LANDIS-II Base Fire v1.2 Extension User Guide

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1 Introduction

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

The fire extension described herein generally follows the behavior of the fire behavior as described in He and Mladenoff (1999). However, there are three critical differences between the Base Fire extension described herein and earlier implementations.

First, the fire initiation and spread probability ($P_{InitSpread}$) follows the formula provided by Jian Yang (*personal communication*):

$$P_{InitSpread} = 1 - e^{-1 \times timeSinceLastFire \times \frac{1}{fireSpreadAge}}$$

If *fireSpreadAge* (years) equals *timeSinceLastFire*, the probability of fire initiation or spread is equal to 0.632. If timeSinceLastFire exceeds *fireSpreadAge*, $P_{InitSpread}$ will increase. *fireSpreadAge* is a user input (see below) that is typically set equal to the expected fire rotation period.

Note: *fireSpreadAge* was previously labeled 'fire rotation period'. However, actual fire rotation period is dependent upon the ignition probability and fire size parameters. Therefore, the fire regime, including the fire rotation period, must be uniquely calibrated for each landscape.

Second, ignition probability, fire spread age, and fire size parameters are unique for each ecoregion.

Third, fire spread is 'shaped' by a wind speed and direction unique to each event.

1.1 Fire Rotation Period (FRP) calibration

The Base Fire extension will not automatically create fires to generate a desired fire rotation period (FRP; defined as duration of simulation divided by proportion of ecoregion burned). Rather, the extension must be calibrated to achieve the desired FRP.

Calibration is typically performed by first setting the fire size parameters. Next, *fireSpreadAge* is typically set equal to the expect fire rotation period (in years). Finally, the ignition probability (see below) is adjusted to achieve the desired FRP.

In instances where there is a significant number of fires spreading from one ecoregion to another, such as when an ecoregion is a relatively small proportion of the landscape or has a complex shape, it may be necessary to also adjust *fireSpreadAge*. This is particularly true when the small or complex ecoregion should have a **longer** FRP than the surrounding matrix. In this case, *fireSpreadAge* will need to be adjusted **higher** to prevent numerous fires from burning into the small or complex ecoregion.

1.2 What's new in version 1.2

This document describes the current version (1.2) of the extension. The previous version released to the user community was version 1.0. Version 1.1 of this extension was originally scheduled to be released with version 5.1 of LANDIS-II, while testing continued on version 1.2. Because that testing was completed ahead of schedule, version 1.2 is now being released.

The differences between this current version (1.2) and the previous publicly-released version (1.0) include:

- Modifications so that the extension is compatible with version 5.1 of the LANDIS-II model.
- The fix for an error when fire spreads to ecoregions without fire parameters.
- The fix for an error in the fire damage table that could have allowed fire intolerant species to persist after severe fire.
- The addition of a summary output file that summarizes the number of events and number of cells burned by ecoregion for every fire time step.
- The addition of the option of using explicit fire ecoregions instead of the main ecoregions.

1.3 References

He, H. S. and Mladenoff, D. J. Spatially explicit and stochastic simulation of forest landscape fire disturbance and succession. Ecology. 1999; 80(1):81-99.

1.4 Acknowledgments

Funding for the development of LANDIS-II has been provided by the North Central Research Station (Rhinelander, Wisconsin) of the U.S. Forest Service. Valuable contributions to the development of the model and extensions were made by Brian R. Sturtevant, Eric J. Gustafson, and David J. Mladenoff.

2 Fire Disturbances

During a fire time step, multiple fire events may happen on the landscape.

2.1 Fire Ignition

Each fire event begins with an ignition. The user assigns a probability of ignition for each ecoregion. At each fire time step and at each active site, the ignition probability is checked and compared to a random number:

$\text{random}_{U}(0, 1)_{site} \leq P_{Ignition} \rightarrow$ fire event starts

Note: The base fire extension adjusts the ignition probability according to the extension time step used (*Ignition Probability * timestep*).

2.2 Initiation and Spread

The user input fire spread age is used to derive the probability of fire initiation and spread ($P_{InitSpread}$). The fire spread age is input for each ecoregion.

To determine if an event is initiated at a site, a random number between 0.0 and 1.0 is generated (uniform distribution) and compared with the $P_{InitSpread}$. If the number is ≤ the $P_{InitSpread}$, an event starts at the site:

$\text{random}_{U}(0, 1)_{site} \leq P_{InitSpread} \rightarrow$ fire event continues

Starting at the initiation site, neighboring active sites are added to the fire event until the combined area of the sites equals the event's size.

Neighboring sites are added dependent upon the wind speed (random $_{U}(0, 1)$) and direction (randomly chosen from the 8 cardinal directions) for each fire event. A fire can spread to nine (9) nearest neighbors. The relative location of the nine neighbors is dependent upon wind direction. In this example, the wind is from the west blowing to the east:

A	B	C	
A	Source	C	D
A	B	C	

The probability of spread to each neighbor type (P_n) is:

(A) Trailing neighbors. P_n = [(4 – wind speed) / 8 * (1 – wind speed)]

(B) Lateral neighbors. P_n = [(4 – wind speed) / 8]

(C) Leading neighbors. P_n = [(4 – wind speed) / 8 * (1 + wind speed)]

(D) Farthest neighbor. P_n = wind speed.

These probabilities are compared to a uniform random number:

$$\text{random}_U(0, 1)_{\text{site}} \leq P_n \rightarrow \text{fire event spreads to neighbor}$$

In this way, a high wind speed will create a more linear fire shape; low wind speed will create a more round fire shape.

A neighbor must be both active and $P_{InitSpread}$ for the neighbor is calculated and compared as above. A fire event cannot spread to a site that belongs to another event that occurs at the same time step.

2.3 Event Size

Fire sizes follow a log-normal distribution with small fire occurring more frequently than large fires. A fire event has a size (units: hectares) that is calculated from fire-event parameters associated with the initiation site's ecoregion:

- minimum fire size (hectares), MinFS
- maximum fire size (hectares), MaxFS
- mean fire size (hectares), MeanFS

The size is a random number generated using a negative exponential distribution whose mean is MeanFS.

$$\text{size}_{\text{generated}} = \text{random}_E(\text{ MeanFS })$$

where

$$\text{random}_E(\ \textit{mean}\ ) \rightarrow \text{pdf}(x) = \lambda\, e^{-x\lambda},\ \lambda = 1 / \textit{mean}$$

If the generated size lies outside the range [MinFS, MaxFS], it is clipped to the nearest end of the range.

$$\text{size} = \begin{cases} \text{MinFS} & \text{if size}_{\text{generated}} < \text{MinFS} \\ \text{MaxFS} & \text{if size}_{\text{generated}} > \text{MaxFS} \\ \text{size}_{\text{generated}} & \text{otherwise} \end{cases}$$

2.4 Fire Severity

At each site, a fire event will have a unique severity. The severity is determined by the fire and wind curves and represents cumulative fuel buildup and fuel decay, respectively. The fire curve determines fire severity based on the time-since-last-fire at that site. The wind curve determines fire severity based on the time-since-last-wind at that site. Both curves are implemented as 5 time periods with time-since-event for each of five (1 – 5) severities. The highest fire severity generated from the two curves will determine the actual fire severity. The severity will subsequently determine fire damage.

2.5 Fire Damage

If fire severity = 5, then all cohorts of all species will be killed. If fire severity < 5, then fire damage is dependent upon the age of the cohorts at each site within an event and the fire tolerance of each species. **The youngest cohorts are most vulnerable.** For each cohort, the difference between the fire severity and fire tolerance is calculated. The difference determines which cohorts are killed; all cohorts below a User input relative age will be killed. **If the simulated differential exceeds the largest differential provided in the table, then the largest differential from the table will be applied.**

Table 1. Example of cohort age and the fire severity-fire tolerance differential. The values below were used in all previous LANDIS versions.

Cohort Ages Killed (% of species longevity)	**Severity – Species Fire Tolerance Differential**
≤ 20%	-2
≤ 50%	-1
≤ 85%	0
≤ 100%	1

A fire event has an associated mean fire severity which is the average of the severities at all of the event's sites.

3 Parameter Input File

Most of the input parameters for this extension are specified in one input file. 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.*

3.1 Example File

```
LandisData  Fire

Timestep  15

FireEcoregions     fire-ecoregions.txt   << optional
FireEcoregionsMap  fire-ecoregions.gis   << optional


>> Fire Event Parameters
>>                                               Fire
>>            Max   Mean  Min   Ignition  Spread
>> Ecoregion  Size  Size  Size  Prob      Age
>> --------------------------------------------
   Eco3       400     24     4   0.001      300
   Eco14      600     48    16   0.02        30
   Eco10      400     24     4   0.00001    150
   Eco9       100     12     1   0.0001    1000


FireCurveTable

>> Ecoregion   S1   S2   S3   S4   S5
>> ----------------------------------
   Eco3        10   20   50   70   120
   Eco14        5   15   20   -1    -1
   Eco10       -1   20   80   90    -1
   Eco9        -1   -1   -1   -1    15 <<e.g., boreal
                                       <<      forest

WindCurveTable

>> Ecoregion   S5   S4   S3   S2   S1
>> ---------------------------------
   Eco3        -1   -1    1    5   10
   Eco14        1    2    4    5   10
   Eco10        1    4    8   16   -1
   Eco9        -1   -1   -1   -1   10


>> continued next page
```

```
FireDamageTable

>> Cohort Age       FireSeverity -
>> % of longevity   FireTolerance
>> --------------   --------------
        20%              -2
        50%              -1
        85%               0
       100%               1

MapNames         fire/severity-{timestep}.gis
LogFile          fire/log.csv
SummaryLogFile   fire/summary-log.csv
```

3.2 LandisData

This parameter's value must be `"Fire"`.

3.3 Timestep

This parameter is the extension's timestep. Value: integer > 0. Units: years.

3.4 FireEcoregions (optional)

This optional parameter is the file with the definitions of the fire ecoregions (see chapter 4). This parameter is optional. If it is not present, then the extension will use the ecoregions defined in the model's ecoregions input file (see chapter 6 *Ecoregions* in the *LANDIS-II Model User Guide*) as the fire ecoregions.

3.5 FireEcoregionsMap (optional)

This parameter is the input map showing where the fire ecoregions are located on the landscape. This parameter is optional; **it should only be used if the FireEcoregions parameter is present**. Each cell value must be one of the map codes listed in the fire ecoregions input file (see chapter 4).

3.6 Tables of Ecoregion-dependent Parameters

The input file has three table of ecoregion-dependent parameters: fire event parameters (section 3.7), fire severity curves (section 3.8) and wind severity curves (section 3.9). Each row in a table contains the parameters for one ecoregion.

3.6.1 Ecoregion Column

The first column in each table contains ecoregion names. The ecoregion names need not be in any order nor do all of the ecoregion names need to be present. If an ecoregion is not listed, all the parameters for that ecoregion are assigned the default value of zero.

3.7 Fire Event Parameter Table

The parameters in this table control the size and frequency of fire events.

3.7.1 Max Size

This parameter is the maximum size of fire events in the ecoregion. Value: number ≥ Min Size. Units: hectares.

3.7.2 Mean Size

This parameter is the mean size of fire events in the ecoregion. Value: number between Min Size and Max Size. Units: hectares.

3.7.3 Min Size

This parameter is the minimum size of fire events in the ecoregion. Value: number ≥ 0. Units: hectares.

3.7.4 Ignition Probability

This parameter is the probability per year that a fire event starts in the ecoregion. Value: 0 ≤ number ≤ 1.

3.7.5 Fire Spread Age

This parameter is typically set equal to the expected fire rotation period. It was referred to as "fire rotation period" in previous implementations of the LANDIS model. Value: integer ≥ 0. Units: years.

3.8 Fire Severity Curves

This table describes fire severities based on time-since-last-fire. The fire curve table reflects fuel accumulation not caused by a disturbance. Typically, fuels will accumulate over time and therefore increase fire severities. Fuel accumulation is balanced by decomposition and therefore, some ecoregions may never reach the highest fire severities.

3.8.1 Table Name

The table's name is `"FireCurveTable"`.

3.8.2 Severity Columns

The 5 severity columns are in **increasing** order from severity 1 to severity 5. The value in each severity column is the minimum value for time-since-last-fire for that severity. The special value of -1 denotes that the severity is to be excluded from the ecoregion. Values: integers ≥ -1. Units: years.

3.9 Wind Severity Curves

This table describes fire severities based on time-since-last-wind. The wind curve table determines the extra fire fuel created by a wind event. Potential increases in fire severity due to wind would be expected to decline over time because of decomposition. **The table is not necessary for the generation of wind events themselves.** Also, a wind extension need not be enabled. If a wind extension is not enabled, the fire extension will simply ignore the wind curve. If the wind curve is not necessary, leave it blank, although the wind curve table name must be inserted after the fire curve table.

3.9.1 Table Name

The table's name is `"WindCurveTable"`.

3.9.2 Severity Columns

The 5 severity columns are in **decreasing** order from severity 5 to severity 1. The value in each severity column is the maximum value for time-since-last-wind for that severity. The special value of -1 denotes that the severity is to be excluded from the ecoregion. Values: integers ≥ -1. Units: years.

3.10 Fire Damage Table

This table describes the fire damage classes. The values shown in the example file above were used in all previous LANDIS versions.

3.10.1 Table Name

The table's name is `"FireDamageTable"`.

3.10.2 Cohort Age

This parameter is the upper bound of the range of cohort ages that a table row applies to. Values: 0% ≤ number ≤ 100%. Units: Percentage of species' longevity.

3.10.3 Fire Severity – Fire Tolerance

This parameter is the minimum difference between the fire's severity and the species' fire tolerance in order for a cohort to be killed by a fire event. Value: integer.

3.11 MapNames

This file parameter is the template for the names of the fire severity output maps (see section 5.1). The parameter value must include the variable "timestep" to ensure that the maps have unique names (see section 3.1.8.1 *Variables* in the *LANDIS-II Model User Guide*). **The user must indicate if the output should be placed in a sub-directory. Also, the user must indicate the file extension.**

3.12 LogFile

The file parameter is the name of the extension's event log file (see section 5.2).

3.13 SummaryLogFile

The file parameter is the name of the extension's summary log file for fire time steps (see section 5.3).

4 Fire Ecoregions Input File

This file contains a table of fire ecoregion definitions. Each row in the table has one fire ecoregion.

4.1 Example File

```
LandisData  "Fire Ecoregions"

>> Map
>> Code  Name   Description
>> ----  -----  -----------
      1  water  water
     22  eco22  “MesicLoam complete fire suppression”
      3  eco3   "Sandy with frequent prescribed fires"
      4  eco4   “Mesic Wildland w/ rare ground fires”
```

4.2 LandisData

This parameter’s value must be `"Fire Ecoregions"`.

4.3 Table Fields

4.3.1 Map Code

This parameter is the code used for the fire ecoregion in the input map (see section 3.5 *FireEcoregionsMap*). Value: $0 \leq$ integer $\leq 65,535$. Each fire ecoregion’s map code must be unique. Map codes do not have to appear in any order, and do not need to be consecutive.

4.3.2 Fire Ecoregion Name

This text parameter is the fire ecoregion’s name. This is the name used in the tables of ecoregion-dependent parameters in the main parameter input file.

4.3.3 Ecoregion Description

This text parameter describes the fire ecoregion for the user’s benefit.

5 Output Files

The Fire Extension generates two types of output files: a) a map of fire severity for each time step, and b) two log files of fire events for the entire scenario.

5.1 Fire Severity Maps

The map of fire severity is labeled 0 for non-active sites, 1 for active and not disturbed sites, [fire severity + 1] for all disturbed sites. A map is produced for each fire time step.

5.2 Fire Event Log

The event log is a text file that contains information about every event over the course of the scenario: year, initiation cell coordinates, total event size (number of sites), number of damaged sites, number of cohorts killed total, mean fire severity across all sites, and number of cells burned by ecoregion. The information is stored as comma-separated values (CSV).

5.3 Fire Time Step Log

The fire time step log is a text file that contains summary information about all the events that occurred during the last fire time step: year, total number of cells burned, total number of events, and total number of cells burned by ecoregion. The information is stored as comma-separated values (CSV).