

THE SPRUCE BUDWORM MODEL:  
SOME QUESTIONS, CORRECTIONS AND COMMENTS

D. D. Jones

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The following items have been assembled from some notes I made while working my way through the Budworm Model. This is not intended to be an analysis of the model but merely some questions, corrections and comments. Many of these arise from apparent conflicts between the FORTRAN Coding, the description written by Jeff Stander and my perception of the real system. The items are grouped into four sections by descending order of ability to shake any earth. Unless otherwise stated the model is the one appearing in Appendix III of "A Simulation Model of the Spruce Budworm and the Forest in New Brunswick" by J.M. Stander, March, 1973. I have not always checked later editions of the model to see if any of these points are no longer appropriate.

Ia. The most significant discovery was that defoliation during any one year does not affect any Budworm processes that same year. Each larva eats .075 sq.ft. = 10.8 sq.inches of foliage each year, independent of larval density. It takes 267 larvae to eat all of the old and new foliage, but there is no direct effect on the 268th larva. Even if all of the foliage has been eaten the adults will lay their eggs on the bare branches.

I do not think the above statements are really true because I strongly suspect--but have no direct way of knowing--that current defoliation is implicitly included in the density effects of the survival curves. As long as we have numbers of Budworm and foliage per acre as variables in the program I would feel more comfortable if the effects of current foliage conditions on insect stages were made explicit.

Ib. The algorithm for assigning octant numbers to the dispersal sink sites is way off in the write-up. The new version is much better but it still does not do what the text says it is supposed to do. Figure 1 shows the 116 sink sites around a central source site (shaded). The number in each square is the octant number assigned by the program. The numbers that are circled do not correspond to the verbal description (Page I.6 of Stander).

The initial effect of this discrepancy is to slightly alter the windrose--with no qualitative difference. But note that the octants, which should theoretically be of nearly equal area, have the following number of sites in each

Octant Number	1	2	3	4	5	6	7	8
Number of Sites	16	12	18	16	14	10	16	14

The average number is 14.5. This has the effect of distorting the windrose. If all effects but wind direction were uniform each month leaving the source site would end up as 1.0166 moths in the surrounding area. A re-normalization would fix this. Additionally, the windrose used in the model does not correspond to the one given on page 14 of Stander. It adds up to 1.04, i.e. a 4% population increase due to wind.

Ic. As a function of distance the probability of dispersal has some problems that cannot be resolved without the aid of the original workshop participants. The text claims that dispersal is normalized to account for all dispersing eggs. When PDIST is summed over all distances we get only 0.537. If  $PDIST * 2\pi * R$  is integrated over all values of R we get a larger value. This has not been calculated because R is not continuous. If we assume uniform wind and calculate the probability associated with each of the surrounding sites we get the array shown in Figure 2.

When we add up all these probabilities we get 1.1504, or an "increase" of 15% due to dispersal--again a need for normalization. If the wind direction probability and the distance probability were first multiplied for each site and then added we would get a total probability of 0.1461. The normalizing factor in the program is 6.25 which gives a net dispersal probability of 0.9132. This is a loss of 8.68% due to "algorithm mortality."

There are two reasons why this issue cannot be resolved without going back to the initial assumptions. The first is that we must know if the dispersal probability function (PDIST, Figure 18 of Stander) has the factors of  $2\pi$  and R built into them. An examination of the experimental design that went into that curve would answer that question.

The second reason concerns the assumption that all adults are accounted for. If there are no losses (prior to a moth coming down into the wrong tree type--

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see Figure 11, Text), then we must normalize the combined probabilities to unity. If there are other losses then we must normalize accordingly.

- IIa. The survival rate for larvae that is used after a spraying policy is the rate corresponding to the pre-spray density. Fecundity rates also apply to the pre-spray density. The implicit assumption is that survival and fecundity rates are determined by the initial density of that stage and are not altered by a subsequent reduction in density.
- IIb. When the third instar density is less than or equal to 0.05/tsf the survival rate is 0.2 for all weather classes. This survival rate is high enough to give a net increase in population and has the effect of always bouncing the population up by a factor of about six whenever it falls below 0.05/tsf.

As an additional hedge against extinction the adult population is always kept above  $10^5$ /tsf.

- IIc. The quantity "PEGGS" needs clarification. It is computed on Pg III-6 as part of the site model, but in fact, it is not used until the dispersal model. The graph (Figure 11) is mislabelled--the caption should read "The Proportion of Eggs Laid in a Sink Site." This factor applies only to eggs at a sink site and not to the native site. The fraction (1-PEGGS) that arrive at a sink site are lost rather than carried on to another site. This assumes that the female only comes down once and only those that chance to land on the right kind of tree can lay eggs.

The foliage effect on egg laying in the native source site is a function of similar form (EZERO, plotted in Figure 16).

- IIIa. The total mortality of the oldest trees is

$$\text{TOMOR} = 0.2 + \text{PDED}$$

This gives a 20% natural mortality plus PDED, a function of accumulated stress (Figure 20).

By definition  $\text{TOMOR} \leq 1$ , but there is no check in the program for this. As it happens the particular functions used give a maximum PDED of .7778 (since  $\text{ICDEF} \leq 100$ ).

It is not obvious to me that these mortalities should be strictly additive. For instance, if they

acted in sequence (in either order) the mortality would be

$$0.2 + 0.8 * PDED$$

IIIb. The FORTRAN Coding for surviving third instars does not match the Figure (Figure 5). Assuming that Figure 5 is what was intended the statement should read

```
IF(SUSM.LT..05)THIRD = (.05-SLI)/SLS*SUSCEP*.05
```

The new version of the code uses

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IF(SUSM.LT..05) SUSM = .05,
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as is implied by Figure 4. All of this is rather unimportant since it is highly unlikely that the egg density will get much above 1250/tsf.

IIIc. Eggs are not allowed to survive on trees younger than ten years but larvae from older trees all equally likely to eat the foliage of all age classes. That is, in-site larval dispersion gives complete mixing among tree age classes.

IIId. On the printout maps the adult density that is plotted is "ADLTS" which has units of adults per 10 acres.

IVa. The fecundity graph (Figure 8) in the text is mislabelled. The y-axis should be eggs/adult rather than eggs/female.

IVb. Two variables are defined inconsistently in the list in Appendix.

FEMLAY (Page I.2) This definition is technically right but it would be more consistent if it were the number of adults laying eggs.

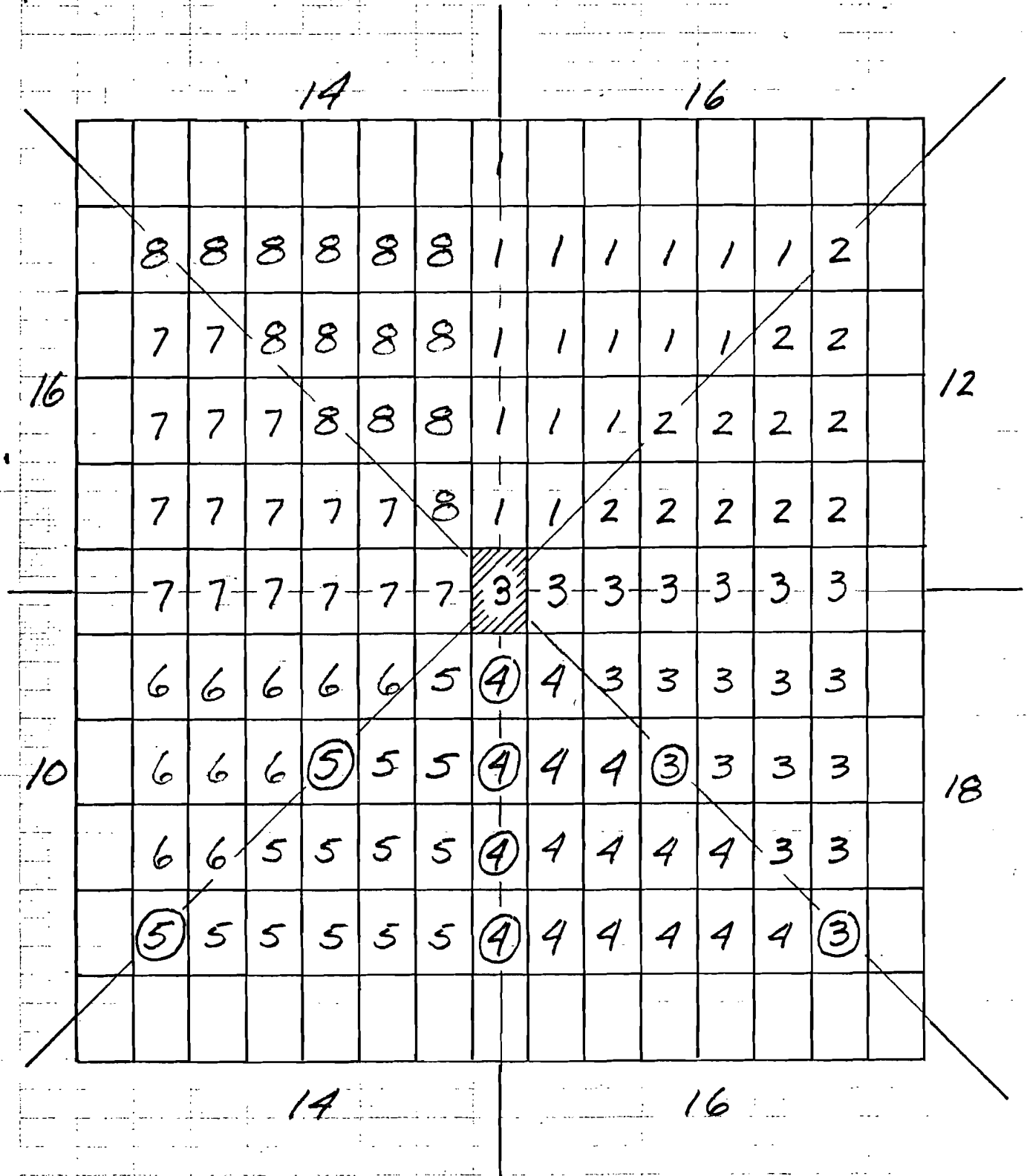
(Page I.3) This one is wrong. It should correspond with that above. Since there are no sex specific factors acting in the model it is convenient to lump the sexes and define fecundity accordingly.

DENSITY(I) (Page I.6) Although this is the way this variable is used in the egg dispersal model it should have the same definition as given on Page I.1, i.e. "Density of Foliage in sq.ft./acre".

IVc. The variable "EGGSI(I)" should be defined (Page I.7) in units of numbers per 10 acres rather than per 10 sq.ft. foliage.

FIG 1

BUDWORM MODEL  
 OCTANT ASSIGNMENTS  
 (SEE TEXT FOR EXPLANATION)



EFFECTIVE TOTAL PROBABILITY = 1.0166

BUDWORM MODEL  
 PROBABILITY OF DISPERSAL  
 (PDIIST)

—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	.0017	.0023	.0017	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	.0029	.0104	.0138	.0104	.0104	.0029	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	.0023	.0138	.0218	.0237	.0218	.0138	.0023	—	—	—	—	—	—	—	—	—	—	—	—	—
—	.0075	.0220	.0260	.0205	.0260	.0220	.0075	—	—	—	—	—	—	—	—	—	—	—	—	—
—	.0012	.0150	.0260	.0142	.0117	.0142	.0150	.0012	—	—	—	—	—	—	—	—	—	—	—	—
—	.0020	.0194	.0232	.0107	.0100	.0107	.0194	.0020	—	—	—	—	—	—	—	—	—	—	—	—
—	.0023	.0202	.0205	.0100	.01	.0100	.0202	.0023	—	—	—	—	—	—	—	—	—	—	—	—
—	.0020	.0194	.0232	.0107	.0100	.0107	.0194	.0020	—	—	—	—	—	—	—	—	—	—	—	—
—	.0012	.0150	.0260	.0142	.0117	.0142	.0150	.0012	—	—	—	—	—	—	—	—	—	—	—	—
—	—	.0075	.0220	.0260	.0205	.0260	.0075	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	.0023	.0138	.0218	.0237	.0218	.0138	.0023	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	.0029	.0104	.0138	.0104	.0029	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	.0017	.0023	.0017	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

$\sum_i \sum_j P_{ij} = 1.1504$