LANDIS-II Biomass Insects v2.0 Extension User Guide

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1 Introduction

This document describes the **Insect Biomass Defoliation** extension for the LANDIS-II model. For information about the model and its core concepts, see the *LANDIS-II Conceptual Model Description*.

The purpose of this extension is to model landscape-level effects on forest growth and mortality, resulting from outbreak defoliation events with annual time steps. It incorporates information from satellite-derived maps to capture realistic spatial and temporal patterns of defoliation intensity, resulting from real outbreaks. Key differences from an earlier LANDIS-II extension for a Biological Disturbance Agent (BDA) include making it functional for annual time steps, partial disturbance, and integrating it with the biomass succession extension (Scheller and Mladenoff 2004; Sturtevant et al. 2004). The LANDIS-II biomass succession extension models basic processes of forest succession including spatially dynamic tree seed dispersal, and tracks accumulation and changes in aboveground live and dead biomass pools for each species cohort at each site.

The **Insect Biomass Defoliation** extension models key aspects of defoliation outbreak dynamics including; disturbance initiation, within-patch variability in intensity and host/non-host response, among-patch disturbance spread and host/non-host response, and disturbance crashes and gradual recovery of surviving hosts. The **Insect Biomass Defoliation** extension (a) stochastically introduces periodic defoliation events parameterized uniquely by defoliator species to capture realistic spatial and temporal patterns, and (b) modifies tree growth and mortality (ANPP) with species-specific response relationships. In addition the extension has the ability to simulate multiple defoliators in the same landscape.

The **Insect Biomass Defoliation** extension determines the amount of leaf biomass lost to defoliation and the amount of growth reduction experienced by each cohort during succession. **Therefore, it is**

necessary that a Biomass Succession extension is selected that calculates biomass for every cohort.

The Insect Defoliation extension must operate at an annual time step. Unlike other stand replacing disturbances like fire or windstorm that take place at a discrete point in time, defoliation outbreaks typically extend over more than a single growing season, causing persistent stress to trees and stands of host species. Significant responses to defoliation include changes in growth and mortality rates of both host and non-host species that can vary on an annual basis as defoliation stress accumulates. Defoliation outbreaks also tend to spread on an intra-annual basis, thus annual time steps allow more realistic simulation of spatial outbreak dynamics as well as forest response.

1.1 What's New Version 2.0

Version 2.0 of the Biomass Insects extension is compatible with LANDIS-II v6.0.

1.2 Outbreak Temporal Patterns

Temporal patterns of defoliation outbreaks are captured by drawing from distributions of intra-outbreak intervals and outbreak durations unique for each defoliator being simulated. The form of these distributions is derived from empirical observations of actual intra-outbreak intervals and durations for a given defoliator species.

Intra-outbreak interval is a normally distributed independent variable with a mean and variance defined by the user as input parameters in the insect-defoliator input file. Insect defoliation outbreaks also have an average duration and variance defined by the user. Outbreak duration follows a negative exponential distribution.

After a new insect defoliation outbreak is initiated, a new intra-outbreak interval and duration is drawn from their respective distributions for the next outbreak. Intra-outbreak interval is counted in years from the start year

of the previous outbreak until a new outbreak is initiated. An outbreak will
then develop and spread for the length of outbreak duration.

Intra-Outbreak Interval: mean=10, sd=2   **Outbreak Duration: rate=1**
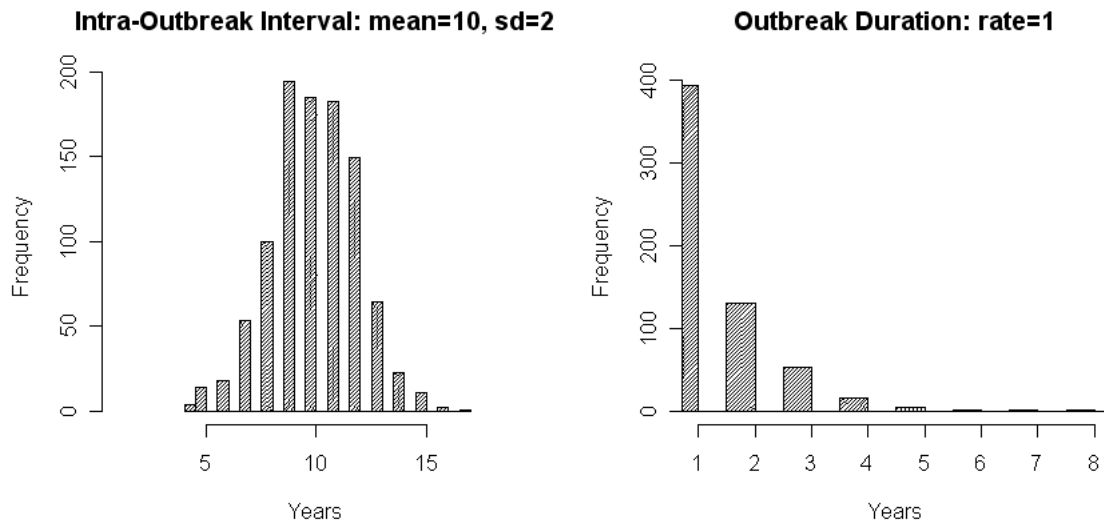
1.3 Defoliation

Defoliation is the amount of leaf biomass removed from the canopy and
transferred to the forest floor due to insect outbreaks. It takes the value
of a proportion ranging from 0-1, representing 0-100% of the canopy
biomass removed by defoliator populations during a single growing
season. We also refer to this term as **defoliation intensity**. The amount
of defoliation experienced by a species cohort in a given outbreak year
is dependent on the susceptibility class of that species, the weighted
average susceptibility of all the species cohorts on the site, and the
average defoliation experienced by neighboring forest sites in the
previous year over an area specified by the user.

1.4 Defoliation: Outbreak Initiation and Spread

Defoliation spatial patterns are "seeded" in the first year of an outbreak
by growing defoliated patches that approximate empirical patch size

distributions for the landscape. Seed defoliation at each site is drawn from a user specified defoliation intensity distribution. Expected site level defoliation values for the first year of the outbreak are then drawn from defoliation intensity distributions that vary depending on the average defoliation intensity calculated for the neighborhood surrounding each site. These distributions are called neighborhood dependent defoliation distributions and they are parameterized by the user based on empirical observations. Different defoliation intensity distributions can be parameterized for neighborhoods with average defoliation classes of 0-20%, 20-40%, 40-60%, 60-80%, and 80-100% of foliar biomass removed. "Seeded" defoliation values are drawn from the 80-100% defoliation class. "Expected" site level defoliation is then drawn from the appropriate neighborhood class based on average "seeded" defoliation within the neighborhood. Neighborhood size is also specified by the used and covers all sites that fall within a given radius centered on the active site.
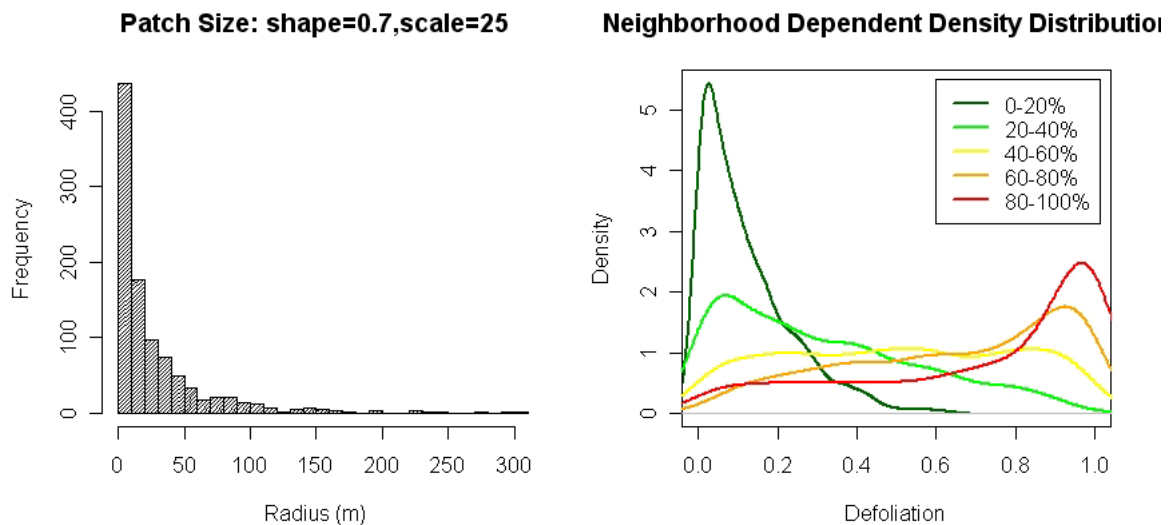
Actual defoliation values for each species at a site are drawn based on the expected site defoliation and the species susceptibility class. All

species of the same susceptibility class are defoliated the same amount in a given year and site. Actual site level defoliation is then calculated as the biomass weighted mean of defoliation intensity across all species and cohorts present on the site. Site level actual defoliation is used in the following year if the outbreak continues to calculate neighborhood average defoliation values to determine which distribution subsequent defoliation intensity values are drawn from.

Defoliation is initiated in the first outbreak year based on the joint distribution of defoliation intensity values and defoliation patch sizes characteristic of the landscape. All subsequent outbreak years draw susceptibility class defoliation values from neighborhood specific defoliation distributions.

1.5 Growth Reduction

Growth reduction is the growth response of individual species and cohorts to a given defoliation intensity. Growth reduction is defined as a reduction in ANPP that results from insect defoliation. Growth decreases from the levels expected in the absence of defoliation stress as a function of the **Cumulative Defoliation** experienced by a species cohort. Cumulative defoliation is the sum of annual defoliation (range 0-1) and can range from 0-*Y*, with *Y* representing the number of years of the duration of the current outbreak, or until all the biomass at a site is dead, whichever occurs sooner. Growth reduction relationships are parameterized by the user for each species in the input files. Parameters can be derived empirically or extracted from the literature. Relationships should predict relative annual growth (varying from 0-1, i.e. 0-100% of expected or average growth) as a function of cumulative defoliation (0-*Y*). Growth reduction can be linear or negative curvilinear to accommodate the patterns most commonly found in the literature.
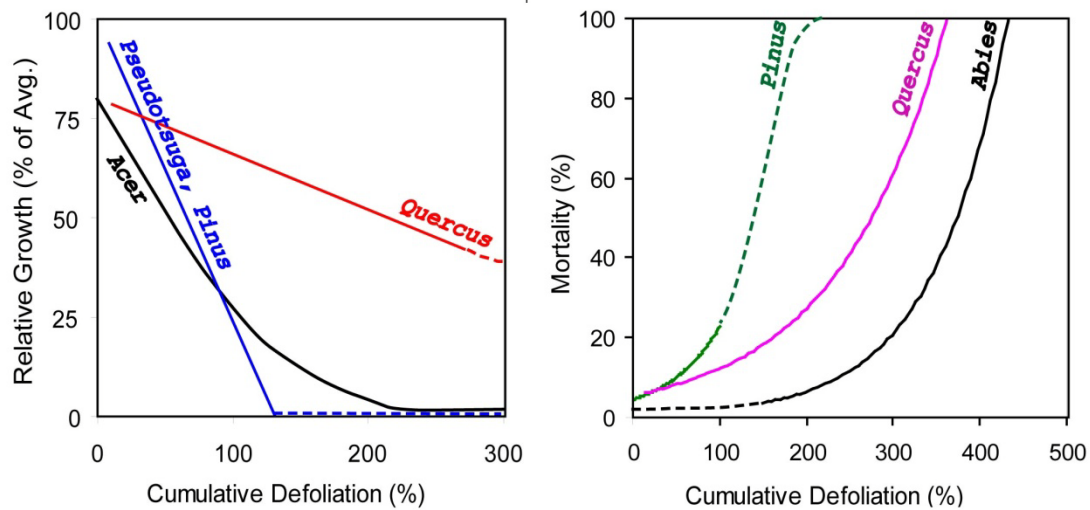
1.6 Mortality

Mortality caused by defoliation stress is a function of the duration and intensity of an outbreak as summarized by the cumulative defoliation. Cumulative defoliation is the sum of the actual biomass weighted mean defoliation for a site.

Formula here...

Cumulative defoliation is translated into a percentage of the cohort removed by user defined relationships. Empirical analysis shows that mortality increases exponentially as a function of cumulative defoliation over 5-10 years subsequent to an outbreak. The rate of increase in mortality varies by species and functional group.

$$\text{percentMortality} = b * e^{(m * \text{cumulativeDefoliation})}$$

Where b and m are parameters derived from empirical data in the literature. The percent mortality ranges from 0-1, with 1 representing complete mortality of a cohort. Percent mortality is multiplied times cohort Biomass to determine the amount of biomass removed due to defoliation related mortality resulting from defoliation stress.

More...This will need to be expanded when we stretch mortality to lag defoliation over a longer period such as over 10 years…

1.7 Acknowledgements

2 Primary Input File

The input parameters for this extension are specified in **two input files**. This text file must comply with the general format requirements described in section 3.1 *Text Input Files* in the *LANDIS-II Model User Guide*.

2.1 LandisData

This parameter value must be "Scenario"

2.2 Timestep

Needs to be removed.

This parameter is the timestep of the wind extension. Value: integer > 0. Units: years.

2.3 Output Maps

The next parameter, MapFileNames, describes where the insect outputs maps are placed and their format. **This convention applies to all map names.** The first portion lists the directory where the maps should be placed relative to the location of the scenario text file (e.g., insect/). The parameter value "timestep" must be included and will be replaced with the output time step. Other characters can be inserted as desired. A meaningful file extension (e.g., .gis) should also be included.

What do the maps represent??

2.4 Log File

The next parameter, LogFile, describes where the log file will be placed.

What is in the log file? I don't know yet.

2.5 Insect Input File List

The final parameter, InsectInputFiles, indicates which text files to be used for each defoliator. An unlimited number of insects can be indicated.

3 Insect Input File

For each insect, a separate file containing appropriate parameters is required.

3.1 LandisData

This parameter value must be "InsectDefoliatior":

```
LandisData InsectDefoliator
```

3.2 Insect Name

Set Insect Name parameter to the species of defoliator being simulated:

```
InsectName     GypsyMoth
```

3.3 Temporal Pattern Parameter Inputs

Temporal patterns are simulated by stochastically drawing from two user defined distributions for the time between outbreaks and outbreak duration. Each distribution is defined by a mean and standard deviation.

3.3.1 Mean Duration and Standard Deviation

Set these values for the mean and standard deviation of outbreak duration in years for a given defoliator species:

```
MeanDuration   4
StdDevDuration 2
```

3.3.2 Mean Time Between Outbreaks and Standard Deviation

Set these values for the mean and standard deviation of number of years between outbreaks for a given defoliator species:

```
MeanTimeBetweenOutbreaks   10
StdDevTimeBetweenOutbreaks 2
```

3.4 Neighborhood Size

The neighborhood size parameter is the radius in meters for a circle centered on each site that represents the neighborhood of cells influencing the probability that a site will experience defoliation of different intensities. For example, if the average defoliation within the surrounding forest

neighborhood was very high in a prior year, defoliation intensity values will be drawn from the appropriate distribution with a higher probability of heavy defoliation. Neighborhood size can be inferred from knowledge of insect dispersal abilities or empirically estimated from patterns of residual defoliation and should be considered in relation to the cell length at which a simulation is being run. The use of neighborhood dependent probability distributions for defoliation intensity is the primary mechanism by which defoliation patterns spread and change from one year of an outbreak to the next. Using a larger neighborhood allows more distant sites to affect defoliation, but it can also dilute mean defoliation values used to select defoliation intensity distributions, quashing defoliation more rapidly than desired.

```
NeighborhoodSize     250    << meters
```

3.5 Spatial Pattern Parameter Inputs

Spatial pattern parameters are used to initialize the pattern of defoliation in the landscape for a given defoliator species. These patterns are used to seed defoliation patterns in the first year of an outbreak only. These first year patterns can be used to mimic epicenter dynamics, where outbreaks start in a few hotspots and spread, or to mimic defoliator species where outbreaks erupt abruptly over larger areas.

3.5.1 Initial Area Calibrator

The initial area calibrator controls the proportion of the landscape into which defoliation patches are seeded. It is a modifier for the initial patch distribution and must be greater than 0, usually ranging between 0 and 1. A value of 1 results in no calibration; seeded defoliation patterns will be drawn with no modification from the initial patch distribution described below.

```
InitialAreaCalibrator     1     << must be > 0.0
```

3.5.2 Initial Patch Distribution

Defoliation outbreaks often appear suddenly, resulting in a large defoliated area even in the first year of an outbreak. In order to capture this sudden onset of defoliation pattern, the initial year of an outbreak is seeded with a defoliation spatial pattern drawn from an initial patch distribution. This distribution is conceptually similar to a traditional patch size distribution that could be derived from traditional defoliation sketch maps or from local autocorrelation analysis of Landsat derived defoliation intensity maps. Patch size in this model is defined by a radius in meters. Weibull, Beta or Gamma distributions can be used to define the patch size distribution for the landscape and species of interest. The initial patch distribution is defined by two parameters, Initial Patch Value 1 and Initial Patch Value 2.

```
InitialPatchDistribution   Weibull     <<Weibull, Beta,
or Gamma

>> Patch size distribution should be based on patch
radius (meters) distribution.

InitialPatchValue1  .7    <<depends on the distribution,
must be > 0.0

InitialPatchValue2  25    <<depends on the distribution,
must be > 0.0
```

3.5.3 Initial Patch Value 1

This parameter corresponds to the scale (mean) for the Weibull distribution.

3.5.4 Initial Patch Value 2

This parameter corresponds to the shape (spread) for the Weibull distribution.

3.6 Tree Species Parameters

Tree species parameters are used to classify the type of host that a tree species represents for a given defoliator and to define unique responses to defoliation stress in terms of reduced growth and increased mortality.

3.6.1 Susceptibility Class

This parameter currently places each tree species into one of three host preference classes for a defoliator. Susceptibility class 1 represents the most preferred hosts, class 2 represents susceptible but less preferred secondary hosts, and class 3 represents immune hosts that are never defoliated by that species. This information can usually be gleaned from the literature for most well studied defoliators.

3.6.2 Growth Reduction – Slope

This parameter is the slope for the relationship between cumulative defoliation and relative growth that defines growth response for a given tree species. Currently, this relationship is linear, but a negative curvilinear response will also be implemented. A slope of -1 would mean that a species cohort defoliated 100% would have zero growth in the same year.

3.6.3 Growth Reduction – Intercept

This parameter specifies the intercept for the above relationship, which should generally take a value of 1, which would mean that with 0 defoliation, growth is 100% of what is expected based on the Biomass succession extension.

3.6.4 Mortality – Slope

Mortality increases exponentially with increasing cumulative defoliation stress following this equation:

$$\text{percentMortality} = b * e^{(m\,*\,\text{cumulativeDefoliation})}$$

The mortality slope parameter represents m, and should be empirically derived to reflect mortality responses for a given species or tree functional group.

Mortality Parameters

Slope   Intercept

          .006   5

          .006   5

          .006   5

3.6.5 Mortality - Intercept

This parameter represents *b* from the above relationship and should be empirically derived.

3.7 Susceptibility Table – Should this be renamed…

This table defines distributions of defoliation intensity that vary based on host susceptibility class (i.e. 1,2,3) and also vary based on the intensity of defoliation in the surrounding neighborhood. These distributions are used to draw the expected defoliation for a site and for a host susceptibility class based on the average neighborhood defoliation intensity. This determines the intensity of defoliation for each species at each site during a defoliation outbreak.

Defoliation intensity is distributed following a Beta distribution, which is bounded from 0 to 1, or 0% and 100% defoliation. These distributions can assume a variety of shapes, from negative exponential to uniform to U-shaped. As neighborhood defoliation increases (i.e. from 0-20% on up to 80-100%), the probability of defoliation intensity will shift from most sites experiencing inconsequential defoliation to many sites experiencing heavy defoliation, close to 100%. Modification of these neighborhood dependent distributions controls the flashiness and spread of defoliation from one year to the next.

Beta Distributions
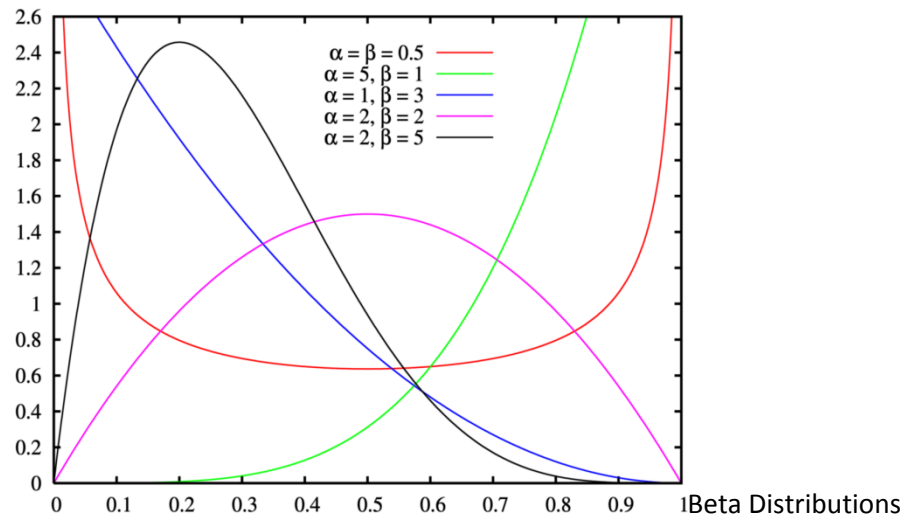
3.7.1 Susceptibility Class

Corresponds to the three susceptibility classes (1,2,3) currently available in the model. Each susceptibility class is assumed to experience a different amount of defoliation given the same defoliator population, and thus each class needs its own probabilities for defoliation intensity.

3.7.2 Distribution: 80, 60, 40, 20, 0

This parameter defines the type of distribution that defoliation intensity follows for each class of average neighborhood defoliation intensity. Average neighborhood defoliation classes range from highest - 80-100%, 60-80%, 40-60%, 20-40%, 0-20% - to lowest.

Currently, all distributions follow Beta distributions. This value should be set to Beta.

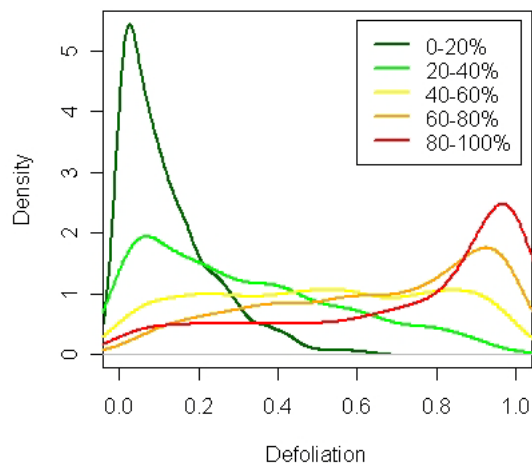### 3.7.3 Value 1: 80, 60, 40, 20, 0

1st parameter for the Beta distribution for a given neighborhood defoliation class.

3.7.4 Value 2: 80, 60, 40, 20, 0

2nd parameter for the Beta distribution for a given neighborhood defoliation class.

3.8 Severity Maps

The next parameter, MapNames, describes where the insect outputs maps are placed and their format. **This convention applies to all map names.** The first portion lists the directory where the maps should be placed relative to the location of the scenario text file (e.g., insect/). The parameter value "timestep" must be included and will be replaced with the output time step. Other characters can be inserted as desired. A meaningful file extension (e.g., .gis) should also be included.

What do the maps represent?? We don't use these yet…

3.9 Log File

The next parameter, LogFile, describes where the log file will be placed.

What is in the log file? We haven't decided yet.

4 Example File

4.1 Primary Input File

```
LandisData "Biomass Insects"

Timestep     1

MapNames      Insects/{insectName}-{timestep}.gis

LogFile             Insects/Insect-log.csv

InsectInputFiles  insect-defoliator.txt
```

4.2 Insect Input File(s)

```
LandisData InsectDefoliatior

InsectName   GypsyMoth

MeanDuration        5

StdDevDuration     0

MeanTimeBetweenOutbreaks      7

StdDevTimeBetweenOutbreaks    0

NeighborhoodSize   250    << meters

>> Lower this number to lower probabilities of patch generation, i.e.
start fewer patches.
InitialAreaCalibrator    0.02  << must be > 0.0

InitialPatchDistribution       Weibull      <<Weibull, Beta, or Gamma
>> Patch size distribution should be based on patch radius distribution?
patch area distribution? Units?
InitialPatchValue1       .7    <<depends on the distribution, must be > 0.0
InitialPatchValue2       25    <<depends on the distribution, must be > 0.0

SpeciesParameters
>> Susceptibility class by species (from Liebhold et al... reference here)
```

```
>> Species   Susceptibility   GrowthReduction MortalityParameters
>>           Class            Slope Intercept  Slope Intercept
>>----------------------------------------------------------------
abiebals   2                 -1    1          0.1   0
acerrubr   2                 -1    1          0.1   0
acersacc   2                 -1    1          0.1   0
betualle   2                 -1    1          0.1   0
betupapy   1                 -1    1          0.1   0
fraxamer   3                 -1    1          0.1   0
piceglau   3                 -1    1          0.1   0
pinubank   3                 -1    1          0.1   0
pinuresi   3                 -1    1          0.1   0
pinustro   3                 -1    1          0.1   0
poputrem   1                 -1    1          0.1   0
querelli   1                 -1    1          0.1   0
querrubr   1                 -1    1          0.1   0
thujocci   3                 -1    1          0.1   0
tiliamer   2                 -1    1          0.1   0


Susceptibilities
>> Host Dist80 S1_80 S2_80 Dist60 S1_60  S2_60  Dist40 S1_40  S2_40  Dist20 S1_20
        S2_20  Dist0 S1_0  S2_0
1       Beta   0.84  0.33  Beta   1.27   0.68   Beta   1.14   1.18   Beta   0.76
        1.68   Beta  0.8   6.0
2       Beta   1.27  0.68  Beta   1.14   1.18   Beta   0.8    1.68   Beta   0.5
        1.68   Beta  0.7   6.0
3       Beta   1     1     Beta   0.8    1.68   Beta   0.5    1.68   Beta   0.3
        1.68   Beta  0.5   6.0


MapNames   insects/severity-{timestep}.gis
LogFile    insects/log.csv
```