Southern Pine Beetle Keyword Component Addfile for Use with FVS

Anthony W. Courter
Forrest L. Oliveria
James (Rusty) Rhea

Abstract—The Southern Pine Beetle Keyword Component Addfile is a keyword set used within the Forest Vegetation Simulator (FVS) to simulate the effects of southern pine beetles (SPB) (*Dendroctonus frontalis*), Zimmermann (*Coleoptera: Scolytidae*). Individual stands are evaluated with a hazard rating system to determine their susceptibility to SPB depredation. SPB-induced mortality is determined, in part, by the stand's hazard rating. This is a strategic model that demonstrates potential pine timber and habitat loss due to SPB. The user can proactively reduce the stand's hazard level by scheduling appropriate management actions within FVS. Once preset conditions are met and a SPB outbreak is scheduled, losses due to SPB will be estimated.

Modeling the effects of insects and pathogens within FVS is conventionally achieved through the use of pest-specific FVS Variant Extensions, which are supported by the staffs of the USDA Forest Service Forest Health Technology Enterprise Team (FHTET) and the USDA Forest Service Forest Management Service Center. These extensions represent the state of the art in pest modeling and have been developed for use exclusively with the Western variants of FVS. These extensions require substantial investment of time and money to build and maintain.

In 2000, the director of Forest Health Protection in USDA Forest Service Southern Region requested assistance from FHTET with FVS-Pest Model solutions for the South addressing southern pine beetle, oak decline, and littleleaf disease. Due to the immediate need and budgetary constraints, it was decided to simulate pest impacts in the South using FVS keyword sets, rather than develop fully integrated pest extensions. These keyword sets can then be bundled into stand-alone **K**eyword **C**om**P**onent Addfiles (*.kcp* files) to be included in FVS simulations as appropriate. One of the advantages of developing pest models with FVS keywords is that the code is stand alone; modifications can be made to the FVS base model without requiring changes to the pest specific .kcp files. Occasionally, traditional pest extensions might require immediate and extensive coding changes if the base FVS code is altered in fundamental ways. Another advantage is the ability of the developer/user to quickly make changes in a single file that drastically streamlines the testing and development phase. The FVS Event Monitor feature allows for the creation and evaluation of user-defined variables that describe stand conditions. These variables can then be used to schedule management actions or growth/mortality functions with the "IF…THEN…ENDIF" FVS keyword.

At its simplest level, the SPB keyword set "kills" a percentage of targeted pine species in a simulated stand by the use of the FVS keyword "FIXMORT" if a drawn random number is less than, or equal to, the estimated probability of a SPB outbreak occurring in that multiyear FVS cycle. The SPB keyword set comprised three geographically specific FVS addfiles that cover the Coastal (*SPB_Coas.kcp*), Piedmont (*SPB_Pied.kcp*), and Mountain (*SPB_Mtn.kcp*) subregions in Region 8 (table 1). The Coastal and Piedmont SPB keyword files may be used with the Southern (SN) and Southeast (SE) FVS variants. The Mountain SPB keyword file may be used with the SN, SE, and Northeast (NE) variants. Coastal and Piedmont hazard ratings are determined in accordance with USDA-Forest Service guidelines (Hess and others 1997). The Mountain hazard rating was developed through the Mountain Risk formula (Heddon 1983). The estimated effects of SPB, as well as probability of outbreak occurrence contained in these three addfiles, represent the best professional judgment of entomologists in Forest Health Protection Region 8 (FHP R8), USDA Forest Service.

Table 1—Targeted species by subregion

Subregion	Pine species	FVS code	Scientific name
Coastal	Loblolly	LP	*Pinus taeda*
	Shortleaf	SP	*Pinus echinata*
	Slash	SA	*Pinus elliottii*
	Longleaf	LL	*Pinus palustris*
Piedmont	Loblolly	LP	*Pinus taeda*
	Shortleaf	SP	*Pinus echinata*
	Virginia	VP	*Pinus virginiana*
Mountain	Shortleaf	SP	*Pinus echinata*
	Virginia	VP	*Pinus virginiana*
	Pitch	PP	*Pinus rigida*
	Eastern white	WP	*Pinus strobus*

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Anthony W. Courter is a Systems Analyst with INTECS International, Inc., Fort Collins, CO, contracting with the Forest Health Technology Enterprise Team, USDA Forest Service, 2150 Centre Ave. (NRRC) Bldg. A, Suite 331, Fort Collins, CO 80526. Forrest L. Oliveria is the Field Office Representative for Forest Health Protection Region 8 Alexandria Field Office, USDA Forest Service, 2500 Shreveport Highway, Pineville, LA 71360. James (Rusty) Rhea is an Entomologist with Forest Health Protection Region 8 Asheville Field Office, USDA Forest Service, P.O. Box 2680, Asheville, NC 28802.

Methods

Assumptions

The SPB keyword sets are based on the following assumptions as theorized by FHP R8 entomologists:

- Seven to eight SPB outbreaks in 120 years
- One catastrophic outbreak in 100 years
- SPB prefer sawtimber to poletimber
- SPB prefer poletimber to saplings
- SPB-induced mortality does not affect pine species less than 1.0 inch d.b.h.
- A catastrophic outbreak applies heavy mortality to diameter classes greater than or equal to 1.0 inch d.b.h.
- SPB-induced mortality is not treated as a release

In response to the current ongoing infestation in upland stands, and upon request from FHP R8 entomologists, eastern white pine (*Pinus strobus*) (WP) was added to the Mountain Keyword set. Because the effects of SPB on WP are not well documented, it was decided that the SPB impact on WP should be estimated as half that of the impact of SPB on other target species. That is, if the mortality leveled against shortleaf pine (*Pinus echinata*) is calculated to be 45 percent, then SPB-induced mortality on WP will be half that, or 22.5 percent.

SPB Hazard

Potential SPB mortality, or percent of basal area loss (PBALOSS), is determined by the SPB event monitor variable HAZARD. A stand's hazard classification, or rating, is defined by current stand conditions and determines the levels of mortality applied to target pine sawtimber, if an outbreak occurs. There are three SPB hazard classifications, low (1), medium (2) and high (3), which are based on the stand's overall susceptibility to SPB depredation. Potential PBALOSS of sawtimber for target pine species is shown in table 2.

Actual PBALOSS is calculated as follows:

$$\text{PBALOSS} = A + (B - A)\ \text{Random2}$$

Where A equals the lower range limit
B equals the upper range limit
Random2 equals a pseudorandom number between zero and one, or
$(0 < \text{Random2} < 1)$

For example, PBALOSS for a high hazard stand (table 2) would be calculated as follows:

$$\text{PBALOSS} = .4 + [(.8 - .4) \times \text{Random2}]$$

Calculating Hazard Near the Coast

SPB hazard in *SPB_Coas.kcp* is calculated by combining the basal area of targeted pine species within the loblolly/shortleaf and slash/longleaf pine communities, compared to the stand mean top height. Low hazard (1) is the default condition unless the stand meets any of the conditions included in tables 3 and 4. A high hazard (3) classification for the shortest tree range in the loblolly and shortleaf pine community was added to the original R8 classification.

Table 2—PBALOSS (sawtimber) by hazard class

Hazard rating	Percent basal area loss
1 - Low	0 to 10
2 - Moderate	20 to 40
3 - High	40 to 80

Table 3—Hazard ratings for coastal loblolly and shortleaf pine communities.

[a]Mean stand top height (ft)	Loblolly and shortleaf pine combined basal area greater than or equal to 50% stand total				
	Pine basal area (ft^2)				
	< 70	70 to 80	80 to 90	90 to 100	> 100
106+	1	2	2	2	3
76 to 105	1	2	2	3	3
66 to 75	1	1	2	3	3
56 to 65	1	1	2[b]	2[b]	3[b]
0 to 55	1	1	1	1	1

1 = Low hazard
2 = Medium hazard
3 = High hazard
[a]Mean stand top height(ft) as calculated from the 40 largest trees by d.b.h.
[b]Indicates change from original hazard classification parameters (Hess and others 1997).

Table 4—Hazard ratings for coastal slash and longleaf pine communities.

[a]Mean stand top height (ft)	Slash and longleaf pine combined basal area greater than or equal to 70% stand total				
	Pine basal area (ft^2)				
	< 70	70 to 80	80 to 90	90 to 100	> 100
106+	1	1	1	1	2
76 to 105	1	1	1	2	2
66 to 75	1	1	2	2	2
0 to 65	1	1	1	1	1

1 = Low hazard
2 = Medium hazard
3 = High hazard
[a]Mean stand top height(ft) as calculated from the 40 largest trees by d.b.h.

Calculating Hazard on the Piedmont

SPB hazard in *SPB_Pied.kcp* is calculated by combining the basal area of targeted pine species within the loblolly and shortleaf/Virginia pine communities, compared to the stand mean top height. Low hazard (1) is the default condition unless the stand meets any of the conditions included in tables 5 and 6. Virginia pine was added to the shortleaf pine community for a combined basal area with a more comprehensive determination of hazard risk in the Piedmont. We added a high hazard (3) classification for the shortest tree classification range in the loblolly community.

Calculating Hazard in the Mountains

SPB hazard in *SPB_Mtn.kcp* is calculated using the Mountain Risk formula (Hedden 1983), incorporating 5-year radial growth (RG) of targeted pines and the percentage of targeted pine basal area (PER_PINE) relative to total stand basal area. The 5-year radial growth of targeted pine species is estimated using the FVS Event Monitor function, SPMCDBH. SPMCDBH can be configured to return average diameter growth, excluding bark. Diameter growth is then divided by two to generate an approximation of radial growth in the multiyear cycle. Average radial growth (avgRG) is then calculated using a weighted mean average for all targeted species. AvgRG is then divided by the Time Interval (TI) and multiplied by 5 to generate a 5-year radial growth (RG) variable, as per: RG = (avgRG / TI)

The variable STAT is then calculated by taking the natural log of the product of RG and 25.4, as per: STAT = ALOG(RG• 25.4)

The Mountain Risk Score is then calculated as per:

SCORE = –1.90 –(3.97• PER_PINE)+(2.14• STAT)

The resulting SCORE is then used to determine the stand's hazard classification (table 7).

The Hazard Regulator

Because SPB-induced mortality is not treated as a Release, logic was built into the SPB keyword sets that assures a stand's hazard rating either stays the same or gets worse over time, based on current stand conditions. Management actions cause the hazard rating to be recalculated based on current stand conditions. This logic was added after it was observed that hazard went down after sizable SPB mortality was applied in a preliminary SPB keyword simulation. According to FHP R8 entomologists, this downturn contradicts what has been observed in the field. In nature, the unaffected portion of the stand that had been attacked by

Table 5—Hazard ratings for coastal loblolly and pine communities.

[a]Mean stand top height (ft)	Loblolly pine combined basal area greater than or equal to 50% stand total				
	Pine basal area (ft^2)				
	< 70	70 to 79	80 to 89	90 to 100	> 100
106+	1	2	2	2	3
76 to 105	1	2	2	2	3
61 to 75	1	1	2	3	3
50 to 60	1	1	2[b]	2[b]	3[b]
0 to 49	1	1	1	1	1

1 = Low hazard
2 = Medium hazard
3 = High hazard
[a]Mean stand top height(ft) as calculated from the 40 largest trees by d.b.h.
[b]Indicates change from original hazard classification parameters (Hess and others 1997).

Table 6—Hazard ratings for piedmont shortleaf and Virginia[b] pine communities.

[a]Mean stand top height (ft)	Shortleaf and Virginia[b] pine combined basal area greater than or equal to 50% stand total				
	Pine basal area (ft^2)				
	< 70	70 to 80	80 to 90	90 to 100	> 100
106+	1	2	2	2	3
76 to 105	1	2	2	3	3
56 to 75	1	2	3	3	3
45 to 55	1	2[b]	2[b]	2[b]	3[b]
0 to 44	1	1	1	1	1

1 = Low hazard
2 = Medium hazard
3 = High hazard
[a]Mean stand top height(ft) as calculated from the 40 largest trees by d.b.h.
[b]Indicates change from original hazard classification parameters (Hess and others 1997).

Table 7—Mountain risk score.

Score comparison	Hazard classification
Score > 0.40	1
0.40 ≥ Score ≥ –0.56	2
Score < –0.56	3

SPB would be as susceptible to a subsequent SPB outbreak as it was to the previous infestation.

SPB Outbreak

The SPB Event Monitor variable "Outbreak" determines if a SPB infestation will occur, and if so, how severe its consequences will be. Outbreak is an integer variable between zero and four, and represents the range of potential outcomes for each FVS multiyear cycle (table 8).

No SPB-induced mortality is leveled against targeted pine species in the simulated stand in a cycle where the variable outbreak = 0 (no outbreak). As determined by the stand's hazard rating (table 9), SPB-induced mortality is differentially applied to various diameter classes in light (1) and moderate (2) outbreaks.

For the purposes of the SPB Event Monitor, the diameter classes are defined with lower d.b.h. breakpoints as sawtimber (10 inch), poletimber (3 inch), and saplings (1 inch). The SPB Event Monitor does not affect pine species smaller than 1 inch.

SPB mortality will be evenly applied to sawtimber, poletimber, and saplings during a heavy outbreak (3) condition. Regardless of hazard classification, extreme SPB mortality will be applied to all diameter classes in catastrophic outbreak (4) condition. Catastrophic mortality will range between 80 and 100 percent of basal area loss.

Yearly Probability of Outbreak Occurrence

Nonzero outbreak values are assigned if a drawn pseudorandom number between zero and one is less than or equal to the estimated probability of that type of outbreak occurring in the multiyear FVS cycle. Yearly probabilities of SPB outbreak occurrence are based on two assumptions: first, R8 entomologists expect a stand to endure seven to eight SPB infestations over a 120-year period, and second, there will be at least one catastrophic event during a 100-year period.

The probability that a catastrophic outbreak will occur is set at 1 percent per year (one outbreak per 100 years). The probability that an outbreak will occur at all (7.5 outbreaks per 120 Years = 0.0625 or 6.25 percent) is the upper probability limit for a light outbreak in a single year. Likewise, moderate and heavy outbreaks have been assigned a yearly probability of occurrence of 5.0 and 2.5 percent, respectively.

Discounting Probability Logic

The Southern Pine Beetle keyword set uses discounting logic to scale the probability of each outbreak event to the length of the multiyear cycle. In this manner, the probability

Table 8—SPB outbreak variable values.

Outbreak severity	Outbreak values
No outbreak	0
Light	1
Moderate	2
Heavy	3
Catastrophic	4

Table 9— Percentage basal area mortality by outbreak severity class. Relative percentage of mortality applied.

Size class	Catastrophic outbreak (4)	Heavy outbreak (3)	Moderate outbreak (2)	Light outbreak (1)
Saplings	80 to 100	100	50	25
Poletimber	80 to 100	100	75	50
Sawtimber	80 to 100	100	100	100

of outbreak occurrence can never exceed 100 percent regardless of the length of the user-defined cycle. This is achieved by raising the probability of the nonevent to the power of the number of years in a cycle, Time Interval (TI). Therefore, the probability of a light outbreak in a cycle is defined as:

$$\text{ProbLightOutbreak} = 1 - (\text{ProbNoLightOutbreak})^{TI}$$

By default, FVS operates in 5-year cycles in the Southern Variant (TI = 5).

For example, if probNoLightOutbreak = 0.9375, the probability that a light outbreak will occur in a 5-year cycle is:

$$\text{ProbLightOutbreak5Yr} = 1 - (.9375)^5$$
$$\text{ProbLightOutbreak5Yr} = 27.6 \text{ percent.}$$

In each multiyear cycle, a pseudorandom number between zero and one is compared to the calculated probability values of each type of outbreak event — light, moderate, heavy, and catastrophic. Determination of an outbreak event and its associated outbreak severity is illustrated in table 10, in which a drawn pseudorandom number between zero and one is compared to the probability of the various nonevents, raised to the power of the Time Interval (TI). Thus, a single pseudorandom number (rN) can determine outbreak occurrence *and* outbreak severity (table 10). A (rN) with a value of 0.223 in a particular FVS cycle will trigger a moderate outbreak of SPB-induced mortality on targeted pine species. A (rN) with a value of 0.333 in a subsequent cycle will represent a No Outbreak scenario, and simulated trees will continue to grow affected only with FVS calculated background mortality and competition effects.

Use of Random Numbers

The SPB keyword set is designed to run deterministically based on the default FVS pseudorandom number seed (55329). However, the user can easily edit the *.kcp* file in any text-editing program to run the SPB keyword set stochastically. To do this the user must remove the comment character "!" from the line of code that reads

```
!RANNSEED   0
```

This establishes "0" as the replacement value for the pseudorandom number seed. Using "0" will cause the results to vary among multiple runs of the same simulation file.

Table 10—Random number comparison assigning outbreak severity in a 5-year cycle.

Outbreak severity	Pseudorandom number (rN) comparison	Probability of outbreak in a 5-year cycle (percent)
No outbreak	1.0 ≥ rN > 0.275	72.5
Light	0.275 ≥ rN > 0.226	4.9
Moderate	0.226 ≥ rN > 0.119	10.7
Heavy	0.119 ≥ rN > 0.049	7.0
Catastrophic	0.049 ≥ rN ≥ 0.0	4.9

Also, the user can set his/her own pseudorandom number seed by replacing the zero with any odd integer (Van Dyck 2002).

Applying Mortality

SPB mortality is leveled against targeted species in the stand by use of the FVS keyword "FIXMORT." In the following example taken directly from the code, targeted pine species are attacked in a moderate outbreak (2) using the Mountain SPB keyword set (table 11). Stand hazard is high (3), and PBALOSS is assigned at 60 percent. Poletimber PBALOSS (POLELOSS) is then calculated at 45 percent, and sapling PBALOSS (SAPLOSS) would be 30 percent. White pine mortality in the same diameter classes is calculated at half that of the other targeted pine species. WPBALOSS, WPPOLE, and WPSAP represent mortality on white pine sawtimber, poletimber, and saplings, respectively.

The FIXMORT keywords are embedded within an event monitor IF-THEN block and will execute only if an outbreak is scheduled. The variable COUNT is used to assure sequential processing of the various code blocks within the SPB keyword set.

The use of zero (0) in FIXMORT field 6 replaces calculated FVS background mortality for targeted species, whereas the use of one (1) in FIXMORT field 7 indicates mortality levels will be applied on a point basis. This simulates SPB taking discrete portions of the stand, thereby reducing release effects among targeted pine species.

Output

The standard FVS output file contains a wealth of information about the simulation the user has created and run.

Table 11—Applying SPB mortality in *SPB_Mtn.kcp*

```
!Test for an outbreak event and differentially
!apply mortality based upon the severity of the
!Outbreak

IF
OUTBREAK NE 0 AND COUNT EQ 10
THEN

! Apply mortality to saplings
FIXMORT 0 PARMS (SP,SAPLOSS,1,3.0,0,1)
FIXMORT 0 PARMS (PP,SAPLOSS,1,3.0,0,1)
FIXMORT 0 PARMS (VP,SAPLOSS,1,3.0,0,1)
FIXMORT 0 PARMS (WP,WPSAP,1,3.0,0,1)

! Apply mortality to poletimber
FIXMORT 0 PARMS (SP,POLELOSS,3,10.0,0,1)
FIXMORT 0 PARMS (PP,POLELOSS,3,10.0,0,1)
FIXMORT 0 PARMS (VP,POLELOSS,3,10.0,0,1)
FIXMORT 0 PARMS (WP,WPPOLE,3,10.0,0,1)

! Apply mortality to sawtimber
FIXMORT 0 PARMS (SP,PBALOSS,10,999,0,1)
FIXMORT 0 PARMS (PP,PBALOSS,10,999,0,1)
FIXMORT 0 PARMS (VP,PBALOSS,10,999,0,1)
FIXMORT 0 PARMS (WP,WPBALOSS,10,999,0,1)

ENDIF
```

The user is urged to pay particular attention to the sections "Stand Composition," "Activity Summary," and "Summary Statistics" of the standard FVS output. The user can gain direct insight into the inner workings of the SPB keyword set with the two postprocessors that directly report all SPB event monitor variables:

- Compute1—Table of Compute Variables (with headers)—good for general assessment and examination of overall trends within the stand.
- Compute2—Table of Concatenated Compute Variables (comma delimited)—presents the same data in comma-delimited format, which can be imported into spreadsheet programs such as Microsoft Excel® or FVS-EMAP (see these proceedings). SPB event monitor variables of particular interest are HAZARD, OUTBREAK, PER_PINE, STAND_BA, and PINEBA. Analysis of event monitor results within the spreadsheet environment is helpful; the user can sort by one or more variables (such as FVS-cycle year). It is relatively easy to copy values from each cycle to individual worksheets and calculate sum totals and/or averages.

Conclusion

The SPB keyword sets are three geographically specific FVS Addfiles that emulate the effects of SPB upon a simulated stand over time. Current stand conditions are evaluated to calculate a SPB hazard rating for that stand in a given cycle. If a drawn pseudorandom number is less than or equal to the probability of an outbreak event, SPB mortality is levied against targeted pine species in the stand, based on the SPB hazard rating and/or the type of SPB outbreak scheduled for the stand in that cycle. SPB-induced mortality is not intended to act as a release for surviving trees. Therefore, unless management actions are scheduled by the user, the stand's hazard rating can only remain the same, or get worse over time. Appropriate management actions, as portrayed by FVS keywords, can reduce a stand's SPB hazard rating and potentially reduce loss of pine basal area due to simulated SPB mortality.

The three SPB keyword sets and User's Guide are available at:

http://www.fs.fed.us/foresthealth/technology/products.htm
or by contacting:

Judy Adams
Program Manager
Forest Health Technology Enterprise Team
USDA Forest Service
2150 Centre Ave (NRRC), Bldg A, Suite 331
Fort Collins, CO 80526-1891
Voice: (970) 295-5846 Fax: (970) 295-5815
jadams04@fs.fed.us

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