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Optimal Level of Expenditure to Control the Southern Pine Beetle

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ABSTRACT

The optimal level of expenditure to control damage to commercial timber stands by the southern pine beetle (SPB) was determined by models that simulated and analyzed SPB attacks during a typical season for 11 Southern States. The optimal level was defined as that which maximized the dollar value of timber saved minus the cost of control (i.e., maximized net benefits). Real discount rates of 4 and 10 percent were used. At 4 percent, maximized net benefits for the entire Southern region are estimated at about $50 million, or a benefit/cost ratio of 6.22; at 10 percent, more than $30 million, or a benefit/cost ratio of 5.93. Alabama, North Carolina, and Texas warrant the largest control programs; Georgia, Louisiana, South Carolina, and Mississippi, moderate programs. Virginia, Tennessee, Arkansas, and Oklahoma justify small control programs. Methods and costs for detection, evaluation, and suppression of SPB infestations are discussed.

Keywords: Dendroctonus frontalis, CLEMBEETLE, OVERFLIGHT, BEAM, cut and leave, cut and salvage, presuppression flights.

Study Overview

This study was conducted to assist State & Private Forestry and various State forestry agencies in the planning and implementation of more efficient southern pine beetle (SPB) control activities. The purpose was to determine the most economically efficient (optimum) level of expenditure to control SPB damage to commercial timber stands in Alabama, Arkansas, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. The basic geographic units of analysis were 16,141 Forest Inventory and Analysis (FIA) survey plots located within the study area. Each plot represented about 4,500 acres of a particular forest stand/site condition. These survey data were obtained from both the Southeastern and the Southern Forest Experiment Stations. The final results of the economic analysis were summarized and reported by State and by the following land ownership classes: Federal, State, forest industry, and nonindustrial private (NIPF).

The three major components of the analytical system used were the CLEMBEETLE stochastic simulation model, the Beetle Economic Analysis Model (BEAM), and the OVERFLIGHT simulation model. CLEMBEETLE is written in IBM-FORTRAN 77 and was developed by Roy Hedden. BEAM is programmed within the Statistical Analysis System (SAS) to run on an IBM computer; OVERFLIGHT is written in BASIC to run on an Apple IIe microcomputer. The latter two programs were developed by J.E. de Steiguer.

Using FIA survey plot data, CLEMBEETLE simulated SPB infestations and the volume of timber lost to SPB for a single day of infestation growth. The OVERFLIGHT model calculated the total number of days that SPB infestations would grow during the course of a single SPB season if (1) no detection takes place (i.e., without control) and (2) various levels of detection are undertaken (i.e., with control). Within BEAM, the simulations generated by CLEMBEETLE and OVERFLIGHT were combined with data from the State forestry pest control officers and other sources concerning control practices and costs, salvage rates, and stumpage prices to obtain estimates of the benefits and costs at the various levels of control. BEAM selected the optimum level of control for each survey plot, and these optima were summed and classified according to State and ownership class. The optimum level of control was defined as that which maximized the value of timber saved less the cost of saving the timber.

Procedures

Economic Model

The optimal level of SPB control was defined as that which maximized net benefits. Net benefits were defined as the present value of timber losses averted due to control minus the cost of control. The analysis simulated SPB damage that could be expected with and without control during a single year, given a typical level of SPB population. This typical level of SPB population was based on average beetle populations over the past 10 years.

The basic geographic units of analysis were 16,141 FIA survey plots, each of which represented about 4,500 acres of a particular forest stand/site condition. Each plot was treated as an independent forest management unit. Plots could be aggregated to multicounty areas called Survey Units, and Survey Units could be aggregated to State levels. The forest owners were assumed to be profit-maximizing producers of pulpwood and sawtimber who did not consider the amenity values of the forest when making pest management decisions. Atomistic competition was assumed so that the actions of any single producer would not influence market output or prices. Also, forest managers were assumed to have perfect knowledge regarding future timber markets, prices, and the consequences of their pest management strategies.

Timber losses due to SPB were treated as small, isolated openings in the existing forest stand which had no effect on future stand rotation schedule or on annual management costs associated with the current stand. Furthermore, timber losses were not compensated by increased growth in the residual stand. All pest management costs were treated as variable.

With these qualifications and assumptions, it is now possible to derive a general solution for the optimal level of SPB control expenditure. The general solution will then serve as a basis for presenting the BEAM model. First, consider a forest stand (FIA survey plot) which is currently "n" years of age and is attacked by SPB. If no action is taken to control damage, the owner expects to lose a volume of timber equal to Q_o. This volume (Q_o) represents the total amount of timber which will be lost to SPB, and consists of the currently standing volume plus the growth that would have been added by the anticipated year of harvest (T). The present value of losses without control (L_o) is:

$$L_o = Q_o\, P/(1+i)^{T-n} \qquad (1)$$

where:

P = stumpage price at harvest
i = discount rate

If, instead, some type of SPB control is elected, the owner will lose some lesser volume of wood (Q_w), but will also incur a control cost (C). The value of losses with control (L_w) may be written as follows:

$$L_w = Q_w\, P/(1+i)^{T-n} + C \qquad (2)$$

The net benefits (NB) of control are found by deducting equation (2) from equation (1) with the following result:

$$NB = (Q_o - Q_w)\, P/(1+i)^{T-n} - C \qquad (3)$$

The forest owner will undertake SPB control as long as the net benefits of control are positive. In other words, control is desirable if the present value of timber losses averted (benefits) exceed the cost of control. However, the problem facing the landowner may be more complex than simply deciding between the options of control vs. no control. Instead, the owner may have to choose the most appropriate level of control. If we assume that by expending more control dollars more timber can be saved, and that $C = f(Q_w)$, then it is possible to derive a theoretical solution for the optimal level of SPB control. If equation (3) is continuous and differentiable, and its shape is concave, first increasing with output and then decreasing, the maximum (optimal) level of net benefits is found where the first derivative of NB with respect to Q_w is equal to zero. Thus, from equation (3) the optimal solution is:

$$\frac{dNB}{dQ_w} = P/(1+i)^{T-n} - f'(Q_w) = 0 \qquad (4)$$

Equation (4) can be rearranged to demonstrate that at optimum, marginal benefits will equal marginal costs:

$$P/(1+i)^{T-n} = f'(Q_w) \qquad (5)$$

The foregoing general solution to the problem of optimal SPB control served as the basis for the BEAM model. However, for BEAM, the basic model was substantially expanded to include factors such as salvage values and the various components of control cost. Also, the optimal solutions were derived through iterative simulations because the damage and control production functions could not be expessed in continuous form.

To understand BEAM, it is necessary to understand the steps involved in the control of SPB outbreaks. SPB control consists of three steps: (1) detection, (2) evaluation, and (3) suppression. Detection is typically conducted from aircraft. In the jargon of SPB control, such detection activities are referred to as "presuppression flights." Once infestations have been detected they must then be evaluated. Evaluation is the on-the-ground inspection of each infestation to determine its extent and condition. Evaluation may be followed by suppression, which is the step where action is taken to halt the spread of the infestation. The most common current methods of suppression, according to State forest pest control officers, are cut and salvage, and cut and leave. Both techniques involve cutting a buffer strip around the advancing head of the infestation. With the former method, the cut timber is salvage for sale, whereas with the latter, the timber is simply left on the ground. Detection and evaluation require cash outlays, hence are referred to as direct costs in this study. Suppression involves both direct and indirect costs. Direct costs are those for tree felling in the case of the cut-and-leave method. Indirect costs result from harvesting the financially immature timber that occupies the buffer strip.

The intensity of control was determined by the frequency of presuppression flights. With increasing numbers of detection flights, timber losses were reduced because infestations had fewer days to spread before evaluation and suppression took place. This concept will be discussed later in greater detail. Here, however, it is important to realize that the intensity of control or the lack of control was reflected in the number of days an infestation was allowed to spread. In BEAM, it was assumed that all infestations, once detected, were evaluated and suppressed, and that all suppression activities were competely effective in stopping the spread of infestations.

From CLEMBEETLE, BEAM obtained simulated estimates of the volume of timber that would be lost to SPB per day of infestation growth, per acre of forest type. These CLEMBEETLE estimates may be expressed as V+G, where V is the volume of currently standing timber lost and G is the growth that would have occurred had the stand reached some assumed rotation age. For the without-control situation (L_o), the present value of timber lost, less salvage value, was calculated as follows:

$$L_o = [D_o(V+G)\ P[(1+r)/(1+i)]^{T-n} - (D_oV)aPb]\ AW \qquad (6)$$

where:

D_o = days of infestation growth without control
P = current timber stumpage prices
r = annual real rate of stumpage price increase
i = real discount rate
T = assumed rotation age
n = current stand age
a = fraction of dead timber salvaged
b = dead timber price as a fraction of green timber price
A = total acres of forest type
W = fraction of Survey Unit in SPB outbreak condition

For the with-control situations (L_w), the present value of timber lost, less salvage value plus control costs, was calculated as follows:

$$L_w = \{[D_w(V+G)\ P[(1+r)/(1+i)]^{T-n} - (D_wV)aPb]\ AW\} + F + E + SD + SI \qquad (7)$$

where:

D_w = days of infestation growth with various levels of control
F = direct cost of presuppression flights
E = direct cost of evaluation
SD = direct cost of suppression
SI = indirect cost of suppression

The values of the various control cost elements were calculated as follows:

$$F = \text{number of flights} \times \text{cost per acre of flying} \times \text{total} \quad (8)$$

$$E = \text{number of infestations} \times \text{fraction of infestations controlled} \times \text{cost of visiting an infestation} \quad (9)$$

$$SD = \text{buffer strip size (acres)} \times \text{fraction of acres subject to cut-and-leave tree felling} \times \text{cost per acre of tree felling} \quad (10)$$

$$SI = \text{buffer strip size (acres)} \times \text{present value/acre of buffer strip timber} - \text{current salvage value of buffer strip timber} \quad (11)$$

The net benefits (NB) of control were calculated by subtracting equation (7) from equation (6). The result, which represents the present value of losses averted minus the change in salvage value minus the cost of control, is:

$$NB = \{[(D_o - D_w)(V+G)\ P[(1+i)/(1+r)]^{T-n} - (D_o - D_w)VaPb]\ AW\} - F - E - SD - SI \quad (12)$$

In the analysis, eight presuppression flights were simulated for each FIA survey plot. This, in turn, generated eight values for the variable D_w. The value of equation (12) was calculated eight separate times, once for each value of D_w. From these eight optional levels of control, the one that yielded the maximum net benefits was selected as the optimum, provided that this maximum value was positive. Figure 1 illustrates the benefits and costs for a typical FIA survey plot. The optimal solutions for the individual plots were summed for the States by forest ownership classes.

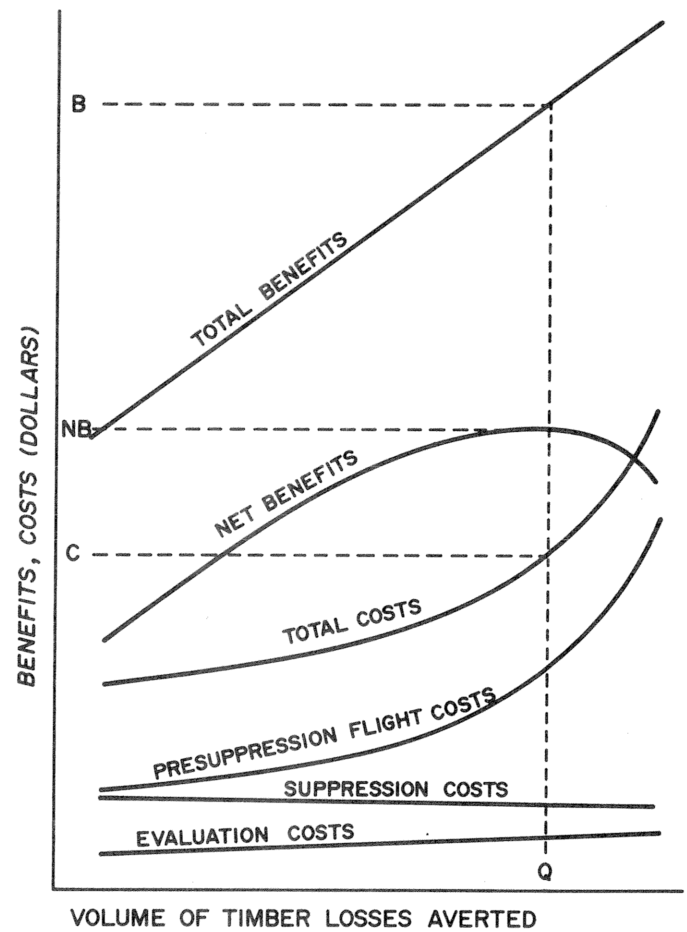
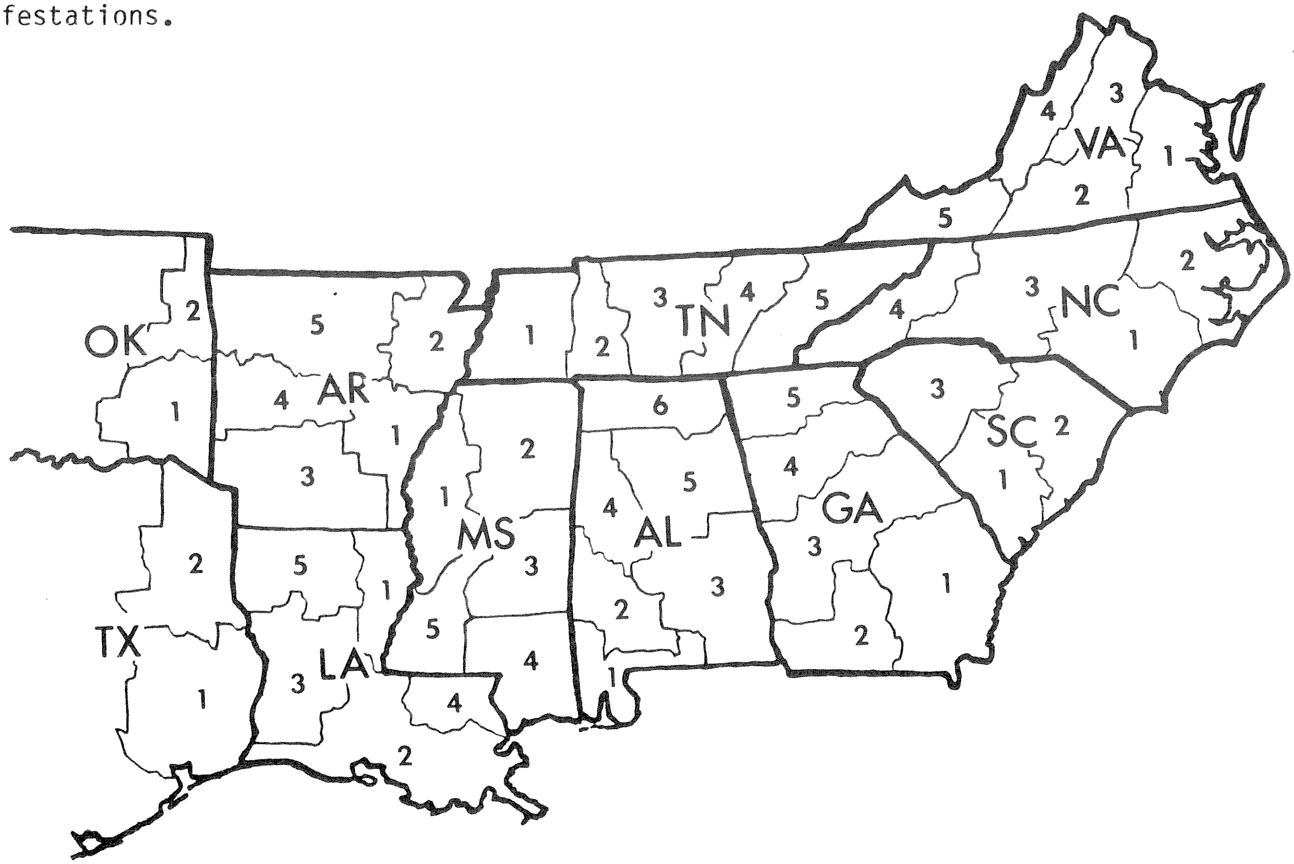


Figure 1.--Benefits and costs of SPB control. Optimal volume of timber saved from the beetle (Q) is found where net benefits are maximized (NB). This is the point of greatest distance between total benefits (B) and total costs (C).

Following is a description of the data used in the study. Real discount rates of 4 and 10 percent were used to provide a sensitivity analysis. The real annual rates of stumpage price increase for pulpwood and sawtimber were, respectively, 1 and 2.5 percent. The costs per acre of detection flights and cut-and-leave land clearing were, respectively, 2 cents and $500, provided by State & Private Forestry (S&PF) personnel. The stand rotation ages, obtained from State forestry pest control officers, were 60 years for Federal forest lands, 45 for State-owned lands, 35 for forest industry lands, and 45 for NIPF lands. The current stand ages and the total acres of forest type were obtained from FIA data. The fraction of the Survey Units in an SPB outbreak condition (fig. 2) represents the portion of the area, based on data for the past 10 years, which has had SPB infestations.

The remaining data used in the study are shown in table 1. These include stumpage prices, salvage rates, dead timber price fractions, fraction of buffer strip to which cut and leave was applied, and the cost of evaluating infestations. Stumpage prices were obtained from Timber Mart--South, Inc., and represented average prices for the past 10 years stated in constant 1984 dollars. Salvage rates were assumed to be 50 percent for the without-control situation based on the advice of S&PF personnel.



Survey Unit	AL	AR	GA	LA	MS	NC	OK	SC	TN	TX	VA
1	.22	.02	.09	.36	.06	.21	.01	.06	.03	.71	.15
2	.53	.37	.04	.03	.71	.30	.00	.13	.10	.31	.35
3	.40	.03	.41	.53	.08	.50		.46	.01		.20
4	.50	.00	.73	.11	.60	.31			.18		.06
5	.46		.51	.38	.20				.44		.00
6	.23										

Figure 2.--Map of Survey Units in the States surveyed, and the fractions of these Survey Units in outbreak condition during the last 10 years.

Table 1.--Stumpage prices, timber salvage rates, and control costs, by State

State	Sawtimber prices per fbm, 1984	Pulpwood prices per cord, 1984	Fraction of dead timber salvaged	Fraction of green price for dead timber	Fraction of infestation cut & salvaged	Fraction of infestation cut & left	Cost of evaluating infestations
	. . . Dollars . . .		. . . .	Percent			$/spot
AL	175.82	18.84	75	100	99	1	25
AR	181.96	13.16	50	50	85	15	25
GA	166.97	24.43	65	75	93	7	30
LA	190.80	13.74	50	50	99	1	25
MS	178.64	13.49	50	45	99	1	50
NC	157.65	9.92	65	75	99	1	25
OK	107.12	11.67	50	50	85	15	25
SC	171.02	18.20	65	75	99	1	25
TN	78.52	7.06	60	75	99	1	15
TX	192.10	13.04	50	50	60	40	35
VA	103.14	10.33	50	50	95	5	25

Table 2.--New SPB infestation occurrence as a percentage of total annual new infestations, by month and region

Month	Gulf[a]	Piedmont & Mountain[b]
	. . . Percent . . .	
January	0	0
February	2	0
March	3	1
April	13	1
May	14	10
June	17	17
July	25	20
August	13	25
September	7	17
October	3	6
November	3	3
December	0	0
Annual total	100	100

[a]Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Texas.

[b]Georgia, North Carolina, South Carolina, Tennessee, Virginia.

Days of Infestation Growth

Within the BEAM model, the intensity of SPB control or lack of control was determined by the frequency of presuppression flights, which were simulated during the SPB season. The total number of days that an infestation was allowed to grow, and thus the volume of timber lost, decreased as the number of detection flights increased. The number of days of infestation growth was calculated by the OVERFLIGHT model.

The OVERFLIGHT model used data obtained from State forestry pest control personnel concerning the relative frequency of new infestation occurrence, by region and month, during a typical SPB season (table 2). The average number of days of infestation growth for the without-control situation was calculated by multiplying the monthly relative frequency of new infestation occurrence by the number of days remaining in the SPB season. These products were summed to obtain the weighted average number of days of growth for an infestation. For each of the eight levels of presuppression flights, the flights were placed within the season to minimize the number of days of infestation growth. The monthly relative frequencies were multiplied by the number of days before the next presuppression flight would occur, and summed for the season. Also, an additional 30 days was allowed in the calculations to account for a lag between detection and suppression. The resulting average number of days of infestation growth for the without-control and the eight with-control situations are presented, by region, in table 3.

Table 3.--Average days of growth for SPB infestations assuming various numbers of presuppression flights per season and allowing 30 days between detection and suppression implementation, by region

No. of flights	Gulf[a]	Piedmont & Mountain[b]
None	166	136
1	100	91
2	81	74
3	73	68
4	67	63
5	62	59
6	60	58
7	59	58
8	59	58

[a]Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Texas.

[b]Georgia, North Carolina, South Carolina, Tennessee, Virginia.

Simulation of Volume Loss

Volume loss due to SPB attack was generated by using a modification of the CLEMBEETLE program.[1,2] Volume loss consisted of trees actually killed by SPB as well as growth loss due to premature death of the tree. Based on average beetle populations from 1971 to 1980, losses were generated for three population levels by the number of spots per 1,000 acres of pine and pine-hardwood: low--0.5 spots, moderate--2.0 spots, high--5.0 spots. For each population level, the simulation of loss consisted of the following steps:

1. Calculate the probability of an infestation occurring per acre (PROB).

2. Generate the number of active trees (AT).

3. Calculate the probability of a spot being inactive at detection (PROBI).

4. Test to see if the spot is inactive.

5. If the spot is inactive at ground check, calculate the number of dead trees (DEADI).

6. If the spot is active, calculate the number of trees killed per day (TKD).

7. Calculate the number of trees killed in an active spot:

   DEADA = (TKD x DAYS) + AT.

8. Calculate the expected number of trees killed (ELOSS):

   a. Inactive spots: ELOSS = PROB x DEADI, and

   b. Active spots: ELOSS = PROB x DEADA.

These steps were repeated 150 times for each FIA survey plot that contained forest types susceptible to SPB attack. The sum of the ELOSS's was divided by 150 to obtain the average expected number of trees killed.

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[1]Hedden, R.L. Impact sub-models for a southern pine beetle pest management program--Phase I. Unpublished progress report to the USDA Forest Service, IPM Program for Bark Beetles of Southern Pines, New Orleans, LA. 1982. 40 pp.

[2]Hedden, R.L. Impact sub-models for a southern pine beetle pest management program--Phase I. Unpublished final report to the USDA Forest Service, IPM Program for Bark Beetles of Southern Pines, New Orleans, LA. 1983. 31 pp.

Separate models for probability of infestation were used for the Mountain, Piedmont, and Coastal Plain regions. Models compatible with FIA survey data were developed for each region from site and stand data collected during the expanded Southern Pine Research and Applications Program.[3] In each region the probability of infestation varies by forest type and the SPB population level. Other variables used were:

Mountain	Piedmont	Coastal Plain
1) Proportion of pine	1) Slope	1) Land form (slope)
	2) Site index	2) Basal area per acre
	3) Stand origin	3) Proportion of pine
		4) Age

The number of active trees was a function of the number of trees per acre (TPA), with dense stands having a greater number of active trees than did less dense stands. Active trees were generated from an exponential distribution with an expected value of 0.15 x TPA. In addition, not all spots will be active (contain attacking adult beetles or developing broods) at the time of detection. In these spots, the average number of dead trees was generated from an exponential distribution with an expected value of 1 tree. In active spots, the number of trees killed was a function of the number of active trees, SPB population level, total basal area per acre, mean stand diameter, and number of days a spot remains active. The expected number of trees killed per acre was the product of the probability of infestation and the number of dead trees.

The expected volume per acre killed by SPB is obtained by multiplying ELOSS by the average pine volume per tree for each survey plot. The average pine volume per tree is derived from the total pine volume per plot and the number of pine growing-stock trees per plot. For the area covered by the Southeastern Forest Experiment Station, the number of growing-stock trees per acre was derived from the total number of live stems per acre, age, and basal area per acre. Survey data for the Southern Forest Experiment Station did not include the number of live stems per acre; therefore, trees per acre were estimated by forest type, age, and observed basal area per acre.

To determine the reliability of the results of the simulation procedure, actual published data on the volume killed by SPB[4] were compared for the Southern region. Data for the decade 1971 to 1980 were used in the analysis. For each Survey Unit, predicted losses for the moderate SPB population level (2.0 spots per 1,000 acres) were multiplied by the proportion of the unit area in an outbreak condition in each year. These adjusted loss estimates were summed to obtain total decade losses by Survey Unit. The unitwide losses were then aggregated to obtain State and region totals.

In order to obtain the loss projections, an estimate of the average number of days a spot is allowed to grow is needed. During outbreak periods, most States make three to four detection flights per year. Assuming the flights were optimally timed and that the spots were either controlled or inactive within 30 days of detection, the average interval of spot growth is:

Number of flights	Days of spot growth: Piedmont	Days of spot growth: Coastal Plain
3	68	73
4	63	67

[3]Coster, J.E.; Searcy, J.L., eds. Site, stand and host characteristics of southern pine beetle infestation. Tech. Bull. 1612. New Orleans, LA: USDA Combined Forest Pest and Development Program; 1981. 115 pp.

[4]Price, T.S.; Doggett, C. A history of southern pine beetle outbreaks in the southeastern United States. Macon, GA: Georgia Forestry Commission. 1982. 32 pp.

Table 4.--Predicted average annual cubic-foot volume of timber killed by SPB in 10 Southern States

Days of spot growth	Predicted volume killed[a] ($ft^3 \times 10^6$)	Difference between predicted and observed[b]	Percent error[c]
65	131.235	3.359	2.56
70	137.619	9.743	7.08
71	138.895	11.019	7.93
76	145.279	17.403	11.98

Data for Oklahoma not included because of negligible SPB activity.

[a]Predicted volume killed includes an average buffer strip volume of 30 percent for all salvaged spots.

[b]Observed average annual volume killed, including buffer strip trees, for 1971 and 1980 (see footnote 4) is 12.788×10^6 ft^3; cords and fbm were converted to cubic feet by using factors of 70 ft^3 per cord and 210 ft^3 per fbm.

[c]Percent error = (predicted - observed)/predicted.

When these periods of spot growth were used to generate expected losses, the results in table 4 were obtained.

The results indicate a positive bias in the predictions. An average period of 65 days between spot occurrence and control is probably optimistic. Reported periods between detection and control in east Texas for 1974 and 1975 were 53 and 35 days, respectively.[5] During this period, the Texas Forest Service was flying seven or more presuppression flights per year, which means that the average period of spot growth was between 66 and 84 days. If it is assumed that the average period a spot grows is 75 days, then the results in table 5 are obtained for each of the States.

On a statewide basis, the poorest predictions were for Arkansas and Tennessee, which are on the extreme northern ranges of the SPB. Even including these States, the rank correlation between the observed and predicted volumes killed is 0.8 (Spearman's rank correlation, statistically significant at the 99.5 percent level).

There are many potential sources of error in this comparison of predicted and observed volume killed by SPB. The data for observed volume killed are reported by each State. The degree of emphasis given to pest control activities, the level of the personnel involved, and the methods of obtaining reported volume killed vary greatly. The data are adequate for internal use by the States, but they may be less than satisfactory for model validation purposes. This situation is especially true for the volume killed but not salvaged. Furthermore, the conversion factors used to obtain cubic-foot volume from cords and board-foot measure (fbm) can also be a source of bias.

There is also potential error associated with the method of determining

[5]Texas Forest Service. Texas forest pest activity 1974-1975 and forest pest control section biennial report. TFS Circ. 226. College Station, TX; 1976. 19 pp.

the buffer strip volume from the simulation results. The State pest control workers reported that of the total volume salvaged, an average of 30 percent consisted of buffer strip trees. This value, expressed as a proportion, was multiplied by the reported average proportion of the total volume killed that was salvaged and by the total volume killed in each State to obtain the predicted volume of buffer strip trees. This volume was added to the predicted volume killed to obtain the combined volume lost due to SPB attack.

The FIA survey is also a source of potential error. The data were collected at a single point in time and were used to generate predicted losses, which were compared with average observed losses over a decade. Aggregate multiyear loss comparisons are necessary since SPB populations are cyclic, whereas forest conditions are dynamically changing; thus, the overall susceptibility and vulnerability of the forest to SPB attack changes from year to year. Furthermore, some modification of the simulation program was necessary to accommodate FIA survey data. These modifications resulted in the use of some submodels with reduced predictive ability.

Lastly, the survey data obtained from the Southern Forest Experiment Station included age, expressed in 10-year increments, but did not include information on the number of trees per acre. Therefore, the number of growing-stock trees had to be generated from other survey plot variables, one of which was age. This procedure was less

Table 5.--Predicted and observed annual cubic-foot volume of timber killed by SPB if the average infestation grows for 75 days

State[a]	Predicted volume killed[b]	Observed volume killed[c]	Percent error[d]
	. . . . . $ft^3 \times 10^6$	. . . . .	
AL	21.250	34.374	-61.76
AR	8.982	1.560	82.44
GA	17.612	20.541	-16.63
LA	14.215	4.434	68.81
MS	12.794	7.050	44.90
NC	26.930	21.272	21.01
SC	13.780	14.862	-7.85
TN	2.285	6.436	-181.66
TX	21.011	14.137	32.72
VA	5.143	3.211	37.56

[a]Oklahoma omitted because of negligible SPB activity.

[b]Predicted volume killed includes an average buffer strip volume of 30 percent of salvaged spots.

[c]Observed average annual volume killed, including buffer strip trees, for 1971 to 1980 (see footnote 4); cords and fbm were converted to cubic feet by using factors of 70 ft^3 per cord and 210 ft^3 per fbm.

[d]Percent error = (predicted - observed)/predicted.

than satisfactory, as is reflected in the simulation results shown in table 6.

These results are also reflected in the range of prediction errors for the States within each FIA survey region. For the Southern Station, the range was -181.66 to 82.44 percent, with five of the six States having errors greater than ±40 percent (table 5). For the Southeastern Station, the range was -16.63 to 37.56 percent, with three of four States having prediction errors less than ±21 percent (table 5). Furthermore, the relative rank of States in the Southeastern Station region is the same with regard to observed and predicted volumes killed. Based on these results, the projections for the States in the Southeastern Station survey region must be considered more reliable.

In addition to simulation of actual volume killed by SPB, estimates of growth loss due to premature harvest (salvaged) were also made. The first step in this process was the development of total cubic-foot volume equations for each State from FIA survey data. The form of equation was:

$$\ln(V) = b_0 + b_1/A + b_2SC + b_3\ln(B) + b_4\ln(B)(A) \quad (13)$$

where:

v = total cubic-foot volume per acre
A = age in years
SC = site class
B = square feet of basal area per acre

To obtain the volume at the end of the projected rotation, harvest ages appropriate to the ownership and projected basal area at rotation were entered in the equation. The typical harvest or rotation ages provided by State forestry pest control officers for various ownership classes were 60 years for Federal lands, 45 years for State lands, 35 years for industry, and 45 years for NIPF lands. The difference between the volume at the time of attack by SPB and the projected volume at the end of the rotation was the estimated growth loss. No growth loss occurred if a stand was older than the appropriate rotation age for the ownership.

The process is dependent upon a method of projecting the basal area per acre at the rotation age. In this study, equations for predicting basal area were developed for different forest types from FIA survey data.

Table 6.--Comparison of predicted and observed volume of timber killed by SPB, based on an average period of spot growth of 75 days

Forest Experiment Station	Predicted volume killed	Observed volume killed	Percent error[a]
	. . . . $ft^3 \times 10^6$. . . .		
Southern[b]	80.437	67.991	15.47
Southeastern[c]	63.465	59.886	5.64

[a]Percent error = (predicted - observed)/predicted.

[b]Alabama, Arkansas, Louisiana, Mississippi, Tennessee, Texas. (Oklahoma omitted because of negligible SPB activity.)

[c]Georgia, North Carolina, South Carolina, Virginia.

$$\ln(B) = b_0 + b_1 SC + b_2/A \quad (14)$$

where:

B = basal area per acre
SC = site class
A = age in years

This equation was used to calculate the difference (DBA) between the basal area per acre for the survey plot and the predicted basal area of the plot given the same site class and age. The equation was then used to predict the expected basal area at the end of the rotation given the same site class and age. This value was added to DBA to obtain the predicted basal area per acre at the end of the rotation. This approach seems to overpredict basal area at the end of the rotation if the initial basal area per acre is high. It also tends to underpredict for low initial basal areas. This method of projection is less than satisfactory; however, due to lack of suitable basal area growth equations, it was the best of the many alternative prediction methods tested. Consequently, there is a source of potential error of unknown magnitude associated with the growth loss projections. Furthermore, the error associated with the growth loss estimated for States in the Southern Forest Experiment Station will be greater than for States from the Southeastern Station area due to the deficiencies in the survey mentioned previously.

Results

Figure 3 illustrates a ranking of the States by the optimal net benefits of SPB control for both the 4 and 10 percent discount rates. The States can be separated into three categories according to their level of net benefits for SPB control. Alabama, North Carolina, and Texas fall into the category of highest net benefits. Georgia, Louisiana, South Carolina, and Mississippi display a moderate level of net benefits. Virginia, Tennessee, Arkansas, and Oklahoma exhibit very low levels of net benefits. Table 7 gives the benefit/cost ratios for the States. These ratios, at the 4 percent discount rate, range from a high of 9.35 for Alabama to a low of 1.12 for Oklahoma.

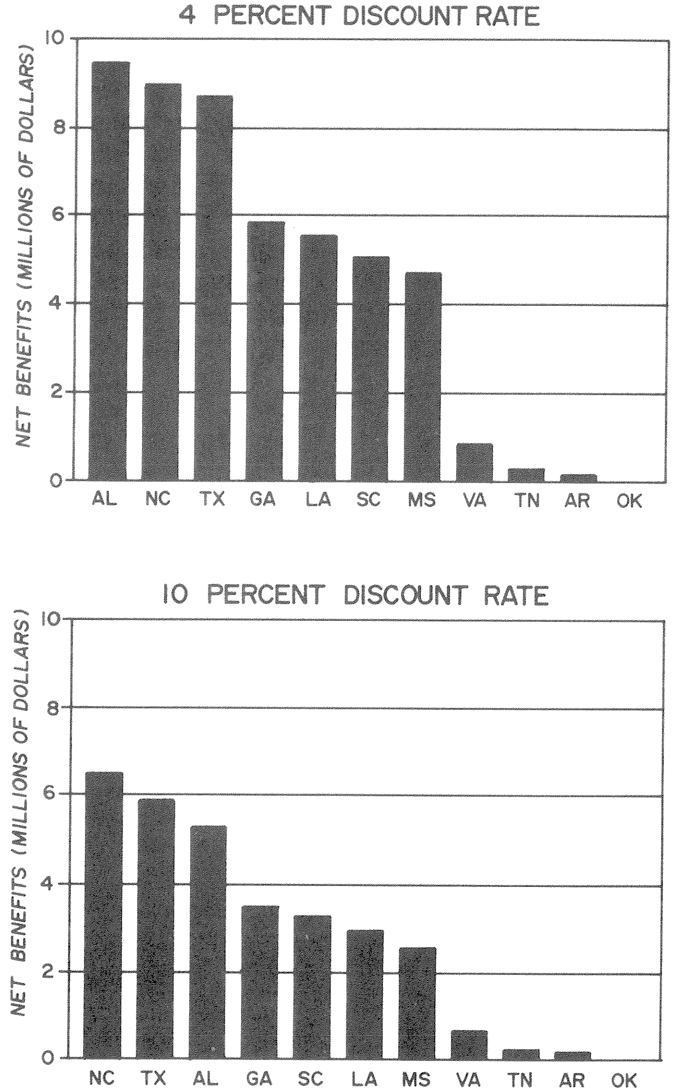

Figure 3.--Optimal net benefits of SPB control, at two discount rates, by State.

Table 7.--Summary of optimal total benefits and total costs for SPB control at two discount rates, assuming a moderate beetle population, in thousands of 1984 dollars, by State

State	Total benefits	Total costs	Net benefits	Benefit/ cost ratio
		4 PERCENT DISCOUNT RATE		
AL	10,586	1,132	9,454	9.35
AR	240	107	133	2.24
LA	6,571	1,003	5,568	6.55
MS	5,882	1,169	4,713	5.03
NC	10,317	1,341	8,976	7.69
OK	0[a]	0[a]	0[a]	1.12
SC	6,024	950	5,074	6.34
TN	371	85	286	4.36
TX	10,468	1,764	8,704	5.94
VA	1,236	381	855	3.26
Regional total	59,097	9,497	49,600	6.22
		10 PERCENT DISCOUNT RATE		
AL	5,912	622	5,290	9.51
AR	197	88	109	2.25
GA	4,450	956	3,494	4.65
LA	3,519	587	2,932	5.99
MS	3,288	735	2,553	4.47
NC	7,472	969	6,503	7.71
OK	0[a]	0[a]	0[a]	1.17
SC	3,917	644	3,273	6.08
TN	243	59	184	4.10
TX	7,242	1,333	5,909	5.43
VA	920	273	647	3.39
Regional total	37,160	6,266	30,894	5.93

[a]Less than $500.

Table 7 summarizes the optimal total costs (both direct and indirect) and benefits for SPB control at both the 4 and 10 percent real discount rates. These results represent the optimal solutions obtained for the individual FIA survey plots summed for each State. The results indicate that the calculations of benefits and costs were very sensitive to the different discount rates. At the 4 percent discount rate, the total benefits were about $59.1 million for the entire region, and the total costs were about $9.5 million, yielding net benefits of $49.6 million. The regional benefit/cost ratio was 6.22. At the 10 percent discount rate, the regional benefits were approximately $37.2 million with total costs of $6.3 million. Net benefits were $30.9 million, and the benefit/cost ratio was 5.93.

Table 8.--Summary of optimal total benefits and direct costs for SPB control, assuming a moderate beetle population, in thousands of 1984 dollars, by State

State	Total benefits	Direct costs	Benefits, net of direct costs	Benefit/direct cost ratio
		4 PERCENT DISCOUNT RATE		
AL	10,586	970	9,616	10.91
AR	240	59	181	4.07
GA	7,402	1,121	6,281	6.60
LA	6,571	688	5,883	9.55
MS	5,882	861	5,021	6.83
NC	10,317	1,041	9,276	9.91
OK	0[a]	0[a]	0[a]	1.96
SC	6,024	705	5,319	8.54
TX	371	73	298	5.08
TX	10,468	1,286	9,182	8.14
VA	1,236	247	989	5.00
Regional total	59,097	7,051	52,046	8.38
		10 PERCENT DISCOUNT RATE		
AL	5,912	599	5,313	9.86
AR	197	50	147	3.94
GA	4,450	813	3,637	5.47
LA	3,519	482	3,037	7.30
MS	3,288	615	2,673	5.34
NC	7,472	839	6,633	8.90
OK	0[a]	0[a]	0[a]	2.00
SC	3,917	558	3,359	7.02
TN	243	55	188	4.42
TX	7,242	1,041	6,201	6.96
VA	920	192	728	4.79
Regional total	37,160	5,244	31,916	7.08

[a]Less than $500.

Table 8 contains study results similar to those in table 7 except that the direct costs of SPB control are given instead of the total control costs. These direct costs represent the actual cash outlays for presuppression flights, evaluation, and suppression, and exclude the opportunity costs involved in the harvesting of financially immature timber to control SPB. The regional benefits net of direct costs were $52 million at the 4 percent discount rate, with a benefit/cost ratio of 8.38. At the 10 percent discount rate, the benefits net of direct costs were about $32 million, yielding a benefit/cost ratio of 7.08.

Table 9.--Summary of optimal regional benefits and costs for SPB control at two discount rates, assuming a moderate beetle population, in thousands of 1984 dollars, by ownership class

Ownership class	Total benefits	Total costs	Net benefits	Benefit/ cost ratio
		4 PERCENT DISCOUNT RATE		
Federal	6,903	908	5,995	7.60
State	1,371	173	1,198	7.93
Forest industry	12,498	2,208	10,290	5.66
NIPF	38,325	6,208	32,117	6.17
Regional total	59,097	9,497	49,600	6.22
		10 PERCENT DISCOUNT RATE		
Federal	2,942	488	2,454	6.03
State	997	124	873	8.07
Forest industry	10,204	1,804	8,400	5.66
NIPF	23,017	3,850	19,167	5.98
Regional total	37,160	6,266	30,894	5.93

Table 9 contains the regional benefits and costs by land ownership class. At the 4 percent discount rate, NIPF lands accounted for 64 percent of the total net benefits; forest industry lands, 20 percent; Federal lands, 12 percent; and State lands, 4 percent. NIPF lands represented 65 percent of the total costs; forest industry lands, 23 percent; Federal lands, 10 percent; and State lands, 2 percent. At the 10 percent discount rate, the general pattern of benefit and cost distribution remains the same, with NIPF lands accounting for the majority of benefits and costs. The benefit/cost ratios, at the 4 percent discount rate, range from 7.93 on State lands to 5.66 on forest industry lands.

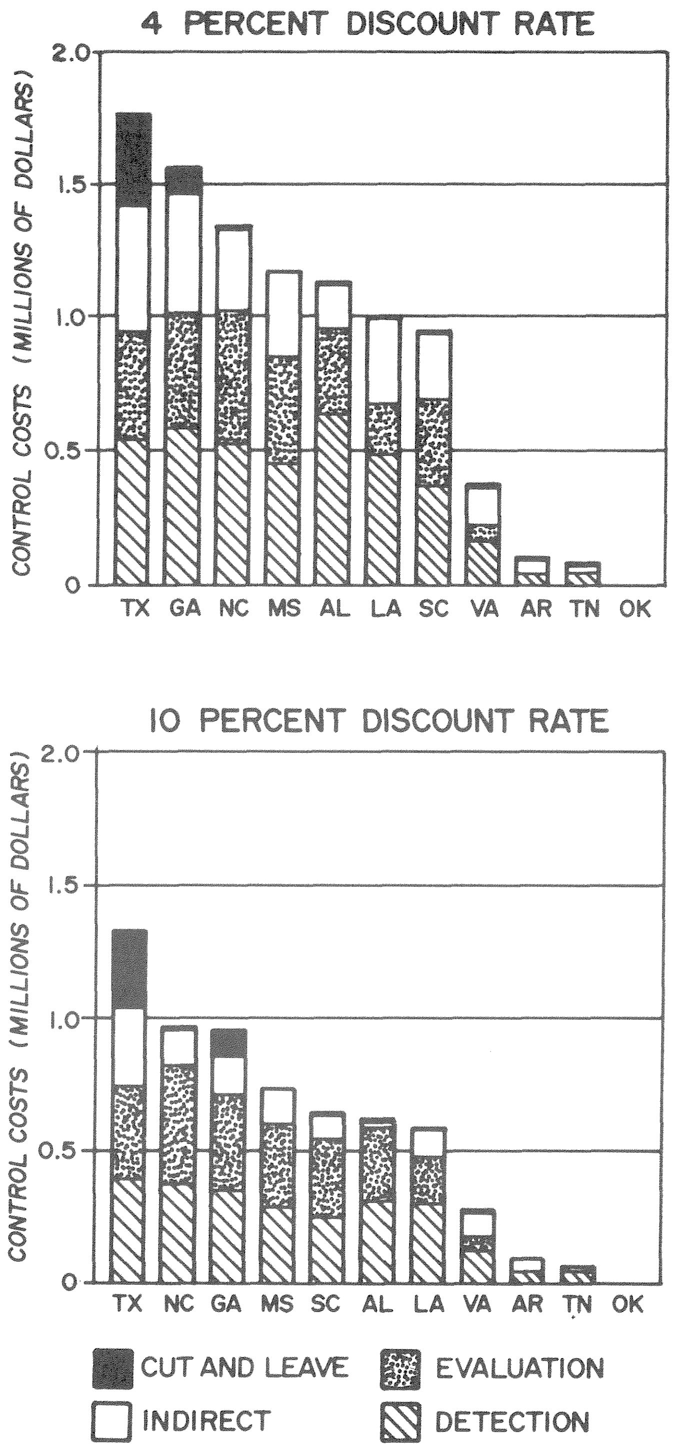

Figure 4.--Components of SPB control costs, at two discount rates, by State.

Figure 4 displays the breakdown of total control cost into the various direct and indirect cost components, by State. For most of the States, the cost of presuppression flights was the largest component of control cost, averaging about 40 percent of total costs. The indirect cost of premature timber harvest was the next largest cost component, averaging about 28 percent of total costs. Evaluation costs averaged 27 percent of total costs, but the direct cost of cut-and-leave suppression constituted only 5 percent. The direct cut-and-leave cost is a larger share of total cost in Georgia and, particularly, Texas because the practice is more common there.

The complete, detailed study results are in the appendix. Table 10 contains the analysis results for the entire Southern region; tables 11-21 contain the results for the separate States. Each table contains the results for both the 4 and 10 percent discount rates. Optimal total benefits, changes in salvage value, direct and indirect costs, and benefit/cost ratios are given by land ownership class. Row and column totals may contain some slight rounding errors.

Conclusion and Discussion

The results of this study indicated that, in a year of typical SPB activity, substantial benefits could be realized from optimal economic control of SPB damage to commercial timber stands. At a 4 percent real rate to discount the value of timber losses, the optimal net benefits of control for the entire Southern region are estimated at about $50 million, yielding a benefit/cost ratio of 6.22. Even at a 10 percent real discount rate, the regional net benefits are estimated to be more than $30 million with a benefit/cost ratio of 5.93.

Seven States--Alabama, North Carolina, Texas, Georgia, Louisiana, South Carolina, and Mississippi--unquestionably warrant large SPB control efforts. Of those, Alabama, North Carolina, and Texas are the three largest in terms of net benefits, averaging about $9 million per State. The remaining four States could generate optimal net benefits of about $5 million each. Virginia, Tennessee, Arkansas, and Oklahoma, under optimal SPB control conditions, would yield net benefits per State of less than $1 million.

From the study results, the total regional optimal annual direct cost for SPB control is estimated to be about $7 to $5 million, depending upon the assumed discount rate of 4 or 10 percent, respectively. The majority of this control expenditure should be applied to presuppression flights and to the evaluation of SPB infestations. The direct cost associated with suppression, i.e., cut and leave and cut and salvage, is a minor component of control activities. The optimal direct control costs for Alabama, North Carolina, Texas, Georgia, Louisiana, South Carolina, and Mississippi range from about $1.2 million to $700,000 annually, per State, depending upon the assumed discount rate of 4 or 10 percent, respectively.

This study was an attempt to provide an economic basis for the planning of SPB control programs. As such, it represents a conceptually complex research activity. The simulation program seems to slightly overpredict volume killed by SPB on a regional basis. Overprediction appears to be greater for the States in the FIA survey region of the Southern Forest Experiment Station. The predictions for States covered by the Southeastern Station survey (Georgia, North Carolina, South Carolina, Virginia) are very close to the observed volume killed when all the sources of potential error are considered. The estimates of future growth loss due to premature death of the trees are subject to an unknown degree of error given the methods used to make the projections.

In spite of these caveats, the use of projected volume killed for the moderate population level weighted by the proportion of the region in an outbreak condition during an average year provides a realistic estimate of the direct mortality due to SPB attack. Because of these results, only the moderate SPB population projections were used in the economic analysis conducted with BEAM. Use of either the low or high population values would result in extreme underestimates or overestimates of loss. Losses calculated from volume killed combined with growth loss due to premature death of trees caused by SPB attack provide the only estimates of the total regional impact of this pest available today. These should furnish suitable initial estimates for evaluating the economics of cooperative control programs.

Further investigations and refinement of the models and data are, perhaps, warranted; however, the authors express confidence in the results that have been generated. Also, sensitivity analyses were conducted to determine the effect of varying assumptions regarding salvage rates, timber prices, etc., on the study results. We determined that the results were not very sensitive to small changes in the data. Indeed, changes in the discount rate had far greater impact on the study results than did changes in the other variables. Thus, data inaccuracies should not be a matter of great concern.

Acknowledgment

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APPENDIX

Table 10.--Optimal level for SPB control in thousands of dollars, by ownership class, for the Southern region

Category	Federal	State	Forest industry	NIPF	Total
	4 PERCENT DISCOUNT RATE				
Benefits					
Timber saved	$7,142	$1,430	$12,964	$39,523	$61,059
Change in salvage	-239	-59	-466	-1,198	-1,962
Total benefits	6,903	1,371	12,498	38,325	59,097
Direct costs					
Presuppression flights	352	73	905	2,544	3,875
Evaluation	237	45	523	1,842	2,645
Cut and leave	56	7	176	292	531
Total direct costs	644	125	1,604	4,677	7,051
Indirect costs (buffer timber)	264	48	604	1,530	2,446
Total costs	908	173	2,208	6,208	9,497
Net benefits	$5,995	$1,198	$10,290	$32,117	$49,600
Benefit/cost ratio	7.60	7.93	5.66	6.17	6.22
	10 PERCENT DISCOUNT RATE				
Benefits					
Timber saved	$2,935	$1,041	$10,560	$23,030	$37,567
Change in salvage	7	-43	-356	-13	-406
Total benefits	2,942	997	10,204	23,017	37,161
Direct costs					
Presuppression flights	175	54	732	1,512	2,474
Evaluation	200	40	490	1,576	2,305
Cut and leave	51	6	165	242	464
Total direct costs	427	100	1,386	3,330	5,243
Indirect costs (buffer timber)	61	23	418	520	1,022
Total costs	488	124	1,804	3,850	6,266
Net benefits	$2,455	$874	$8,400	$19,167	$30,895
Benefit/cost ratio	6.03	8.07	5.66	5.98	5.93

Table 11.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Alabama

Cagetory	Federal	State	Forest industry	NIPF	Total
			4 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$645	$232	$2,804	$7,954	$11,636
Change in salvage	-66	-26	-217	-740	-1,050
Total benefits	579	206	2,587	7,214	10,586
Direct costs					
Presuppression flights	33	9	174	426	642
Evaluation	15	5	82	214	316
Cut and leave	1	0	3	9	13
Total direct costs	48	14	260	649	970
Indirect costs (buffer timber)	12	1	50	98	162
Total costs	61	14	310	747	1,132
Net benefits	$519	$192	$2,277	$6,467	$9,454
Benefit/cost ratio	9.54	14.44	8.35	9.66	9.35
			10 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$110	$171	$2,040	$3,726	$6,047
Change in salvage	49	-18	-139	-27	-136
Total benefits	159	153	1,901	3,699	5,912
Direct costs					
Presuppression flights	9	6	119	183	316
Evaluation	11	4	75	180	270
Cut and leave	1	0	3	8	12
Total direct costs	20	10	198	371	599
Indirect costs (buffer timber)	1	0	17	5	23
Total costs	21	10	214	376	622
Net benefits	$138	$143	$1,687	$3,323	$5,290
Benefit/cost ratio	7.51	15.26	8.87	9.84	9.51

Table 12.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Arkansas

Catetory	Federal	State	Forest industry	NIPF	Total
			4 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$0	$7	$115	$124	$246
Change in salvage	0	0	-3	-3	-7
Total benefits	0	7	112	121	240
Direct costs					
Presuppression flights	0	1	22	22	45
Evaluation	0	0	2	2	4
Cut and leave	0	0	5	5	10
Total direct costs	0	2	29	29	59
Indirect costs (buffer timber)	0	1	24	23	48
Total costs	0	3	52	51	107
Net benefits	$0	$4	$60	$69	$133
Benefit/cost ratio	--	2.24	2.14	2.34	2.24
			10 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$0	$7	$108	$87	$203
Change in salvage	0	0	-3	-2	-5
Total benefits	0	7	105	85	197
Direct costs					
Presuppression flights	0	1	20	16	37
Evaluation	0	0	2	2	4
Cut and leave	0	0	5	5	9
Total direct costs	0	2	26	23	50
Indirect costs (buffer timber)	0	1	22	15	38
Total costs	0	3	48	37	88
Net benefits	$0	$4	$58	$48	$109
Benefit/cost ratio	--	2.36	2.21	2.28	2.25

Table 13.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Georgia

Category	Federal	State	Forest industry	NIPF	Total
	4 PERCENT DISCOUNT RATE				
Benefits					
Timber saved	$681	$50	$1,079	$5,628	$7,438
Change in salvage	1	0	-8	-30	-37
Total benefits	682	50	1,071	5,599	7,402
Direct costs					
Presuppression flights	43	5	97	440	586
Evaluation	31	3	53	345	432
Cut and leave	7	1	17	78	103
Total direct costs	81	9	168	863	1,121
Indirect costs (buffer timber)	41	4	76	324	444
Total costs	121	13	244	1,187	1,565
Net benefits	$561	$37	$828	$4,412	$5,837
Benefit/cost ratio	5.62	3.77	4.40	4.72	4.73
	10 PERCENT DISCOUNT RATE				
Benefits					
Timber saved	$382	$25	$840	$3,030	$4,276
Change in salvage	22	2	7	143	173
Total benefits	403	27	847	3,172	4,450
Direct costs					
Presuppression flights	25	3	72	251	351
Evaluation	26	2	50	289	367
Cut and leave	6	1	17	71	95
Total direct costs	57	6	139	611	813
Indirect costs (buffer timber)	15	1	37	90	143
Total costs	72	7	176	701	956
Net benefits	$332	$20	$671	$2,472	$3,493
Benefit/cost ratio	5.62	3.65	4.81	4.53	4.65

Table 14.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Louisiana

Category	Federal	State	Forest industry	NIPF	Total
			4 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$1,038	$322	$2,175	$3,254	$6,789
Change in salvage	-41	-13	-66	-97	-218
Total benefits	997	308	2,109	3,157	6,571
Direct costs					
Presuppression flights	52	14	163	258	487
Evaluation	21	6	64	102	194
Cut and leave	1	0	3	4	8
Total direct costs	74	20	230	364	688
Indirect costs (buffer timber)	34	10	106	164	315
Total costs	108	30	336	528	1,003
Net benefits	$889	$278	$1,772	$2,629	$5,568
Benefit/cost ratio	9.25	10.20	6.27	5.98	6.55
			10 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$230	$161	$1,737	$1,544	$3,672
Change in salvage	-13	-12	-61	-67	-153
Total benefits	218	149	1,676	1,477	3,519
Direct costs					
Presuppression flights	17	9	137	139	302
Evaluation	17	6	61	88	172
Cut and leave	1	0	3	4	7
Total direct costs	35	15	201	231	482
Indirect costs (buffer timber)	2	1	73	30	106
Total costs	37	16	273	261	587
Net benefits	$180	$133	$1,402	$1,217	$2,932
Benefit/cost ratio	5.82	9.46	6.13	5.67	5.99

Table 15.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Mississippi

Category	Federal	State	Forest industry	NIPF	Total
			4 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$1,040	$115	$1,468	$3,428	$6,051
Change in salvage	-32	-3	-39	-95	-169
Total benefits	1,008	112	1,429	3,333	5,882
Direct costs					
Presuppression flights	72	12	101	276	460
Evaluation	50	8	98	237	392
Cut and leave	1	0	2	5	8
Total direct costs	123	20	201	517	861
Indirect costs (buffer timber)	51	8	66	184	309
Total costs	174	28	267	701	1,169
Net benefits	$834	$85	$1,162	$2,632	$4,712
Benefit/cost ratio	5.80	4.07	5.35	4.75	5.03
			10 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$401	$88	$1,082	$1,844	$3,414
Change in salvage	-15	-3	-36	-72	-126
Total benefits	386	85	1,046	1,772	3,288
Direct costs					
Presuppression flights	35	8	79	164	286
Evaluation	38	6	90	188	323
Cut and leave	1	0	2	4	7
Total direct costs	74	14	172	356	615
Indirect costs (buffer timber)	8	5	43	64	120
Total costs	82	19	214	420	735
Net benefits	$304	$66	$832	$1,352	$2,553
Benefit/cost ratio	4.69	4.42	4.89	4.22	4.47

Table 16.--Optimal level for SPB control, in thousands of dollars, by ownership class, for North Carolina

Category	Federal	State	Forest industry	NIPF	Total
			4 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$332	$292	$509	$9,284	$10,417
Change in salvage	-1	-8	-3	-89	-100
Total benefits	332	284	506	9,195	10,317
Direct costs					
Presuppression flights	24	12	43	449	528
Evaluation	16	9	21	454	500
Cut and leave	1	0	1	11	13
Total direct costs	41	21	65	914	1,041
Indirect costs (buffer timber)	11	7	25	257	300
Total costs	52	28	90	1,171	1,341
Net benefits	$280	$256	$416	$8,024	$8,975
Benefit/cost ratio	6.36	10.31	5.60	7.85	7.69
			10 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$194	$236	$451	$6,548	$7,429
Change in salvage	12	-6	0	38	43
Total benefits	205	230	450	6,586	7,472
Direct costs					
Presuppression flights	14	9	36	317	378
Evaluation	15	9	20	404	449
Cut and leave	1	0	1	10	12
Total direct costs	30	19	58	732	839
Indirect costs (buffer timber)	3	3	17	107	131
Total costs	33	22	75	839	969
Net benefits	$173	$208	$375	$5,747	$6,503
Benefit/cost ratio	6.30	10.36	6.01	7.85	7.71

Table 17.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Oklahoma

Category	Federal	State	Forest industry	NIPF	Total
	4 PERCENT DISCOUNT RATE				
Benefits					
Timber saved	$0.52	$0	$0	$0	$0.52
Change in salvage	-.02	0	0	0	-.02
Total benefits	.51	0	0	0	.51
Direct costs					
Presuppression flights	.22	0	0	0	.22
Evaluation	.01	0	0	0	.01
Cut and leave	.03	0	0	0	.03
Total direct costs	.26	0	0	0	.26
Indirect costs (buffer timber)	.19	0	0	0	.19
Total costs	.45	0	0	0	.45
Net benefits	$.05	$0	$0	$0	$.05
Benefit/cost ratio	1.12	--	--	--	1.12
	10 PERCENT DISCOUNT RATE				
Benefits					
Timber saved	$0.31	$0	$0	$0	$0.31
Change in salvage	.01	0	0	0	.01
Total benefits	.32	0	0	0	.32
Direct costs					
Presuppression flights	.11	0	0	0	.11
Evaluation	.01	0	0	0	.01
Cut and leave	.04	0	0	0	.04
Total direct costs	.16	0	0	0	.16
Indirect costs (buffer timber)	.12	0	0	0	.12
Total costs	.27	0	0	0	.27
Net benefits	$.05	$0	$0	$0	$.05
Benefit/cost ratio	1.17	--	--	--	1.17

Table 18.--Optimal level for SPB control, in thousands of dollars, by ownership class, for South Carolina

Category	Federal	State	Forest industry	NIPF	Total
	4 PERCENT DISCOUNT RATE				
Benefits					
Timber saved	$577	$159	$566	$4,724	$6,025
Change in salvage	9	-2	-3	-6	-1
Total benefits	586	156	563	4,718	6,024
Direct costs					
Presuppression flights	38	7	48	279	371
Evaluation	26	6	26	267	324
Cut and leave	1	0	1	7	9
Total direct costs	64	13	75	552	705
Indirect costs (buffer timber)	25	5	36	179	245
Total costs	90	18	110	732	950
Net benefits	$497	$138	$453	$3,986	$5,074
Benefit/cost ratio	6.54	8.58	5.10	6.45	6.34
	10 PERCENT DISCOUNT RATE				
Benefits					
Timber saved	$350	$139	$442	$2,870	$3,801
Change in salvage	33	-1	1	84	117
Total benefits	383	138	444	2,953	3,917
Direct costs					
Presuppression flights	21	6	39	185	251
Evaluation	23	5	24	246	298
Cut and leave	1	0	1	7	9
Total direct costs	45	12	64	437	558
Indirect costs (buffer timber)	8	3	19	56	86
Total costs	53	15	83	493	644
Net benefits	$330	$123	$360	$2,460	$3,273
Benefit/cost ratio	7.23	9.47	5.33	5.99	6.08

Table 19.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Tennessee

Category	Federal	State	Forest industry	NIPF	Total
			4 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$104	$14	$26	$223	$367
Change in salvage	0	1	1	3	4
Total benefits	104	15	26	225	371
Direct costs					
Presuppression flights	8	3	4	35	51
Evaluation	4	1	2	14	21
Cut and leave	0	0	0	1	1
Total direct costs	12	4	6	50	73
Indirect costs (buffer timber)	2	1	1	8	12
Total costs	15	5	7	58	85
Net benefits	$90	$10	$19	$167	$286
Benefit/cost ratio	7.19	2.83	3.73	3.86	4.36
			10 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$53	$11	$23	$141	$228
Change in salvage	4	1	1	10	16
Total benefits	56	12	24	151	243
Direct costs					
Presuppression flights	5	3	4	23	35
Evaluation	3	1	1	12	18
Cut and leave	0	0	0	1	1
Total direct costs	9	4	5	37	55
Indirect costs (buffer timber)	0	0	1	3	5
Total costs	9	4	6	40	59
Net benefits	$47	$8	$18	$111	$184
Benefit/cost ratio	6.15	2.82	3.92	3.79	4.10

Table 20.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Texas

Category	Federal	State	Forest industry	NIPF	Total
	4 PERCENT DISCOUNT RATE				
Benefits					
Timber saved	$2,671	$190	$4,020	$3,964	$10,845
Change in salvage	-110	-6	-126	-135	-377
Total benefits	2,561	183	3,894	3,829	10,468
Direct costs					
Presuppression flights	71	6	228	238	543
Evaluation	70	6	164	159	399
Cut and leave	43	4	140	157	344
Total direct costs	185	16	532	553	1,286
Indirect costs (buffer timber)	80	8	197	193	478
Total costs	265	24	729	746	1,764
Net benefits	$2,297	$160	$3,165	$3,083	$8,704
Benefit/cost ratio	9.68	7.76	5.34	5.13	5.94
	10 PERCENT DISCOUNT RATE				
Benefits					
Timber saved	$1,184	$159	$3,665	$2,568	$7,575
Change in salvage	-85	-6	-123	-119	-333
Total benefits	1,099	153	3,541	2,448	7,242
Direct costs					
Presuppression flights	42	5	204	147	398
Evaluation	63	5	156	126	350
Cut and leave	40	4	131	119	293
Total direct costs	145	13	491	391	1,041
Indirect costs (buffer timber)	21	6	172	93	292
Total costs	166	19	663	485	1,333
Net benefits	$933	$134	$2,878	$1,964	$5,909
Benefit/cost ratio	6.61	8.10	5.34	5.05	5.43

Table 21.--Optimal level for SPB control, in thousands of dollars, by ownership class, for Virginia

Category	Federal	State	Forest industry	NIPF	Total
			4 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$53	$50	$202	$941	$1,245
Change in salvage	0	-1	-2	-6	-8
Total benefits	53	49	200	935	1,237
Direct costs					
Presuppression flights	11	4	26	123	163
Evaluation	4	2	10	48	63
Cut and leave	1	1	3	16	21
Total direct costs	16	6	39	186	247
Indirect costs (buffer timber)	7	3	22	99	132
Total costs	23	10	61	285	380
Net benefits	$30	$39	$139	$650	$858
Benefit/cost ratio	2.31	4.93	3.27	3.28	3.26
			10 PERCENT DISCOUNT RATE		
Benefits					
Timber saved	$31	$45	$172	$673	$921
Change in salvage	1	-1	-1	0	-1
Total benefits	32	45	171	673	920
Direct costs					
Presuppression flights	7	4	22	87	119
Evaluation	3	2	9	41	55
Cut and leave	1	0	3	14	19
Total direct costs	11	6	34	142	192
Indirect costs (buffer timber)	3	3	17	57	80
Total costs	14	9	51	198	272
Net benefits	$19	$36	$120	$474	$649
Benefit/cost ratio	2.34	5.22	3.34	3.39	3.39

de Steiguer, J.E.; Hedden, Roy L.; Pye, John M.

Optimal level of expenditure to control the southern pine beetle. Res. Pap. SE-263. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1987. 30 pp.

Optimal level of expenditure to control damage to commercial timber stands by the southern pine beetle was determined by models that simulated and analyzed beetle attacks during a typical season for 11 Southern States. At a real discount rate of 4 percent, maximized net benefits for the Southern region are estimated at about $50 million; at 10 percent, more than $30 million. Methods and costs for detection, evaluation, and suppression of beetle infestation are discussed. Tables of optimal level for the 11 States are included.

KEYWORDS: Dendroctonus frontalis, CLEMBEETLE, OVERFLIGHT, BEAM, cut and leave, cut and salvage, presuppression flights.

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