PnET-Succession v1.0 Extension User Guide

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Last Revised: June 11, 2014

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1 Introduction

This document describes the **PnET-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.*

The PnET-Succession extension is based on the Biomass Succession extension of Sheller and Mladenoff (2004), embedding elements of the PnET-II ecophysiology model of Aber et al (1995) to simulate growth as a competition for available light and water, replacing the existing competition for "growing space" algorithms.

1.1 Major modifications made to PnET algorithms

Several modifications were made to PnET algorithms to make them tractable at landscape scale, primarily by broadening the scale of integration operations. (1) The PnET timestep was broadened from daily to monthly. (2) The number of sub-layers within a canopy layer was 50 in Pnet, but is here dynamically determined with a minimum of 5, where each sub-layer represents an even proportion of the total LAI within the layer. It can increase dynamically when transpiration would otherwise exceed soil water. These smaller subcanopy layers tighten the feedback between photosynthesis and water stress. (3) Cohort biomass is used as a surrogate for tree height to simulate canopy layers. The user specifies the ages at which the canopy adds layers. (4) Photosynthates are allocated to four pools (foliage, root, wood and non-structural carbon (reserves)). Net photosynthesis is initially allocated to the NSC pool, and then foliage allocation occurs, followed by allocation to root and wood pools such that the root:stem ratio is preserved. Maintenance respiration is then deducted from the NSC pool. Details of model structure and modifications can be found in De Bruijn et al (in press).

1.2 Advantages and disadvantages of PnET-Succession compared to Biomass Succession

The goal for PnET-Succession was to make the simulation of growth and competition more mechanistic and more explicitly linked to fundamental drivers that are changing, such as climate and atmospheric composition (e.g., CO_2 and ozone). It is believed that this more mechanistic approach will be more robust for making projections under climate and other global changes (Gustafson 2103).

Advantages of PnET-Succession compared to Biomass Succession

1) PnET-Succession replaces the input parameters $ANPP_{max}$ and B_{max} of LANDIS-II Biomass Succession with mechanistic calculations of growth and senescence that depend on climatic conditions and competition for resources. Establishment and growth are now emergent properties of the model and are explicitly linked to changing fundamental drivers such as climate and CO_2 concentrations.

2) Dynamic calculations of LAI and photosynthesis allow cohorts to die prior to senescence, based on physiological constraints (too few carbon reserves). This can typically occur when carbon reserves production is insufficient to support growth due to shading, water competition, drought, diseases or pests. This allows more realistic simulation of cohort death in the course of stand development (i.e., mortality is highest in the younger cohorts), and a more realistic accounting of biomass accumulation. An added benefit is that the number of cohorts to be simulated is reduced.

3) PnET-Succession allows a more explicit simulation of species' survival strategies, by implementing a dynamic competition for light and water. For example, one can parameterize species or species-group combinations of respiration losses and water use efficiency to implement competition advantages or disadvantages for particular species in sites that are dry or shaded due to competing vegetation.

Disadvantages of PnET-Succession compared to Biomass Succession

1) PnET-Succession requires more parameters, which adds to uncertainty and increases the parameter burden when using the model. However, uncertainty may be no higher than when making *ad hoc* assumptions for other succession extensions about how novel conditions will affect modeled processes.

2) Runtimes tend to be somewhat longer, but only slightly longer because many cohorts senesce prior to reaching longevity age, greatly reducing the number of cohorts that must be simulated. In both BiomassSuccession and PnET-Succession, simulation of dispersal is more time consuming than the forest growth part.

1.3 References

Aber, J.D., Ollinger, S.V., Federer, A., Reich, P.B., Goulden, M.L., Kicklighter D.W., Melillo J.M., Lathrop R.G. 1995. Predicting the effects of climate change on water yield and forest production in the northeastern United States. Climate Research 5:207-222**.**

De Bruijn AMG., Gustafson E.J, Sturtevant B., Foster J., Miranda B., Lichti N., Jacobs D.F. in press. Toward more robust projections of forest landscape dynamics under novel environmental conditions: embedding PnET within LANDIS-II.. Ecological Modelling.

Gustafson, E.J. 2013. When relationships estimated in the past cannot be used to predict the future: using mechanistic models to predict landscape ecological dynamics in a changing world. Landscape Ecology 28:1429-1437.

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

1.4 Acknowledgments

Funding for the development of the PnET-Succession extension was provided by a grant from the USDA/NASA NIFA/AFRI program to Purdue University. Valuable scientific contributions to the development of the extension were made by Arjan De Bruijn, Eric J. Gustafson, Brian R. Sturtevant and Mark Kubiske.

Funding for the development of LANDIS-II was provided by the Northern Research Station (Rhinelander, Wisconsin) of the U.S. Forest Service. Valuable contributions to the development of LANDIS-II were made by Robert M. Scheller, Brian R. Sturtevant, Eric J. Gustafson, and David J. Mladenoff.

2 PnET-Succession

The PnET-Succession Extension generally follows the methods of the Biomass Succession Extension: Age cohorts reproduce, grow (add biomass), age, and die. The PnET-Succession Extension replaces the simple growth and competition algorithms from the Biomass Succession Extension with the photosynthesis and respiration equations from PnET-II to simulate growth of specific cohort biomass components (root, foliage, wood, non-structural carbon) as a competition for water and light.

PnET-Succession simulates the competition of cohorts for water and light as a function of photosynthetic processes. Competition for water is simulated on each site (grid cell) through a dynamic soil water balance that receives precipitation and loses water as runoff, interception, percolation out of the rooting zone and consumption by cohorts through photosynthesis, respiration and transpiration. Competition for light is modeled by tracking solar radiation through canopy layers (related to cohort age) according to a standard Lambert-Beer formula. PnET-Succession requires average monthly temperature, precipitation, photosynthetically active radiation and atmospheric CO_2 concentration as inputs.

Because monthly climate data are provided as an input to the extension, species establishment probability is also calculated at each time step as a function of the climate conditions during the time step.

The PnET-Succession Extension also changes the calculation of shade. LAI is estimated for multiple canopy layers, and available light is computed for each layer, including the sub-canopy (i.e., ground).

The PnET-Succession Extension tracks biomass in four live pools (foliage, roots, wood and non-structural (C reserves)) and two dead pools (woody and leaf litter).

2.1 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 PnET-Succession extension uses its growth algorithms to iterate 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. Additionally, climate data are required back to t - oldest cohort age. To facilitate climatic input in years where weather records do not exist, it is possible to supply mean monthly climate data for a range of years (see section 6.2)

This biomass initialization does not account for disturbances that would likely happen prior to initialization and therefore tends to overestimate initial live biomass and underestimate initial dead biomass.

2.2 LAI Shade Calculation

Site shade is calculated based on LAI in canopy layers (see section 2.5).

2.3 Cohort Reproduction and Establishment

Cohort establishment is the result of two distinct processes. 1) production and dispersal of seeds and 2) seed germination and successful recruitment of a viable new cohort.

Seed is produced by every cohort that is at least the age of sexual maturity. Seed dispersal is modeled as a spatial process according to the dispersal method selected by the user, as in the Biomass Succession extension.

When seeds disperse to a cell, establishment (recruitment) first requires sufficient light (amount dependent on species shade tolerance) and is then stochastic based on a probability of establishment that is calculated as a function of soil moisture and sub-canopy radiation during the time step. Establishment is only attempted during optimal months, computed from the climate file as the first three physiologically active months in the year and one month before until after the maximum precipitation. Initial biomass is computed for a 1-year old cohort.

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

2.4 Cohort Competition

Similar to LANDIS Biomass Succession, PnET-Succession assumes that LAI and biomass are spatially homogeneous on a site (i.e., cell). PnET-Succession defines canopy layers according to biomass, associating proportions of biomass to canopy layers as a function of cohort ages. (Section 3.10). The upper layer has first access to radiation and the radiation that is available to the next younger age category is equal to the average of radiation that has passed through the cohorts in the higher, older canopy layer. All species age cohorts within an age category have equal access to light. Species portions of sub-canopy layers are processed for photosynthesis in random order, so access to water is not biased by species or canopy position.

2.5 Cohort Growth and Ageing

Biomass growth is driven by photosynthesis, which depends on light, soil moisture and leaf area index (LAI). The reduction of radiation intensity through the canopy is estimated using an exponential decrease function (i.e., Beer-Lambert law), where the fraction of incoming radiation drives photosynthetic activity (Aber and Federer, 1992). A laboratory-derived relationship between foliar nitrogen concentration and assimilation rates under optimal growth conditions is used to estimate potential gross photosynthesis.

Multiplicative reduction factors are applied to gross photosynthesis to account for water stress, suboptimal radiation, vapor pressure deficit, and temperature. Soil water is calculated in a bulk-hydrology model that updates soil water depending on precipitation and consumption by the trees. Water stress is estimated as the ratio of actual transpiration and potential transpiration. Vapor pressure deficit is calculated from the temperature fluctuations during the day, and accounts for the effect of supra-optimal atmospheric CO_2. Species-specific minimum and – optimum temperature are input as model parameters, and species specific maximum temperature is derived assuming a parabolic, symmetric optimum between species-specific maximum and minimum temperature for photosynthesis.

Foliar respiration is calculated as a user-defined fraction of maximum gross photosynthesis. Net photosynthesis is estimated by subtracting respiration from gross photosynthesis. Resulting net photosynthesis is then allocated to the root, foliage, wood and non-structural biomass pools, according to fixed allocation ratios. A proportion of foliage and wood biomass is also moved to the dead pools to simulate leaf-fall and branch death.

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

2.6 Cohort Senescence and Mortality

Senescence is implemented as a reduction of gross photosynthetic rate with age such that respiration eventually exceeds production and cohorts die. A cohort dies when non-structural carbon decreases to <1% of the combined structural biomass pools. The PsnAgeRed parameter controls the shape of the function used to calculate the age-related reduction factor, which reaches zero at the longevity specified in the LANDIS-II species parameter file.

2.7 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 average of the user-supplied species specific decay rates (KWdLit KNWdLit woody and non-woody litter) and corrected according to the moisture conditions of the site (i.e. through actual evapotranspiration or AET) and the current pool decay rate, weighted by biomass. Disturbances can alter the dead biomass pools. They can add dead biomass (e.g., wind) and/or remove dead biomass (e.g., fire may add some woody dead biomass and remove all leaf dead biomass).

2.8 Interactions with Age-Only Disturbances

PnET-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 PnET-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 PnET-Succession.

The interface is specified in a separate LandisData parameter file: "Age-only Disturbances - Biomass Parameters". See Chapter 8.

3 PnET-Succession Input File

The input parameters for this extension are specified in two input files: the PnET-Succession input file and the PnET Species Parameters input file. The general species parameter input file used by all versions of LANDIS is also required, and is described in Chapter 6 of the *LANDIS-II Model User Guide*. The input files must comply with the general format requirements described in section 3.1 *Text Input Files* in the *LANDIS-II Model User Guide*.

3.1 Example PnET-Succession input file

```
LandisData  "PnET-Succession"

Timestep  10

StartYear 2000

SeedingAlgorithm  WardSeedDispersal

InitialCommunities      initial-communities.txt
InitialCommunitiesMap   initial-communities.img

Latitude          34

CanopyLayerBiomassCategories     CanopyCategories.txt

PNEToutputsites
9  9

SpeciesParameterFile             SpeciesParameters.txt

EstRadSensitivity EstRadiationTable.txt
EstMoistureSensitivity   EstMoistureTable.txt

EcoregionParameters
>>        AET    WHC    PrecipLossFrac LeakageFrac    ClimateFileName
>>        mm/yr  (mm)
eco1      740    162    0.5            0.06   BdApache_climate.txt
```

3.2 LandisData

This parameter's value must be "PnET-Succession"

3.3 Timestep

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

3.4 StartYear

This parameter indicates the climate year in which simulation begins. Climate file observations prior to this date are used for spin-up (as necessary) and observations from this date forward are used for simulations. The climate file may contain more years than will actually be used by the model. Value: integer > 0. Units: years.

3.5 SeedingAlgorithm

This parameter is the seed dispersal 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*.

3.6 InitialCommunities

This parameter gives the name of the initial communities text file. This file assigns species and cohorts to each value found in the initial communities map (see chapter 4).

3.7 InitialCommunitiesMap

This parameter gives the file name of the initial communities map. This map contains a unique integer value for each combination of species and cohorts found on the landscape. Each cell value for an active site on the landscape must be one of the map codes listed in the initial communities input file

3.8 Latitude

The approximate latitude of the study area. Value: -90< integer <90. Units: degrees of latitude.

3.9 CanopyLayerBiomassCategories

This parameter table is used to assign cohorts to canopy layers by defining target cumulative proportional biomass values for each canopy layer. These threshold proportions can be varied according to stand age (maximum cohort age in the cell), so separate lines are given for each range of stand ages for which the user wishes to define distinct threshold values. Cohorts are assigned to canopy layers beginning with the smallest biomass cohort, which is assigned to the lowest layer (larger canopy layer numbers reflect higher canopy position). Increasingly large cohorts are assigned to the layer for which the cumulative proportion of the total cell biomass already assigned exceeds the threshold given for the layer. A cohort can be assigned to only one canopy layer, so if the addition of a cohort to a layer would cause the cumulative proportion of biomass now assigned to layers to exceed the threshold for a higher layer, the cohort would be assigned to the higher layer. The number of potential layers is determined by the number of layers the user creates in the table (three layers in the example).

Example file:

```
CanopyLayerBiomassCategories

MaxCohortAge      Layer0    Layer1    Layer2

20                1         1         1

50                0.2       1         1

MAX               0.2       0.5       1
```

In this example, there are three sets of thresholds given. The first line is applied to stands of age 1-20 and all cohorts are assigned to Layer0 because the cumulative proportional biomass assigned to Layer0 can never exceed the 1.0 given for Layer0. The second line is applied to stands aged 21-50, and successively larger cohorts are assigned to Layer0 until the cumulative proportional biomass exceeds 0.2, and the remainder is assigned to Layer1. The third line is for stands >50 years of age (51 to MAXimum possible age), and successively larger cohorts are assigned to Layer0 until the cumulative proportional biomass exceeds 0.2, and then cohorts are assigned to Layer1 until the cumulative proportional biomass exceeds 0.5, and the remainder is assigned to Layer2. Cohorts will be assigned to the highest canopy layer for which the cumulative proportional biomass threshold is exceeded, so in some cases an intermediate canopy layer may be empty.

3.10PNETоutputsites

Optional: Specify the specific cell(s) that will have PnET state variables output. Leave blank to have no cells output. Values are the row and column location of a cell for which you want output from your initial-communities image file. Writing this file is very time-consuming, so use only as needed. Value: integer > 0. Units: row and column number.

3.11 SpeciesParameterFile

This parameter gives the name of the PnET Species Parameter text file. This file contains PnET-II-related parameters. The format of this file is described in chapter 7.

3.12 EcoregionParameters

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

3.12.1 Ecoregion

The ecoregion name given must be defined in the ecoregion input file (see chapter 7 in the *LANDIS-II Model User Guide*). Ecoregions may appear in any order.

3.12.2 AET

Actual Evapotranspiration. AET is the actual amount of water delivered to the atmosphere by evaporation and transpiration. Parameter reflects aridity and is used to estimate leaf decay rates. Value: <0 integer <10,000. (Note: the value is typically <1000). Units: mm $year^{-1}$.

3.12.3 WHC

Average Water Holding Capacity of the soils in the ecoregion. Value: Decimal >0.0. Units: mm.

3.12.4 PrecLossFrac

Precipitation Loss Fraction. Proportion of precipitation that does not enter the soil (e.g., evaporation or runoff not due to soil saturation). Value: 0.0≤ decimal ≤1.0. Units: proportion.

3.12.5 LeakageFrac

Leakage Loss Fraction. Proportion of soil water that percolates through and out of the rooting zone, becoming unavailable to trees. Value: 0.0≤ decimal ≤1.0. Units: proportion.

3.12.6 ClimateFileName

This parameter gives the name of the climate file for the ecoregion. The user may specify the same file for multiple ecoregions.

4 Input File – Input community file

This file contains the definitions of the initial community classes. Each active site on the landscape is assigned to an initial community class. The class specifies the tree species that are present along with the particular age cohorts that are present for each species.

4.1 Example File

```
LandisData "Initial Communities"

>>Old jackpine oak
MapCode 7
   acerrubr 30
   pinubank 80 90
   pinuresi 110 140
   querelli 40 120 240

>> young jackpine oak
MapCode 0
   pinubank 30 50
   querelli 10 40 70

>> young aspen
MapCode 2
   poputrem 10 20

>> old maple hardwoods
MapCode 55
   abiebals 10 60 120
   acerrubr 90 120
   acersacc 20 50 150 200
   betualle 40 140 200
   fraxamer 10 100 130 180
   piceglau 180
   querrubr 100 160 180
   thujocci 200 240 260
   tiliamer 20 80 110 150
   tsugcana 30 80 120 220 320 340

>> old pine - spruce - fir
MapCode 6
   abiebals 10 50 80
   piceglau 100 140 180 200 220
   pinuresi 140 160 180
   pinustro 200 280 350
```

4.2 LandisData

This parameter's value must be "Initial Communities".

4.3 Initial Community Class Definitions

Each class has an associated map code and a list of species present at sites in the class.

4.3.1 MapCode

This parameter is the code used for the class in the input map (see chapter 5). Value: $0 \leq$ integer $\leq 65{,}535$. Each class map code must be unique. Map codes can appear in any order, and need not be consecutive.

4.3.2 Species Present

A list of species present at the class' sites comes after the map code. Each species is listed on a separate data line.

```
species age age age ...
```

The species name comes first, followed by one or more ages. The name and ages are separated by whitespace. An age is an integer and must be between 1 and the species' Longevity parameter. The ages can appear in any order.

```
acersacc 10 5 21 60 100
```

The list may be empty, which will result in the sites in the class being initialized with no species cohorts.

4.3.3 Grouping Species Ages into Cohorts

The list of ages for each species is grouped into cohorts based on the succession extension's timestep. This timestep determines the size of each cohort. For example, if the timestep is 20, then the cohorts are ages 1 to 20, 21 to 40, 41 to 60, etc.

Suppose an initial community class has this species in its list:

```
acersacc 10 25 30 40 183 200
```

If the succession timestep is 10, then the cohorts for this species initially at each site in this class will be:

```
acersacc 10 20 30 40 190 200
```

5 Input File – Input community map

This is a GIS file of the initial community classes. Each active site on the landscape is assigned to a MapCode that links to the initial community class defined in the Initial Community Class Definitions.

6 Input File – Climate

This file contains weather records of monthly parameter values.

6.1.1 Example File #1

Year	Month	TMax	TMin	PAR	Prec	CO2
2007	1	11.86	-13.39	564.2	1.651	383
2007	2	17.93	-8.45	698.7	1.7272	383
2007	3	24.73	-10.18	872.0	2.921	383
2007	4	25.05	-2.853	930.5	4.0132	383
2007	5	27.72	3.424	890.4	4.1449	383
2007	6	35.24	8.7	1069.0	0.928	383
2007	7	36.35	12.75	891.1	3.7338	383
2007	8	34.15	13.64	927.9	5.0806	383
2007	9	30.44	6.647	875.3	5.7138	383
2007	10	26.67	-3.804	836.2	0.4064	383
2007	11	21.84	-9.4	660.5	0.2794	383
2007	12	17.03	-10.49	579.8	3.5304	383
2008	1	11.81	-14.41	622.1	1.2192	385
2008	2	19.35	-8.78	792.4	1.9558	385
2008	3	21.74	-9.21	930.0	1.0922	385
2008	4	25.86	-5.333	1045.2	0.4826	385
2008	5	31.97	0.023	1014.7	1.1176	385
2008	6	34.43	8.84	1042.4	0	385
2008	7	33.24	11.32	836.7	10.368	385
2008	8	32.81	11.46	918.0	7.8738	385
2008	9	29.71	5.53	900.8	1.1176	385
2008	10	26.3	-2.018	775.7	6.0198	385
2008	11	21.96	-7.66	671.0	0.4064	385
2008	12	20.11	-10.58	532.7	1.4224	385

6.1.2 Example File #2

Year	Month	TMax	TMin	PAR	Prec	CO2

```
1900-2007 1     11.86      -13.39         564.2    1.651         383
1900-2007 2     17.93       -8.45         698.7    1.7272        383
1900-2007 3     24.73      -10.18         872.0    2.921         383
1900-2007 4     25.05       -2.853        930.5    4.0132        383
1900-2007 5     27.72        3.424        890.4    4.1449        383
1900-2007 6     35.24        8.7         1069.0    0.928         383
1900-2007 7     36.35       12.75         891.1    3.7338        383
1900-2007 8     34.15       13.64         927.9    5.0806        383
1900-2007 9     30.44        6.647        875.3    5.7138        383
1900-2007 10    26.67       -3.804        836.2    0.4064        383
1900-2007 11    21.84       -9.4          660.5    0.2794        383
1900-2007 12    17.03      -10.49         579.8    3.5304        383
2008       1    11.81      -14.41         622.1    1.2192        385
2008       2    19.35       -8.78         792.4    1.9558        385
2008       3    21.74       -9.21         930.0    1.0922        385
2008       4    25.86       -5.333       1045.2    0.4826        385
2008       5    31.97        0.023       1014.7    1.1176        385
2008       6    34.43        8.84        1042.4    0             385
2008       7    33.24       11.32         836.7   10.368         385
2008       8    32.81       11.46         918.0    7.8738        385
2008       9    29.71        5.53         900.8    1.1176        385
2008      10    26.3        -2.018        775.7    6.0198        385
2008      11    21.96       -7.66         671.0    0.4064        385
2008      12    20.11      -10.58         532.8   14.224         387
```

6.2 Header Information

The first line of the file must contain the following text:

```
Year     Month  TMax     TMin      PAR      Prec      CO2
```

6.3 Observations

Subsequent lines of the file contain monthly values for the 7 variables. Observations must appear in chronological order.

6.3.1 Year

The year of the weather observation. Alternatively, a range of years may appear, delineated by a hyphen (see example 6.1.2). Value: 4-digit integer >0.

6.3.2 Month

The month of the weather observation. Value: 1≤ integer ≤12.

6.3.3 TMax

The maximum temperature observed in the month. Value: decimal. Units: degrees C.

6.3.4 TMin

The minimum temperature observed in the month. Value: decimal. Units: degrees C.

6.3.5 PAR

Mean monthly value of Photosynthetically Active Radiation during daylight hours. Value: decimal ≥ 0.0. Units: User choice. Typically μmol/m2/sec or W/m^2. The units for the half-saturation constant (SpeciesParameter file) must be the same as PAR. **THE MODEL WILL NOT CHECK TO ENSURE THAT THE UNITS ARE THE SAME.** This is a user responsibility.

6.3.6 Prec

The sum of precipitation observed in the month. Value: decimal ≥0. Units: mm.

6.3.7 CO2

Atmospheric CO_2 concentration. Value: decimal >0. Units: ppm.

7 Input File – SpeciesParameterFile

```
PnETSpeciesParameters

SpeciesName    GrMstSens    FolN   TOfol  FolRet       TOroot
  TOwood       GDDFolSt     CDDFolEnd     AmaxA AmaxB
  HalfSat      BFolResp     WltPnt        PsnAgeRed    Q10
  PsnTMin      PsnTOpt      SLWmax        SLWDel       k
  DVPD1 DVPD2  WUEcnst      MaintResp     DNSC  RtStRatio
  EstMoist     EstRad       KWdLit KNWdLit

pinuedul 0.3   1.21   0.167 0     0.04  0.03  200   2000
  14.3   0     800    0.1   0.05  3     1.7   4     25
  242    0     275    0.58  0.05  2     28    0.002 0.08
  0.55   3     0.5

junimono 0.3   1.06   0.167 0     0.05  0.04  200   2000
  22.3   0     950    0.06  0.05  3     2.2   4     25
  490    0     275    0.58  0.05  2     30    0.002 0.09
  0.55   2     0.5
```

7.1 Example File

LandisData

This parameter's value must be "PnETSpeciesParameters"

7.2 Parameter Names

The second line of the file must contain the following space- or tab-delimited text (**note:** all on one line, not case-sensitive):

```
SpeciesName    GrMstSens    FolN   TOfol  FolRet TOroot
  TOwood       GDDFolSt     CDDFolEnd     AmaxA        AmaxB
  HalfSat      BFolResp     WltPnt        PsnAgeRed    Q10
  PsnTMin      PsnTOpt      SLWmax        SLWDel       k
  DVPD1        DVPD2        WUEcnst       MaintResp    DNSC
  RtStRatio    EstMoist     EstRad, KWdLit, KNWdLit
```

7.3 Parameter Table

All parameters for a species appear on a single line.

7.3.1 SpeciesName

The species name as it appears in the species parameter input file (see Chapter 6 of the *LANDIS-II Model User Guide*).

7.3.2 GrMstSens

Sensitivity of photosynthesis and growth rates to moisture stress. High values indicate high sensitivity (lower growth for a given moisture stress) according to dWater (water stress reduction factor) = wfps^ GrowthMoistureSensitivity, in which wfps is water filled pore space or (soilwater-wilting_point) / (whc-wilting_point) – all in mm. Value: decimal > 0.0 Units: none.

7.3.3 FolN

Foliar nitrogen content (%). Value: 0<decimal <10. Units: %.

7.3.4 TOfol

Turnover of Foliage - Fraction of foliage biomass lost per year. Typically the reciprocal of leaf longevity. Value: 0.0≤ decimal ≤1.0. Units: proportion per year.

7.3.5 FolRet

Foliage Carbon Retention - Fraction of foliage biomass returned to the non-structural carbon pool per year. Value: 0.0≤ decimal ≤1.0. Units: proportion per year.

7.3.6 TORoot, TOWood

Turnover of Root, Wood - Fraction of root or woody biomass (respectively) lost per year to damage, breakage or death. Value: 0.0≤ decimal ≤1.0. Units: proportion per year.

7.3.7 KWdLit, KNWdLit

Turnover of dead material - Fraction of woody or non-woody litter (respectively) lost per year. Value: 0.0≤ decimal ≤1.0. Units: proportion per year.

7.3.8 GDDFolStart

Growing degree days (base =PsnTMin (see below)) at which foliage production begins. Value: integer >0. Units: degree-days.

7.3.9 GDDFolEnd

Growing degree days (base =PsnTMin (see below)) at which foliage production ends. Value: integer >0. Units: degree-days.

7.3.10 CDDFolEnd

Chilling degree days (base =PsnTMin (see below)) that triggers foliage senescence. CDD is calculated beginning in August and foliage is shed at the beginning of the month in which CDD exceeds this value. Value: integer >0. Units: degree-days.

7.3.11 AmaxA

Intercept of relationship between foliar N and maximum net photosynthetic rate. Units: nmol CO_2 g^{-1} leaf s^{-1}. Value: -500<double<+500

7.3.12 AmaxB

Slope of relationship between foliar N and maximum net photosynthetic rate, such that Amax (nmol CO_2 g^{-1} leaf s^{-1}) = AmaxA + AmaxB*FoliarN. Units $\%N^{-1}$. Value: decimal >0.

7.3.13 HalfSat

Half saturation light level for photosynthesis. Lower values reflect more shade tolerance. Value: integer >0. Units: User choice. Typically μmol/m2/sec or W/m^2. The units of PAR in the climate input file must be the same as HalfSat. **THE MODEL WILL NOT CHECK TO ENSURE THAT THE UNITS ARE THE SAME.** This is a user responsibility.

7.3.14 BFolResp

Base Foliar Respiration Fraction - Foliar respiration as a fraction of maximum photosynthetic rate. Value: 0.0≤ decimal ≤1.0. Units: proportion.

7.3.15 WltPnt

Wilting Point - Fraction of WHC below which species are unable to take up water. Value: 0.0≤ decimal ≤1.0. Units: proportion.

7.3.16 PsnAgeRed

Reduction factor reducing leaf photosynthesis rate as cohorts age, beginning at age 1 and ending at the longevity specified in the LANDIS-II species parameter file. . A value <1.0 results in a rapid initial decline in max photosynthesis with age, a value of 1.0 results in a linear decline and a value >1.0 results in slow initial decline, according to y=(age/longevity)^PsnAgeDecline. Cohorts die when NSC is <1% of the value of the other biomass pools combined at the end of a calendar year. Value: 0.0< decimal <infinity. Units: proportion per year.

7.3.17 Q10

Respiration Q_{10} value for foliar respiration, a measure of the rate of change of respiration when temperature is increased by 10 °C. Value: 0.0≤ decimal ≤10.0. Units: none.

7.3.18 PsnTMin

Minimum temperature for photosynthesis. Value: decimal ≥0.0. Units: °C.

7.3.19 PsnTOpt

Optimal temperature for photosynthesis. Value: decimal ≥0.0. Units: °C.

7.3.20 SLWmax

Specific leaf weight at the top of canopy. Value: 0<decimal <1000. Units: g/m^2.

7.3.21 SLWDel

Rate of change in specific leaf weight from the top of the canopy to the bottom. Set to zero to make SLW constant throughout canopy. Value: 0.0≤ decimal ≤2. Units: g^{-1}fol.

7.3.22 k

Canopy light attenuation constant (light extinction coefficient). Value: 0.0≤ decimal ≤1.0. Units: none.

7.3.23 DVPD1, DVPD2

Coefficients for converting vapor pressure deficit (VPD) to DVPD according to DVPD = 1 -DVPD1 * vpd^DVPD2 (photosynthesis reduction factor due to vapor pressure). Value: decimal. Units: kPa-1.

7.3.24 WUECnst

Constant in equation for computing water use efficiency (WUE) as a function of VPD. WUE=WUEConst/VPD.   Higher values result in higher WUE. Value: decimal >0.0. Units: none.

7.3.25 MaintResp

Loss of NSC due to maintenance respiration, depends on biomass according to Loss = MaintResp * Biomass. Value: 0.0≤ decimal ≤1.0.   Units: proportion of NSC lost per month.

7.3.26 DNSC

Fraction of the current NSC pool that is allocated to structural biomass pools (i.e., all pools other than the non-structural carbon pool) per month. Allocations are made only during the growing season as defined by GDDFolStart and SenescStart. Value: 0.0≤ decimal ≤1.0. Units: proportion of NSC allocated per month.

7.3.27 RtStRatio

Root-Stem Ratio - Ratio of the size of root to stem biomass pools. For example RtStRatio=0.2 results in the root pool being 20% the size of the stem pool, and values >1 result in the root pool being greater than the stem pool. Allocations vary at each time step to maintain this ratio. Value: 0.0≤ decimal ≤5.0. Units: proportion.

7.3.28 EstMoist

Tuning parameter to control the sensitivity of establishment (Pest) to soil moisture. Calculated using (water/WHC)^EstMoist. High values make establishment more sensitive to moisture stress. A value of 1.0 results in a linear relationship between moisture stress and Pest, and little additional effect occurs with values over 50. Value: 0.0≤ decimal. Units: unitless.

7.3.29 EstRad

Tuning parameter to control the sensitivity of establishment (Pest) to light level (radiation). Calculated using(sub-canopy radiation/(2*HalfSat))^EstRad. High values make establishment more sensitive to radiation stress. A value of 1.0 results in a linear relationship between light availability and Pest, and little additional effect occurs with values over 50. Value: 0.0≤ decimal. Units: unitless.

7.4 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.

7.4.1 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.

7.4.2 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.

7.4.3 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.

7.5 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.

7.5.1 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.

7.5.2 Woody

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

7.5.3 Non-Woody

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

8 PnET-Succession Extension Outputs

The PnET-Succession Extension writes some output files directly. This section describes these outputs.

8.1 SiteData Table (Optional)

This comma-delimited table contains site-level PnET state variable values at the end of each month from the start of the spin-up period to the end of the simulation. The sites reported are specified in the input file. Values are for the entire cell and include the presence of all species and cohorts on the cell. Units for each variable are given in the header. This output is turned on in the PnET-Succession Input File by specifying the cell(s) to be output.

8.1.1 NrOfCohorts

Number of cohorts (all species) occurring on the cell.

8.1.2 Tday(C)

Mean air temperature (^{o}C) in the daytime, derived from TMin and TMax from the climate file.

8.1.3 Precip(mm_mo)

The monthly precipitation (as read from the climate file, mm/mo).

8.1.4 RunOff(mm_mo)

Monthly runoff that occurs from precipitation when the soil is saturated (mm/mo).

8.1.5 WaterLeakage(mm_mo)

Monthly loss of water from the soil via percolation through the rooting zone (leakage) (mm/mo).

8.1.6 Transpiration(mm_mo)

Monthly transpiration (mm/mo).

8.1.7 PrecipLoss(mm_mo)

Precipitation lost to evaporation and surface runoff as a function of the PrecipLossFrac parameter (mm/mo).

8.1.8 Water(mm)

Available soil water as calculated by the bulk hydrology model (mm).

8.1.9 SnowPack (mm)

Water equivalent contained in the snowpack (mm).

8.1.10 LAI(m2)

Leaf Area Index (all species combined)

8.1.11 VPD(kPa)

Mean vapor pressure deficit for the month (kPa).

8.1.12 GrossPsn(gC/mo)

Gross photosynthesis of all species combined (gC/mo).

8.1.13 NetPsn(gC/mo)

Net photosynthesis of all species combined (gC/mo).

8.1.14 AutoResp(gC/mo)

Autotrophic (living biomass) respiration of all species combined (gC/mo).

8.1.15 HeteroResp(gC/mo)

Heterotrophic (dead biomass) respiration (decomposition) of all species combined (gC/mo).

8.1.16 TotalBiomass(gDW)

Sum of aboveground woody biomass of all species (gDW).

8.1.17 TotalRoot(gDW)

Sum of root biomass of all species (gDW)

8.1.18 TotalFol(gDW)

Sum of foliage biomass of all species (gDW).

8.1.19 TotalNSC(gC)

Sum of NSC (Non-structural carbon) of all species (gC).

8.1.20 Litter(gDW)

Biomass (all species) in the litter dead biomass pool (gDW/m^2).

8.1.21 CWD(gDW/m^2)

Biomass (all species) in the coarse woody debris dead biomass pool (gDW/m^2).

8.2 CohortData Table (Optional)

This table contains monthly PnET cohort-level state variable values for the sites specified in the input file. A file is created when a cohort is established, and the records give month-end state variable values for the cohort from establishment to death (or the end of the simulation). Files are also produced for cohorts established during the spin-up period. Units for each variable are given in the header. This output is turned on in the PnET-Succession Input File by specifying the cell(s) to be output.

8.2.1 Age

Current age of the cohort (calendar years).

8.2.2 CanopyLayer

The canopy layer that the cohort is part of. Canopy layers are numbered from bottom to top, with 0 (zero) being the lowest layer.

8.2.3 PAR0(W_m2)

PAR (photosynthetically active radiation) reaching the canopy layer of which this cohort is a part (W/m2).

8.2.4 Leaf-On

Flag indicating growing season status. Is FALSE before new leaves are added and again after leaf senescence; is TRUE during the growing season. This flag is initialized to TRUE, so it may be TRUE before the first growing season begins.

8.2.5 LAI(m2)

Leaf area index of the cohort.

8.2.6 GDD(C) base=PsnTMin

Cumulative growing degree days (^{o}C) experienced by the cohort since the beginning of the calendar year. Base temperature = PsnTmin.

8.2.7 GrossPsn(gC/m2/mo)

Cohort gross photosynthesis (gC/m2/mo).

8.2.8 FolResp(gC/m2/mo)

Cohort foliar respiration (gC/m2/mo).

8.2.9 MaintResp(gC/m2/mo)

Cohort maintenance respiration, including tissue repair and nutrient transport (gC/m2/mo). This amount comes out of the NSC pool.

8.2.10 NetPsn(gC/m2/mo)

Cohort net photosynthesis (gC/m2/mo).

8.2.11 ReleasedNSC (gC/m2/mo)

Amount of NSC released from the NSC pool and allocated to structural carbon pools (gC/mo).

8.2.12 Folalloc(gC/m2/mo)

Amount of carbon allocated to foliage (gC/m2/mo).

8.2.13 RootAlloc(gC/m2/mo)

Amount of carbon allocated to roots (gC/mo).

8.2.14 WoodAlloc(gC/m2/mo)

Amount of carbon allocated to aboveground wood (gC/mo).

8.2.15 VPD(kPa)

Mean vapor pressure deficit during the month (kPa).

8.2.16 WUE(g/mm)

Cohort mean water use efficiency (g/mm).

8.2.17 DelAmax(-)

Response factor in the photosynthesis calculation due to higher atmospheric CO_2.

8.2.18 Transpiration(mm/mo)

Cohort water actually lost to transpiration (mm/mo).

8.2.19 Fol(gDW/m^2)

Biomass of the cohort foliage pool (gDW/m^2).

8.2.20 Root(gDW/m^2)

Biomass of the cohort root pool (gDW/m^2).

8.2.21 Wood(gDW/m^2)

Biomass of the cohort wood pool (gDW/m^2).

8.2.22 NCS(gC/m^2)

Amount of carbon in the cohort non-structural carbon pool (gC/m^2). Cohorts die when NSC is <1% of the value of the other biomass pools combined at the end of a calendar year.

8.2.23 fWater(-)

Reduction factor related to water availability.

8.2.24 fTemp_psn(-)

Reduction factor related to sub-optimal temperature for photosynthesis.

8.2.25 fTemp_resp(-)

Reduction factor related to temperature effects on maintenance respiration.

8.2.26 fAge(-)

Reduction factor for age-related declines in photosynthesis efficiency.

8.2.27 fRad(-)

Reduction factor related to mean light availability across all sub-canopy layers within the canopy layer occupied by the cohort.

8.3 SiteEstData Table (Optional)

This comma-delimited table reports site-level values related to species establishment at their levels at the end of each month. The sites reported are specified in the input file. Units for each variable are given in the header. This output is turned on in the PnET-Succession Input File by specifying the cell(s) to be output.

8.3.1 Water(mm)

Amount of water in the soil (mm).

8.3.2 SubCanopyPAR(user-defined)

PAR (photosynthetically active radiation) reaching the ground (user-defined in input files).

8.3.3 Pest_speciesname

There is a column for each species containing the calculated probability of establishment as a function of the values of water and PAR. Pest = fRad^EstRadSensitivity*fWater^EstMoistSensitivity.