Landscape Habitat Output v1.0
LANDIS-II Extension
User Guide

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Table of Contents

1 Introduction

This document describes the Landscape Habitat Output Extension for the LANDIS-II model. Source code for this extension can be found on the Landis-II-Foundation GitHub site: https://github.com/LANDIS-II-Foundation/Extension-Output-Bird-Habitat. Users should read the LANDIS-II Model User's Guide prior to reading this document.

The habitat equations modeled by this extension are intended to be generic and not tied to a specific analysis. However, the extension was initially designed to support a specific analysis relating bird abundance and environmental factors that could be modeled by LANDIS-II. The extension may require modification to accommodate different forms of habitat equations.

This extension is differentiated from the Local Habitat Suitability Output extension in that it incorporates neighborhood variables and distance variables which take into consideration the landscape context of a site, and not just local site attributes. The Local Habitat Suitability Output extension does provide the ability to use local disturbance history in the determination of habitat suitability, which this extension does not.

1.1 Extension Description

This output extension is designed to estimate a quantity of suitability or abundance for multiple species, using environmental variables that can be provided internally by LANDIS-II. Variables can include climate (through the climate library or externally provided), aboveground biomass, forest type, or land cover, at various spatial scales.

1.1.1 Habitat Modeling

Habitat models can be constructed for a variety of organisms (plants and animals), limited solely by the ability to estimate model parameters for relevant environmental predictors. This extension relies on model parameter estimates that have been derived externally, for predictors that can be modeled within LANDIS-II.

This version of the extension has a single model format, though the extension could be extended to handle different equation forms.

1.1.2 Estimated Habitat Quantity

This extension estimates a habitat quantity (y) assuming a model with the general form of:

$$e^y = \beta 0 + \beta 1 \times x1 + \beta 2 \times x2 \ldots$$

The reported habitat quantity values have been back-transformed to the original units of *y* (reported values are not e^y). Habitat quantity can be any quantitative value including population abundance, habitat suitability, detection rates, etc.

1.1.3 Predictor Variables

Model predictor variables can represent a variety of environmental factors and spatial scales.

1.1.3.1 Local Variables

Local variables define the dominant forest type of each site using generally the same logic as the Output Biomass Reclassification Extension to determine the dominant forest type from the present tree cohorts. Users can identify the tree species and age ranges that are indicative (or contraindicative) of each forest type.

1.1.3.2 Derived Local Variables

Derived local variables are additive combinations of local variable classes as defined above (1.1.3.1). For example, a derived local variable might include a general conifer forest type as the combination of multiple forest types with dominant conifers (UplandConifer = Pine + Fir).

1.1.3.3 Neighborhood Variables

Neighborhood variables quantify the proportional abundance of attributes within a specified distance from the target cell. Users identify the relevant Local or Derived Local variables and the desired neighborhood radius (meters). Also, an active ecoregion can be used (by name) as a local variable for neighborhood analysis. Neighborhood variables can also be transformed by log10 or natural log transformations. For example, a neighborhood variable might be the proportion of UplandConifer within a 200m neighborhood. Proportions are calculated based on the sites (both active and non-active) with centroids falling within the neighborhood radius from the focal cell centroid.

1.1.3.4 Climate Variables

Climate variables can be drawn from the Climate Library (see Climate Library User Guide) or from a provided CSV text file, or a combination of both sources. Any climate variable provided by the climate sources can be used as predictors in this extension. Climate predictors can also be specified to use the previous year’s values (for a lagged response), and to summarize annually or seasonally (specific months). Climate variables can also be transformed by log10 or natural log transformations.

1.1.3.5 Distance Variables

Distance variables measure the distance to the nearest cell with a certain attribute. Users identify the relevant Local or Derived Local variables, or an ecoregion (by name). Distance variables can also be transformed by log10 or natural log transformations.

1.1.4 Species Models

The Species Models define the specific predictor variables and their associated coefficients for each species being modeled. Given the general model structure of:

$$e^{y} = \beta 0 + \beta 1 \times x1 + \beta 2 \times x2 \ldots,$$

the species models define the x predictor variables and provide the β coefficients. The models can use any combination of the defined Local, Derived Local, Neighborhood, Climate and Distance Variables, as well as site biomass or ln(biomass) as predictor variables. The model typically also includes an intercept (β0), and can incorporate simple interactions between predictor variables (e.g., $\beta 6 \times x1 \times x2$).

1.1.5 Bird Abundance Example

The methods used for analyzing bird abundance data and environmental variables are included here as an example (see Grinde et al. 2017 for details). Other methods of analysis that build predictive models could be used in conjunction with this extension.

Point count surveys tabulating the number of detections of each bird species in each point count provided the relative abundance index. Other sampling/measurement methods that provide a quantitative index of suitability or abundance could also be used.

Predictor variables used to build the statistical models included stand-level variables associated with a 100-m neighborhood around the sample site, land cover proportion variables calculated at the 200-m, 500-m and 1000-m neighborhood scales, and annual and seasonal weather variables (PDSI, temperature, precipitation).

A generalized linear mixed-effects model (glmer) with negative binomial error from the lme4 R package (Bates et al. 2015) was used to build models of species abundance based on the environmental predictor variables. Models developed with this method have the general form of:

$$e^{y} = \beta 0 + \beta 1 \times x1 + \beta 2 \times x2 \ldots$$

Where y is abundance index (number of detections per survey), $\beta 0$ is the intercept term, $\beta 1$ is the coefficient for predictor $x1$, $\beta 2$ is the coefficient for predictor $x2$, etc.

1.2 Major Releases

1.2.1 Version 1.0

Date – January 2020

The first official release of the extension. This version is compatible with the LANDIS-II Core v7, and can be used with all succession extensions that carry biomass cohort attributes (i.e., use Library.BiomassCohorts-v3.dll and higher). This version is compatible with the Climate Library (v4).

1.3 Minor Releases

None to date.

1.4 Acknowledgments

Contributions to the development of this extension have been provided by Gerald Niemi (Natural Resources Research Institute, University of Minnesota Duluth) and Hannah Panci (Great Lakes Indian Fish & Wildlife Commission). Funding was provided by USDA AFRI (2012-68002-19896), USDA Forest Service Northern Research Station, and the USDA Forest Service National Fire Plan. Data were collected for The National Forest Bird Monitoring Program and funded by Chippewa National Forest.

1.5 References

Bates, D., Mächler, M., Bolker, B. M. and Walker, S. C. 2015. Fitting linear mixed-effects models using lme4. J. Stat. Softw. 67: 1–48

Grinde, Alexis R., G. J. Niemi, B. R. Sturtevant, H. Panci, W. Thogmartin, and P. Wolter. 2017. "Importance of scale, land cover, and weather on the abundance of bird species in a managed forest." Forest Ecology and Management 405:295-308. doi: 10.1016/j.foreco.2017.09.057.

2 Input Files

The text file must comply with the general format requirements described in section 3.1 Text Input Files in the LANDIS-II Model User Guide. Note that multi-line parameter inputs are not supported, even though they may appear that way in this formatted guide. In the example below, under DerivedLocalVariables, the text that follows " Forest -> " must all be a single line of text. In this example the text has wrapped to the next line to fit the margin formatting, but there is no line break separating the text.

2.1 Example Input File

```
LandisData  "Landscape Habitat Output"


Timestep   10


LocalVariables
>> Name       Forest Type   AgeRange     Species
>> --------   -----------   --------     -------
reclass1 ->   Open          All          None
              Regen         1 to 15      All
              LowlandCon    All          Tamarack BlackSpruce
              LowlandHdwd   All          RedMaple BlackAsh
              LowlandMix    All          Tamarack BlackSpruce RedMaple BlackAsh
              UplandCon     All          BalsamFir JackPine
              UplandHdwd    All          SugarMaple YellowBirch
              UplandMix     All          BalsamFir JackPine SugarMaple YellowBirch


DerivedLocalVariables
>> Name       Calc
>> --------   --------
LowlandFor    ->  reclass1[LowlandCon] + reclass1[LowlandHdwd] + reclass1[LowlandMix]
UplandFor     ->  reclass1[UplandCon] + reclass1[UplandHdwd] + reclass1[UplandMix]
Forest        ->  reclass1[LowlandCon] + reclass1[LowlandHdwd] + reclass1[LowlandMix] +
                  reclass1[UplandCon] + reclass1[UplandHdwd] + reclass1[UplandMix]


NeighborhoodVariables
>> Name       Local Variable      NeighborRadius      Transform
```

```
>> --------   ----------          --------------      ---------
loguc200      reclass1[UplandCon] 200                 ln
uf500         UplandFor           500                 none
logforest200  Forest              200                 ln
logw1000      ecoregion[water]    1000                ln

ClimateVariables
>> Name       Year    Months      Source                      ClimateVar   Transform
>> --------   ------  ------      ------                      ----------   ---------
temp          current 3 to 6      Library                     Temp         none
logprevprecip prev    3 to 6      Library                     Precip       ln
pdsi          current 3 to 6      monthly_climate.csv         PDSI         none
logprecip     current 3 to 6      Library                     Precip       ln

DistanceVariables
>> Name       Local Variable      Transform
>> --------   --------            ---------
lognearfor    Forest              ln

SpeciesModels
>> Species    Parameter           Type          Value
>> -------    ---------           ----          -----
SPP1   ->     intercept           int           0.70589
              loguc200            neighbor      1.25531
              logprevprecip       climate       -1.94542
SPP2   ->     intercept           int           -7.88
              biomass             biomass       -0.00004077
              logforest200        neighbor      0.9294
              logw1000            neighbor      1.312
              logw1000*temp       neighbor*climate    -0.0758
SPP3   ->     intercept           int           1.19624
              lognearfor          distance      -0.97316
              logforest200        neighbor      0.81119
              uf500               neighbor      -0.04465
SPP4   ->     intercept           int           -5.85534
```

```
        logbiomass          lnbiomass     -0.05404
        loguc200            neighbor      0.89742

LocalVarMapFileNames        output/bird-habitat/{local-var-name}-{timestep}.img
NeighborVarMapFileNames     output/bird-habitat/{neighbor-var-name}-{timestep}.img
ClimateVarMapFileNames      output/bird-habitat/{climate-var-name}-{timestep}.img
DistanceVarMapFileNames     output/bird-habitat/{distance-var-name}-{timestep}.img
SpeciesMapFileNames         output/bird-habitat/habitat-{species-name}-{timestep}.img

SpeciesLogFileNames         output/bird-habitat/{species-name}_log.csv
LogFile                     output/bird-habitat/bird_habitat_log.csv
```

2.2 LandisData

This parameter's value must be "`Landscape Habitat Output`".

2.3 Timestep

This parameter is the time step of the output extension. Value: integer > 0. Units: years.

2.4 LocalVariables (optional)

This table defines a biomass reclassification table generally using the same logic as the Output Biomass Reclassification Extension. See that extension's Users Guide for more details. The key differences applied for this extension include the ability to define the absence of species (keyword 'None') as defining a forest type, the ability to restrict a forest type to a defined age range, and the ability to include all species (keyword 'All') in a forest type definition or age range. The LocalVariables table is optional, but is required if any of the other variables (i.e., DerivedLocalVariables, NeighborhoodVariables, DistanceVariables) or models (SpeciesModels) refer to the LocalVariables.

The LocalVariables input is a table describing the name of the Local Variable (reclassification), the forest types for the reclassification, the age ranges and species within (or excluded from) each forest type (Table 1).

Table 1.

Parameter	Data type	Example
Local Variable Name	string	`reclass1`
Forest Type	string	`LowlandCon`
Age Range	string	`All`

Species	string	`Tamarack BlackSpruce`

First, the Local Variable Name must be given, followed by the symbol ‘->’. Do not use spaces in the variable name. Immediately following is the first forest type, such as NorthernPine or “Southern Oak” (quotes required if spaces used). Each subsequent forest type is listed on a separate line. Following the name of each forest type is a numeric range or keyword ‘All’ that defines the ages that contribute to the forest type. Age ranges are specified as the numeric lowest age and the numeric highest age, separated by “ to “ (e.g., 1 to 15). Following the age range is a list of species to be included or excluded. If a species should contribute to the dominance value of a forest type, list the species name. If a species should be subtracted from a forest type, list the species name preceded by a ‘-‘ (negative) sign. **Not all species need be included and a species may be listed in more than one forest type.** The keywords ‘None’ or ‘All’ can be used to designate that no species or all species contribute to the forest type, respectively.

2.5 DerivedLocalVariables (optional)

Derived Local Variables are combinations of Local Variable classes as defined above (2.4). The DerivedLocalVariables table is optional, but is required if any of the other variables (i.e., NeighborhoodVariables, DistanceVariables) or models (SpeciesModels) refer to the DerivedLocalVariables.

First, the Derived Local Variable Name must be given, followed by the symbol ‘->’. Do not use spaces in the variable name. Immediately following are the local variables that contributes to the Derived Local Variable, separated by “ + “, indicating that the Derived variable is the simple summation of the specified Local Variables. The format for referencing a specific Local Variable forest type is LocalVariableName[ForestType].

2.6 NeighborhoodVariables (optional)

Neighorhood Variables are measures of proportional abundance of local variables within a defined neighborhood. The NeighborhoodVariables table is optional, but is required if any of the other variables (i.e., DistanceVariables) or models (SpeciesModels) refer to the NeighborhoodVariables.

The NeighborhoodVariables input is a table describing the name of the Neighborhood Variable, the corresponding local variable name, the neighborhood radius (meters) and any applicable transformation (Table 2).

Table 2.

Parameter	Data type	Example

Neighborhood Variable Name	string	`loguc200`
Local Variable	string	`reclass1[UplandCon]`
Neighborhood Radius	int	`200`
Transformation	string	`ln`

The format for referencing a specific Local Variable forest type is LocalVariableName[ForestType], and Derived Local Variables can be directly referenced by name. Ecoregion classes can also be evaluated as Neighborhood Variables, specified by "ecoregion[ecoName]", where ecoName is the Name attribute assigned in the scenario Ecoregions text file. Currently, only active ecoregions can be referenced.

Transformation options include "none" for no transformation, "log" for Log10 transformation, and "ln" for natural log transformation. Transformation is applied to the proportional abundance value for the specified variable on each cell.

2.7 ClimateVariables (optional)

The ClimateVariables table is optional, but is required if any of the models (SpeciesModels) refer to the ClimateVariables. The ClimateVariables input is a table describing the name of the Climate Variable, the year of data to apply (current or previous), the months of the year to summarize, the source of the climate data, the variable name in the climate data file, and any applicable transformation (Table 3).

Table 3.

Parameter	Data type	Example
Climate Variable Name	string	`logprecip`
Year	string	`current`
Months	string	`3 to 6`
Source	string	`Library`
ClimateVar	string	`Precip`
Transformation	string	`ln`

The options for Year are "current" or "prev" to utilize the current year's climate value or the previous year's value, respectively. The range of months to summarize should be specified as "startMonth to endMonth", where startMonth and endMonth are the numerical indices for months (e.g., January = 1, February = 2, etc.). For annual summaries, use "1 to 12".

The Source can be either "Library" to use values provided through the Climate Library (must be specified in the succession extension), or the path and filename of a CSV formatted table of climate values. Provided climate tables are required to be monthly data, formatted with a header row, and must include the columns “Year” and “Month”, with months formatted as numerical indices (e.g., January = 1, February = 2, etc.). Additional columns can represent any climate variables in numeric format, and can be referred to by their column name as the ClimateVar parameter in the ClimateVariables table.

Example climate table:

```
Year,Month,PDSI
2000,1,3.666576
2000,2,0.5331982
2000,3,5.880105
2000,4,2.942633
2000,5,4.381177
2000,6,0.4977259
2000,7,2.420861
2000,8,1.518062
2000,9,-3.762948
2000,10,-3.431658
2000,11,-5.438645
2000,12,2.20145
```

Climate variable transformation options include “none” for no transformation, “log” for Log10 transformation, and “ln” for natural log transformation. Transformation is applied to the summarized climate value for the specified variable on each cell.

2.8 DistanceVariables (optional)

Distance variables are measures of a site’s distance to the nearest cell with a certain attribute. The DistanceVariables table is optional, but is required if any of the models (SpeciesModels) refer to the DistanceVariables.

Table 3.

Parameter	Data type	Example
Distance Variable Name	string	`lognearfor`
Local Variable	string	`Forest`
Transformation	string	`ln`

The first column in the table is the name for the distance variable. The second column identifies the corresponding local variable, the attribute to which distance is being measured. The local variables can include any of the LocalVariables, DerivedLocalVariables or ecoregions. The format for referencing a specific Local Variable forest type is LocalVariableName[ForestType], and Derived Local Variables can be directly referenced by name. Ecoregion classes can be specified by “ecoregion[ecoName]”, where ecoName is the Name attribute assigned in the scenario Ecoregions text file. Currently, only active ecoregions can be referenced.

2.9 SpeciesModels

The Species Models define the specific predictor variables and their associated coefficients for each species being modeled, assuming the general model structure of:

$$e^y = \beta 0 + \beta 1 \times x1 + \ \beta 2 \ \times x2 \ldots$$

The SpeciesModels table is a required model input.

Table 4.

Parameter	Data type	Example
Species Model Name	string	`CONW`
Parameter	string	`intercept`
Type	string	`int`
Value	numeric	`0.70589`

The first column includes the name of the species model. The model name is followed by “->” and then the specified model parameters and their coefficients. The Parameter column can include “intercept”, “biomass”, “logbiomass”, plus any of the NieghborhoodVariables, ClimateVariables and DistanceVariables. The parameters “logbiomass” and “biomass” use the site aboveground live biomass as the predictor, either log-transformed or not. Parameter interactions can be designated by listing the interacting parameters, separated by “*”. The third column identifies the parameter type, with possible values of “int” for intercept, “biomass” or “lnbiomass” for biomass predictors, “neighbor” for NeighborhoodVariables, “climate” for ClimateVariables and “distance” for DistanceVariables. For interacting parameters, the corresponding types should be entered in the same order and also separated by “*”. The final column represents the parameter coefficient value (numeric).

Note: LocalVariables and DerivedLocalVariables cannot be directly used in the SpeciesModels because the LocalVariables represent categorical classifications of the forest types. However, whether specific cell matches a specific forest type could be represented in the model by defining a NeighborhoodVariable with a neighborhood radius smaller than the cell size. This would effectively create a binary variable with a value of 1.0 if the cell matches the specified Local/DerivedLocal Variable, or a value of 0 if it does not match.

2.10 Output Map File Names

Optional output maps include maps of LocalVariables, NeighborhoodVariables, ClimateVariables, DistanceVariables and SpeciesMaps.

2.10.1 LocalVarMapFileNames (Optional)

The keyword LocalVarMapFileNames is followed by a path and template filename. The filename must include "{local-var-name}", and "{timestep}", will be replaced by the name of the LocalVariable, and the simulation year at the time the map is written. All LocalVariables will be output when this parameter is provided.

2.10.2 NeighborVarMapFileNames (Optional)

The keyword NeighborVarMapFileNames is followed by a path and template filename. The filename must include "{neighbor-var-name}", and "{timestep}", will be replaced by the name of the NeighborhoodVariable, and the simulation year at the time the map is written. All NeighborhoodVariables will be output when this parameter is provided.

2.10.3 ClimateVarMapFileNames (Optional)

The keyword ClimateVarMapFileNames is followed by a path and template filename. The filename must include "{climate-var-name}", and "{timestep}", will be replaced by the name of the ClimateVariable, and the simulation year at the time the map is written. All ClimateVariables will be output when this parameter is provided.

2.10.4 DistanceVarMapFileNames (Optional)

The keyword DistanceVarMapFileNames is followed by a path and template filename. The filename must include "{distance-var-name}", and "{timestep}", will be replaced by the name of the DistanceVariable, and the simulation year at the time the map is written. All DistanceVariables will be output when this parameter is provided.

2.10.5 SpeciesMapFileNames

The keyword SpeciesMapFileNames is followed by a path and template filename. The filename must include "{species-name}", and "{timestep}", will be replaced by the name of the SpeciesModel, and the simulation year at the time the map is written. Maps for all SpeciesModels will be output.

2.11 Output Log File Names

Two formats of log files are produced by the extension.

2.11.1 SpeciesLogFileNames

Output logs for each SpeciesModel are defined using the SpeciesLogFileNames keyword, followed by a path and template file name. The filename must include "{species-name}", which will be replace by the name of the SpeciesModel when the file is written. The species log contains the following columns:

Table 5.

Column	Description
SpeciesModel	Name of species model
Time	Simulation year
Ecoregion	Ecoregion name (or "TotalLandscape")
Index	Average index value

Index values are averaged across all cells in each ecoregion or for the whole landscape (TotalLandscape) for the given simulation year.

2.11.2 LogFile

A combined log file is defined using the LogFile keyword, followed by a path and filename. The log file contains the same columns of information as the species logs, though in a different order (Time, Ecoregion, SpeciesModel, Index).

3 Output Files

3.1 Variable Maps

Optional output maps include maps of LocalVariables, NeighborhoodVariables, ClimateVariables and DistanceVariables. Maps for these variables are written at each timestep and for each variable of the type listed. The maps represent the cell values for the variable at each timestep.

3.2 Species Index Maps

Species maps represent the modeled index value for each cell at each timestep. **Mapped values have been multiplied by 100** in order to fit the integer map format.

3.3 Species Logs

The species logs summarize the average index values for each SpeciesModel in each ecoregion (or TotalLandscape) at each timestep.

3.4 Summary Log

The summary log summarize the average index values for all SpeciesModels in each ecoregion (or TotalLandscape) at each timestep.