MODELING MANUAL

Modeling the Carbon Implications of Ecologically-Based Forest Management

Joint Base Lewis McChord – Modeling Manual

SERDP Project RC-2118

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List of Acronyms

DBH – Diameter at Breast Height (1.37 m)
JBLM – Joint Base Lewis McChord
NECB – Net Ecosystem Carbon Balance
NEE – Net Ecosystem Exchange
NEP – Net Ecosystem Production
NPP – Net Primary Productivity
R_h – Heterotrophic Respiration
TEC – Total Ecosystem Carbon

Acknowledgements

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Background

The forest carbon cycle can be generically described as a series of carbon pools that interact with each other and the atmosphere through a series of fluxes (Figure 1). Carbon is removed from the atmosphere through photosynthesis by trees and understory vegetation, and some of this carbon is released back to the atmosphere through respiration. Once sequestered, carbon in plant material eventually transitions to the snag, woody debris, or surface fuel pool for trees, and the surface fuel pool in the case of understory vegetation. During decomposition, some of the carbon from the dead plant material is incorporated into the organic horizon and mineral soil. In the absence of disturbance, the expectation is that the carbon stock grows to a theoretical maximum where Net Ecosystem Productivity (NEP, the annual change in the total ecosystem carbon stock) approaches zero (Hudiburg et al., 2009).

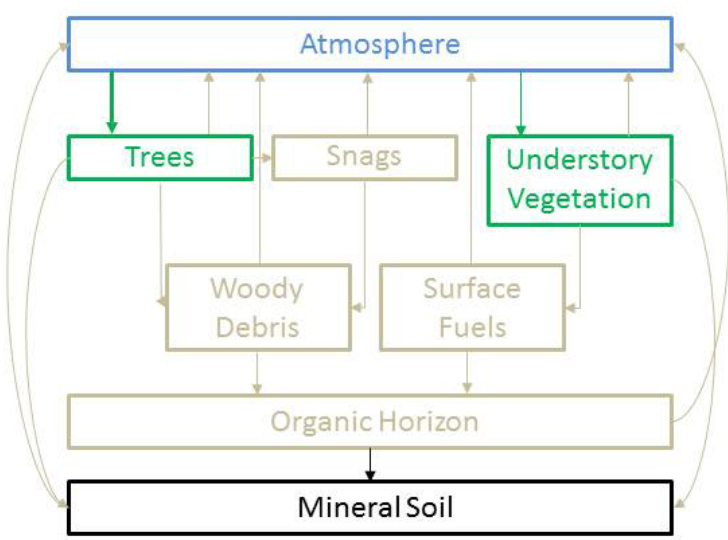


Figure 1: Generalized forest carbon pools and fluxes.

When fire enters into the equation, fluxes back to the atmosphere increase as a function of fire severity (Meigs et al., 2009; Wiedinmyer and Hurteau, 2010). Furthermore, increasing fire severity increases tree mortality (Agee and Skinner, 2005). When fire severity and tree mortality are high, NEP and carbon storage can decline precipitously (Dore et al., 2008; Meigs et al., 2009) and carbon stocks decline over longer time horizons as compared to forests experiencing lower fire severity (Hurteau and North, 2009; Hurteau, 2013). In fire-prone systems, the carbon carrying capacity - quantity of carbon that can be maintained under naturally prevailing conditions (Keith et al., 2009) - likely represents an appropriate target for carbon life-cycle management (Figure 2).

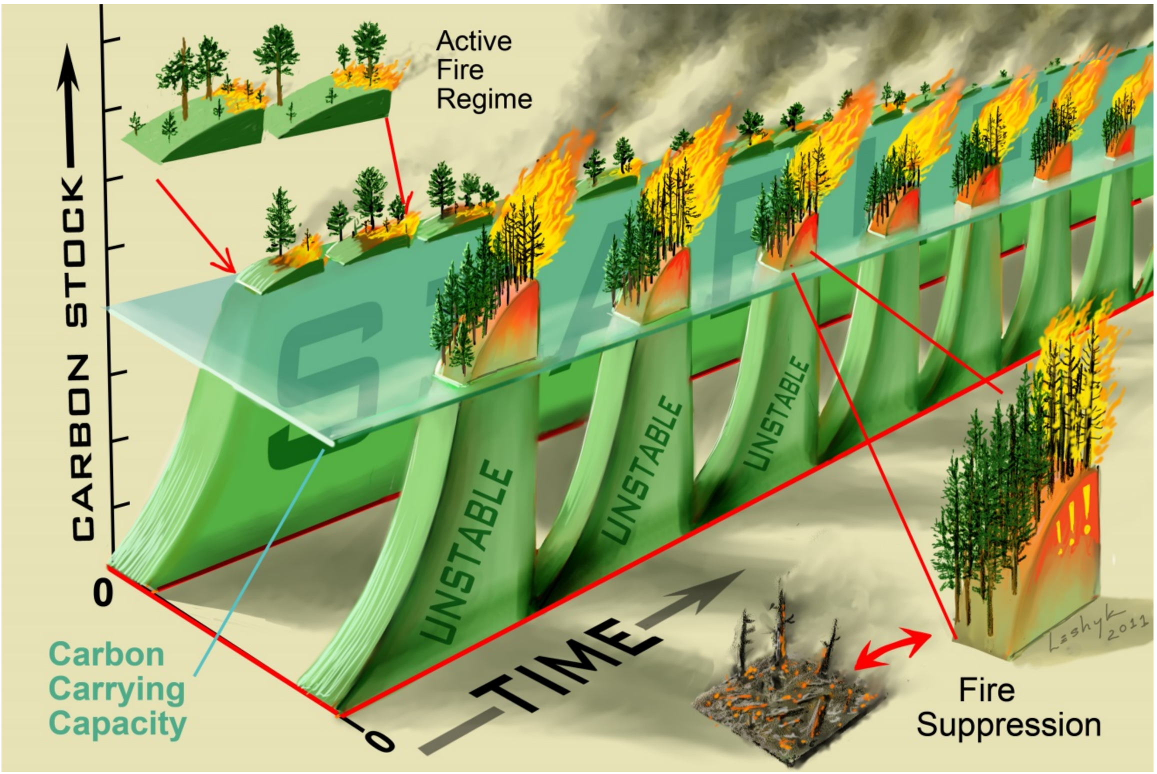


Figure 2: In dry, fire-prone forest types, the C stock varies as a function of the frequency of disturbance. An active fire regime results in a relatively stable C stock because frequent fires maintain fuel loads at levels that result in low-intensity fire. When we exclude fire from these systems, the C stock exceeds the C carrying capacity because of increased tree density and fuel buildup. When wildfire occurs in the fire-excluded forest, the C stock is reduced below the carrying capacity because of high fire severity. The C stock recovery following wildfire depends on the successional path of the forest recovery (from Hurteau , 2013).

Because forest carbon sequestration is a major part of the global carbon cycle (Canadell and Raupach, 2008), management actions that affect forest carbon dynamics are being increasingly scrutinized. In particular, the role of fire management, including its impacts on forest carbon and the resultant emissions is garnering substantial attention (Hurteau, 2013; Hurteau et al., 2013). Thus, quantifying the expected effects of management actions on forest carbon stocks prior to management implementation is increasingly important.

The objectives of this document are to present the modeling approach used to simulate forest carbon dynamics at Joint Base Lewis McChord, WA as part of SERDP funded project RC-2118.

LANDIS-II Model

This work used the LANDIS-II model, a landscape-scale forest succession and disturbance model that simulates forest succession using age cohorts of species (Scheller et al. 2007). The study area is gridded and each grid cell populated with age cohorts of species from forest inventory data. Species regeneration, growth, and mortality are functions of a species' life history characteristics and the environment within a given grid cell. The LANDIS-II base model has a number of extensions to expand its capabilities. As part of this research, we parameterized the Century Succession, Dynamic Fuels and Fire System, Leaf Biomass Fuels, and Leaf Biomass Harvest extensions. Executable files for the base model and extensions can be downloaded from http://www.landis-ii.org/.

Data Sources

Forest data: JBLM inventory data, LEMMA GNN data

Soils data: NRCS SSURGO

Climate data: NCDC station data (station ID GHCND: USC00454486)

Files Used in FB LANDIS-II Simulations

All simulations:

Initial Communities: initial-communities.txt/ ic_activeonly0.img

Ecoregions: ecoregionsS.txt/ eco_activeonly0.img

Species: species.txt

Century Succession: century-succession_6_25.txt

Climate: century-climate-inputsS.txt

Age only disturbances: bio-reductions-standard.txt

Leaf biomass output: output-leaf-biomass.txt

Forest Management:

<u>Leaf biomass harvest</u>

Maps: Management areas: MgmtAreas4_activeonly0.img; Stands: Stands9018.img

Leaf biomass harvest:

LeafBiomassControlNOharvest.txt - Used in no harvest (control)

LeafBiomassRxburnOnly.txt – Used in burn only

LeafBiomassThinRxburn.txt - Used in thin and burn

LeafBiomassThinOnly.txt – Used in thin only

<u>Dynamic Fire & Fuels</u>

Dynamic Fuel System: fuels-DFFS.txt – Used in all scenarios

Dynamic Fire System: fire-DFFS.txt – Used in all scenarios

Fire regions: Fire3ActiveOnlySigned.img

Slope: slope_percent.img

Azimuth: UpslopeAzi.img

Fire weather: Fire_Weather_Data_Enumclaw.csv

Scenario file: jblmcontrol.txt, jblmthin.txt, jblmburn.txt, jblmthinburn.txt

File Descriptions

This section uses the thin and burn scenario (jblmthinburn.txt) simulated for this project to demonstrate how the different input files are used to set up simulations. The purpose of the thin and burn scenario is to provide a sustainable flow of wood volume, while reducing competition for oak in the prairie colonization forest. It involves thinning Douglas-fir at approximately 40% of net annual growth, focused primarily on prairie colonization forest.

The model uses the scenario file to call the species file, the ecoregions text and img files, and the extension files. For the jblmthinburn.txt scenario file, the model calls the Century Succession extension using century-succession_6_25.txt, the Leaf Biomass Harvest extension using LeafBiomassThinRxburn.txt, the Dynamic Leaf Biomass Fuels extension using fuels-DFFS.txt, the Dynamic Fire System extension using fire-DFFS.txt, and the Output Leaf Biomass extension using output-leaf-biomass.txt.

Species File

The species file (FBSPP5.txt) includes parameter values for the life history parameters for the tree species simulated at Joint Base Lewis McChord (JBLM). The full list of species already parameterized includes:

- ABGR - *Abies grandis*
- ACMA - *Acer macrophyllum*
- ALRU - *Alnus rubra*
- FRLA - *Fraxis latifolia*
- PIPO - *Pinus ponderosa*
- PSME - *Pseudotsuga menziesii*
- QUGA - *Quercus garrayana*
- THPL - *Thuja plicata*
- TSHE - *Tsuga heterophylla*

Century Succession File

The four letter species codes are used to reference physiological parameters for each species in the Century Succession file (century-succession_6_25.txt). The Century Succession extension is used to model fluxes and pools of carbon and nitrogen. It can also be used to simulate projected changes in climate using simulated climate data. The Century Succession extension requires a range of physiological parameter values for each species (e.g. growing degree days, drought tolerance, leaf longevity, etc). We parameterized the species using values from the peer-reviewed literature (see Appendix 1). The Century Succession file also includes soil parameter values, which were obtained from NRCS SSURGO data. The Century Succession extension calls the initial communities text file, map files, and the climate file. The climate file is used to create monthly climate distributions for each ecoregion (subdivision within the installation) using climate data. The model draws from these distributions to obtain weather data for each calculation. The climate data file (century-climate-inputsS.txt) was developed using 51 years of meteorological data (1962-2012) from the Landsburg, WA weather station (station ID GHCND: USC00454486). The Century Succession extension also calls the age-only disturbances file (bio-reductions-standard.txt). This file allows the biomass of age-cohorts to be distributed to the proper dead biomass pools once they are killed by disturbance.

Leaf Biomass Harvest File

The Leaf Biomass Harvest extension is used to simulate structural manipulations. The harvest extension requires that the simulation landscape be divided into management areas or stands and the map file of stands (MgmtAreas4_activeonly0.img) is called by the harvest extension file. In this study we simulated on silvicultural prescription, thinning focused on mid-sized individuals, with prescribed burning in the prairies and prairie colonization forest. To be able to simulate both prescribed burning and wildfire, we used the Leaf Biomass Harvest extension to simulate prescribed burning.

The harvest input file is structured such that each harvest type is specified individually. It is important to remember that LANDIS-II is simulating age-cohorts of species and not individual trees. As a result, harvesting simulations specify the minimum age at which the harvest will occur and the minimum time between harvests. For each harvest type, the user specifies the percentage of age cohorts to be removed for each species. As an example, to initiate the thin treatment, we prescribe the following in the harvest file:

```
LeafBiomassThinRxburn.txt - Notepad
File  Edit  Format  View  Help
 LandisData  "Leaf Biomass Harvest" <<July 8, 2014  11565-28105 MgAGB removed ar

Timestep 1
>>---------------------------------------------------------------------------

>>Management Areas: map that define the management areas
>>Stands: the map that defines the stands, each stand can only be in one mgmt ar
>>---------------------------------------------------------------------------


ManagementAreas "C:\My Documents\JBLM LANDIS\MgmtAreas4_activeonly0.img"
Stands       "C:\My Documents\JBLM LANDIS\Stands9018.img"  <<

>>Prescriptions

>>---------------------------------------------------------------------------
  Prescription PSMEthin_annual
     StandRanking  RegulateAges
     MinimumAge 60
     StandAdjacency 40
     AdjacencyType StandAge
     AdjacencyNeighborSetAside  40
     MinimumTimeSinceLastHarvest 100
     SiteSelection Complete
     MinTimeSinceDamage 10
     CohortsRemoved  SpeciesList
      >> Species   Selection
      >> -------   --------
            psme     70-180 (67%)
            acma     20-80  (2%)
            alru     20 80  (2%)
            quga     20 80  (2%)
            thpl     20 80  (2%)
            tshe     20 80  (2%)
            frla     20 80  (2%)
            abgr     20 80  (2%)
            pipo     20-80  (2%)
>>---------------------------------------------------------------------------
```

This particular prescription tells the model to harvest 67% of PSME cohorts age 70-180 and 2% of cohorts age 20-80 to account for mechanical damage. This prescription is implemented on 1% of the forested area per year throughout the simulation period as a function of stand conditions. We have also used this extension to simulate prescribed burning. In the prescribed fire prescription, we prescribed the following in the harvest file to simulate burning in the prairie colonization forest:

```
>>------------------------------------------------------------------------------
Prescription Rxburn
StandRanking FireHazard
>> Fuel Type Index    Rank
>>----------------    --------
        1              70
        2              70
        3              70
        4              60
        5              50
        6              20
        7              20
        8              20
        9              10
        10             50
        11             50
        13             90
        14             100
        15             100
MinimumAge 25
MinimumTimeSinceLastHarvest 10
SiteSelection Complete
MinTimeSinceDamage 10
CohortsRemoved SpeciesList
    >> Species   Selection
    >> -------   ---------
        pipo      1-24 (5%)
        psme      1-26 (85%) 27-30 (16.7%) 31-53  (3%)  54-80 (2%)  81-400 (1%)
        acma      1-15 (90%) 16-50 (50%)   51-200 (10%)
        alru      1-15 (90%) 16-50 (50%)   51-200 (10%)
        quga      1-5  (90%) 6-10  (50%)   11-20  (25%) 21-30 (20%) 31-400 (5%)
        thpl      1-15 (90%) 16-50 (50%)   51-200 (10%)
        tshe      1-15 (90%) 16-50 (50%)   51-200 (10%)
        frla      1-15 (90%) 16-50 (50%)   51-200 (10%)
        abgr      1-15 (90%) 16-50 (50%)   51-200 (10%)
```

This prescription tells the model to harvest between 5 and 90% of the youngest cohorts as a function of species. We also simulated prescribed burning in the prairie areas to diminish encroachment by trees using the following prescription:

```
>>---------------------------
Prescription PrairieRxburn
StandRanking FireHazard
>> Fuel Type Index    Rank
>>----------------    --------
        1              70
        2              70
        3              70
        4              60
        5              50
        6              20
        7              20
        8              20
        9              10
        10             50
        11             50
        13             90
        14             100
        15             100
MinimumAge 10
MinimumTimeSinceLastHarvest 10
SiteSelection Complete
MinTimeSinceDamage 10
CohortsRemoved SpeciesList
     >> Species   Selection
     >> -------   ---------
        pipo      1-24 (5%)
        psme      1-26 (85%) 27-30 (16.7%)  31-53  (3%)  54-80 (2%)  81-400 (1%)
        acma      1-15 (90%) 16-50 (50%)    51-200 (10%)
        alru      1-15 (90%) 16-50 (50%)    51-200 (10%)
        quga      1-5  (90%) 6-10  (50%)    11-20  (25%) 21-30 (20%) 31-400 (5%)
        thpl      1-15 (90%) 16-50 (50%)    51-200 (10%)
        tshe      1-15 (90%) 16-50 (50%)    51-200 (10%)
        frla      1-15 (90%) 16-50 (50%)    51-200 (10%)
        abgr      1-15 (90%) 16-50 (50%)    51-200 (10%)
```

This prescription is similar to the one simulating prescribed burning in the colonization forests, but set up to occur more frequently. The Leaf Biomass Harvest file also controls the area treated and frequency.

```
>>----------------------------------------------------------------------------------
>> Harvest Implementation Table

HarvestImplementations
>> Mgmt Area             Prescription     Harvest Area          Begin Time      End Time
>>-----------------      --------------   ----------------      -------------   -----------


        1       PSMEthin_annual          1%     0       100
        9       PSMEthin_annual          1%     0       100  <<allow pasture colonization
        10      PSMEthin_annual          1%     0       100
        23      PSMEthin_annual          1%     0       100

        31      PSMEthin_annual          1%     0       100 <<not burning 31 b/c is tshe only
        33      PSMEthin_annual          1%     0       100 <<not burning 33 b/c is talru thpl and psme

         2      PSMEthin_annual          .5%     0      100
        1010    PSMEthin_annual          .5%     0      100
        2323    PSMEthin_annual          .5%     0      100
        3131    PSMEthin_annual          .5%     0      100
        3333    PSMEthin_annual          .5%     0      100

        1        Rxburn          5%     0       100
        9        PrairieRxburn   20%     0      100  <<allow, but slow, pasture colonization
        10       Rxburn          5%     0       100
        23       Rxburn          5%     0       100


>>      374     Oldest communities
>>      1000    Riparian
>>------------------------------------------------------------------------------------
```

This portion of the file indicates the time-step in which treatments begin and how much of the land area is treated each year. The PSMEthin_annual prescription tells the model to thin 1% of the management areas per year. The Rxburn prescription tells the model to simulate prescribed burning of colonization forest at a rate of 5% per year, equivalent to a 20 year fire return interval. The PrairieRxburn prescription simulates 20% of the prairie being burned every year, equivalent to a 5 year fire return interval. The harvest file also prescribes the output files. In this case, we tell the model to provide maps of where harvest was implemented and how much biomass was removed for each time-step. We also output harvest logs in .csv format.

Dynamic Fire System File

The Dynamic Fire System is used to simulate wildfire. In the thin and burn simulation that included wildfire, we used this extension to simulate wildfire with a probability of occurrence ranging from 0.125 (12 in 100 chance of occurrence) in the prairies to 0.002 (2 in 1000 chance of occurrence) in the forest.

```
fire-DFFS.txt - Notepad
File  Edit  Format  View  Help
UphillSlopeAzimuthMap  "C:\My Documents\JBLM LANDIS\UpslopeAzi.img"   <<updated 8/5/2014.
SeasonTable
>> Season  Leaf,    Prop of  Percent  DayLength
>> Name    Status   Fires    Curing   Proportion
>> ------  -------  -------  -------  ----------  <<proportion of fires to equal 1. using USFS fire data w/in 100km of jblm (215
   Spring  LeafOff  0.02     50         1.0
   Summer  LeafOn   0.88     51         1.0
   Fall    LeafOff  0.1     100         1.0  <<fall need to be in tenths...???

InitialWeatherDatabase  "C:\My Documents\JBLM LANDIS\Fire_Weather_Data_Enumclaw.csv"  << 1995-2006 3/13-11/15 puget sound fire r


DynamicWeatherTable
>>Year  FileName

FuelTypeTable
>> Allowed base types:  Conifer, ConiferPlantation, Deciduous, Slash, Open
>> Allowed surface types:  See Canadian Fire Behavior System (CFBS)
>> The fuel types in the example file (below) are derived from the CFBS. <<a b c rate of spread parameters
>>updated initprob Nov2014 to reflect fri for dominant landscape type

>> Index  BaseType              SurfaceType InitProb a   b      c   q    BUI maxBE CBH  <<BUI is BUI(0) mean BUI for fuel type
>> -----  --------              ----------- -------- --- ---    --- ---  --- ----- ---


  1     Open                    O1a         .125     190  0.0310 1.4 1.0   1  1.000 0
  2     Open                    O1b         .125     250  0.0350 1.7 1.0   1  1.000 0

  3     Conifer                 C4          0.013    110  0.0293 1.5 0.80 120 1.184  2

  4     Conifer                 C7          0.013     45  0.0305 2.0  .85 106 1.134 2  <<psme 0-20
  5     Conifer                 C7          0.013     45  0.0305 2.0  .85 106 1.134 3  <<psme 21-150
  6     Conifer                 C7          0.013     45  0.0305 2.0  .85 106 1.134 5  <<psme 151-300

  7     Conifer                 C7          0.002     45  0.0305 2.0  .85 106 1.134 2 <<mixed conifer no psme 0-40
  8     Conifer                 C7          0.002     45  0.0305 2.0  .85 106 1.134 4 <<mixed conifer with psme 0-400

  9     Deciduous               D1          0.002     30  0.0232 1.6 0.90 32  1.179 2
 10     Conifer                 M1          0.002      0  0      0   0.80 50  1.250 6
 11     Conifer                 M2          0.002      0  0      0   0.80 50  1.250 6
 12     Conifer                 C7          0.05      45  0.0305 2.0  .85 106 1.134 4   <<quga
 13     Conifer                 C7          0.013     45  0.0305 2.0  .85 106 1.134 7  <<thin only
 14     Conifer                 C7          0.013     45  0.0305 2.0  .85 106 1.134 8  <<thin and burn
 15     Conifer                 C7          0.013     45  0.0305 2.0  .85 106 1.134 5  <<burn only
```

The fire extension requires a fire regions map (Fire3ActiveOnlySigned.img), a fire weather file (Fire_Weather_Data_Enumclaw.csv), and a fuel input file (fuels-DFFS.txt). The fuels file classifies fuels as a function of species, age, and other characteristics. Specific information regarding the parameter values in the fuels file can be found in the LANDIS-II Dynamic Leaf Biomass Fuel System Extension v2.0 User Guide. Given the role of topography in determining fire behavior, we also include a file that provides slope (slope_percent.img) and aspect (UpslopeAzi.img) for the wildfire simulations.

The fire input file specifies fire parameters for each fire region, including a distribution for fire size. In the thin and burn simulations, we prescribed the following fire size characteristics:

```
>>                 |                  | Spring (Sp)               Summer (Su)                 Fall (Fa)                    |
>> Code Name       | Mu Sigma Max     | SpFMCLo SpFMCHi SpHiPr SuFMCLo SuFMCHi SuFMCPr FaFMCLo FaFMCHi FaHiPr      | OpenFuel NumIgns
>> -----------      ------------        --------------------------------------------------------------------------  ----------------

     2    fire2 38.9   47.2 300    85       120      1      120      120      1        120      120      1          1        115      <<f
     1    fire1 0.125 .152 1278   85       120      1      120      120      1        120      120      1          1        62     <<USF
     3    fire3 0.125 .152 1278   85       120      1      120      120      1        120      120      1          1        3

>>OpenFuel type index will be used to calculate spread rates if no spp-age cohorts are present on a cell within the ecoregion.
```

Using fire1 as an example, this file provides the model with a distribution from which to draw the number of ignitions in a time-step (NumIgns). The NumIgns value is used as the average number of ignitions for a Poisson distribution for a given fire region. In the case of fire1, the average number of fires is 62. The model draws the number of ignitions from the distribution and then randomly selects cells from the fire region and determines if a fire occurs based on the ignition and fuel type. Fire size is determined using a lognormal distribution with Mu being the mean of the associated normal distribution and Sigma being the scale parameter of the lognormal distribution. The Max parameter defines the maximum fire size. The spring foliar moisture content provides the low (SpFMCL) and high (SpFMCH) foliar moisture values and the spring high proportion parameter (SpHProp) specifies the proportion of fires that occur during the high foliar moisture content period. The same parameters are provided for summer and fall. The open fuel type index (OpFuelIndex) is used to calculate fire spread rates when no trees are present in a grid cell. The season table is used to specify the season in which fires occur.

```
GroundSlopeFile        "C:\My Documents\JBLM LANDI
UphillSlopeAzimuthMap  "C:\My Documents\JBLM LANDI
SeasonTable
>> Season  Leaf,    Prop of  Percent  DayLength
>> Name    Status   Fires    Curing   Proportion
>> ------  -------  -------  -------  ----------
   Spring  LeafOff  0.02      50        1.0
   Summer  LeafOn   0.88      51        1.0
   Fall    LeafOff  0.1      100        1.0      <
```

In the season table, the user specifies leaf off or leaf on for deciduous species, the proportion of fires that happen within each season, the degree that grasses in the understory have cured, and the proportion of each 24-hour day that fires can spread. The fuel type table specifies the ignition probability for each fuel type and parameter values specific to calculating fire behavior for each fuel type.

```
FuelTypeTable
>> Allowed base types:  Conifer, ConiferPlantation, Deciduous, Slash, Open
>> Allowed surface types:  See Canadian Fire Behavior System (CFBS)
>> The fuel types in the example file (below) are derived from the CFBS. <<a b c rate of spread parameters
>>updated initprob Nov2014 to reflect fri for dominant landscape type

>> Index  BaseType              SurfaceType InitProb a   b      c   q    BUI maxBE CBH  <<BUI is BUI(0) mean BUI for fuel type
>> -----  --------              ----------- -------- --- ---    --- ---  --- ----- ---


  1     Open                    O1a         .125      190  0.0310 1.4 1.0   1  1.000 0
  2     Open                    O1b         .125      250  0.0350 1.7 1.0   1  1.000 0

  3     Conifer                 C4          0.013     110  0.0293 1.5 0.80 120 1.184  2

  4     Conifer                 C7          0.013      45  0.0305 2.0  .85 106 1.134 2  <<psme 0-20
  5     Conifer                 C7          0.013      45  0.0305 2.0  .85 106 1.134 3  <<psme 21-150
  6     Conifer                 C7          0.013      45  0.0305 2.0  .85 106 1.134 5  <<psme 151-300

  7     Conifer                 C7          0.002      45  0.0305 2.0  .85 106 1.134 2 <<mixed conifer no psme 0-40
  8     Conifer                 C7          0.002      45  0.0305 2.0  .85 106 1.134 4 <<mixed conifer with psme 0-400

  9     Deciduous               D1          0.002      30  0.0232 1.6 0.90 32  1.179 2
 10     Conifer                 M1          0.002       0  0       0   0.80 50  1.250 6
 11     Conifer                 M2          0.002       0  0       0   0.80 50  1.250 6
 12     Conifer                 C7          0.05       45  0.0305 2.0  .85 106 1.134 4   <<quga
 13     Conifer                 C7          0.013      45  0.0305 2.0  .85 106 1.134 7  <<thin only
 14     Conifer                 C7          0.013      45  0.0305 2.0  .85 106 1.134 8  <<thin and burn
 15     Conifer                 C7          0.013      45  0.0305 2.0  .85 106 1.134 5  <<burn only
```

The fire damage table is used to determine fire effects on tree age-cohorts. Fire tolerance is prescribed based on the percentage of a species maximum longevity. The fire severity – fire tolerance parameter determines mortality by fire and is the minimum difference between the severity of a fire event and the fire tolerance for an individual species.

```
FireDamageTable  <<describes fire dam
>> Cohort Age       FireSeverity -
>> % of longevity   FireTolerance
>> --------------   --------------
     20%               -2
     50%               -1
     85%                0
    100%                1
```

The fire input file is also used to specify the simulation outputs related to fire. In this case, we have specified a fire log summary and fire severity maps for each time-step.

Getting Started

You will need to download and install the following:

- LANDIS-II 6.0
- Century Succession
- Dynamic Fuels and Fire System
- Leaf Biomass Fuels
- Leaf Biomass Harvest
- Leaf Biomass Output
- Cohort Statistics Output

Once you have installed the model and extensions, you will need to create a directory for your input files. In your My Documents folder, create a new folder called "JBLM LANDIS". Copy and paste the provided files into this folder.

The next step is to ensure that all of your input files are referenced properly in the text files. You will need to edit the file path to match your working directory in the following files:

Scenario File: jblmcontrol.txt, jblmthin.txt, jblmburn.txt, jblmthinburn.txt

Century File: century-succession_6_25.txt

Fire File: fire-DFFS.txt

Harvest File: LeafBiomassControlNOharvest.txt, LeafBiomassRxburnOnly.txt, LeafBiomassThinRxburn.txt, LeafBiomassThinOnly.txt

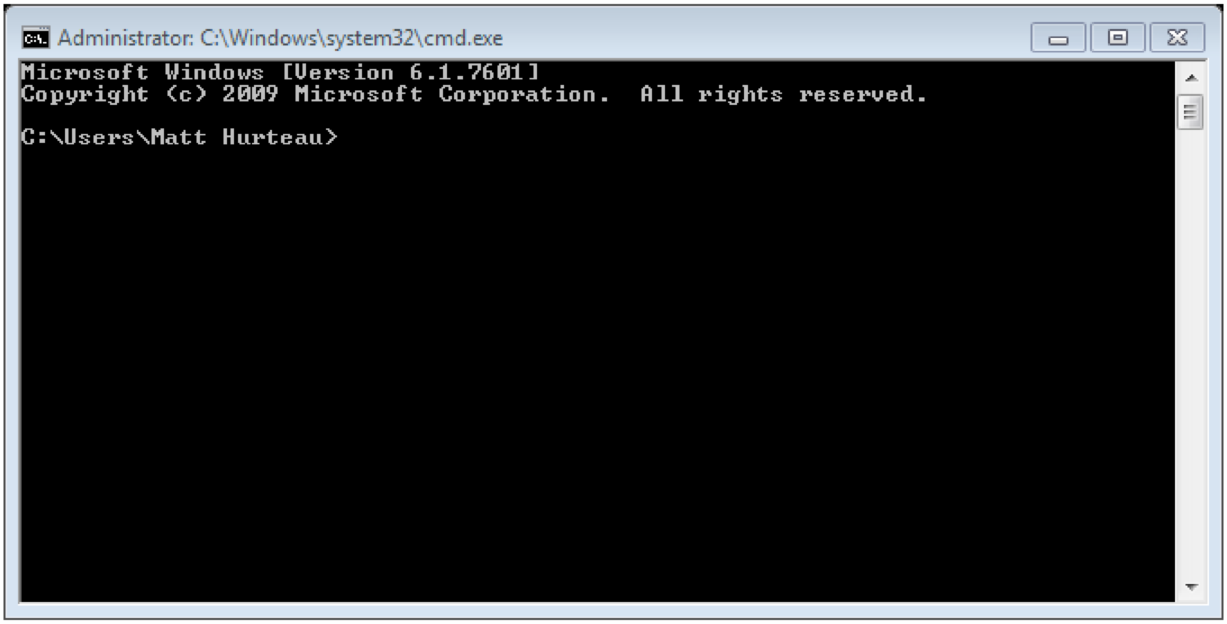
Example scenario file. Note that there are nine different file paths that require updating. The files that are preceded by >> are turned off. In this scenario file, only the thin and prescribed burn harvest scenario will be implemented.

jblmthinburn.txt - Notepad

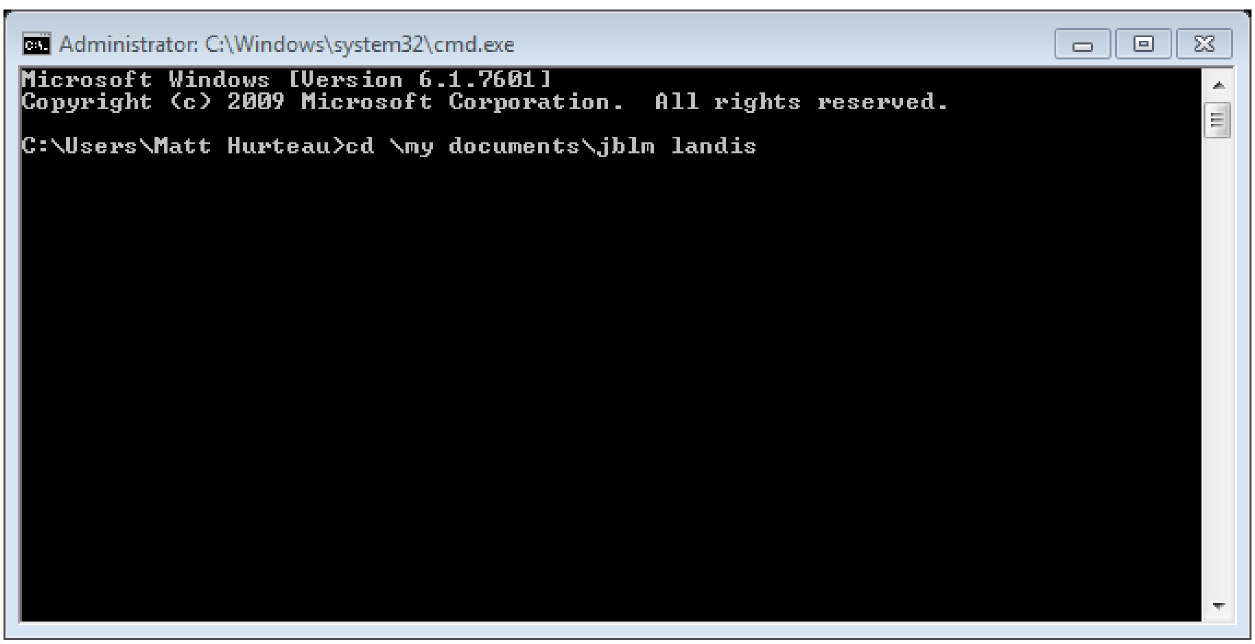
File Edit Format View Help

```
LandisData  Scenario

Duration  100

Species   "C:\My Documents\JBLM LANDIS\species.txt"

Ecoregions      "C:\My Documents\JBLM LANDIS\ecoregionsS.txt"
EcoregionsMap   "C:\My Documents\JBLM LANDIS\eco_activeonly0.img"

CellLength  200 << meters, 200 x 200 m = 4 ha


>> Succession Extension     Initialization File
>> --------------------     -------------------
   "Century Succession"     "C:\My Documents\JBLM LANDIS\century-succession_6_25.txt"


>> Disturbance Extensions   Initialization File
>> ----------------------   -------------------

>>"Leaf Biomass Harvest"     "C:\My Documents\JBLM LANDIS\LeafBiomassControlNOharvest.txt"
>>"Leaf Biomass Harvest"     "C:\My Documents\JBLM LANDIS\LeafBiomassThinOnly.txt"
  "Leaf Biomass Harvest"     "C:\My Documents\JBLM LANDIS\LeafBiomassThinRxburn.txt"
>>"Leaf Biomass Harvest"     "C:\My Documents\JBLM LANDIS\LeafBiomassRxburnOnly.txt"



  "Dynamic Fuel System"          "C:\My Documents\JBLM LANDIS\fuels-DFFS.txt"
  "Dynamic Fire System"          "C:\My Documents\JBLM LANDIS\fire-DFFS.txt"

>>  DisturbancesRandomOrder  yes  << optional parameter; default = no

>> Other Extensions         Initialization File
>> ----------------         -------------------
   "Output Cohort Statistics"    "C:\My Documents\JBLM LANDIS\cohort-stats.output.txt"
    "Output Leaf Biomass"           "C:\My Documents\JBLM LANDIS\output-leaf-biomass.txt"

>>RandomNumberSeed  2545  << optional parameter; default = the seed is
                         << randomly generated using the current time
```

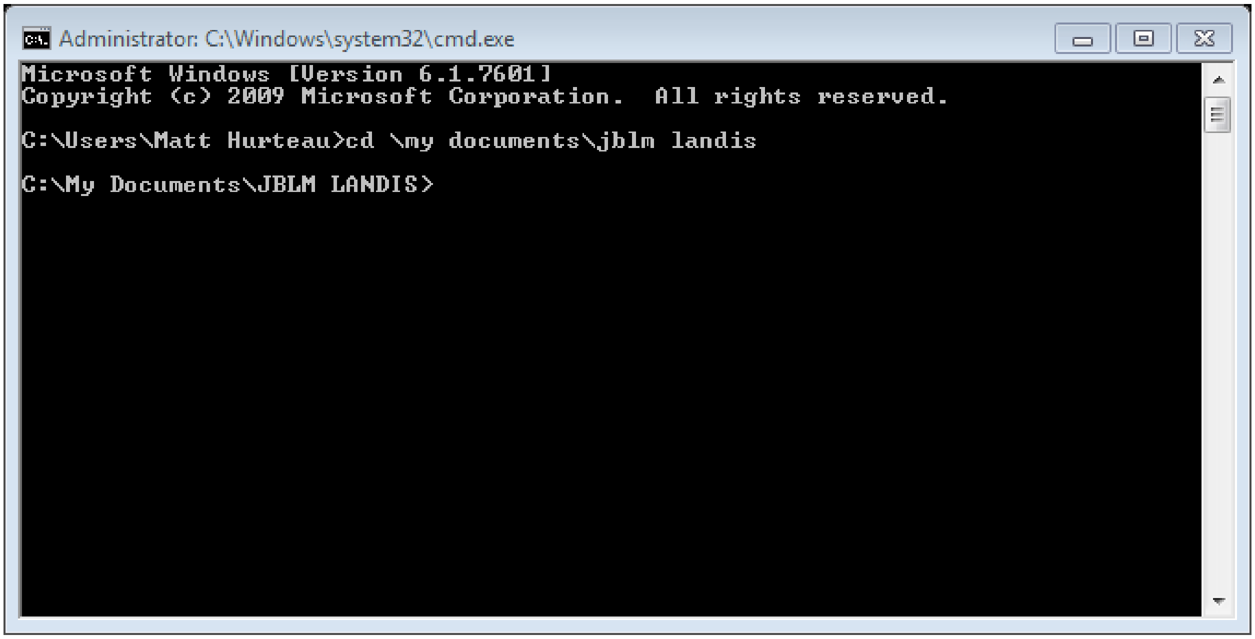
To open the model, you will need to open the ms dos prompt by typing “cmd” in the search box on the start menu.



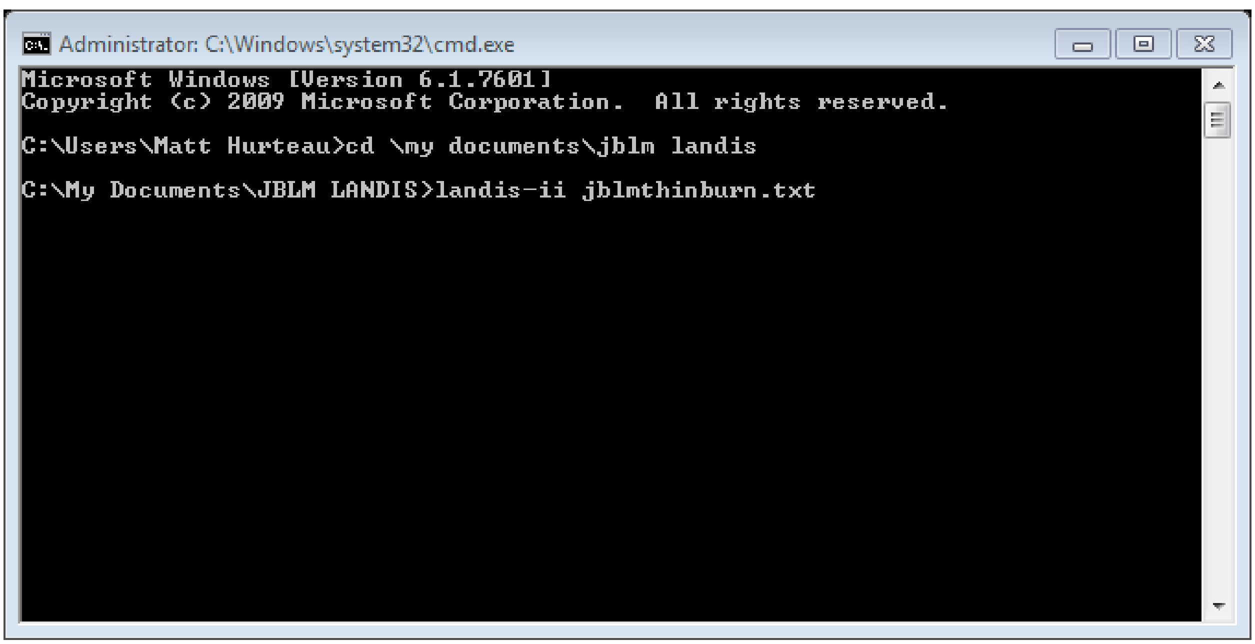
Next you will need to map to the folder you just created. To do this you will need to use the change directory command (cd).



Once you have typed the new directory command, your prompt should indicate that you are working from the JBLM LANDIS folder.



To initiate a model run, you need to type landis-ii followed by the name of the scenario file.



The model will initiate after hitting enter. The command window will show progress through each time-step as the model runs. If the model stops running, the command window will display any file reference issues.

Model Outputs

The model run produces a number of output files. In your working folder (FB LANDIS) you will find the following outputs:

Folders:

- Output-leaf-biomass – biomass by species for each simulation time-step
- Century – NPP, NEE, soil C, total C maps for each time-step
- Leaf-biomass-harvest – biomass removed maps for each time-step
- DFFS-output – time of last fire maps for each time-step
- Dynamic-fire-test-log – fire information (e.g. number of pixels, fires) in each ecoregion for each time-step
- fire – maps of fire severity, fuel type, and tree mortality for each time-step

Files:

- Century-prob-establish-log.csv – probability of establishment for each species in each ecoregion for each time-step
- Century-succession-log.csv – annual outputs of carbon and nitrogen pools and fluxes by ecoregion
- Century-succession-montly-log.csv – monthly outputs of precipitation, temperature, respiration, net ecosystem exchange, and nitrogen deposition for each ecoregion.
- Landis-log.txt – simulation log
- Spp-biomass-log.csv – biomass of each species by ecoregion for each time-step

Model Output Considerations

There are a few things that you need to consider when examining model outputs. We have parameterized the model such that each grid cell is 200 x 200 m (4 hectares). We have divided the JBLM landscape into two ecoregions based on soil type. The land area by ecoregion is displayed in Table 2. To calculate average carbon pools and fluxes across the installation, you will need to use a weighted average and weight each ecoregion value by the area occupied by that ecoregion.

Table 2: Number of grid cells and land area by ecoregion.

Ecoregion	Grid Cells (number)	Total Land Area (ha)
Eco1	4453	17,812
Eco2	2933	11,732

As an example, if we have the following model output for Net Ecosystem Exchange of Carbon (NEEC) for one time-step:

Ecoregion	Grid Cells (number)	NEEC	% of Total	NEEC Contribution
Eco1	4453	-217.42	0.602897	-131.08
Eco2	2933	-279.51	0.397102	-110.99
Total Grid Cells	7386		**Total NEEC**	**-242.07**

Flux results are in g m^{-2} yr^{-1} and pools are in g m^{-2}. NEE flux is from an atmospheric perspective and when a value is negative it means carbon is being removed from the atmosphere and sequestered by the forest. In this case, forests at JBLM sequestered on average 242.07 g m^{-2} in this particular simulation year. Multiplying the g m^{-2} value by 0.01 converts to megagrams (10^6 gC) per hectare (10^4 m^2), in this case giving a value of 2.42 MgC ha^{-1}. The NEE value accounts for carbon sequestered by the ecosystem through photosynthesis, carbon lost through respiration, and carbon emitted from burning. The Century-succession-log.csv output file provides pool and flux values for a number of ecosystem attributes. The most useful outputs for the purposes of evaluating the effects of different management actions on carbon pools and fluxes are presented in Table 3. The Century-succession-monthly-log.csv output file allows you to evaluate the monthly fluxes of carbon. The net primary productivity (NPPC) value provides a monthly carbon uptake value by ecoregion. The respiration (Resp) value provides a monthly value of carbon respired by the ecosystem by ecoregion.

Table 3: Century Succession outputs useful for evaluating the effects of forest management on carbon pools and fluxes.

Output	Name	Units	Conversion
NEEC	Net Ecosystem Exchange	gC m^{-2} yr^{-1}	multiply by -1 to get C sequestered; multiply by 0.01 to get Mg ha^{-1}
SOMTC	Soil Organic Matter Total C	gC m^{-2}	multiply by 0.01 to get Mg ha^{-1}
AGB	Aboveground Biomass	gBiomass m^{-2}	multiply by 0.5 to get carbon; multiply by 0.01 to get Mg ha^{-1}
FireCEfflux	Fire emission of Carbon	gC m^{-2} yr^{-1}	multiply by 0.01 to get Mg ha^{-1}

Additional Resources

Scheller, RM, M Lucash (Eds). Forecasting forested landscapes: an introduction to LANDIS-II with exercises 2nd edition.

www.landis-ii.org

There are manuals for the core model and each extension on the LANDIS-II website.

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Appendix 1 – Parameter Values

Appendix 1 contains parameter values used for LANDIS-II simulations and a list of references used to determine parameter values.

Table A1: Species-specific parameter values used for the species file.

Species	Longevity (years)	Sexual Maturity (years)	Shade Tolerance (1-5)	Fire Tolerance (1-5)	Effective Seed Dispersal Distance (m)	Maximum Seed Dispersal Distance (m)
Abies grandis	300	20	4	2	54	100
Acer macrophyllum	150	20	2	2	15	120
Alnus rubra	100	10	2	2	50	100
Fraxis latifolia	150	30	3	2	5	300
Pinus ponderosa	600	16	2	5	37	120
Pseudotsuga menziesii	750	25	3	3	100	1500
Quercus garryana	500	20	2	4	6	400
Thuja plicata	1000	25	5	2	100	122
Tsuga heterophylla	400	30	5	1	100	1600

Species	Vegetative reproduction probability (0-1)	Minimum age of sprouting	Maximum age of sprouting	Post-fire Regeneration
Abies grandis	0	0	0	None
Acer macrophyllum	0.7	0	100	resprout
Alnus rubra	0.7	0	10	resprout
Fraxis latifolia	0.7	0	100	resprout
Pinus ponderosa	0	0	3	None
Pseudotsuga menziesii	0	0	0	None

Quercus garryana	0.7	0	200	resprout
Thuja plicata	0.5	0	200	None
Tsuga heterophylla	0.3	0	2	None

Table A2: Species-specific parameter values for the Century Succession extension of LANDIS-II.

Species	**Functional Type**	**N Fixation**	**Growing Degree Days Min**	**Growing Degree Days Max**	**Minimum Jan Temp**	**Max Drought**	**Leaf Longevity**	**Epicormic Sprouting**
Abies grandis	2	N	500	2450	-9	0.8	6	N
Acer macrophyllum	1	N	900	3100	-25	0.7	1	Y
Alnus rubra	1	Y	600	2200	-24	0.8	1	Y
Fraxis latifolia	1	N	150	2400	-22	0.7	1	N
Pinus ponderosa	2	N	800	3900	-41	0.9	4.5	N
Pseudotsuga menziesii	2	N	500	2500	-37	0.8	4.8	N
Quercus garryana	3	N	1400	2600	-34	0.9	1	Y
Thuja plicata	2	N	500	2000	-36	0.7	8.9	N
Tsuga heterophylla	2	N	500	1900	-31	0.7	1.6	N

Species	**Leaf Lignin**	**Fine Root Lignin**	**Wood Lignin**	**Coarse Root Lignin**	**Leaf C:N**	**Fine Root C:N**	**Wood C:N**	**Coarse Root C:N**	**Litter C:N**
Abies grandis	0.25	**0.22**	**0.35**	**0.35**	**42**	**27**	**500**	**170**	**77**
Acer macrophyllum	0.192	**0.224**	**0.25**	**0.26**	**20**	**30**	**440**	**90**	**62**
Alnus rubra	0.117	0.151	0.25	0.19	23	25	50	50	24
Fraxis latifolia	0.122	0.159	0.25	0.2	24	38	400	90	55
Pinus ponderosa	0.28	0.233	0.35	0.277	43	47	380	284	85
Pseudotsuga menziesii	0.155	0.296	0.269	0.323	42	52	455	214	68

Quercus garryana	0.176	0.22	0.14	0.26	32	63	63	62	33
Thuja plicata	0.18	0.205	0.293	0.245	53	29	80	38	100
Tsuga heterophylla	0.191	0.216	0.288	0.245	46	50	380	313	37

Table A3: Functional group parameters for the Century Succession extension of LANDIS-II.

Functional Group Name	Index	PPDF1 T-Mean	PPDF2 T-Max	PPDF3 T-Shape	PPDF4-T-Shape	FCFRAC Leaf	BTOLAI	KLAI	MAXLAI
Hdwd_mesic	1	18.5	40.0	5.0	0.8	0.3	0.004	1000	4.0
Hdwd_dry	3	22.0	40.0	1.0	3.0	0.3	0.007	1000	4.0
Conifers	2	18.0	40.0	5.0	0.7	0.2	0.004	5000	12.0

Functional Group Name	Index	PPRPTS2	PPRPTS3	Wood Decay Rate	Monthly Wood Mortality	Mortality Age Shape	Leaf Drop Month
Hdwd_mesic	1	1.0	0.8	0.4	0.0024	10	10
Hdwd_dry	3	1.0	0.4	0.3	0.0024	15	10
Conifers	2	1.0	0.8	0.4	0.0015	15	10

Table A4: Ecoregion parameters for the Century Succession extension of LANDIS-II.

Initial Ecoregion Parameters Name	SOM1 C Surf	SOM1 N Surf	SOM1 C Soil	SOM1 N Soil	SOM2 C	SOM2 N	SOM3 C	SOM3 N	Minrl N
Eco1	267	7	226.8	18.9	4158	207.9	3175.2	317.5	0.306
Eco2	2064	52	137.2	11.4	2514.6	125.7	1920.2	192	0.476

	Soil Depth	% Clay	% Sand	Field Cap	Wilt Point	StormF Frac	BaseF Frac	Drain	Atm N dep	Atm N intercept	Latitude
Eco1	100	0.035	0.823	0.069	0.034	0.01	0.14	0.9	0.0044	0.0343	47.0
Eco2	100	0.023	0.630	0.100	0.059	0.00	0.10	0.7	0.0044	0.0343	47.0

Ecoregion Parameters cont.	Decay Surf	Decay SOM1	Decay SOM2	Decay SOM3	Denitrifi
Eco1	0.3	0.2	0.025	0.00008	0.01
Eco2	0.3	0.7	0.060	0.00001	0.01

Table A5: Species productivity parameters for the Century Succession extension of LANDIS-II.

MonthlyMaxNPP (g m^{-2} $month^{-1}$)

	Eco1	**Eco2**
Abies grandis	400	400
Acer macrophyllum	300	300
Alnus rubra	400	400
Fraxis latifolia	400	400
Pinus ponderosa	300	300
Pseudotsuga menziesii	350	350
Quercus garryana	200	200
Thuja plicata	300	300
Tsuga heterophylla	300	300

Maximum Biomass (g m^{-2})

	Eco1	**Eco2**
Abies grandis	50000	50000
Acer macrophyllum	50000	50000
Alnus rubra	50000	50000
Fraxis latifolia	50000	50000
Pinus ponderosa	60000	60000
Pseudotsuga menziesii	100000	100000
Quercus garryana	15000	15000
Thuja plicata	70000	70000
Tsuga heterophylla	100000	100000

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