Land Use Plus (LU+) v4.0
LANDIS-II Extension
User Guide

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Last Revised: July 19, 2024

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1 Introduction

This document describes the **Land Use Plus** extension (LU+) for the LANDIS-II model. Users should read the *LANDIS-II Conceptual Model Description* and the *LANDIS-II Model v7.0 User Guide* prior to reading this document.

LU+ allows users to incorporate land use or land cover change into LANDIS simulations, with the additional ability to pause LANDIS to create reactive land use or land cover changes. For a review of the basis for LU+ and its application, see Thompson et al., 2016.

1.1 Release history

1.1.1 Major releases

Version 4.0 (August 2024)

- LU+ was upgraded to be compatible with LANDIS-II v8

Version 3.0 – official release (February 2021)

- LU+ 3.0 was upgraded to be compatible with LANDIS-II v7 and PnET v4
- Established extension's official name as Land-Use-Plus and updated documentation

Version 2.0 – official release (May 2018)

- Support for repeat harvesting in the RemoveTrees land use change
- Pause functionality for transforming data between model run time steps was added. Additional routines can be executed during each time step by specifying external scripting tools.

Version 1.0 – official release (November 8, 2015)

- The project was upgraded for the latest LANDIS-II version (6.1).
- The source code for the project was relocated to GitHub.
- The initial public release began June 28, 2015

1.1.2 Minor releases (this Major Release)

1.2 References

Thompson, J.T., E. Simons-Legaard, K. Legaard, J.B. Domingo, 2016. A LANDIS-II extension for incorporating land use and other disturbances. Environ. Model. & Software. 75:202-205.

1.3 Acknowledgements

Funding for the development of this extension was provided by Harvard Forest, the Dynamics of Coupled Natural and Human Systems (CNH) and the Long-Term Ecological Research (LTER) programs of the National Science Foundation (USA), and the University of Notre Dame.

2 Land Use Change

The LU+ extension allows users to incorporate a sequence of maps depicting changes in land use, land cover, or other user-defined disturbances into LANDIS-II simulations. Maps can be developed manually in a Geographic Information System, derived from an external program (e.g., Dinamica EGO), or created/modified in situ using external scripts. Map values correspond to prescribed forest changes that are defined in an associated text input file, described below. A change in map value at a site from one time-step to the next triggers the prescribed forest change (e.g. cohort removal, change to unmanaged forest).

The user specifies how cohorts will be treated when the map code changes between time steps. In the input text file, where map values are identified, the user may specify species to be removed; species to be planted; and/or whether the establishment of new cohorts is prevented. This text file of map codes with the associated forest changes is derived from, and analogous to, the harvest prescriptions used in the Biomass Harvest extension.

These capabilities can be used to simulate, for example, total removal of cohorts and prevention of establishment of new cohorts as a result of a site being converted from forest to developed land. In addition, users can also specify if a change in land use or land cover removes a site from consideration for timber harvesting in subsequent time steps, as in the case of a new conservation easement or forest preserve being established.

2.1 Land use categories

Land use change is modeled in LU+ through a time-series of raster maps containing values, where each value represents a specific land use and its associated land cover change. For example, a land use could be “Conserved Forest” and the associated land cover change (LandCoverChange) could be “NoChange” which would indicate that the forest continues to grow and develop with no defined intervention. Current valid values of land cover changes are: NoChange and RemoveTrees (see below for details).

Land use raster maps are required for each time step within the simulation. Maps can be developed in advance of the LANDIS simulation and provided for each time step, or they can be created in the previous or current time step using the Pause function (see section 2.5) and an external script. Maps for each time step must be available to LANDIS before the start of that time step, even if the provided maps are placeholder maps that are modified through the Pause function in that time step. The Pause function initiates before land cover changes are applied, so maps can be modified and used in the same time step.

2.1.1 NoChange

NoChange indicates that there is no land cover change or action to be taken associated with this land use in this time step (e.g., forest without management).

2.1.2 RemoveTrees

A percent of cohort biomass is removed based on species and age range indicated. RemoveTrees depends on the BiomassHarvest extension to remove species biomass. Biomass removal is applied at the beginning of the time step.

2.2 Harvest functions

2.2.1 AllowHarvest

This parameter indicates whether or not the land use allows timber harvesting through another harvest extension.

2.2.2 RepeatHarvest

Removal or stress of cohorts can take place yearly until a land cover change occurs, despite the time step being used in the model (RepeatHarvest on), or only the year in which the pixel switches to the given land use type (RepeatHarvest off).

2.3 Preventing establishment

Establishment of new cohorts can be prevented while growth continues for remaining cohorts within all sites implementing this particular LandUse parameter. PreventEstablishment is designed for use with RemoveTrees only. The concept is designed to mimic the effects of forest conversion to developed uses, when sites are fully or partially deforested and do not regenerate back to forest. Establishment can reinitiate if a site switches to a new LandUse category without PreventEstablishment.

2.4 Planting new species

New or specific species can be intentionally introduced to a site and will survive based on competition for resources within the site. The specifications for planting follow the Base Harvest extension.

2.5 Pause function

At each time step, the Pause function can be evoked to pause the model, which then sources an external script that creates new LU+ input maps. This functionality allows LU+ maps to dynamically respond to changes in the landscape, either as a result of land use change in previous time steps or the results of other extensions (e.g., Base Fire), or additional land cover change scripts (e.g., insect dispersal model). External scripts can be written in various languages (e.g., R, python) and must result in a new LU+ map for the current or following time step. The external command is initiated before any land use changes are applied, allowing the script to create maps for the current or any future time step. External scripts can be initiated by specifying a console command and providing a PATH to a scripting engine (.exe). These parameters are documented below. LU+ will ignore the pause functionality if both of the pause parameters are not specified.

3 Input files

This extension has two types of input files: a set of land use maps and a text file with input parameters. When using pause functionality, external scripts for a given programming language must also be specified.

3.1 Land use maps

This extension requires a time-series of thematic raster maps (16-bit signed integer/datatype= "INT2S" which must be positive values). The maps indicate the location of the land uses (or other disturbances) to be applied on active sites throughout the simulation. One land use map must be provided for the spin-up time step (0). Users can supply maps for each extension time step or use the Pause functionality to generate maps on-the-fly at each time step. In either case, LU+ requires a map for every time step.

The cell values for the raster map for time step t is the map code for the land use for that cell at time t. These map codes and land uses are then associated with specific landcover changes that will be applied to that cell during that time step. The naming conventions for the maps are provided below.

When reading the land use map for time step t, the extension determines if a cell's (i.e. site's) land use has changed since the previous time step. When a cell's land use changes, the extension applies the land-cover change associated with the new land use to the cell. Otherwise, the cell continues with the land use from the previous time step.

3.2 Input parameters text file

The text file with these parameters must comply with the general format requirements described in section 3.1 Text Input Files of the LANDIS-II Model User Guide. LU+ expects keywords to be defined in a specific order. An example input file for LU+, with parameters called in the proper order, is in Section 4.

3.2.1 LandisData

This parameter's value must be "Land Use".

3.2.2 Timestep

This parameter is the extension's time step, $\Delta t_{\text{LAND USE}}$. The time step does not need to match other extensions' time step (like the succession extension).

3.2.3 InputMaps

This parameter identifies the time series of land-use maps. The value is a template for the file paths of the maps. The variable "{timestep}" must be included as part of the template; it is replaced with the current time step to generate the file path of the land-use map for the current time step. The image file format (**only .tif allowed**) must also be included.

Example:

```
InputMaps               ./land-use-{timestep}.tif
```

In the given example, the series of maps (format is ERDAS IMAGINE) are stored in the current working directory as (assuming a 5-year time step): land-use-5.img, land-use-10.img, etc.

3.2.4 SiteLog (optional)

This is an optional parameter that is the file path of the extension's event log file. If this parameter is present, a log file in CSV format will be written that identifies the 1) time step; 2) row and column; 3) and biomass (g/m2) removed by species for the RemoveTree LandCoverChange. **Warning:** This file can become extremely large.

Example:

SiteLog ./land use/site-log.csv

3.2.5 ExternalExecutable (optional)

PATH to an executable (.exe) program for processing script files executed during pause functionality (e.g., Rscript.exe, python.exe). This file must be specific to the programming language for the script file. **Importantly, the path to this executable must exist on the local computer where LANDIS is executing and the correct path provided**.

3.2.6 ExternalScript (optional)

PATH to a script file (e.g., Python (.py), R (.r), Matlab (.m)) to be executed each time step by the pause functionality. **Errors will occur if script file does not match the programming language given by the executable (.exe).**

3.2.7 LandUse

This parameter defines the name of a particular land use. If the name includes more than one word separated by spaces, it must be enclosed in double quotes.

Example:

LandUse "Residential Development"

3.2.8 MapCode

This parameter is the unique value that represents the land use in the input maps. Value: integer between 0 and 65,535. Raster maps must contain signed integers within this range.

Example:

MapCode 110

3.2.9 AllowHarvest? (optional)

Valid values are yes or no, as described in section 3.1.6 of the LANDIS-II Model v7.0 User Guide. The default value is yes, so specification is only required when preventing harvest, as in the following example:

Example:

AllowHarvest? no
AllowHarvest? No

AllowHarvest? n

Note: If given a value of no, those sites with this land use will be excluded from the calculation of StandSiteCount by the Base or Biomass Harvest extensions in later time steps. This exclusion will have the effect of reducing the calculated size of a stand, which may impact stand ranking within a management unit or achievement of size targets for individual harvests.

3.2.10 PreventEstablishment (optional)

PreventEstablishment is activated when reading the LU+ map at each time step. If PreventEstablishment is specified in the LandUse, new cohorts will not be allowed to establish on cells with that LandUse type. If PreventEstablishment is not specified, cohort establishment occurs as normal within the succession extension. PreventEstablishment only works when RemoveTrees is being applied to the cell. Establishment will begin again when the cell is assigned a new LandUse type that does not have PreventEstablishment.

3.2.11 LandCoverChange

As discussed above, there are two types of LandCoverChange available within LU+: NoChange and RemoveTrees. If the value NoChange is specified, the land use definition does not require additional parameters since LU+ will not take any action on those cells. If RemoveTrees is specified, then the land use definition requires additional parameters, based on the BiomassHarvest functionality for specifying cohorts of trees for modification. See Species List for more information.

Example (one LandCoverChange within one LandUse):

```
>>----------------------------------
LandUse "Urban development"
>>----------------------------------
LandCoverChange RemoveTrees
        acersacc  1-40(50%)  50(65%)  65-70  71-107(15%)
        acersacc 108-200       <<100% removal implicit if no (%) unspecified
```

Note: due to the way RemoveTrees is implemented with Harvesting modules in the background, tree removal will happen instantaneously at the beginning of the time step.

Since LU+ only looks for cells that have changed LandUse from the previous time step, without any further specification, the LandCoverChange will only take place in the time step when a cell goes from one LandUse to another. See RepeatHarvest for variations.

3.2.12 RepeatHarvest? (optional)

Repeat Harvest allows LandCoverChange to be applied to a site each year despite the LU+ time step or failure of a cell to move from one LandUse to another. The default behavior **is not** to repeat harvests across time steps, but this optional parameter can be quite useful for mimicking an ongoing disturbance such as a slow mortality (that occurs over many years) of all cohorts of a species.

If RepeatHarvest is not enabled for RemoveTrees, tree removal will only occur once when a cell transitions to that LandUse category.

Example:

```
LandCoverChange RemoveTrees
RepeatHarvest? Yes
```

3.2.13 Species List

A list of species to remove is required for the LandCoverChange type RemoveTrees. This list must include at least one species. If there are multiple species, each must be on a separate line. The species do not need to appear in any particular order.

Example:

```
speciescode    age-range      (XX%)
```

In RemoveTrees, each species' name, age, and age range for harvesting are listed. An individual age cannot be repeated in the list. Ranges cannot overlap nor include any listed individual age. After the age range the percent removal (integers with "%") should be specified within parentheses. If nothing is specified, 100% will be assumed.
In the RemoveTrees call, the percentage values indicate the percent biomass to remove.

Example:

```
LandCoverChange RemoveTrees
    acersacc 1-40(50%)  41-50(65%)  51-107(15%)
    acersacc 108-200      <<100% removal implicit if (%) unspecified
    pinustro 1-300(90%)
    fagugran 1-300(90%)
```

3.2.14 Plant (optional)

Value: A list of one or more species names separated by whitespace. Plant will be invoked when a cell switches to a LandUse with Plant active. If RepeatHarvest is also yes, plant will happen each year until the cell switches to a new LandUse that does not have Plant active.

Example:

```
Plant  pinustro acersacc acerrubr
```

4 Example Input File

```
LandisData "Land Use"

Timestep   5
InputMaps  land-use-{timestep}.tif
SiteLog    land-use/site-log.csv    << optional: default = don't generate log

ExternalScript "YOUR_FULL_PATH_NAME_HERE/test_simple.R" <<need both
ExternalExecutable "C:/Program Files/R/R-3.6.1/bin/RScript.exe"  <<need both

>>----------------------------------
LandUse forest
>>----------------------------------
MapCode         1
AllowHarvest?    yes
LandCoverChange  NoChange

>>----------------------------------
LandUse "Urban development"
>>----------------------------------
MapCode         2
AllowHarvest?    No
PreventEstablishment
LandCoverChange  RemoveTrees
RepeatHarvest? Yes
                pinustro 1-300(90%)
                tsugcana 1-300(90%)
                fagugran 1-300(90%)
>>----------------------------------
LandUse "Garden"
>>----------------------------------
MapCode         3
AllowHarvest?    no
LandCoverChange  RemoveTrees
RepeatHarvest? Yes

                acersacc 108-200        <<100% removal implicit if (%) unspecified
Plant pinustro

>>----------------------------------
LandUse "no-harvest easement"
>>----------------------------------
MapCode         4
AllowHarvest?    no
LandCoverChange  NoChange
```