Forecasting Timber, Biomass, and Tree Carbon Pools with the Output of State and Transition Models

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Abstract

The Integrated Landscape Assessment Project (ILAP) uses spatial vegetation data and state and transition models (STM) to forecast future vegetation conditions and the interacting effects of natural disturbances and management activities. Results from ILAP will help land managers, planners, and policymakers evaluate management strategies that reduce fire risk, improve wildlife habitat, and benefit rural communities. This case study illustrates the methodology for modeling timber volume, biomass estimates, and the forest carbon over time with the output of STM simulations. It presents how the Forest Inventory and Analysis data were applied to assist the interpretation of STM simulation results and derives useful information to the public. The method was applied in the central Washington study area to project the timber production, biomass supply potential, and aboveground carbon stock for two alternative management scenarios.

Keywords: State and transition model, biomass estimation, timber volume, aboveground tree carbon.

Introduction

The Integrated Landscape Assessment Project (ILAP) forecasts potential future vegetation conditions under long-term landscape management scenarios using Path (http://www.apexrms.com) and Vegetation Dynamics Development Tool (VDDT) (ESSA 2007), a state and transition modeling (STM) platform. Future vegetation conditions and the disturbance information from STM simulations are summarized in terms of acres by management allocation (ownership and management types), watershed, and vegetation state classes. The simulation output does not carry the key variables for estimating volume and biomass over time during the simulation such as tree species, diameter, and height. The vegetation conditions are summarized by management allocation for each watershed (table 1a), and the disturbance effects are also displayed by acres with detailed information about the state class changes associated with disturbance types (table 1b). The challenge for people who are interested in information about timber products and biomass is how area-only-related outputs can be translated to the desired attributes. The approach developed for this study uses Forest Inventory and Analysis (FIA) plot information to build look-up tables with volume and biomass attributes linked to each state class for each region. This paper will describe procedures to develop look-up tables for calculating timber volume and biomass as well as tree carbon from VDDT output. The method is demonstrated for central Washington to get the estimates of timber volume, biomass, and aboveground live tree carbon for both management and non-management scenarios. The method can be applied to other landscapes in the ILAP study regions.

Study Area

The study area is in central Washington and encompasses 2.65 million acres of mostly forested land in 25 5th hydrologic unit code (HUC) level watersheds and 16 combinations of ownership and management types (fig. 1). The terrain is mountainous with the highest peaks at over 7,874 feet (2400 m) elevation and the lowest valley bottoms at less than 1,640 feet (500 m). Forested vegetation ranges from very dry environments that support ponderosa pine (*Pinus ponderosa* Lawson and C. Lawson) stands to upper elevation forests of subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and mountain hemlock (*Tsuga mertensiana* (Bong.) Carrière). Much of the forest consists of mixed-conifer stands

Table 1a—VDDT inventory output example—dry mixed conifer PVT for general management in the Washington East Cascades ecoregion

Time	Watershed code	Ownership	State class code	Acres
1	104	Forest Service	22210	21.91
1	104	Private	322705	30.11
1	105	Washington state	182705	43.00
1	131	Yakama Nation	332705	8.91
…	…			
5	104	Forest Service	372705	20.50
5	104	Washington state	462235	15.00
5	105	Forest Service	452235	50.90
5	106	Private	192210	18.71
5	131	Yakama Nation	462235	110.21

Table 1b—VDDT Output example for disturbances—dry mixed conifer PVT model for general management on Forest Service lands in the Washington East Cascades ecoregion

Time	Watershed code	Disturbance	From state class code	To state class code	Treated acres
1	104	Partial harvest, small—medium size and medium density	242210	182210	40.5
1	105	Partial harvest, small—medium size and medium density	312210	262210	31.9
1	106	Partial harvest, small—medium size and high density	292705	282705	11.1
2	105	Partial harvest, small –medium size and high density	212705	182705	20.4
3	105	Partial harvest, large—medium size and high density	362705	352705	7.8
3	106	Partial harvest, small—medium size and medium density	282210	262210	16.0

dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.), and ponderosa pine.

Data and Methodology

The existing vegetation conditions in ILAP came from Gradient Nearest Neighbor (GNN) imputation of inventory plots to 98-feet (30-m) pixels (Ohmann and Gregory 2002) http://www.fsl.orst.edu/lemma/method/methods.php) and other geographic information system (GIS) layers. Each 30-m pixel was associated with an FIA inventory plot. To develop the look-up table with the attributes of volume and biomass, the plots initially assigned to the GNN pixels for the modeling region were retrieved from the inventory database with the detailed individual sample tree information including species, diameter, and height. The following steps were taken to build the volume/biomass look-up table and estimate the volume and biomass:

- Step 1: Collect the plot data (tree list) from the FIA periodic or annual data used in GNN.
- Step 2: Assign a state class to each plot using predefined rules.
- Step 3: Calculate the volume and biomass for each plot associated with the state class using the equations documented in Zhou and Hemstrom (2010).
- Step 4: Summarize volume and biomass attributes for each plot and by product groups or for the total.
- Step 5: Compute average volume and biomass attributes for each state class and build a look-up table.

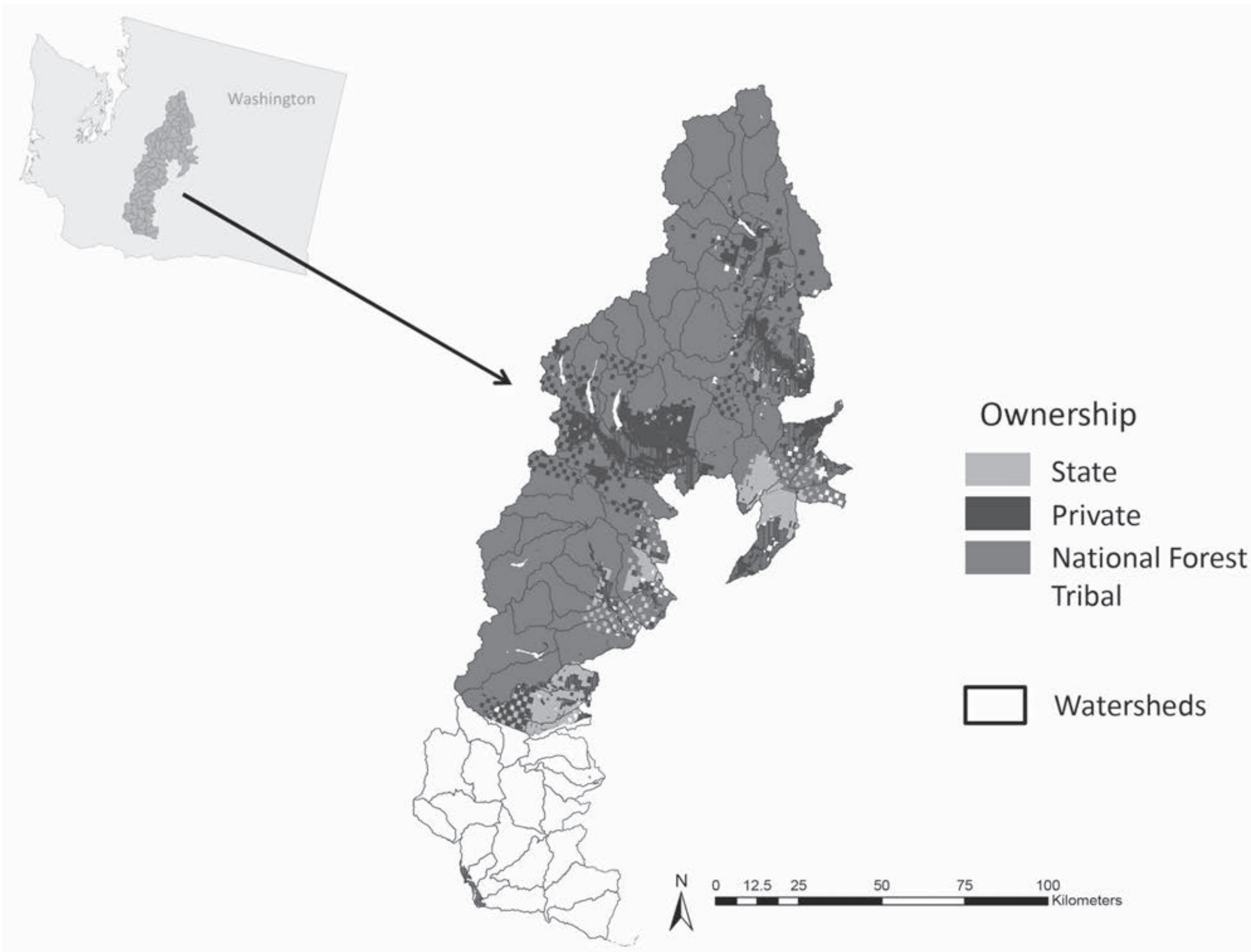

Figure 1—Central Washington landscape study area.

- Step 6: Fill data holes for state classes with inadequate plot representation using a hierarchical rule set for state class similarity.
- Step 7: Calculate volume and biomass by matching the state class from the VDDT output to the look-up table to generate estimates of volume and biomass by landscape stratum and year.
- Step 8: Calculate volume and biomass removals based on the difference in each state class before and after treatment assuming that the treatment happens middle of the year and there is no growth during the treatment year.

Look-up tables are built for each different landscape eco-region. Table 2a shows an example of total volume and biomass for each state class and potential vegetation type (PVT) for the Washington East Cascades (WEC). Volume attributes include total volume (for trees with a diameter at breast height (dbh $\geq$1 in), merchantable tree volume (dbh $\geq$5 in) and sawtimber volume (dbh $\geq$9 in for softwood and dbh $\geq$11 in for hardwood); biomass attributes include biomass of stem, branch, bark and leaf; the total biomass is the sum of all these parts. Merchantable biomass is computed separately. Table 2b is an example of a look-up table with detailed product classes for the WEC ecological region. Five products are defined in this study based on tree diameters: (1) small tree—dbh <5 in; (2) chip tree—5 in ≤dbh <7 in;

Table 2a—Volume (cubic feet/acre) and biomass (pounds/acre) look-up table example (total) in the Washington East Cascades ecoregion

Potential vegetation type	State class code	Total volume	Merchantable volume	…	Stem biomass	Branch biomass	Total biomass
		cf/ac	*cf/ac*		*lb/ac*	*lb/ac*	*lb/ac*
Dry mixed conifer	332705	1,031	977		24,886	3,778	40,597
Dry mixed conifer	342705	3,835	3,642		97,080	15,004	147,451
Dry mixed conifer	352705	2,732	2,582		67,771	10,765	105,275
Dry mixed conifer	362705	8,584	8,242		237,485	36,817	341,420
Dry mixed conifer	372705	1,866	1,767	…	43,816	6,260	66,699
Pacific silver fir	342710	7,286	6,960		178,732	27,411	274,912
Pacific silver fir	352710	1,203	1,144		31,421	6,303	58,604
Pacific silver fir	392710	10,733	10,186		262,566	38,511	400,021
Pacific silver fir	422710	4,492	4,324		106,910	17,916	159,528

Table 2b—Volume (cubic feet/acre) and biomass (pounds/acre) look-up table example by product groups in the Washington East Cascades ecoregion

Potential vegetation type	State class code	Product group	Total volume	Merchantable volume	…	Stem biomass	Branch biomass	Total biomass
			cf/ac	*cf/ac*		*lb/ac*	*lb/ac*	*lb/ac*
Dry mixed conifer	332705	Small tree	27	0		326	1,942	3,988
Dry mixed conifer	332705	Chip tree	29	9		278	140	577
Dry mixed conifer	332705	Pole tree	42	11		312	93	502
Dry mixed conifer	332705	Small saw	489	375		10,303	2,176	14,826
Dry mixed conifer	332705	Large saw	602	582	…	15,024	2,821	20,703
Pacific silver fir	392710	Small tree	131	0		2,325	2,625	6,651
Pacific silver fir	392710	Chip tree	150	92		3,378	1,027	5,396
Pacific silver fir	392710	Pole tree	248	204		6,011	1,543	9,012
Pacific silver fir	392710	Small saw	3,630	3,470		93,675	21,125	132,599
Pacific silver fir	392710	Large saw	6,642	6,420	…	171,187	39,810	246,362

(3) pole tree—7 in ≤dbh <9 in for softwood and 7 in ≤dbh < 11 in for hardwood; (4) small sawtimber—9 in ≤dbh <20in for softwood and 11 in ≤dbh <20 in for hardwood; and (5) large sawtimber—dbh ≥20 in.

Two management scenarios were simulated for 300 years using STMs in ILAP. The no-management scenario assumed no-management treatments except continued current levels of wildfire suppression; unsuppressed wildfires, and other natural disturbances were allowed to run their course. The current management scenario was based on estimated forest management treatment rates currently in place by land ownership and management types. Management type differed widely among ownerships and land allocations from no treatment (except wildfire suppression) in wilderness and similar reserved areas to commercial timber harvest on private timberlands. We worked with local collaborative groups to gather estimated treatment rates by ownership and land allocation. Treatments included regeneration harvests, commercial thinning, precommercial thinning, tree planting, prescribed fire, and mechanical fuel treatments. Wildfire probabilities were computed by PVT (dry, moist, and cold forest) using data from the Monitoring Trends in Burn Severity study (http://www.mtbs.gov, accessed on 11/29/2011) and reflect wildfire occurrence in the Washington East Cascades ecological region for the 1984 to 2008 time period.

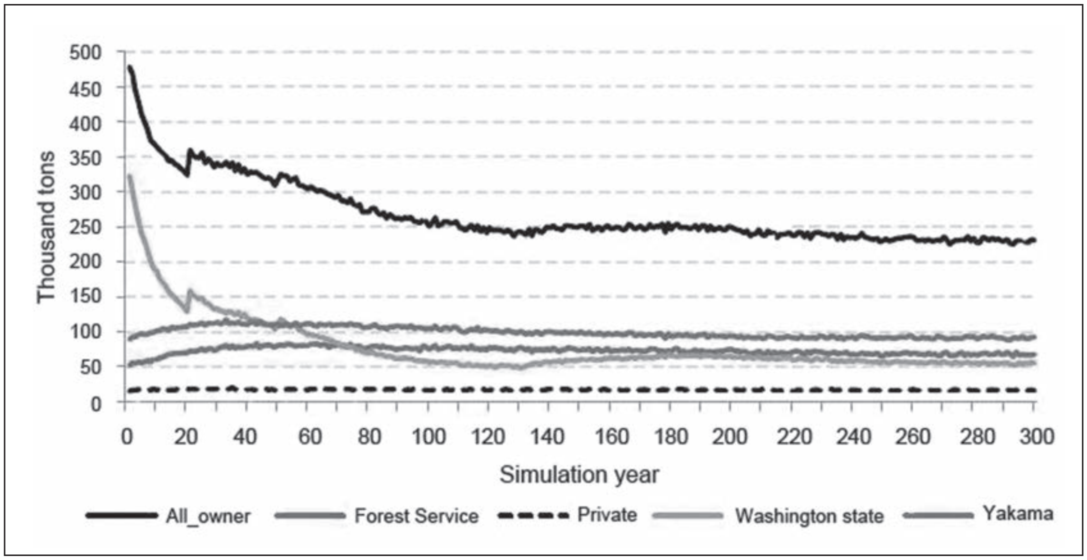

Figure 2—Total tree biomass removals by human disturbances (fuel treatments).

Results

The Biomass Removals From Fuel Reduction Treatment

The materials removed by fuel reduction treatment include merchantable timber products, and small trees or other non-merchantable parts of the trees such as branches, bark, and tops, which might be used as biomass for energy production or other purposes. Of course, depending on how the biomass is defined, potential biomass removals will be different. For simplicity, we considered biomass removals to include everything but foliage; a definition that can be easily changed since biomass components are computed separately. Simulated removals from Forest Service lands and Yakama Tribe lands increase gradually over the first two to three decades and then stabilize. The removals from private lands are relatively low during the entire simulation period because of the low acreage of privately owned lands in this study region (fig. 2). The removals from Washington state forests initially are about 67 percent of the total removals from all ownerships, it decreases dramatically for the first three decades to less than 40 percent of the total, ultimately stabilizing at 20 to 25 percent of the total biomass removals. Conversely, biomass removals from Forest Service and tribal lands increase steadily. The removals from Forest Service lands average 11 percent at the beginning and reach 25 percent at the end of 50 years, and removals from tribal lands during the same period increase from 19 to 35 percent. The removals from private forest land are projected to increase from 3.2 to 5.3 percent of the total biomass removals for the first 50 simulation years.

The Merchantable Tree Volumes

The total standing merchantable tree inventory increased rapidly under both management and no-management scenarios during the first three decades, stabilized for 10 to 20 years, and then decreased (fig. 3). The inventory under the current management scenario peeks at 10.9 billion cubic feet around year 33, about 13.5 percent higher than the initial inventory, and then declines. The inventory under the no-management scenario reaches its maximum, 11.5 billion cubic feet, around year 40, 20 percent more than the beginning inventory; remains steady for about a decade, then declines. In both scenarios, the inventories at the end of simulation period are above original levels although the merchantable tree inventory under the no-management scenario is projected to be 9.7 percent higher than the inventory under the management scenario.

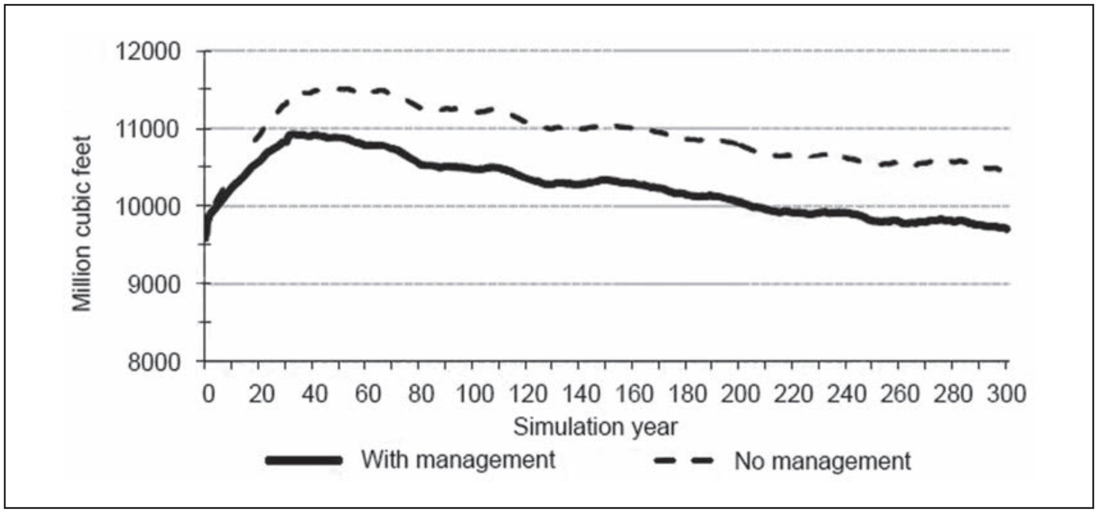

Figure 3—Total merchantable tree inventory in central Washington.

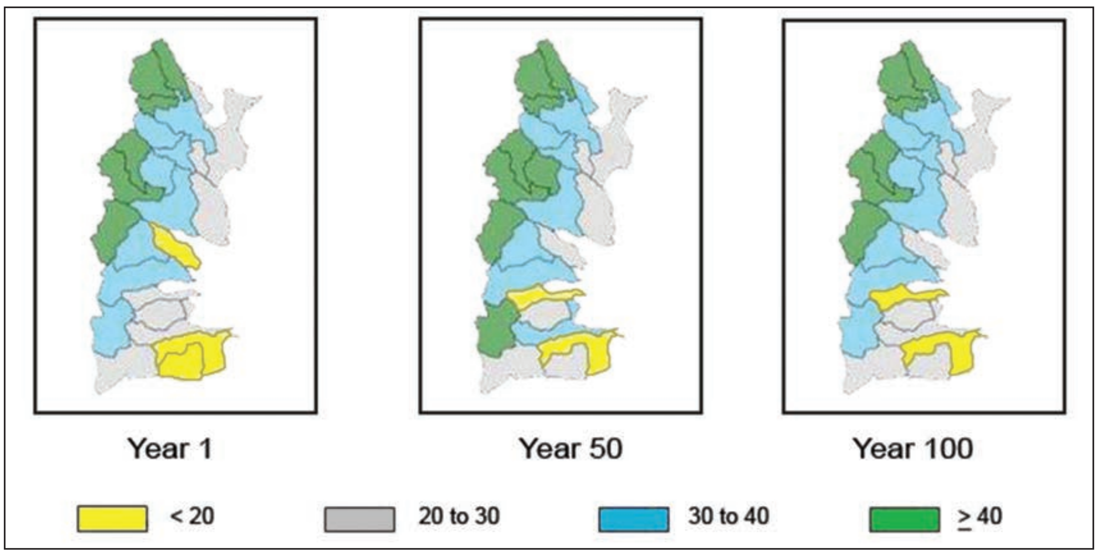

Figure 4—Aboveground carbon stock over time (tons/acre).

Aboveground Tree Carbon Stock Over Simulation Period

We estimate the tree carbon pool by multiplying whole-tree biomass by 0.5 (Heath 2007). Although other carbon pools, such as those in dead trees and soil, are equally important on forest lands, we calculate only the tree-based, aboveground carbon pool. The aboveground tree-based carbon stock varies over time under different management scenarios. The average total aboveground, tree-based carbon stock increased for 21 of the 25 watersheds during the first 50 years (fig. 4). Carbon pools decline slowly in 11 watersheds during the second fifty year and remain relatively constant in the rest. The aboveground live tree carbon stock was relatively stable after the first century for almost all the watersheds.

Discussion and Conclusion

State and transition models can project vegetation structures and landscape condition over time for different management assumptions across a variety of vegetation types, land ownerships, and land management allocations. Forest inventory data provide plot and tree level information to build look-up tables with the attributes of tree volume and biomass that can be attached to STM output. This process provides useful information to forest managers and other decision makers for forest management planning. Our methods could be applied to generate similar look-up tables for soil carbon, dead tree biomass, and other landscape attribute estimates. These estimates can be used to examine the potential long-term effects of various management approaches on forest vegetation conditions (including wildlife habitats, fuels, and others) and general amounts, types, and production locations of economically valuable forest products.

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