LANDIS-II Biomass Succession v1.2 Extension User Guide

Robert M. Scheller[1,2]
James B. Domingo[1,3]

[1]University of Wisconsin-Madison
[2]Current: Conservation Biology Institute
[3]Current: Green Code LLC

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1 Introduction

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

1.1 What's new in version 1.2

This document describes the current version (1.2) of the extension. The differences between this version and version 1.1 include:

- A new succession library that includes a significant seeding performance enhancement and removes a bug in the original seed dispersal neighborhood.
- Maximum biomass input units are now **kg/ha/year**.
- A patch to repair a bug that was producing zeros for dead biomass.
- A patch to repair a bug with biomass cohorts that caused underestimates of aboveground biomass.
- A patch to repair a bug that caused negative mortality when cohorts have very low biomass.

1.2 What's new in version 1.1

The differences between this version and the previous version (1.0) include:

- The addition of the climate-change functionality. With this feature, the user can change various input parameters during a scenario to simulate the effects of climate change.
- The patch to repair a bug with post-fire regeneration. Because of the bug, cohorts killed by fire disturbances were not triggering post-fire reproduction.

1.3 References

Scheller, R. M. and Mladenoff, D. J. A forest growth and biomass module for a landscape simulation model, LANDIS: Design, validation, and application. Ecological Modelling. 2004; 180(1):211-229.

1.4 Acknowledgments

Funding for the development of LANDIS-II has been provided by the Northern 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 Biomass Succession

The Biomass Succession Extension generally follows the methods of the Age-Only Succession Extension: Cohorts reproduce, age, and die. However, in addition to simply presence of species cohorts and age classes, cohort biomass (kg/ha) is included. Therefore, cohorts must have an initial cohort density and this density changes over time.

The Biomass Succession Extension also changes the calculation of shade.

Lastly, the Biomass Succession Extension tracks dead biomass over time, divided into two pools: woody and leaf litter.

2.1 Biomass Shade Calculation

Site shade is calculated based on the ratio between the biomass present on a site and the maximum possible biomass on a site. The maximum possible biomass can vary by ecoregion.

2.2 Cohort Reproduction – Disturbance Interactions

Recall that every disturbance will trigger succession at each site at the time step that the disturbance(s) occur. In succession, there is a hierarchy of reproduction options following a disturbance. The goal of this design was to give reproductive precedence to species with propagules available on site.

If planting (currently possible only through a Harvest extension) is triggered for one or more species, then no other reproduction will occur. Planting is given highest precedence as we assume that a viable cohort is generated. However, the probability of establishment must be greater than zero.

If serotiny (only possible immediately following a fire) is triggered for one or more species, then neither resprouting nor seeding will occur. Serotiny is given precedence over resprouting as it typically has a higher threshold for success than resprouting. This slightly favors serotinous species when mixed with species able to resprout following a fire.

If resprouting (which can be induced by many disturbance types) is triggered, then seeding will not occur.

Finally, if neither planting, serotiny, nor resprouting occurred, seeding dispersal into a sight will occur.

2.3 Cohort Reproduction – Initial Biomass

Cohort reproduction is the establishment of a cohort, aged 1 year and the calculation of its initial biomass.

initial biomass = 0.025 * B_{MAX} * e(-1.6 * B_{SUM} / B_{MAX})

where B_{MAX} is the maximum biomass possible for the ecoregion and B_{SUM} is the current total biomass for the site (not including other new cohorts). Initial biomass must be ≥ 1 (kg / ha); if < 1, initial biomass is set equal to 1.

Note: this initial cohort will be grouped ('binned') appropriately into a larger cohort (e.g., 1 – 10) at the next successional time step.

2.4 Cohort Growth and Ageing

Cohort net growth is based on the principles outlined in Scheller and Mladenoff (2004). Cohort net growth takes into consideration the age of the cohort, species, ecoregion, and competition. Cohort net growth is gross growth minus development-related mortality.

Cohort ageing is simply the addition of the time step to each existing cohort.

2.5 Cohort Senescence and Mortality

As a cohort nears its longevity age, there will be an increase in the loss of biomass. This is called **age-related mortality**, and the age at which this mortality begins to be a factor is species-specific and controlled by the user.. The biomass will decline to near zero at the maximum life span. Cohorts are **not** randomly killed as in Age-Only Succession.

If a cohort exceeds the longevity for that species, then the cohort dies.

2.6 Dead Biomass Decay

When a cohort dies and is not consumed by a mortality agent (e.g., fire or harvest), its biomass is added to one or both of the two dead biomass pools: **woody** and **leaf**.

There is a mean decay rate for each pool at each site, determined by using an weighted average (weighted by mass) of the new dead material decay rate (user-determined) and the existing pool decay rate.

Disturbances can alter the dead biomass pools. They can add dead biomass (e.g., wind) and/or remove dead biomass (e.g., fire will add some woody dead biomass and remove all leaf dead biomass).

2.7 Initializing Biomass

At the beginning of a scenario, the initial communities begin with appropriate living and dead biomass values estimated for each site. **However, the user does not supply the initial biomass estimates.** Rather, the Biomass Succession extension iterates the number of time steps equal to the maximum cohort age for each site. Beginning at time (t - oldest cohort age), cohorts are added at each time step corresponding to the time when the existing cohorts were established. Thus, each cohort undergoes growth and mortality for the number of years equal to its current age, and its initial biomass value reflects competition among cohorts. Note: this is a computationally intensive process that may require significant time for complex initial landscapes.

This biomass initialization does not account for disturbances that would likely happen prior to initialization and therefore overestimates initial live biomass and underestimates initial dead biomass quantities.

2.8 Interactions with Age-Only Disturbances

Biomass Succession was written to allow disturbances that operate on age-only cohorts to interact with the two dead biomass pools. For example, a User is able to run the Base Fire or Base Wind extensions with Biomass Succession. Although neither disturbance extension is ‘biomass aware’, a simple interface was created that enables the biomass of cohorts killed by the disturbance to be allocated to dead biomass pools. The interface allows a User to indicate a) whether and how much non-woody or woody **live biomass** is transferred to their respective dead pools by a disturbance type and b) whether and how much of the non-woody or woody **dead biomass pools** are removed by a disturbance type.

For example, if a fire kills a cohort, we would expect that all of its non-woody and some of the woody biomass to be volatilized immediately and this biomass would not enter a dead biomass pool. In addition, we would expect some of the existing woody dead biomass pool to be volatilized during a fire and perhaps all of the existing non-woody biomass pool (i.e., the forest floor) to be volatilized.

This interface does not allow dynamic changes in the transfer rates into and out of the dead pools. Rather, the interface was designed to allow existing age-cohort disturbances to be used with Biomass Succession.

The interface is specified in a separate LandisData parameter file: "Age-only Disturbances - Biomass Parameters". See Chapter 4.

3 Succession Input File

Almost all the input parameters for this extension are specified in one main 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 LandisData

This parameter's value must be `"Biomass Succession"`.

3.2 Timestep

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

3.3 SeedingAlgorithm

This parameter is the seeding algorithm to be used. Valid values are `"WardSeedDispersal"`, `"NoDispersal"` or `"UniversalDispersal"`. The algorithms are described in section 4.5.1 *Seeding* of the *LANDIS-II Conceptual Model Description*.

3.4 MinRelativeBiomass Table

This table contains the minimum relative biomass for all the shade classes.

3.4.1 First Row – Ecoregions

The first row in the table is a list of all the active ecoregions defined in the ecoregions input file (see chapter 6 in the *LANDIS-II Model User Guide*. The ecoregions can appear in any order; they do not need to appear in the same order as in the ecoregions input file.

3.4.2 Other Rows

There are 5 other rows in the table, one row for each shade class.

3.4.3 Shade Class

This column contains shade class values: $1 \leq$ integer ≤ 5. The shade classes must be in increasing order: class 1 first and ending with class 5. Shade class 5 represents the most shade.

3.4.4 Minimum Biomass Percentage per Ecoregion

Each ecoregion listed in the table's first row (see section 3.4.1) must have a separate column of minimum biomass by shade class. The percentages represent the lower threshold of biomass on a site relative to the ecoregion's maximum possible biomass (for any species) for the site to enter the shade class indicated in column 1. Sites with less than the lowest threshold value will be assigned to shade class 0 (full sunlight). The maximum biomass for an ecoregion is the maximum growth rate (for any species) multiplied by 30 (equation 2, Scheller and Mladenoff 2004). Value: $0.0 \leq$ decimal number ≤ 100.0. Units: percent.

3.5 BiomassParameters Table

This table contains species' biomass parameters. Each row in the table has the parameters for one species. Every active species must have an entry.

3.5.1 Species

The species must be defined in the species input file (see chapter 5 in the *LANDIS-II Model User Guide*). Species may appear in any order.

3.5.2 Leaf Longevity

This parameter is the average longevity of a leaf or needle. Value: $1.0 \leq$ decimal number ≤ 10.0. Units: years.

3.5.3 Woody Decay Rate

This parameter, *k*, defines the rate (e^{-k}) at which the species' dead wood decomposes in the ecoregion. Value: $0.0 \leq$ number ≤ 1.0. Unitless.

Decomposition is calculated according to Equation 7 in Scheller and Mladenoff (2004) such that Dead Biomass (t+1) = Dead Biomass(t)*e^-*k*. The time step in the equation is1 year, and the Biomass Extension correctly applies the formula regardless of the extension time step.

3.5.4 Mortality Curve – Shape Parameter

This parameter determines how quickly age-related mortality begins. Value: $5.0 \leq$ decimal number ≤ 25.0. If the parameter = 5, then age-related mortality will begin at 10% of life span. If the parameter = 25, then age-related mortality will begin at 85% of life span.

3.6 Ecoregion-dependent Species Parameters

The biomass extension uses some species parameters that vary by ecoregion:

- probability of establishment,
- maximum ANPP (aboveground net primary production), and
- decay rate of leaf litter.

Each parameter has its own table.

3.6.1 First Row – Ecoregions

The first row in a table is a list of one or more active ecoregions defined in the ecoregions input file (see chapter 6 in the *LANDIS-II Model User Guide*). The ecoregions can appear in any order; they do not need to appear in the same order as in the ecoregions input file.

Every active ecoregion that is not in a table's first row will have default parameter values assigned to all the species (given below). The sections below which describe the individual parameter tables also specify the default value for each table.

3.6.2 Other Rows – Species Parameters

All other rows in a table after the initial row contain species parameter values. Each row contains the parameter values for one species. The species name comes first, followed by one or more parameter values. The name and values are separated by whitespace. There must be one parameter value for each of the ecoregions listed in the table's first row.

The species can be listed in any order in a table. A species can be omitted. If so, it will be assigned the default parameter value for all active ecoregions.

3.6.3 EstablishmentProbabilities Table

This parameter is the probability that the species establishes in the ecoregion. Value: $0.0 \leq$ decimal number ≤ 1.0. Default value: 0.0

3.6.4 MaximumANPP Table

This parameter is the maximum possible aboveground net primary productivity (ANPP) for the species in the ecoregion. Value: $0 \leq$ integer $\leq 100{,}000$. Units: kg/ ha / year. Default value: 0

3.6.5 LeafLitter:DecayRates Table

This parameter, *k*, defines the rate (e^{-k}) at which the species' leaf litter decomposes in the ecoregion. Value: 0.0 ≤ decimal number ≤ 1.0. Unitless. Default value: 0.0

Decomposition is calculated according to Equation 7 in Scheller and Mladenoff (2004) such that LeafLitter Biomass (t+1) = LeafLitter Biomass (t)*e^-*k*. The time step in the equation is1 year, and the Biomass Extension correctly applies the formula regardless of the extension time step.

3.7 AgeOnlyDisturbances:BiomassParameters

This optional file parameter is the path of a text file with the biomass parameters to be used with age-cohort disturbances (e.g., Base Wind, Base Fire, Base BDA). The format of that file is described in chapter 4.

3.8 Climate Change Table

This optional table specifies changes to certain parameters that should occur during the scenario due to changes in climate. Each row in the table represents a change in the parameters at a particular year.

3.8.1 Year

This column is the year that the parameters change. Value: integer or year expression between the scenario's start and end years. Units: year.

A year expression represents a year relative to the scenario's start year or end year. The valid forms for a year expression are:

```
start            (e.g., 1990)
start+integer    (e.g., 1990+35)
end              (e.g., 2100)
end-integer      (e.g., 2100-25)
```

The names `"start"` and `"end"` refer to the scenario's start year and end year, respectively. The integer is an offset either added to the start year or subtracted from the end year.

The rows in the table must be increasing order by year; therefore, the year in a row must be greater than the year in the previous row.

3.8.2 Parameter File

This column is the path to a text file that contains the new parameter values to use. The format of the file is described in chapter 5.

4 Input File – Age-only Disturbances

This optional auxiliary input file contains the biomass parameters used when age-only disturbances kill biomass cohorts (see section 3.7 *AgeOnlyDisturbances:BiomassParameters*). 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*.

4.1 LandisData

This parameter's value must be `"Age-only Disturbances - Biomass Parameters"`.

4.2 CohortBiomassReductions Table

This table describes how much a dead cohort's biomass is reduced by a disturbance before the biomass is added to the corresponding dead pool. Each row describes the reductions associated with a particular type of disturbance.

4.2.1 Disturbance

This text parameter is the type of the disturbance. The disturbance name must be consistent with the LandisData name given in the disturbance extension. The keyword `"(default)"` specifies the reductions for all disturbance types not listed in the table. The row with the default reductions must be present in the table.

4.2.2 Woody

This parameter is the percentage by which the disturbance reduces a dead cohort's woody biomass. Value: 0% ≤ integer percentage ≤ 100%. The biomass remaining after the reduction is added to the dead woody pool at the site where the cohort was killed.

4.2.3 Non-Woody

This parameter is the percentage by which the disturbance reduces a dead cohort's non-woody biomass. Value: 0% ≤ integer percentage ≤ 100%. The biomass remaining after the reduction is added to the dead non-woody pool at the site where the cohort was killed.

4.3 DeadPoolReductions Table

This table describes how much a disturbance reduces the dead biomass pools at the sites it disturbs. Each row describes the reductions associated with a particular type of disturbance.

4.3.1 Disturbance

This text parameter is the type of the disturbance. The disturbance name must be consistent with the LandisData name given in the disturbance extension. The keyword `"(default)"` specifies the reductions for all disturbance types not listed in the table. The row with the default reductions must be present in the table.

4.3.2 Woody

This parameter is the percentage by which the disturbance reduces a site’s dead woody biomass. Value: 0% ≤ integer percentage ≤ 100%.

4.3.3 Non-Woody

This parameter is the percentage by which the disturbance reduces a site’s dead non-woody biomass. Value: 0% ≤ integer percentage ≤ 100%.

5 Input File – Climate Change

This optional auxiliary input file contains an updated set of biomass parameters that represent the effects of climate change (see section 3.8 *Climate Change Table*). 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*.

5.1 LandisData

This parameter's value must be `"Biomass Succession – Climate Change"`.

5.2 MinRelativeBiomass Table

This table contains the minimum relative biomass for all the shade classes. The table has the same format as its counterpart in the main input file (see section 3.4 for details).

5.3 BiomassParameters Table

This table contains species' biomass parameters. The table has the same format as its counterpart in the main input file (see section 3.5 for details).

5.4 EstablishmentProbabilities Table

This table contains the probabilities that species establish in various ecoregions. The table has the same format as its counterpart in the main input file (see section 3.6.3 for details).

5.5 MaximumANPP Table

This table contains the maximum ANPP (aboveground net primary production) for species in various ecoregions. The table has the same format as its counterpart in the main input file (see section 3.6.4 for details).

5.6 LeafLitter:DecayRates Table

This table contains the rates at which pecies' leaf litter decomposes in various ecoregions. The table has the same format as its counterpart in the main input file (see section 3.6.5 for details).

6 Example Files

6.1 Main Parameter File

```
LandisData  "Biomass Succession"

Timestep  10

SeedingAlgorithm  WardSeedDispersal


>> **********************
   MinRelativeBiomass

>> Shade
>> Class     Ecoregions
>> -----     ------------
             eco1    eco2

     1       25%     20%
     2       35%     30%
     3       45%     40%
     4       60%     50%
     5       95%     80%


>> **************************************************
   BiomassParameters

>> Species   Leaf        Woody        Mortality Curve
>>           Longevity   Decay Rate   Shape Parameter
>> --------  ---------   ----------   ---------------
   abiebals     4.0         0.071           10
   acerrubr     1.0         0.096           10
   acersacc     1.0         0.096           10
   betualle     1.0         0.096           10
```

(continued next page)

```
>> ****************************
   EstablishProbabilities

>> Species        Ecoregions
>> --------       -------------
                  eco1    eco2

   abiebals       0.9     0.05
   acerrubr       1.0     0.6
   acersacc       0.82    0.3
   betualle       0.64    0.24


>> *************************
   MaxANPP

>> Species      Ecoregions
>> --------     ------------
                eco1    eco2

   abiebals      8000     7870
   acerrubr      7420     7830
   acersacc      7400     7830
   betualle      7600     7990


>> **************************
   LeafLitter:DecayRates

>> Species      Ecoregions
>> --------     -------------
                eco1    eco2

   abiebals     0.207   0.189
   acerrubr     0.385   0.445
   acersacc     0.395   0.456
   betualle     0.381   0.441

AgeOnlyDisturbances:BiomassParameters  bio/AODist.txt


>> ********************
   ClimateChange

>> Year  Parameter File
>> ----  --------------
   1990   climate-change/input-1990.txt
   2025  climate-change/input-2025.txt
   2100   "climate-change/input-2100.txt"
```

6.2 Disturbance Interactions File

```
LandisData  "Age-only Disturbances - Biomass Parameters"


CohortBiomassReductions

>> Disturbance   Woody   Non-Woody
>> -----------   -----   ---------
    fire           33%       100%
    wind            0%         0%
    harvest        85%         0%
    (default)      15%         0%


DeadPoolReductions

>> Disturbance   Woody   Non-Woody
>> -----------   -----   ---------
    fire            8%       100%
    (default)       0%         0%
```

6.3 Climate Change Input File

```
LandisData  "Biomass Succession – Climate Change"


>> *********************
   MinRelativeBiomass

>> Shade
>> Class     Ecoregions
>> -----     ------------
             eco1    eco2

     1       25%     20%
     2       35%     30%
     3       45%     40%
     4       60%     50%
     5       95%     80%


>> **************************************************
   BiomassParameters

>> Species   Leaf        Woody        Mortality Curve
>>           Longevity   Decay Rate   Shape Parameter
>> --------  ---------   ----------   ---------------
   abiebals     4.0         0.071           10
   acerrubr     1.0         0.096           10
   acersacc     1.0         0.096           25
   betualle     1.0         0.096           15
```

```
>> ****************************
   EstablishProbabilities

>> Species         Ecoregions
>> --------        -------------
                   eco1    eco2

   abiebals        0.9     0.05
   acerrubr        1.0     0.6
   acersacc        0.82    0.3
   betualle        0.64    0.24


>> *************************
   MaxANPP

>> Species       Ecoregions
>> --------      ------------
                 eco1    eco2

   abiebals       8000     7870
   acerrubr       7420     7830
   acersacc       7400     7830
   betualle       7600     7990


>> **************************
   LeafLitter:DecayRates

>> Species       Ecoregions
>> --------      -------------
                 eco1    eco2

   abiebals      0.207   0.189
   acerrubr      0.385   0.445
   acersacc      0.395   0.456
   betualle      0.381   0.441
```