LANDIS-II SCRAPPLE (v1.0) User Guide

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1. Introduction

This document describes the Social-Climate Related Pyrogenic Processes and their Landscape Effects (SCRAPPLE) extension for the LANDIS-II model. For information about the model and its core concepts, see the *LANDIS-II Conceptual Model Description.* A description of this extension has not yet been published.

1.1. Fire Simulation

We included three types of fires in the model: Lightning, Human Unintentional (‘Accidental’), and Prescribed Fire (‘RxFire’). Each has its own ignition and suppression and intensity patterns. All fires behave similarly in regards to spread and mortality. Our model consists of four primary algorithms: Ignition, Spread, Fire Intensity, and Fire Severity, described below.

1.1.1. Ignition

Our ignitions follow a “supply and allocation” model whereby the supply of ignitions are generated from a zero-inflated Poisson model and then ignitions are allocated across the landscape with an ignition surface.

For Accidental and Lightning fires, the number of ignitions per day is determined from empirical data relating the number of ignitions (by each of three types) to FWI. The following equation was fit to available ignition and climatic data:

Number of fires = eb0 + b1*FWI (Equation 1)

This is a zero-inflated Poisson distribution, which requires fitting two parameters, which vary by ignition type. Fire Weather Index (FWI) follows the calculations from the Canadian Fire Prediction System (1992) and is a smoothed averaged that integrates long- and short-term variation in precipitation and temperature. FWI was calculated for each day-of-the-year and the appropriate number of ignitions were generated for each day. For fractional ignitions (i.e. number of ignitions = 1.6), simple rounding will determine the number of ignitions. The location of each ignition is determined below.

For RxFire, a set number of fires are generated per year, based on expert input and/or scenario design. For each day of the year, a single RxFire is attempted, given that FWI is within a specified range and that the wind speed is below an allowable maximum. RxFires are attempted sequentially (by day of year) until the expected number of fires is successfully ignited. Conditions are placed on RxFire ignitions based on a minimum FWI (necessary to maintain fire spread, below), a maximum FWI (conditions under which prescribed fire would be avoided), and a maximum wind speed (again, conditions under which prescribed fire would be avoided).

A continuous weighted surface of historic ignitions occurrences is provided for each of the three ignition types and used to allocate ignitions. For regions where ignitions have no spatial pattern, this surface would be a constant value or a smoothed average of ignition rates. For other regions, the spatial pattern of ignitions could be projected based on climate change estimates. All available sites are then randomly shuffled, with an algorithm that biases selection by the weights (constant, historic, or projected) provided; ignition locations begin at the top of the shuffled list. The list of ignitions sites is re-shuffled at the beginning of each year.

In combination, the three ignition sources generate the total number of fires per year per fire type and is dependent upon FWI.

1.1.1.1. Fire Spread (Growth)

From the point of ignition, fire spreads. Fire can spread to each adjacent cell dependent upon a probability of spread (Pspread) to adjacent neighbor (out of four nearest neighbors). Fire spread is from cell-to-cell and determines fire size. A fire will continue burning until no more cells are selected for spread.

Fire spread was built from a general equation relating event probability to FWI (Beverly and Wotton 2007):

Probability of Fire Spread = $1 / 1 + e\beta 0$ Equation 2

here $\beta 0$ is the probability of spread into a site given condition on that site:
$\beta 0 = \beta 0' + \beta 1 * FWI + \beta 2 * EffectiveWindSpeed + \beta 3 * FineFuels$ Equation 3

Where EffectiveWindSpeed is an adjusted wind speed whereby reported wind speed and direction for the region (from meteorological stations) is downscaled to individual sites by accounting for slope angle and the slope azimuth relative to the wind direction (see Nelson 2002 for complete information). EffectiveWindSpeed also incorporates the intensity of the source fire. A high severity fire burning upslope generates a greater EffectiveWindSpeed than a moderate or light fire. This in turn feeds back into the estimate of fire intensity (see below), creating self-sustaining high-intensity fires under certain conditions.

During model execution, fire fuels are estimated from endogenous (internal to the model framework) litter estimates. Notably, during model execution, fine fuels are dynamic over time to reflect reductions from fuel treatments or prescribed fire and additions from overstory mortality, e.g., from insect outbreaks.

A fire will spread until it has reached a maximum area for the day. Spread area is defined as the increase in day-to-day area of total fire perimeter. Maximum area is determined empirically:

Maximum daily spread area = $\beta 0 + \beta 1 * FWI + \beta 2 * EffectiveWindSpeed$
Equation 4

Note that the FWI and Effective wind speed parameters used to determine maximum daily spread area entirely separate from, and derived differently from the parameters fit to determine successful cell-to-cell fire spread (described below). In simulations, cell-to-cell and maximum daily fire spread are updated with daily FWI estimates until the fire can no longer spread (e.g. disconnected fuels), FWI levels reduces spread rates, or suppression is applied.

To estimate the fire spread parameters, spatial data are needed for daily FWI, daily wind speed, daily wind direction, and fine fuel loading for a set of reference fires. Daily fire perimeters are then overlain on each of the datasets to extract successful and unsuccessful spread areas. Our approach allows unburned islands within fire perimeters.

1.1.1.2. Fire Intensity

We developed three classes of fire intensity, Low: < 4’ flame lengths; Moderate: 4-8’; and High: >8’. These intensity classes correspond to metrics of intensity commonly used by fire managers. Corresponding mortality severity classes were also defined (see below).

We defined three risk conditions:

1. Does the mass (g m-2) of fine fuels exceed a pre-determined risk level?
2. Does the mass (g m-2) of ladder fuels exceed a pre-determined risk level? Ladder fuels are assigned via a list of species with maximum ages that can be regarded as ‘ladder fuels’. For example, white spruce aged 0-25 might be regarded as ladder fuels.
3. Is the fire intensity of the source site (the neighboring site from where a fire spread) high intensity? A high severity fire will promote high severity fire as it spreads.

The default is low intensity. If one of these three conditions is true, the intensity become moderate. If two or more conditions are true, the fire is high intensity. Relationships between these three conditions and historical fire intensity were created by assigning historical fires one of the three fire intensity classes described above and extracting the fuel loading data that corresponded to that fire.

1.1.1.3. Fire Severity

Fire severity is the mortality caused by fire at each site and varies depending on the tree species and ages present. A low severity fire, for example, may cause extensive mortality if the forest is dominated by fire-intolerant tree species. For each fire intensity class, a fire severity table is defined that includes the age ranges and associated probability of mortality for each tree species. A single random number is drawn for each burned site (ensuring a consistent effect on all trees). If Pmortality (from the corresponding fire severity table) exceeds the random number, the cohort is killed. Biomass loss is determined by cohort mortality. These data were collected using an expert opinion approach whereby five fire experts for the LTB provided estimates of mortality for varying species and age combinations. These data were collected independently and collated and areas of disagreement (indicated by high variance among experts) discussed and refined.

1.2. Major Versions

1.2.1. Version 1.0 (April 2018)

First release.

1.3. Minor Versions

1.4. Source Code

https://github.com/LANDIS-II-Foundation/Extension-SCRAPPLE

1.5. References

Beverly, J. L., and B. M. Wotton. 2007. Modelling the probability of sustained flaming: predictive value of fire weather index components compared with observations of site weather and fuel moisture conditions. International Journal of Wildland Fire 16:161-173.

Nelson, R.M. 2002. An effective wind speed for models of fire spread. International Journal of Wildland Fire 11: 153–161.

Scheller, R.M., A.M. Kretchun, T. Hawbaker, and P. Henne. Social-Climate Related Pyrogenic Processes and their Landscape Effects (SCRAPPLE): A Landscape Model of Variable Social-ecological Fire Regimes. *In preparation.*

1.6. Acknowledgments

Funding for this extension was provided by USFS Southwest Region.

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

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

2.2. Timestep

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

2.3. AccidentalIgnitionsMap

This parameter specifies a raster map to represent where accidental ignition occur. The map units are double (allowing for fractions). Units are not specified. The map data weights the location of accidental ignitions occurrence whereby the list of values are sorted with higher values more likely near the top; ignitions are sequentially drawn from this weighted, sorted list.

User Tip: If empirical ignition data exist, these can be used to create a continuous surface of probability of ignition per year. If no such data exist, the map can have a single value and will therefore random locations will be selected.

2.4. LightningIgnitionsMap

This parameter specifies a raster map to represent where lightning ignitions occur. The map units are double (allowing for fractions). Units are not specified. The map data weights the location of accidental ignitions occurrence whereby the list of values are sorted with higher values more likely near the top; ignitions are sequentially drawn from this weighted, sorted list.

2.5. RxIgnitionsMap

This parameter specifies a raster map to represent where prescribed fire occur. The map units are double (allowing for fractions). Units are not specified. The map data weights the location of accidental ignitions occurrence whereby the list of values are sorted with higher values more likely near the top; ignitions are sequentially drawn from this weighted, sorted list.

2.6. AccidentalSuppressionMap

This parameter specifies a raster map to represent where and how accidental fires are suppressed. The map units are integers and should only include: 0, 1, 2, 3, indicating no suppression, light, moderate, and maximal suppression.

2.7. LightningSuppressionMap

This parameter specifies a raster map to represent where and how lightning fires are suppressed. The map units are integers and should only include: 0, 1, 2, 3, indicating no suppression, light, moderate, and maximal suppression.

2.8. RxSuppressionMap

This parameter specifies a raster map to represent where and how prescribed fires are suppressed. The map units are integers and should only include: 0, 1, 2, 3, indicating no suppression, light, moderate, and maximal suppression.

2.9. GroundSlopeFile

This parameter specifies a raster map to represent percent ground slope. The map should have integer values representing percent slope on the ground.

2.10. UphillSlopeAzimuthMap

This parameter specifies a raster map to represent the direction of uphill slope. Values in this map should be integers ranging from 0 to 360 degrees, specifying the direction upslope. Note: this is the opposite of the way aspect is commonly defined.

2.11. LightningIgnitionsB0

The B0 parameter from equation 1 (Scheller et al. in prep.). This value is empirically derived for lightning ignitions.

2.12. LightningIgnitionsB1

The B1 parameter from equation 1 (Scheller et al. in prep.). This value is empirically derived for lightning ignitions.

2.13. AccidentalIgnitionsB0

The B0 parameter from equation 1 (Scheller et al. in prep.). This value is empirically derived for accidental ignitions.

2.14. AccidentalIgnitionsB1

The B1 parameter from equation 1 (Scheller et al. in prep.). This value is empirically derived for accidental ignitions.

2.15. MaximumFineFuels

The amount of fine fuels (g m^{-2}) used to rescale the fine fuel parameter in equations 3 and 6 of Scheller et al. (in prep.). This parameter can be estimated from ‘typical’ conditions not including prior large disturbance (e.g., fire or insect mortality) events. Fine fuels are estimated from surficial organic matter.

2.16. MaximumRxWindSpeed

The maximum wind speed under which prescribed fires will be ignited on the landscape.

2.17. MaximumRxFireWeatherIndex

The maximum Fire Weather Index under which prescribed fires will be put on the landscape.

2.18. MinimumRxFireWeatherIndex

The minimum Fire Weather Index under which prescribed fires will be put on the landscape. Typically prescribed fires will *not* be attempted if fuels are too moist.

2.19. MaximumRXFireIntesnity

The maximum allowable fire intensity for prescribed fires. Prescribed fires will not exceed this intensity level.

2.20. NumberRxAnnualFires

The number of prescribed fires attempted per year.

2.21. FirstDayRxFires

The first Julian day in which a prescribed fire can begin. This is important if fall burning is preferred over spring burning.

2.22. MaximumSpreadAreaB0

The B0 parameter from equation 4 (Scheller et al. in prep.). This value is empirically derived from all fires in the landscape or region.

Note: Though empirically derived, this parameter can be used to match fire regime calibration targets.

2.23. MaximumSpreadAreaB1

The B1 parameter from equation 4 (Scheller et al. in prep.). This value is empirically derived from all fires in the landscape or region.

2.24. MaximumSpreadAreaB2

The B2 parameter from equation 4 (Scheller et al. in prep.). This value is empirically derived from all fires in the landscape or region.

2.25. SpreadProbabilityB0

The B0 parameter from equation 6 (Scheller et al. in prep.). This value is empirically derived from all fires in the landscape or region.

Note: Though empirically derived, this parameter can be used to match fire regime calibration targets.

2.26. SpreadProbabilityB1

The B1 parameter from equation 6 (Scheller et al. in prep.). This value is empirically derived from all fires in the landscape or region.

2.27. SpreadProbabilityB2

The B2 parameter from equation 6 (Scheller et al. in prep.). This value is empirically derived from all fires in the landscape or region.

2.28. SpreadProbabilityB3

The B3 parameter from equation 6 (Scheller et al. in prep.). This value is empirically derived from all fires in the landscape or region.

2.29. IntensityFactor:FineFuelPercent

The first of three fuels factors that help determine fire intensity. The fraction (0.0 – 1.0) of fine fuel (see 2.15) that substantially increases the risk of a fire becoming either moderate or high severity.

2.30. IntensityFactor:LadderFuelMaxAge

The second of three fuels factors that help determine fire intensity. The maximum age at which a cohort is considered a ladder fuel. The biomass of all cohorts ≥`LadderFuelMaxAge` listed in `LadderFuelSpeciesList` are summed and compared against `SeverityFactor:LadderFuelBiomass`, also below.

2.31. IntensityFactor:LadderFuelBiomass

The third of three fuels factors that help determine fire intensity. The ladder fuel biomass (see 2.15) that substantially increases the risk of a fire becoming either moderate or high severity.

2.32. LadderFuelSpeciesList

A list of species codes for species that are considered ladder fuels.

2.33. SuppressionMaxWindSpeed

The wind speed (m $^{s-1}$) above which no resources would be deployed to suppress a fire. This parameter is intended to capture weather conditions under which fire response is prohibitively dangerous.

2.34. DeadWoodTable

This table was designed to track snags generated by fire. There can be zero or more lines, each corresponding to a species. For each species, there's a minimum age at which a cohort generates snags due to fire. For example:

```
DeadWoodTable

PinuJeff    50
```

2.35. FireIntensityClass_1_DamageTable

For each damage table, a given age range for each species is associated with a probability of mortality, assuming that fire intensity = 1 (< 4" flame length). There is no limit to the number of species or age ranges; the default value for an unlisted species or age-range is 0.0.

2.35.1. Species Name

2.35.2. Minimum Age

2.35.3. Maximum Age

2.35.4. Probability of Mortality

Range of 0.0 – 1.0. Compared against a randomly generated uniform value to determine mortality. All mortality is total.

2.36. FireIntensityClass_2_DamageTable

Same as above; applied to fire intensity = 2 (4-8" flame length).

2.37. FireIntensityClass_3_DamageTable

Same as above; applied to fire intensity = 3 (> 8" flame length).

3. Output Files

The extension outputs were designed to be able to correctly parameterize and analyze fire behavior in the simulation. The Fire ignition table is designed to capture the relationship between attempted FWI and number of fire ignitions for each type, for each day and year. The Fire event table is designed to record the fire characteristics of each individual fire event. The Fire landscape table is designed to summarize fire characteristics at the landscape scale.

3.1. Day of Fire Maps

The map of 'fire days' tracks on which day of the year a cell burned. Map values equal Julian day of time step.

3.2. Fire Intensity Maps

The map of fire intensity reports at which intensity (1-3) a cell burned. Map values: 0 = Unburned site, 1-3 = Fire intensity 1-3

3.3. Fire Ignition Type Maps

There are three ignition types with values: 0 = Unburned or non-active site, 1 = Accidental; 2 = Lightning; 3 = Rx.

3.4. Fire Ignition Log

This log file tracks the number of ignitions and the climatic conditions under which they occurred: year, Julian day of year, number of attempted ignitions, Fire Weather Index, and type of ignition

3.5. Fire Event Log

The event log is a text file that contains information about every event over the course of the scenario: year, ignition row number, ignition column number, initial Fire Weather Index, initial Julian day, ignition type, number of days a fire burned, total sites burned, number of cohorts killed, mean wind speed, mean effective wind speed, mean wind azimuth direction, mean suppression effectiveness level, mean Fire Weather Index, mean spread probability, mean fire severity, total biomass killed, number of cells in fire intensity class 1, number of cells in fire intensity class 2, number of cells in fire intensity class 3. The information is stored as comma-separated values (CSV).

3.6. Fire Summary Log

The fire time step log is a text file that contains summary information about all the events that occurred during each fire time step: year, number of cells burned by accidental human ignited fires, number of cells burned by lightning ignited fires, number of cells burned by prescribed fires, number of accidental human ignited fires, number of lighting ignited fires, number of prescribed fires, total biomass killed by human accidental ignited fires, total biomass killed by lightning ignited fires, total biomass killed by prescribed fires, number of cells in fire intensity class 1, number of cells in fire intensity class 2, and number of cells in fire intensity class 3.

The information is stored as comma-separated values (CSV).

4. Sample Input File

```
LandisData  "SCRAPPLE"


>> Note:  All inputs are provided as examples only.  They are not intended to serve as
            default values.
Timestep                            1


AccidentalIgnitionsMap     ./Accidental_Ignition_Map.img
LightningIgnitionsMap  ./Lightning_Ignition_Map.img
RxIgnitionsMap  ./Lightning_Ignition_Map.img


AccidentalSuppressionMap      ./test_suppress.img
LightningSuppressionMap              ./test_suppress.img
RxSuppressionMap              ./test_suppress.img


GroundSlopeMap GroundSlope.gis
UphillSlopeAzimuthMap  UphillSlope.gis


LightningIgnitionsB0  -3.0
LightningIgnitionsB1  0.005
AccidentalIgnitionsB0 -3.0
AccidentalIgnitionsB1 0.005


MaximumFineFuels 60.0  << Use the NECN primary log file to determine typical values


>>Prescribed fire burn window parameters
MaximumRxWindSpeed 10.0
MaximumRxFireWeatherIndex 30.0
MinimumRxFireWeatherIndex 5.0
MaximumRxFireIntensity 1
NumberRxAnnualFires 5
FirstDayRxFires 25


MaximumSpreadAreaB0   3.1
MaximumSpreadAreaB1   0.0
MaximumSpreadAreaB2   0.0


SpreadProbabilityB0 -1.0
SpreadProbabilityB1 0.085  <<FWI
SpreadProbabilityB2 -0.005  << fine fuels
SpreadProbabilityB3 -0.33  << wind speed
```

```
SeverityFactor:FineFuelPercent  50.0
SeverityFactor:LadderFuelMaxAge 50
SeverityFactor:LadderFuelBiomass -1.0

LadderFuelSpeciesList
acersacc pinustro

SuppressionMaxWindSpeed 40
SuppressionTable
>>Type          FWI1    FWI2    Lo      Md      High-Effectiveness
Accidental      20      40      5       5       5
Lightning       20      40      5       5       5
Rx              20      40      5       5       5

DeadWoodTable
acersacc  20
pinustro  20

FireIntensityClass_1_DamageTable
>> Format = species [maxAge Pmortality] ... [repeating]  Any missing data is 0.0
acersacc 0 50  0.9
acersacc 51 100 0.5

FireIntensityClass_2_DamageTable
>> Format = species [maxAge Pmortality] ... [repeating]  Any missing data is 0.0
acersacc 0 50  0.9
acersacc 51 100 0.5

FireIntensityClass_3_DamageTable
>> Format = species [maxAge Pmortality] ... [repeating]  Any missing data is 0.0
acersacc 0 50  0.9
acersacc 51 100 0.5
```