Social-Climate Related Pyrogenic Processes and their Landscape Effects (SCRAPPLE): A Landscape Model of Variable Social-ecological Fire Regimes

Extension User Guide

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# 1. INTRODUCTION

This document describes the **Social-Climate Related Pyrogenic Processes and their Landscape Effects** or ‘SCRAPPLE’ extension for the LANDIS-II landscape change model. For information about the LANDIS-II model and its core concepts including succession, see *LANDIS-II Conceptual Model Description* and the LANDIS\_II website ([www.landis-ii.org](http://www.landis-ii.org))

SCRAPPLE is a data-driven extension intended to simulate landscape-scale fire regimes. SCRAPPLE captures 1) the influence of climate, fuels, topography, 2) fuel treatments effects, 3) the spatial patterns of fire suppression, and 4) the spatial and temporal patterns of prescribed fires. In general, four processes dictate how fires are represented in SCRAPPLE: ignitions, spread, fire severity, and tree mortality. In addition to the extension, there are several accompanying R tools intended to assist users with data pre-processing and parameter generation from available exogenous (e.g., remote sensing, expert opinion) and endogenous (data existing within the model, e.g., tree species, ages, biomass) data.

# 1.1 Ignitions

SCRAPPLE models three unique ignition types: lightning, human accidental, and prescribed. Different natural and social processes dictate the spatial patterns of each of these ignition types. Therefore they are modeled independently. Each ignition type has its own probability input map, which determines the spatial patterning of ignitions across the landscape (discussed in more detail below).

*Number of ignitions*

For Accidental and Lightning fires, the number of ignitions per day is determined from empirical data relating the number of ignition (by each of three types) to FWI. The following equation was fit to available ignition and climatic data (Zuur et al 2009).

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. 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. 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).

*Ignition maps*

A continuous weighted surface of ignitions must be generated for each of the three ignition types from the fire record data, and used as input maps to the model. For example, the cumulative fires per cell from the fire record could serve as this weighted input map. All available sites are then randomly shuffled, with an algorithm that biases selection by the weights 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.

# 1.2 Fire spread

From the point of ignition, fire spreads in response to topographic and climatic conditions on adjacent cells. Fire can spread to each adjacent cell dependent upon a probability of spread (Pspread) to adjacent neighbor (out of four nearest neighbors). Spread is a product of three variables known to have significant control over how and where fires burn (discussed in more detail in ‘SCRAPPLE INPUT FILE’): FWI, effective wind speed, and fine fuel biomass. Maximum spread area is separately modeled as a function of FWI and effective wind speed. Fire spread is from cell-to-cell and determines fire size. A fire will continue burning until no more cells are selected for spread.

*Cell-to-cell fire spread*

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

P(spread) = 1 / 1 + eβ0) Equation 2

Where P(spread) is the probability of spread into a site given condition on that site:

β0 = β0’ + β1 \* FWI + β2\*EffectiveWindSpeed + β3\*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).

*Maximum spread area*

A fire will spread until it has reach a maximum area for the day. Maximum area is determined empirically:

Maximum daily spread area = β0 + β1 \* FWI + β2\*EffectiveWindSpeed Equation 4

# 1.3 Fire suppression

Suppression is also explicitly modeled within SCRAPPLE, by applying uniquely parameterized suppression efficacy levels to different areas across the landscape. Suppression accounts for the capacity to reduce spread probability in a prioritized fashion and is unique for each fire type. Parameters for fire suppression are derived empirically and through expert consultation.

Suppression is implemented as four zones per fire type: none, minimal, moderate, maximal suppression. Each zone is assigned an integer reflecting suppression effectiveness that reduce Pspread as a fraction (effectiveness / 100). Zones are inputs as unique maps for each fire type.

# 1.4 Fire Intensity

Fire intensity within SCRAPPLE is categorized into three classes: low, medium, and high intensity. For the initial development, this was conceptualized as roughly equivalent to three flame length classes: < 4’ flame lengths, 4-8’, >8’. These intensity classes correspond to metrics of intensity commonly used by fire managers.

Unlike fire ignition and spread, empirical data of fire intensity are not available at the regional scale. Three risk conditions are defined:

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.

# 1.5 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 was defined. The table 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.

See PARAMETERS INPUT FILE section for formatting of fire severity tables

# 2. PARAMETER INPUT FILE

2.1 Timestep

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

2.2 Ignitions Maps

These three parameters (AccidentalIgnitionsMap, LightningIgnitionsMap , RxIgnitionsMap ) are input maps dictating spatial distribution of each ignition type (section 1.1). Cell values: 0 ≤ Value ≤1

2.3 Suppression Maps

These three parameters (AccidentalSuppressionMap, LightningSuppressionMap, RxSuppressionMap) are input maps dictating suppression zones for each ignition type. Cell values correspond to suppression level: none, minimal, moderate, maximal suppression. Cell values: 0-4.

2.4 GroundSlopeMap

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

2.5 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.

2.6 Lightning and human Accidental ignition parameters

These four parameters (LightningIgnitionsB0, LightningIgnitionsB1, AccidentalIgnitionsB0, AccidentalIgnitionsB1) are the fitted parameters that dictate the number of ignitions for lightning and human accidental ignitions (Section 1.1, Eqn 1).

2.7 MaximumFineFuels

For prescribed fire ignitions, the fine fuel biomass over which prescribed fires will not be ignited. Unit: g biomass/m2

2.8 MaximumRxWindSpeed

For prescribed fire ignitions, the wind speed velocity over which prescribed fires will not be ignited. Units: m/s

2.9 MaximumFireWeatherIndex, MiinimumFireWeatherIndex

For prescribed fire ignitions, these two parameters create the FWI window in which prescrived fires can be ignited.

2.10 NumberRxAnnualFires

This parameter specifies how many prescribed fires will attempt to be ignited per year.

2.11 MaximumSpreadArea

These three parameters (MaximumSpreadAreaB0, MaximumSpreadAreaB1, MaximumSpreadAreaB2) specify the maximum area a fire can spread in a day. These parameters correspond to Section 1.2, Eqn 4 and are empirically derived.

2.12 SpreadProbability

These four parameters (SpreadProbabilityB0, SpreadProbabilityB1, SpreadProbabilityB2, SpreadProbabilityB3) specify cell-to-cell spread probability. They correspond to Section 1.2, Eqn 3 and are empirically derived.

2.13 SeverityFactor

These three parameters (SeverityFactor:FineFuelPercent, SeverityFactor:LadderFuelMaxAge, SeverityFactor:LadderFuelBiomass) specify the risk conditions that define fire intensity class.

SeverityFactor:FineFuelPercent – percentage of maximum fine fuel biomass (0-1). Maximum fine fuel biomass is the amount of biomass (g/m2) over which fire severity risk does not increase. Therefore this parameter helps determine how quickly fine fuel accumulation increases fire intensity. Note: Higher values for this parameter increase fire severity risk more slowly.

SeverityFactor:LadderFuelMaxAge – the maximum age that designated ladder fuel species will be considered in fire intensity class calculations. Units: years

SeverityFactor:LadderFuelBiomass – Biomass of species age cohorts defined as ladder fuels that increase fire severity risk. Ladder fuel species-age cohorts are defined by ‘LadderFuelSpeciesList’ and ‘LadderFuelMaxAge’. Units: g biomass/m2

2.14 LadderFuelSpeciesList

This parameter specifies which species will be considered ladder fuels, and thus contribute to fire intensity calculations. This parameter interacts with SeverityFactor:LadderFuelMaxAge to determine how many cohorts at a given site will be considered ladder fuels.

2.15 SuppressionEffectiveness

These nine parameters (SuppressionEffectiveness:LightningLow, SuppressionEffectiveness:LightningMedium, SuppressionEffectiveness:LightningHigh, SuppressionEffectiveness:RxLow, SuppressionEffectiveness:RxMedium, SuppressionEffectiveness:RxHigh, SuppressionEffectiveness:AccidentalLow, SuppressionEffectiveness:AccidentalMedium, SuppressionEffectiveness:AccidentalHigh) specify how effective each suppression level is for each ignition type (see section 1.3). Effectiveness is defined by the percentage reduction in the probability of fire spread (e.g. effectiveness of 75 means a 75% in probability of spread). Suppression levels (low, medium, high) correspond to suppression map values (1, 2, 3; Section 2.3).

2.16 FireIntensityClass tables

These three tables (FireIntensityClass\_1\_DamageTable, FireIntensityClass\_2\_DamageTable, FireIntensityClass\_3\_DamageTable) define the probability of mortality by species for each fire intensity class. The tables include the age ranges and associated probability of mortality for each tree species. Each line of the table specifies: minimum age, maximum age, mortality probability (see examples below).

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.

Examples:   
FireIntensityClass\_1\_DamageTable   
SugarMaple 0 100 0.95

SugarMaple 0 100 0.80  
[Sugar maple cohorts aged 1-100 has a 95% probability of mortality under a low intensity fire. Older cohorts have an 80% probability]

FireIntensityClass\_2\_DamageTable   
PonderosaPine 1 20 .50

PonderosaPine 21 100 .50

PonderosaPine 100 400 .001  
[Ponderosa pine cohorts aged 1-20 have a 50% probability of mortality under a moderate intensity fire; 20% probability ages 21-100; <1% probability ages 100+.]

FireIntensityClass\_3\_DamageTable   
JeffreyPine 0 50 .9

JeffreyPine 50 150 .7

JeffreyPine 150 500 .5  
[Jeffrey pine cohorts aged 1-50 have a 90% probability of mortality under a high intensity fire; 70% probability ages 51-150; 50% probability ages 150+.]