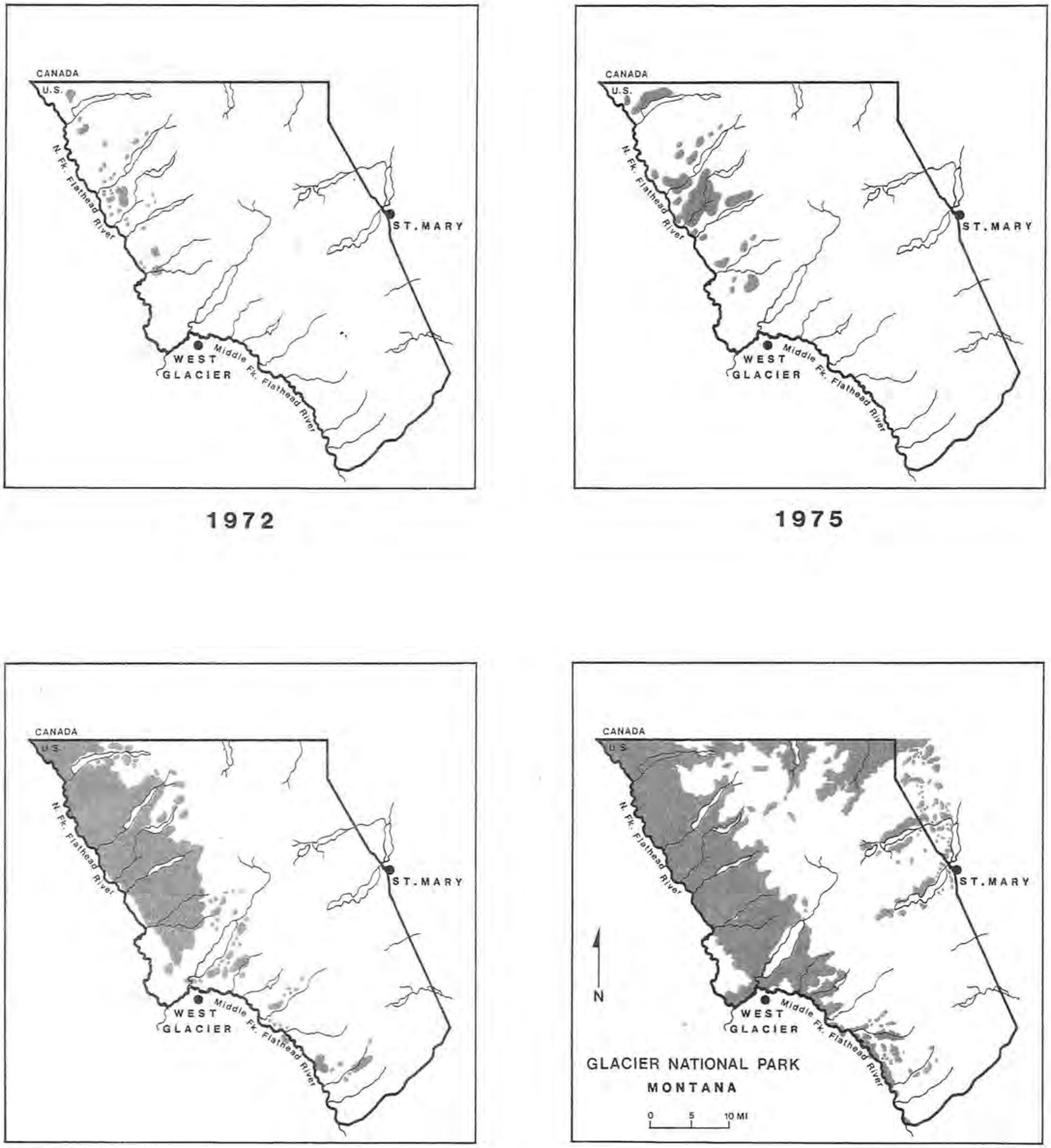

Figure 5.—Chronology of mountain pine beetle infestations, Glacier National Park and Blackfeet Indian Reservation, Mont. 1972-1980. (McGregor and others 1982)

Historical maps are useful in areas that have suffered repeated severe outbreaks where remaining stands can be hazard rated. Through forest inventory and survey data, forest cover types can be delineated showing mature, overmature, pole, and reproduction-size stands. When location and stand composition are known, maps can be composed depicting susceptible stands. These maps provide a rough hazard rating over large areas, which managers can use to initiate strategies to prevent future infestations or to salvage logs and reduce fuel loads in stands devastated by the mountain pine beetle. Usually managers can expect that another epidemic will begin within 20 to 40 years, when remaining trees reach size classes with phloem thickness conducive to a population buildup (Amman 1975). However, this depends on characteristics of stands and how soon residual trees become susceptible; and it is likely that infestation recurrence will be prolonged in managed stands. Historical maps, timber type maps, and timber inventory surveys can provide the basis for hazard rating stands. The ratings can be in very broad, but also extremely accurate, categories (McGregor 1982). However, significant differences occur within areas rated high hazard as to the amount and rate at which mortality develops, peaks, and subsides in various stands. Relating mortality with habitat type on a stand basis has helped refine hazard rating of lodgepole pine stands in the Forest Service Northern Region.

The Insect and Disease Damage Survey Model (INDIDS) (Bousfield 1981) and our Rate of Loss Model were tested using approximately 1,200 stands with mountain pine beetle infestations ranging from 1 year to the end of the epidemic (McGregor and others 1982.) The INDIDS Model is used to analyze forest insect and disease data collected from variable or fixed plots. It uses summaries of detailed mensurational data of infested and residual green stands—a tree species, size class, and damage class for each designated survey type. Use of INDIDS Model results in computations of tree and volume loss and basal area killed per acre (Dilworth and Bell 1968).

The Rate of Loss Model was integrated with the INDIDS Model to estimate mortality trends for infested stands or to obtain loss estimates (tree, cubic, and board foot volume) by diameter class over infestation time for green stands, should they become infested (table 5).

Table 5.—*Estimated trees/acre and volume loss by diameter class over time using the rate of spread for mountain pine beetle model for lodgepole pine*

a. Mixed species stand: 25.4 percent alpine fir, 12.4 percent Engelmann spruce, 12.4 percent whitebark pine, 37.3 percent lodgepole pine, 12.4 percent Douglas-fir

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MOUNTAIN PINE BEETLE MODEL FOR LODGEPOLE PINE

LODGEPOLE PINE TREES PER ACRE AND CUBIC FEET VOLUME BEFORE AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	Total
T/A	.00	.00	.00	.00	.00	31.85	31.37	.00	9.32	.00	72.54
Mort.	.00	.00	.00	.00	.00	1.12	1.57	.00	1.40	.00	4.09
CFA	.00	.00	.00	.00	.00	691.56	943.91	.00	457.15	.00	2,092.62

TREES PER ACRE LOSS DURING 10-YEAR OUTBREAK

	0-2.9		3-4.9		5-6.9		7-8.9		9-10.9		11-12.9		13-14.9		15-16.9		17-18.9		19+	
Year	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort
1	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	27.6	3.12	18.7	11.10	.0	.00	1.4	6.55	.0	.00
2	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	20.5	7.12	.7	18.01	.0	.00	.0	1.37	.0	.00
3	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	10.4	10.09	.0	.69	.0	.00	.0	.00	.0	.00
4	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	4.0	6.42	.0	.00	.0	.00	.0	.00	.0	.00
5	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	2.1	1.82	.0	.00	.0	.00	.0	.00	.0	.00
6	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	1.8	.34	.0	.00	.0	.00	.0	.00	.0	.00
7	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	1.7	.06	.0	.00	.0	.00	.0	.00	.0	.00
8	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	1.7	.01	.0	.00	.0	.00	.0	.00	.0	.00
9	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	1.7	.00	.0	.00	.0	.00	.0	.00	.0	.00
10	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00	1.7	.00	.0	.00	.0	.00	.0	.00	.0	.00

LODGEPOLE PINE TREES PER ACRE AND CFV AFTER AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	Total	% Mortality
T/A	.00	.00	.00	.00	.00	1.74	.00	.00	.00	.00	1.74	97.6
CFA	.00	.00	.00	.00	.00	37.72	.08	.00	.00	.00	37.80	98.2

Attack	Unsec	LP Total	Percent
.00	.00	56.54	.00

Attack CFA	Unsec CFA	LPCFV Total	Percent CFV
.00	.00	1,608.99	.00

Table 5.— *con.*

b. Mixed species stand: 15 percent lodgepole pine; 85 percent Douglas-fir, subalpine fir, Engelmann spruce

FLATHEAD NATIONAL FOREST 734 07791 734

MOUNTAIN PINE BEETLE MODEL FOR LODGEPOLE PINE

LODGEPOLE PINE TREES PER ACRE AND CUBIC FEET VOLUME BEFORE AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	Total
T/A	.00	.00	.00	.00	6.91	.00	11.46	.00	.00	.00	18.38
Mort	.00	.00	.00	.00	.14	.00	.57	.00	.00	.00	.72
CFA	.00	.00	.00	.00	143.42	.00	323.26	.00	.00	.00	466.68

TREES PER ACRE LOSS DURING 10-YEAR OUTBREAK

	0-2.9		3-4.9		5-6.9		7-8.9		9-10.9		11-12.9		13-14.9		15-16.9		17-18.9		19+	
Year	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort
1	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.03	.0	.00	9.2	1.70	.0	.00	.0	.00	.0	.00
2	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.01	.0	.00	5.5	3.65	.0	.00	.0	.00	.0	.00
3	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	1.9	3.66	.0	.00	.0	.00	.0	.00
4	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.6	1.24	.0	.00	.0	.00	.0	.00
5	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.19	.0	.00	.0	.00	.0	.00
6	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.02	.0	.00	.0	.00	.0	.00
7	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.00	.0	.00	.0	.00	.0	.00
8	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.00	.0	.00	.0	.00	.0	.00
9	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.00	.0	.00	.0	.00	.0	.00
10	.0	.00	.0	.00	.0	.00	.0	.00	6.7	.00	.0	.00	.4	.00	.0	.00	.0	.00	.0	.00

LODGEPOLE PINE TREES PER ACRE AND CFV AFTER AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	Total	% Mortality
T/A	.00	.00	.00	.00	6.73	.00	.41	.00	.00	.00	7.13	61.2
CFA	.00	.00	.00	.00	139.53	.00	11.51	.00	.00	.00	151.04	67.6

Attack	Unsec	LP Total	Percent
.00	.00	10.45	.00

Attack CFA	Unsec CFA	LPCFV Total	Percent CFV
.00	.00	242.77	.00

Table 5.— *con.*

c. Mixed species stand: 65 percent alpine fir, 29 percent Engelmann spruce, and 6 percent lodgepole pine

GALLATIN NATIONAL FOREST 611 05049 611

MOUNTAIN PINE BEETLE MODEL FOR LODGEPOLE PINE

LODGEPOLE PINE TREES PER ACRE AND CUBIC FEET VOLUME BEFORE AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	Total
T/A	.00	60.00	33.67	176.07	30.58	49.86	14.09	12.30	.00	4.11	380.68
Mort	.00	.00	.13	2.25	.63	1.76	.70	1.76	.00	.62	7.85
CFA	.00	.00	149.92	1,452.10	417.93	1,271.31	455.69	495.95	.00	247.44	4,490.34

TREES PER ACRE LOSS DURING 10-YEAR OUTBREAK

	0-2.9		3-4.9		5-6.9		7-8.9		9-10.9		11-12.9		13-14.9		15-16.9		17-18.9		19+	
Year	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort	GT	Mort
1	.0	.00	60.0	.00	33.5	.03	166.8	6.97	29.3	.66	40.7	7.44	10.9	2.53	1.3	9.20	.0	.00	1.6	1.88
2	.0	.00	60.0	.00	33.5	.01	147.0	19.85	28.6	.69	20.0	20.66	5.1	5.73	.0	1.34	.0	.00	.2	1.46
3	.0	.00	60.0	.00	33.5	.00	102.5	44.49	27.9	.69	2.8	17.22	.9	4.19	.0	.00	.0	.00	.0	.13
4	.0	.00	60.0	.00	33.5	.00	45.7	56.82	27.2	.68	.5	2.25	.3	.66	.0	.00	.0	.00	.0	.00
5	.0	.00	60.0	.00	33.5	.00	16.3	29.41	26.6	.65	.4	.10	.2	.05	.0	.00	.0	.00	.0	.00
6	.0	.00	60.0	.00	33.5	.00	9.5	6.74	26.0	.61	.4	.00	.2	.00	.0	.00	.0	.00	.0	.00
7	.0	.00	60.0	.00	33.5	.00	8.4	1.10	25.4	.56	.4	.00	.2	.00	.0	.00	.0	.00	.0	.00
8	.0	.00	60.0	.00	33.5	.00	8.3	.17	24.9	.50	.4	.00	.2	.00	.0	.00	.0	.00	.0	.00
9	.0	.00	60.0	.00	33.5	.00	8.2	.03	24.5	.44	.4	.00	.2	.00	.0	.00	.0	.00	.0	.00
10	.0	.00	60.0	.00	33.5	.00	8.2	.00	24.1	.38	.4	.00	.2	.00	.0	.00	.0	.00	.0	.00

LODGEPOLE PINE TREES PER ACRE AND CFV AFTER AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	Total	% Mortality
T/A	.00	60.00	33.51	8.25	24.10	.43	.22	.00	.00	.02	126.52	66.8
CFA	.00	.00	149.19	68.01	329.32	10.98	7.02	.00	.00	1.25	565.76	87.4

Attack	Unsec	LP Total	Percent
.00	.00	190.20	.00

Attack CFA	Unsec CFA	LPCFV Total	Percent CFV
.00	.00	2,256.65	.00

Table 5.— *con.*

d. Mixed species stand: 10 percent alpine fir, 77.1 percent lodgepole pine, 12.6 percent Douglas-fir

GALLATIN NF 709 02014 709

MOUNTAIN PINE BEETLE MODEL FOR LODGEPOLE PINE

LODGEPOLE PINE TREES PER ACRE AND CUBIC FT. VOLUME BEFORE AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	TOTAL
T/A	94.74	.00	72.32	99.93	48.68	34.83	14.25	3.28	1.14	1.65	370.82
MORT.	.00	.00	11.47	18.72	11.95	14.48	5.89	.47	1.14	1.65	65.77
CFA	.00	.00	303.49	925.85	775.39	755.39	435.55	137.38	75.42	141.69	3,550.61

TREES PER ACRES LOSS DURING 10-YEAR OUTBREAK

	0-2.9		3-4.9		5-6.9		7-8.9		9-10.9		11-12.9		13-14.9		15-16.9		17-18.9		19+	
Year	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.
1	94.7	.00	.0	.00	56.5	4.39	57.8	23.41	24.0	12.73	5.1	15.24	1.5	6.91	1.6	1.19	.0	.00	.0	.00
2	94.7	.00	.0	.00	54.9	1.59	37.8	20.02	15.2	8.75	1.2	3.92	.2	1.27	.4	1.22	.0	.00	.0	.00
3	94.7	.00	.0	.00	54.3	.57	26.3	11.52	11.2	4.09	.8	.37	.1	.06	.1	.31	.0	.00	.0	.00
4	94.7	.00	.0	.00	54.1	.20	21.3	4.96	9.7	1.51	.8	.03	.1	.00	.1	.03	.0	.00	.0	.00
5	94.7	.00	.0	.00	54.0	.07	19.5	1.84	9.1	.51	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00
6	94.7	.00	.0	.00	54.0	.02	18.8	.64	9.0	.16	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00
7	94.7	.00	.0	.00	54.0	.01	18.6	.22	8.9	.05	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00
8	94.7	.00	.0	.00	54.0	.00	18.5	.07	8.9	.02	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00
9	94.7	.00	.0	.00	54.0	.00	18.5	.02	8.9	.01	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00
10	94.7	.00	.0	.00	54.0	.00	18.5	.01	8.9	.00	.8	.00	.1	.00	.1	.00	.0	.00	.0	.00

LODGEPOLE PINE TREES PER ACRES AND CFV AFTER AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	TOTAL	% MORTALITY
T/A	94.74	.00	53.99	18.51	8.91	.79	.13	.06	.00	.00	177.13	52.2
CFA	.00	.00	226.57	171.48	138.38	17.61	3.85	2.70	.00	.00	560.49	84.2

ATTACK	UNSEC	LP TOTAL	PERCENT
65.31	.00	161.67	40.39

ATTACK CFA	UNSEC CFA	LPCFV TOT.	PERCENT CFV
1118.04	.00	1709.80	65.39

Table 5.— *con.*

e. Mixed species stand: 28.6 percent alpine fir, 0.2 percent whitebark pine, 60.6 percent lodgepole pine, 10.6 percent Douglas-fir

GALLATIN NF 709 02012 709

MOUNTAIN PINE BEETLE MODEL FOR LODGEPOLE PINE

LODGEPOLE PINE TREES PER ACRE AND CUBIC FT. VOLUME BEFORE AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	TOTAL
T/A	245.45	.00	16.28	8.81	59.05	24.13	3.95	.00	.00	.00	357.66
MORT.	.00	.00	.06	8.81	26.13	9.93	.20	.00	.00	.00	45.13
CFA	.00	.00	57.19	78.37	840.12	501.31	94.03	.00	.00	.00	1,571.02

TREES PER ACRES LOSS DURING 10-YEAR OUTBREAK

	0-2.9		3-4.9		5-6.9		7-8.9		9-10.9		11-12.9		13-14.9		15-16.9		17-18.9		19+	
Year	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.
1	245.5	.00	.0	.00	16.2	.01	.0	.00	13.0	19.94	5.5	8.69	3.5	.21	.0	.00	.0	.00	.0	.00
2	245.5	.00	.0	.00	16.2	.00	.0	.00	6.4	6.60	2.4	3.10	3.3	.22	.0	.00	.0	.00	.0	.00
3	245.5	.00	.0	.00	16.2	.00	.0	.00	5.0	1.34	1.8	.62	3.1	.21	.0	.00	.0	.00	.0	.00
4	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.23	1.7	.10	2.9	.19	.0	.00	.0	.00	.0	.00
5	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.04	1.7	.02	2.8	.16	.0	.00	.0	.00	.0	.00
6	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.01	1.7	.00	2.6	.13	.0	.00	.0	.00	.0	.00
7	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.00	1.7	.00	2.5	.10	.0	.00	.0	.00	.0	.00
8	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.00	1.7	.00	2.5	.07	.0	.00	.0	.00	.0	.00
9	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.00	1.7	.00	2.4	.05	.0	.00	.0	.00	.0	.00
10	245.5	.00	.0	.00	16.2	.00	.0	.00	4.8	.00	1.7	.00	2.4	.04	.0	.00	.0	.00	.0	.00

LODGEPOLE PINE TREES PER ACRES AND CFV AFTER AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	TOTAL	% MORTALITY
T/A	245.5	.00	16.21	.00	4.76	1.67	2.38	.00	.00	.00	270.47	24.6
CFA	.00	.00	56.94	.00	67.68	34.60	56.78	.00	.00	.00	216.01	86.3

ATTACK	UNSEC	LP TOTAL	PERCENT
44.87	.00	278.91	16.09

ATTACK CFA	UNSEC CFA	LPCFV TOT.	PERCENT CFV
710.12	.00	1,247.91	56.90

Table 5.— *con.*

f. Pure lodgepole pine stand

FLATHEAD NF 747 05573 747

MOUNTAIN PINE BEETLE MODEL FOR LODGEPOLE PINE

LODGEPOLE PINE TREES PER ACRE AND CUBIC FT. VOLUME BEFORE AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	TOTAL
T/A	85.71	300.00	141.46	48.95	22.59	.00	.00	8.35	.00	.00	607.07
MORT.	.00	.00	.54	.63	.47	.00	.00	1.19	.00	.00	2.82
CFA	.00	.00	484.47	459.73	301.62	.00	.00	258.85	.00	.00	1,504.67

TREES PER ACRES LOSS DURING 10-YEAR OUTBREAK

	0-2.9		3-4.9		5-6.9		7-8.9		9-10.9		11-12.9		13-14.9		15-16.9		17-18.9		19+	
Year	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.	GT	Mort.
1	85.7	.00	300.0	.00	140.4	.49	47.8	.55	21.8	.36	.0	.00	.0	.00	1.8	5.39	.0	.00	.0	.00
2	85.7	.00	300.0	.00	140.0	.45	47.3	.47	21.5	.28	.0	.00	.0	.00	.0	1.76	.0	.00	.0	.00
3	85.7	.00	300.0	.00	139.6	.41	46.9	.40	21.3	.21	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
4	85.7	.00	300.0	.00	139.2	.37	46.6	.34	21.1	.16	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
5	85.7	.00	300.0	.00	138.9	.34	46.3	.29	21.0	.12	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
6	85.7	.00	300.0	.00	138.6	.31	46.0	.24	20.9	.09	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
7	85.7	.00	300.0	.00	138.3	.28	45.8	.20	20.8	.07	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
8	85.7	.00	300.0	.00	138.0	.25	45.7	.17	20.8	.05	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
9	85.7	.00	300.0	.00	137.8	.22	45.5	.14	20.7	.04	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00
10	85.7	.00	300.0	.00	137.6	.20	45.4	.11	20.7	.03	.0	.00	.0	.00	.0	.00	.0	.00	.0	.00

LODGEPOLE PINE TREES PER ACRES AND CFV AFTER AN OUTBREAK

	0-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-14.9	15-16.9	17-18.9	19+	TOTAL	% MORTALITY
T/A	85.71	300.00	137.60	45.40	20.72	.00	.00	.00	.00	.00	589.43	2.9
CFA	.00	.00	471.24	426.41	276.58	.00	.00	.01	.00	.00	1,174.25	22.0

ATTACK	UNSEC	LP TOTAL	PERCENT
.00	.00	559.90	.00

ATTACK CFA	UNSEC CFA	LPCFV TOT.	PERCENT CFV
.00	.00	1,375.11	.00

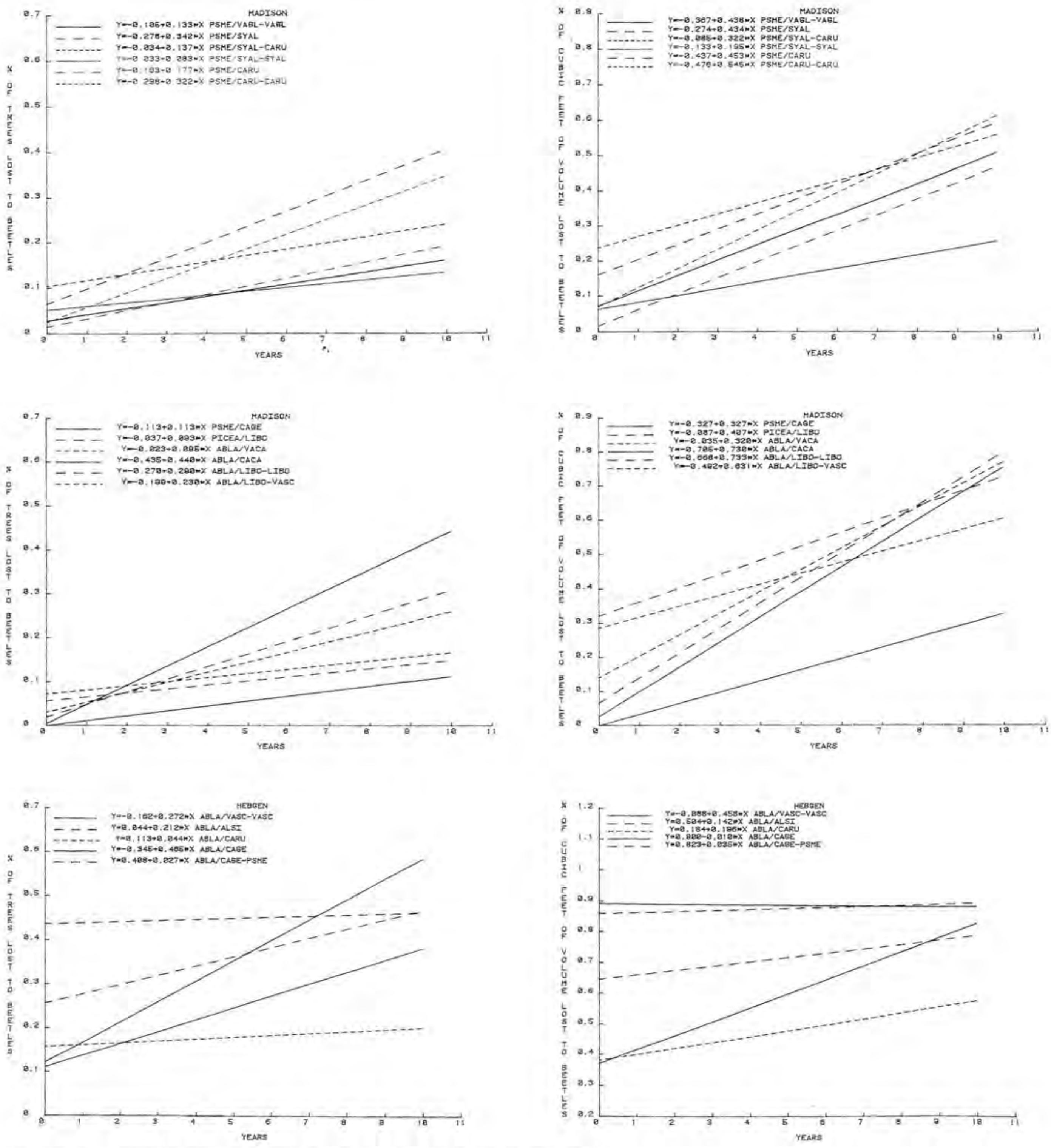

Figure 6.—Predicted lodgepole pine trees and volume loss from mountain pine beetle by habitat type over time for Madison Ranger District, Beaverhead National Forest, and Hebgen Lake Ranger District, Gallatin National Forest, Mont.

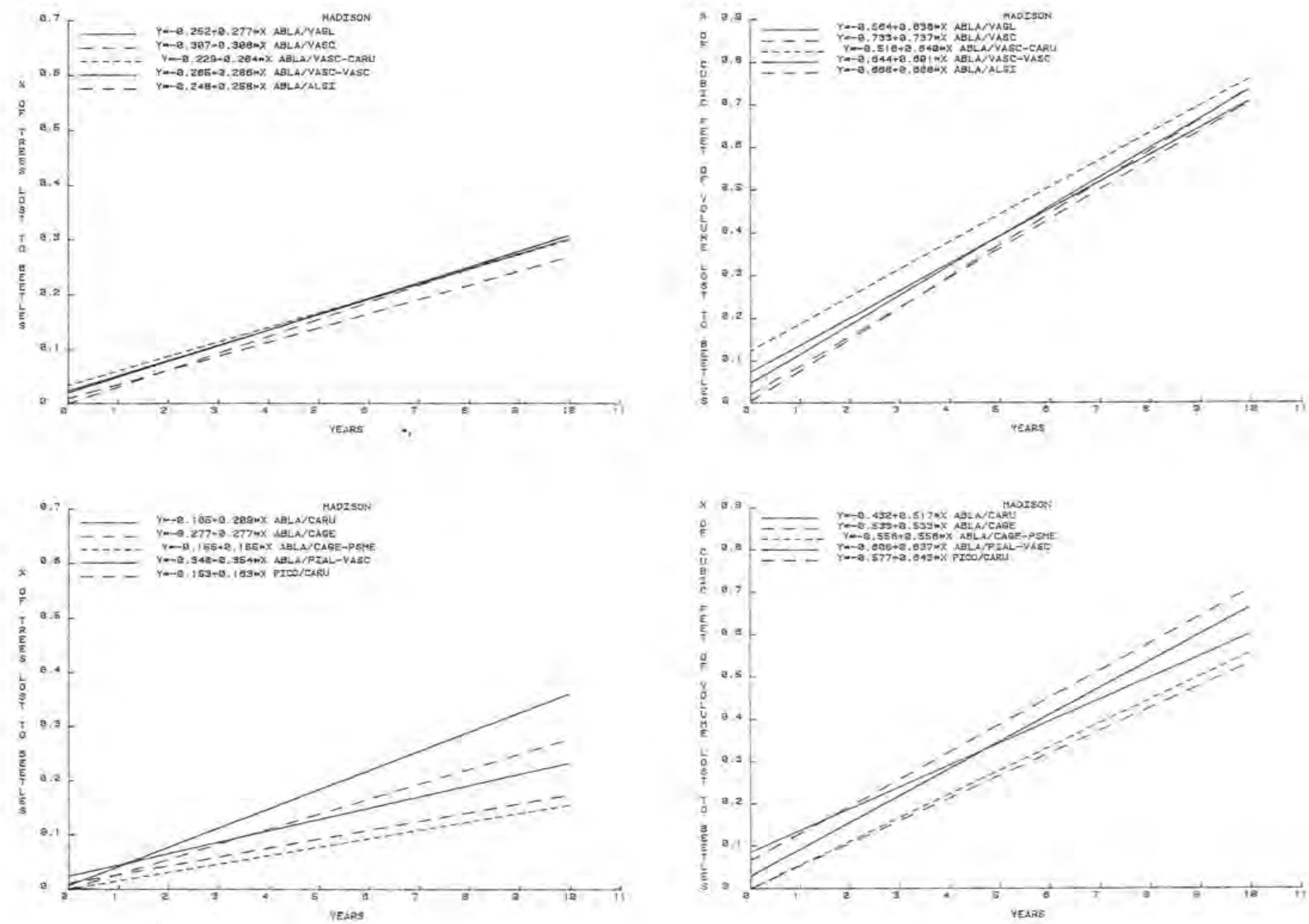

Figure 6.—(con.)

Stand data were then subjected to analysis of variance and analysis of covariance for completely randomized design and graphed to show lodgepole pine mortality by habitat type over time (fig. 6). Analysis shows that the percentage of lodgepole pine killed and volume loss vary by habitat type.

In some habitat types, tree mortality increased rapidly and most susceptible trees and all volume are killed in a relatively short time (fig. 6; ABLA/VASC-VASC, ABLA/ALSI). In others, mortality may occur over a 10-year period and never exceed 30 percent of the stand (fig. 6, ABLA/CARU, ABLA/LIBO-LIBO). All susceptible trees may be killed in other habitat types, but it may require 8 to 10 years. These data provide guidance as to which stands within those classed as high hazard should receive priority management. For example, management may be postponed until the next decade if stand mortality does not exceed 20 to 30 percent over a 10-year period. Meanwhile, stands can be rated and management implemented in the stands containing habitat types where considerable tree mortality or volume loss is predicted to occur over a short time. By putting the higher risk stands under management, loss would probably be prevented in some high-, many moderate-, and many low-risk stands.

INTEGRATION WITH FORPLAN

The Forest Service currently uses FORPLAN, a linear programing model (Johnson and others 1980), for land management planning which is the basis for land use allocations and scheduling of management activities. The management activities and associated products, costs, and environmental effects used in FORPLAN are reflected in prescriptions for stands within analysis areas. In the Forest Service Northern Region, analysis areas are lands that meet certain common classification criteria; these lands are not usually contiguous. Classification criteria include habitat type, timber size class, slope class, and other characteristics. Prescriptions describe specific management practices used to manage specific stands.

One approach to modeling tree mortality caused by the mountain pine beetle using FORPLAN has been to predict susceptible areas within analysis areas and probable mortality over two decades. Although it might be possible to predict rate of loss caused by the beetles throughout a forest, this information would be of little value for adjusting yield tables if the locations of high-, moderate-, and low-risk stands are not identified within analysis areas. The FORPLAN model would spread bark beetle effects over the next two decades for all stands within analysis areas, which would not allow scheduling earlier harvest of stands with a high probability of infestation and mortality.

Another approach is recommended when the location of stands within analysis areas is identified through timber surveys or stand examinations. Beetle attack may then be simulated by a "prescription" that shows the effects of an epidemic in the absence of timber management. If other management practices were not implemented, it would be necessary to constrain the beetle "prescription" by assignment to a certain acreage. Thus there would be two prescriptions—one for some stands in parts of the analysis area with infestation, and one for other parts with no effects of infestation.

Stands in the Helena National Forest were analyzed in a FORPLAN run by grouping habitat types so mortality factors could be directly applied to yield tables. A procedure was adopted and used to adjust yield tables based on the coefficients developed for the Helena National Forest plan (Brohman and others 1982). Coefficients were based on the assumption that a 50 percent loss of lodgepole pine would occur over a 5-year period. The estimated loss as a percentage of volume by age classes was determined as shown:

$$Y_1' = Y_1 (1 - \tfrac{1}{4} L)$$
$$Y_1' = Y_2 (1 - \tfrac{3}{4} L)$$
$$Y_j' = Y_j (1 - L),\ j \geq 3$$

where

L = proportion of volume lost to beetles (50 percent = 0.50),
Y_j = tabular volume for decade j of the plan, and
Y_j' = adjusted volume expected to exist in decade j.

Such coefficients must be derived for each habitat type or habitat type group to be applicable to the model. Decade 1, 2, or 3 of the Forest Plan may correspond to different decades in the yield table for different stands or habitat type groups within analysis areas. For example, if groups of stands are 105 years old, then Y_1 is the tabular yield shown at 110 years (25 percent loss by year 5). If the current age is 165 years, then Y_1 is the tabular yield shown for 170 years (25 percent loss by year 5, and 75 percent loss by year 10 at 175 years). The graphs in figure 7 were developed using this approach and the INDIDS/Rate of Loss Model for the Helena National Forest in the absence of beetle attack. The factor or proportionality is $(1-L)$, the proportion of stand volume not killed.

That the predicted results graphed in figure 7 will actually happen is questionable. Beetle-induced mortality will reduce competition for trees that are not attacked. However, trees not susceptible to bark beetle attack are usually smaller and less vigorous. These trees will probably respond to a decrease in competition. But amount of response will depend on tree age and various site factors. We do not know at what rate the remaining live stand will grow compared to what it would have done without attack.

The final step in the FORPLAN run for the Helena National Forest plan was to adjust existing yield tables by the appropriate coefficient for each habitat type group. Regenerated stand tables were not adjusted, because management should prevent mountain pine beetle outbreaks over a rotation. The assumption that the beetle will infest susceptible stands throughout the National Forest in the next 20 years may not be totally correct, but it seems probable based on available information. By including coefficients in the yield tables, the FORPLAN model should show which highly susceptible lodgepole stands need immediate harvesting, and which stands should be harvested before becoming highly susceptible. By using assessments from FORPLAN and harvesting in high-hazard, susceptible stands before an epidemic develops, land managers should be able to minimize tree mortality caused by the beetle.

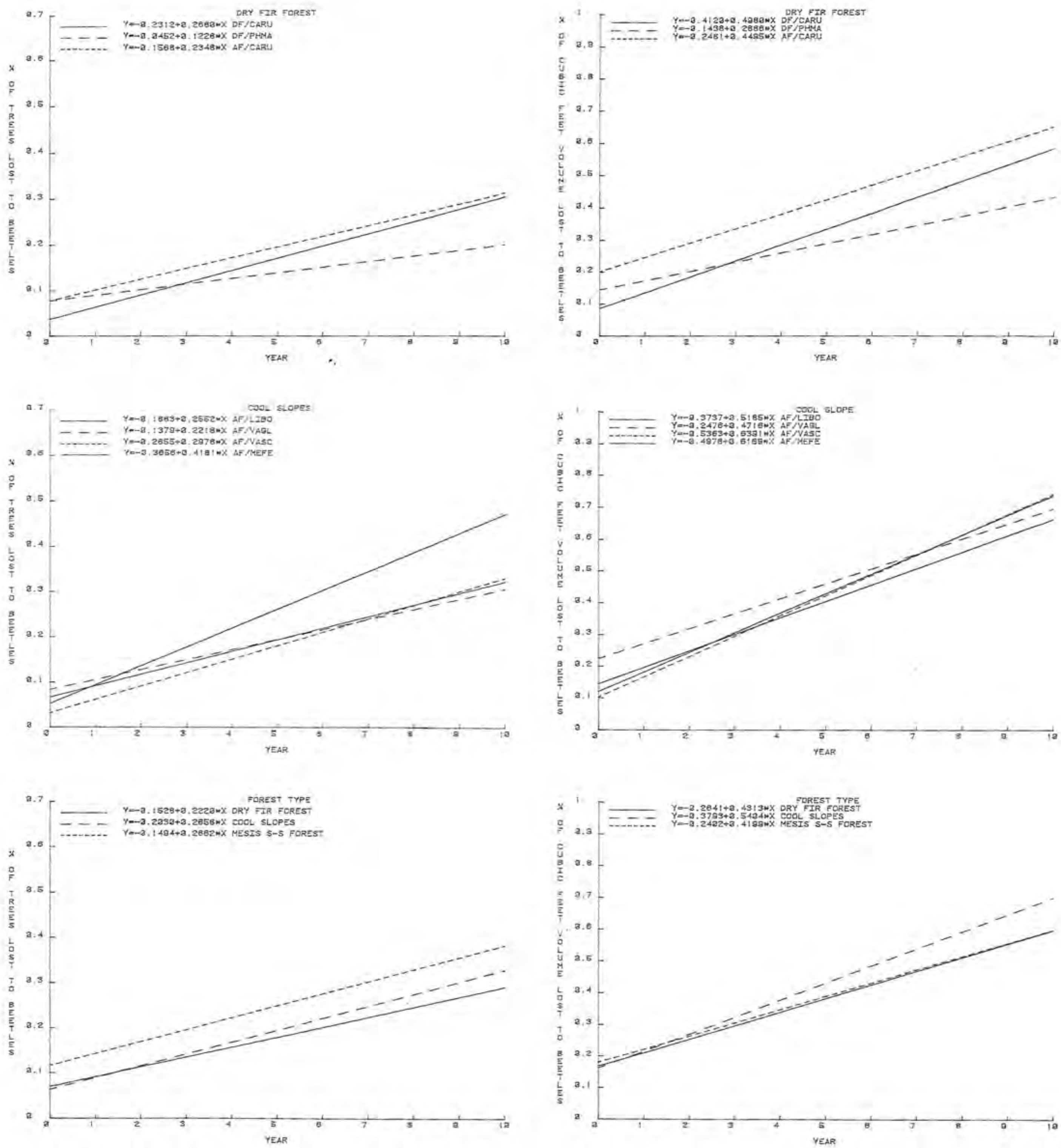

Figure 7.—Projected tree and volume loss from mountain pine beetle for lodgepole pine habitat type groups within dry fir, cool slopes, and mesic sites on the Helena National Forest.

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Forest managers have less than a 50 percent chance of growing lodgepole pine to 16-inch diameters in unmanaged stands because of recurrent depredation from the mountain pine beetle. Hazard rating methods provide techniques for managers to identify susceptible stands. The Rate of Loss Model refines existing risk rating systems, and provides a method for predicting tree and volume loss by habitat types. This model is provided to assist land managers in projecting tree mortality over time, and as a link with the FORPLAN Model for use in forest planning.

KEYWORDS: Mountain pine beetle, *Dendroctonus ponderosae* Hopkins, risk rating model, lodgepole pine, *Pinus contorta* var. *latifolia*, forest planning