MODELING MANUAL

Modeling the Carbon Implications of Ecologically-Based Forest Management

Camp Navajo – Modeling Manual

SERDP Project RC-2118

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List of Acronyms

DBH – Diameter at Breast Height (1.37 m)
CN – Camp Navajo
NECB – Net Ecosystem Carbon Balance
NEE – Net Ecosystem Exchange
NEP – Net Ecosystem Production
NPP – Net Primary Productivity
R_h – Heterotrophic Respiration
RCW – Red-cockaded Woodpecker
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).

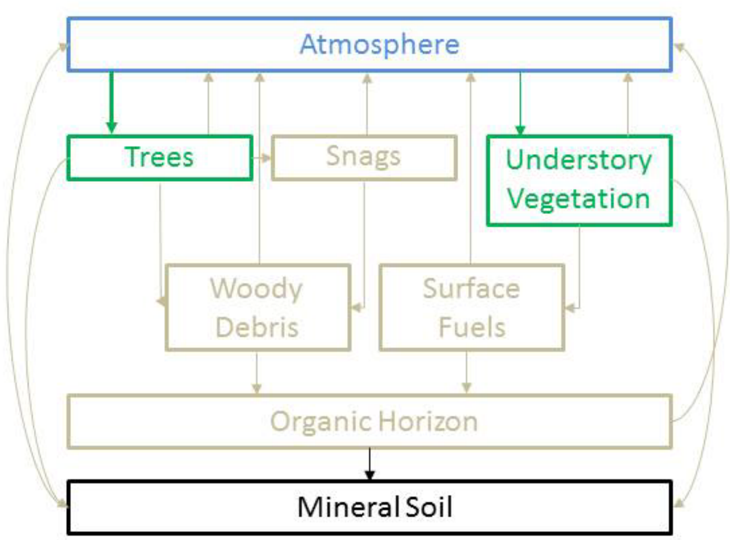


Figure 1: Generalized forest carbon pools and fluxes.

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).

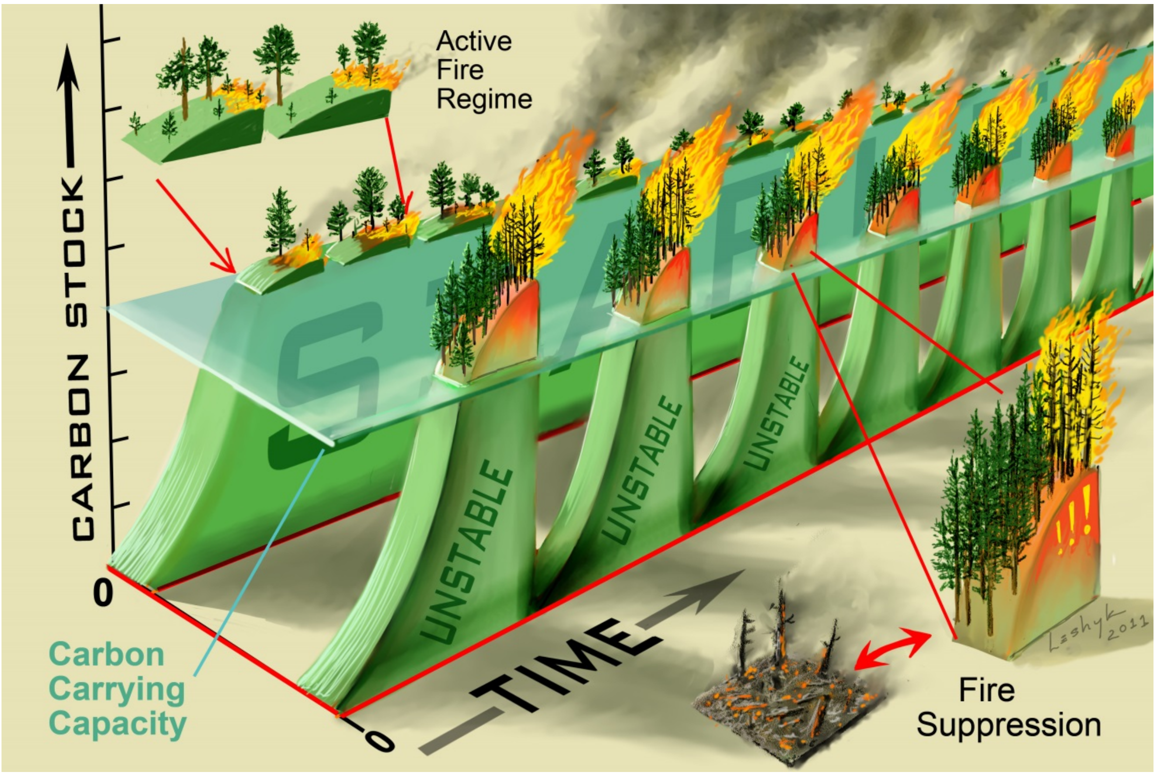


Figure 2: In dry, fire-prone forest types, the C stock varies as a function of the frequency of disturbance. An active fire regime results in a relatively stable C stock because frequent fires maintain fuel loads at levels that result in low-intensity fire. When we exclude fire from these systems, the 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 Camp Navajo, AZ as part of SERDP funded project RC-2118.

LANDIS-II Model

This research 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: Camp Navajo inventory data

Soils data: NRCS SSURGO

Climate data: NCDC station data (station ID GHCND: USW00003103)

Files Used in FB LANDIS-II Simulations

All simulations:

Initial Communities: CNIC21J.txt/ CNIC126.img

Ecoregions: CNER1.txt/ CNER1.img

Species: CNSPP1.txt

Century Succession: CNSUCC10Feb1.txt

Climate: CNClimate1.txt

Age only disturbances: CNBioRedux.txt

Leaf biomass output: CNLeafBio.txt

Forest Management:

Leaf biomass harvest

Maps: Management areas: CNMgmt2.img; Stands: CNStands2.img

Leaf biomass harvest:

CNThinRxFire12Feb.txt - Used in thin and burn

CNThinOnly12Feb.txt – Used in thin only

Dynamic Fire & Fuels

Dynamic Leaf biomass fuels:

CNLeafFuels.txt – Used in thin and burn

CNLeafFuelsThinOnly.txt – Used in thin only

Dynamic Fire System: CNDyWF11F3.txt

Fire regions: CNFR1.img

Slope: CNSlope1.img

Azimuth: CNUpAsp1.img

Fire weather: CNIFW.csv

Scenario files: CNThinOnlyWF.TXT/ CNThinBurnWF.TXT

File Descriptions

This section uses the thin and burn with wildfire scenario (CNThinBurnWF.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 reduce fire risk across the installation. It excludes areas with steep slopes and potential Mexican spotted owl nesting habitat.

The model uses the scenario file to call the species file, the ecoregions text and img files, and the extension files. For the CNThinBurnWF.txt scenario file, the model calls the Century Succession extension using CNCSUCC10FEB1.txt, the Leaf Biomass Harvest extension using CNThinRxFire12Feb.txt, the Dynamic Leaf Biomass Fuels extension using CNLeafFuels.txt, the Dynamic Fire System extension using CNDyWF11F3.txt, and the Output Leaf Biomass extension using CNLeafBio.txt.

Species File

The species file (CNSPP1.txt) includes parameter values for the life history parameters for the species simulated at Camp Navajo. The full list of species already parameterized includes:

- PIPO – Pinus ponderosa
- QUGA – Quercus gambelii

Century Succession File

The four letter species codes are used to reference physiological parameters for each species in the Century Succession file (CNCSUCC10FEB1.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. 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 (CNClimate1.txt) was developed using 104 years of meteorological data (1909-2012) from the Pulliam Airport Flagstaff, AZ weather station (station ID GHCND: USW00003103). The Century Succession extension also calls the age-only disturbances file (CNBioRedux.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 (CNMgmt2.img) is called by the harvest extension file. In this study we simulated one silvicultural prescription, thin-from-below, with and without prescribed burning. 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 a thin-from-below treatment, we prescribe the following in the harvest file:

```
>> CN Fuel Reduction Thinning treatment

LandisData "Leaf Biomass Harvest"

Timestep 1

>>-------------------------------------------------------------------------------

>>Management Areas: map that define the management areas
>>-------------------------------------------------------------------------------

ManagementAreas "C:\My Documents\CN LANDIS\CNMgmt2.img"
>> Areas are defined by areas at CN

>>Stands: the map that defines the stands, each stand can only be in one mgmt  area

Stands "C:\My Documents\CN LANDIS\CNStands2.img"

>>Prescriptions

>>----------------------------------------------------------------------------------------
Prescription ThRxBurn << Target younger cohorts (thin from below)

StandRanking MaxCohortAge
MinimumAge 30
MinimumTimeSinceLastHarvest 100
SiteSelection Complete

CohortsRemoved SpeciesList
>>  Species      Selection
>>------------   -------------
PIPO            1-10 (90%) 11-30 (80%) 31-50 (66%) 51-70 (60%) 71-90 (40%) 91-100 (5%)
QUGA           1-5 (90%) 6-10(50%) 11-20 (25%)

>>-----------------------------------------------------------------------------------------
```

This prescription tells the model to harvest 90% of PIPO cohorts age 1-10, 80% of PIPO cohorts age 11-30, and so on. This prescription is implemented periodically throughout the simulation period as a function of stand conditions. We have also used this extension to simulate prescribed burning. In the prescribed fire prescribed fire prescription, we prescribed the following in the harvest file:

```
>>------------------------------------------------------------------
Prescription RxFire << mimic Rx Fire

StandRanking FireHazard
>> Fuel Type Index    Rank
>>----------------    --------
70                    100
80                    100
90                    100
91                    100

>>MinimumAge 30
MinimumTimeSinceLastHarvest 10
SiteSelection Complete
CohortsRemoved SpeciesList
>>Species       Selection
>>-----------   -----------
PIPO            1-10 (90%) 11-30 (33%) 31-50 (10%) 51-80 (2%)
QUGA            1-5 (90%) 6-10(50%) 11-20 (25%) 21-50 (2%)
```

In this prescription we remove the majority of the youngest cohorts and a small percentage of older cohorts to simulate fire-induced mortality. The Leaf Biomass Harvest file also controls the area treated and the frequency.

```
>> Harvest Implementation Table
>>changed end time for ThRxBurn for both 4 and 5 from 12 (katies original) to 100
HarvestImplementations
>> Mgmt Area            Prescription    Harvest Area        Begin Time     End Time
>>-----------------     --------------  ----------------   -------------  -----------
4                       ThRxBurn           12%                  1          100
5                       ThRxBurn           12%                  1          100
4                       RxFire             100%                 10         100
5                       RxFire             100%                 10         100
6                       ThRxBurn           10%                  12         100
6                       RxFire             100%                 22         100


>>----------------------------------------------------------------------------------------------

>> Output files
PrescriptionMaps ThinRxMap/prescripts-{timestep}.img
BiomassMaps   ThinMAP/biomass-removed-{timestep}.img

EventLog        Thin/log.csv
SummaryLog      Thin/summarylog.csv
```

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 ThRxBurn prescription tells the model that beginning in the first year management areas 4 and 5 will be thinned at a rate of 12% per year. The RxFire prescription simulates the prescribed fire treatment every ten years beginning in year ten. 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 equivalent to 0.02 (1 in 50 chance of occurrence).

The fire extension requires a fire regions map (CNFR1.img), a fire weather file (CNIFW.csv), and a fuel input file (CNLeafFuels.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 (CNSlope1.img) and aspect (CNUpAsp1.img) for the wildfire simulations.

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

```
LandisData "Dynamic Fire System"

Timestep 1

EventSizeType   size_based << or 'duration_based'
>> EventSizeType duration_based << or 'size based'

BuildUpIndex yes << yes or no
WeatherRandomizer 0 << optional (0-4)

>>Fire Sizes (parameters applied for both size and duration based)
>>Eco  EcoName   Mu   Sigma   Max   SpFMCLo   SpFMCHi  SpHiProp  SuFMCLo  SuFMCHi  SuHiProp  FFMCLo  FFMCHi  FHiProp OpenFuel NumFires
>>----------------------------------------------------------------------------------------------------------------------------------
0      inactive 0       0      0      0        0        0         0        0        0         0       0       0        0        0
1      Eco1     5       2.2    3000   135      175      0.05      85       100      0.9       75      90      0.05     20       75
```

This file provides the model with a distribution from which to draw the number of ignitions in a time-step (NumFires). The NumFires value is used as the average number of ignitions for a Poisson distribution for a given fire region. The average number of fires is 75. 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.

```
SeasonTable
>> Name          LeafStatus      Proportion Fire         Percent Curing  DayLengthProportion
>>-------        ----------      ----------------        --------------  -------------------
Spring           LeafOff         0.05                    0               1.0
Summer           LeafOn          0.87                    51              1.0
Fall             LeafOff         0.08                    100             1.0

InitialWeatherDatabase  "c:\My Documents\CN LANDIS\CNIFW.csv"
DynamicWeatherTable
```

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
>> Fuel Input Table
>> Index         BaseFuel        SurfType        IgnProb         a       b        c       q       BUI     maxBE   CBH
>>-------        --------        ---------       --------        ---     ---      ---     ---     -----   -----
20                Open           O1b              0.02           250      0.0350   1.7     1.0      1       1.00    0
30                Conifer        C4               0.02           110      0.0293   1.5     0.80    120      1.184   0
40                Conifer        C4               0.02           110      0.0293   1.5     0.80    120      1.184   1
50                Conifer        C4               0.02           110      0.0293   1.5     0.80    120      1.184   1
60                Deciduous      D1               0.001          30       0.0232   1.6     0.90    32       1.179   0
70                Conifer        C7               0.001          30       0.0200   2.0     0.85    25       1.000   5
80                Conifer        C7               0.001          30       0.0200   2.0     0.85    25       1.000   5
90                Conifer        C4               0.02           30       0.0200   1.5     0.85    25       1.000   3
91                Conifer        C4               0.02           30       0.0200   1.5     0.85    25       1.000   5
10                Conifer        M1               0.02            0       0        0       0.8     50       1.250   0
```

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.

```
SeverityCalibrationFactor 0.0
FireDamageTable
>>Cohort Age    Fire Severity- Fire Tolerance
>>% longevity
>>------------- -----------------------------
2.5%            -2
12.5%           -1
20%              0
85%              1
100%             2

MapNames wf/sev/{timestep}-sev.img
LogFile  wf/burnlog.csv
SummaryLogFile wf/summary-log.csv
```

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 "CN 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: CNThinWF.txt or CNThinBurnWF.txt

Century File: CNCSUCC10Feb1.txt

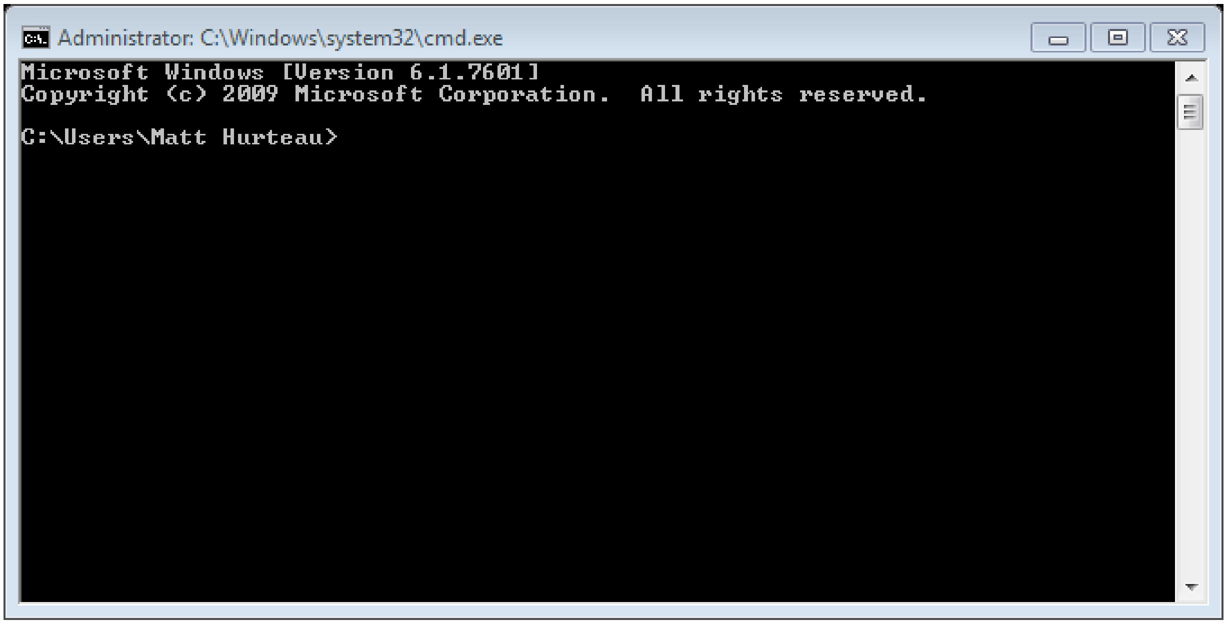
Fire File: CNDyWF11F3.txt

Harvest File: CNThinRxFire12Feb.txt or CNThinOnly12Feb.txt

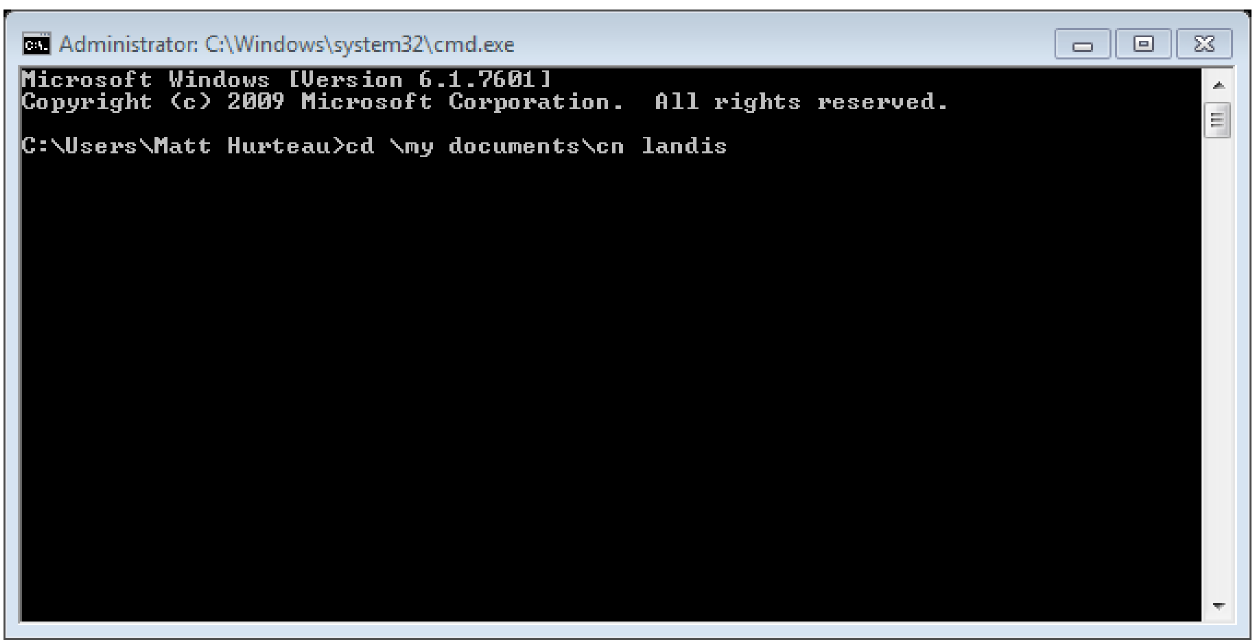
Example scenario file. Note that there are seven different file paths that require updating.

```
CNThinRxFire12Feb.txt - Notepad
File  Edit  Format  View  Help
>> CN Fuel Reduction Thinning treatment

LandisData "Leaf Biomass Harvest"

Timestep 1

>>----------------------------------------------------------------------------

>>Management Areas: map that define the management areas
>>----------------------------------------------------------------------------

ManagementAreas "C:\My Documents\CN LANDIS\CNMgmt2.img"
>> Areas are defined by areas at CN

>>Stands: the map that defines the stands, each stand can only be in one mgmt  area

Stands "C:\My Documents\CN LANDIS\CNStands2.img"

>>Prescriptions

>>------------------------------------------------------------------------------------
Prescription ThRxBurn << Target younger cohorts (thin from below)

StandRanking MaxCohortAge
MinimumAge 30
MinimumTimeSinceLastHarvest 100
SiteSelection Complete

CohortsRemoved SpeciesList
>>  Species     Selection
>>------------  -------------
PIPO            1-10 (90%) 11-30 (80%) 31-50 (66%) 51-70 (60%) 71-90 (40%) 91-100 (5%)
QUGA           1-5 (90%) 6-10(50%) 11-20 (25%)

>>------------------------------------------------------------------------------------
```

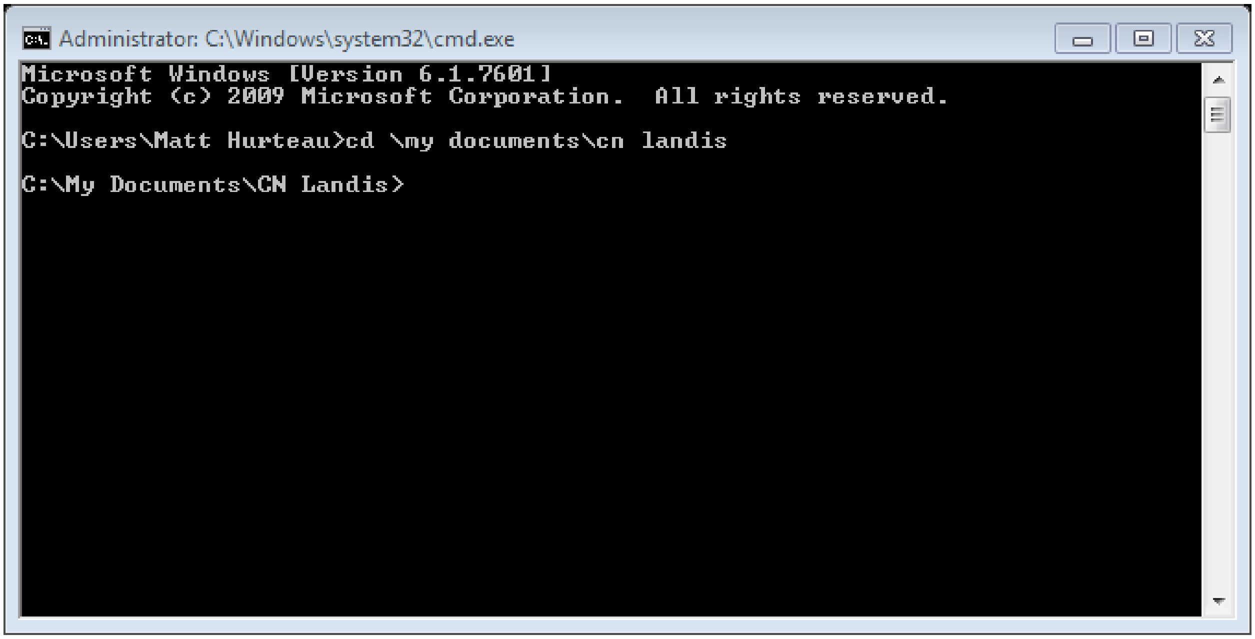
To open the model, you will need to open the ms dos prompt by typing “cmd” in the search box on the start menu.



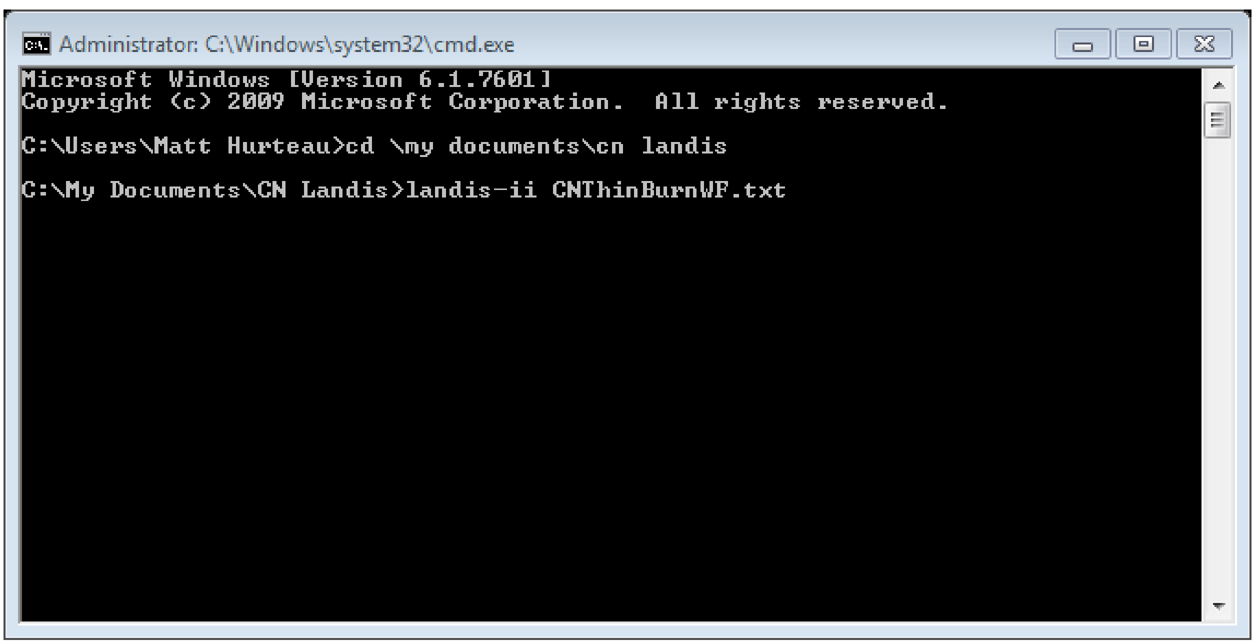
Next you will need to map to the folder you just created. To do this you will need to use the change directory command (cd).



Once you have typed the new directory command, your prompt should indicate that you are working from the CN 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 (CN LANDIS) you will find the following outputs:

Folders:

- bioMAP – biomass by species for each simulation time-step
- conmap – percent conifer maps for each time-step
- deadfirmap – percent dead fir maps for each time-step
- DFFS-output – time of last fire maps for each time-step
- Sev – maps of fire severity for each time-step
- FuelMap – fuel maps for each time-step
- NEEMap – maps of net ecosystem exchange for each time-step
- NPPMap – maps of net primary productivity for each time-step
- SoilCMap – maps of soil carbon 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 150 x 150 m (2.25 hectares). We have divided the Camp Navajo landscape into six ecoregions based on soil type and climate. 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	197	443.25
Eco2	1578	3550.5
Eco3	137	308.25
Eco4	400	900
Eco5	2611	5874.75
Eco6	237	533.25

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	197	-111.11	0.03817	-4.24
Eco2	1578	-94.91	0.30581	-29.02
Eco3	137	-129.83	0.02655	-3.44
Eco4	400	-206.14	0.07751	-15.97
Eco5	2611	-63.32	0.50600	-32.04
Eco6	237	-269.97	0.04593	-12.39
Total Grid Cells	5160		**Total NEEC**	**-97.13**

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 Camp Navajo sequestered on average 97.13 gC 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 0.9713 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)
Pinus ponderosa	400	7	2	4	35	120
Quercus gambelii	90	3	3	3	30	1000

Species	Vegetative reproduction probability (0-1)	Minimum age of sprouting	Maximum age of sprouting	Post-fire Regeneration
Pinus ponderosa	0	0	3	None
Quercus gambelii	0.75	1	80	resprout

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
Pinus ponderosa	1	N	155	4000	-5	0.92	4.5	N
Quercus gambelii	2	N	800	4000	-5	0.90	1.0	Y

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
Pinus ponderosa	0.28	**0.2**	**0.25**	**0.25**	**48**	**48**	**250**	**170**	**100**
Quercus gambelii	0.175	**0.23**	**0.23**	**0.23**	**30**	**48**	**500**	**333**	**46**

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
Pine	1	23.0	38.0	0.05	6.0	0.2	0.004	5000.0	10.0
Hardwood	2	23.0	35.0	0.05	7.0	0.3	0.004	5000.0	20.0

Functional Group Name	Index	PPRPTS2	PPRPTS3	Wood Decay Rate	Monthly Wood Mortality	Mortality Age Shape	Leaf Drop Month
Pine	1	1.0	0.5	0.4	0.002	10	10
Hardwood	2	1.0	0.5	0.4	0.002	10	10

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

InitialEcoregionParameters									
Name	SOM1 C surf	SOM1 N surf	SOM1 C soil	SOM1 N soil	SOM2 C	SOM2 N	SOM3 C	SOM3 N	Minrl N
Eco1	412	4.5	90	7.5	2100	42	810	20	2.4
Eco2	412	4.5	90	7.5	2100	42	810	20	2.4
Eco3	412	4.5	90	7.5	2100	42	810	20	2.4
Eco4	412	4.5	90	7.5	2100	42	810	20	2.4
Eco5	412	4.5	90	7.5	2100	42	810	20	2.4
Eco6	412	4.5	90	7.5	2100	42	810	20	2.4

	Soil Depth	% Clay	% Sand	Field Cap	Wilt Point	StormF Frac	BaseF Frac	Drain	Atm N dep	Atm N intercept	Latitude
Eco1	100	0.13	0.55	0.24	0.09	0.3	0.6	0.7	0.035	0.004	35.2
Eco2	100	0.30	0.34	0.33	0.14	0.3	0.6	0.7	0.035	0.004	35.2
Eco3	100	0.30	0.34	0.33	0.14	0.3	0.6	0.7	0.035	0.004	35.2
Eco4	100	0.13	0.55	0.24	0.09	0.3	0.6	0.7	0.035	0.004	35.2
Eco5	100	0.30	0.34	0.33	0.14	0.3	0.6	0.7	0.035	0.004	35.2
Eco6	100	0.30	0.34	0.33	0.14	0.3	0.6	0.7	0.035	0.004	35.2

Ecoregion Parameters cont	Decay Surf	Decay SOM1	Decay SOM2	Decay SOM3	Denitrifi
Eco1	0.15	1.0	0.018	0.00035	0.1
Eco2	0.15	1.0	0.018	0.00035	0.1
Eco3	0.15	1.0	0.018	0.00035	0.1
Eco4	0.15	1.0	0.018	0.00035	0.1
Eco5	0.15	1.0	0.018	0.00035	0.1
Eco6	0.15	1.0	0.018	0.00035	0.1

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

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

	Eco1	Eco2	Eco3	Eco4	Eco5	Eco6
PIPO	150	150	150	150	150	150
QUGA	75	75	75	75	75	75

Maximum Biomass (g m^{-2})

	Eco1	Eco2	Eco3	Eco4	Eco5	Eco6
PIPO	16000	16000	16000	16000	16000	16000
QUGA	10000	10000	10000	10000	10000	10000

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