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# User's Guide to the Douglas-fir Beetle Impact Model

Michael A. Marsden  
Bov B. Eav  
Matthew K. Thompson



### Abstract

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Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopk.) occurs throughout the range of its principal host, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). At epidemic levels, the beetle causes considerable mortality in large-diameter Douglas-fir trees. Wind storms, drought, fire, and other factors have been reported as precedent conditions for epidemics of Douglas-fir beetle. An impact model has been developed to simulate tree mortality during such epidemics. The model has been linked to the Stand Prognosis Model (Forest Vegetation Simulator). This is a guide for using the model.

**Keywords:** Douglas-fir beetle, simulation, stand modeling, tree mortality, Prognosis.

# **User's Guide to the Douglas-fir Beetle Impact Model**

**Michael A. Marsden, Biometrician  
Rocky Mountain Forest and Range Experiment Station<sup>1</sup>**

**Bov B. Eav, Supervisory Operations Research Analyst  
Forest Pest Management, Methods Application Group**

**Matthew K. Thompson, Senior Systems Analyst/Programmer  
Management Assistance Corporation of America**

<sup>1</sup> *Headquarters is in Fort Collins in cooperation with Colorado State University.*

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## INTRODUCTION

### Douglas-fir Beetle and Its Impact

Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopk.) typically operates as a subtle component in western forests throughout the range of its principal host, Douglas-fir (*Pseudotsugae menziesii* (Mirb.) Franco). When at endemic levels, the beetle kills only a few trees in a stand. These trees are often weakened by fire, injuries, root disease, or competition. At epidemic levels, however, the beetle causes considerable mortality in large-diameter Douglas-fir trees.

The shift of bark beetle populations from endemic to epidemic levels has been attributed to several factors. Heavy blow down caused by windstorms has been cited as a major antecedent condition because adult bark beetles are attracted to windthrown trees. If these trees are large, then brood survival is often high; and the next generation of bark beetles builds quickly to epidemic population levels (Johnson and Pettinger 1961). For several years thereafter, the population of bark beetles is sufficient to successfully attack healthy host trees.

Other factors such as fire or drought also have been suggested as catalysts to surges in bark beetle populations (Cornelius 1955; R. Furniss 1936, 1941; M. Furniss 1965; Johnson et al. 1959; Johnson and Belluschi 1969). Logging slash has been reported to serve the same role as windthrown trees (Rudinsky 1966). Growth rates of host trees were considered a factor by Lessard and Schmid (1990) in attack success during an outbreak in Colorado. Trees weakened by defoliation also may be less resistant to attack by beetles. For example, Wickman (1978) and Wright et al. (1984) reported outbreaks of Douglas-fir beetle following defoliation by Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough), Lepidoptera: Lymantriidae), and by western spruce budworm (*Choristoneura occidentalis* Freeman, Lepidoptera: Tortricidae) (Fredericks and Jenkins 1988). Frequently, several precedent conditions contribute to

the build-up of Douglas-fir beetle (Ciesla et al. 1971, M. Furniss et al. 1981, James and Goheen 1981).

### Modeling the Douglas-fir Beetle Impacts

There are three recognizable levels of Douglas-fir beetle populations: (1) endemic levels with occasional tree mortality; (2) widespread epidemics following catastrophic events such as those in western Oregon after the Tillamook Burn of 1933, or the wind storms in 1949–50 and 1958 (Cornelius 1955; R. Furniss 1936, 1941; Johnson et al. 1959); and, (3) local epidemics involving one or a few adjacent stands.

We make no attempt here to model endemic levels. We also assume that low levels of the bark beetle occur in or near any Douglas-fir stand being simulated. No attempt will be made to model bark beetle flight between stands. For this reason, simulation of widespread epidemics is limited. A local epidemic contained within a stand will be modeled and is referred to as an outbreak, or stand outbreak. With some innovative use of this model and the joint simulation of stands, a range of outbreaks can be simulated.

Accelerated mortality of large-diameter Douglas-fir trees is the main impact of Douglas-fir beetle not accounted for in the existing system of models. Tree mortality for many variants of the Prognosis stand growth system (Forest Vegetation Simulator) is concentrated in small diameter trees. However, dominant and co-dominant Douglas-fir trees are often attacked by this bark beetle. Death of these host trees and the beetle's success in raising a brood within these trees go together because successfully attacked trees attract more beetles. If the tree also is weakened by other factors, then the beetle may have a greater chance for success.

In the Western Root Disease Model, certain interactions of bark beetles and root disease were modeled (Stage et al. 1990). In the Other Agents sub-model, "BBTYPE2" represents the impact of Douglas-fir beetle or some other pest with similar characteristics. The sub-model requires that suitable host trees, as specified by species and a minimum diameter, be

first windthrown. Windthrow is a sub-model of the Western Root Disease Model. Subsequent mortality of standing host trees depends on the number of suitable windthrown host trees. Mortality is meant to represent the killing of trees on the edge of root disease centers by a combination of windthrow and bark beetles. The number of trees to be killed by the beetle is only slightly fewer than the number of suitable host trees that are windthrown. Such tree mortality may change the rate of spread of root disease within the stand (Shaw and Eav 1993).

However, for stands which are not infected with root diseases, the ability to simulate impacts of Douglas-fir beetle does not exist in the current Prognosis growth and yield modeling system.

## MODEL DESCRIPTION

This model simulates the impact of Douglas-fir beetle on tree mortality under a wide range of stand conditions.

### Outbreak Initiation

The model allows the user to set the probabilities of an area-wide outbreak and the probability of any particular stand being a part of such an outbreak through user-controlled parameters.

The area-wide outbreak concept is designed to represent such events as drought, ice storms, or other weather phenomena. These events may coincidentally stress trees in many stands which may enable beetles to be more successful. Possible global-warming effects also could be simulated with this component of the model.

Once an area-wide outbreak is scheduled, then each individual stand is tested to see if it should be included. For inclusion, two conditions must be met: (1) 25 percent or more of the stand basal area for trees 4.5 inches dbh or larger must be Douglas-fir; and (2) the average diameter for the host trees that are 4.5 inches dbh or larger must be at least 9 inches. If both of these conditions are not met, then the probability of the stand being a part of the area-wide outbreak is set to zero. When these conditions are met, the probability of inclusion is calculated as the ratio of the basal area of host trees over 9 inches dbh to the total stand basal area for trees over 9 inches dbh. When this ratio exceeds 0.90, it is set to 0.90.

The user can override this calculated probability of the stand being included in an outbreak to account

for such precedent conditions as the presence of logging slash, recent host tree defoliation, or poor site conditions.

Besides these two probability factors, the user can directly specify the timing of an outbreak. This option allows for the simulation of a stand with a known history of outbreak, including a current outbreak.

If windthrow of large-diameter Douglas-fir trees is simulated for a stand located within an active area-wide outbreak, then a bark beetle outbreak is automatically scheduled.

### Ongoing Outbreak

An ongoing outbreak of Douglas-fir beetle also can be modeled. Tree mortality from an outbreak in progress can be initialized from the Prognosis inventory tree list using damage codes. The Prognosis tree list damage codes recognized by the Douglas-fir Beetle Impact Model (DFBIM) are a damage code of 3 (Douglas-fir beetle) and severity codes 3 (successful bole attack) and 4 (top kill).

### Douglas-fir Mortality

The number of Douglas-fir trees/acre to be killed in an outbreak is calculated by the following function:

mortality = normal(expected,stdev) \* (badf/ba) \* length {1}

normal = a function that returns a random number from a normal distribution around a mean, given a mean and a standard deviation

expected = the expected yearly mortality (default = 6)

stdev = standard deviation of normal distribution (default = 2)

badf = basal area of Douglas-fir trees greater than 9 inches dbh

ba = basal area of all trees in the stand greater than 9 inches dbh

length = the length of the outbreak in years (default = 4)

The tree mortality calculated above is apportioned to the sample tree records by dbh or by basal area. The dbh method is explained by the following function:

mort(i) = mortality \* (trees/acre(i) \* DBH(i)) / SUMDF9

mort(i) = mortality for sample tree record i  
 mortality = total trees/acre that will be killed in outbreak  
 trees/acre(i) = trees/acre of sample tree record i  
 DBH(i) = dbh of sample tree record i  
 SUMDF9 = the sum of all Douglas-fir trees with a 9-inch or greater dbh multiplied by its dbh

The MORTDIS (mortality distribution) keyword allows the user to select the alternate basal area method of apportioning tree mortality to the sample tree records. This method distributes mortality to each sample tree record using basal area in the same equation described for the dbh method.

For reporting purposes, the mortality is grouped into 20, 2-inch dbh classes. A report of the mortality is printed for each outbreak.

### Windthrow

The windthrow model is activated by entering the WINDTHR keyword. The date entered with the keyword specifies the first year a windthrow event can occur in a simulation. A windthrow event does not occur until the number of eligible trees/acre reaches a user specified threshold level indicated in field three of the WINDTHR keyword. A tree is eligible for windthrow if it is in the largest 20 percent of the diameter distribution, and if it has a height greater than 20 feet. When the threshold is reached, then a windthrow event occurs and a proportion of the eligible trees are windthrown. The proportion windthrown is entered in field two of the WINDTHR keyword. If at least one Douglas-fir tree/acre greater than 9 inches dbh is windthrown and a regional Douglas-fir beetle outbreak is occurring, then a stand-level outbreak of Douglas-fir beetle will occur. When this outbreak occurs, the total number of standing Douglas-fir trees killed is the expected number for an outbreak plus the same number of Douglas-fir trees greater than 9-inches dbh that were windthrown. If a second windthrow event is needed, then a second WINDTHR keyword must be supplied.

### Model Structure

The DFBIM is currently linked to the Prognosis growth and yield modeling system (Wykoff et al. 1982). The order in which the model simulates the impact of Douglas-fir beetle appears in figure 1. The

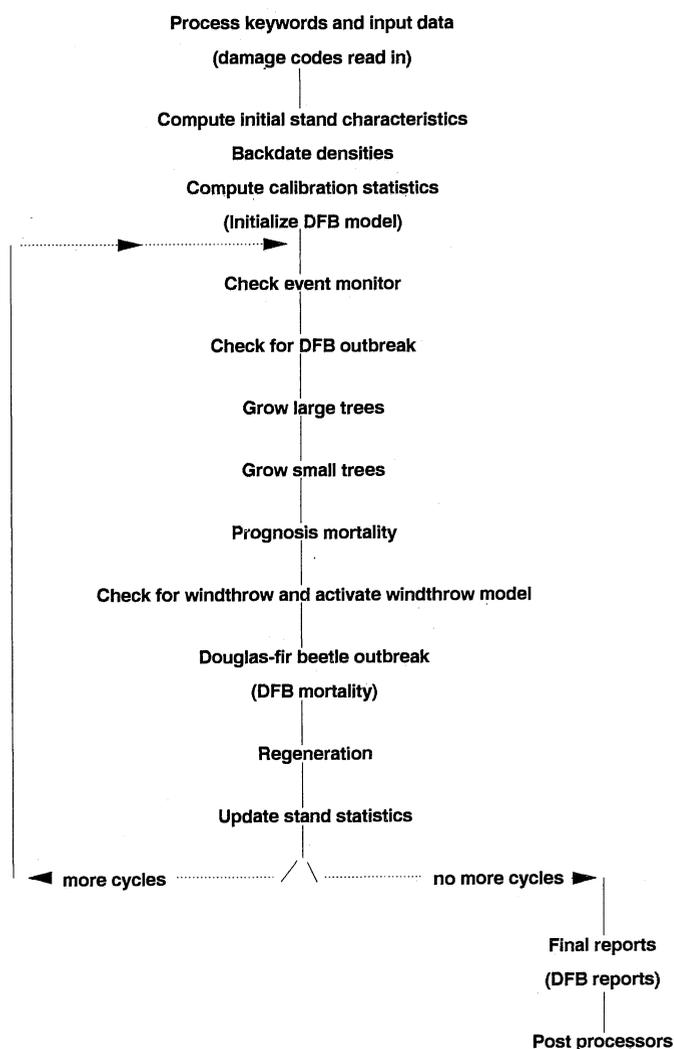


Figure 1. — Flow diagram for Prognosis and the Douglas-fir Beetle Impact Model.

model calculates tree mortality caused by Douglas-fir beetle based on tree information imported from the Prognosis model. Tree mortality caused by the bark beetle is then checked against the background mortality calculated by Prognosis and the larger of the two values is used to update the tree list information within Prognosis.

Output tables created by the DFBIM show live trees/acre for all tree species, live trees/acre for Douglas-fir, trees/acre killed by the bark beetle, and the cubic foot volume lost due to the bark beetle. These values are printed for 20, 2-inch dbh classes and are printed for each outbreak (table 1). A summary table of outbreak information shows when regional and stand outbreaks occurred and the stand outbreak probability at every cycle, normally 10 years (table 2).

Table 1. — Summary of tree mortality simulated by the Douglas-fir Beetle Impact Model for first outbreak.

Douglas-fir Beetle Mortality				
Year of the outbreak: 1990				
Projected mortality (trees/acre): 13.7				
DBH class	Total trees/acre alive	DF trees/acre alive	DF trees/acre killed	DF CU/FT vol lost
1-3	114.3	.0	.0	.0
3-5	14.3	14.3	.0	.0
5-7	45.2	29.1	.0	.0
7-9	49.3	16.4	.0	.0
9-11	56.2	24.8	6.6	75.6
11-13	10.5	.0	.0	.0
13-15	5.0	1.9	.8	18.9
15-17	.0	.0	.0	.0
17-19	3.2	.0	.0	.0
19-21	3.8	.0	.0	.0
21-23	1.2	1.2	1.0	93.4
23-25	1.5	.5	.5	34.7
25-27	.8	.0	.0	.0
27-29	2.9	2.2	3.2	413.6
29-31	.6	.6	1.1	163.1
31-33	.0	.0	.0	.0
33-35	.1	.1	.3	56.3
35-37	.1	.1	.3	59.5
37-39	.4	.0	.0	.0
39-40+	.0	.0	.0	.0
	309.5	91.3	13.7	915.1

## KEYWORDS

The DFBIM uses keywords similar in structure to those in the Prognosis keyword system (Wykoff et al. 1982) to control program options and specify model parameters. Keywords with their associated parameters are placed in a runstream file that is input as a set of instructions and data to initiate a specific simulation. In Prognosis, keywords are used to define stand attributes and silvicultural prescriptions, modify growth and mortality functions, define output options, and control other simulation effects. Keywords for the DFBIM are grouped and placed in a Prognosis keyword runstream to control program execution, scheduling of outbreaks, outbreak factors, and windthrow within the DFBIM.

A "keyword" is a one line record in a file that consists of a keyword field and seven parameter fields that specifies an action within the simulation model. The keyword field is the first 10 columns of the record. The keyword must be left justified. After the keyword field, seven numerical fields follow, each 10 columns wide. Numerical values can be placed in

Table 2. — Activities schedule for the present simulation by the Douglas-fir Beetle Impact Model.

Stand ID: S6001007; Management ID: None				
Douglas-fir beetle activity summary				
Cycle Number	Years	Year of regional DFB outbreak	Conditional probability of stand outbreak	Was there an outbreak in this stand
2	2000-2010	2000	.428	YES
3	2010-2020		.375	NO
4	2020-2030		.383	NO
5	2030-2040		.388	NO
6	2040-2050		.393	NO
7	2050-2060		.398	NO
8	2060-2070		.399	NO
9	2070-2080	2070	.399	YES
10	2080-2090	2080	.328	NO

these fields or the fields may be left blank. If a field is blank, then a default value will be used. A numeric value can be placed anywhere in a field if it has a decimal point; otherwise, it must be right justified. If any field that is specified as mandatory is left blank, then the keyword will be ignored. If a supplemental record is specified for a keyword, then the supplemental record will be the next record in the file and will be formatted as specified by the keyword. The only necessary keywords to run the DFBIM are DFB and END. If these are the only keywords specified, then all other keywords are defaulted and random scheduling of outbreaks will occur. The keywords entered are printed in the keyword summary section of the Prognosis output.

## Program Execution

The DFB and END keywords signify the beginning and ending of the DFBIM keywords. The RANNSEED keyword changes the seed value for the random number generator, and the DFBCHO keyword allows the user to print the summary output to a separate file for post-processing programs.

DFB = Signifies that the DFBIM is to be called. All keywords between the DFB keyword and the END keyword must be DFBIM keywords. This keyword is mandatory.

END = Signifies the end of the DFBIM keywords. This keyword is mandatory.

RANNSEED = Changes the random seed.  
*Field 1:* The new random seed. (default = 55329)

DFBECHO = Creates an output file of the DFBIM summary tables for use in post processor programs. A supplemental record is required.  
*Supplemental record:* Holds the name of the file in which summary tables will be written. If the supplemental record is blank, then the file name is DFBOU.

### Outbreak Scheduling

The outbreak scheduling method used for the DFBIM is the same as that used for the Douglas-fir Tussock Moth Model (Monserud and Crookston 1982, Stage 1978). Scheduling outbreaks is a two-step process. In the first step, the user can specify when regional outbreaks will occur. This scheduling can be done randomly with the keyword RANSCHED or manually with the keyword MANSCHED. These keywords allow the user to represent events such as drought and other conditions in the area around the stand (the local region).

The second step specifies when this particular stand will be included in a regional outbreak. This specification can be done with the keyword RANSTART, which tests the probability of a stand outbreak against a random number, each cycle there is a regional outbreak. The probability of a stand outbreak will be calculated as a function of the proportion of stand basal area, for trees greater than 9 inches dbh, that is in Douglas-fir or the user can enter the probability using the keyword STOPROB. The keyword MANSTART causes the stand to be in every regional outbreak scheduled.

RANSCHED = Causes the model to create regional outbreaks that are randomly scheduled over the length of the simulation. This is done by specifying the minimum number of years between outbreaks, a yearly outbreak probability, and the year of the last outbreak. This method is the default for scheduling regional outbreaks. If MANSCHED or RANSCHED are not used, then regional outbreaks will be scheduled using the defaults listed below:

*Field 1:* Minimum number of years between outbreaks. (default = 10)  
*Field 2:* Probability of outbreak. (default = 0.05 as annual probability)  
*Field 3:* Year of the last recorded Douglas-fir beetle outbreak. (default - 1950)

MANSCHED = Allows the user to specify the calendar year or cycle number in which a regional outbreak will occur. The default is for regional outbreaks to be scheduled randomly (RANSCHED).

*Field 1:* Year or cycle that regional outbreak will occur. If the number entered is less than or equal to 40, then the number is assumed to be a cycle number. (default = 1)

RANSTART = Causes the stand to be included in a regional outbreak based on a probability. The probability is calculated as the basal area of DF trees greater than 9 inches dbh divided by the basal area of the whole stand in trees greater than 9 inches dbh. This probability is tested against a random number and the outbreak occurs if the random number is less than the calculated probability. This is the default method of scheduling stand outbreaks.

MANSTART = Causes the stand to be included in all regional outbreaks. The default is RANSTART (stand outbreaks are scheduled randomly).

STOPROB = Specifies a stand outbreak probability. This keyword is used with the random method of scheduling a stand outbreak (RANSTART). The probability entered here replaces the probability calculated by the model.  
*Field 1:* Outbreak probability. (If blank, then the model will calculate the outbreak probability)

### Outbreak Factors

These keywords allow users to modify the severity of outbreaks in the model. The OLENGTH keyword allows users to modify the length of an expected outbreak. Mortality levels can be modified

with the EXYRMORT keyword which allows users to enter expected levels of mortality in each year of an outbreak. If an outbreak was in progress at the time of inventory, then the keyword CUROUTBK can be used to enter the amount of mortality that was caused by Douglas-fir beetle before the inventory. Also, the mortality distribution (method by which mortality is spread across the tree records) can be changed using the MORTDIS keyword.

**OLENGTH** = Changes the length (in years) of a Douglas-fir beetle outbreak.

*Field 1:* The length in years. (default = 4)

**EXYRMORT** = Specifies the number of Douglas-fir trees/acre expected to be killed by Douglas-fir beetle in each year of an outbreak if the stand is a pure Douglas-fir stand. The number that is actually killed is picked randomly from a normal distribution. This number is adjusted in the model based on the basal area of Douglas-fir greater than 9 inches dbh compared to that of all trees greater than 9 inches dbh.

*Field 1:* The expected number of trees/acre to die in each year of an outbreak. (default = 6.0)

*Field 2:* The standard deviation of the normal distribution. (default = 2.0)

**CUROUTBK** = Indicates an outbreak was in progress at the time of inventory. This keyword adjusts the number of trees/acre that will be killed during the remainder of the outbreak. This keyword will only work properly if the outbreak length totals four years and the stand is in the first, second or third year of the outbreak.

*Field 1:* The number of years the outbreak has been in progress. (mandatory field)

*Field 2:* The number of trees/acre that have been killed by the outbreak so far. If this field is left blank, then the number of trees/acre already killed will be read from the damage codes in the tree list.

**MORTDIS** = Changes the method of mortality distribution used in the model. The

default dbh method uses the dbh multiplied by the trees/acre of a sample tree record divided by the sum of the dbh of all Douglas-fir trees with a 9 inch or greater dbh as the proportion of the calculated mortality that will be removed from the sample tree record. If the MORTDIS keyword is used, then mortality is distributed using basal area instead of dbh. This keyword has no fields.

## Windthrow

A sub-model within the DFBIM simulates a windthrow event within the stand. If the WINDTHR keyword is used, then the model will test for windthrow based on the values entered in the keyword. If the stand meets the criteria for a windthrow event, then trees will be windthrown and a Douglas-fir beetle outbreak will occur if a regional outbreak is scheduled during the cycle.

**WINDTHR** = Specify one windthrow event.

*Field 1:* The earliest year or cycle windthrow event can occur. (default = 1)

*Field 2:* Proportion of eligible trees that can be windthrown. (default = 0.8)

*Field 3:* The minimum density of eligible trees/acre necessary for windthrow event. (default = 0.0)

## SAMPLE MODEL APPLICATION

### Description of the Sample Stand

The sample stand is a mature Douglas-fir stand in the Five-Point project area on the La Grande Ranger District of the Wallowa-Whitman National Forest, Oregon. This stand is in plant community type CW-G1-12. The elevation is 5200 feet and the stand is on a 50% south-facing slope. At inventory in 1990, the stand had 323 trees/acre, with a volume of 4003 cubic feet/acre. The overstory is Douglas-fir, ponderosa pine (*Pinus ponderosa*) and western larch (*Larix occidentalis*), while the understory is a mixture of grand fir (*Abies grandis*) and Douglas-fir. The keywords which specify this simulation of DFBIM in this stand are:

```

DFB
RANSCHED
RANSTART
WINDTHR          9.
END

```

Three outbreaks occur in the model simulation for this stand. The first and second result from the default conditions for the RANSCHED and RANSTART keywords. These are: last known outbreak in 1950; probability of an outbreak is 0.05; and, minimum waiting period of 10 years between outbreaks. The third outbreak in the simulation has the precedent condition of a windthrow event. The windthrow event occurs in the 9th simulation cycle, and 80 percent of the Douglas-fir in the largest 20 percent of the diameter distribution are blown down.

A record of the activities scheduled in this simulation by the DFBIM appear in table 2. Four regional outbreaks were scheduled and our sample stand was included in three of these. A summary of the tree mortality in the first outbreak is given in table 1. A similar table is produced each time the sample stand is included in an outbreak. Notice mortality is restricted to Douglas-fir trees with a diameter of 9 inches or greater.

The windthrow event in 2070 resulted in a blowdown of 7.12 trees per acre; 1.50 of which were Douglas-fir. The subsequent beetle outbreak resulted in the tree mortality seen in table 3.

In simulating the growth of mixed conifer stands, we can allow for the possible impact of Douglas-fir beetle only for a stand with a specified level of host trees. An example of this is the following set of keywords for use with the Prognosis Event Monitor (Crookston 1990):

```

IF
SPMCDBH (1,3,0,9) GT 30
THEN
DFB
MANSCHED          1.
MANSTART
END
ENDIF

```

SPMCDBH (1,3,0,9) (Crookston 1990) returns the trees/acre (1), that are Douglas-fir (3), in all tree-value classes (0), greater than 9-inches dbh (9). When this frequency of suitable host trees is greater than 30 trees/acre, the stand has an outbreak.

### SUMMARY

The Douglas-fir Beetle Impact Model generally performs to expectations. In the first outbreak, our test stand has a quadratic mean diameter of 10.6 inches. A sufficient number of large-diameter Douglas-fir trees per acre exists for an outbreak to occur. The effect of the outbreak can be seen in table 1 and figure 2.

Table 3. — Summary of tree mortality simulated by the Douglas-fir Beetle Impact Model for third outbreak.

Douglas-fir Beetle Mortality									
Year of the outbreak: 2070									
Projected mortality (trees/acre): 12.0									
DBH class	Total trees/acre alive	DF trees/acre alive	DF trees/acre killed	DF CU/FT vol lost	DBH class	Total trees/acre alive	DF trees/acre alive	DF trees/acre killed	DF CU/FT vol lost
1-3	25.9	.0	.0	.0	23-25	7.7	3.1	1.5	214.6
3-5	11.5	.0	.0	.0	25-27	7.1	1.7	.9	144.5
5-7	.0	.0	.0	.0	27-29	3.9	.8	.5	89.6
7-9	.0	.0	.0	.0	29-31	1.6	.4	.3	62.7
9-11	.3	.1	.0	.1	31-33	1.0	.3	.2	54.8
11-13	6.1	2.4	.4	2.3	33-35	1.5	.1	.1	25.0
13-15	7.1	4.4	1.0	32.9	35-37	.6	.1	.1	40.4
15-17	12.2	6.4	1.7	77.5	37-39	.4	.2	.3	92.8
17-19	12.6	5.1	1.7	127.9	39-40+	.5	.1	.1	36.7
19-21	15.1	4.3	1.7	148.9					
21-23	13.8	3.7	1.6	175.3					
						128.9	33.1	12.0	1325.9

In the third outbreak, the sample stand contains many more large-diameter Douglas-fir. This outbreak is also triggered by a windthrow event. Mortality occurs throughout the large diameter classes and removes more of the large Douglas-fir than if the Douglas-fir Beetle model was not run (fig. 3).

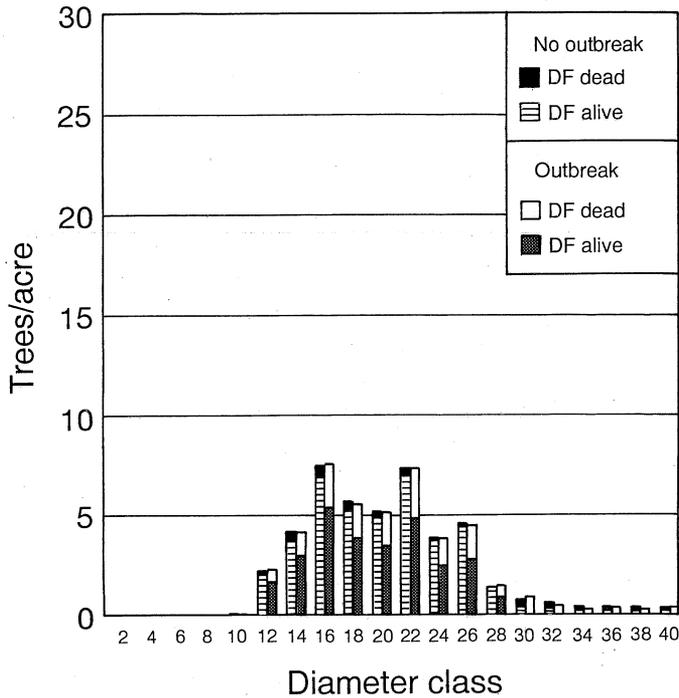


Figure 2. — Douglas-fir mortality in 1990 with and without beetle outbreak.

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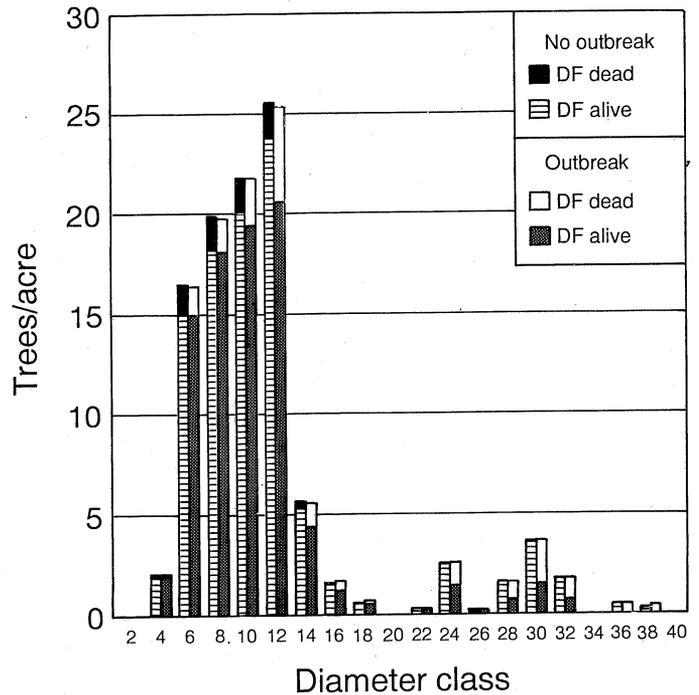


Figure 3. — Douglas-fir mortality in 2070 with and without beetle outbreak.

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