LANDIS-II Net Ecosystem Carbon and Nitrogen (NECN) Succession v6.0 Extension User Guide

Robert M. Scheller[1]
Melissa S. Lucash[2]
Alec Kretchun[2]

[1]North Carolina State University
[2]Portland State University

Last Revised: December 6, 2018

Table of Contents

1 Introduction

This document describes the **Net Ecosystem Carbon and Nitrogen (NECN) Succession** extension for the LANDIS-II model. For information about the LANDIS-II model and its core concepts including succession, see the *LANDIS-II Conceptual Model Description* and the LANDIS-II website (www.landis-ii.org).

The NECN Succession Extension calculates how cohorts grow, reproduce, age, and die (Scheller et al. 2011). Dead biomass is tracked over time, divided into four pools: surface wood, soil wood (dead coarse roots), surface litter (dead leaves), and soil litter (dead fine roots). In addition, three principle soil pools: fast (soil organic matter (SOM) 1), slow (SOM2), and passive (SOM3) are simulated, following the Century soil model (Parton et al. 1993, Schimel et al. 1994, Parton et al. 1994, Pan et al. 1998).

For a schematic drawing of the NECN extension, see Scheller et al 2011.

1.1 Cohort Reproduction – Probability of Establishment

The probability of establishment (P_{EST}) is internally calculated at an annual time step and is dependent upon input weather data. Although calculated annually, establishment can only occur following a disturbance or at a succession time step. P_{EST} is based on the minimum of three limiting factors: 1) growing degree days (GDD), 2) drought tolerance, 3) minimum January temperature. These represent **site-scale** limits to species establishment in that the requisite parameters vary by ecoregion. Available light is calculated as a function of LAI (via the MaximumLAI table, described below) and is included as a part of the **site scale** limits to establishment.

1.2 Cohort Growth

At each time step, cohort growth is determined by estimated leaf area index (LAI), water availability, temperature, growing space capacity and nitrogen availability. Cohort growth generally follows the algorithms found in Century, except for N uptake. In the spring, the amount of resorbed N is calculated (leaf N - litter N), which can be “used” by the cohort when conditions are conducive to growth. In hardwoods, resorbed N is used primarily in the spring; resorbed N can be utilized throughout the year in conifers. After the pool of resorbed N is depleted, the cohort takes up N from the mineral N pool. Uptake of N is proportional to above-ground net primary productivity (ANPP), with greater N uptake by faster growing cohorts. When mineral N is limiting, competition for N between cohorts is determined by the relative amount of their coarse root biomass.

1.3 Soil and Dead Biomass Decay

Decay processes generally follow the algorithm and science from Century v4.5 whereby there are four litter pools (structural and metabolic material either on the surface or within the soil) and three soil organic matter (SOM) pools (SOM 1,2,3). SOM1 is further subdivided into SOM1 surface and SOM1 soil.

Decay rates of SOMsurf, SOM1soil, SOM 2 and SOM 3 are universal.

1.4 Initializing Biomass and Soil Properties

The initial biomass is provided by the user and therefore there is no model "spin-up".

Note: *An initial (time zero) climate stream is still required for initialization (see the climate library user's manual- LANDIS-II Climate Library v1.0 User Guide). This is an artifact of the Climate Library and this data is not used.*

The user MUST supply the initial biomass estimates for each cohort. This is described below.

1.5 Interactions with Disturbances

NECN provides an interface to dead biomass for all disturbances, regardless whether they are Base ('age-only') or Biomass disturbances. For example, a User is able to run the Base Wind extension with NECN Succession. Although the wind disturbance extension is not 'biomass aware', the extension enables the biomass of cohorts killed by the disturbance to be allocated to the proper dead biomass pools.

1.6 Available Light

Available light (the conceptual inverse of shade) calculations uses cumulative LAI to determine the amount shade.

1.7 Cohort Reproduction – Disturbance Interactions

See the rules and algorithm outlined for Biomass Succession (v2).

1.8 Cohort Reproduction – Initial Biomass

See the rules and algorithm outlined for Biomass Succession (v2).

1.9 Cohort Senescence

See the rules and algorithm outlined for Biomass Succession (v2).

1.10 Major Releases

1.10.1 Version 6.0 (September 2018)

Compatible with Core v7.

1.10.2 Version 5.0 (April 2018)

NECN v5.0 departs from previous NECN versions and *all prior succession extensions* in several important ways:

- *Ecoregions are no longer used to define abiotic conditions.* This extension is essentially 'ecoregion free'. Soils vary site-to-site. Climate is grouped into climate regions.
- The extension does not 'spin up'. All initial parameters, including species biomass, are provided at time zero. This eliminates the initial processing time required during spin-up and initial conditions reflect available data.
- Establishment probabilities are calculated per site, per succession time step. Available light is calculated as a function of LAI and is included as a part of the **site scale** limits to establishment.
- Growth-related mortality is now a function of ANPP, similar to the algorithms in Biomass Succession.

1.10.3 Version 4.2 (June 2017)

Added compatibility with the Metadata Library. The Metadata Library outputs metadata for all model outputs, allowing compatibility with visualization tools.

In addition, a fix is provided to provide proper allocation of dead material when partial cohort removal is used during biomass harvesting.

1.10.4 Version 4.1 (September 2016)

In version 4.1, we renamed what was the Century Succession extension to the Net Ecosystem Carbon and Nitrogen (NECN) Succession extension. We did so for clarity. This extension is now so substantially different from Century (see changes listed below) that the name is no longer justified. In addition, many people were confused about the distinctions between this extension and the CENTURY model. From the beginning, the only similarity was the belowground processing of soil organic matter. The CENTURY model (all versions) does not simulate succession or changing tree species dominance; this extension always did.

In addition, v4.1 now uses the Biomass Libraries. This enables this extension – in addition to Biomass Succession and PnET Succession to use the same Biomass extensions (including Land Use, Drought, Fuels, Harvest, Insects, Output, Reclassification Output, and Biomass-by-Age). The Leaf Biomass extensions therefore will be retired.

1.10.5 Version 4.0

In version 4.0, we added a climate library to the NECN extension to enable a suite of LANDIS-II model extensions to use the same stream of climate data (see the climate library user's manual (LANDIS-II Climate Library v1.0 User Guide). By feeding in climate data only once, the climate is seamlessly integrated across all extensions specified in the scenario file. As outlined in the climate library user's guide, the user can feed in daily or monthly data without having to calculate standard deviation like in NECN version 3.1 or earlier.

In this version, we also significantly revised the soil water algorithms, correcting errors in the timing of snowfall, snowmelt, runoff and available water.

We modified retranslocation for conifers so that they could utilized the resorbed N throughout the year. In previous versions, conifers were restricted to using resorbed N in the spring (like hardwoods), but in this version, conifers are able to use this N source whenever tree growth is occurring.

We modified the calibrate mode so that it runs from July to June, the same way the model normally runs (see Section 1.10.4). In previous versions of NECN, the calibrate mode ran from Jan to Dec.

We also corrected several minor errors. We corrected an error in units, which was causing baseflow to be an order of magnitude higher than the stormflow in previous versions of NECN. We corrected an error in the calibration mode that caused the trees to grow faster than in normal mode. We modified LAI so that it was set to zero in hardwoods when leaf drop occurred and modified the BTOLAI and KLAI parameters to make them easier to calibrate. Finally, we corrected an error in the N intercept parameter, which was not being used in the calculation of N deposition. Now both the N slope and intercept parameters can influence N deposition to account for wet (slope) and dry (intercept) deposition.

Finally, we increased the range of soil organic matter inputs to account for the large amount of carbon stored in productive forests, like in the Pacific Northwest. We also reduced the minimum fraction of leaf biomass (Fcfrac) allowed in the input file to account for the small ratio of leaf: wood biomass in these forests.

1.10.6 Version 3.1

We fixed frass N, which was artificially creating large increases in mineral N during defoliation events when NECN was run with the Leaf Biomass Insects Extension. Now when insect defoliation occurs, there is a small increase in frass N that corresponds to values observed in the field.

In the NECN output table, we redefined the soil N pool by removing the surficial dead wood and soil dead wood. This makes the soil N pool consistent with the soil C pool, which doesn't include dead material.

We also adjusted the mineral N so that it can not be depleted to zero, which caused errors for N uptake until more N deposition occurred. Now mineral N can be very small (<0.01) but not zero, allowing the calculation of N uptake even when the rates are very low.

1.10.7 Version 3.0

In this version of NECN, we made major improvements to **nitrogen cycling**, made minor changes to **belowground productivity**, **probability of establishment**, and added an **output file** that is generated when NECN is run in calibrate mode.

Nitrogen cycling in previous versions of NECN Succession focused primarily on how N regulates C cycling, rather than describing N dynamics, per se.

In version 3.0, total nitrogen, (NH_4^+, NO_3^-, and organic N), is now fully integrated throughout the extension with all the major inputs (deposition, N-fixation, insect frass), outputs (leaching and volatilization) and fluxes (resorption, litterfall, uptake, decomposition) simulated within the extension. This allows users to track C and N cycling in their landscape and better understand the relative importance of N in regulating productivity.

Specifically, we added N resorption, the amount of N withdrawn from the leaves just prior to senescence. Retranslocation is a significant source of N uptake in the spring and can be 10-80% of N uptake depending on species, site and the time since disturbance (Killingbeck 1996, Covelo et al. 2008). Retranslocation for each cohort is calculated in August of each year as the difference between leaf and litter N, and is used the following spring to satisfy the cohorts' early demand for N. After the resorptive pool is depleted, the cohort satisfies its need for N by withdrawing N from the soil (i.e. mineral N).

We also added insect frass to the C and N budget. Most large insect outbreaks occur in the summer before retranslocation occurs, causing a significant decline in the ability of trees to resorb N and potentially decreasing growth the following spring (Lovett et al. 2002). The addition of C and N in frass can cause changes in decomposition rates, which may affect long-term nutrient availability and productivity. In the extension, defoliation events trigger deposition of frass C and N deposition, the relative amount of which is a function of the amount of leaf biomass removed during defoliation. Since C/N ratio of frass (C/N =23 from Lovett and Ruesink, 1995) may differ from litterfall, frass can also cause changes in the decomposition rates of the soil pools that can affect long-term carbon cycling and productivity.

We added N leaching which is a function of soil texture, the amount of available mineral N and the relative rates of base and storm flow. The calculations are based on the original CENTURY model by Parton et al. (1983), though modified so that only NO_3^- (and not total N) is leached from soils. The direct loss of mineral N to the atmosphere – not dependent upon fire as an agent - was modified so that the relative amount can vary with different ecosystems within the landscape. The relative amount of N loss through ammonia volatilization and denitrification is now an input parameter for each ecoregion. This is particularly useful when the landscape includes both uplands and wetlands, since wetlands have a much higher denitrification rates than uplands (Seitzinger et al. 2006). Overall, ammonia volatilization is relatively low (<0.1 g m-2 y-1) from unfertilized forest ecosystems (Schlesinger and Hartley 1992), but denitrification rates can be significant, especially in forested wetlands (0.8 g m^{-2} y^{-1}, (Seitzinger et al. 2006).

We modified how N limits aboveground productivity, switching from a categorical (i.e. N tolerance) to a more process-based approach. When N is limiting, mineral N is allocated between cohorts based on their biomass (i.e. coarse root biomass). This value is divided by the N demand for each cohort (amount of N needed for growth) to get a relative index (0-1) of how much N is limiting growth for that cohort.

N limitation = N allocation / N demand

We added input parameters for the decay rates of the fast-cycling soil pool so the user can better regulate the respiration and N mineralization rates of the SOM1surf and SOM1soil pools. The decay constants of all three soil pools (fast, slow and passive) can now be adjusted to ensure that the relative decomposition rates between pools are realistic and reflect the expected annual changes in each pool.

We modified the relationship between **belowground** and aboveground **productivity**, based on new studies (Albaugh et al. 2006, Park et al. 2008). We increased belowground productivity, such that fine root biomass is now 75% of leaf biomass (was 70% in v2) and coarse root biomass is 50% (rather than 30%) of wood biomass.

We added an input parameter that adjusts the **probability of establishment** based on the time step you specify in NECN. This allows users to account for differences in establishment depending on the succession timestep. The expectation is that shorter time steps will have smaller P_{EST}. For example, if you were operating at a 5-year time step and you decided to step it down to a 1-year time step, the adjustment factor of 0.2 should be applied to arrive at equivalent P_{EST}.

We also added a new **output file** that is generated when NECN is run in calibrate mode. This output file allows the user to (among other things) determine what is limiting growth of each cohort at each time step.

We added a new **optional** parameter table that can be used in conjunction with the Leaf Biomass Harvest extension (see "LANDIS-II Leaf Biomass Harvest v2.0 User Guide"). This table indicates the proportion of dead wood and leaf biomass that should be removed as a function of a specific harvest activity. The dead biomass includes cohorts killed from the harvest activity and dead biomass (e.g., coarse woody debris, leaf litter) already present in the forest. **If this table is not used, the harvested cohorts will be follow the parameters in the age-only-disturbance file (see below).** This table may be used if, for example, after a harvest event, a controlled burn would be applied to a stand to remove a proportion of leaf litter and coarse woody debris. *If the table is used be sure to remove harvesting from the age-only-disturbance file.*

1.10.8 Version 2.0

NECN Succession is now compatible with LANDIS-II v6.0. All succession extensions for v6.0 are required to include the initial communities text file and inputs map. Previously these were input in the **Scenario** file. These details are outlined below. Internal Time Steps

Although NECN Succession is limited to annual or multiple-year time steps, **cohort growth and soil decomposition operate at a monthly time step**. Both growth and decomposition reflect monthly climate and monthly climate is a required input.

Because most disturbances occur in the summer months, the monthly cycle proceeds from July to June. Therefore, **disturbances and reproduction both occur between June and July**.

1.11 Minor Releases

1.11.1 Version 6.0.1 (December 2018)

Corrected a bug in the Leaf-biomass-cohorts library that was preventing correct biomass reduction under partial cohort removal (e.g., harvest thinning). Added error message if a species or functional group is missing. Correct minor rounding error.

1.11.2 Version 4.1.1

In version 4.1.1, we fixed a bug that was preventing users from running the harvest extension with NECN.

1.11.3 Version 4.0.2

In version 4.0.2, we fixed a bug that was caused NECN to crash when it was run with harvesting due to a conflict between reseeding and planting. We also fixed a bug in PET that was preventing winter respiration. We reduced the acceptable range of values for field capacity and wilting point.

1.11.4 Version 4.0.1

In version 4.0.1, we fixed a bug that was causing NECN to ignore the timestep specified in the input file and using the timestep supplied by Dynamic Fire. This was only an issue when both NECN and Dynamic Fir were enabled in the scenario fire.

1.11.5 Version 3.1.1

We eliminated the ClimateChangeTable in the NECN input file. It was not used to calculate ANPP in versions 3.0 or 3.1, so it was removed from the code to eliminate any confusion.

1.12 References

Aber, J.D., D.B. Botkin, and J.M. Melillo. 1979. Predicting the effects of different harvesting regimes on productivity and yield in northern hardwoods. Canadian Journal of Forest Research **9**: 10-14.

Albaugh, T., H. Allen, and L. Kress. 2006. Root and stem partitioning of *Pinus taeda*. Trees - Structure and Function 20:176-185.

Botkin, D.B., J.F. Janak, and J.R. Wallis. 1973. Some ecological consequences of a computer model of forest growth. Journal of Ecology **60**: 849-872

Covelo, F., J. Duran, and A. Gallardo. 2008. Leaf resorption efficiency and proficiency in a *Quercus robur* population following forest harvest. Forest Ecology and Management.

Johnson, D. W., M. E. Fenn, W. W. Miller, and C. T. Hunsaker. 2009. Fire effects on carbon and nitrogen cycling in forests of the Sierra Nevada. Pages 405-423 in A. Bytnerowicz, M. Arbaugh, C. Andersen, and A. Riebau, editors. Wildland Fires and Air Pollution. Developments in Environmental Science 8. Elsevier, The Netherlands.

Killingbeck, K. T. 1996. Nutrients in senesced leaves: Keys to the search for potential resorption and resorption proficiency. Ecology 77:1716-1727.

Lovett, G. M., L. M. Christenson, P. M. Groffman, C. G. Jones, J. E. Hart, and M. J. Mitchell. 2002. Insect defoliation and nitrogen cycling in forests. BioScience 52:335-341.

Lovett, G. M. and A. E. Ruesink. 1995. Carbon and nitrogen mineralization from decomposing gypsy moth frass. Oecologia 104:133-138.

Kimmins, J. P., D. Mailly, and B. Seely. 1999. Modelling forest ecosystem net primary production: the hybrid simulation approach used in FORECAST. Ecological Modelling 122:195-224.

Pan, Y., J.M. Melillo, A.D. McGuire, D.W. Kicklighter, L.F. Pitelka, K. Hibbard, L.L. Pierce, S.W. Running, D.S. Ojima, W.J. Parton, D.S. Schimel, and VEMAP Members. 1998. Modeled responses of terrestrial ecosystems to elevated atmospheric CO_2: a comparison of simulations by the biogeochemistry models of the Vegetation /Ecosystem Modeling and Analysis Project (VEMAP). Oecologia 114: 389-404.

Park, B., R. Yanai, T. Fahey, S. Bailey, T. Siccama, J. Shanley, and N. Cleavitt. 2008. Fine root dynamics and forest production across a calcium gradient in northern hardwood and conifer ecosystems. Ecosystems 11:325-341.

Parton, W. J., D. S. Ojima, C. V. Cole, and D. S. Schimel. 1994. "A General Model for Soil Organic Matters Dynamics: Sensitivity to Litter Chemistry, Texture and Management." Pp. 147-67 in Quantitative Modeling of Soil Forming Processes: Proceedings of a Symposium Sponsored by Divisions S-5 and S-9 of the Soil Science Society of America Minneapolis, Minnesota, USA, editors R. B. Bryant and R. W. Arnold. Madison, Wisconsin, USA: Soil Science Society of America.

Parton, W.J., J.M.O. Scurlock, D.S. Ojima, T.G. Gilmanov, R.J. Scholes, D.S. Schimel, T. Kirchner, J.C. Menaut, T. Seastedt, E. Garcia Moya, A. Kamnalrut, and J.I. Kinyamario. 1993. Observations and modeling of biomass and soil organic matter dynamics for the grassland biome worldwide. Global Biogeochemical Cycles 7: 785-809.

Ryan, D. F. and F. H. Bormann. 1982. Nutrient resorption in northern hardwood forests. BioScience 32:29-32.

Scheller, R. M., D. Hua, P. V. Bolstad, R. A. Birdsey, and D. J. Mladenoff. 2011. The effects of forest harvest intensity in combination with wind disturbance on carbon dynamics in Lake States mesic forests. Ecological Modelling 222:144-153.

Scheller, R.M., S. Van Tuyl, K. Clark, J. Hom, I. La Puma. 2011. Carbon sequestration in the in the New Jersey pine barrens under different scenarios of fire management. Ecosystems. DOI: 10.1007/s10021-011-9462-6

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.

Schimel, D.S., B.H. Braswell, E.A. Holland, R. McKeown, D.S. Ojima, T.H. Painter, W.J. Parton, and A.R. Townsend. 1994. Climatic, edaphic, and biotic controls over storage and turnover of carbon in soils. Global Biogeochemical Cycles 8: 279-293.

Seitzinger, S., J. A. Harrison, J. K. Böhlke, A. F. Bouwman, R. Lowrance, B. Peterson, C. Tobias, and G. V. Drecht. 2006. Denitrification across landscapes and waterscapes: A synthesis. Ecological Applications 16:2064-2090.

Schlesinger, W. H. and A. E. Hartley. 1992. A global budget for atmospheric NH_3. Biogeochemistry 15:191-211.

1.13 Acknowledgments

Funding for the development of LANDIS-II has been provided by the Climate Change Program (New Town Square, Pennsylvania) of the U.S. Forest Service. Funding for NECN version 3.2 – 4.1 has been provided by USDA AFRI.

2 Succession Input File

Nearly 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*.

2.1 LandisData

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

2.2 Timestep

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

Note: When changing the timestep of this extension (e.g., from a 5-year time step to a 1-year time step), you may need to adjust the probability of establishment adjustment factor (ProbEstablishAdjust) to retain the same regeneration rates (see section 2.13 below).

2.3 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*.

2.4 InitialCommunities

This parameter is the file with the definitions of the initial communities at the active sites on the landscape (see section 4).

2.5 InitialCommunitiesMap

This parameter is the input map indicating the initial communities at the active sites 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 (see section 4).

2.6 ClimateConfigFile

The climate configuration file contains required climatic inputs. The format of that file and its contents are described in the climate library user's manual (LANDIS-II Climate Library v1.0 User Guide).

2.7 SoilDepthMapName

The depth of the soil simulated, cm.

User Tip: The depth specified here has a large influence on soil water holding capacity.

2.8 SoilDrainMapName, SoilBaseFlowMapName, SoilStormFlowMapName

Determines the amount of water runoff and leaching. This affects the amount of N leaching (N loss) which, in turn, affects the amount of mineral N.

- Drain - the fraction of excess water lost by drainage. The soil drainage factor allows a soil to have differing degrees of wetness (e.g., DRAIN=1 for well drained sandy soils and DRAIN=0 for a poorly drained clay soil).
- BaseFlow - fraction per month of subsoil water going into stream flow
- StormFlow - the fraction of the soil water content lost as fast stream flow

2.9 SoilFieldCapacityMapName, SoilWiltingPointMapName

Field capacity and wilting point expressed as a fraction (range from 0.0 to 1.0). In the model algorithms, field capacity and wilting point are calculated as this fraction multiplied by soil depth.

2.10 SoilPercentClayMapName, SoilPercentSandMapName

Percent clay and sand are expressed as a fraction (0.0 – 1.0).

2.11 InitialSOM1CsurfMapName

The initial (time 0) amount of C in the soil surface, typically assumed to include the humus layer (g m^{-2}).

2.12 InitialSOM1NsurfMapName

The initial (time 0) amount of N in the soil surface (g m^{-2}).

2.13 InitialSOM1CsoilMapName

The initial (time 0) amount of C in the soil sub-surface; SOM1 indicates that this is the most labile C (g m^{-2}).

2.14 InitialSOM1NsoilMapName

The initial (time 0) amount of N in the soil sub-surface.

2.15 InitialSOM2CMapName

The initial (time 0) amount of C in the ‘slow’ soil pool (SOM2) (g m^{-2}).

2.16 InitialSOM2NMapName

The initial (time 0) amount of N in the ‘slow’ soil pool (SOM2) (g m^{-2}).

2.17 InitialSOM3CMapName

The initial (time 0) amount of C in the ‘passive’ soil pool (SOM3) (g m^{-2}).

2.18 InitialSOM3NMapName

The initial (time 0) amount of N in the 'passive' soil pool (SOM3) (g m^{-2}).

2.19 InitialDeadWoodSurfaceMapName

The initial (time 0) amount of surficial dead woody material, e.g., logs (g m^{-2}).

2.20 InitialDeadWoodSoilMapName

The initial (time 0) amount of belowground dead woody material, e.g., dead roots (g m^{-2}).

2.7 CalibrateMode

Determines whether the model is run in calibrate mode whereby additional parameters are added to a log file ("NECN-calibrate-log.csv"). **The calibrate mode should only be used when simulating a single site due to the volume of model output in the calibrate log file.** The intention is to view output of additional parameters, such as what factors are limiting growth at each time step.

2.8 SmokeModelOutputs

These are outputs specific to subsequent (external) calculations of smoke emissions. If true, maps of conifer needle biomass, surface dead wood, and SOM1-surface (litter) are produced.

2.9 Water Decay Function

The WaterDecayFunction parameter determines the effect of moisture on decay rate can be either linear or based on a ratio. The Century 4.0 Help file states that linear option is to be when only the relative water content in the top 15 cm affects decay rates. If ratio, the ratio of rainfall to potential evaporation rate determines the effect of moisture on decay rates.

Options: "Linear" or "Ratio"

User Tip: *Linear is generally appropriate for sandy soils; ratio for more mesic soils.*

2.10 Probability of Establishment Adjustment

This optional parameter adjusts the probability of establishment. The default value is one.

User Tip: *This value can be reduced (<1) if overall regeneration rates are too high. Keep in mind that p-est is dependent on the successional time step. For example, you might want to lower the adjustment factor if you shift from a 5-year time step to a 1-year time step.*

2.11 InitialMineralN

The amount of mineral N (g m^{-2}).

2.12 InitialFineFuels

The amount of fine fuel biomass (internally, the SoilStructural and SoilMetabolic layers) as a fraction of initial dead wood. This accounts for recent disturbance that may have deposited large volumes of both dead wood and fine fuels.

2.21 Nitrogen Inputs- Slope, Intercept

Determines N deposition rates (including wet deposition, dry deposition, non-symbiotic fixation and N fertilization) using simple regression:

Total N deposition = (AtmosNslope*precipitation) + AtmosNinter

The AtmosNslope parameter controls how the amount of wet deposition, i.e. how much N is deposited during rain events, with higher slopes generating more N deposition. Dry deposition is controlled by the N intercept parameter, which is constant and is not a function of precipitation.

User Tip: *Adjust the slope and intercept until the monthly or annual N deposition in the NECN-succession-monthly-log.csv is similar to literature values.*

2.13 Latitude

The latitude of the study site (°).

2.13.1 N volatilization and Denitrification

The fraction of mineral N lost through ammonia volatilization and denitrification **per month**. This fraction is not fire related; fire related volatilization is modeled separately. Units: dimensionless.

User Tip: *This parameter should be adjusted so that Nvol (output parameter of N volatilization) ranges from 0 to ~0.3 for uplands and 0.3 to 1 g m^{-2} $year^{-1}$ for wetlands (Seitzinger et al. 2006).*

2.13.2 Decay Rates of SOM1 surface, SOM1 soil, SOM2 and SOM3

The decay rates for SOM1-surface, SOM1-soil, SOM2, and SOM3 determine the **maximum** decomposition rate (k) of the four soil organic matter pools.

User Tip: *The decay rates should be adjusted to so that the changes in each of the soil pools between year 0 (input file) and year 1 are realistic. In most landscapes, the relative changes in the soil pools are higher in the upper than the lower horizons. Therefore, the maximum decay rates should be higher in the surficial than the deeper pools (i.e. DecayRateSurf>DecayRateSOM1> DecayRateSOM2>DecayRateSOM3). Also,* *the total amount of C in soil should slowly increase over time in the absence of disturbance.*

2.14 MaximumLAI Table

The `MaximumLAI` table defines how much Leaf Area Index must be at a site to achieve the five available light classes (in previous extensions, 'shade classes'). LAI is cumulative at a site. The table contains the maximum LAI required for each available light class, 1 - 5.

2.14.1 Available Light Class

This column contains available light class values: 1 ≤ integer ≤ 5. The classes must be in increasing order: class 1 first and ending with class 5. Available light class 5 represents the least light (most shade). A site will be class 0 (complete light) if LAI ranges from 0 up to the maximum LAI (%) for class 1. Likewise, if maximum LAI is between the amount defined for classes 1 and 2, the site is given an available light class of 1. And so on up to class 5.

2.14.2 Maximum LAI

Each light class has an associated maximum LAI. Value: 0.0 ≤ decimal number ≤ 20.0.

2.15 LightEstablishmentTable

This table allows the user to control site-scale P_{EST} dependent upon species light requirements (i.e., shade class) and available light. For example, if a species is mid-tolerant of low light (light requirement = 3) and the available light class is 5 (very low light), the probability may be low but not zero. If the user indicates a low probability, then there would still some small chance that a mid-tolerant can become established as may be the case in small gaps.

2.15.1 Species Shade Tolerance Class

This column contains light requirement (shade) class values: 1 ≤ integer ≤ 5. The classes must be in increasing order: class 1 first and ending with class 5. Class 5 represents species with the lowest light requirements, i.e., the most shade tolerant.

2.15.2 Probability of Establishment, given light conditions

Each possible site-level light condition (0 – 6) has an associated probability for each species light requirement class (1 – 5). Value: 0.0 ≤ decimal number ≤ 1.0.

2.16 SpeciesParameters Table

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

2.16.1 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.

2.16.2 Functional Type

This is an index into the `FunctionalTypeParameters` table, below.

2.16.3 Nitrogen Fixers

This should be either yes (Y) or no (N), depending on whether the species can fix N.

2.16.4 GDD minimum/maximum

Growing Degree Day (GDD) maximum and minimum are used to define a species climatic envelope following the algorithm by Botkin (1973). GDD is calculated on a 5°C base.

2.16.5 Minimum January Temperature

A species has a minimum tolerable January temperature (the mean of January nights). If the stochastically generated January minimum temperature is below the minimum, a species cannot establish. Units: degrees Celsius.

2.16.6 Maximum Allowable Drought

If available water falls below zero for a percent of the growing season greater than this value, a species cannot establish. Units: fraction of the growing season (0.0 – 1.0). Lower values indicate species whose establishment is more sensitive to drought.

2.16.7 Leaf Longevity

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

2.16.8 Epicormic resprouting

Does the species resprout via epicormic branching following a fire? Value: Y/N; yes, no.

2.16.9 Lignin: Leaf, Fine Root, Wood, Coarse Root

The fraction of lignin in each plant component (leaf, fine root, wood, and coarse root) per species. Value: 0.0 ≤ decimal number ≤ 1.0.

2.16.10 CN Ratios: Leaf, Fine Root, Wood, Coarse Root, Litter

The carbon to nitrogen ratios for leaf, fine root, wood, coarse root, and litter components. The difference between leaf and litter CN ratios represents the amount of N that is resorbed (i.e. retranslocated) prior to leaf mortality.

Note: *For retranslocation to work properly, litter CN* ***must be*** *higher than leaf CN for each species.*

2.16.11 Maximum ANPP

This parameter is the maximum possible aboveground net primary productivity (ANPP) for each cohort of each species. The value is specified as the ANPP in the month of the year with maximum growth (e.g., June). Value: $0 \leq$ integer $\leq 100{,}000$. Units: g biomass m^{-2} $month^{-1}$. Default value: 0.

Note: This parameter is in units of biomass but output from Landis-NECN is in units of C (C generally comprises roughly 50% of biomass).

Note: This is the maximum monthly ANPP during peak growing season, not the annual ANPP often reported in the literature.

2.16.12 Maximum Biomass

This parameter defines the maximum allowable aboveground biomass (AGB) for each species. This is a life history attribute and determines the overall growth form of a species (shrub vs. understory vs. overstory) as determined by evolutionary history. This parameter interacts with KLAI and ANPP to determine the growth rate and maximum biomass of each species. Value: $0 \leq$ integer. Units: g biomass m^{-2}. Default value: 0.

2.17 Functional Group Parameters

These parameters are either not generally resolved to the level of species or are similar across genera. **The number of functional groups cannot exceed 25.**

2.17.1 Name

The name is for display purposes only to help users organize the inputs.

2.17.2 Functional Type

An index to the species table.

2.17.3 PPDF: 1, 2, 3, 4

- These four parameters define a temperature growth curve. ppdf(1)- optimum temperature for production for parameterization of a Poisson Density Function curve to simulate temperature effect on growth
- ppdf(2) - maximum temperature for production for parameterization of a Poisson Density Function curve to simulate temperature effect on growth

- ppdf(3) - left curve shape for parameterization of a Poisson Density Function curve to simulate temperature effect on growth
- ppdf(4) - right curve shape for parameterization of a Poisson Density Function curve to simulate temperature effect on growth

For a more detailed explanation of these parameters, see the CENTURY 4.5 manual and help files (https://www2.nrel.colostate.edu/projects/century/MANUAL/html_manual/man96.html).

2.17.4 FRACleaf

The fraction of aboveground net primary productivity that is allocated to leaves. Units: fraction of ANPP (0.0 – 1.0).

2.17.5 BTOLAI, KLAI, MAXLAI

These three parameters determine how LAI is calculated which subsequently limits growth. Therefore these parameters help determine the initial rate of growth in the landscape. BTOLAI - biomass to leaf area index (LAI) conversion factor for trees

- KLAI - large wood mass (g C/m^2) at which half of theoretical maximum leaf area (maxlai) is achieved
- MAXLAI - theoretical maximum leaf area index achieved in a mature forest and is additive within a cell

For definitions, see the Century 4.5 on-line manual (http://www.nrel.colostate.edu/projects/century/manual4/man96.html). BTOLAI determines LAI as a function of leaf biomass. KLAI and MAXLAI determine LAI as a function of wood biomass. If MAXLAI = 0.0, then only leaf biomass determines LAI and the growth limits.

For a more detailed explanation of these parameters, see the CENTURY 4.5 manual and help files (https://www2.nrel.colostate.edu/projects/century/MANUAL/html_manual/man96.html).

2.17.6 PPRPTS2, PPRPTS3

These two parameters determine growth sensitivity to low available water, e.g., drought conditions.

- pprpts(2) - the effect of water content on the intercept
- pprpts(3)- the lowest ratio of available water to potential evapotranspiration at which there is no restriction on production

For a more detailed explanation of these parameters, see the CENTURY 4.5 manual and help files (https://www2.nrel.colostate.edu/projects/century/MANUAL/html_manual/man96.html).

2.17.7 Woody Decay Rate

This parameter defines the maximum fraction of the species' dead wood that decomposes in the ecoregion. Value: 0.0 ≤ number ≤ 1.0. Unitless.

2.17.8 Monthly Wood Mortality

This parameter is now obsolete. Growth-related mortality is now a function of ANPP, similar to the algorithms in Biomass Succession. Units: fraction of wood biomass (0.0 – 1.0).

2.17.9 Mortality Curve – Shape Parameter

This parameter determines how quickly age-related mortality begins and operates as in Biomass Succession v1 and v2. Value: 5.0 ≤ 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.

2.17.10 Leaf Drop Month

This parameter determines when the leaves will drop and become part of the litter pool.

Note: *Note that LeafDropMonth=9 means that half the leaves will drop in October (one month offset) and the other half drop in November.*

2.17.11 Coarse Root Fraction and Fine Root Fraction

The fraction of aboveground net primary productivity that is used to compute the ANPP of coarse and fine roots. Units: fraction of ANPP (0.0 – 1.0).

2.18 Fire Reduction Parameters

The `FireReductionParameters` table allows users to specify how much dead wood and litter will be removed as a function of fire severity. The reduction of wood and litter will occur **after** fire induced mortality of cohorts. After a fire kills a cohort, the dead biomass is deposited on the forest floor and is then subsequently volatilized in the same time step.

Note: This table is required even if fire extensions are not being used.

2.18.1 Fire Severity

The first column is fire severity, classes 1 – 5. Severity should be listed in ascending order.

2.18.2 Wood Reduction

The second column is the proportion (0.0 – 1.0) of dead wood biomass that is volatilized. The proportion will be applied to both C and N components.

2.18.3 Litter Reduction

The third column is the proportion (0.0 – 1.0) of dead litter biomass that is volatilized. The proportion will be applied to both C and N components.

2.19 Harvest Reduction Parameters

The `HarvestReductionParameters` table specifies how much dead wood and litter will be removed as a function of harvest activity ***and how much cohort wood and leaf biomass is moved off site during harvesting***. Cohort wood is typically removed from the site during harvesting. The reduction of dead wood and litter will occur **after** harvest induced mortality of cohorts. After a harvest event kills a cohort, the dead biomass is removed from the forest. If a prescription is not listed (or is not spelled identically to the name used in the harvest prescription file), the defaults are zero for all values.

2.19.1 Prescription Name

The first column is prescription name. Each prescription name must be identical to the prescription names in the Leaf Biomass Harvest file (see "LANDIS-II Base Harvest v2.0 User Guide"). Prescriptions can be in any order; they do *not* need to appear in the same order as in the Leaf Biomass Harvest input file.

2.19.2 Dead Wood Reduction

The second column is the proportion (0.0 – 1.0) of dead wood biomass that is removed. The proportion will be applied to both C and N components.

2.19.3 Dead Litter Reduction

The third column is the proportion (0.0 – 1.0) of dead litter biomass that is removed. The proportion will be applied to both C and N components.

2.19.4 Cohort Wood Removal

The fourth column is the proportion (0.0 – 1.0) of cohort *living* wood biomass that is removed from the site. *The remainder is typically regarded as slash.* The proportion will be applied to both C and N components.

2.19.5 Cohort Leaf Removal

The fifth column is the proportion (0.0 – 1.0) of cohort *living* foliar biomass that is removed from the site. *The remainder is typically regarded as slash.* The proportion will be applied to both C and N components.

3 Output Files

The NECN Succession extension produces a number of outputs. The maps of soil C, ANPP, and NEE are described above.

In Version 5+, additional maps have been added to track water:

- Annual Water Budget: Excess soil moisture after evapotranspiration. Defined as water inputs (precipitation + irract) – actual evapotranspiration (AET)
- Available water: amount of water available to trees

In addition to the maps, there are three primary log files and one optional log files. These are all comma delimited (*.csv) files that are typically read using Excel.

Note: *When you run NECN, xml files are created for the NECN-succession-log and NECN-succession-monthly-log files in the folder called Metadata****. These xml files can be opened in any internet browser and will list all the output parameters, their description and units.***

1. NECN-succession-log: The primary log file that outputs a snapshot of data at every successional time step. These data are averaged by climate region and are most useful for analyzing variation over time and across climate regions.

2. NECN-succession-monthly-log: This log file contains an abbreviated set of data that are useful at a monthly time step. These include NPP, heterotrophic respiration, N deposition and NEE. These data can be compared to monthly flux tower data. Also included are monthly temperature and precipitation. These allow a quick cross-reference to your input data.

3. NECN-prob-establish-log: This log file contains the data used to calculate the probability of establishment for each climate region at each succession time step. The probability of establishment is the minimum of all limiting factors. However, these values do not take shade and presence of seed sources into account and therefore do not reflect the actual probability of establishment in a given site.

Note: *The probability of establishment is calculated annually and averaged over the succession time step.*

4. NECN-calibrate-log: A detailed monthly output for **every cohort at each month**. Due to the volume of data, this file should only be used with single cell runs.

In the calibrate log file, BTOLAI is labelled as rLAI and KLAI as tLAI to make it consistent with the original Century code.

Metadata for the calibrate log file can be found on the NECN web site.

4 Initial Communities Input 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 classes and associated biomass (g m^{-2}) that are present for each of those species.

4.1 Example File

```
LandisData   "Initial Communities"

>>Old jackpine oak
MapCode  7
   acerrubr 30 (204)
   pinubank 80 (1968) 90 (15212)
   pinuresi 110 (204) 140 (42)
   querelli 40 (204) 120 (1968) 240 (47)

>> young jackpine oak
MapCode  0
   pinubank 30 (204) 50 (2512)
   querelli 10 (6) 40 (23) 70 (1968)

>> young aspen
MapCode 2
   poputrem 10 (419) 20 (879)
```

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 section 2.5). Value: $0 \leq$ integer $\leq 65{,}535$. Each class' map code must be unique. Map codes do not have to appear in any order, and do not need to be consecutive.

4.3.2 Species Present and Biomass

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 (biomass) age (biomass) age (biomass)``...`

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 do not have to appear in any order.

```
acersacc 10 (240) 5 (16) 21 (769) 60 (1968) 100 (210)
```

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 (biomass left out here for simplicity):

```
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 should be:

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

Note that biomass values will be totaled when cohorts are grouped.

If the succession timestep is 20, then the cohorts for this species initially at each site in this class will be:

```
acersacc  20  40  200
```