LANDIS-II Base Fire v4.0 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 critical differences between the Base Fire extension described herein and earlier implementations.

1.1 Fire Ignition

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

random $_U(0, 1)$ $_{site}$ ≤ $P_{Ignition}$ → fire event starts

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

1.2 Initiation and Spread

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

$$P_{InitSpread} = 1 - e^{-1 \times timeSinceLastFire \times \frac{1}{k}}$$
(1)

If *k* (years) equals *timeSinceLastFire*, the probability of fire initiation or spread is equal to 0.632. If *timeSinceLastFire* exceeds *k*, $P_{InitSpread}$ will increase.

Note: *k* determines how quickly fuels accumulate. A lower value of *k* will result in **faster fuel accumulation**. *k* is unique 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:

random $_U(0, 1)$ $_{site}$ ≤ $P_{InitSpread}$ → 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.

Fire spread is 'shaped' by a wind speed and direction unique to each event. 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. $P_n = [(4 - \text{wind speed}) / 8 * (1 - \text{wind speed})]$

(B) Lateral neighbors. $P_n = [(4 - \text{wind speed}) / 8]$

(C) Leading neighbors. $P_n = [(4 - \text{wind speed}) / 8 * (1 + \text{wind speed})]$

(D) Farthest neighbor. $P_n = \text{wind speed}$.

These probabilities are compared to a uniform random number:

random $_U(0, 1)_{\text{site}} \leq P_n \rightarrow$ 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 $P_{\text{InitSpread}}$ 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.

1.3 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

$$\text{random}_E(\text{ mean }) \;\rightarrow\; \text{pdf}(x) = \lambda\, e^{-x\,\lambda}, \lambda = 1/\text{mean} \qquad (2)$$

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

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

1.4 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.

1.5 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.

1.6 Fire Rotation Period (FRP) calibration

The Base Fire extension will not automatically 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, k 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. However, the variables chosen for calibration will vary depending on what data is available.

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 k. This is particularly true when the small or complex ecoregion should have a **longer** FRP than the surrounding matrix. In this case, k will need to be adjusted **higher** to prevent numerous fires from burning into the small or complex ecoregion.

1.7 Major Version History

1.7.1 Version 4.0 (August 2018)

Compatible with Core v7.

1.7.2 Version 3.1

Added compatibility with the Metadata library. The Metadata Library outputs metadata for all model outputs, allowing compatibility with visualization tools.

1.7.3 Version 3.0

The extension is compatible with Core v6.0

1.7.4 Version 2.1

Users will only notice a few small changes: The name of the **DynamicFireRegionTable**, the name of the **FuelCurveTable**, and the format of the **log file**. The variable that was previously referred to as *fireSpreadAge* has been given a more abstract name, *k*.

1.7.5 Version 2.0

Version 2.0 adds temporally dynamic fire regions. Fire regions are conceptually similar to ecoregions: they are collections of one or more cells with the same parameters. If there are multiple cells, they need not be contiguous.

The user designates parameters (e.g., ignition probability, mean/min/max size) for all the fire regions in a table. The user also indicates the initial fire regions map. The user can no longer default to the succession ecoregions, although the succession ecoregion map can be used as a fire regions map. A subsequent optional table allows the fire regions map to be updated at any time step.

Finally, a discrepancy was discovered between the summary log file and the severity map. Previously, we had not mapped a severity if no cohorts were killed and did not register the site as having been disturbed. However, as our fire science matures and we begin exploring how fires affect other disturbances and carbon and nutrient cycling, this assumption loses validity. Therefore, *all* fires are now mapped and reported, regardless of severity or number of cohorts killed.

Although the science represented by version 2.0 remains the same as previous versions, because the interface (the input text file) has changed, a full version change was required.

1.7.6 Version 1.2

The differences between version (1.2) and the previous publicly-released version (1.0) included:

- 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 regions 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.

1.8 Minor Version History

1.8.1 Version 3.1.1 (November 2017)

Various small bug fixes includes variable names for compatibility with other extensions.

1.8.2 Version 2.01

A bug was fixed that scrambled the mean/min/max fire size entries. As a result, *the order of entry for these parameters has changed*.

1.9 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.

1.10 Acknowledgments

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2 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*.

2.1 LandisData (note name change)

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

2.2 Timestep

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

2.3 Fire Region Parameters Table

The parameters in this table control the size and frequency of fire events, according to the respective fire regions.

2.3.1 Fire Region 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.The fire region names need not be in any order. If a fire region is not listed, all the parameters for that region are assigned the default value of zero.

2.3.2 Map Code

This parameter is the code used for the fire ecoregion in the input map. Value: $0 \le$ integer $\le 65{,}535$. Each fire region map code must be unique. Map codes do not have to appear in any order, and do not need to be consecutive.

2.3.3 Mean Size

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

2.3.4 Min Size

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

2.3.5 Max Size

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

2.3.6 Ignition Probability

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

2.3.7 k

This parameter is often initially set equal to the expected fire rotation period. It was referred to as "fire spread age" in previous versions. However, it is **not** the fire rotation period. It is a value in equation (1) above and it relates to the probability of a fire spreading through a site as a function of age. In general, smaller values of *k* will increase fire spread; larger values will decrease fire spread. Value: integer ≥ 0.

2.4 Initial Fire Region Map

The *InitialFireRegionsMap* parameter is the input map showing where the fire regions are located on the landscape. This parameter is **NOT** optional. Each cell value must be one of the map codes listed in the fire regions input table (above).

2.5 Dynamic Fire Regions Table

This table enables the user to allow fire regions to change spatially through the course of a simulation. In additions, fire regions can be introduced over time, provided that they are listed in the fire regions parameter table above. The *InitialFireRegionsMap* will be applied until the simulation time step reaches a year listed in this table. Likewise, the new map will be applied until the time step reaches another year listed in the table.

Use of the DynamicFireRegionTable is optional. If no additional maps are included in this table, the program will use the InitialFireEcoregionsMap for the entire simulation.

2.5.1 Year

The first column represents the simulation time step (year) when the new map should be applied. The years need not be listed in any order nor do they need to be sequential. However, the new map will only be loaded if year matches exactly the simulation time step.

2.5.2 File name

The second column gives the filename of the new fire regions map.

2.6 Fuel Curve Table

This table describes fire severities based on time-since-last-fire, *assuming that fuels increase with time*. The fuel 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.

2.6.1 Table Name

The table's name is "FuelCurveTable".

2.6.2 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 $\geq$ -1. Units: years.

2.7 Wind Curve Table

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.

2.7.1 Table Name

The table's name is "WindCurveTable".

2.7.2 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.

2.8 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.

2.8.1 Table Name

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

2.8.2 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.

2.8.3 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.

2.9 MapNames

This file parameter is the template for the names of the fire severity output maps (see section 3.1). 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.**

2.10 LogFile

The file parameter is the name of the extension's event log file (see section 3.2).

2.11 SummaryLogFile

The file parameter is the name of the extension's summary log file for fire time steps (see section 3.3).

3 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.

3.1 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.

3.2 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).

3.3 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).

4 Example File

```
LandisData  "Base Fire"

Timestep  15

>> Fire Region Parameters
>>                                         Fire
>> Region Map    Mean  Min   Max   Ignition
>> Name    Code  Size  Size  Size  Prob      k
>> ------------------------------------------
   Eco3    1     24    4     400   0.001     300
   Eco14   2     48    16    600   0.02      30
   Eco10   3     24    4     400   0.00001   150
   Eco9    4     12    1     100   0.0001    1000


InitialFireRegionsMap      ecoregions.gis

DynamicFireRegionTable  << Optional
>>Year   FileName
   20          Fire_regions20.gis << only if table active

FuelCurveTable

>> 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


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
```